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Volume 3: General-Purpose and System Instructions

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Revision History

Date	Revision	Description
September 2007	3.14	Added minor clarifications and corrected typographical and formatting errors.
July 2007	3.13	Added the following instructions: "LZCNT" on page 153, "POPCNT" on page 188, "MONITOR" on page 284, and "MWAIT" on page 290. Reformatted information on instruction support indicated by CPUID feature bits into Table 3-1. Added minor clarifications and corrected typographical and formatting errors.
September 2006	3.12	Added minor clarifications and corrected typographical and formatting errors.
December 2005	3.11	Added SVM instructions; added PAUSE instructions; made factual changes.
January 2005	3.10	Clarified CPUID information in exception tables on instruction pages. Added information under "CPUID" on page 103. Made numerous small corrections.
September 2003	3.09	Corrected table of valid descriptor types for LAR and LSL instructions and made several minor formatting, stylistic and factual corrections. Clarified several technical definitions.
April 2003	3.08	Corrected description of the operation of flags for RCL, RCR, ROL, and ROR instructions. Clarified description of the MOVSXD and IMUL instructions. Corrected operand specification for the STOS instruction. Corrected opcode of SET*cc*, J*cc*, instructions. Added thermal control and thermal monitoring bits to CPUID instruction. Corrected exception tables for POPF, SFENCE, SUB, XLAT, IRET, LSL, MOV(CR*n*), SGDT/SIDT, SMSW, and STI instructions. Corrected many small typos and incorporated branding terminology.

Preface

About This Book

This book is part of a multivolume work entitled the *AMD64 Architecture Programmer's Manual*. This table lists each volume and its order number.

Title	Order No.
Volume 1: Application Programming	24592
Volume 2: System Programming	24593
Volume 3: General-Purpose and System Instructions	24594
Volume 4: 128-Bit Media Instructions	26568
Volume 5: 64-Bit Media and x87 Floating-Point Instructions	26569

Audience

This volume (Volume 3) is intended for all programmers writing application or system software for a processor that implements the AMD64 architecture. Descriptions of general-purpose instructions assume an understanding of the application-level programming topics described in Volume 1. Descriptions of system instructions assume an understanding of the system-level programming topics described in Volume 2.

Organization

Volumes 3, 4, and 5 describe the AMD64 architecture's instruction set in detail. Together, they cover each instruction's mnemonic syntax, opcodes, functions, affected flags, and possible exceptions.

The AMD64 instruction set is divided into five subsets:

- General-purpose instructions
- System instructions
- 128-bit media instructions
- 64-bit media instructions
- x87 floating-point instructions

Several instructions belong to—and are described identically in—multiple instruction subsets.

This volume describes the general-purpose and system instructions. The index at the end cross-references topics within this volume. For other topics relating to the AMD64 architecture, and for information on instructions in other subsets, see the tables of contents and indexes of the other volumes.

Definitions

Many of the following definitions assume an in-depth knowledge of the legacy x86 architecture. See "Related Documents" on page xxvi for descriptions of the legacy x86 architecture.

Terms and Notation

In addition to the notation described below, "Opcode-Syntax Notation" on page 339 describes notation relating specifically to opcodes.

1011b

A binary value—in this example, a 4-bit value.

F0EAh

A hexadecimal value—in this example a 2-byte value.

[1,2)

A range that includes the left-most value (in this case, 1) but excludes the right-most value (in this case, 2).

7–4

A bit range, from bit 7 to 4, inclusive. The high-order bit is shown first.

128-bit media instructions

Instructions that use the 128-bit XMM registers. These are a combination of the SSE and SSE2 instruction sets.

64-bit media instructions

Instructions that use the 64-bit MMX registers. These are primarily a combination of MMX™ and 3DNow!™ instruction sets, with some additional instructions from the SSE and SSE2 instruction sets.

16-bit mode

Legacy mode or compatibility mode in which a 16-bit address size is active. See *legacy mode* and *compatibility mode*.

32-bit mode

Legacy mode or compatibility mode in which a 32-bit address size is active. See *legacy mode* and *compatibility mode*.

64-bit mode

A submode of *long mode*. In 64-bit mode, the default address size is 64 bits and new features, such as register extensions, are supported for system and application software.

#GP(0)

Notation indicating a general-protection exception (#GP) with error code of 0.

absolute

Said of a displacement that references the base of a code segment rather than an instruction pointer. Contrast with *relative*.

biased exponent

The sum of a floating-point value's exponent and a constant bias for a particular floating-point data type. The bias makes the range of the biased exponent always positive, which allows reciprocation without overflow.

byte

Eight bits.

clear

To write a bit value of 0. Compare *set*.

compatibility mode

A submode of *long mode*. In compatibility mode, the default address size is 32 bits, and legacy 16-bit and 32-bit applications run without modification.

commit

To irreversibly write, in program order, an instruction's result to software-visible storage, such as a register (including flags), the data cache, an internal write buffer, or memory.

CPL

Current privilege level.

CR0–CR4

A register range, from register CR0 through CR4, inclusive, with the low-order register first.

CR0.PE = 1

Notation indicating that the PE bit of the CR0 register has a value of 1.

direct

Referencing a memory location whose address is included in the instruction's syntax as an immediate operand. The address may be an absolute or relative address. Compare *indirect*.

dirty data

Data held in the processor's caches or internal buffers that is more recent than the copy held in main memory.

displacement

A signed value that is added to the base of a segment (absolute addressing) or an instruction pointer (relative addressing). Same as *offset*.

doubleword

Two words, or four bytes, or 32 bits.

double quadword

Eight words, or 16 bytes, or 128 bits. Also called *octword*.

DS:rSI

The contents of a memory location whose segment address is in the DS register and whose offset relative to that segment is in the rSI register.

EFER.LME = 0

Notation indicating that the LME bit of the EFER register has a value of 0.

effective address size

The address size for the current instruction after accounting for the default address size and any address-size override prefix.

effective operand size

The operand size for the current instruction after accounting for the default operand size and any operand-size override prefix.

element

See *vector*.

exception

An abnormal condition that occurs as the result of executing an instruction. The processor's response to an exception depends on the type of the exception. For all exceptions except 128-bit media SIMD floating-point exceptions and x87 floating-point exceptions, control is transferred to the handler (or service routine) for that exception, as defined by the exception's vector. For floating-point exceptions defined by the IEEE 754 standard, there are both masked and unmasked responses. When unmasked, the exception handler is called, and when masked, a default response is provided instead of calling the handler.

FF /0

Notation indicating that FF is the first byte of an opcode, and a subopcode in the ModR/M byte has a value of 0.

flush

An often ambiguous term meaning (1) writeback, if modified, and invalidate, as in "flush the cache line," or (2) invalidate, as in "flush the pipeline," or (3) change a value, as in "flush to zero."

GDT

Global descriptor table.

IDT

Interrupt descriptor table.

IGN

Ignore. Field is ignored.

indirect

Referencing a memory location whose address is in a register or other memory location. The address may be an absolute or relative address. Compare *direct*.

IRB

The virtual-8086 mode interrupt-redirection bitmap.

IST

The long-mode interrupt-stack table.

IVT

The real-address mode interrupt-vector table.

LDT

Local descriptor table.

legacy x86

The legacy x86 architecture. See “Related Documents” on page xxvi for descriptions of the legacy x86 architecture.

legacy mode

An operating mode of the AMD64 architecture in which existing 16-bit and 32-bit applications and operating systems run without modification. A processor implementation of the AMD64 architecture can run in either *long mode* or *legacy mode*. Legacy mode has three submodes, *real mode*, *protected mode*, and *virtual-8086 mode*.

long mode

An operating mode unique to the AMD64 architecture. A processor implementation of the AMD64 architecture can run in either *long mode* or *legacy mode*. Long mode has two submodes, *64-bit mode* and *compatibility mode*.

lsb

Least-significant bit.

LSB

Least-significant byte.

main memory

Physical memory, such as RAM and ROM (but not cache memory) that is installed in a particular computer system.

mask

(1) A control bit that prevents the occurrence of a floating-point exception from invoking an exception-handling routine. (2) A field of bits used for a control purpose.

MBZ

Must be zero. If software attempts to set an MBZ bit to 1, a general-protection exception (#GP) occurs.

memory

Unless otherwise specified, *main memory.*

ModRM

A byte following an instruction opcode that specifies address calculation based on mode (Mod), register (R), and memory (M) variables.

moffset

A 16, 32, or 64-bit offset that specifies a memory operand directly, without using a ModRM or SIB byte.

msb

Most-significant bit.

MSB

Most-significant byte.

multimedia instructions

A combination of *128-bit media instructions* and *64-bit media instructions*.

octword

Same as *double quadword.*

offset

Same as *displacement*.

overflow

The condition in which a floating-point number is larger in magnitude than the largest, finite, positive or negative number that can be represented in the data-type format being used.

packed

See *vector.*

PAE

Physical-address extensions.

physical memory

Actual memory, consisting of *main memory* and cache.

probe

A check for an address in a processor's caches or internal buffers. *External probes* originate outside the processor, and *internal probes* originate within the processor.

protected mode

A submode of *legacy mode*.

quadword

Four words, or eight bytes, or 64 bits.

RAZ

Read as zero (0), regardless of what is written.

real-address mode

See *real mode*.

real mode

A short name for *real-address mode,* a submode of *legacy mode*.

relative

Referencing with a displacement (also called offset) from an instruction pointer rather than the base of a code segment. Contrast with *absolute*.

reserved

Fields marked as reserved may be used at some future time.

To preserve compatibility with future processors, reserved fields require special handling when read or written by software.

Reserved fields may be further qualified as MBZ, RAZ, SBZ or IGN (see definitions).

Software must not depend on the state of a reserved field, nor upon the ability of such fields to return to a previously written state.

If a reserved field is not marked with one of the above qualifiers, software must not change the state of that field; it must reload that field with the same values returned from a prior read.

REX

An instruction prefix that specifies a 64-bit operand size and provides access to additional registers.

RIP-relative addressing

Addressing relative to the 64-bit RIP instruction pointer.

set

To write a bit value of 1. Compare *clear.*

SIB

A byte following an instruction opcode that specifies address calculation based on scale (S), index (I), and base (B).

SIMD

Single instruction, multiple data. See *vector.*

SSE

Streaming SIMD extensions instruction set. See *128-bit media instructions* and *64-bit media instructions*.

SSE2

Extensions to the SSE instruction set. See *128-bit media instructions* and *64-bit media instructions*.

SSE3

Further extensions to the SSE instruction set. See *128-bit media instructions.*

sticky bit

A bit that is set or cleared by hardware and that remains in that state until explicitly changed by software.

TOP

The x87 top-of-stack pointer.

TPR

Task-priority register (CR8).

TSS

Task-state segment.

underflow

The condition in which a floating-point number is smaller in magnitude than the smallest nonzero, positive or negative number that can be represented in the data-type format being used.

vector

(1) A set of integer or floating-point values, called *elements*, that are packed into a single operand. Most of the 128-bit and 64-bit media instructions use vectors as operands. Vectors are also called *packed* or *SIMD* (single-instruction multiple-data) operands.

(2) An index into an interrupt descriptor table (IDT), used to access exception handlers. Compare *exception*.

virtual-8086 mode

A submode of *legacy mode*.

word

Two bytes, or 16 bits.

x86

See *legacy x86*.

Registers

In the following list of registers, the names are used to refer either to a given register or to the contents of that register:

AH–DH

The high 8-bit AH, BH, CH, and DH registers. Compare *AL–DL*.

AL–DL

The low 8-bit AL, BL, CL, and DL registers. Compare *AH–DH*.

AL–r15B

The low 8-bit AL, BL, CL, DL, SIL, DIL, BPL, SPL, and R8B–R15B registers, available in 64-bit mode.

BP

Base pointer register.

CRn

Control register number *n*.

CS

Code segment register.

eAX–eSP

The 16-bit AX, BX, CX, DX, DI, SI, BP, and SP registers or the 32-bit EAX, EBX, ECX, EDX, EDI, ESI, EBP, and ESP registers. Compare *rAX–rSP*.

EFER

Extended features enable register.

eFLAGS

16-bit or 32-bit flags register. Compare *rFLAGS*.

EFLAGS

32-bit (extended) flags register.

eIP

16-bit or 32-bit instruction-pointer register. Compare *rIP*.

EIP

32-bit (extended) instruction-pointer register.

FLAGS

16-bit flags register.

GDTR

Global descriptor table register.

GPRs

General-purpose registers. For the 16-bit data size, these are AX, BX, CX, DX, DI, SI, BP, and SP. For the 32-bit data size, these are EAX, EBX, ECX, EDX, EDI, ESI, EBP, and ESP. For the 64-bit data size, these include RAX, RBX, RCX, RDX, RDI, RSI, RBP, RSP, and R8–R15.

IDTR

Interrupt descriptor table register.

IP

16-bit instruction-pointer register.

LDTR

Local descriptor table register.

MSR

Model-specific register.

r8–r15

The 8-bit R8B–R15B registers, or the 16-bit R8W–R15W registers, or the 32-bit R8D–R15D registers, or the 64-bit R8–R15 registers.

rAX–rSP

The 16-bit AX, BX, CX, DX, DI, SI, BP, and SP registers, or the 32-bit EAX, EBX, ECX, EDX, EDI, ESI, EBP, and ESP registers, or the 64-bit RAX, RBX, RCX, RDX, RDI, RSI, RBP, and RSP registers. Replace the placeholder *r* with nothing for 16-bit size, “E” for 32-bit size, or “R” for 64-bit size.

RAX

64-bit version of the EAX register.

RBP

64-bit version of the EBP register.

RBX

64-bit version of the EBX register.

RCX

64-bit version of the ECX register.

RDI

64-bit version of the EDI register.

RDX

64-bit version of the EDX register.

rFLAGS

16-bit, 32-bit, or 64-bit flags register. Compare *RFLAGS*.

RFLAGS

64-bit flags register. Compare *rFLAGS*.

rIP

16-bit, 32-bit, or 64-bit instruction-pointer register. Compare *RIP*.

RIP

64-bit instruction-pointer register.

RSI

64-bit version of the ESI register.

RSP

64-bit version of the ESP register.

SP

Stack pointer register.

SS

Stack segment register.

TPR

Task priority register, a new register introduced in the AMD64 architecture to speed interrupt management.

TR

Task register.

Endian Order

The x86 and AMD64 architectures address memory using little-endian byte-ordering. Multibyte values are stored with their least-significant byte at the lowest byte address, and they are illustrated with their least significant byte at the right side. Strings are illustrated in reverse order, because the addresses of their bytes increase from right to left.

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1 Instruction Formats

The format of an instruction encodes its operation, as well as the locations of the instruction's initial operands and the result of the operation. This section describes the general format and parameters used by all instructions. For information on the specific format(s) for each instruction, see:

- Chapter 3, "General-Purpose Instruction Reference."
- Chapter 4, "System Instruction Reference."
- "128-Bit Media Instruction Reference" in Volume 4.
- "64-Bit Media Instruction Reference" in Volume 5.
- "x87 Floating-Point Instruction Reference" in Volume 5.

1.1 Instruction Byte Order

An instruction can be between one and 15 bytes in length. Figure 1-1 shows the byte order of the instruction format.

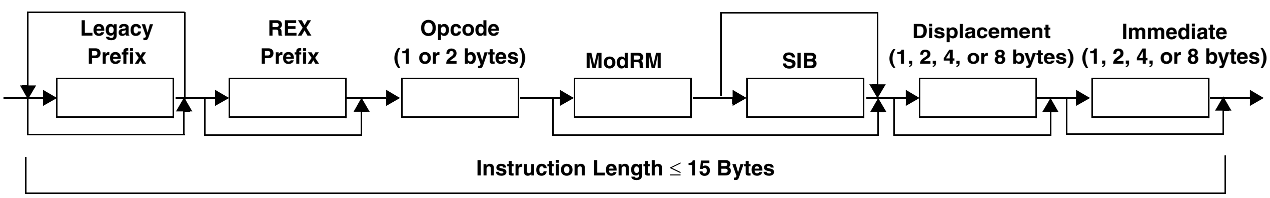


Figure 1-1. Instruction Byte-Order

Instructions are stored in memory in little-endian order. The least-significant byte of an instruction is stored at its lowest memory address, as shown in Figure 1-2 on page 2.

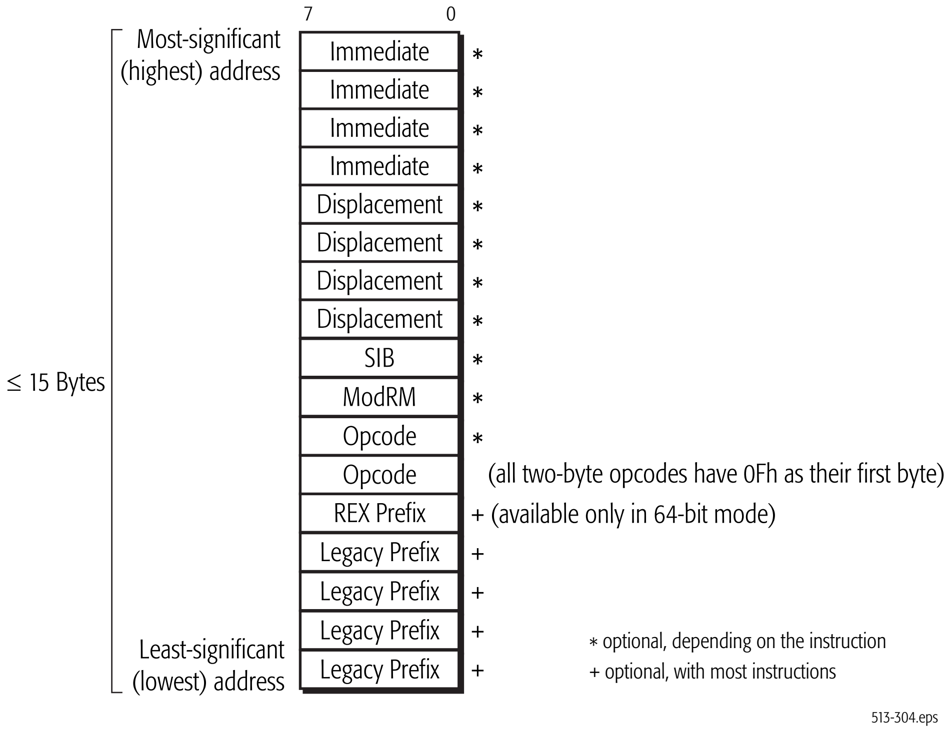


Figure 1-2. Little-Endian Byte-Order of Instruction Stored in Memory

The basic operation of an instruction is specified by an *opcode*. The opcode is one or two bytes long, as described in “Opcode” on page 17. An opcode can be preceded by any number of *legacy prefixes*. These prefixes can be classified as belonging to any of the five groups of prefixes described in “Instruction Prefixes” on page 3. The legacy prefixes modify an instruction’s default address size, operand size, or segment, or they invoke a special function such as modification of the opcode, atomic bus-locking, or repetition. The *REX prefix* can be used in 64-bit mode to access the register extensions illustrated in “Application-Programming Register Set” in Volume 1. If a REX prefix is used, it must immediately precede the first opcode byte.

An instruction’s opcode consists of one or two bytes. In several 128-bit and 64-bit media instructions, a legacy operand-size or repeat prefix byte is used in a special-purpose way to modify the opcode. The opcode can be followed by a *mode-register-memory (ModRM) byte*, which further describes the operation and/or operands. The opcode, or the opcode and ModRM byte, can also be followed by a *scale-index-base (SIB) byte*, which describes the scale, index, and base forms of memory addressing. The ModRM and SIB bytes are described in “ModRM and SIB Bytes” on page 17, but their legacy functions can be modified by the REX prefix (“Instruction Prefixes” on page 3).

The 15-byte instruction-length limit can only be exceeded by using redundant prefixes. If the limit is exceeded, a general-protection exception occurs.

1.2 Instruction Prefixes

The instruction prefixes shown in Figure 1-1 on page 1 are of two types: legacy prefixes and REX prefixes. Each of the legacy prefixes has a unique byte value. By contrast, the REX prefixes, which enable use of the AMD64 register extensions in 64-bit mode, are organized as a group of byte values in which the value of the prefix indicates the combination of register-extension features to be enabled.

1.2.1 Summary of Legacy Prefixes

Table 1-1 on page 4 shows the legacy prefixes—that is, all prefixes except the REX prefixes, which are described on page 11. The legacy prefixes are organized into five groups, as shown in the left-most column of Table 1-1. A single instruction should include a maximum of one prefix from each of the five groups. The legacy prefixes can appear in any order within the position shown in Figure 1-1 for legacy prefixes. The result of using multiple prefixes from a single group is unpredictable.

Some of the restrictions on legacy prefixes are:

- *Operand-Size Override*—This prefix affects only general-purpose instructions and a few x87 instructions. When used with 128-bit and 64-bit media instructions, this prefix acts in a special way to modify the opcode.
- *Address-Size Override*—This prefix affects only memory operands.
- *Segment Override*—In 64-bit mode, the CS, DS, ES, and SS segment override prefixes are ignored.
- *LOCK Prefix*—This prefix is allowed only with certain instructions that modify memory.
- *Repeat Prefixes*—These prefixes affect only certain string instructions. When used with 128-bit and 64-bit media instructions, these prefixes act in a special way to modify the opcode.

Table 1-1. Legacy Instruction Prefixes

Prefix Group[1]	Mnemonic	Prefix Byte (Hex)	Description
Operand-Size Override	none	66[2]	Changes the default operand size of a memory or register operand, as shown in Table 1-2 on page 5.
Address-Size Override	none	67[3]	Changes the default address size of a memory operand, as shown in Table 1-3 on page 6.
Segment Override	CS	2E[4]	Forces use of the current CS segment for memory operands.
	DS	3E[4]	Forces use of the current DS segment for memory operands.
	ES	26[4]	Forces use of the current ES segment for memory operands.
	FS	64	Forces use of the current FS segment for memory operands.
	GS	65	Forces use of the current GS segment for memory operands.
	SS	36[4]	Forces use of the current SS segment for memory operands.
Lock	LOCK	F0[5]	Causes certain kinds of memory read-modify-write instructions to occur atomically.
Repeat	REP	F3[6]	Repeats a string operation (INS, MOVS, OUTS, LODS, and STOS) until the rCX register equals 0.
	REPE or REPZ		Repeats a compare-string or scan-string operation (CMPSx and SCASx) until the rCX register equals 0 or the zero flag (ZF) is cleared to 0.
	REPNE or REPNZ	F2[6]	Repeats a compare-string or scan-string operation (CMPSx and SCASx) until the rCX register equals 0 or the zero flag (ZF) is set to 1.

Note:

1. *A single instruction should include a maximum of one prefix from each of the five groups.*
2. *When used with 128-bit and 64-bit media instructions, this prefix acts in a special way to modify the opcode. The prefix is ignored by 64-bit media floating-point (3DNow!™) instructions. See "Instructions that Cannot Use the Operand-Size Prefix" on page 5.*
3. *This prefix also changes the size of the RCX register when used as an implied count register.*
4. *In 64-bit mode, the CS, DS, ES, and SS segment overrides are ignored.*
5. *The LOCK prefix should not be used for instructions other than those listed in "Lock Prefix" on page 8.*
6. *This prefix should be used only with compare-string and scan-string instructions. When used with 128-bit and 64-bit media instructions, the prefix acts in a special way to modify the opcode.*

1.2.2 Operand-Size Override Prefix

The default operand size for an instruction is determined by a combination of its opcode, the D (default) bit in the current code-segment descriptor, and the current operating mode, as shown in Table 1-2. The operand-size override prefix (66h) selects the non-default operand size. The prefix can be used with any general-purpose instruction that accesses non-fixed-size operands in memory or general-purpose registers (GPRs), and it can also be used with the x87 FLDENV, FNSTENV, FNSAVE, and FRSTOR instructions.

In 64-bit mode, the prefix allows mixing of 16-bit, 32-bit, and 64-bit data on an instruction-by-instruction basis. In compatibility and legacy modes, the prefix allows mixing of 16-bit and 32-bit operands on an instruction-by-instruction basis.

Table 1-2. Operand-Size Overrides

<table>
<tr><th colspan="2" rowspan="2">Operating Mode</th><th rowspan="2">Default Operand Size (Bits)</th><th rowspan="2">Effective Operand Size (Bits)</th><th colspan="2">Instruction Prefix[1]</th></tr>
<tr><th>66h</th><th>REX.W[3]</th></tr>
<tr><td rowspan="7">Long Mode</td><td rowspan="3">64-Bit Mode</td><td rowspan="3">32[2]</td><td>64</td><td>don’t care</td><td>yes</td></tr>
<tr><td>32</td><td>no</td><td>no</td></tr>
<tr><td>16</td><td>yes</td><td>no</td></tr>
<tr><td rowspan="4">Compatibility Mode</td><td rowspan="2">32</td><td>32</td><td>no</td><td rowspan="8">Not Applicable</td></tr>
<tr><td>16</td><td>yes</td></tr>
<tr><td rowspan="2">16</td><td>32</td><td>yes</td></tr>
<tr><td>16</td><td>no</td></tr>
<tr><td colspan="2" rowspan="4">Legacy Mode (Protected, Virtual-8086, or Real Mode)</td><td rowspan="2">32</td><td>32</td><td>no</td></tr>
<tr><td>16</td><td>yes</td></tr>
<tr><td rowspan="2">16</td><td>32</td><td>yes</td></tr>
<tr><td>16</td><td>no</td></tr>
</table>

Note:
1. *A “no’ indicates that the default operand size is used.*
2. *This is the typical default, although some instructions default to other operand sizes. See Appendix B, “General-Purpose Instructions in 64-Bit Mode,” for details.*
3. *See “REX Prefixes” on page 11.*

In 64-bit mode, most instructions default to a 32-bit operand size. For these instructions, a REX prefix (page 13) can specify a 64-bit operand size, and a 66h prefix specifies a 16-bit operand size. The REX prefix takes precedence over the 66h prefix. However, if an instruction defaults to a 64-bit operand size, it does not need a REX prefix and it can only be overridden to a 16-bit operand size. It cannot be overridden to a 32-bit operand size, because there is no 32-bit operand-size override prefix in 64-bit mode. Two groups of instructions have a default 64-bit operand size in 64-bit mode:

- Near branches. For details, see “Near Branches in 64-Bit Mode” in Volume 1.
- All instructions, except far branches, that implicitly reference the RSP. For details, see “Stack Operation” in Volume 1.

Instructions that Cannot Use the Operand-Size Prefix. The operand-size prefix should be used only with general-purpose instructions and the x87 FLDENV, FNSTENV, FNSAVE, and FRSTOR instructions, in which the prefix selects between 16-bit and 32-bit operand size. The prefix is ignored by all other x87 instructions and by 64-bit media floating-point (3DNow!™) instructions.

When used with 64-bit media *integer* instructions, the 66h prefix acts in a special way to modify the opcode. This modification typically causes an access to an XMM register or 128-bit memory operand and thereby converts the 64-bit media instruction into its comparable 128-bit media instruction. The result of using an F2h or F3h repeat prefix along with a 66h prefix in 128-bit or 64-bit media instructions is unpredictable.

Operand-Size and REX Prefixes. The REX operand-size prefix takes precedence over the 66h prefix. See “REX.W: Operand Width” on page 13 for details.

1.2.3 Address-Size Override Prefix

The default address size for instructions that access non-stack memory is determined by the current operating mode, as shown in Table 1-3. The address-size override prefix (67h) selects the non-default address size. Depending on the operating mode, this prefix allows mixing of 16-bit and 32-bit, or of 32-bit and 64-bit addresses, on an instruction-by-instruction basis. The prefix changes the address size for memory operands. It also changes the size of the RCX register for instructions that use RCX implicitly.

For instructions that implicitly access the stack segment (SS), the address size for stack accesses is determined by the D (default) bit in the stack-segment descriptor. In 64-bit mode, the D bit is ignored, and all stack references have a 64-bit address size. However, if an instruction accesses both stack and non-stack memory, the address size of the non-stack access is determined as shown in Table 1-3.

Table 1-3. Address-Size Overrides

Operating Mode		Default Address Size (Bits)	Effective Address Size (Bits)	Address-Size Prefix (67h)[1] Required?
Long Mode	64-Bit Mode	64	64	no
			32	yes
	Compatibility Mode	32	32	no
			16	yes
		16	32	yes
			16	no
Legacy Mode (Protected, Virtual-8086, or Real Mode)		32	32	no
			16	yes
		16	32	yes
			16	no

Note:

1. *A “no” indicates that the default address size is used.*

As Table 1-3 shows, the default address size is 64 bits in 64-bit mode. The size can be overridden to 32 bits, but 16-bit addresses are not supported in 64-bit mode. In compatibility and legacy modes, the default address size is 16 bits or 32 bits, depending on the operating mode (see “Processor Initialization and Long Mode Activation” in Volume 2 for details). In these modes, the address-size prefix selects the non-default size, but the 64-bit address size is not available.

Certain instructions reference pointer registers or count registers implicitly, rather than explicitly. In such instructions, the address-size prefix affects the size of such addressing and count registers, just as it does when such registers are explicitly referenced. Table 1-4 lists all such instructions and the registers referenced using the three possible address sizes.

Table 1-4. Pointer and Count Registers and the Address-Size Prefix

Instruction	Pointer or Count Register		
	16-Bit Address Size	32-Bit Address Size	64-Bit Address Size
CMPS, **CMPSB**, **CMPSW**, **CMPSD, CMPSQ**—Compare Strings	SI, DI, CX	ESI, EDI, ECX	RSI, RDI, RCX
INS, INSB, INSW, INSD—Input String	DI, CX	EDI, ECX	RDI, RCX
JCXZ, **JECXZ, JRCXZ**—Jump on CX/ECX/RCX Zero	CX	ECX	RCX
LODS, **LODSB**, **LODSW**, **LODSD, LODSQ**—Load String	SI, CX	ESI, ECX	RSI, RCX
LOOP, LOOPE, LOOPNZ, **LOOPNE, LOOPZ**—Loop	CX	ECX	RCX
MOVS, **MOVSB**, **MOVSW**, **MOVSD, MOVSQ**—Move String	SI, DI, CX	ESI, EDI, ECX	RSI, RDI, RCX
OUTS, OUTSB, OUTSW, OUTSD—Output String	SI, CX	ESI, ECX	RSI, RCX
REP, REPE, REPNE, REPNZ, REPZ—Repeat Prefixes	CX	ECX	RCX
SCAS, **SCASB**, **SCASW**, **SCASD, SCASQ**—Scan String	DI, CX	EDI, ECX	RDI, RCX
STOS, **STOSB**, **STOSW**, **STOSD, STOSQ**—Store String	DI, CX	EDI, ECX	RDI, RCX
XLAT, **XLATB**—Table Look-up Translation	BX	EBX	RBX

1.2.4 Segment-Override Prefixes

Segment overrides can be used only with instructions that reference non-stack memory. Most instructions that reference memory are encoded with a ModRM byte (page 17). The default segment for such memory-referencing instructions is implied by the base register indicated in its ModRM byte, as follows:

- *Instructions that Reference a Non-Stack Segment*—If an instruction encoding references any base register other than rBP or rSP, or if an instruction contains an immediate offset, the default segment is the data segment (DS). These instructions can use the segment-override prefix to select one of the non-default segments, as shown in Table 1-5.
- *String Instructions*—String instructions reference two memory operands. By default, they reference both the DS and ES segments (DS:rSI and ES:rDI). These instructions can override their DS-segment reference, as shown in Table 1-5, but they cannot override their ES-segment reference.
- *Instructions that Reference the Stack Segment*—If an instruction's encoding references the rBP or rSP base register, the default segment is the stack segment (SS). All instructions that reference the stack (push, pop, call, interrupt, return from interrupt) use SS by default. These instructions cannot use the segment-override prefix.

Table 1-5. Segment-Override Prefixes

Mnemonic	Prefix Byte (Hex)	Description
CS[1]	2E	Forces use of current CS segment for memory operands.
DS[1]	3E	Forces use of current DS segment for memory operands.
ES[1]	26	Forces use of current ES segment for memory operands.
FS	64	Forces use of current FS segment for memory operands.
GS	65	Forces use of current GS segment for memory operands.
SS[1]	36	Forces use of current SS segment for memory operands.

Note:
1. *In 64-bit mode, the CS, DS, ES, and SS segment overrides are ignored.*

Segment Overrides in 64-Bit Mode. In 64-bit mode, the CS, DS, ES, and SS segment-override prefixes have no effect. These four prefixes are not treated as segment-override prefixes for the purposes of multiple-prefix rules. Instead, they are treated as null prefixes.

The FS and GS segment-override prefixes are treated as true segment-override prefixes in 64-bit mode. Use of the FS or GS prefix causes their respective segment bases to be added to the effective address calculation. See "FS and GS Registers in 64-Bit Mode" in Volume 2 for details.

1.2.5 Lock Prefix

The LOCK prefix causes certain kinds of memory read-modify-write instructions to occur atomically. The mechanism for doing so is implementation-dependent (for example, the mechanism may involve bus signaling or packet messaging between the processor and a memory controller). The prefix is intended to give the processor exclusive use of shared memory in a multiprocessor system.

The LOCK prefix can only be used with forms of the following instructions that write a memory operand: ADC, ADD, AND, BTC, BTR, BTS, CMPXCHG, CMPXCHG8B, CMPXCHG16B, DEC, INC, NEG, NOT, OR, SBB, SUB, XADD, XCHG, and XOR. An invalid-opcode exception occurs if the LOCK prefix is used with any other instruction.

1.2.6 Repeat Prefixes

The repeat prefixes cause repetition of certain instructions that load, store, move, input, or output strings. The prefixes should only be used with such string instructions. Two pairs of repeat prefixes, REPE/REPZ and REPNE/REPNZ, perform the same repeat functions for certain compare-string and scan-string instructions. The repeat function uses rCX as a count register. The size of rCX is based on address size, as shown in Table 1-4 on page 7.

REP. The REP prefix repeats its associated string instruction the number of times specified in the counter register (rCX). It terminates the repetition when the value in rCX reaches 0. The prefix can be used with the INS, LODS, MOVS, OUTS, and STOS instructions. Table 1-6 shows the valid REP prefix opcodes.

Table 1-6. REP Prefix Opcodes

Mnemonic	Opcode
REP INS *reg/mem8*, DX REP INSB	F3 6C
REP INS *reg/mem16/32*, DX REP INSW REP INSD	F3 6D
REP LODS *mem8* REP LODSB	F3 AC
REP LODS *mem16/32/64* REP LODSW REP LODSD REP LODSQ	F3 AD
REP MOVS *mem8*, *mem8* REP MOVSB	F3 A4
REP MOVS *mem16/32/64*, *mem16/32/64* REP MOVSW REP MOVSD REP MOVSQ	F3 A5
REP OUTS DX, *reg/mem8* REP OUTSB	F3 6E

Table 1-6. REP Prefix Opcodes (continued)

Mnemonic	Opcode
REP OUTS DX, *reg/mem16/32* REP OUTSW REP OUTSD	F3 6F
REP STOS *mem8* REP STOSB	F3 AA
REP STOS *mem16/32/64* REP STOSW REP STOSD REP STOSQ	F3 AB

REPE and REPZ. REPE and REPZ are synonyms and have identical opcodes. These prefixes repeat their associated string instruction the number of times specified in the counter register (rCX). The repetition terminates when the value in rCX reaches 0 or when the zero flag (ZF) is cleared to 0. The REPE and REPZ prefixes can be used with the CMPS, CMPSB, CMPSD, CMPSW, SCAS, SCASB, SCASD, and SCASW instructions. Table 1-7 shows the valid REPE and REPZ prefix opcodes.

Table 1-7. REPE and REPZ Prefix Opcodes

Mnemonic	Opcode
REPx CMPS *mem8*, *mem8* REPx CMPSB	F3 A6
REPx CMPS *mem16/32/64*, *mem16/32/64* REPx CMPSW REPx CMPSD REPx CMPSQ	F3 A7
REPx SCAS *mem8* REPx SCASB	F3 AE
REPx SCAS *mem16/32/64* REPx SCASW REPx SCASD REPx SCASQ	F3 AF

REPNE and REPNZ. REPNE and REPNZ are synonyms and have identical opcodes. These prefixes repeat their associated string instruction the number of times specified in the counter register (rCX). The repetition terminates when the value in rCX reaches 0 or when the zero flag (ZF) is set to 1. The REPNE and REPNZ prefixes can be used with the CMPS, CMPSB, CMPSD, CMPSW, SCAS, SCASB, SCASD, and SCASW instructions. Table 1-8 on page 11 shows the valid REPNE and REPNZ prefix opcodes.

Table 1-8. REPNE and REPNZ Prefix Opcodes

Mnemonic	Opcode
REPNx CMPS *mem8*, *mem8* REPNx CMPSB	F2 A6
REPNx CMPS *mem16/32/64*, *mem16/32/64* REPNx CMPSW REPNx CMPSD REPNx CMPSQ	F2 A7
REPNx SCAS *mem8* REPNx SCASB	F2 AE
REPNx SCAS *mem16/32/64* REPNx SCASW REPNx SCASD REPNx SCASQ	F2 AF

Instructions that Cannot Use Repeat Prefixes. In general, the repeat prefixes should only be used in the string instructions listed in tables 1-6, 1-7, and 1-8, and in 128-bit or 64-bit media instructions. When used in media instructions, the F2h and F3h prefixes act in a special way to modify the opcode rather than cause a repeat operation. The result of using a 66h operand-size prefix along with an F2h or F3h prefix in 128-bit or 64-bit media instructions is unpredictable.

Optimization of Repeats. Depending on the hardware implementation, the repeat prefixes can have a setup overhead. If the repeated count is variable, the overhead can sometimes be avoided by substituting a simple loop to move or store the data. Repeated string instructions can be expanded into equivalent sequences of inline loads and stores or a sequence of stores can be used to emulate a REP STOS.

For repeated string moves, performance can be maximized by moving the largest possible operand size. For example, use REP MOVSD rather than REP MOVSW and REP MOVSW rather than REP MOVSB. Use REP STOSD rather than REP STOSW and REP STOSW rather than REP MOVSB.

Depending on the hardware implementation, string moves with the direction flag (DF) cleared to 0 (up) may be faster than string moves with DF set to 1 (down). DF = 1 is only needed for certain cases of overlapping REP MOVS, such as when the source and the destination overlap.

1.2.7 REX Prefixes

REX prefixes are a group of instruction-prefix bytes that can be used only in 64-bit mode. They enable access to the AMD64 register extensions. Figure 1-1 on page 1 and Figure 1-2 on page 2 show how a REX prefix fits within the byte order of instructions. REX prefixes enable the following features in 64-bit mode:

- Use of the extended GPR (Figure 2-3 on page 25) or XMM registers (Figure 2-8 on page 30).
- Use of the 64-bit operand size when accessing GPRs.

- Use of the extended control and debug registers, as described in “64-Bit-Mode Extended Control Registers” in Volume 2 and “64-Bit-Mode Extended Debug Registers” in Volume 2.
- Use of the uniform byte registers (AL–R15).

Table 1-9 shows the REX prefixes. The value of a REX prefix is in the range 40h through 4Fh, depending on the particular combination of AMD64 register extensions desired.

Table 1-9. REX Instruction Prefixes

Prefix Type	Mnemonic	Prefix Code (Hex)	Description
Register Extensions	REX.W	40[1] through 4F[1]	Access an AMD64 register extension.
	REX.R		
	REX.X		
	REX.B		

Note:
1. *See Table 1-11 for encoding of REX prefixes.*

A REX prefix is normally required with an instruction that accesses a 64-bit GPR or one of the extended GPR or XMM registers. Only a few instructions have an operand size that defaults to (or is fixed at) 64 bits in 64-bit mode, and thus do not need a REX prefix. These exceptions to the normal rule are listed in Table 1-10.

Table 1-10. Instructions Not Requiring REX Size Prefix in 64-Bit Mode

CALL (Near)	POP reg/mem
ENTER	POP reg
J*cc*	POP FS
J*r*CXZ	POP GS
JMP (Near)	POPFQ
LEAVE	PUSH imm8
LGDT	PUSH imm32
LIDT	PUSH reg/mem
LLDT	PUSH reg
LOOP	PUSH FS
LOOP*cc*	PUSH GS
LTR	PUSHFQ
MOV CR(*n*)	RET (Near)
MOV DR(*n*)	

An instruction can have only one REX prefix, although the prefix can express several extension features. If a REX prefix is used, it must immediately precede the first opcode byte in the instruction format. Any other placement of a REX prefix, or any use of a REX prefix in an instruction that does not access an extended register, is ignored. The legacy instruction-size limit of 15 bytes still applies to instructions that contain a REX prefix.

REX prefixes are a set of sixteen values that span one row of the main opcode map and occupy entries 40h through 4Fh. Table 1-11 and Figure 1-3 on page 15 show the prefix fields and their uses.

Table 1-11. REX Prefix-Byte Fields

Mnemonic	Bit Position	Definition
—	7–4	0100
REX.W	3	0 = Default operand size 1 = 64-bit operand size
REX.R	2	1-bit (high) extension of the ModRM *reg* field[1], thus permitting access to 16 registers.
REX.X	1	1-bit (high) extension of the SIB *index* field[1], thus permitting access to 16 registers.
REX.B	0	1-bit (high) extension of the ModRM *r/m* field[1], SIB *base* field[1], or opcode *reg* field, thus permitting access to 16 registers.

Note:
1. For a description of the ModRM and SIB bytes, see "ModRM and SIB Bytes" on page 17.

REX.W: Operand Width. Setting the REX.W bit to 1 specifies a 64-bit operand size. Like the existing 66h operand-size prefix, the REX 64-bit operand-size override has no effect on byte operations. For non-byte operations, the REX operand-size override takes precedence over the 66h prefix. If a 66h prefix is used together with a REX prefix that has the REX.W bit set to 1, the 66h prefix is ignored. However, if a 66h prefix is used together with a REX prefix that has the REX.W bit cleared to 0, the 66h prefix is not ignored and the operand size becomes 16 bits.

REX.R: Register. The REX.R bit adds a 1-bit (high) extension to the ModRM *reg* field (page 17) when that field encodes a GPR, XMM, control, or debug register. REX.R does not modify ModRM *reg* when that field specifies other registers or opcodes. REX.R is ignored in such cases.

REX.X: Index. The REX.X bit adds a 1-bit (high) extension to the SIB *index* field (page 17).

REX.B: Base. The REX.B bit adds a 1-bit (high) extension to either the ModRM *r/m* field to specify a GPR or XMM register, or to the SIB *base* field to specify a GPR. (See Table 2-2 on page 40 for more about the REX.B bit.)

Encoding Examples. Figure 1-3 on page 15 shows four examples of how the R, X, and B bits of REX prefixes are concatenated with fields from the ModRM byte, SIB byte, and opcode to specify register and memory addressing. The R, X, and B bits are described in Table 1-11 on page 13.

Byte-Register Addressing. In the legacy architecture, the byte registers (AH, AL, BH, BL, CH, CL, DH, and DL, shown in Figure 2-2 on page 24) are encoded in the ModRM *reg* or *r/m* field or in the opcode *reg* field as registers 0 through 7. The REX prefix provides an additional byte-register addressing capability that makes the least-significant byte of any GPR available for byte operations (Figure 2-3 on page 25). This provides a uniform set of byte, word, doubleword, and quadword registers better suited for register allocation by compilers.

Special Encodings for Registers. Readers who need to know the details of instruction encodings should be aware that certain combinations of the ModRM and SIB fields have special meaning for register encodings. For some of these combinations, the instruction fields expanded by the REX prefix are not decoded (treated as don't cares), thereby creating aliases of these encodings in the extended registers. Table 1-12 on page 16 describes how each of these cases behaves.

Implications for INC and DEC Instructions. The REX prefix values are taken from the 16 single-byte INC and DEC instructions, one for each of the eight GPRs. Therefore, these single-byte opcodes for INC and DEC are not available in 64-bit mode, although they are available in legacy and compatibility modes. The functionality of these INC and DEC instructions is still available in 64-bit mode, however, using the ModRM forms of those instructions (opcodes FF /0 and FF /1).

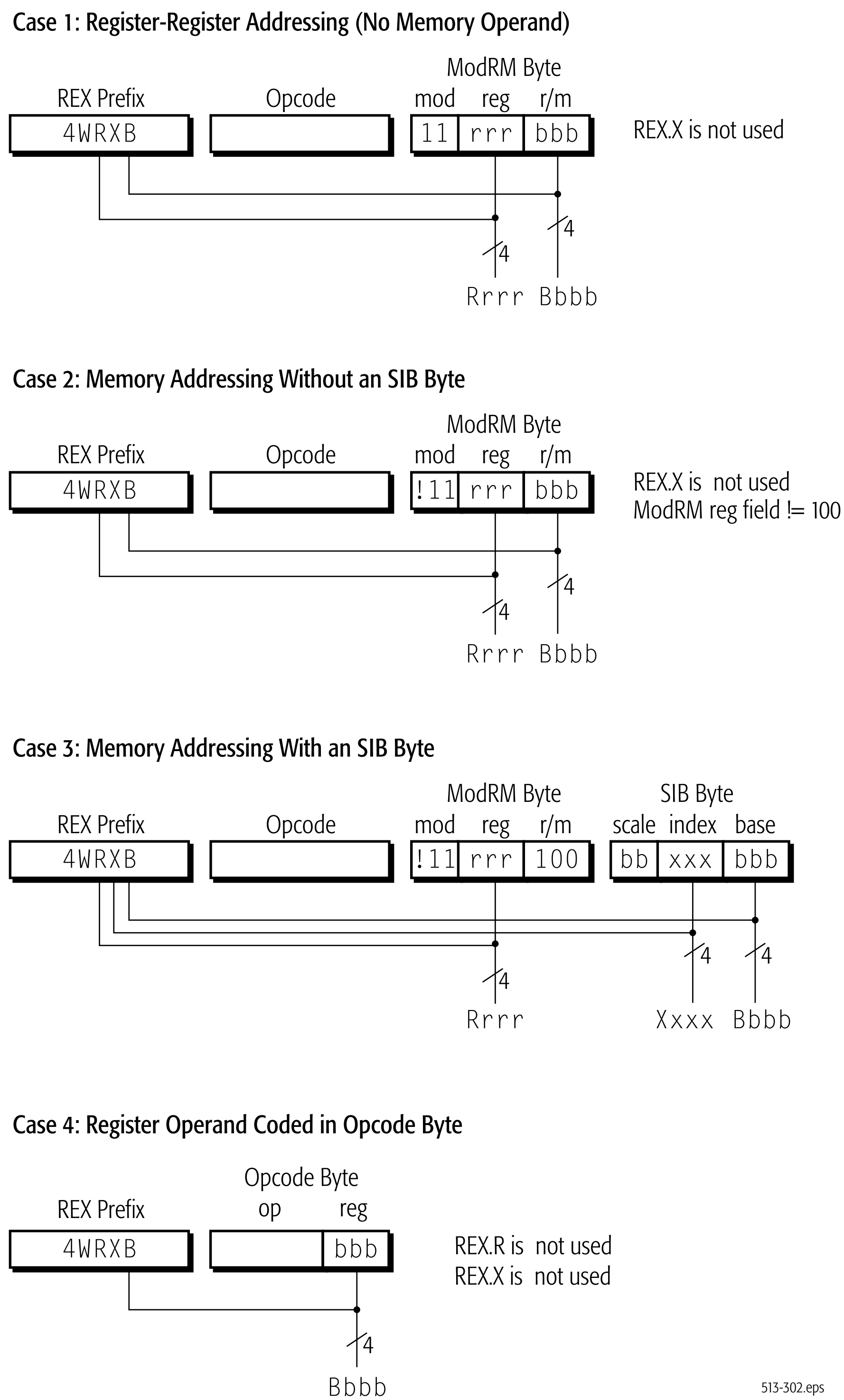


Figure 1-3. Encoding Examples of REX-Prefix R, X, and B Bits

Table 1-12. Special REX Encodings for Registers

ModRM and SIB Encodings[2]	Meaning in Legacy and Compatibility Modes	Implications in Legacy and Compatibility Modes	Additional REX Implications
ModRM Byte: • mod ≠ 11 • r/m[1] = 100 (ESP)	SIB byte is present.	SIB byte is required for ESP-based addressing.	REX prefix adds a fourth bit (b), which is decoded and modifies the base register in the SIB byte. Therefore, the SIB byte is also required for R12-based addressing.
ModRM Byte: • mod = 00 • r/m[1] = x101 (EBP)	Base register is not used.	Using EBP without a displacement must be done by setting mod = 01 with a displacement of 0 (with or without an index register).	REX prefix adds a fourth bit (x), which is not decoded (don't care). Therefore, using RBP or R13 without a displacement must be done via mod = 01 with a displacement of 0.
SIB Byte: • index[1] = x100 (ESP)	Index register is not used.	ESP cannot be used as an index register.	REX prefix adds a fourth bit (x), which is decoded. Therefore, there are no additional implications. The expanded index field is used to distinguish RSP from R12, allowing R12 to be used as an index.
SIB Byte: • base = b101 (EBP) • ModRM.mod = 00	Base register is not used if ModRM.mod = 00.	Base register depends on mod encoding. Using EBP with a scaled index and without a displacement must be done by setting mod = 01 with a displacement of 0.	REX prefix adds a fourth bit (b), which is not decoded (don't care). Therefore, using RBP or R13 without a displacement must be done via mod = 01 with a displacement of 0 (with or without an index register).

Note:

1. *The REX-prefix bit is shown in the fourth (most-significant) bit position of the encodings for the ModRM r/m, SIB index, and SIB base fields. The lower-case "x" for ModRM r/m (rather than the upper-case "B" shown in Figure 1-3 on page 15) indicates that the REX-prefix bit is not decoded (don't care).*
2. *For a description of the ModRM and SIB bytes, see "ModRM and SIB Bytes" on page 17.*

1.3 Opcode

Each instruction has a unique opcode, although assemblers can support multiple mnemonics for a single instruction opcode. The opcode specifies the operation that the instruction performs and, in certain cases, the kinds of operands it uses. An opcode consists of one or two bytes, but certain 128-bit media instructions also use a prefix byte in a special way to modify the opcode. The 3-bit *reg* field of the ModRM byte ("ModRM and SIB Bytes" on page 17) is also used in certain instructions either for three additional opcode bits or for a register specification.

128-Bit and 64-Bit Media Instruction Opcodes. Many 128-bit and 64-bit media instructions include a 66h, F2h, or F3h prefix byte in a special way to modify the opcode. These same byte values can be used in certain general-purpose and x87 instructions to modify operand size (66h) or repeat the operation (F2h, F3h). In 128-bit and 64-bit media instructions, however, such prefix bytes modify the opcode. If a 128-bit or 64-bit media instruction uses one of these three prefixes, and also includes any other prefix in the 66h, F2h, and F3h group, the result is unpredictable.

All opcodes for 64-bit media instructions begin with a 0Fh byte. In the case of 64-bit floating-point (3DNow!) instructions, the 0Fh byte is followed by a second 0Fh opcode byte. A third opcode byte occupies the same position at the end of a 3DNow! instruction as would an immediate byte. The value of the immediate byte is shown as the third opcode byte-value in the syntax for each instruction in "64-Bit Media Instruction Reference" in Volume 5. The format is:

```
0Fh 0Fh ModRM [SIB] [displacement] 3DNow!_third_opcode_byte
```

For details on opcode encoding, see Appendix A, "Opcode and Operand Encodings."

1.4 ModRM and SIB Bytes

The ModRM byte is used in certain instruction encodings to:

- Define a register reference.
- Define a memory reference.
- Provide additional opcode bits with which to define the instruction's function.

ModRM bytes have three fields—*mod, reg*, and *r/m*. The *reg* field provides additional opcode bits with which to define the function of the instruction or one of its operands. The *mod* and *r/m* fields are used together with each other and, in 64-bit mode, with the REX.R and REX.B bits of the REX prefix (page 11), to specify the location of an instruction's operands and certain of the possible addressing modes (specifically, the non-complex modes).

Figure 1-4 on page 18 shows the format of a ModRM byte.

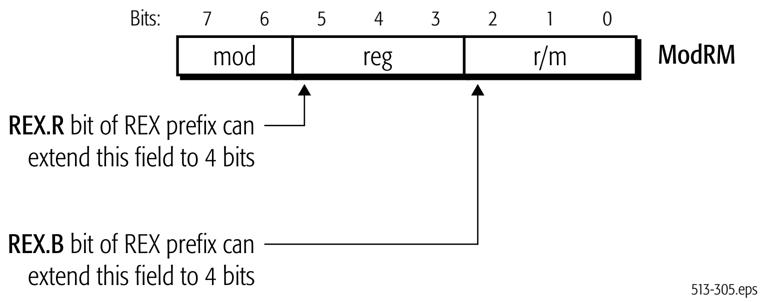


Figure 1-4. ModRM-Byte Format

In some instructions, the ModRM byte is followed by an SIB byte, which defines memory addressing for the complex-addressing modes described in "Effective Addresses" in Volume 1. The SIB byte has three fields—*scale, index*, and *base*—that define the scale factor, index-register number, and base-register number for 32-bit and 64-bit complex addressing modes. In 64-bit mode, the REX.B and REX.X bits extend the encoding of the SIB byte's *base* and *index* fields.

Figure 1-5 shows the format of an SIB byte.

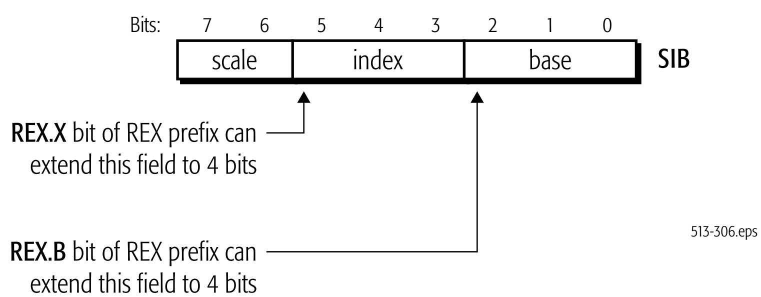


Figure 1-5. SIB-Byte Format

The encodings of ModRM and SIB bytes not only define memory-addressing modes, but they also specify operand registers. The encodings do this by using 3-bit fields in the ModRM and SIB bytes, depending on the format:

- *ModRM:* the *reg* and *r/m* fields of the ModRM byte. (Case 1 in Figure 1-3 on page 15 shows an example of this).
- *ModRM with SIB:* the *reg* field of the ModRM byte and the *base* and *index* fields of the SIB byte. (Case 3 in Figure 1-3 on page 15 shows an example of this).

- *Instructions without ModRM:* the *reg* field of the opcode. (Case 4 in Figure 1-3 on page 15 shows an example of this).

In 64-bit mode, the bits needed to extend each field for accessing the additional registers are provided by the REX prefixes, as shown in Figure 1-4 and Figure 1-5 on page 18.

For details on opcode encoding, see Appendix A, "Opcode and Operand Encodings."

1.5 Displacement Bytes

A *displacement* (also called an *offset)* is a signed value that is added to the base of a code segment (absolute addressing) or to an instruction pointer (relative addressing), depending on the addressing mode. The size of a displacement is 1, 2, or 4 bytes. If an addressing mode requires a displacement, the bytes (1, 2, or 4) for the displacement follow the opcode, ModRM, or SIB byte (whichever comes last) in the instruction encoding.

In 64-bit mode, the same ModRM and SIB encodings are used to specify displacement sizes as those used in legacy and compatibility modes. However, the displacement is sign-extended to 64 bits during effective-address calculations. Also, in 64-bit mode, support is provided for some 64-bit displacement and immediate forms of the MOV instruction. See "Immediate Operand Size" in Volume 1 for more information on this.

1.6 Immediate Bytes

An *immediate* is a value—typically an operand value—encoded directly into the instruction. Depending on the opcode and the operating mode, the size of an immediate operand can be 1, 2, 4, or 8 bytes. 64-bit immediates are allowed in 64-bit mode on MOV instructions that load GPRs, otherwise they are limited to 4 bytes. See "Immediate Operand Size" in Volume 1 for more information.

If an instruction takes an immediate operand, the bytes (1, 2, 4, or 8) for the immediate follow the opcode, ModRM, SIB, or displacement bytes (whichever come last) in the instruction encoding. Some 128-bit media instructions use the immediate byte as a condition code.

1.7 RIP-Relative Addressing

In 64-bit mode, addressing relative to the contents of the 64-bit instruction pointer (program counter)—called RIP-relative addressing or PC-relative addressing—is implemented for certain instructions. In such cases, the effective address is formed by adding the displacement to the 64-bit RIP of the next instruction.

In the legacy x86 architecture, addressing relative to the instruction pointer is available only in control-transfer instructions. In the 64-bit mode, any instruction that uses ModRM addressing can use RIP-relative addressing. This feature is particularly useful for addressing data in position-independent code and for code that addresses global data.

Without RIP-relative addressing, ModRM instructions address memory relative to zero. With RIP-relative addressing, ModRM instructions can address memory relative to the 64-bit RIP using a signed 32-bit displacement. This provides an offset range of ±2 Gbytes from the RIP.

Programs usually have many references to data, especially global data, that are not register-based. To load such a program, the loader typically selects a location for the program in memory and then adjusts program references to global data based on the load location. RIP-relative addressing of data makes this adjustment unnecessary.

1.7.1 Encoding

Table 1-13 shows the ModRM and SIB encodings for RIP-relative addressing. Redundant forms of 32-bit displacement-only addressing exist in the current ModRM and SIB encodings. There is one ModRM encoding with several SIB encodings. RIP-relative addressing is encoded using one of the redundant forms. In 64-bit mode, the ModRM *Disp32* (32-bit displacement) encoding is redefined to be *RIP + Disp32* rather than displacement-only.

Table 1-13. Encoding for RIP-Relative Addressing

ModRM and SIB Encodings	Meaning in Legacy and Compatibility Modes	Meaning in 64-bit Mode	Additional 64-bit Implications
ModRM Byte: • mod = 00 • r/m = 101 (none)	Disp32	RIP + Disp32	Zero-based (normal) displacement addressing must use SIB form (see next row).
SIB Byte: • base = 101 (none) • index = 100 (none) • scale = 1, 2, 4,8	If mod = 00, Disp32	Same as Legacy	None

1.7.2 REX Prefix and RIP-Relative Addressing

ModRM encoding for RIP-relative addressing does not depend on a REX prefix. In particular, the *r/m* encoding of 101, used to select RIP-relative addressing, is not affected by the REX prefix. For example, selecting R13 (REX.B = 1, r/m = 101) with mod = 00 still results in RIP-relative addressing.

The four-bit *r/m* field of ModRM is not fully decoded. Therefore, in order to address R13 with no displacement, software must encode it as R13 + 0 using a one-byte displacement of zero.

1.7.3 Address-Size Prefix and RIP-Relative Addressing

RIP-relative addressing is enabled by 64-bit mode, not by a 64-bit address-size. Conversely, use of the address-size prefix (“Address-Size Override Prefix” on page 6) does not disable RIP-relative addressing. The effect of the address-size prefix is to truncate and zero-extend the computed effective address to 32 bits, like any other addressing mode.

2 Instruction Overview

2.1 Instruction Subsets

For easier reference, the instruction descriptions are divided into five instruction subsets. The following sections describe the function, mnemonic syntax, opcodes, affected flags, and possible exceptions generated by all instructions in the AMD64 architecture:

- *Chapter 3, "General-Purpose Instruction Reference"*—The general-purpose instructions are used in basic software execution. Most of these load, store, or operate on data in the general-purpose registers (GPRs), in memory, or in both. Other instructions are used to alter sequential program flow by branching to other locations within the program or to entirely different programs.
- *Chapter 4, "System Instruction Reference"*—The system instructions establish the processor operating mode, access processor resources, handle program and system errors, and manage memory.
- *"128-Bit Media Instruction Reference" in Volume 4*—The 128-bit media instructions load, store, or operate on data located in the 128-bit XMM registers. These instructions define both vector and scalar operations on floating-point and integer data types. They include the SSE and SSE2 instructions that operate on the XMM registers. Some of these instructions convert source operands in XMM registers to destination operands in GPR, MMX, or x87 registers or otherwise affect XMM state.
- *"64-Bit Media Instruction Reference" in Volume 5*—The 64-bit media instructions load, store, or operate on data located in the 64-bit MMX registers. These instructions define both vector and scalar operations on integer and floating-point data types. They include the legacy MMX™ instructions, the 3DNow!™ instructions, and the AMD extensions to the MMX and 3DNow! instruction sets. Some of these instructions convert source operands in MMX registers to destination operands in GPR, XMM, or x87 registers or otherwise affect MMX state.
- *"x87 Floating-Point Instruction Reference" in Volume 5*—The x87 instructions are used in legacy floating-point applications. Most of these instructions load, store, or operate on data located in the x87 ST(0)–ST(7) stack registers (the FPR0–FPR7 physical registers). The remaining instructions within this category are used to manage the x87 floating-point environment.

The description of each instruction covers its behavior in all operating modes, including legacy mode (real, virtual-8086, and protected modes) and long mode (compatibility and 64-bit modes). Details of certain kinds of complex behavior—such as control-flow changes in CALL, INT, or FXSAVE instructions—have cross-references in the instruction-detail pages to detailed descriptions in volumes 1 and 2.

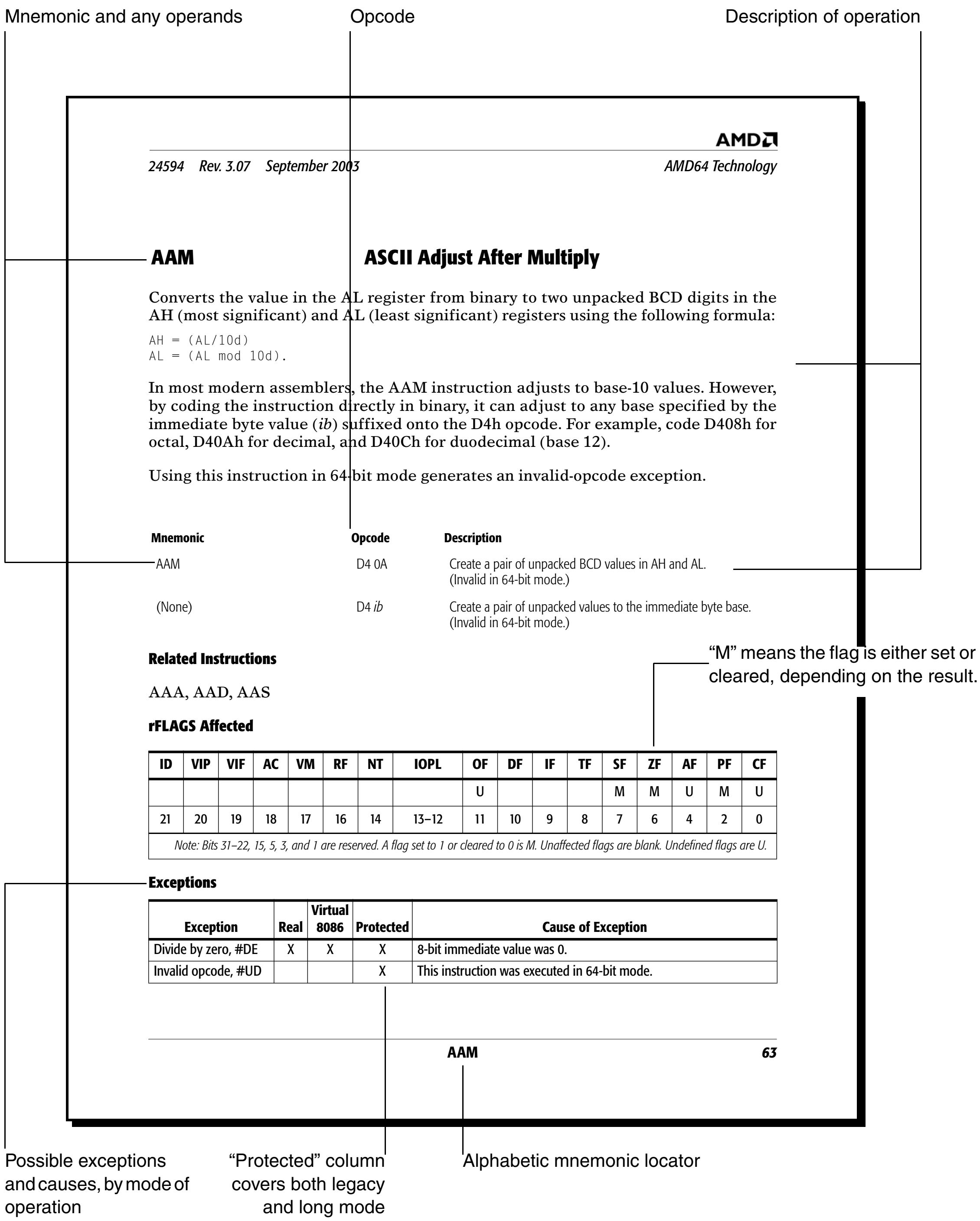
Two instructions—CMPSD and MOVSD—use the same mnemonic for different instructions. Assemblers can distinguish them on the basis of the number and type of operands with which they are used.

2.2 Reference-Page Format

Figure 2-1 on page 23 shows the format of an instruction-detail page. The instruction mnemonic is shown in bold at the top-left, along with its name. In this example, *POPFD* is the mnemonic and *POP to EFLAGS Doubleword* is the name. Next, there is a general description of the instruction's operation. Many descriptions have cross-references to more detail in other parts of the manual.

Beneath the general description, the mnemonic is shown again, together with the related opcode(s) and a description summary. Related instructions are listed below this, followed by a table showing the flags that the instruction can affect. Finally, each instruction has a summary of the possible exceptions that can occur when executing the instruction. The columns labeled "Real" and "Virtual-8086" apply only to execution in legacy mode. The column labeled "Protected" applies both to legacy mode and long mode, because long mode is a superset of legacy protected mode.

The 128-bit and 64-bit media instructions also have diagrams illustrating the operation. A few instructions have examples or pseudocode describing the action.



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AAM **ASCII Adjust After Multiply**

Converts the value in the AL register from binary to two unpacked BCD digits in the AH (most significant) and AL (least significant) registers using the following formula:

```
AH = (AL/10d)
AL = (AL mod 10d).
```

In most modern assemblers, the AAM instruction adjusts to base-10 values. However, by coding the instruction directly in binary, it can adjust to any base specified by the immediate byte value (*ib*) suffixed onto the D4h opcode. For example, code D408h for octal, D40Ah for decimal, and D40Ch for duodecimal (base 12).

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
AAM	D4 0A	Create a pair of unpacked BCD values in AH and AL. (Invalid in 64-bit mode.)
(None)	D4 *ib*	Create a pair of unpacked values to the immediate byte base. (Invalid in 64-bit mode.)

Related Instructions

AAA, AAD, AAS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				M	M	U	M	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M. Unaffected flags are blank. Undefined flags are U.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Divide by zero, #DE	X	X	X	8-bit immediate value was 0.
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

AAM 63

Figure 2-1. Format of Instruction-Detail Pages

2.3 Summary of Registers and Data Types

This section summarizes the registers available to software using the five instruction subsets described in "Instruction Subsets" on page 21. For details on the organization and use of these registers, see their respective chapters in volumes 1 and 2.

2.3.1 General-Purpose Instructions

Registers. The size and number of general-purpose registers (GPRs) depends on the operating mode, as do the size of the flags and instruction-pointer registers. Figure 2-2 shows the registers available in legacy and compatibility modes.

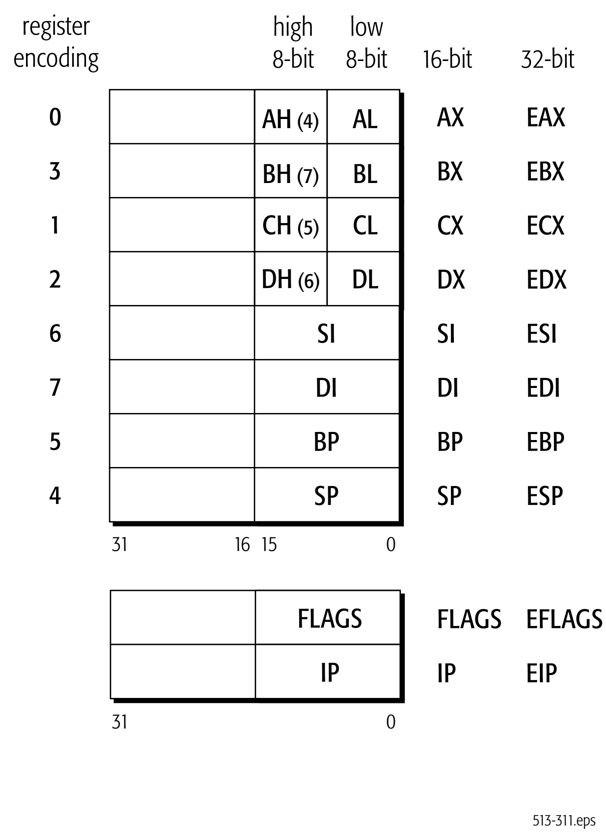


Figure 2-2. General Registers in Legacy and Compatibility Modes

Figure 2-3 on page 25 shows the registers accessible in 64-bit mode. Compared with legacy mode, registers become 64 bits wide, eight new data registers (R8–R15) are added and the low byte of all 16 GPRs is available for byte operations, and the four high-byte registers of legacy mode (AH, BH, CH, and DH) are not available if the REX prefix is used. The high 32 bits of doubleword operands are zero-extended to 64 bits, but the high bits of word and byte operands are not modified by operations in 64-

bit mode. The RFLAGS register is 64 bits wide, but the high 32 bits are reserved. They can be written with anything but they read as zeros (RAZ).

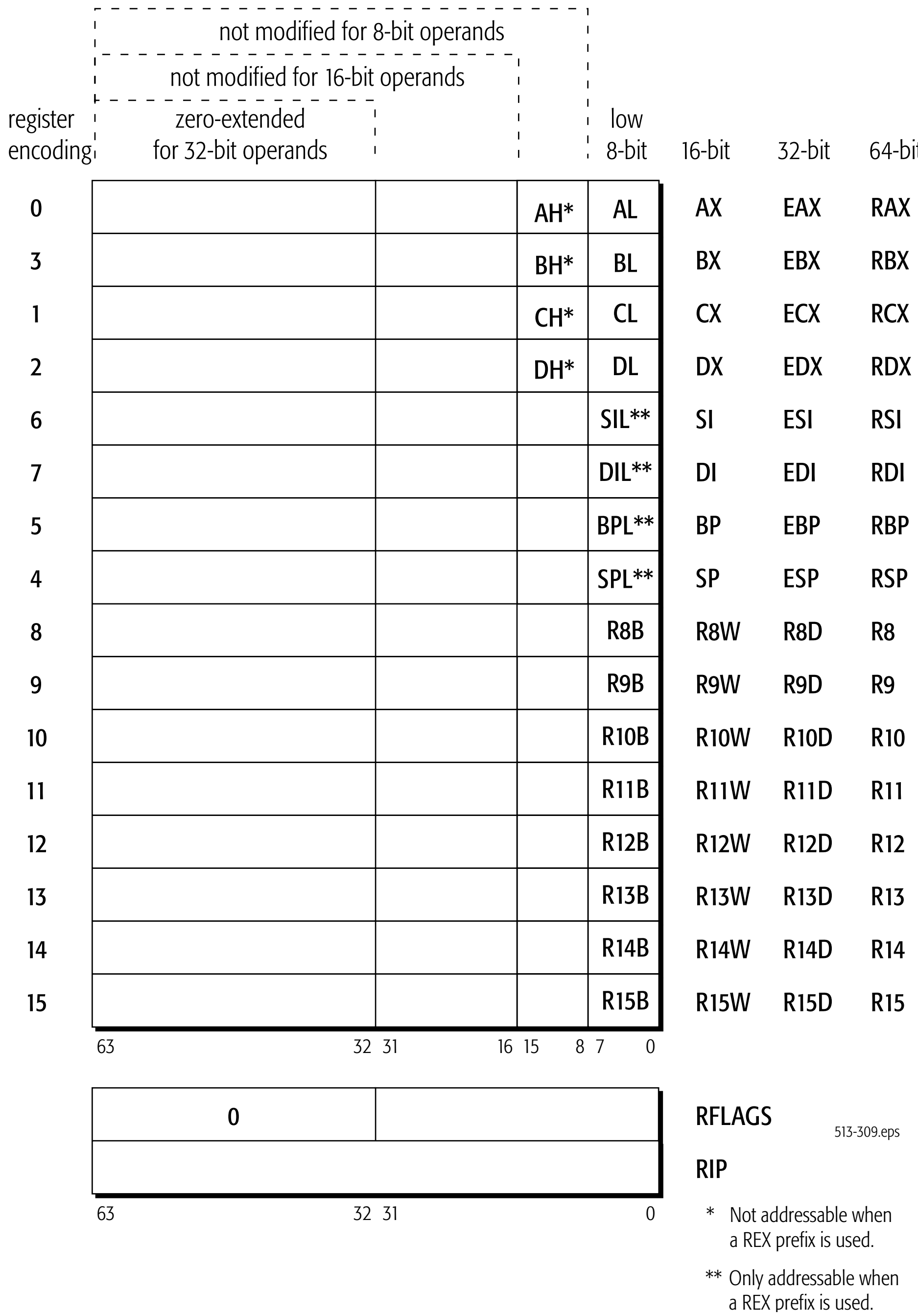


Figure 2-3. General Registers in 64-Bit Mode

For most instructions running in 64-bit mode, access to the extended GPRs requires a REX instruction prefix (page 11).

Figure 2-4 shows the segment registers which, like the instruction pointer, are used by all instructions. In legacy and compatibility modes, all segments are accessible. In 64-bit mode, which uses the flat (non-segmented) memory model, only the CS, FS, and GS segments are recognized, whereas the contents of the DS, ES, and SS segment registers are ignored (the base for each of these segments is assumed to be zero, and neither their segment limit nor attributes are checked). For details, see "Segmented Virtual Memory" in Volume 2.

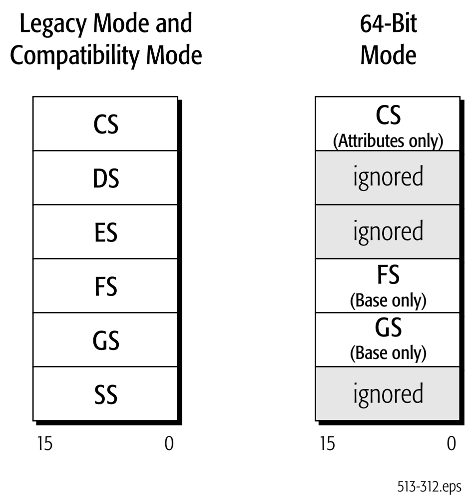


Figure 2-4. Segment Registers

Data Types. Figure 2-5 on page 27 shows the general-purpose data types. They are all scalar, integer data types. The 64-bit (quadword) data types are only available in 64-bit mode, and for most instructions they require a REX instruction prefix.

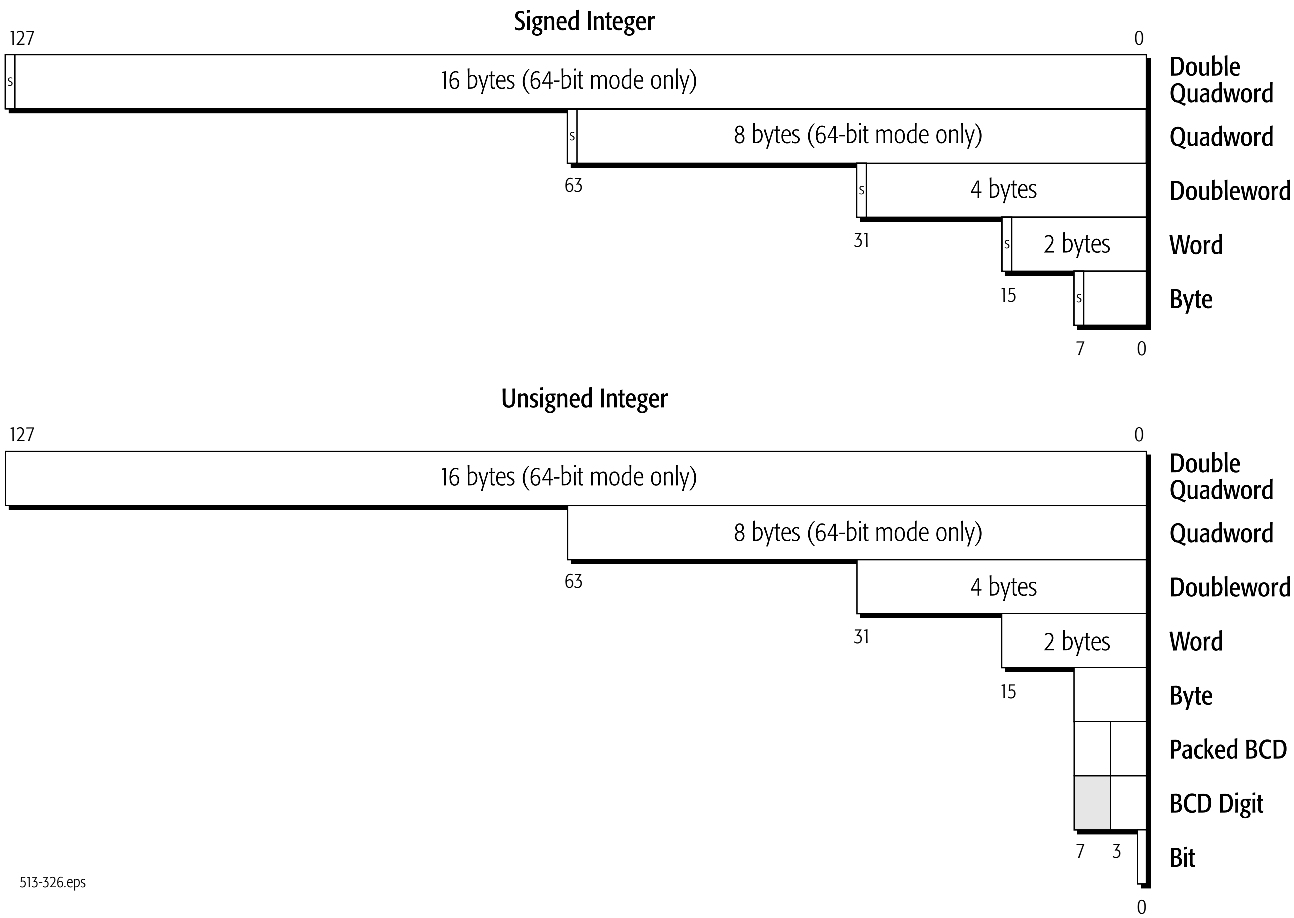


Figure 2-5. General-Purpose Data Types

2.3.2 System Instructions

Registers. The system instructions use several specialized registers shown in Figure 2-6 on page 28. System software uses these registers to, among other things, manage the processor's operating environment, define system resource characteristics, and monitor software execution. With the exception of the RFLAGS register, system registers can be read and written only from privileged software.

All system registers are 64 bits wide, except for the descriptor-table registers and the task register, which include 64-bit base-address fields and other fields.

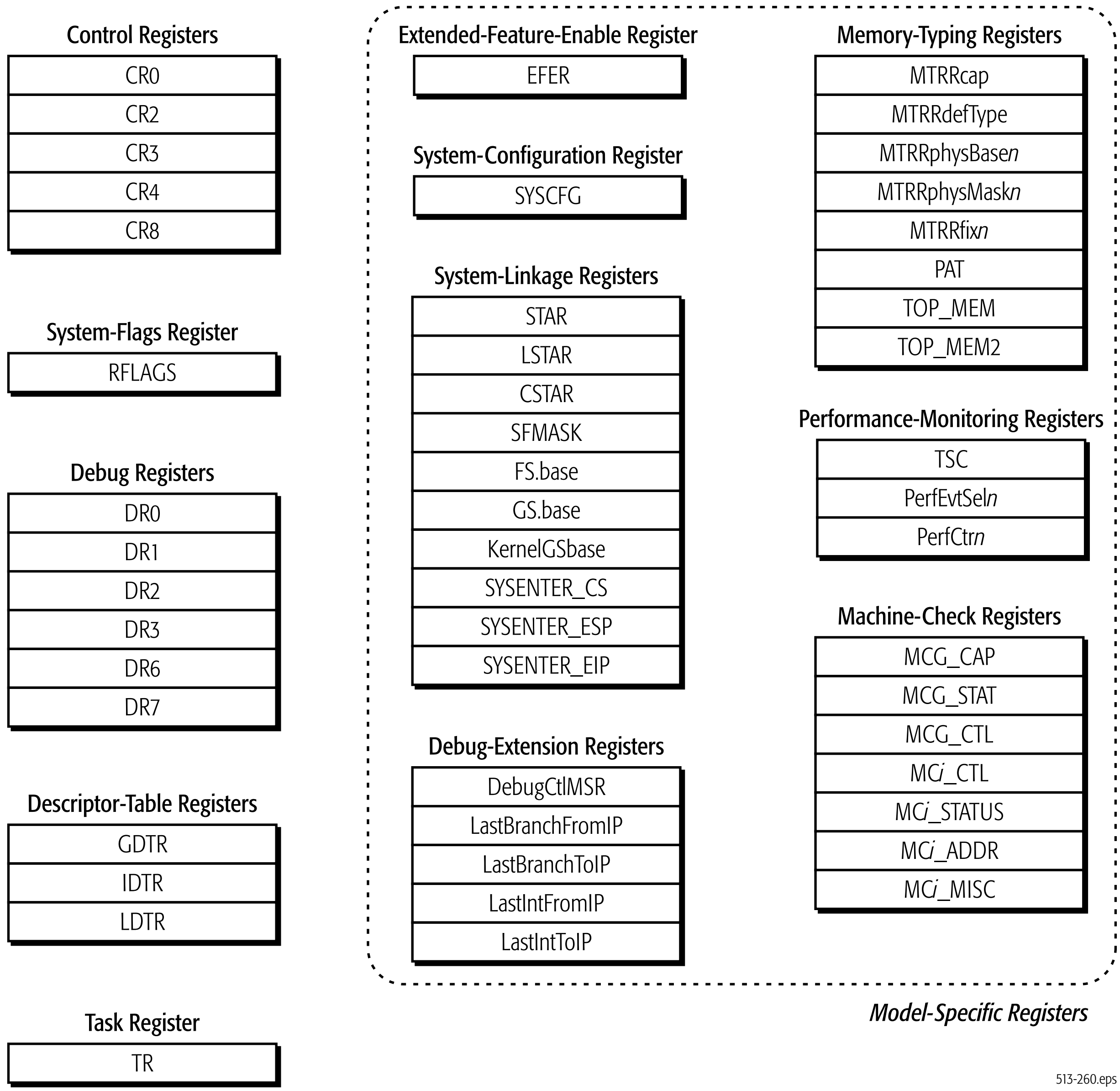


Figure 2-6. System Registers

Data Structures. Figure 2-7 on page 29 shows the system data structures. These are created and maintained by system software for use in protected mode. A processor running in protected mode uses these data structures to manage memory and protection, and to store program-state information when an interrupt or task switch occurs.

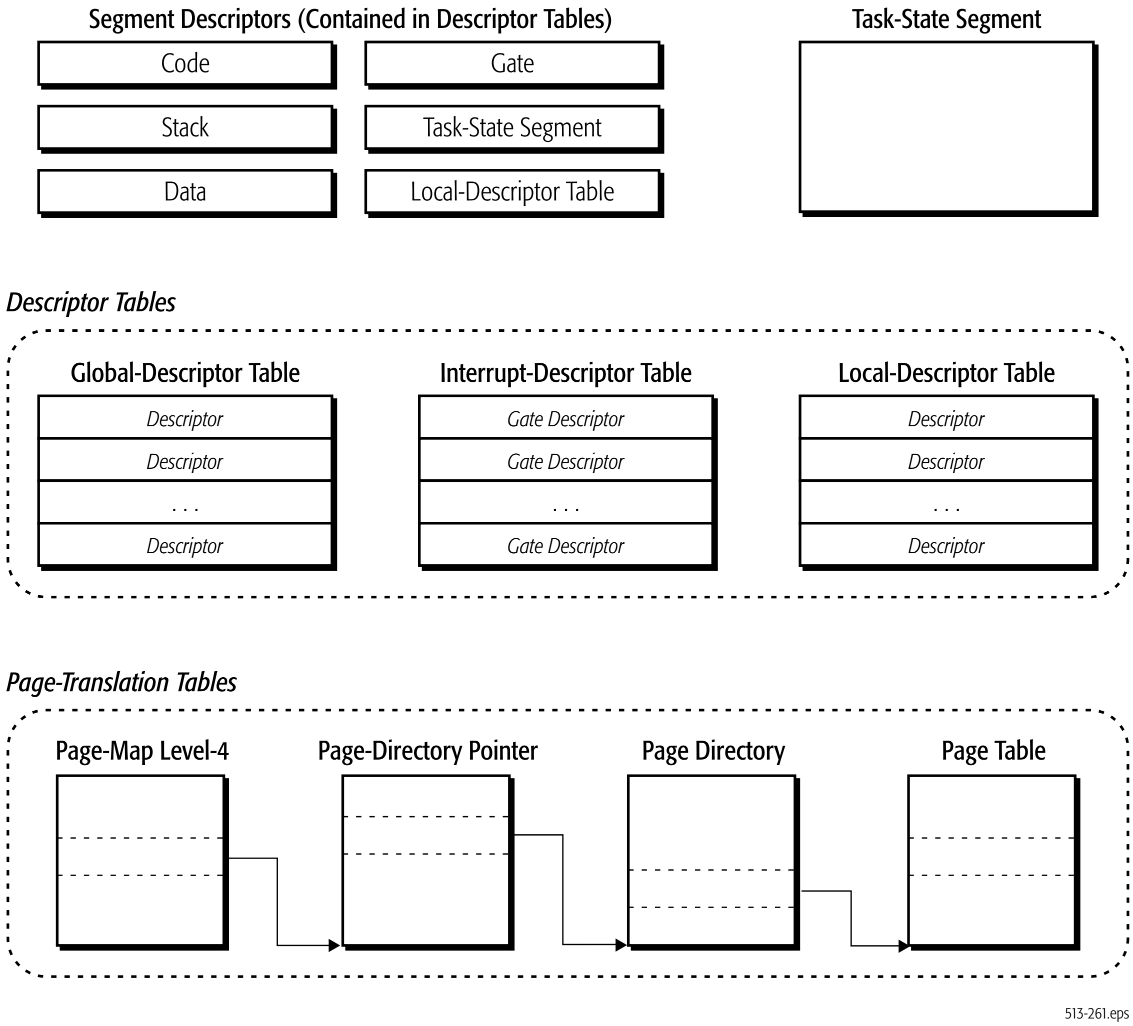


Figure 2-7. System Data Structures

2.3.3 128-Bit Media Instructions

Registers. The 128-bit media instructions use the 128-bit XMM registers. The number of available XMM data registers depends on the operating mode, as shown in Figure 2-8 on page 30. In legacy and compatibility modes, the eight legacy XMM data registers (XMM0–XMM7) are available. In 64-bit mode, eight additional XMM data registers (XMM8–XMM15) are available when a REX instruction prefix is used.

The MXCSR register contains floating-point and other control and status flags used by the 128-bit media instructions. Some 128-bit media instructions also use the GPR (Figure 2-2 and Figure 2-3) and the MMX registers (Figure 2-10 on page 32) or set or clear flags in the rFLAGS register (see Figure 2-2 and Figure 2-3).

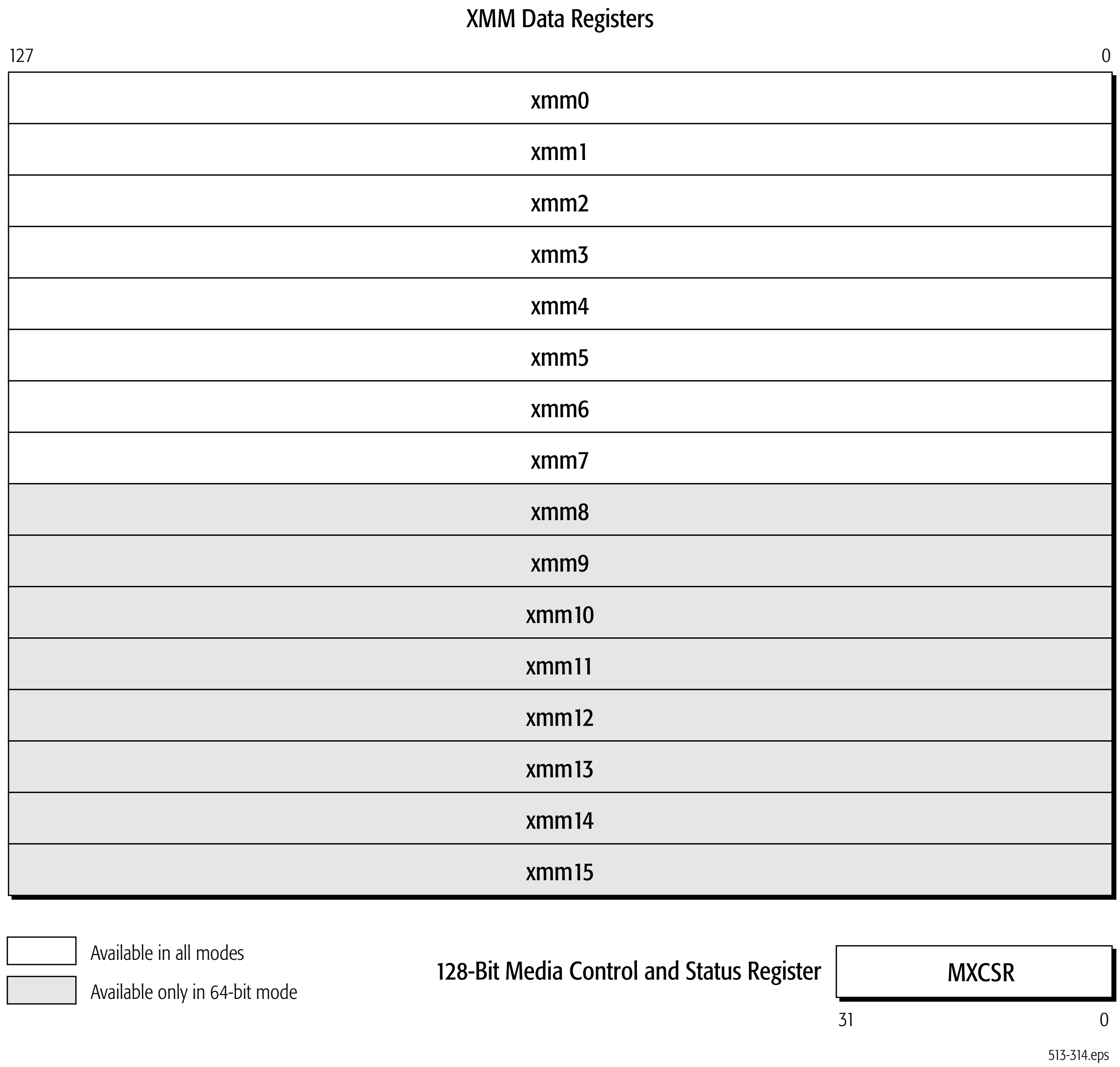


Figure 2-8. 128-Bit Media Registers

Data Types. Figure 2-9 on page 31 shows the 128-bit media data types. They include floating-point and integer vectors and floating-point scalars. The floating-point data types include IEEE-754 single precision and double precision types.

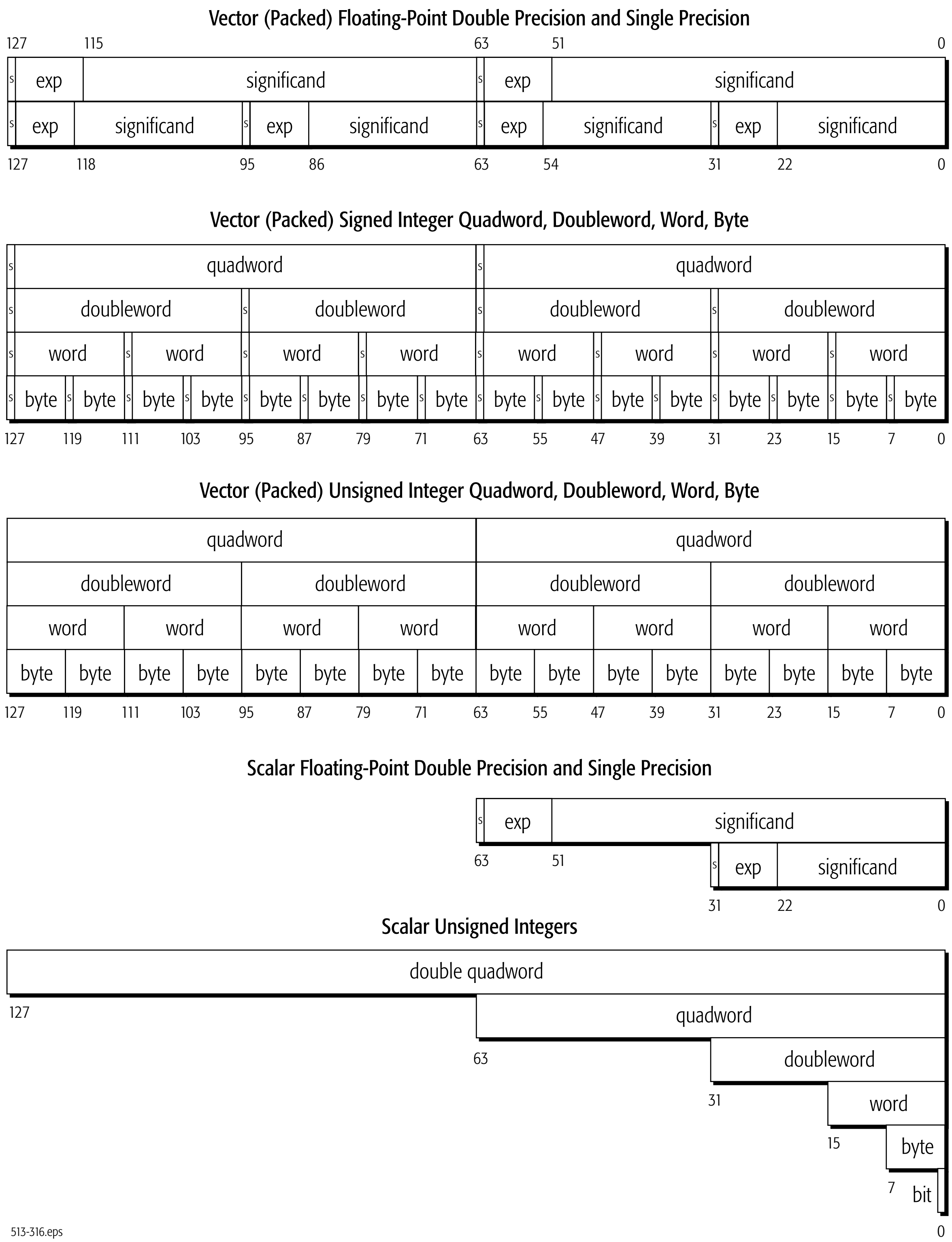


Figure 2-9. 128-Bit Media Data Types

2.3.4 64-Bit Media Instructions

Registers. The 64-bit media instructions use the eight 64-bit MMX registers, as shown in Figure 2-10. These registers are mapped onto the x87 floating-point registers, and 64-bit media instructions write the x87 tag word in a way that prevents an x87 instruction from using MMX data.

Some 64-bit media instructions also use the GPR (Figure 2-2 and Figure 2-3) and the XMM registers (Figure 2-8).

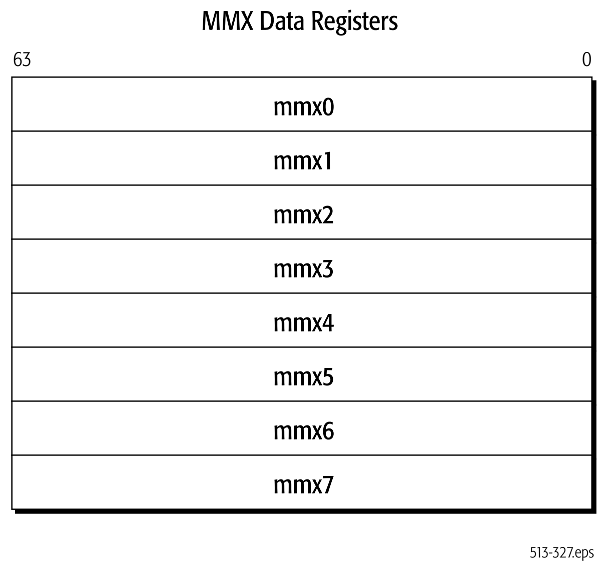


Figure 2-10. 64-Bit Media Registers

Data Types. Figure 2-11 on page 33 shows the 64-bit media data types. They include floating-point and integer vectors and integer scalars. The floating-point data type, used by 3DNow! instructions, consists of a packed vector or two IEEE-754 32-bit single-precision data types. Unlike other kinds of floating-point instructions, however, the 3DNow!™ instructions do not generate floating-point exceptions. For this reason, there is no register for reporting or controlling the status of exceptions in the 64-bit-media instruction subset.

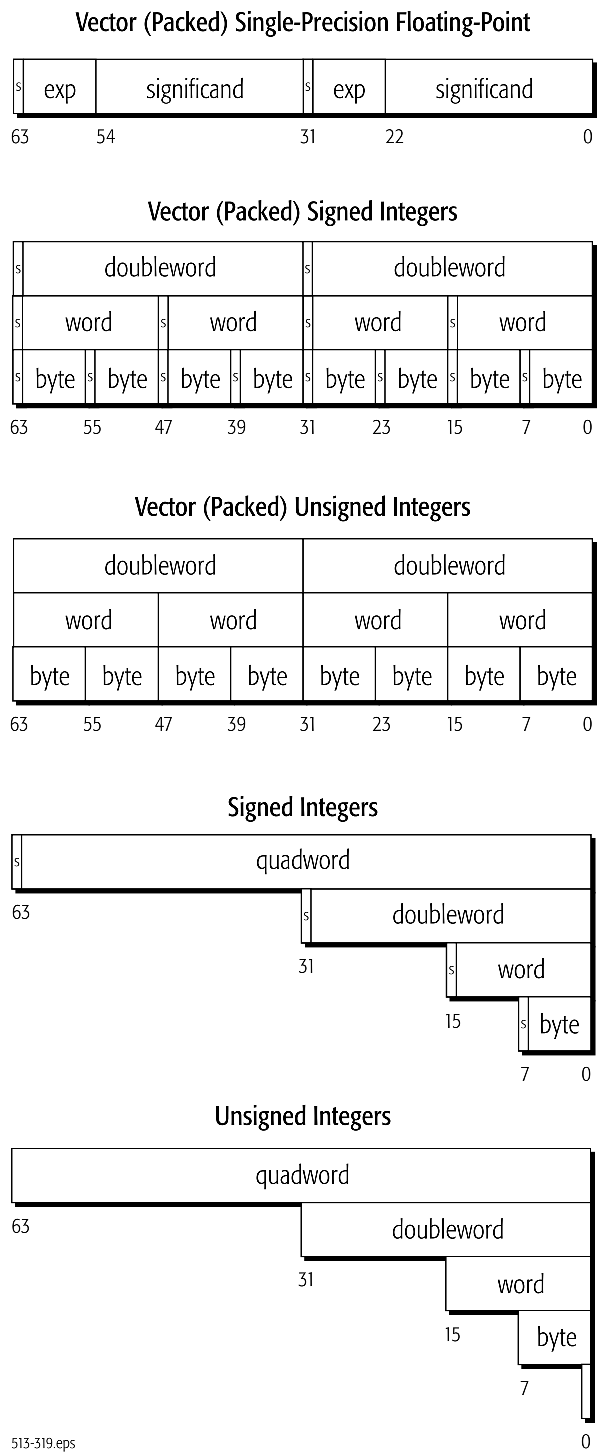


Figure 2-11. 64-Bit Media Data Types

2.3.5 x87 Floating-Point Instructions

Registers. The x87 floating-point instructions use the x87 registers shown in Figure 2-12. There are eight 80-bit data registers, three 16-bit registers that hold the x87 control word, status word, and tag word, and three registers (last instruction pointer, last opcode, last data pointer) that hold information about the last x87 operation.

The physical data registers are named FPR0–FPR7, although x87 software references these registers as a stack of registers, named ST(0)–ST(7). The x87 instructions store operands only in their own 80-bit floating-point registers or in memory. They do not access the GPR or XMM registers.

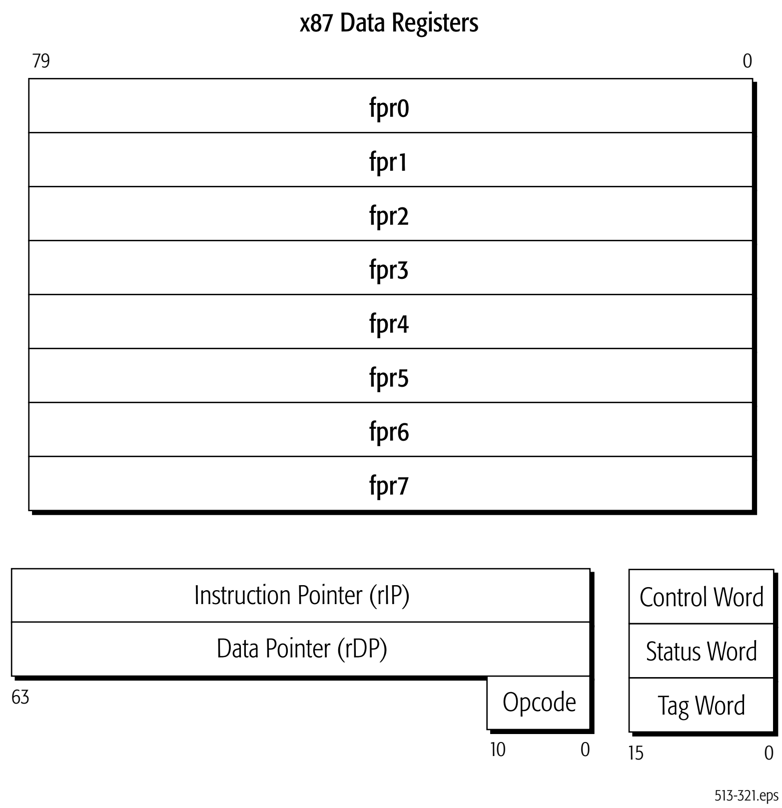


Figure 2-12. x87 Registers

Data Types. Figure 2-13 on page 35 shows all x87 data types. They include three floating-point formats (80-bit double-extended precision, 64-bit double precision, and 32-bit single precision), three signed-integer formats (quadword, doubleword, and word), and an 80-bit packed binary-coded decimal (BCD) format.

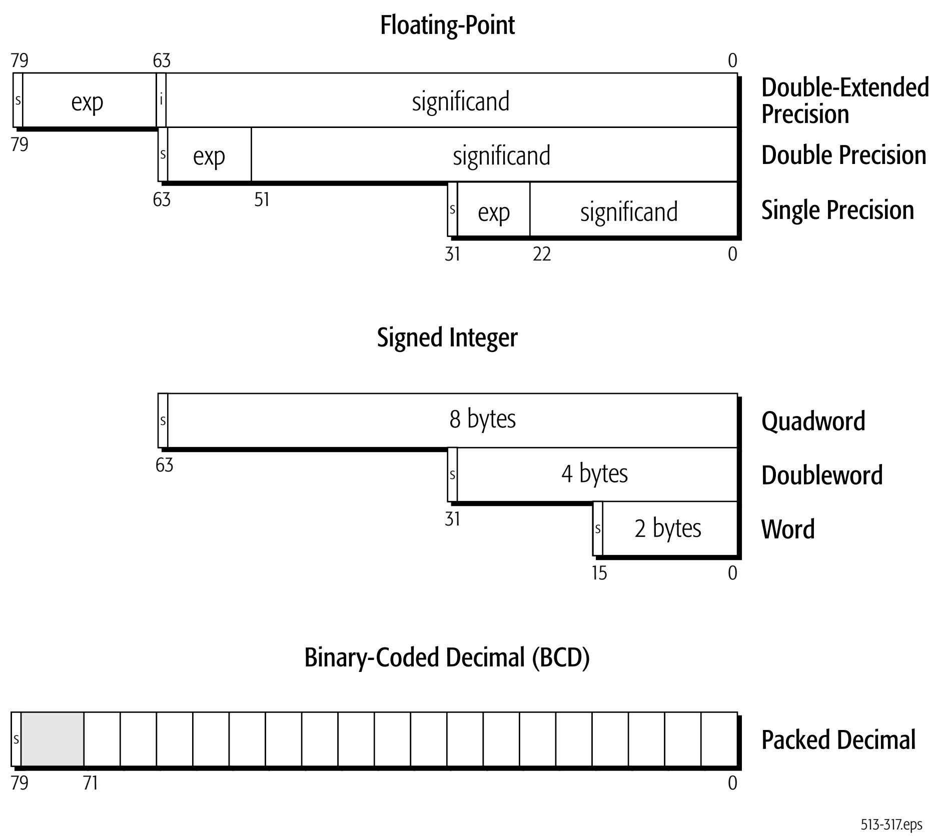


Figure 2-13. x87 Data Types

2.4 Summary of Exceptions

Table 2-1 on page 36 lists all possible exceptions. The table shows the interrupt-vector numbers, names, mnemonics, source, and possible causes. Exceptions that apply to specific instructions are documented with each instruction in the instruction-detail pages that follow.

Table 2-1. Interrupt-Vector Source and Cause

Vector	Interrupt (Exception)	Mnemonic	Source	Cause
0	Divide-By-Zero-Error	#DE	Software	DIV, IDIV, AAM instructions
1	Debug	#DB	Internal	Instruction accesses and data accesses
2	Non-Maskable-Interrupt	#NMI	External	External NMI signal
3	Breakpoint	#BP	Software	INT3 instruction
4	Overflow	#OF	Software	INTO instruction
5	Bound-Range	#BR	Software	BOUND instruction
6	Invalid-Opcode	#UD	Internal	Invalid instructions
7	Device-Not-Available	#NM	Internal	x87 instructions
8	Double-Fault	#DF	Internal	Interrupt during an interrupt
9	Coprocessor-Segment-Overrun	—	External	Unsupported (reserved)
10	Invalid-TSS	#TS	Internal	Task-state segment access and task switch
11	Segment-Not-Present	#NP	Internal	Segment access through a descriptor
12	Stack	#SS	Internal	SS register loads and stack references
13	General-Protection	#GP	Internal	Memory accesses and protection checks
14	Page-Fault	#PF	Internal	Memory accesses when paging enabled
15	Reserved	—		
16	Floating-Point Exception-Pending	#MF	Software	x87 floating-point and 64-bit media floating-point instructions
17	Alignment-Check	#AC	Internal	Memory accesses
18	Machine-Check	#MC	Internal External	Model specific
19	SIMD Floating-Point	#XF	Internal	128-bit media floating-point instructions
20—29	Reserved (Internal and External)	—		
30	SVM Security Exception	#SX	External	Security-Sensitive Events
31	Reserved (Internal and External)	—		
0—255	External Interrupts (Maskable)	#INTR	External	External interrupt signal
0—255	Software Interrupts	—	Software	INT*n* instruction

2.5 Notation

2.5.1 Mnemonic Syntax

Each instruction has a syntax that includes the mnemonic and any operands that the instruction can take. Figure 2-14 shows an example of a syntax in which the instruction takes two operands. In most instructions that take two operands, the first (left-most) operand is both a source operand (the first source operand) and the destination operand. The second (right-most) operand serves only as a source, not a destination.

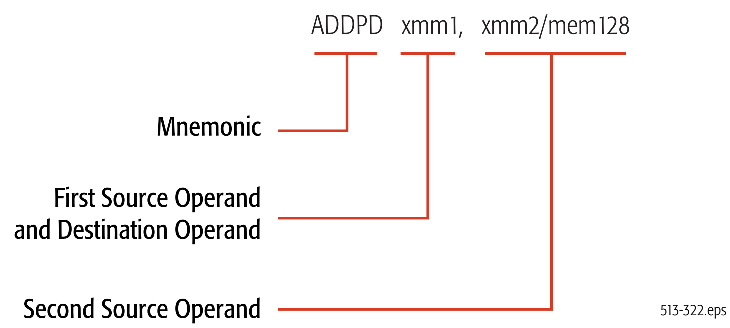


Figure 2-14. Syntax for Typical Two-Operand Instruction

The following notation is used to denote the size and type of source and destination operands:

- *cReg*—Control register.
- *dReg*—Debug register.
- *imm8*—Byte (8-bit) immediate.
- *imm16*—Word (16-bit) immediate.
- *imm16/32*—Word (16-bit) or doubleword (32-bit) immediate.
- *imm32*—Doubleword (32-bit) immediate.
- *imm32/64*—Doubleword (32-bit) or quadword (64-bit) immediate.
- *imm64*—Quadword (64-bit) immediate.
- *mem*—An operand of unspecified size in memory.
- *mem8*—Byte (8-bit) operand in memory.
- *mem16*—Word (16-bit) operand in memory.
- *mem16/32*—Word (16-bit) or doubleword (32-bit) operand in memory.
- *mem32*—Doubleword (32-bit) operand in memory.
- *mem32/48*—Doubleword (32-bit) or 48-bit operand in memory.
- *mem48*—48-bit operand in memory.

- *mem64*—Quadword (64-bit) operand in memory.
- *mem128*—Double quadword (128-bit) operand in memory.
- *mem16:16*—Two sequential word (16-bit) operands in memory.
- *mem16:32*—A doubleword (32-bit) operand followed by a word (16-bit) operand in memory.
- *mem32real*—Single-precision (32-bit) floating-point operand in memory.
- *mem32int*—Doubleword (32-bit) integer operand in memory.
- *mem64real*—Double-precision (64-bit) floating-point operand in memory.
- *mem64int*—Quadword (64-bit) integer operand in memory.
- *mem80real*—Double-extended-precision (80-bit) floating-point operand in memory.
- *mem80dec*—80-bit packed BCD operand in memory, containing 18 4-bit BCD digits.
- *mem2env*—16-bit x87 control word or x87 status word.
- *mem14/28env*—14-byte or 28-byte x87 environment. The x87 environment consists of the x87 control word, x87 status word, x87 tag word, last non-control instruction pointer, last data pointer, and opcode of the last non-control instruction completed.
- *mem94/108env*—94-byte or 108-byte x87 environment and register stack.
- *mem512env*—512-byte environment for 128-bit media, 64-bit media, and x87 instructions.
- *mmx*—Quadword (64-bit) operand in an MMX register.
- *mmx1*—Quadword (64-bit) operand in an MMX register, specified as the left-most (first) operand in the instruction syntax.
- *mmx2*—Quadword (64-bit) operand in an MMX register, specified as the right-most (second) operand in the instruction syntax.
- *mmx/mem32*—Doubleword (32-bit) operand in an MMX register or memory.
- *mmx/mem64*—Quadword (64-bit) operand in an MMX register or memory.
- *mmx1/mem64*—Quadword (64-bit) operand in an MMX register or memory, specified as the left-most (first) operand in the instruction syntax.
- *mmx2/mem64*—Quadword (64-bit) operand in an MMX register or memory, specified as the right-most (second) operand in the instruction syntax.
- *moffset*—Direct memory offset that specifies an operand in memory.
- *moffset8*—Direct memory offset that specifies a byte (8-bit) operand in memory.
- *moffset16*—Direct memory offset that specifies a word (16-bit) operand in memory.
- *moffset32*—Direct memory offset that specifies a doubleword (32-bit) operand in memory.
- *moffset64*—Direct memory offset that specifies a quadword (64-bit) operand in memory.
- *pntr16:16*—Far pointer with 16-bit selector and 16-bit offset.
- *pntr16:32*—Far pointer with 16-bit selector and 32-bit offset.
- *reg*—Operand of unspecified size in a GPR register.
- *reg8*—Byte (8-bit) operand in a GPR register.

- *reg16*—Word (16-bit) operand in a GPR register.
- *reg16/32*—Word (16-bit) or doubleword (32-bit) operand in a GPR register.
- *reg32*—Doubleword (32-bit) operand in a GPR register.
- *reg64*—Quadword (64-bit) operand in a GPR register.
- *reg/mem8*—Byte (8-bit) operand in a GPR register or memory.
- *reg/mem16*—Word (16-bit) operand in a GPR register or memory.
- *reg/mem32*—Doubleword (32-bit) operand in a GPR register or memory.
- *reg/mem64*—Quadword (64-bit) operand in a GPR register or memory.
- *rel8off*—Signed 8-bit offset relative to the instruction pointer.
- *rel16off*—Signed 16-bit offset relative to the instruction pointer.
- *rel32off*—Signed 32-bit offset relative to the instruction pointer.
- *segReg or sReg*—Word (16-bit) operand in a segment register.
- *ST(0)*—x87 stack register 0.
- *ST(i)*—x87 stack register *i*, where *i* is between 0 and 7.
- *xmm*—Double quadword (128-bit) operand in an XMM register.
- *xmm1*—Double quadword (128-bit) operand in an XMM register, specified as the left-most (first) operand in the instruction syntax.
- *xmm2*—Double quadword (128-bit) operand in an XMM register, specified as the right-most (second) operand in the instruction syntax.
- *xmm/mem64*—Quadword (64-bit) operand in a 128-bit XMM register or memory.
- *xmm/mem128*—Double quadword (128-bit) operand in an XMM register or memory.
- *xmm1/mem128*—Double quadword (128-bit) operand in an XMM register or memory, specified as the left-most (first) operand in the instruction syntax.
- *xmm2/mem128*—Double quadword (128-bit) operand in an XMM register or memory, specified as the right-most (second) operand in the instruction syntax.

2.5.2 Opcode Syntax

In addition to the notation shown above in “Mnemonic Syntax” on page 37, the following notation indicates the size and type of operands in the syntax of an instruction opcode:

- */digit*—Indicates that the ModRM byte specifies only one register or memory (r/m) operand. The digit is specified by the ModRM reg field and is used as an instruction-opcode extension. Valid digit values range from 0 to 7.
- */r*—Indicates that the ModRM byte specifies both a register operand and a reg/mem (register or memory) operand.
- *cb, cw, cd, cp*—Specifies a code-offset value and possibly a new code-segment register value. The value following the opcode is either one byte (cb), two bytes (cw), four bytes (cd), or six bytes (cp).

- *ib, iw, id, iq*—Specifies an immediate-operand value. The opcode determines whether the value is signed or unsigned. The value following the opcode, ModRM, or SIB byte is either one byte (ib), two bytes (iw), or four bytes (id). Word and doubleword values start with the low-order byte.
- *+rb, +rw, +rd, +rq*—Specifies a register value that is added to the hexadecimal byte on the left, forming a one-byte opcode. The result is an instruction that operates on the register specified by the register code. Valid register-code values are shown in Table 2-2.
- *m64*—Specifies a quadword (64-bit) operand in memory.
- *+i*—Specifies an x87 floating-point stack operand, ST(*i*). The value is used only with x87 floating-point instructions. It is added to the hexadecimal byte on the left, forming a one-byte opcode. Valid values range from 0 to 7.

Table 2-2. +rb, +rw, +rd, and +rq Register Value

REX.B Bit[1]	Value	Specified Register			
		+rb	+rw	+rd	+rq
0 or no REX Prefix	0	AL	AX	EAX	RAX
	1	CL	CX	ECX	RCX
	2	DL	DX	EDX	RDX
	3	BL	BX	EBX	RBX
	4	AH, SPL[1]	SP	ESP	RSP
	5	CH, BPL[1]	BP	EBP	RBP
	6	DH, SIL[1]	SI	ESI	RSI
	7	BH, DIL[1]	DI	EDI	RDI
1	0	R8B	R8W	R8D	R8
	1	R9B	R9W	R9D	R9
	2	R10B	R10W	R10D	R10
	3	R11B	R11W	R11D	R11
	4	R12B	R12W	R12D	R12
	5	R13B	R13W	R13D	R13
	6	R14B	R14W	R14D	R14
	7	R15B	R15W	R15D	R15

1. See “REX Prefixes” on page 11.

2.5.3 Pseudocode Definitions

Pseudocode examples are given for the actions of several complex instructions (for example, see “CALL (Near)” on page 76). The following definitions apply to all such pseudocode examples:

```
/////////////////////////////////////////////////////////////////////////////////
// Basic Definitions
/////////////////////////////////////////////////////////////////////////////////

// All comments start with these double slashes.

REAL_MODE      = (cr0.pe=0)
PROTECTED_MODE = ((cr0.pe=1) && (rflags.vm=0))
VIRTUAL_MODE   = ((cr0.pe=1) && (rflags.vm=1))
LEGACY_MODE    = (efer.lma=0)
LONG_MODE      = (efer.lma=1)
64BIT_MODE     = ((efer.lma=1) && (cs.L=1) && (cs.d=0))
COMPATIBILITY_MODE = (efer.lma=1) && (cs.L=0)
PAGING_ENABLED = (cr0.pg=1)
ALIGNMENT_CHECK_ENABLED = ((cr0.am=1) && (eflags.ac=1) && (cpl=3))
CPL            = the current privilege level (0-3)
OPERAND_SIZE   = 16, 32, or 64 (depending on current code and 66h/rex prefixes)
ADDRESS_SIZE   = 16, 32, or 64 (depending on current code and 67h prefixes)
STACK_SIZE     = 16, 32, or 64 (depending on current code and SS.attr.B)

old_RIP        = RIP at the start of current instruction
old_RSP        = RSP at the start of current instruction
old_RFLAGS     = RFLAGS at the start of the instruction
old_CS         = CS selector at the start of current instruction
old_DS         = DS selector at the start of current instruction
old_ES         = ES selector at the start of current instruction
old_FS         = FS selector at the start of current instruction
old_GS         = GS selector at the start of current instruction
old_SS         = SS selector at the start of current instruction

RIP            = the current RIP register
RSP            = the current RSP register
RBP            = the current RBP register
RFLAGS         = the current RFLAGS register
next_RIP       = RIP at start of next instruction

CS             = the current CS descriptor, including the subfields:
                 sel base limit attr
SS             = the current SS descriptor, including the subfields:
                 sel base limit attr

SRC            = the instruction’s Source operand
DEST           = the instruction’s Destination operand

temp_*           // 64-bit temporary register
```

```
temp_*_desc      // temporary descriptor, with subfields:
                 //     if it points to a block of memory: sel base limit attr
                 //     if it's a gate descriptor: sel offset segment attr

NULL = 0x0000    // null selector is all zeros

// V,Z,A,S are integer variables, assigned a value when an instruction begins
// executing (they can be assigned a different value in the middle of an
// instruction, if needed)

V = 2 if OPERAND_SIZE=16
    4 if OPERAND_SIZE=32
    8 if OPERAND_SIZE=64

Z = 2 if OPERAND_SIZE=16
    4 if OPERAND_SIZE=32
    4 if OPERAND_SIZE=64

A = 2 if ADDRESS_SIZE=16
    4 if ADDRESS_SIZE=32
    8 if ADDRESS_SIZE=64

S = 2 if STACK_SIZE=16
    4 if STACK_SIZE=32
    8 if STACK_SIZE=64


/////////////////////////////////////////////////////////////////////////////////
// Bit Range Inside a Register
/////////////////////////////////////////////////////////////////////////////////

temp_data.[X:Y]          // Bit X through Y in temp_data, with the other bits
                         // in the register masked off.


/////////////////////////////////////////////////////////////////////////////////
// Moving Data From One Register To Another
/////////////////////////////////////////////////////////////////////////////////

temp_dest.b = temp_src   // 1-byte move (copies lower 8 bits of temp_src to
                         // temp_dest, preserving the upper 56 bits of temp_dest)
temp_dest.w = temp_src   // 2-byte move (copies lower 16 bits of temp_src to
                         // temp_dest, preserving the upper 48 bits of temp_dest)
temp_dest.d = temp_src   // 4-byte move (copies lower 32 bits of temp_src to
                       // temp_dest, and zeros out the upper 32 bits of temp_dest)
temp_dest.q = temp_src   // 8-byte move (copies all 64 bits of temp_src to
                         // temp_dest)

temp_dest.v = temp_src   // 2-byte move if V=2,
                         // 4-byte move if V=4,
                         // 8-byte move if V=8
```

```
temp_dest.z = temp_src    // 2-byte move if Z=2,
                          // 4-byte move if Z=4

temp_dest.a = temp_src    // 2-byte move if A=2,
                          // 4-byte move if A=4,
                          // 8-byte move if A=8

temp_dest.s = temp_src    // 2-byte move if S=2,
                          // 4-byte move if S=4,
                          // 8-byte move if S=8


////////////////////////////////////////////////////////////////////////////////
// Bitwise Operations
////////////////////////////////////////////////////////////////////////////////

temp = a AND b
temp = a OR b
temp = a XOR b
temp = NOT a
temp = a SHL b
temp = a SHR b


////////////////////////////////////////////////////////////////////////////////
// Logical Operations
////////////////////////////////////////////////////////////////////////////////

IF (FOO && BAR)
IF (FOO || BAR)
IF (FOO = BAR)
IF (FOO != BAR)
IF (FOO > BAR)
IF (FOO < BAR)
IF (FOO >= BAR)
IF (FOO <= BAR)


////////////////////////////////////////////////////////////////////////////////
// IF-THEN-ELSE
////////////////////////////////////////////////////////////////////////////////

IF (FOO)
    ...

IF (FOO)
    ...
ELSIF (BAR)
    ...
ELSE
```

```
    ...

IF ((FOO && BAR) || (CONE && HEAD))
    ...


////////////////////////////////////////////////////////////////////////////////
// Exceptions
////////////////////////////////////////////////////////////////////////////////

EXCEPTION [#GP(0)]       // error code in parenthesis
EXCEPTION [#UD]          // if no error code

possible exception types:

#DE     // Divide-By-Zero-Error Exception (Vector 0)
#DB     // Debug Exception (Vector 1)
#BP     // INT3 Breakpoint Exception (Vector 3)
#OF     // INTO Overflow Exception (Vector 4)
#BR     // Bound-Range Exception (Vector 5)
#UD     // Invalid-Opcode Exception (Vector 6)
#NM     // Device-Not-Available Exception (Vector 7)
#DF     // Double-Fault Exception (Vector 8)
#TS     // Invalid-TSS Exception (Vector 10)
#NP     // Segment-Not-Present Exception (Vector 11)
#SS     // Stack Exception (Vector 12)
#GP     // General-Protection Exception (Vector 13)
#PF     // Page-Fault Exception (Vector 14)
#MF     // x87 Floating-Point Exception-Pending (Vector 16)
#AC     // Alignment-Check Exception (Vector 17)
#MC     // Machine-Check Exception (Vector 18)
#XF     // SIMD Floating-Point Exception (Vector 19)


////////////////////////////////////////////////////////////////////////////////
// READ_MEM
// General memory read. This zero-extends the data to 64 bits and returns it.
////////////////////////////////////////////////////////////////////////////////

usage:
    temp = READ_MEM.x [seg:offset]    // where x is one of {v, z, b, w, d, q}
                                      // and denotes the size of the memory read

definition:

    IF ((seg AND 0xFFFC) = NULL)     // GP fault for using a null segment to
                                  // reference memory
        EXCEPTION [#GP(0)]

    IF ((seg=CS) || (seg=DS) || (seg=ES) || (seg=FS) || (seg=GS))
                     // CS,DS,ES,FS,GS check for segment limit or canonical
```

```
        IF ((!64BIT_MODE) && (offset is outside seg's limit))
            EXCEPTION [#GP(0)]
                     // #GP fault for segment limit violation in non-64-bit mode
        IF ((64BIT_MODE) && (offset is non-canonical))
            EXCEPTION [#GP(0)]
                     // #GP fault for non-canonical address in 64-bit mode
    ELSIF (seg=SS)   // SS checks for segment limit or canonical
        IF ((!64BIT_MODE) && (offset is outside seg's limit))
            EXCEPTION [#SS(0)]
                    // stack fault for segment limit violation in non-64-bit mode
        IF ((64BIT_MODE) && (offset is non-canonical))
            EXCEPTION [#SS(0)]
                     // stack fault for non-canonical address in 64-bit mode
    ELSE // ((seg=GDT) || (seg=LDT) || (seg=IDT) || (seg=TSS))
                     // GDT,LDT,IDT,TSS check for segment limit and canonical
        IF (offset > seg.limit)
            EXCEPTION [#GP(0)]  // #GP fault for segment limit violation
                                // in all modes
        IF ((LONG_MODE) && (offset is non-canonical))
           EXCEPTION [#GP(0)]  // #GP fault for non-canonical address in long mode

    IF ((ALIGNMENT_CHECK_ENABLED) && (offset  misaligned, considering its
                                       size and alignment))
        EXCEPTION [#AC(0)]

    IF ((64_bit_mode) && ((seg=CS) || (seg=DS) || (seg=ES) || (seg=SS))
        temp_linear = offset
    ELSE
        temp_linear = seg.base + offset

    IF ((PAGING_ENABLED) && (virtual-to-physical translation for temp_linear
                             results in a page-protection violation))
        EXCEPTION [#PF(error_code)]  // page fault for page-protection violation
                                     // (U/S violation, Reserved bit violation)

    IF ((PAGING_ENABLED) && (temp_linear is on a not-present page))
        EXCEPTION [#PF(error_code)]  // page fault for not-present page

    temp_data = memory [temp_linear].x   // zero-extends the data to 64
                                         // bits, and saves it in temp_data

    RETURN (temp_data)                   // return the zero-extended data


/////////////////////////////////////////////////////////////////////////////////
// WRITE_MEM  // General memory write
/////////////////////////////////////////////////////////////////////////////////

usage:
    WRITE_MEM.x [seg:offset] = temp.x   // where <X> is one of these:
                                        // {V, Z, B, W, D, Q} and denotes the
```

```
                                        // size of the memory write

definition:

    IF ((seg & 0xFFFC)= NULL)      // GP fault for using a null segment
                                   // to reference memory
        EXCEPTION [#GP(0)]

    IF (seg isn't writable)    // GP fault for writing to a read-only segment
        EXCEPTION [#GP(0)]

    IF ((seg=CS) || (seg=DS) || (seg=ES) || (seg=FS) || (seg=GS))
                      // CS,DS,ES,FS,GS check for segment limit or canonical
        IF ((!64BIT_MODE) && (offset is outside seg's limit))
            EXCEPTION [#GP(0)]
                      // #GP fault for segment limit violation in non-64-bit mode
        IF ((64BIT_MODE) && (offset is non-canonical))
            EXCEPTION [#GP(0)]
                      // #GP fault for non-canonical address in 64-bit mode
    ELSIF (seg=SS)    // SS checks for segment limit or canonical
        IF ((!64BIT_MODE) && (offset is outside seg's limit))
            EXCEPTION [#SS(0)]
                     // stack fault for segment limit violation in non-64-bit mode
        IF ((64BIT_MODE) && (offset is non-canonical))
            EXCEPTION [#SS(0)]
                      // stack fault for non-canonical address in 64-bit mode
    ELSE // ((seg=GDT) || (seg=LDT) || (seg=IDT) || (seg=TSS))
                      // GDT,LDT,IDT,TSS check for segment limit and canonical
        IF (offset > seg.limit)
            EXCEPTION [#GP(0)]
                      // #GP fault for segment limit violation in all modes
        IF ((LONG_MODE) && (offset is non-canonical))
            EXCEPTION [#GP(0)]
                      // #GP fault for non-canonical address in long mode

    IF ((ALIGNMENT_CHECK_ENABLED) && (offset is misaligned, considering
                                      its size and alignment))
        EXCEPTION [#AC(0)]

    IF ((64_bit_mode) && ((seg=CS) || (seg=DS) || (seg=ES) || (seg=SS))
        temp_linear = offset
    ELSE
        temp_linear = seg.base + offset

    IF ((PAGING_ENABLED) && (the virtual-to-physical translation for
       temp_linear results in a page-protection violation))
    {
        EXCEPTION [#PF(error_code)]
                       // page fault for page-protection violation
                       // (U/S violation, Reserved bit violation)
    }
```

```
    IF ((PAGING_ENABLED) && (temp_linear is on a not-present page))
        EXCEPTION [#PF(error_code)]      // page fault for not-present page

    memory [temp_linear].x = temp.x      // write the bytes to memory


//////////////////////////////////////////////////////////////////////////////////
// PUSH // Write data to the stack
//////////////////////////////////////////////////////////////////////////////////

usage:
    PUSH.x temp         // where x is one of these: {v, z, b, w, d, q} and
                        // denotes the size of the push

definition:

    WRITE_MEM.x [SS:RSP.s - X] = temp.x      // write to the stack
    RSP.s = RSP - X                         // point rsp to the data just written


//////////////////////////////////////////////////////////////////////////////////
// POP  // Read data from the stack, zero-extend it to 64 bits
//////////////////////////////////////////////////////////////////////////////////

usage:
    POP.x temp            // where x is one of these: {v, z, b, w, d, q} and
                          // denotes the size of the pop

definition:

    temp = READ_MEM.x [SS:RSP.s]           // read from the stack
    RSP.s = RSP + X                       // point rsp above the data just written


//////////////////////////////////////////////////////////////////////////////////
// READ_DESCRIPTOR // Read 8-byte descriptor from GDT/LDT, return the descriptor
//////////////////////////////////////////////////////////////////////////////////

usage:
    temp_descriptor = READ_DESCRIPTOR (selector, chktype)
    // chktype field is one of the following:
    // cs_chk     used for far call and far jump
    // clg_chk    used when reading CS for far call or far jump through call gate
    // ss_chk     used when reading SS
    // iret_chk   used when reading CS for IRET or RETF
    // intcs_chk  used when readin the CS for interrupts and exceptions

definition:

    temp_offset = selector AND 0xfff8  // upper 13 bits give an offset
```

```
                                       // in the descriptor table

    IF (selector.TI = 0)              // read 8 bytes from the gdt, split it into
                                       // (base,limit,attr) if the type bits
        temp_desc = READ_MEM.q [gdt:temp_offset]
                                       // indicate a block of memory, or split
                                       // it into (segment,offset,attr)
                                       // if the type bits indicate
                                      // a gate, and save the result in temp_desc
    ELSE
        temp_desc = READ_MEM.q [ldt:temp_offset]
                                      // read 8 bytes from the ldt, split it into
                                       // (base,limit,attr) if the type bits
                                       // indicate a block of memory, or split
                                     // it into (segment,offset,attr) if the type
                                     // bits indicate a gate, and save the result
                                       // in temp_desc

    IF (selector.rpl or temp_desc.attr.dpl is illegal for the current mode/cpl)
        EXCEPTION [#GP(selector)]

    IF (temp_desc.attr.type is illegal for the current mode/chktype)
        EXCEPTION [#GP(selector)]

    IF (temp_desc.attr.p=0)
        EXCEPTION [#NP(selector)]

    RETURN (temp_desc)


////////////////////////////////////////////////////////////////////////////////
// READ_IDT // Read an 8-byte descriptor from the IDT, return the descriptor
////////////////////////////////////////////////////////////////////////////////

usage:
    temp_idt_desc = READ_IDT (vector)
                                    // "vector" is the interrupt vector number

definition:

    IF (LONG_MODE)         // long-mode idt descriptors are 16 bytes long
        temp_offset = vector*16
    ELSE // (LEGACY_MODE) legacy-protected-mode idt descriptors are 8 bytes long
        temp_offset = vector*8

    temp_desc = READ_MEM.q [idt:temp_offset]
                          // read 8 bytes from the idt, split it into
                          // (segment,offset,attr), and save it in temp_desc

    IF (temp_desc.attr.dpl is illegal for the current mode/cpl)
                        // exception, with error code that indicates this idt gate
```

```
        EXCEPTION [#GP(vector*8+2)]

    IF (temp_desc.attr.type is illegal for the current mode)
                        // exception, with error code that indicates this idt gate
        EXCEPTION [#GP(vector*8+2)]

    IF (temp_desc.attr.p=0)
        EXCEPTION [#NP(vector*8+2)]
                        // segment-not-present exception, with an error code that
                          // indicates this idt gate

    RETURN (temp_desc)


//////////////////////////////////////////////////////////////////////////////////
// READ_INNER_LEVEL_STACK_POINTER
// Read a new stack pointer (rsp or ss:esp) from the tss
//////////////////////////////////////////////////////////////////////////////////

usage:
    temp_SS_desc:temp_RSP = READ_INNER_LEVEL_STACK_POINTER (new_cpl, ist_index)

definition:

    IF (LONG_MODE)
    {
        IF (ist_index>0)
                    // if IST is selected, read an ISTn stack pointer from the tss
            temp_RSP = READ_MEM.q [tss:ist_index*8+28]
        ELSE // (ist_index=0)
                      // otherwise read an RSPn stack pointer from the tss
            temp_RSP = READ_MEM.q [tss:new_cpl*8+4]

        temp_SS_desc.sel = NULL + new_cpl
                      // in long mode, changing to lower cpl sets SS.sel to
                      // NULL+new_cpl
    }
    ELSE // (LEGACY_MODE)
    {
        temp_RSP = READ_MEM.d [tss:new_cpl*8+4]          // read ESPn from the tss
        temp_sel = READ_MEM.d [tss:new_cpl*8+8]          // read SSn from the tss
        temp_SS_desc = READ_DESCRIPTOR (temp_sel, ss_chk)
    }

    return (temp_RSP:temp_SS_desc)
```

```
////////////////////////////////////////////////////////////////////////////////
// READ_BIT_ARRAY  // Read 1 bit from a bit array in memory
////////////////////////////////////////////////////////////////////////////////

usage:
    temp_value = READ_BIT_ARRAY ([mem], bit_number)

definition:

    temp_BYTE = READ_MEM.b [mem + (bit_number SHR 3)]
                                 // read the byte containing the bit

    temp_BIT = temp_BYTE SHR (bit_number & 7)
                                 // shift the requested bit position into bit 0

    return (temp_BIT & 0x01)     // return '0' or '1'
```

3 General-Purpose Instruction Reference

This chapter describes the function, mnemonic syntax, opcodes, affected flags, and possible exceptions generated by the general-purpose instructions. General-purpose instructions are used in basic software execution. Most of these instructions load, store, or operate on data located in the general-purpose registers (GPRs), in memory, or in both. The remaining instructions are used to alter the sequential flow of the program by branching to other locations within the program, or to entirely different programs. With the exception of the MOVD, MOVMSKPD and MOVMSKPS instructions, which operate on MMX/XMM registers, the instructions within the category of general-purpose instructions do not operate on any other register set.

Most general-purpose instructions are supported in all hardware implementations of the AMD64 architecture, however it may be necessary to use the CPUID instruction to test for support for a small set of general-purpose instructions. These instructions are listed in Table 3-1, along with the CPUID function, the register and bit used to test for the presence of the instruction.

Table 3-1. Instruction Support Indicated by CPUID Feature Bits

Instruction	Register[Bit]	Feature Mnemonic	CPUID Function(s)
CMPXCHG8B	EDX[8]	CMPXCHG8B	0000_0001h, 8000_0001h
CMPXCHG16B	ECX[13]	CMPXCHG16B	0000_0001h
CMOV*cc* (Conditional Moves)	EDX[15]	CMOV	0000_0001h, 8000_0001h
CLFLUSH	EDX[19]	CLFSH	0000_0001h
LZCNT	ECX[5]	Advanced Bit Manipulation (ABM)	8000_0001h
Long Mode instructions	EDX[29]	Long Mode (LM)	8000_0001h
MFENCE, LFENCE	EDX[26]	SSE2	0000_0001h
MOVD	EDX[25]	SSE	0000_0001h
	EDX[26]	SSE2	
MOVNTI	EDX[26]	SSE2	0000_0001h
POPCNT	ECX[23]	POPCNT	0000_0001h
PREFETCH/W	ECX[8]	3DNow!™ Prefetch	8000_0001h
	EDX[29]	LM	
	EDX[31]	3DNow!™	
SFENCE	EDX[25]	FXSR	0000_0001h

The general-purpose instructions can be used in legacy mode or 64-bit long mode. Compilation of general-purpose programs for execution in 64-bit long mode offers three primary advantages: access to the eight extended, 64-bit general-purpose registers (for a register set consisting of GPR0–GPR15), access to the 64-bit virtual address space, and access to the RIP-relative addressing mode.

For further information about the general-purpose instructions and register resources, see:

- “General-Purpose Programming” in Volume 1.
- “Summary of Registers and Data Types” on page 24.
- “Notation” on page 37.
- “Instruction Prefixes” on page 3.
- Appendix B, “General-Purpose Instructions in 64-Bit Mode.” In particular, see “General Rules for 64-Bit Mode” on page 373.

AAA ASCII Adjust After Addition

Adjusts the value in the AL register to an unpacked BCD value. Use the AAA instruction after using the ADD instruction to add two unpacked BCD numbers.

If the value in the lower nibble of AL is greater than 9 or the AF flag is set to 1, the instruction increments the AH register, adds 6 to the AL register, and sets the CF and AF flags to 1. Otherwise, it does not change the AH register and clears the CF and AF flags to 0. In either case, AAA clears bits 7–4 of the AL register, leaving the correct decimal digit in bits 3–0.

This instruction also makes it possible to add ASCII numbers without having to mask off the upper nibble '3'.

MXCSR Flags Affected

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
AAA	37	Create an unpacked BCD number. (Invalid in 64-bit mode.)

Related Instructions

AAD, AAM, AAS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	M	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

AAD ASCII Adjust Before Division

Converts two unpacked BCD digits in the AL (least significant) and AH (most significant) registers to a single binary value in the AL register using the following formula:

```
AL = ((10d * AH) + (AL))
```

After the conversion, AH is cleared to 00h.

In most modern assemblers, the AAD instruction adjusts from base-10 values. However, by coding the instruction directly in binary, it can adjust from any base specified by the immediate byte value (*ib*) suffixed onto the D5h opcode. For example, code D508h for octal, D50Ah for decimal, and D50Ch for duodecimal (base 12).

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
AAD	D5 0A	Adjust two BCD digits in AL and AH. (Invalid in 64-bit mode.)
(None)	D5 *ib*	Adjust two BCD digits to the immediate byte base. (Invalid in 64-bit mode.)

Related Instructions

AAA, AAM, AAS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				M	M	U	M	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

AAM ASCII Adjust After Multiply

Converts the value in the AL register from binary to two unpacked BCD digits in the AH (most significant) and AL (least significant) registers using the following formula:

```
AH = (AL/10d)
AL = (AL mod 10d)
```

In most modern assemblers, the AAM instruction adjusts to base-10 values. However, by coding the instruction directly in binary, it can adjust to any base specified by the immediate byte value (*ib*) suffixed onto the D4h opcode. For example, code D408h for octal, D40Ah for decimal, and D40Ch for duodecimal (base 12).

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
AAM	D4 0A	Create a pair of unpacked BCD values in AH and AL. (Invalid in 64-bit mode.)
(None)	D4 *ib*	Create a pair of unpacked values to the immediate byte base. (Invalid in 64-bit mode.)

Related Instructions

AAA, AAD, AAS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				M	M	U	M	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M. Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Divide by zero, #DE	X	X	X	8-bit immediate value was 0.
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

AAS ASCII Adjust After Subtraction

Adjusts the value in the AL register to an unpacked BCD value. Use the AAS instruction after using the SUB instruction to subtract two unpacked BCD numbers.

If the value in AL is greater than 9 or the AF flag is set to 1, the instruction decrements the value in AH, subtracts 6 from the AL register, and sets the CF and AF flags to 1. Otherwise, it clears the CF and AF flags and the AH register is unchanged. In either case, the instruction clears bits 7–4 of the AL register, leaving the correct decimal digit in bits 3–0.

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
AAS	3F	Create an unpacked BCD number from the contents of the AL register. (Invalid in 64-bit mode.)

Related Instructions

AAA, AAD, AAM

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	M	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

ADC Add with Carry

Adds the carry flag (CF), the value in a register or memory location (first operand), and an immediate value or the value in a register or memory location (second operand), and stores the result in the first operand location. The instruction cannot add two memory operands. The CF flag indicates a pending carry from a previous addition operation. The instruction sign-extends an immediate value to the length of the destination register or memory location.

This instruction evaluates the result for both signed and unsigned data types and sets the OF and CF flags to indicate a carry in a signed or unsigned result, respectively. It sets the SF flag to indicate the sign of a signed result.

Use the ADC instruction after an ADD instruction as part of a multibyte or multiword addition.

The forms of the ADC instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
ADC AL, *imm8*	14 *ib*	Add *imm8* to AL + CF.
ADC AX, *imm16*	15 *iw*	Add *imm16* to AX + CF.
ADC EAX, *imm32*	15 *id*	Add *imm32* to EAX + CF.
ADC RAX, *imm32*	15 *id*	Add sign-extended *imm32* to RAX + CF.
ADC *reg/mem8*, *imm8*	80 /2 *ib*	Add *imm8* to *reg/mem8* + CF.
ADC *reg/mem16*, *imm16*	81 /2 *iw*	Add *imm16* to *reg/mem16* + CF.
ADC *reg/mem32*, *imm32*	81 /2 *id*	Add *imm32* to *reg/mem32* + CF.
ADC *reg/mem64*, *imm32*	81 /2 *id*	Add sign-extended *imm32* to *reg/mem64* + CF.
ADC *reg/mem16*, *imm8*	83 /2 *ib*	Add sign-extended *imm8* to *reg/mem16* + CF.
ADC *reg/mem32*, *imm8*	83 /2 *ib*	Add sign-extended *imm8* to *reg/mem32* + CF.
ADC *reg/mem64*, *imm8*	83 /2 *ib*	Add sign-extended *imm8* to *reg/mem64* + CF.
ADC *reg/mem8*, *reg8*	10 */r*	Add *reg8* to *reg/mem8* + CF
ADC *reg/mem16*, *reg16*	11 */r*	Add *reg16* to *reg/mem16* + CF.
ADC *reg/mem32*, *reg32*	11 */r*	Add *reg32* to *reg/mem32* + CF.
ADC *reg/mem64*, *reg64*	11 */r*	Add *reg64* to *reg/mem64* + CF.
ADC *reg8*, *reg/mem8*	12 */r*	Add *reg/mem8* to *reg8* + CF.
ADC *reg16*, *reg/mem16*	13 */r*	Add *reg/mem16* to *reg16* + CF.
ADC *reg32*, *reg/mem32*	13 */r*	Add *reg/mem32* to *reg32* + CF.
ADC *reg64*, *reg/mem64*	13 */r*	Add *reg/mem64* to *reg64* + CF.

Related Instructions

ADD, SBB, SUB

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

ADD Signed or Unsigned Add

Adds the value in a register or memory location (first operand) and an immediate value or the value in a register or memory location (second operand), and stores the result in the first operand location. The instruction cannot add two memory operands. The instruction sign-extends an immediate value to the length of the destination register or memory operand.

This instruction evaluates the result for both signed and unsigned data types and sets the OF and CF flags to indicate a carry in a signed or unsigned result, respectively. It sets the SF flag to indicate the sign of a signed result.

The forms of the ADD instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
ADD AL, *imm8*	04 *ib*	Add *imm8* to AL.
ADD AX, *imm16*	05 *iw*	Add *imm16* to AX.
ADD EAX, *imm32*	05 *id*	Add *imm32* to EAX.
ADD RAX, *imm32*	05 *id*	Add sign-extended *imm32* to RAX.
ADD *reg/mem8*, *imm8*	80 /0 *ib*	Add *imm8* to *reg/mem8*.
ADD *reg/mem16*, *imm16*	81 /0 *iw*	Add *imm16* to *reg/mem16*
ADD *reg/mem32*, *imm32*	81 /0 *id*	Add *imm32* to *reg/mem32*.
ADD *reg/mem64*, *imm32*	81 /0 *id*	Add sign-extended *imm32* to *reg/mem64*.
ADD *reg/mem16*, *imm8*	83 /0 *ib*	Add sign-extended *imm8* to *reg/mem16*
ADD *reg/mem32*, *imm8*	83 /0 *ib*	Add sign-extended *imm8* to *reg/mem32.*
ADD *reg/mem64*, *imm8*	83 /0 *ib*	Add sign-extended *imm8* to *reg/mem64.*
ADD *reg/mem8, reg8*	00 */r*	Add *reg8* to *reg/mem8*.
ADD *reg/mem16*, *reg16*	01 */r*	Add *reg16* to *reg/mem16.*
ADD *reg/mem32*, *reg32*	01 */r*	Add *reg32* to *reg/mem32.*
ADD *reg/mem64*, *reg64*	01 */r*	Add *reg64* to *reg/mem64.*
ADD *reg8*, *reg/mem8*	02 */r*	Add *reg/mem8* to *reg8*.
ADD *reg16*, *reg/mem16*	03 */r*	Add *reg/mem16* to *reg16*.
ADD *reg32*, *reg/mem32*	03 */r*	Add *reg/mem32* to *reg32*.
ADD *reg64*, *reg/mem64*	03 */r*	Add *reg/mem64* to *reg64*.

Related Instructions

ADC, SBB, SUB

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

AND Logical AND

Performs a bitwise AND operation on the value in a register or memory location (first operand) and an immediate value or the value in a register or memory location (second operand), and stores the result in the first operand location. The instruction cannot AND two memory operands.

The instruction sets each bit of the result to 1 if the corresponding bit of both operands is set; otherwise, it clears the bit to 0. The following table shows the truth table for the AND operation:

X	Y	X AND Y
0	0	0
0	1	0
1	0	0
1	1	1

The forms of the AND instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
AND AL, *imm8*	24 *ib*	AND the contents of AL with an immediate 8-bit value and store the result in AL.
AND AX, *imm16*	25 *iw*	AND the contents of AX with an immediate 16-bit value and store the result in AX.
AND EAX, *imm32*	25 *id*	AND the contents of EAX with an immediate 32-bit value and store the result in EAX.
AND RAX, *imm32*	25 *id*	AND the contents of RAX with a sign-extended immediate 32-bit value and store the result in RAX.
AND *reg/mem8*, *imm8*	80 /4 *ib*	AND the contents of *reg/mem8* with *imm8*.
AND *reg/mem16*, *imm16*	81 /4 *iw*	AND the contents of *reg/mem16* with *imm16*.
AND *reg/mem32*, *imm32*	81 /4 *id*	AND the contents of *reg/mem32* with *imm32*.
AND *reg/mem64*, *imm32*	81 /4 *id*	AND the contents of *reg/mem64* with sign-extended *imm32*.
AND *reg/mem16*, *imm8*	83 /4 *ib*	AND the contents of *reg/mem16* with a sign-extended 8-bit value.
AND *reg/mem32*, *imm8*	83 /4 *ib*	AND the contents of *reg/mem32* with a sign-extended 8-bit value.
AND *reg/mem64*, *imm8*	83 /4 *ib*	AND the contents of *reg/mem64* with a sign-extended 8-bit value.
AND *reg/mem8*, *reg8*	20 /*r*	AND the contents of an 8-bit register or memory location with the contents of an 8-bit register.

Mnemonic	Opcode	Description
AND *reg/mem16*, *reg16*	21 */r*	AND the contents of a 16-bit register or memory location with the contents of a 16-bit register.
AND *reg/mem32*, *reg32*	21 */r*	AND the contents of a 32-bit register or memory location with the contents of a 32-bit register.
AND *reg/mem64*, *reg64*	21 */r*	AND the contents of a 64-bit register or memory location with the contents of a 64-bit register.
AND *reg8*, *reg/mem8*	22 */r*	AND the contents of an 8-bit register with the contents of an 8-bit memory location or register.
AND *reg16*, *reg/mem16*	23 */r*	AND the contents of a 16-bit register with the contents of a 16-bit memory location or register.
AND *reg32*, *reg/mem32*	23 */r*	AND the contents of a 32-bit register with the contents of a 32-bit memory location or register.
AND *reg64*, *reg/mem64*	23 */r*	AND the contents of a 64-bit register with the contents of a 64-bit memory location or register.

Related Instructions

TEST, OR, NOT, NEG, XOR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								0				M	M	U	M	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BOUND Check Array Bound

Checks whether an array index (first operand) is within the bounds of an array (second operand). The array index is a signed integer in the specified register. If the operand-size attribute is 16, the array operand is a memory location containing a pair of signed word-integers; if the operand-size attribute is 32, the array operand is a pair of signed doubleword-integers. The first word or doubleword specifies the lower bound of the array and the second word or doubleword specifies the upper bound.

The array index must be greater than or equal to the lower bound and less than or equal to the upper bound. If the index is not within the specified bounds, the processor generates a BOUND range-exceeded exception (#BR).

The bounds of an array, consisting of two words or doublewords containing the lower and upper limits of the array, usually reside in a data structure just before the array itself, making the limits addressable through a constant offset from the beginning of the array. With the address of the array in a register, this practice reduces the number of bus cycles required to determine the effective address of the array bounds.

Using this instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
BOUND *reg16*, *mem16&mem16*	62 /r	Test whether a 16-bit array index is within the bounds specified by the two 16-bit values in mem16&mem16. (Invalid in 64-bit mode.)
BOUND *reg32*, *mem32&mem32*	62 /r	Test whether a 32-bit array index is within the bounds specified by the two 32-bit values in mem32&mem32. (Invalid in 64-bit mode.)

Related Instructions

INT, INT3, INTO

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Bound range, #BR	X	X	X	The bound range was exceeded.
Invalid opcode, #UD	X	X	X	The source operand was a register.
			X	Instruction was executed in 64-bit mode.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit
General protection, #GP	X	X	X	A memory address exceeded a data segment limit.
			X	A null data segment was used to reference memory.

Exception	Real	Virtual 8086	Protected	Cause of Exception
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BSF Bit Scan Forward

Searches the value in a register or a memory location (second operand) for the least-significant set bit. If a set bit is found, the instruction clears the zero flag (ZF) and stores the index of the least-significant set bit in a destination register (first operand). If the second operand contains 0, the instruction sets ZF to 1 and does not change the contents of the destination register. The bit index is an unsigned offset from bit 0 of the searched value.

Mnemonic	Opcode	Description
BSF *reg16*, *reg/mem16*	0F BC /r	Bit scan forward on the contents of *reg/mem16*.
BSF *reg32*, *reg/mem32*	0F BC /r	Bit scan forward on the contents of *reg/mem32*.
BSF *reg64*, *reg/mem64*	0F BC /r	Bit scan forward on the contents of *reg/mem64*

Related Instructions

BSR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	M	U	U	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BSR — Bit Scan Reverse

Searches the value in a register or a memory location (second operand) for the most-significant set bit. If a set bit is found, the instruction clears the zero flag (ZF) and stores the index of the most-significant set bit in a destination register (first operand). If the second operand contains 0, the instruction sets ZF to 1 and does not change the contents of the destination register. The bit index is an unsigned offset from bit 0 of the searched value.

Mnemonic	Opcode	Description
BSR *reg16*, *reg/mem16*	0F BD /r	Bit scan reverse on the contents of *reg/mem16*.
BSR *reg32*, *reg/mem32*	0F BD /r	Bit scan reverse on the contents of *reg/mem32*.
BSR *reg64*, *reg/mem64*	0F BD /r	Bit scan reverse on the contents of *reg/mem64*.

Related Instructions

BSF

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	M	U	U	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded the data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BSWAP Byte Swap

Reverses the byte order of the specified register. This action converts the contents of the register from little endian to big endian or vice versa. In a doubleword, bits 7–0 are exchanged with bits 31–24, and bits 15–8 are exchanged with bits 23–16. In a quadword, bits 7–0 are exchanged with bits 63–56, bits 15–8 with bits 55–48, bits 23–16 with bits 47–40, and bits 31–24 with bits 39–32. A subsequent use of the BSWAP instruction with the same operand restores the original value of the operand.

The result of applying the BSWAP instruction to a 16-bit register is undefined. To swap the bytes of a 16-bit register, use the XCHG instruction and specify the respective byte halves of the 16-bit register as the two operands. For example, to swap the bytes of AX, use `XCHG AL, AH`.

Mnemonic	Opcode	Description
BSWAP *reg32*	0F C8 +*rd*	Reverse the byte order of *reg32*.
BSWAP *reg64*	0F C8 +*rq*	Reverse the byte order of *reg64*.

Related Instructions

XCHG

rFLAGS Affected

None

Exceptions

None

BT Bit Test

Copies a bit, specified by a bit index in a register or 8-bit immediate value (second operand), from a bit string (first operand), also called the bit base, to the carry flag (CF) of the rFLAGS register.

If the bit base operand is a register, the instruction uses the modulo 16, 32, or 64 (depending on the operand size) of the bit index to select a bit in the register.

If the bit base operand is a memory location, bit 0 of the byte at the specified address is the bit base of the bit string. If the bit index is in a register, the instruction selects a bit position relative to the bit base in the range -2^{63} to $+2^{63} - 1$ if the operand size is 64, -2^{31} to $+2^{31} - 1$, if the operand size is 32, and -2^{15} to $+2^{15} - 1$ if the operand size is 16. If the bit index is in an immediate value, the bit selected is that value modulo 16, 32, or 64, depending on operand size.

When the instruction attempts to copy a bit from memory, it accesses 2, 4, or 8 bytes starting from the specified memory address for 16-bit, 32-bit, or 64-bit operand sizes, respectively, using the following formula:

Effective Address + ($NumBytes_i$ * (BitOffset DIV $NumBits_{i*8}$))

When using this bit addressing mechanism, avoid referencing areas of memory close to address space holes, such as references to memory-mapped I/O registers. Instead, use a MOV instruction to load a register from such an address and use a register form of the BT instruction to manipulate the data.

Mnemonic	Opcode	Description
BT *reg/mem16*, *reg16*	0F A3 /r	Copy the value of the selected bit to the carry flag.
BT *reg/mem32, reg32*	0F A3 /r	Copy the value of the selected bit to the carry flag.
BT *reg/mem64, reg64*	0F A3 /r	Copy the value of the selected bit to the carry flag.
BT *reg/mem16*, *imm8*	0F BA /4 *ib*	Copy the value of the selected bit to the carry flag.
BT *reg/mem32, imm8*	0F BA /4 *ib*	Copy the value of the selected bit to the carry flag.
BT *reg/mem64, imm8*	0F BA /4 *ib*	Copy the value of the selected bit to the carry flag.

Related Instructions

BTC, BTR, BTS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BTC Bit Test and Complement

Copies a bit, specified by a bit index in a register or 8-bit immediate value (second operand), from a bit string (first operand), also called the bit base, to the carry flag (CF) of the rFLAGS register, and then complements (toggles) the bit in the bit string.

If the bit base operand is a register, the instruction uses the modulo 16, 32, or 64 (depending on the operand size) of the bit index to select a bit in the register.

If the bit base operand is a memory location, bit 0 of the byte at the specified address is the bit base of the bit string. If the bit index is in a register, the instruction selects a bit position relative to the bit base in the range -2^{63} to $+2^{63} - 1$ if the operand size is 64, -2^{31} to $+2^{31} - 1$, if the operand size is 32, and -2^{15} to $+2^{15} - 1$ if the operand size is 16. If the bit index is in an immediate value, the bit selected is that value modulo 16, 32, or 64, depending the operand size.

This instruction is useful for implementing semaphores in concurrent operating systems. Such an application should precede this instruction with the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
BTC *reg/mem16*, *reg16*	0F BB /r	Copy the value of the selected bit to the carry flag, then complement the selected bit.
BTC *reg/mem32, reg32*	0F BB /r	Copy the value of the selected bit to the carry flag, then complement the selected bit.
BTC *reg/mem64, reg64*	0F BB /r	Copy the value of the selected bit to the carry flag, then complement the selected bit.
BTC *reg/mem16*, *imm8*	0F BA /7 *ib*	Copy the value of the selected bit to the carry flag, then complement the selected bit.
BTC *reg/mem32, imm8*	0F BA /7 *ib*	Copy the value of the selected bit to the carry flag, then complement the selected bit.
BTC *reg/mem64, imm8*	0F BA /7 *ib*	Copy the value of the selected bit to the carry flag, then complement the selected bit.

Related Instructions

BT, BTR, BTS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BTR Bit Test and Reset

Copies a bit, specified by a bit index in a register or 8-bit immediate value (second operand), from a bit string (first operand), also called the bit base, to the carry flag (CF) of the rFLAGS register, and then clears the bit in the bit string to 0.

If the bit base operand is a register, the instruction uses the modulo 16, 32, or 64 (depending on the operand size) of the bit index to select a bit in the register.

If the bit base operand is a memory location, bit 0 of the byte at the specified address is the bit base of the bit string. If the bit index is in a register, the instruction selects a bit position relative to the bit base in the range -2^{63} to $+2^{63} - 1$ if the operand size is 64, -2^{31} to $+2^{31} - 1$, if the operand size is 32, and -2^{15} to $+2^{15} - 1$ if the operand size is 16. If the bit index is in an immediate value, the bit selected is that value modulo 16, 32, or 64, depending on the operand size.

This instruction is useful for implementing semaphores in concurrent operating systems. Such applications should precede this instruction with the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
BTR *reg/mem16*, *reg16*	0F B3 /r	Copy the value of the selected bit to the carry flag, then clear the selected bit.
BTR *reg/mem32, reg32*	0F B3 /r	Copy the value of the selected bit to the carry flag, then clear the selected bit.
BTR *reg/mem64, reg64*	0F B3 /r	Copy the value of the selected bit to the carry flag, then clear the selected bit.
BTR *reg/mem16*, *imm8*	0F BA /6 *ib*	Copy the value of the selected bit to the carry flag, then clear the selected bit.
BTR *reg/mem32, imm8*	0F BA /6 *ib*	Copy the value of the selected bit to the carry flag, then clear the selected bit.
BTR *reg/mem64, imm8*	0F BA /6 *ib*	Copy the value of the selected bit to the carry flag, then clear the selected bit.

Related Instructions

BT, BTC, BTS

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

BTS Bit Test and Set

Copies a bit, specified by bit index in a register or 8-bit immediate value (second operand), from a bit string (first operand), also called the bit base, to the carry flag (CF) of the rFLAGS register, and then sets the bit in the bit string to 1.

If the bit base operand is a register, the instruction uses the modulo 16, 32, or 64 (depending on the operand size) of the bit index to select a bit in the register.

If the bit base operand is a memory location, bit 0 of the byte at the specified address is the bit base of the bit string. If the bit index is in a register, the instruction selects a bit position relative to the bit base in the range -2^{63} to $+2^{63} - 1$ if the operand size is 64, -2^{31} to $+2^{31} - 1$, if the operand size is 32, and -2^{15} to $+2^{15} - 1$ if the operand size is 16. If the bit index is in an immediate value, the bit selected is that value modulo 16, 32, or 64, depending on the operand size.

This instruction is useful for implementing semaphores in concurrent operating systems. Such applications should precede this instruction with the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
BTS *reg/mem16*, *reg16*	0F AB /r	Copy the value of the selected bit to the carry flag, then set the selected bit.
BTS *reg/mem32, reg32*	0F AB /r	Copy the value of the selected bit to the carry flag, then set the selected bit.
BTS *reg/mem64, reg64*	0F AB /r	Copy the value of the selected bit to the carry flag, then set the selected bit.
BTS *reg/mem16*, *imm8*	0F BA /5 *ib*	Copy the value of the selected bit to the carry flag, then set the selected bit.
BTS *reg/mem32, imm8*	0F BA /5 *ib*	Copy the value of the selected bit to the carry flag, then set the selected bit.
BTS *reg/mem64, imm8*	0F BA /5 *ib*	Copy the value of the selected bit to the carry flag, then set the selected bit.

Related Instructions

BT, BTC, BTR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CALL (Near) Near Procedure Call

Pushes the offset of the next instruction onto the stack and branches to the target address, which contains the first instruction of the called procedure. The target operand can specify a register, a memory location, or a label. A procedure accessed by a near CALL is located in the same code segment as the CALL instruction.

If the CALL target is specified by a register or memory location, then a 16-, 32-, or 64-bit rIP is read from the operand, depending on the operand size. A 16- or 32-bit rIP is zero-extended to 64 bits.

If the CALL target is specified by a displacement, the signed displacement is added to the rIP (of the following instruction), and the result is truncated to 16, 32, or 64 bits, depending on the operand size. The signed displacement is 16 or 32 bits, depending on the operand size.

In all cases, the rIP of the instruction after the CALL is pushed on the stack, and the size of the stack push (16, 32, or 64 bits) depends on the operand size of the CALL instruction.

For near calls in 64-bit mode, the operand size defaults to 64 bits. The E8 opcode results in RIP = RIP + 32-bit signed displacement and the FF /2 opcode results in RIP = 64-bit offset from register or memory. No prefix is available to encode a 32-bit operand size in 64-bit mode.

At the end of the called procedure, RET is used to return control to the instruction following the original CALL. When RET is executed, the rIP is popped off the stack, which returns control to the instruction after the CALL.

See CALL (Far) for information on far calls—calls to procedures located outside of the current code segment. For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
CALL *rel16off*	E8 *iw*	Near call with the target specified by a 16-bit relative displacement.
CALL *rel32off*	E8 *id*	Near call with the target specified by a 32-bit relative displacement.
CALL *reg/mem16*	FF /2	Near call with the target specified by *reg/mem16*.
CALL *reg/mem32*	FF /2	Near call with the target specified by *reg/mem32*. (There is no prefix for encoding this in 64-bit mode.)
CALL *reg/mem64*	FF /2	Near call with the target specified by *reg/mem64*.

For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Related Instructions

CALL(Far), RET(Near), RET(Far)

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Alignment Check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.
Page Fault, #PF		X	X	A page fault resulted from the execution of the instruction.

CALL (Far) Far Procedure Call

Pushes procedure linking information onto the stack and branches to the target address, which contains the first instruction of the called procedure. The operand specifies a target selector and offset.

The instruction can specify the target directly, by including the far pointer in the CALL (Far) opcode itself, or indirectly, by referencing a far pointer in memory. In 64-bit mode, only indirect far calls are allowed, executing a direct far call (opcode 9A) generates an undefined opcode exception. For both direct and indirect far calls, if the CALL (Far) operand-size is 16 bits, the instruction's operand is a 16-bit selector followed by a 16-bit offset. If the operand-size is 32 or 64 bits, the operand is a 16-bit selector followed by a 32-bit offset.

The target selector used by the instruction can be a code selector in all modes. Additionally, the target selector can reference a call gate in protected mode, or a task gate or TSS selector in legacy protected mode.

- *Target is a code selector*—The CS:rIP of the next instruction is pushed to the stack, using operand-size stack pushes. Then code is executed from the target CS:rIP. In this case, the target offset can only be a 16- or 32-bit value, depending on operand-size, and is zero-extended to 64 bits. No CPL change is allowed.
- *Target is a call gate*—The call gate specifies the actual target code segment and offset. Call gates allow calls to the same or more privileged code. If the target segment is at the same CPL as the current code segment, the CS:rIP of the next instruction is pushed to the stack.

  If the CALL (Far) changes privilege level, then a stack-switch occurs, using an inner-level stack pointer from the TSS. The CS:rIP of the next instruction is pushed to the new stack. If the mode is legacy mode and the param-count field in the call gate is non-zero, then up to 31 operands are copied from the caller's stack to the new stack. Finally, the caller's SS:rSP is pushed to the new stack.

  When calling through a call gate, the stack pushes are 16-, 32-, or 64-bits, depending on the size of the call gate. The size of the target rIP is also 16, 32, or 64 bits, depending on the size of the call gate. If the target rIP is less than 64 bits, it is zero-extended to 64 bits. Long mode only allows 64-bit call gates that must point to 64-bit code segments.
- *Target is a task gate or a TSS*—If the mode is legacy protected mode, then a task switch occurs. See “Hardware Task-Management in Legacy Mode” in volume 2 for details about task switches. Hardware task switches are not supported in long mode.

See CALL (Near) for information on near calls—calls to procedures located inside the current code segment. For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
CALL FAR *pntr16:16*	9A *cd*	Far call direct, with the target specified by a far pointer contained in the instruction. (Invalid in 64-bit mode.)
CALL FAR *pntr16:32*	9A *cp*	Far call direct, with the target specified by a far pointer contained in the instruction. (Invalid in 64-bit mode.)
CALL FAR *mem16:16*	FF /3	Far call indirect, with the target specified by a far pointer in memory.
CALL FAR *mem16:32*	FF /3	Far call indirect, with the target specified by a far pointer in memory.

Action

```
// See "Pseudocode Definitions" on page 41.

CALLF_START:

IF (REAL_MODE)
    CALLF_REAL_OR_VIRTUAL
ELSIF (PROTECTED_MODE)
    CALLF_PROTECTED
ELSE // (VIRTUAL_MODE)
    CALLF_REAL_OR_VIRTUAL

CALLF_REAL_OR_VIRTUAL:

    IF (OPCODE = callf [mem])     // CALLF Indirect
    {
        temp_RIP = READ_MEM.z [mem]
        temp_CS  = READ_MEM.w [mem+Z]
    }
    ELSE // (OPCODE = callf direct)
    {
        temp_RIP = z-sized offset specified in the instruction
                   zero-extended to 64 bits
        temp_CS  = selector specified in the instruction
    }

    PUSH.v old_CS
    PUSH.v next_RIP

    IF (temp_RIP>CS.limit)
        EXCEPTION [#GP(0)]

    CS.sel  = temp_CS
    CS.base = temp_CS SHL 4
    RIP = temp_RIP
    EXIT
```

```
CALLF_PROTECTED:

    IF (OPCODE = callf [mem])      //CALLF Indirect
    {
        temp_offset = READ_MEM.z [mem]
        temp_sel    = READ_MEM.w [mem+Z]
    }
    ELSE // (OPCODE = callf direct)
    {
      IF (64BIT_MODE)
            EXCEPTION [#UD]         // 'CALLF direct' is illegal in 64-bit mode.
      temp_offset = z-sized offset specified in the instruction
                      zero-extended to 64 bits
      temp_sel    = selector specified in the instruction
    }

    temp_desc = READ_DESCRIPTOR (temp_sel, cs_chk)

    IF (temp_desc.attr.type = 'available_tss')
        TASK_SWITCH    // Using temp_sel as the target TSS selector.
    ELSIF (temp_desc.attr.type = 'taskgate')
        TASK_SWITCH    // Using the TSS selector in the task gate
                       // as the target TSS.
    ELSIF (temp_desc.attr.type = 'code')
                       // If the selector refers to a code descriptor, then
                       // the offset we read is the target RIP.
    {
        temp_RIP = temp_offset
        CS = temp_desc
        PUSH.v old_CS
        PUSH.v next_RIP
        IF ((!64BIT_MODE) && (temp_RIP > CS.limit))
                                    // temp_RIP can't be non-canonical because
           EXCEPTION [#GP(0)]        // it's a 16- or 32-bit offset, zero-extended
                                    // to 64 bits.
        RIP = temp_RIP
        EXIT
    }
    ELSE   // (temp_desc.attr.type = 'callgate')
           // If the selector refers to a call gate, then
           // the target CS and RIP both come from the call gate.
    {
        IF (LONG_MODE)
                   // The size of the gate controls the size of the stack pushes.
            V=8-byte
                   // Long mode only uses 64-bit call gates, force 8-byte opsize.
        ELSIF (temp_desc.attr.type = 'callgate32')
            V=4-byte
                   // Legacy mode, using a 32-bit call-gate, force 4-byte opsize.
        ELSE       // (temp_desc.attr.type = 'callgate16')
            V=2-byte
```

```
            // Legacy mode, using a 16-bit call-gate, force 2-byte opsize.

temp_RIP = temp_desc.offset

IF (LONG_MODE)     // In long mode, we need to read the 2nd half of a
                   // 16-byte call-gate from the GDT/LDT, to get the upper
                   // 32 bits of the target RIP.
{
    temp_upper = READ_MEM.q [temp_sel+8]
    IF (temp_upper's extended attribute bits != 0)
        EXCEPTION [#GP(temp_sel)]
    temp_RIP = tempRIP + (temp_upper SHL 32)
                   // Concatenate both halves of RIP
}

CS = READ_DESCRIPTOR (temp_desc.segment, clg_chk)

IF (CS.attr.conforming=1)
   temp_CPL = CPL
ELSE
   temp_CPL = CS.attr.dpl

IF (CPL=temp_CPL)
{
    PUSH.v old_CS
    PUSH.v next_RIP

    IF ((64BIT_MODE) && (temp_RIP is non-canonical)
       || (!64BIT_MODE) && (temp_RIP > CS.limit))
    {
        EXCEPTION[#GP(0)]
    }

    RIP = temp_RIP
    EXIT
}
ELSE // (CPL != temp_CPL), Changing privilege level.
{
   CPL = temp_CPL
   temp_ist = 0          // Call-far doesn't use ist pointers.
   temp_SS_desc:temp_RSP = READ_INNER_LEVEL_STACK_POINTER (CPL, temp_ist)

   RSP.q = temp_RSP
   SS = temp_SS_desc
   PUSH.v old_SS         // #SS on this and following pushes use
                         // SS.sel as error code.
   PUSH.v old_RSP
   IF (LEGACY_MODE)     // Legacy-mode call gates have
   {                    // a param_count field.
        temp_PARAM_COUNT = temp_desc.attr.param_count
```

```
                FOR (I=temp_PARAM_COUNT; I>0; I--)
                {
                    temp_DATA = READ_MEM.v [old_SS:(old_RSP+I*V)]
                    PUSH.v temp_DATA
                }
            }
            PUSH.v old_CS
            PUSH.v next_RIP
             IF ((64BIT_MODE) && (temp_RIP is non-canonical)
                || (!64BIT_MODE) && (temp_RIP > CS.limit))
             {
                EXCEPTION [#GP(0)]
             }
             RIP = temp_RIP
             EXIT
        }
    }
```

Related Instructions

CALL (Near), RET (Near), RET (Far)

rFLAGS Affected

None, unless a task switch occurs, in which case all flags are modified.

Exceptions

<table>
<tr><th>Exception</th><th>Real</th><th>Virtual 8086</th><th>Protected</th><th>Cause of Exception</th></tr>
<tr><td rowspan="2">Invalid opcode, #UD</td><td>X</td><td>X</td><td>X</td><td>The far CALL indirect opcode (FF /3) had a register operand.</td></tr>
<tr><td></td><td></td><td>X</td><td>The far CALL direct opcode (9A) was executed in 64-bit mode.</td></tr>
<tr><td rowspan="8">Invalid TSS, #TS (selector)</td><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector or rSP in the TSS was beyond the TSS limit.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector in the TSS was a null selector.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack selector’s TI bit was set, but LDT selector was a null selector.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector in the TSS was beyond the limit of the GDT or LDT descriptor table.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector in the TSS contained a RPL that was not equal to its DPL.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector in the TSS contained a DPL that was not equal to the CPL of the code segment selector.</td></tr>
<tr><td></td><td></td><td>X</td><td>As part of a stack switch, the target stack segment selector in the TSS was not a writable segment.</td></tr>
</table>

Exception	Real	Virtual 8086	Protected	Cause of Exception
Segment not present, #NP (selector)			X	The accessed code segment, call gate, task gate, or TSS was not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical, and no stack switch occurred.
Stack, #SS (selector)			X	After a stack switch, a memory access exceeded the stack segment limit or was non-canonical.
			X	As part of a stack switch, the SS register was loaded with a non-null segment selector and the segment was marked not present.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
General protection, #GP (selector)			X	The target code segment selector was a null selector.
			X	A code, call gate, task gate, or TSS descriptor exceeded the descriptor table limit.
			X	A segment selector's TI bit was set but the LDT selector was a null selector.
			X	The segment descriptor specified by the instruction was not a code segment, task gate, call gate or available TSS in legacy mode, or not a 64-bit code segment or a 64-bit call gate in long mode.
			X	The RPL of the non-conforming code segment selector specified by the instruction was greater than the CPL, or its DPL was not equal to the CPL.
			X	The DPL of the conforming code segment descriptor specified by the instruction was greater than the CPL.
			X	The DPL of the callgate, taskgate, or TSS descriptor specified by the instruction was less than the CPL, or less than its own RPL.
			X	The segment selector specified by the call gate or task gate was a null selector.
			X	The segment descriptor specified by the call gate was not a code segment in legacy mode, or not a 64-bit code segment in long mode.
			X	The DPL of the segment descriptor specified by the call gate was greater than the CPL.
			X	The 64-bit call gate's extended attribute bits were not zero.
			X	The TSS descriptor was found in the LDT.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CBW CWDE CDQE — Convert to Sign-Extended

Copies the sign bit in the AL or eAX register to the upper bits of the rAX register. The effect of this instruction is to convert a signed byte, word, or doubleword in the AL or eAX register into a signed word, doubleword, or double quadword in the rAX register. This action helps avoid overflow problems in signed number arithmetic.

The CDQE mnemonic is meaningful only in 64-bit mode.

Mnemonic	Opcode	Description
CBW	98	Sign-extend AL into AX.
CWDE	98	Sign-extend AX into EAX.
CDQE	98	Sign-extend EAX into RAX.

Related Instructions

CWD, CDQ, CQO

rFLAGS Affected

None

Exceptions

None

CWD
CDQ
CQO

Convert to Sign-Extended

Copies the sign bit in the rAX register to all bits of the rDX register. The effect of this instruction is to convert a signed word, doubleword, or quadword in the rAX register into a signed doubleword, quadword, or double-quadword in the rDX:rAX registers. This action helps avoid overflow problems in signed number arithmetic.

The CQO mnemonic is meaningful only in 64-bit mode.

Mnemonic	Opcode	Description
CWD	99	Sign-extend AX into DX:AX.
CDQ	99	Sign-extend EAX into EDX:EAX.
CQO	99	Sign-extend RAX into RDX:RAX.

Related Instructions

CBW, CWDE, CDQE

rFLAGS Affected

None

Exceptions

None

CLC Clear Carry Flag

Clears the carry flag (CF) in the rFLAGS register to zero.

Mnemonic	Opcode	Description
CLC	F8	Clear the carry flag (CF) to zero.

Related Instructions

STC, CMC

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
																0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

None

CLD Clear Direction Flag

Clears the direction flag (DF) in the rFLAGS register to zero. If the DF flag is 0, each iteration of a string instruction increments the data pointer (index registers rSI or rDI). If the DF flag is 1, the string instruction decrements the pointer. Use the CLD instruction before a string instruction to make the data pointer increment.

Mnemonic	Opcode	Description
CLD	FC	Clear the direction flag (DF) to zero.

Related Instructions

CMPS*x*, INSx, LODSx, MOVSx, OUTSx, SCASx, STD, STOSx

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
									0							
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

None

CLFLUSH Cache Line Flush

Flushes the cache line specified by the *mem8* linear-address. The instruction checks all levels of the cache hierarchy—internal caches and external caches—and invalidates the cache line in every cache in which it is found. If a cache contains a dirty copy of the cache line (that is, the cache line is in the *modified* or *owned* MOESI state), the line is written back to memory before it is invalidated. The instruction sets the cache-line MOESI state to *invalid*.

The instruction also checks the physical address corresponding to the linear-address operand against the processor's write-combining buffers. If the write-combining buffer holds data intended for that physical address, the instruction writes the entire contents of the buffer to memory. This occurs even though the data is not cached in the cache hierarchy. In a multiprocessor system, the instruction checks the write-combining buffers only on the processor that executed the CLFLUSH instruction.

The CLFLUSH instruction is weakly-ordered with respect to other instructions that operate on memory. Speculative loads initiated by the processor, or specified explicitly using cache-prefetch instructions, can be reordered around a CLFLUSH instruction. Such reordering can invalidate a speculatively prefetched cache line, unintentionally defeating the prefetch operation. The only way to avoid this situation is to use the MFENCE instruction after the CLFLUSH instruction to force strong-ordering of the CLFLUSH instruction with respect to subsequent memory operations. The CLFLUSH instruction may also take effect on a cache line while stores from previous store instructions are still pending in the store buffer. To ensure that such stores are included in the cache line that is flushed, use an MFENCE instruction ahead of the CLFLUSH instruction. Such stores would otherwise cause the line to be re-cached and modified after the CLFLUSH completed. The LFENCE, SFENCE, and serializing instructions are *not* ordered with respect to CLFLUSH.

The CLFLUSH instruction behaves like a load instruction with respect to setting the page-table accessed and dirty bits. That is, it sets the page-table accessed bit to 1, but does not set the page-table dirty bit.

The CLFLUSH instruction is supported if CPUID function 0000_0001h sets EDX bit 19. CPUID function 0000_0001h returns the CLFLUSH size in EBX bits 23:16. This value reports the size of a line flushed by CLFLUSH in quadwords. See CPUID for details.

The CLFLUSH instruction executes at any privilege level. CLFLUSH performs all the segmentation and paging checks that a 1-byte read would perform, except that it also allows references to execute-only segments.

Mnemonic	Opcode	Description
CFLUSH *mem8*	0F AE /7	flush cache line containing *mem8.*

Related Instructions

INVD, WBINVD

rFLAGS Affected

None

Exceptions

Exception (vector)	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The CLFLUSH instruction is not supported, as indicated by EDX bit 19 of CPUID function 0000_0001h.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.

CMC — Complement Carry Flag

Complements (toggles) the carry flag (CF) bit of the rFLAGS register.

Mnemonic	Opcode	Description
CMC	F5	Complement the carry flag (CF).

Related Instructions

CLC, STC

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
																M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

None

CMOV*cc* Conditional Move

Conditionally moves a 16-bit, 32-bit, or 64-bit value in memory or a general-purpose register (second operand) into a register (first operand), depending upon the settings of condition flags in the rFLAGS register. If the condition is not satisfied, the instruction has no effect.

The mnemonics of CMOVcc instructions denote the condition that must be satisfied. Most assemblers provide instruction mnemonics with A (above) and B (below) tags to supply the semantics for manipulating unsigned integers. Those with G (greater than) and L (less than) tags deal with signed integers. Many opcodes may be represented by synonymous mnemonics. For example, the CMOVL instruction is synonymous with the CMOVNGE instruction and denote the instruction with the opcode 0F 4C.

Support for CMOV*cc* instructions depends on the processor implementation. To determine whether a processor can perform CMOV*cc* instructions, use the CPUID instruction to determine whether EDX bit 15 of CPUID function 0000_0001h or function 8000_0001h is set to 1.

Mnemonic	Opcode	Description
CMOVO *reg16*, *reg/mem16* CMOVO *reg32*, *reg/mem32* CMOVO *reg64*, *reg/mem64*	0F 40 */r*	Move if overflow (OF = 1).
CMOVNO *reg16*, *reg/mem16* CMOVNO *reg32*, *reg/mem32* CMOVNO *reg64*, *reg/mem64*	0F 41 */r*	Move if not overflow (OF = 0).
CMOVB *reg16*, *reg/mem16* CMOVB *reg32*, *reg/mem32* CMOVB *reg64*, *reg/mem64*	0F 42 */r*	Move if below (CF = 1).
CMOVC *reg16*, *reg/mem16* CMOVC *reg32*, *reg/mem32* CMOVC *reg64*, *reg/mem64*	0F 42 */r*	Move if carry (CF = 1).
CMOVNAE *reg16*, *reg/mem16* CMOVNAE *reg32*, *reg/mem32* CMOVNAE *reg64*, *reg/mem64*	0F 42 */r*	Move if not above or equal (CF = 1).
CMOVNB *reg16,reg/mem16* CMOVNB *reg32,reg/mem32* CMOVNB *reg64,reg/mem64*	0F 43 */r*	Move if not below (CF = 0).
CMOVNC *reg16,reg/mem16* CMOVNC *reg32,reg/mem32* CMOVNC *reg64,reg/mem64*	0F 43 */r*	Move if not carry (CF = 0).
CMOVAE *reg16*, *reg/mem16* CMOVAE *reg32*, *reg/mem32* CMOVAE *reg64*, *reg/mem64*	0F 43 */r*	Move if above or equal (CF = 0).
CMOVZ *reg16*, *reg/mem16* CMOVZ *reg32*, *reg/mem32* CMOVZ *reg64*, *reg/mem64*	0F 44 */r*	Move if zero (ZF = 1).

Mnemonic	Opcode	Description
CMOVE *reg16*, *reg/mem16* CMOVE *reg32*, *reg/mem32* CMOVE *reg64*, *reg/mem64*	0F 44 */r*	Move if equal (ZF =1).
CMOVNZ *reg16*, *reg/mem16* CMOVNZ *reg32*, *reg/mem32* CMOVNZ *reg64*, *reg/mem64*	0F 45 */r*	Move if not zero (ZF = 0).
CMOVNE *reg16*, *reg/mem16* CMOVNE *reg32*, *reg/mem32* CMOVNE *reg64*, *reg/mem64*	0F 45 */r*	Move if not equal (ZF = 0).
CMOVBE *reg16*, *reg/mem16* CMOVBE *reg32*, *reg/mem32* CMOVBE *reg64*, *reg/mem64*	0F 46 */r*	Move if below or equal (CF = 1 or ZF = 1).
CMOVNA *reg16*, *reg/mem16* CMOVNA *reg32*, *reg/mem32* CMOVNA *reg64*, *reg/mem64*	0F 46 */r*	Move if not above (CF = 1 or ZF = 1).
CMOVNBE *reg16, reg/mem16* CMOVNBE *reg32,reg/mem32* CMOVNBE *reg64,reg/mem64*	0F 47 */r*	Move if not below or equal (CF = 0 and ZF = 0).
CMOVA *reg16*, *reg/mem16* CMOVA *reg32*, *reg/mem32* CMOVA *reg64*, *reg/mem64*	0F 47 */r*	Move if above (CF = 0 and ZF = 0).
CMOVS *reg16*, *reg/mem16* CMOVS *reg32*, *reg/mem32* CMOVS *reg64*, *reg/mem64*	0F 48 */r*	Move if sign (SF =1).
CMOVNS *reg16*, *reg/mem16* CMOVNS *reg32*, *reg/mem32* CMOVNS *reg64*, *reg/mem64*	0F 49 */r*	Move if not sign (SF = 0).
CMOVP *reg16*, *reg/mem16* CMOVP *reg32*, *reg/mem32* CMOVP *reg64*, *reg/mem64*	0F 4A */r*	Move if parity (PF = 1).
CMOVPE *reg16*, *reg/mem16* CMOVPE *reg32*, *reg/mem32* CMOVPE *reg64*, *reg/mem64*	0F 4A */r*	Move if parity even (PF = 1).
CMOVNP *reg16*, *reg/mem16* CMOVNP *reg32*, *reg/mem32* CMOVNP *reg64*, *reg/mem64*	0F 4B */r*	Move if not parity (PF = 0).
CMOVPO *reg16*, *reg/mem16* CMOVPO *reg32*, *reg/mem32* CMOVPO *reg64*, *reg/mem64*	0F 4B */r*	Move if parity odd (PF = 0).
CMOVL *reg16*, *reg/mem16* CMOVL *reg32*, *reg/mem32* CMOVL *reg64*, *reg/mem64*	0F 4C */r*	Move if less (SF <> OF).
CMOVNGE *reg16*, *reg/mem16* CMOVNGE *reg32*, *reg/mem32* CMOVNGE *reg64*, *reg/mem64*	0F 4C */r*	Move if not greater or equal (SF <> OF).

Mnemonic	Opcode	Description
CMOVNL *reg16*, *reg/mem16* CMOVNL *reg32*, *reg/mem32* CMOVNL *reg64*, *reg/mem64*	0F 4D */r*	Move if not less (SF = OF).
CMOVGE *reg16*, *reg/mem16* CMOVGE *reg32*, *reg/mem32* CMOVGE *reg64*, *reg/mem64*	0F 4D */r*	Move if greater or equal (SF = OF).
CMOVLE *reg16*, *reg/mem16* CMOVLE *reg32*, *reg/mem32* CMOVLE *reg64*, *reg/mem64*	0F 4E */r*	Move if less or equal (ZF = 1 or SF <> OF).
CMOVNG *reg16*, *reg/mem16* CMOVNG *reg32*, *reg/mem32* CMOVNG *reg64*, *reg/mem64*	0F 4E */r*	Move if not greater (ZF = 1 or SF <> OF).
CMOVNLE *reg16*, *reg/mem16* CMOVNLE *reg32*, *reg/mem32* CMOVNLE *reg64*, *reg/mem64*	0F 4F */r*	Move if not less or equal (ZF = 0 and SF = OF).
CMOVG *reg16*, *reg/mem16* CMOVG *reg32*, *reg/mem32* CMOVG *reg64*, *reg/mem64*	0F 4F */r*	Move if greater (ZF = 0 and SF = OF).

Related Instructions

MOV

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The CMOV*cc* instruction is not supported, as indicated by EDX bit 15 of CPUID function 0000_0001h or function 8000_0001h.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CMP Compare

Compares the contents of a register or memory location (first operand) with an immediate value or the contents of a register or memory location (second operand), and sets or clears the status flags in the rFLAGS register to reflect the results. To perform the comparison, the instruction subtracts the second operand from the first operand and sets the status flags in the same manner as the SUB instruction, but does not alter the first operand. If the second operand is an immediate value, the instruction sign-extends the value to the length of the first operand.

Use the CMP instruction to set the condition codes for a subsequent conditional jump (J*cc*), conditional move (CMOV*cc*), or conditional SET*cc* instruction. Appendix E, “Instruction Effects on RFLAGS,” shows how instructions affect the rFLAGS status flags.

Mnemonic	Opcode	Description
CMP AL, *imm8*	3C *ib*	Compare an 8-bit immediate value with the contents of the AL register.
CMP AX, *imm16*	3D *iw*	Compare a 16-bit immediate value with the contents of the AX register.
CMP EAX, *imm32*	3D *id*	Compare a 32-bit immediate value with the contents of the EAX register.
CMP RAX, *imm32*	3D *id*	Compare a 32-bit immediate value with the contents of the RAX register.
CMP *reg/mem8*, *imm8*	80 /7 *ib*	Compare an 8-bit immediate value with the contents of an 8-bit register or memory operand.
CMP *reg/mem16*, *imm16*	81 /7 *iw*	Compare a 16-bit immediate value with the contents of a 16-bit register or memory operand.
CMP *reg/mem32*, *imm32*	81 /7 *id*	Compare a 32-bit immediate value with the contents of a 32-bit register or memory operand.
CMP *reg/mem64*, *imm32*	81 /7 *id*	Compare a 32-bit signed immediate value with the contents of a 64-bit register or memory operand.
CMP *reg/mem16*, *imm8*	83 /7 *ib*	Compare an 8-bit signed immediate value with the contents of a 16-bit register or memory operand.
CMP *reg/mem32*, *imm8*	83 /7 *ib*	Compare an 8-bit signed immediate value with the contents of a 32-bit register or memory operand.
CMP *reg/mem64*, *imm8*	83 /7 *ib*	Compare an 8-bit signed immediate value with the contents of a 64-bit register or memory operand.
CMP *reg/mem8*, *reg8*	38 */r*	Compare the contents of an 8-bit register or memory operand with the contents of an 8-bit register.
CMP *reg/mem16*, *reg16*	39 */r*	Compare the contents of a 16-bit register or memory operand with the contents of a 16-bit register.
CMP *reg/mem32*, *reg32*	39 */r*	Compare the contents of a 32-bit register or memory operand with the contents of a 32-bit register.
CMP *reg/mem64*, *reg64*	39 */r*	Compare the contents of a 64-bit register or memory operand with the contents of a 64-bit register.

Mnemonic	Opcode	Description
CMP *reg8*, *reg/mem8*	3A */r*	Compare the contents of an 8-bit register with the contents of an 8-bit register or memory operand.
CMP *reg16*, *reg/mem16*	3B */r*	Compare the contents of a 16-bit register with the contents of a 16-bit register or memory operand.
CMP *reg32*, *reg/mem32*	3B */r*	Compare the contents of a 32-bit register with the contents of a 32-bit register or memory operand.
CMP *reg64*, *reg/mem64*	3B */r*	Compare the contents of a 64-bit register with the contents of a 64-bit register or memory operand.

When interpreting operands as unsigned, flag settings are as follows:

Operands	CF	ZF
dest > source	0	0
dest = source	0	1
dest < source	1	0

When interpreting operands as signed, flag settings are as follows:

Operands	OF	ZF
dest > source	SF	0
dest = source	0	1
dest < source	NOT SF	0

Related Instructions

SUB, CMPS*x*, SCAS*x*

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CMPS
CMPSB
CMPSW
CMPSD
CMPSQ

Compare Strings

Compares the bytes, words, doublewords, or quadwords pointed to by the rSI and rDI registers, sets or clears the status flags of the rFLAGS register to reflect the results, and then increments or decrements the rSI and rDI registers according to the state of the DF flag in the rFLAGS register. To perform the comparison, the instruction subtracts the second operand from the first operand and sets the status flags in the same manner as the SUB instruction, but does not alter the first operand. The two operands must be the same size.

If the DF flag is 0, the instruction increments rSI and rDI; otherwise, it decrements the pointers. It increments or decrements the pointers by 1, 2, 4, or 8, depending on the size of the operands.

The forms of the CMPSx instruction with explicit operands address the first operand at *seg*:[rSI]. The value of *seg* defaults to the DS segment, but may be overridden by a segment prefix. These instructions always address the second operand at ES:[rDI]. ES may not be overridden. The explicit operands serve only to specify the type (size) of the values being compared and the segment used by the first operand.

The no-operands forms of the instruction use the DS:[rSI] and ES:[rDI] registers to point to the values to be compared. The mnemonic determines the size of the operands.

Do not confuse this CMPSD instruction with the same-mnemonic CMPSD (compare scalar double-precision floating-point) instruction in the 128-bit media instruction set. Assemblers can distinguish the instructions by the number and type of operands.

For block comparisons, the CMPS instruction supports the REPE or REPZ prefixes (they are synonyms) and the REPNE or REPNZ prefixes (they are synonyms). For details about the REP prefixes, see “Repeat Prefixes” on page 9. If a conditional jump instruction like JL follows a CMPS*x* instruction, the jump occurs if the value of the *seg*:[rSI] operand is less than the ES:[rDI] operand. This action allows lexicographical comparisons of string or array elements. A CMPS*x* instruction can also operate inside a loop controlled by the LOOP*cc* instruction.

Mnemonic	Opcode	Description
CMPS *mem8*, *mem8*	A6	Compare the byte at DS:rSI with the byte at ES:rDI and then increment or decrement rSI and rDI.
CMPS *mem16*, *mem16*	A7	Compare the word at DS:rSI with the word at ES:rDI and then increment or decrement rSI and rDI.
CMPS *mem32*, *mem32*	A7	Compare the doubleword at DS:rSI with the doubleword at ES:rDI and then increment or decrement rSI and rDI.
CMPS *mem64*, *mem64*	A7	Compare the quadword at DS:rSI with the quadword at ES:rDI and then increment or decrement rSI and rDI.

Mnemonic	Opcode	Description
CMPSB	A6	Compare the byte at DS:rSI with the byte at ES:rDI and then increment or decrement rSI and rDI.
CMPSW	A7	Compare the word at DS:rSI with the word at ES:rDI and then increment or decrement rSI and rDI.
CMPSD	A7	Compare the doubleword at DS:rSI with the doubleword at ES:rDI and then increment or decrement rSI and rDI.
CMPSQ	A7	Compare the quadword at DS:rSI with the quadword at ES:rDI and then increment or decrement rSI and rDI.

Related Instructions

CMP, SCAS*x*

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CMPXCHG Compare and Exchange

Compares the value in the AL, AX, EAX, or RAX register with the value in a register or a memory location (first operand). If the two values are equal, the instruction copies the value in the second operand to the first operand and sets the ZF flag in the rFLAGS register to 1. Otherwise, it copies the value in the first operand to the AL, AX, EAX, or RAX register and clears the ZF flag to 0.

The OF, SF, AF, PF, and CF flags are set to reflect the results of the compare.

When the first operand is a memory operand, CMPXCHG always does a read-modify-write on the memory operand. If the compared operands were unequal, CMPXCHG writes the same value to the memory operand that was read.

The forms of the CMPXCHG instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
CMPXCHG *reg/mem8*, *reg8*	0F B0 */r*	Compare AL register with an 8-bit register or memory location. If equal, copy the second operand to the first operand. Otherwise, copy the first operand to AL.
CMPXCHG *reg/mem16*, *reg16*	0F B1 */r*	Compare AX register with a 16-bit register or memory location. If equal, copy the second operand to the first operand. Otherwise, copy the first operand to AX.
CMPXCHG *reg/mem32*, *reg32*	0F B1 */r*	Compare EAX register with a 32-bit register or memory location. If equal, copy the second operand to the first operand. Otherwise, copy the first operand to EAX.
CMPXCHG *reg/mem64*, *reg64*	0F B1 */r*	Compare RAX register with a 64-bit register or memory location. If equal, copy the second operand to the first operand. Otherwise, copy the first operand to RAX.

Related Instructions

CMPXCHG8B, CMPXCHG16B

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CMPXCHG8B — Compare and Exchange Eight Bytes
CMPXCHG16B — Compare and Exchange Sixteen Bytes

Compares the value in the rDX:rAX registers with a 64-bit or 128-bit value in the specified memory location. If the values are equal, the instruction copies the value in the rCX:rBX registers to the memory location and sets the zero flag (ZF) of the rFLAGS register to 1. Otherwise, it copies the value in memory to the rDX:rAX registers and clears ZF to 0.

If the effective operand size is 16-bit or 32-bit, the CMPXCHG8B instruction is used. This instruction uses the EDX:EAX and ECX:EBX register operands and a 64-bit memory operand. If the effective operand size is 64-bit, the CMPXCHG16B instruction is used; this instruction uses RDX:RAX and RCX:RBX register operands and a 128-bit memory operand.

The CMPXCHG8B and CMPXCHG16B instructions always do a read-modify-write on the memory operand. If the compared operands were unequal, the instructions write the same value to the memory operand that was read.

The CMPXCHG8B and CMPXCHG16B instructions support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Support for the CMPXCHG8B and CMPXCHG16B instructions depends on the processor implementation. To find out if a processor can execute the CMPXCHG8B instruction, use the CPUID instruction to determine whether EDX bit 8 of CPUID function 0000_0001h or function 8000_0001h is set to 1. To find out if a processor can execute the CMPXCHG16B instruction, use the CPUID instruction to determine whether ECX bit 13 of CPUID function 0000_0001h is set to 1.

The memory operand used by CMPXCHG16B must be 16-byte aligned or else a general-protection exception is generated.

Mnemonic	Opcode	Description
CMPXCHG8B *mem64*	0F C7 /1 *m64*	Compare EDX:EAX register to 64-bit memory location. If equal, set the zero flag (ZF) to 1 and copy the ECX:EBX register to the memory location. Otherwise, copy the memory location to EDX:EAX and clear the zero flag.
CMPXCHG16B *mem128*	0F C7 /1 *m128*	Compare RDX:RAX register to 128-bit memory location. If equal, set the zero flag (ZF) to 1 and copy the RCX:RBX register to the memory location. Otherwise, copy the memory location to RDX:RAX and clear the zero flag.

Related Instructions

CMPXCHG

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The CMPXCHG8B instruction is not supported, as indicated by EDX bit 8 of CPUID function 0000_0001h or function 8000_0001h.
			X	The CMPXCHG16B instruction is not supported, as indicated by ECX bit 13 of CPUID function 0000_0001h.
	X	X	X	The operand was a register.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
			X	The memory operand for CMPXCHG16B was not aligned on a 16-byte boundary.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

CPUID Processor Identification

Provides information about the processor and its capabilities through a number of different functions. Software should load the number of the CPUID function to execute into the EAX register before executing the CPUID instruction. The processor returns information in the EAX, EBX, ECX, and EDX registers; the contents and format of these registers depend on the function.

The architecture supports CPUID information about *standard functions* and *extended functions*. The standard functions have numbers in the 0000_*xxxx*h series (for example, standard function 1). To determine the largest standard function number that a processor supports, execute CPUID function 0.

The extended functions have numbers in the 8000_*xxxx*h series (for example, extended function 8000_0001h). To determine the largest extended function number that a processor supports, execute CPUID extended function 8000_0000h. If the value returned in EAX is greater than 8000_0000h, the processor supports extended functions.

Software operating at any privilege level can execute the CPUID instruction to collect this information. In 64-bit mode, this instruction works the same as in legacy mode except that it zero-extends 32-bit register results to 64 bits.

CPUID is a serializing instruction.

Mnemonic	Opcode	Description
CPUID	0F A2	Returns information about the processor and its capabilities. EAX specifies the function number, and the data is returned in EAX, EBX, ECX, EDX.

Testing for the CPUID Instruction

To avoid an invalid-opcode exception (#UD) on those processor implementations that do not support the CPUID instruction, software must first test to determine if the CPUID instruction is supported. Support for the CPUID instruction is indicated by the ability to write the ID bit in the rFLAGS register. Normally, 32-bit software uses the PUSHFD and POPFD instructions in an attempt to write rFLAGS.ID. After reading the updated rFLAGS.ID bit, a comparison determines if the operation changed its value. If the value changed, the processor executing the code supports the CPUID instruction. If the value did not change, rFLAGS.ID is not writable, and the processor does not support the CPUID instruction.

The following code sample shows how to test for the presence of the CPUID instruction using 32-bit code.

```
pushfd                        ; save EFLAGS
pop         eax               ; store EFLAGS in EAX
mov         ebx, eax          ; save in EBX for later testing
xor         eax, 00200000h    ; toggle bit 21
push        eax               ; push to stack
popfd                         ; save changed EAX to EFLAGS
```

```
pushfd                    ; push EFLAGS to TOS
pop       eax             ; store EFLAGS in EAX
cmp       eax, ebx        ; see if bit 21 has changed
jz        NO_CPUID        ; if no change, no CPUID
```

Standard Function 0 and Extended Function 8000_0000h

CPUID standard function 0 loads the EAX register with the largest CPUID *standard* function number supported by the processor implementation; similarly, CPUID extended function 8000_0000h loads the EAX register with the largest *extended* function number supported.

Standard function 0 and extended function 8000_0000h both load a 12-character string into the EBX, EDX, and ECX registers identifying the processor vendor. For AMD processors, the string is `AuthenticAMD`. This string informs software that it should follow the AMD CPUID definition for subsequent CPUID function calls. If the function returns another vendor's string, software must use that vendor's CPUID definition when interpreting the results of subsequent CPUID function calls. Table 3-2 shows the contents of the EBX, EDX, and ECX registers after executing function 0 on an AMD processor.

Table 3-2. Processor Vendor Return Values

Register	Return Value	ASCII Characters
EBX	6874_7541h	"h t u A"
EDX	6974_6E65h	"i t n e"
ECX	444D_4163h	"D M A c"

For more detailed on CPUID standard and extended functions, see the *AMD CPUID Specification*, order# 25481.

Related Instructions

None

rFLAGS Affected

None

Exceptions

None

DAA Decimal Adjust after Addition

Adjusts the value in the AL register into a packed BCD result and sets the CF and AF flags in the rFLAGS register to indicate a decimal carry out of either nibble of AL.

Use this instruction to adjust the result of a byte ADD instruction that performed the binary addition of one 2-digit packed BCD values to another.

The instruction performs the adjustment by adding 06h to AL if the lower nibble is greater than 9 or if AF = 1. Then 60h is added to AL if the original AL was greater than 99h or if CF = 1.

If the lower nibble of AL was adjusted, the AF flag is set to 1. Otherwise AF is not modified. If the upper nibble of AL was adjusted, the CF flag is set to 1. Otherwise, CF is not modified. SF, ZF, and PF are set according to the final value of AL.

Using this instruction in 64-bit mode generates an invalid-opcode (#UD) exception.

Mnemonic	Opcode	Description
DAA	27	Decimal adjust AL. (Invalid in 64-bit mode.)

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

DAS Decimal Adjust after Subtraction

Adjusts the value in the AL register into a packed BCD result and sets the CF and AF flags in the rFLAGS register to indicate a decimal borrow.

Use this instruction to adjust the result of a byte SUB instruction that performed a binary subtraction of one 2-digit, packed BCD value from another.

This instruction performs the adjustment by subtracting 06h from AL if the lower nibble is greater than 9 or if AF = 1. Then 60h is subtracted from AL if the original AL was greater than 99h or if CF = 1.

If the adjustment changes the lower nibble of AL, the AF flag is set to 1; otherwise AF is not modified. If the adjustment results in a borrow for either nibble of AL, the CF flag is set to 1; otherwise CF is not modified. The SF, ZF, and PF flags are set according to the final value of AL.

Using this instruction in 64-bit mode generates an invalid-opcode (#UD) exception.

Mnemonic	Opcode	Description
DAS	2F	Decimal adjusts AL after subtraction. (Invalid in 64-bit mode.)

Related Instructions

DAA

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.

DEC Decrement by 1

Subtracts 1 from the specified register or memory location. The CF flag is not affected.

The one-byte forms of this instruction (opcodes 48 through 4F) are used as REX prefixes in 64-bit mode. See “REX Prefixes” on page 11.

The forms of the DEC instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

To perform a decrement operation that updates the CF flag, use a SUB instruction with an immediate operand of 1.

Mnemonic	Opcode	Description
DEC *reg/mem8*	FE /1	Decrement the contents of an 8-bit register or memory location by 1.
DEC *reg/mem16*	FF /1	Decrement the contents of a 16-bit register or memory location by 1.
DEC *reg/mem32*	FF /1	Decrement the contents of a 32-bit register or memory location by 1.
DEC *reg/mem64*	FF /1	Decrement the contents of a 64-bit register or memory location by 1.
DEC *reg16*	48 *+rw*	Decrement the contents of a 16-bit register by 1. (See “REX Prefixes” on page 11.)
DEC *reg32*	48 *+rd*	Decrement the contents of a 32-bit register by 1. (See “REX Prefixes” on page 11.)

Related Instructions

INC, SUB

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded the data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

DIV Unsigned Divide

Divides the unsigned value in a register by the unsigned value in the specified register or memory location. The register to be divided depends on the size of the divisor.

When dividing a word, the dividend is in the AX register. The instruction stores the quotient in the AL register and the remainder in the AH register.

When dividing a doubleword, quadword, or double quadword, the most-significant word of the dividend is in the rDX register and the least-significant word is in the rAX register. After the division, the instruction stores the quotient in the rAX register and the remainder in the rDX register.

The following table summarizes the action of this instruction:

Division Size	Dividend	Divisor	Quotient	Remainder	Maximum Quotient
Word/byte	AX	reg/mem8	AL	AH	255
Doubleword/word	DX:AX	reg/mem16	AX	DX	65,535
Quadword/doubleword	EDX:EAX	reg/mem32	EAX	EDX	$2^{32} - 1$
Double quadword/ quadword	RDX:RAX	reg/mem64	RAX	RDX	$2^{64} - 1$

The instruction truncates non-integral results towards 0 and the remainder is always less than the divisor. An overflow generates a #DE (divide error) exception, rather than setting the CF flag.

Division by zero generates a divide-by-zero exception.

Mnemonic	Opcode	Description
DIV *reg/mem8*	F6 /6	Perform unsigned division of AX by the contents of an 8-bit register or memory location and store the quotient in AL and the remainder in AH.
DIV *reg/mem16*	F7 /6	Perform unsigned division of DX:AX by the contents of a 16-bit register or memory operand store the quotient in AX and the remainder in DX.
DIV *reg/mem32*	F7 /6	Perform unsigned division of EDX:EAX by the contents of a 32-bit register or memory location and store the quotient in EAX and the remainder in EDX.
DIV *reg/mem64*	F7 /6	Perform unsigned division of RDX:RAX by the contents of a 64-bit register or memory location and store the quotient in RAX and the remainder in RDX.

Related Instructions

MUL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Divide by zero, #DE	X	X	X	The divisor operand was 0.
	X	X	X	The quotient was too large for the designated register.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

ENTER Create Procedure Stack Frame

Creates a stack frame for a procedure.

The first operand specifies the size of the stack frame allocated by the instruction.

The second operand specifies the nesting level (0 to 31—the value is automatically masked to 5 bits). For nesting levels of 1 or greater, the processor copies earlier stack frame pointers before adjusting the stack pointer. This action provides a called procedure with access points to other nested stack frames.

The 32-bit `enter N, 0` (a nesting level of 0) instruction is equivalent to the following 32-bit instruction sequence:

```
push  ebp         ; save current EBP
mov   ebp, esp    ; set stack frame pointer value
sub   esp, N      ; allocate space for local variables
```

The ENTER and LEAVE instructions provide support for block structured languages. The LEAVE instruction releases the stack frame on returning from a procedure.

In 64-bit mode, the operand size of ENTER defaults to 64 bits, and there is no prefix available for encoding a 32-bit operand size.

Mnemonic	Opcode	Description
ENTER *imm16*, 0	C8 *iw* 00	Create a procedure stack frame.
ENTER *imm16*, 1	C8 *iw* 01	Create a nested stack frame for a procedure.
ENTER *imm16, imm8*	C8 *iw ib*	Create a nested stack frame for a procedure.

Action

```
// See "Pseudocode Definitions" on page 41.

ENTER_START:

    temp_ALLOC_SPACE = word-sized immediate specified in the instruction
                       (first operand), zero-extended to 64 bits
    temp_LEVEL = byte-sized immediate specified in the instruction
                       (second operand), zero-extended to 64 bits

    temp_LEVEL = temp_LEVEL AND 0x1f
                                // only keep 5 bits of level count

    PUSH.v old_RBP

    temp_RBP = RSP              // This value of RSP will eventually be loaded
                                // into RBP.
    IF (temp_LEVEL>0)           // Push "temp_LEVEL" parameters to the stack.
    {
        FOR (I=1; I<temp_LEVEL; I++)
```

```
                                // All but one of the parameters are copied
                                // from higher up on the stack.
        {
            temp_DATA = READ_MEM.v [SS:old_RBP-I*V]
            PUSH.v temp_DATA
        }
        PUSH.v temp_RBP         // The last parameter is the offset of the old
                                // value of RSP on the stack.
    }
    RSP.s = RSP - temp_ALLOC_SPACE   // Leave "temp_ALLOC_SPACE" free bytes on
                                     // the stack

    WRITE_MEM.v [SS:RSP.s] = temp_unused   // ENTER finishes with a memory write
                                           // check on the final stack pointer,
                                           // but no write actually occurs.

    RBP.v = temp_RBP
    EXIT
```

Related Instructions

LEAVE

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack-segment limit or was non-canonical.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

IDIV Signed Divide

Divides the signed value in a register by the signed value in the specified register or memory location. The register to be divided depends on the size of the divisor.

When dividing a word, the dividend is in the AX register. The instruction stores the quotient in the AL register and the remainder in the AH register.

When dividing a doubleword, quadword, or double quadword, the most-significant word of the dividend is in the rDX register and the least-significant word is in the rAX register. After the division, the instruction stores the quotient in the rAX register and the remainder in the rDX register.

The following table summarizes the action of this instruction:

Division Size	Dividend	Divisor	Quotient	Remainder	Quotient Range
Word/byte	AX	reg/mem8	AL	AH	–128 to +127
Doubleword/word	DX:AX	reg/mem16	AX	DX	–32,768 to +32,767
Quadword/doubleword	EDX:EAX	reg/mem32	EAX	EDX	-2^{31} to $2^{31}-1$
Double quadword/ quadword	RDX:RAX	reg/mem64	RAX	RDX	-2^{63} to $2^{63}-1$

The instruction truncates non-integral results towards 0. The sign of the remainder is always the same as the sign of the dividend, and the absolute value of the remainder is less than the absolute value of the divisor. An overflow generates a #DE (divide error) exception, rather than setting the OF flag.

To avoid overflow problems, precede this instruction with a CBW, CWD, CDQ, or CQO instruction to sign-extend the dividend.

Mnemonic	Opcode	Description
IDIV *reg/mem8*	F6 /7	Perform signed division of AX by the contents of an 8-bit register or memory location and store the quotient in AL and the remainder in AH.
IDIV *reg/mem16*	F7 /7	Perform signed division of DX:AX by the contents of a 16-bit register or memory location and store the quotient in AX and the remainder in DX.
IDIV *reg/mem32*	F7 /7	Perform signed division of EDX:EAX by the contents of a 32-bit register or memory location and store the quotient in EAX and the remainder in EDX.
IDIV *reg/mem64*	F7 /7	Perform signed division of RDX:RAX by the contents of a 64-bit register or memory location and store the quotient in RAX and the remainder in RDX.

Related Instructions

IMUL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	U	U	U	U
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Divide by zero, #DE	X	X	X	The divisor operand was 0.
	X	X	X	The quotient was too large for the designated register.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

IMUL Signed Multiply

Multiplies two signed operands. The number of operands determines the form of the instruction.

If a single operand is specified, the instruction multiplies the value in the specified general-purpose register or memory location by the value in the AL, AX, EAX, or RAX register (depending on the operand size) and stores the product in AX, DX:AX, EDX:EAX, or RDX:RAX, respectively.

If two operands are specified, the instruction multiplies the value in a general-purpose register (first operand) by an immediate value or the value in a general-purpose register or memory location (second operand) and stores the product in the first operand location.

If three operands are specified, the instruction multiplies the value in a general-purpose register or memory location (second operand), by an immediate value (third operand) and stores the product in a register (first operand).

The IMUL instruction sign-extends an immediate operand to the length of the other register/memory operand.

The CF and OF flags are set if, due to integer overflow, the double-width multiplication result cannot be represented in the half-width destination register. Otherwise the CF and OF flags are cleared.

Mnemonic	Opcode	Description
IMUL *reg/mem8*	F6 /5	Multiply the contents of AL by the contents of an 8-bit memory or register operand and put the signed result in AX.
IMUL *reg/mem16*	F7 /5	Multiply the contents of AX by the contents of a 16-bit memory or register operand and put the signed result in DX:AX.
IMUL *reg/mem32*	F7 /5	Multiply the contents of EAX by the contents of a 32-bit memory or register operand and put the signed result in EDX:EAX.
IMUL *reg/mem64*	F7 /5	Multiply the contents of RAX by the contents of a 64-bit memory or register operand and put the signed result in RDX:RAX.
IMUL *reg16*, *reg/mem16*	0F AF */r*	Multiply the contents of a 16-bit destination register by the contents of a 16-bit register or memory operand and put the signed result in the 16-bit destination register.
IMUL *reg32*, *reg/mem32*	0F AF */r*	Multiply the contents of a 32-bit destination register by the contents of a 32-bit register or memory operand and put the signed result in the 32-bit destination register.
IMUL *reg64*, *reg/mem64*	0F AF */r*	Multiply the contents of a 64-bit destination register by the contents of a 64-bit register or memory operand and put the signed result in the 64-bit destination register.
IMUL *reg16*, *reg/mem16*, *imm8*	6B */r ib*	Multiply the contents of a 16-bit register or memory operand by a sign-extended immediate byte and put the signed result in the 16-bit destination register.

Mnemonic	Opcode	Description
IMUL *reg32*, *reg/mem32*, *imm8*	6B */r ib*	Multiply the contents of a 32-bit register or memory operand by a sign-extended immediate byte and put the signed result in the 32-bit destination register.
IMUL *reg64*, *reg/mem64*, *imm8*	6B */r ib*	Multiply the contents of a 64-bit register or memory operand by a sign-extended immediate byte and put the signed result in the 64-bit destination register.
IMUL *reg16*, *reg/mem16*, *imm16*	69 */r iw*	Multiply the contents of a 16-bit register or memory operand by a sign-extended immediate word and put the signed result in the 16-bit destination register.
IMUL *reg32*, *reg/mem32*, *imm32*	69 */r id*	Multiply the contents of a 32-bit register or memory operand by a sign-extended immediate double and put the signed result in the 32-bit destination register.
IMUL *reg64*, *reg/mem64*, *imm32*	69 */r id*	Multiply the contents of a 64-bit register or memory operand by a sign-extended immediate double and put the signed result in the 64-bit destination register.

Related Instructions

IDIV

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

IN Input from Port

Transfers a byte, word, or doubleword from an I/O port (second operand) to the AL, AX or EAX register (first operand). The port address can be an 8-bit immediate value (00h to FFh) or contained in the DX register (0000h to FFFFh).

The port is in the processor's I/O address space. For 8-bit I/O port accesses, the opcode determines the port size. For 16-bit and 32-bit accesses, the operand-size attribute determines the port size. If the operand size is 64-bits, IN reads only 32 bits from the I/O port.

If the CPL is higher than IOPL, or the mode is virtual mode, IN checks the I/O permission bitmap in the TSS before allowing access to the I/O port. (See Volume 2 for details on the TSS I/O permission bitmap.)

Mnemonic	Opcode	Description
IN AL, *imm8*	E4 *ib*	Input a byte from the port at the address specified by *imm8* and put it into the AL register.
IN AX, *imm8*	E5 *ib*	Input a word from the port at the address specified by *imm8* and put it into the AX register.
IN EAX, *imm8*	E5 *ib*	Input a doubleword from the port at the address specified by *imm8* and put it into the EAX register.
IN AL, DX	EC	Input a byte from the port at the address specified by the DX register and put it into the AL register.
IN AX, DX	ED	Input a word from the port at the address specified by the DX register and put it into the AX register.
IN EAX, DX	ED	Input a doubleword from the port at the address specified by the DX register and put it into the EAX register.

Related Instructions

INS*x*, OUT, OUTS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X		One or more I/O permission bits were set in the TSS for the accessed port.
			X	The CPL was greater than the IOPL and one or more I/O permission bits were set in the TSS for the accessed port.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.

INC Increment by 1

Adds 1 to the specified register or memory location. The CF flag is not affected, even if the operand is incremented to 0000.

The one-byte forms of this instruction (opcodes 40 through 47) are used as REX prefixes in 64-bit mode. See “REX Prefixes” on page 11.

The forms of the INC instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

To perform an increment operation that updates the CF flag, use an ADD instruction with an immediate operand of 1.

Mnemonic	Opcode	Description
INC *reg/mem8*	FE /0	Increment the contents of an 8-bit register or memory location by 1.
INC *reg/mem16*	FF /0	Increment the contents of a 16-bit register or memory location by 1.
INC *reg/mem32*	FF /0	Increment the contents of a 32-bit register or memory location by 1.
INC *reg/mem64*	FF /0	Increment the contents of a 64-bit register or memory location by 1.
INC *reg16*	40 *+rw*	Increment the contents of a 16-bit register by 1. (These opcodes are used as REX prefixes in 64-bit mode. See “REX Prefixes” on page 11.)
INC *reg32*	40 *+rd*	Increment the contents of a 32-bit register by 1. (These opcodes are used as REX prefixes in 64-bit mode. See “REX Prefixes” on page 11.)

Related Instructions

ADD, DEC

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

INS
INSB
INSW
INSD

Input String

Transfers data from the I/O port specified in the DX register to an input buffer specified in the rDI register and increments or decrements the rDI register according to the setting of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments rDI by 1, 2, or 4, depending on the number of bytes read. If the DF flag is 1, it decrements the pointer by 1, 2, or 4.

In 16-bit and 32-bit mode, the INS instruction always uses ES as the data segment. The ES segment cannot be overridden with a segment override prefix. In 64-bit mode, INS always uses the unsegmented memory space.

The INS instructions use the explicit memory operand (first operand) to determine the size of the I/O port, but always use ES:[rDI] for the location of the input buffer. The explicit register operand (second operand) specifies the I/O port address and must always be DX.

The INSB, INSW, and INSD instructions copy byte, word, and doubleword data, respectively, from the I/O port (0000h to FFFFh) specified in the DX register to the input buffer specified in the ES:rDI registers.

If the operand size is 64-bits, the instruction behaves as if the operand size were 32-bits.

If the CPL is higher than the IOPL or the mode is virtual mode, INS*x* checks the I/O permission bitmap in the TSS before allowing access to the I/O port. (See volume 2 for details on the TSS I/O permission bitmap.)

The INSx instructions support the REP prefix for block input of rCX bytes, words, or doublewords. For details about the REP prefix, see “Repeat Prefixes” on page 9.

Mnemonic	Opcode	Description
INS *mem8*, DX	6C	Input a byte from the port specified by DX, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.
INS *mem16*, DX	6D	Input a word from the port specified by DX register, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.
INS *mem32*, DX	6D	Input a doubleword from the port specified by DX, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.
INSB	6C	Input a byte from the port specified by DX, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.

Mnemonic	Opcode	Description
INSW	6D	Input a word from the port specified by DX, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.
INSD	6D	Input a doubleword from the port specified by DX, put it into the memory location specified in ES:rDI, and then increment or decrement rDI.

Related Instructions

IN, OUT, OUTS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
		X		One or more I/O permission bits were set in the TSS for the accessed port.
			X	The CPL was greater than the IOPL and one or more I/O permission bits were set in the TSS for the accessed port.
			X	A null data segment was used to reference memory.
			X	The destination operand was in a non-writable segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

INT Interrupt to Vector

Transfers execution to the interrupt handler specified by an 8-bit unsigned immediate value. This value is an interrupt vector number (00h to FFh), which the processor uses as an index into the interrupt-descriptor table (IDT).

For detailed descriptions of the steps performed by INT*n* instructions, see the following:

- *Legacy-Mode Interrupts:* "Legacy Protected-Mode Interrupt Control Transfers" in Volume 2.
- *Long-Mode Interrupts:* "Long-Mode Interrupt Control Transfers" in Volume 2.

See also the descriptions of the INT3 instruction on page 259 and the INTO instruction on page 129.

Mnemonic	Opcode	Description
INT *imm8*	CD *ib*	Call interrupt service routine specified by interrupt vector *imm8*.

Action

```
// See "Pseudocode Definitions" on page 41.

INT_N_START:

IF (REAL_MODE)
    INT_N_REAL
ELSIF (PROTECTED_MODE)
    INT_N_PROTECTED
ELSE // (VIRTUAL_MODE)
    INT_N_VIRTUAL


INT_N_REAL:
    temp_int_n_vector = byte-sized interrupt vector specified in the instruction,
                        zero-extended to 64 bits

    temp_RIP = READ_MEM.w [idt:temp_int_n_vector*4]
                          // read target CS:RIP from the real-mode idt
    temp_CS  = READ_MEM.w [idt:temp_int_n_vector*4+2]

    PUSH.w old_RFLAGS
    PUSH.w old_CS
    PUSH.w next_RIP

    IF (temp_RIP>CS.limit)
        EXCEPTION [#GP]

    CS.sel  = temp_CS
    CS.base = temp_CS SHL 4

    RFLAGS.AC,TF,IF,RF cleared
```

```
    RIP = temp_RIP
    EXIT


INT_N_PROTECTED:

    temp_int_n_vector = byte-sized interrupt vector specified in the instruction,
                        zero-extended to 64 bits
    temp_idt_desc = READ_IDT (temp_int_n_vector)

    IF (temp_idt_desc.attr.type = 'taskgate')
        TASK_SWITCH   // using tss selector in the task gate as the target tss

    IF (LONG_MODE)     // The size of the gate controls the size of the
                       // stack pushes.
        V=8-byte       // Long mode only uses 64-bit gates.
    ELSIF ((temp_idt_desc.attr.type = 'intgate32')
          || (temp_idt_desc.attr.type = 'trapgate32'))
        V=4-byte       // Legacy mode, using a 32-bit gate
    ELSE // gate is intgate16 or trapgate16
        V=2-byte       // Legacy mode, using a 16-bit gate

    temp_RIP = temp_idt_desc.offset

    IF (LONG_MODE)
                       // In long mode, we need to read the 2nd half of a
                       // 16-byte interrupt-gate from the IDT, to get the
                       // upper 32 bits of the target RIP
    {
       temp_upper = READ_MEM.q [idt:temp_int_n_vector*16+8]

       temp_RIP = tempRIP + (temp_upper SHL 32) // concatenate both halves of RIP
    }

    CS = READ_DESCRIPTOR (temp_idt_desc.segment, intcs_chk)

    IF (CS.attr.conforming=1)
           temp_CPL = CPL
        ELSE
           temp_CPL = CS.attr.dpl

    IF (CPL=temp_CPL)    // no privilege-level change
    {
        IF (LONG_MODE)
        {
            IF (temp_idt_desc.ist!=0)
                        // In long mode, if the IDT gate specifies an IST pointer,
                        // a stack-switch is always done
                RSP = READ_MEM.q [tss:ist_index*8+28]

            RSP = RSP AND 0xFFFFFFFFFFFFFFF0
```

```
                    // In long mode, interrupts/exceptions align RSP to a
                    // 16-byte boundary

        PUSH.q old_SS    // In long mode, SS:RSP is always pushed to the stack
        PUSH.q old_RSP
    }

    PUSH.v old_RFLAGS
    PUSH.v old_CS
    PUSH.v next_RIP

    IF ((64BIT_MODE) && (temp_RIP is non-canonical)
       || (!64BIT_MODE) && (temp_RIP > CS.limit))
        EXCEPTION [#GP(0)]

    RFLAGS.VM,NT,TF,RF cleared
    RFLAGS.IF cleared if interrupt gate

    RIP = temp_RIP
    EXIT
}
ELSE // (CPL > temp_CPL), changing privilege level
{
    CPL = temp_CPL

    temp_SS_desc:temp_RSP = READ_INNER_LEVEL_STACK_POINTER
                            (CPL, temp_idt_desc.ist)

    IF (LONG_MODE)
        temp_RSP = temp_RSP AND 0xFFFFFFFFFFFFFFF0
                        // in long mode, interrupts/exceptions align rsp
                        // to a 16-byte boundary

    RSP.q = temp_RSP
    SS = temp_SS_desc

    PUSH.v old_SS  // #SS on the following pushes uses SS.sel as error code
    PUSH.v old_RSP
    PUSH.v old_RFLAGS
    PUSH.v old_CS
    PUSH.v next_RIP

    IF ((64BIT_MODE) && (temp_RIP is non-canonical)
       || (!64BIT_MODE) && (temp_RIP > CS.limit))
        EXCEPTION [#GP(0)]

    RFLAGS.VM,NT,TF,RF cleared
    RFLAGS.IF cleared if interrupt gate
    RIP = temp_RIP
    EXIT
}
```

```
INT_N_VIRTUAL:

    temp_int_n_vector = byte-sized interrupt vector specified in the instruction,
                        zero-extended to 64 bits

    IF (CR4.VME=0)                  // vme isn't enabled
    {
     IF (RFLAGS.IOPL=3)
            INT_N_VIRTUAL_TO_PROTECTED
        ELSE
            EXCEPTION [#GP(0)]
    }

    temp_IRB_BASE = READ_MEM.w [tss:102] - 32
                       // check the vme Int-n Redirection Bitmap (IRB), to see
                       // if we should redirect this interrupt to a virtual-mode
                       // handler
    temp_VME_REDIRECTION_BIT = READ_BIT_ARRAY ([tss:temp_IRB_BASE],
                                               temp_int_n_vector)

    IF (temp_VME_REDIRECTION_BIT=1)
    {                  // the virtual-mode int-n bitmap bit is set, so don't
                       // redirect this interrupt
        IF (RFLAGS.IOPL=3)
            INT_N_VIRTUAL_TO_PROTECTED
        ELSE
            EXCEPTION [#GP(0)]
    }
    ELSE               // redirect interrupt through virtual-mode idt
    {
        temp_RIP = READ_MEM.w [0:temp_int_n_vector*4]
                       // read target CS:RIP from the virtual-mode idt at
                       // linear address 0
        temp_CS  = READ_MEM.w [0:temp_int_n_vector*4+2]

        IF (RFLAGS.IOPL < 3)
           old_RFLAGS = old_RFLAGS with VIF bit shifted into IF bit, and IOPL = 3

        PUSH.w old_RFLAGS
        PUSH.w old_CS
        PUSH.w next_RIP

        CS.sel  = temp_CS
        CS.base = temp_CS SHL 4

        RFLAGS.TF,RF cleared
        RIP = temp_RIP      // RFLAGS.IF cleared if IOPL = 3
                            // RFLAGS.VIF cleared if IOPL < 3
        EXIT
    }
```

```
INT_N_VIRTUAL_TO_PROTECTED:

    temp_idt_desc = READ_IDT (temp_int_n_vector)
    IF (temp_idt_desc.attr.type = 'taskgate')
        TASK_SWITCH  // using tss selector in the task gate as the target tss

    IF ((temp_idt_desc.attr.type = 'intgate32')
       || (temp_idt_desc.attr.type = 'trapgate32'))
                    // the size of the gate controls the size of the stack pushes
        V=4-byte   // legacy mode, using a 32-bit gate
    ELSE // gate is intgate16 or trapgate16
        V=2-byte            // legacy mode, using a 16-bit gate

    temp_RIP = temp_idt_desc.offset
    CS = READ_DESCRIPTOR (temp_idt_desc.segment, intcs_chk)

    IF (CS.attr.dpl!=0)       // Handler must run at CPL 0.
        EXCEPTION [#GP(CS.sel)]

    CPL = 0

    temp_ist = 0             // Legacy mode doesn't use ist pointers
    temp_SS_desc:temp_RSP = READ_INNER_LEVEL_STACK_POINTER (CPL, temp_ist)

    RSP.q = temp_RSP
    SS = temp_SS_desc

    PUSH.v old_GS      // #SS on the following pushes use SS.sel as error code.
    PUSH.v old_FS
    PUSH.v old_DS
    PUSH.v old_ES
    PUSH.v old_SS
    PUSH.v old_RSP
    PUSH.v old_RFLAGS  // Pushed with RF clear.
    PUSH.v old_CS
    PUSH.v next_RIP

    IF (temp_RIP > CS.limit)
        EXCEPTION [#GP(0)]

    DS = NULL    // can't use virtual-mode selectors in protected mode
    ES = NULL    // can't use virtual-mode selectors in protected mode
    FS = NULL    // can't use virtual-mode selectors in protected mode
    GS = NULL    // can't use virtual-mode selectors in protected mode

    RFLAGS.VM,NT,TF,RF cleared
    RFLAGS.IF cleared if interrupt gate

    RIP = temp_RIP
    EXIT
```

Related Instructions

INT 3, INTO, BOUND

rFLAGS Affected

If a task switch occurs, all flags are modified. Otherwise settings are as follows:

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
		M	M	M	0	M				M	0					
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid TSS, #TS (selector)		X	X	As part of a stack switch, the target stack segment selector or rSP in the TSS was beyond the TSS limit.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was a null selector.
		X	X	As part of a stack switch, the target stack segment selector's TI bit was set, but the LDT selector was a null selector.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was beyond the limit of the GDT or LDT descriptor table.
		X	X	As part of a stack switch, the target stack segment selector in the TSS contained a RPL that was not equal to its DPL.
		X	X	As part of a stack switch, the target stack segment selector in the TSS contained a DPL that was not equal to the CPL of the code segment selector.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was not a writable segment.
Segment not present, #NP (selector)		X	X	The accessed code segment, interrupt gate, trap gate, task gate, or TSS was not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical, and no stack switch occurred.
Stack, #SS (selector)		X	X	After a stack switch, a memory address exceeded the stack segment limit or was non-canonical.
		X	X	As part of a stack switch, the SS register was loaded with a non-null segment selector and the segment was marked not present.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
		X		The IOPL was less than 3 and CR4.VME was 0.
		X		IOPL was less than 3, CR4.VME was 1, and the corresponding bit in the VME interrupt redirection bitmap was 1.
General protection, #GP (selector)	X	X	X	The interrupt vector was beyond the limit of IDT.
		X	X	The descriptor in the IDT was not an interrupt, trap, or task gate in legacy mode or not a 64-bit interrupt or trap gate in long mode.
		X	X	The DPL of the interrupt, trap, or task gate descriptor was less than the CPL.
		X	X	The segment selector specified by the interrupt or trap gate had its TI bit set, but the LDT selector was a null selector.
		X	X	The segment descriptor specified by the interrupt or trap gate exceeded the descriptor table limit or was a null selector.
		X	X	The segment descriptor specified by the interrupt or trap gate was not a code segment in legacy mode, or not a 64-bit code segment in long mode.
			X	The DPL of the segment specified by the interrupt or trap gate was greater than the CPL.
		X		The DPL of the segment specified by the interrupt or trap gate pointed was not 0 or it was a conforming segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

INTO Interrupt to Overflow Vector

Checks the overflow flag (OF) in the rFLAGS register and calls the overflow exception (#OF) handler if the OF flag is set to 1. This instruction has no effect if the OF flag is cleared to 0. The INTO instruction detects overflow in signed number addition. See *AMD64 Architecture Programmer's Manual Volume 1: Application Programming* for more information on the OF flag.

Using this instruction in 64-bit mode generates an invalid-opcode exception.

For detailed descriptions of the steps performed by INT instructions, see the following:

- *Legacy-Mode Interrupts:* "Legacy Protected-Mode Interrupt Control Transfers" in Volume 2.
- *Long-Mode Interrupts:* "Long-Mode Interrupt Control Transfers" in Volume 2.

Mnemonic	Opcode	Description
INTO	CE	Call overflow exception if the overflow flag is set. (Invalid in 64-bit mode.)

Action

```
IF (64BIT_MODE)
   EXCEPTION[#UD]
IF (RFLAGS.OF = 1)      // #OF is a trap, and pushes the rIP of the instruction
   EXCEPTION [#OF]      // following INTO.
EXIT
```

Related Instructions

INT, INT 3, BOUND

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Overflow, #OF	X	X	X	The INTO instruction was executed with 0F set to 1.
Invalid opcode, #UD			X	Instruction was executed in 64-bit mode.

J*cc* Jump on Condition

Checks the status flags in the rFLAGS register and, if the flags meet the condition specified by the condition code in the mnemonic (*cc*), jumps to the target instruction located at the specified relative offset. Otherwise, execution continues with the instruction following the J*cc* instruction.

Unlike the unconditional jump (JMP), conditional jump instructions have only two forms—*short and near conditional jumps*. Different opcodes correspond to different forms of one instruction. For example, the JO instruction (jump if overflow) has opcode 0Fh 80h for its near form and 70h for its short form, but the mnemonic is the same for both forms. The only difference is that the near form has a 16- or 32-bit relative displacement, while the short form always has an 8-bit relative displacement.

Mnemonics are provided to deal with the programming semantics of both signed and unsigned numbers. Instructions tagged A (above) and B (below) are intended for use in unsigned integer code; those tagged G (greater) and L (less) are intended for use in signed integer code.

If the jump is taken, the signed displacement is added to the rIP (of the following instruction) and the result is truncated to 16, 32, or 64 bits, depending on operand size.

In 64-bit mode, the operand size defaults to 64 bits. The processor sign-extends the 8-bit or 32-bit displacement value to 64 bits before adding it to the RIP.

These instructions cannot perform far jumps (to other code segments). To create a far-conditional-jump code sequence corresponding to a high-level language statement like:

```
IF A = B THEN GOTO FarLabel
```

where FarLabel is located in another code segment, use the opposite condition in a conditional short jump before an unconditional far jump. Such a code sequence might look like:

```
      cmp   A,B               ; compare operands
      jne   NextInstr         ; continue program if not equal
      jmp   far FarLabel      ; far jump if operands are equal

NextInstr:                    ; continue program
```

For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
JO *rel8off* JO *rel16off* JO *rel32off*	70 cb 0F 80 *cw* 0F 80 *cd*	Jump if overflow (OF = 1).
JNO *rel8off* JNO *rel16off* JNO *rel32off*	71 *cb* 0F 81 *cw* 0F 81 *cd*	Jump if not overflow (OF = 0).
JB *rel8off* JB *rel16off* JB *rel32off*	72 *cb* 0F 82 *cw* 0F 82 *cd*	Jump if below (CF = 1).

Mnemonic	Opcode	Description
JC *rel8off* JC *rel16off* JC *rel32off*	72 *cb* 0F 82 *cw* 0F 82 *cd*	Jump if carry (CF = 1).
JNAE *rel8off* JNAE *rel16off* JNAE *rel32off*	72 *cb* 0F 82 *cw* 0F 82 *cd*	Jump if not above or equal (CF = 1).
JNB *rel8off* JNB *rel16off* JNB *rel32off*	73 *cb* 0F 83 *cw* 0F 83 *cd*	Jump if not below (CF = 0).
JNC *rel8off* JNC *rel16off* JNC *rel32off*	73 *cb* 0F 83 *cw* 0F 83 *cd*	Jump if not carry (CF = 0).
JAE *rel8off* JAE *rel16off* JAE *rel32off*	73 *cb* 0F 83 *cw* 0F 83 *cd*	Jump if above or equal (CF = 0).
JZ *rel8off* JZ *rel16off* JZ *rel32off*	74 *cb* 0F 84 *cw* 0F 84 *cd*	Jump if zero (ZF = 1).
JE *rel8off* JE *rel16off* JE *rel32off*	74 *cb* 0F 84 *cw* 0F 84 *cd*	Jump if equal (ZF = 1).
JNZ *rel8off* JNZ *rel16off* JNZ *rel32off*	75 *cb* 0F 85 *cw* 0F 85 *cd*	Jump if not zero (ZF = 0).
JNE *rel8off* JNE *rel16off* JNE *rel32off*	75 *cb* 0F 85 *cw* 0F 85 *cd*	Jump if not equal (ZF = 0).
JBE *rel8off* JBE *rel16off* JBE *rel32off*	76 *cb* 0F 86 *cw* 0F 86 *cd*	Jump if below or equal (CF = 1 or ZF = 1).
JNA *rel8off* JNA *rel16off* JNA *rel32off*	76 *cb* 0F 86 *cw* 0F 86 *cd*	Jump if not above (CF = 1 or ZF = 1).
JNBE *rel8off* JNBE *rel16off* JNBE *rel32off*	77 *cb* 0F 87 *cw* 0F 87 *cd*	Jump if not below or equal (CF = 0 and ZF = 0).
JA *rel8off* JA *rel16off* JA *rel32off*	77 *cb* 0F 87 *cw* 0F 87 *cd*	Jump if above (CF = 0 and ZF = 0).
JS *rel8off* JS *rel16off* JS *rel32off*	78 *cb* 0F 88 *cw* 0F 88 *cd*	Jump if sign (SF = 1).
JNS *rel8off* JNS *rel16off* JNS *rel32off*	79 *cb* 0F 89 *cw* 0F 89 *cd*	Jump if not sign (SF = 0).

Mnemonic	Opcode	Description
JP *rel8off*	7A *cb*	
JP *rel16off*	0F 8A *cw*	Jump if parity (PF = 1).
JP *rel32off*	0F 8A *cd*	
JPE *rel8off*	7A *cb*	
JPE *rel16off*	0F 8A *cw*	Jump if parity even (PF = 1).
JPE *rel32off*	0F 8A *cd*	
JNP *rel8off*	7B *cb*	
JNP *rel16off*	0F 8B *cw*	Jump if not parity (PF = 0).
JNP *rel32off*	0F 8B *cd*	
JPO *rel8off*	7B *cb*	
JPO *rel16off*	0F 8B *cw*	Jump if parity odd (PF = 0).
JPO *rel32off*	0F 8B *cd*	
JL *rel8off*	7C *cb*	
JL *rel16off*	0F 8C *cw*	Jump if less (SF <> OF).
JL *rel32off*	0F 8C *cd*	
JNGE *rel8off*	7C *cb*	
JNGE *rel16off*	0F 8C *cw*	Jump if not greater or equal (SF <> OF).
JNGE *rel32off*	0F 8C *cd*	
JNL *rel8off*	7D *cb*	
JNL *rel16off*	0F 8D *cw*	Jump if not less (SF = OF).
JNL *rel32off*	0F 8D *cd*	
JGE *rel8off*	7D *cb*	
JGE *rel16off*	0F 8D *cw*	Jump if greater or equal (SF = OF).
JGE *rel32off*	0F 8D *cd*	
JLE *rel8off*	7E *cb*	
JLE *rel16off*	0F 8E *cw*	Jump if less or equal (ZF = 1 or SF <> OF).
JLE *rel32off*	0F 8E *cd*	
JNG *rel8off*	7E *cb*	
JNG *rel16off*	0F 8E *cw*	Jump if not greater (ZF = 1 or SF <> OF).
JNG *rel32off*	0F 8E *cd*	
JNLE *rel8off*	7F *cb*	
JNLE *rel16off*	0F 8F *cw*	Jump if not less or equal (ZF = 0 and SF = OF).
JNLE *rel32off*	0F 8F *cd*	
JG *rel8off*	7F *cb*	
JG *rel16off*	0F 8F *cw*	Jump if greater (ZF = 0 and SF = OF).
JG *rel32off*	0F 8F *cd*	

Related Instructions

JMP (Near), JMP (Far), JrCXZ

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical.

JCXZ
JECXZ
JRCXZ

Jump if rCX Zero

Checks the contents of the count register (rCX) and, if 0, jumps to the target instruction located at the specified 8-bit relative offset. Otherwise, execution continues with the instruction following the J*r*CXZ instruction.

The size of the count register (CX, ECX, or RCX) depends on the address-size attribute of the JrCXZ instruction. Therefore, JRCXZ can only be executed in 64-bit mode and JCXZ cannot be executed in 64-bit mode.

If the jump is taken, the signed displacement is added to the rIP (of the following instruction) and the result is truncated to 16, 32, or 64 bits, depending on operand size.

In 64-bit mode, the operand size defaults to 64 bits. The processor sign-extends the 8-bit displacement value to 64 bits before adding it to the RIP.

For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
JCXZ *rel8off*	E3 *cb*	Jump short if the 16-bit count register (CX) is zero.
JECXZ *rel8off*	E3 *cb*	Jump short if the 32-bit count register (ECX) is zero.
JRCXZ *rel8off*	E3 *cb*	Jump short if the 64-bit count register (RCX) is zero.

Related Instructions

J*cc*, JMP (Near), JMP (Far)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical

JMP (Near) Near Jump

Unconditionally transfers control to a new address without saving the current rIP value. This form of the instruction jumps to an address in the current code segment and is called a *near jump*. The target operand can specify a register, a memory location, or a label.

If the JMP target is specified in a register or memory location, then a 16-, 32-, or 64-bit rIP is read from the operand, depending on operand size. This rIP is zero-extended to 64 bits.

If the JMP target is specified by a displacement in the instruction, the signed displacement is added to the rIP (of the following instruction), and the result is truncated to 16, 32, or 64 bits depending on operand size. The signed displacement can be 8 bits, 16 bits, or 32 bits, depending on the opcode and the operand size.

For near jumps in 64-bit mode, the operand size defaults to 64 bits. The E9 opcode results in RIP = RIP + 32-bit signed displacement, and the FF /4 opcode results in RIP = 64-bit offset from register or memory. No prefix is available to encode a 32-bit operand size in 64-bit mode.

See JMP (Far) for information on far jumps—jumps to procedures located outside of the current code segment. For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
JMP *rel8off*	EB *cb*	Short jump with the target specified by an 8-bit signed displacement.
JMP *rel16off*	E9 *cw*	Near jump with the target specified by a 16-bit signed displacement.
JMP *rel32off*	E9 *cd*	Near jump with the target specified by a 32-bit signed displacement.
JMP *reg/mem16*	FF /4	Near jump with the target specified *reg/mem16*.
JMP *reg/mem32*	FF /4	Near jump with the target specified *reg/mem32*. (No prefix for encoding in 64-bit mode.)
JMP *reg/mem64*	FF /4	Near jump with the target specified *reg/mem64*.

Related Instructions

JMP (Far), J*cc*, J*r*CX

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

JMP (Far) Far Jump

Unconditionally transfers control to a new address without saving the current CS:rIP values. This form of the instruction jumps to an address outside the current code segment and is called a *far jump*. The operand specifies a target selector and offset.

The target operand can be specified by the instruction directly, by containing the far pointer in the jmp far opcode itself, or indirectly, by referencing a far pointer in memory. In 64-bit mode, only indirect far jumps are allowed, executing a direct far jmp (opcode EA) will generate an undefined opcode exception. For both direct and indirect far calls, if the JMP (Far) operand-size is 16 bits, the instruction's operand is a 16-bit selector followed by a 16-bit offset. If the operand-size is 32 or 64 bits, the operand is a 16-bit selector followed by a 32-bit offset.

In all modes, the target selector used by the instruction can be a code selector. Additionally, the target selector can also be a call gate in protected mode, or a task gate or TSS selector in legacy protected mode.

- *Target is a code segment*—Control is transferred to the target CS:rIP. In this case, the target offset can only be a 16 or 32 bit value, depending on operand-size, and is zero-extended to 64 bits. No CPL change is allowed.
- *Target is a call gate*—The call gate specifies the actual target code segment and offset, and control is transferred to the target CS:rIP. When jumping through a call gate, the size of the target rIP is 16, 32, or 64 bits, depending on the size of the call gate. If the target rIP is less than 64 bits, it's zero-extended to 64 bits. In long mode, only 64-bit call gates are allowed, and they must point to 64-bit code segments. No CPL change is allowed.
- *Target is a task gate or a TSS*—If the mode is legacy protected mode, then a task switch occurs. See "Hardware Task-Management in Legacy Mode" in volume 2 for details about task switches. Hardware task switches are not supported in long mode.

See JMP (Near) for information on near jumps—jumps to procedures located inside the current code segment. For details about control-flow instructions, see "Control Transfers" in Volume 1, and "Control-Transfer Privilege Checks" in Volume 2.

Mnemonic	Opcode	Description
JMP FAR *pntr16:16*	EA *cd*	Far jump direct, with the target specified by a far pointer contained in the instruction. (Invalid in 64-bit mode.)
JMP FAR *pntr16:32*	EA *cp*	Far jump direct, with the target specified by a far pointer contained in the instruction. (Invalid in 64-bit mode.)
JMP FAR *mem16:16*	FF /5	Far jump indirect, with the target specified by a far pointer in memory.
JMP FAR *mem16:32*	FF /5	Far jump indirect, with the target specified by a far pointer in memory.

Action

```
// Far jumps (JMPF)
// See "Pseudocode Definitions" on page 41.

JMPF_START:

IF (REAL_MODE)
    JMPF_REAL_OR_VIRTUAL
ELSIF (PROTECTED_MODE)
    JMPF_PROTECTED
ELSE // (VIRTUAL_MODE)
    JMPF_REAL_OR_VIRTUAL


JMPF_REAL_OR_VIRTUAL:

    IF (OPCODE = jmpf [mem]) //JMPF Indirect
    {
        temp_RIP = READ_MEM.z [mem]
        temp_CS  = READ_MEM.w [mem+Z]
    }
    ELSE // (OPCODE = jmpf direct)
    {
        temp_RIP = z-sized offset specified in the instruction,
                   zero-extended to 64 bits
        temp_CS  = selector specified in the instruction
    }

    IF (temp_RIP>CS.limit)
        EXCEPTION [#GP(0)]

    CS.sel  = temp_CS
    CS.base = temp_CS SHL 4
    RIP = temp_RIP
    EXIT

JMPF_PROTECTED:
    IF (OPCODE = jmpf [mem]) // JMPF Indirect
    {
        temp_offset = READ_MEM.z [mem]
        temp_sel    = READ_MEM.w [mem+Z]
    }
    ELSE // (OPCODE = jmpf direct)
    {
        IF (64BIT_MODE)
           EXCEPTION [#UD]             // 'jmpf direct' is illegal in 64-bit mode

        temp_offset = z-sized offset specified in the instruction,
                      zero-extended to 64 bits
        temp_sel    = selector specified in the instruction
    }
```

```
temp_desc = READ_DESCRIPTOR (temp_sel, cs_chk)
                     // read descriptor, perform protection and type checks

IF (temp_desc.attr.type = 'available_tss')
    TASK_SWITCH      // using temp_sel as the target tss selector
ELSIF (temp_desc.attr.type = 'taskgate')
    TASK_SWITCH      // using the tss selector in the task gate as the
                     // target tss
ELSIF (temp_desc.attr.type = 'code')
                     // if the selector refers to a code descriptor, then
                     // the offset we read is the target RIP
{
    temp_RIP = temp_offset
    CS = temp_desc
    IF ((!64BIT_MODE) && (temp_RIP > CS.limit))
                     // temp_RIP can't be non-canonical because
                     // it's a 16- or 32-bit offset, zero-extended to 64 bits
    {
        EXCEPTION [#GP(0)]
    }
    RIP = temp_RIP
    EXIT
}
ELSE
{
       // (temp_desc.attr.type = 'callgate')
       // if the selector refers to a call gate, then
       // the target CS and RIP both come from the call gate
    temp_RIP = temp_desc.offset

    IF (LONG_MODE)
    {
       // in long mode, we need to read the 2nd half of a 16-byte call-gate
       // from the gdt/ldt to get the upper 32 bits of the target RIP
        temp_upper = READ_MEM.q [temp_sel+8]
        IF (temp_upper's extended attribute bits != 0)
            EXCEPTION [#GP(temp_sel)]       // Make sure the extended
                                            // attribute bits are all zero.

        temp_RIP = tempRIP + (temp_upper SHL 32)
                         // concatenate both halves of RIP
    }
    CS = READ_DESCRIPTOR (temp_desc.segment, clg_chk)
                         // set up new CS base, attr, limits
    IF ((64BIT_MODE) && (temp_RIP is non-canonical)
       || (!64BIT_MODE) && (temp_RIP > CS.limit))
        EXCEPTION [#GP(0)]
    RIP = temp_RIP
    EXIT
}
```

Related Instructions

JMP (Near), J*cc*, J*r*CX

rFLAGS Affected

None, unless a task switch occurs, in which case all flags are modified.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The far JUMP indirect opcode (FF /5) had a register operand.
			X	The far JUMP direct opcode (EA) was executed in 64-bit mode.
Segment not present, #NP (selector)			X	The accessed code segment, call gate, task gate, or TSS was not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
			X	A null data segment was used to reference memory.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP (selector)			X	The target code segment selector was a null selector.
			X	A code, call gate, task gate, or TSS descriptor exceeded the descriptor table limit.
			X	A segment selector's TI bit was set, but the LDT selector was a null selector.
			X	The segment descriptor specified by the instruction was not a code segment, task gate, call gate or available TSS in legacy mode, or not a 64-bit code segment or a 64-bit call gate in long mode.
			X	The RPL of the non-conforming code segment selector specified by the instruction was greater than the CPL, or its DPL was not equal to the CPL.
			X	The DPL of the conforming code segment descriptor specified by the instruction was greater than the CPL.
			X	The DPL of the callgate, taskgate, or TSS descriptor specified by the instruction was less than the CPL or less than its own RPL.
			X	The segment selector specified by the call gate or task gate was a null selector.
			X	The segment descriptor specified by the call gate was not a code segment in legacy mode or not a 64-bit code segment in long mode.
			X	The DPL of the segment descriptor specified the call gate was greater than the CPL and it is a conforming segment.
			X	The DPL of the segment descriptor specified by the callgate was not equal to the CPL and it is a non-conforming segment.
			X	The 64-bit call gate's extended attribute bits were not zero.
			X	The TSS descriptor was found in the LDT.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

LAHF Load Status Flags into AH Register

Loads the lower 8 bits of the rFLAGS register, including sign flag (SF), zero flag (ZF), auxiliary carry flag (AF), parity flag (PF), and carry flag (CF), into the AH register.

The instruction sets the reserved bits 1, 3, and 5 of the rFLAGS register to 1, 0, and 0, respectively, in the AH register.

The LAHF instruction can only be executed in 64-bit mode if supported by the processor implementation. Check the status of ECX bit 0 returned by CPUID function 8000_0001h to verify that the processor supports LAHF in 64-bit mode.

Mnemonic	Opcode	Description
LAHF	9F	Load the SF, ZF, AF, PF, and CF flags into the AH register.

Related Instructions

SAHF

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction is not supported in 64-bit mode, as indicated by ECX bit 0 returned by CPUID function 8000_0001h.

LDS LES LFS LGS LSS — Load Far Pointer

Loads a far pointer from a memory location (second operand) into a segment register (mnemonic) and general-purpose register (first operand). The instruction stores the 16-bit segment selector of the pointer into the segment register and the 16-bit or 32-bit offset portion into the general-purpose register. The operand-size attribute determines whether the pointer is 32-bit or 48-bit.

These instructions load associated segment-descriptor information into the hidden portion of the specified segment register.

Using LDS or LES in 64-bit mode generates an invalid-opcode exception.

Executing LFS, LGS, or LSS with a 64-bit operand size only loads a 32-bit general purpose register and the specified segment register.

Mnemonic	Opcode	Description
LDS *reg16, mem16:16*	C5 */r*	Load DS:reg16 with a far pointer from memory. (Invalid in 64-bit mode.)
LDS *reg32, mem16:32*	C5 */r*	Load DS:reg32 with a far pointer from memory. (Invalid in 64-bit mode.)
LES *reg16, mem16:16*	C4 */r*	Load ES:reg16 with a far pointer from memory. (Invalid in 64-bit mode.)
LES *reg32, mem16:32*	C4 */r*	Load ES:reg32 with a far pointer from memory. (Invalid in 64-bit mode.)
LFS *reg16, mem16:16*	0F B4 */r*	Load FS:reg16 with a far pointer from memory.
LFS *reg32, mem16:32*	0F B4 */r*	Load FS:reg32 with a far pointer from memory.
LGS *reg16, mem16:16*	0F B5 */r*	Load GS:reg16 with a far pointer from memory.
LGS *reg32, mem16:32*	0F B5 */r*	Load GS:reg32 with a far pointer from memory.
LSS *reg16, mem16:16*	0F B2 */r*	Load SS:*reg16* with a far pointer from memory.
LSS *reg32, mem16:32*	0F B2 */r*	Load SS:*reg32* with a far pointer from memory.

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The source operand was a register.
			X	LDS or LES was executed in 64-bit mode.
Segment not present, #NP (selector)			X	The DS, ES, FS, or GS register was loaded with a non-null segment selector and the segment was marked not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)			X	The SS register was loaded with a non-null segment selector and the segment was marked not present.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
General protection, #GP (selector)			X	A segment register was loaded, but the segment descriptor exceeded the descriptor table limit.
			X	A segment register was loaded and the segment selector's TI bit was set, but the LDT selector was a null selector.
			X	The SS register was loaded with a null segment selector in non-64-bit mode or while CPL = 3.
			X	The SS register was loaded and the segment selector RPL and the segment descriptor DPL were not equal to the CPL.
			X	The SS register was loaded and the segment pointed to was not a writable data segment.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was a data or non-conforming code segment, but the RPL or CPL was greater than the DPL.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was not a data segment or readable code segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

LEA Load Effective Address

Computes the effective address of a memory location (second operand) and stores it in a general-purpose register (first operand).

The address size of the memory location and the size of the register determine the specific action taken by the instruction, as follows:

- If the address size and the register size are the same, the instruction stores the effective address as computed.
- If the address size is longer than the register size, the instruction truncates the effective address to the size of the register.
- If the address size is shorter than the register size, the instruction zero-extends the effective address to the size of the register.

If the second operand is a register, an undefined-opcode exception occurs.

The LEA instruction is related to the MOV instruction, which copies data from a memory location to a register, but LEA takes the address of the source operand, whereas MOV takes the contents of the memory location specified by the source operand. In the simplest cases, LEA can be replaced with MOV. For example:

```
lea eax, [ebx]
```

has the same effect as:

```
mov eax, ebx
```

However, LEA allows software to use any valid ModRM and SIB addressing mode for the source operand. For example:

```
lea eax, [ebx+edi]
```

loads the sum of the EBX and EDI registers into the EAX register. This could not be accomplished by a single MOV instruction.

The LEA instruction has a limited capability to perform multiplication of operands in general-purpose registers using scaled-index addressing. For example:

```
lea eax, [ebx+ebx*8]
```

loads the value of the EBX register, multiplied by 9, into the EAX register. Possible values of multipliers are 2, 4, 8, 3, 5, and 9.

The LEA instruction is widely used in string-processing and array-processing to initialize an index register (rSI or rDI) before performing string instructions such as MOVSx. It is also used to initialize the rBX register before performing the XLAT instruction in programs that perform character translations. In data structures, the LEA instruction can calculate addresses of operands stored in memory, and in particular, addresses of array or string elements.

Mnemonic	Opcode	Description
LEA *reg16*, *mem*	8D /*r*	Store effective address in a 16-bit register.
LEA *reg32, mem*	8D /*r*	Store effective address in a 32-bit register.
LEA *reg64, mem*	8D /*r*	Store effective address in a 64-bit register.

Related Instructions

MOV

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The source operand was a register.

LEAVE Delete Procedure Stack Frame

Releases a stack frame created by a previous ENTER instruction. To release the frame, it copies the frame pointer (in the rBP register) to the stack pointer register (rSP), and then pops the old frame pointer from the stack into the rBP register, thus restoring the stack frame of the calling procedure.

The 32-bit LEAVE instruction is equivalent to the following 32-bit operation:

```
MOV ESP,EBP
POP EBP
```

To return program control to the calling procedure, execute a RET instruction after the LEAVE instruction.

In 64-bit mode, the LEAVE operand size defaults to 64 bits, and there is no prefix available for encoding a 32-bit operand size.

Mnemonic	Opcode	Description
LEAVE	C9	Set the stack pointer register SP to the value in the BP register and pop BP.
LEAVE	C9	Set the stack pointer register ESP to the value in the EBP register and pop EBP. (No prefix for encoding this in 64-bit mode.)
LEAVE	C9	Set the stack pointer register RSP to the value in the RBP register and pop RBP.

Related Instructions

ENTER

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

LFENCE Load Fence

Acts as a barrier to force strong memory ordering (serialization) between load instructions preceding the LFENCE and load instructions that follow the LFENCE. Loads from differing memory types may be performed out of order, in particular between WC/WC+ and other memory types. The LFENCE instruction assures that the system completes all previous loads before executing subsequent loads.

The LFENCE instruction is weakly-ordered with respect to store instructions, data and instruction prefetches, and the SFENCE instruction. Speculative loads initiated by the processor, or specified explicitly using cache-prefetch instructions, can be reordered around an LFENCE.

In addition to load instructions, the LFENCE instruction is strongly ordered with respect to other LFENCE instructions, MFENCE instructions, and serializing instructions. Further details on the use of MFENCE to order accesses among differing memory types may be found in *AMD64 Architecture Programmer's Manual Volume 2: System Programming*, section 7.4 "Memory Types" on page 170.

Support for the LFENCE instruction is indicated when the SSE2 bit (bit 26) is set to 1 in EDX after executing CPUID function 0000_0001h.

Mnemonic	Opcode	Description
LFENCE	0F AE E8	Force strong ordering of (serialize) load operations.

Related Instructions

MFENCE, SFENCE

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The LFENCE instruction is not supported as indicated by EDX bit 26 of CPUID function 0000_0001h.

LODS
LODSB
LODSW
LODSD
LODSQ

Load String

Copies the byte, word, doubleword, or quadword in the memory location pointed to by the DS:rSI registers to the AL, AX, EAX, or RAX register, depending on the size of the operand, and then increments or decrements the rSI register according to the state of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments rSI; otherwise, it decrements rSI. It increments or decrements rSI by 1, 2, 4, or 8, depending on the number of bytes being loaded.

The forms of the LODS instruction with an explicit operand address the operand at *seg*:[rSI]. The value of *seg* defaults to the DS segment, but may be overridden by a segment prefix. The explicit operand serves only to specify the type (size) of the value being copied and the specific registers used.

The no-operands forms of the instruction always use the DS:[rSI] registers to point to the value to be copied (they do not allow a segment prefix). The mnemonic determines the size of the operand and the specific registers used.

The LODS*x* instructions support the REP prefixes. For details about the REP prefixes, see “Repeat Prefixes” on page 9. More often, software uses the LODS*x* instruction inside a loop controlled by a LOOP*cc* instruction as a more efficient replacement for instructions like:

```
mov eax, dword ptr ds:[esi]
add esi, 4
```

The LODSQ instruction can only be used in 64-bit mode.

Mnemonic	Opcode	Description
LODS *mem8*	AC	Load byte at DS:rSI into AL and then increment or decrement rSI.
LODS *mem16*	AD	Load word at DS:rSI into AX and then increment or decrement rSI.
LODS *mem32*	AD	Load doubleword at DS:rSI into EAX and then increment or decrement rSI.
LODS *mem64*	AD	Load quadword at DS:rSI into RAX and then increment or decrement rSI.
LODSB	AC	Load byte at DS:rSI into AL and then increment or decrement rSI.
LODSW	AD	Load the word at DS:rSI into AX and then increment or decrement rSI.

Mnemonic	Opcode	Description
LODSD	AD	Load doubleword at DS:rSI into EAX and then increment or decrement rSI.
LODSQ	AD	Load quadword at DS:rSI into RAX and then increment or decrement rSI.

Related Instructions

MOVS*x*, STOS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

LOOP LOOPE LOOPNE LOOPNZ LOOPZ — Loop

Decrements the count register (rCX) by 1, then, if rCX is not 0 and the ZF flag meets the condition specified by the mnemonic, it jumps to the target instruction specified by the signed 8-bit relative offset. Otherwise, it continues with the next instruction after the LOOP*cc* instruction.

The size of the count register used (CX, ECX, or RCX) depends on the address-size attribute of the LOOP*cc* instruction.

The LOOP instruction ignores the state of the ZF flag.

The LOOPE and LOOPZ instructions jump if rCX is not 0 and the ZF flag is set to 1. In other words, the instruction exits the loop (falls through to the next instruction) if rCX becomes 0 or ZF = 0.

The LOOPNE and LOOPNZ instructions jump if rCX is not 0 and ZF flag is cleared to 0. In other words, the instruction exits the loop if rCX becomes 0 or ZF = 1.

The LOOP*cc* instruction does not change the state of the ZF flag. Typically, the loop contains a compare instruction to set or clear the ZF flag.

If the jump is taken, the signed displacement is added to the rIP (of the following instruction) and the result is truncated to 16, 32, or 64 bits, depending on operand size.

In 64-bit mode, the operand size defaults to 64 bits without the need for a REX prefix, and the processor sign-extends the 8-bit offset before adding it to the RIP.

Mnemonic	Opcode	Description
LOOP *rel8off*	E2 *cb*	Decrement rCX, then jump short if rCX is not 0.
LOOPE *rel8off*	E1 *cb*	Decrement rCX, then jump short if rCX is not 0 and ZF is 1.
LOOPNE *rel8off*	E0 *cb*	Decrement rCX, then Jump short if rCX is not 0 and ZF is 0.
LOOPNZ *rel8off*	E0 *cb*	Decrement rCX, then Jump short if rCX is not 0 and ZF is 0.
LOOPZ *rel8off*	E1 *cb*	Decrement rCX, then Jump short if rCX is not 0 and ZF is 1.

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical.

LZCNT Count Leading Zeros

Counts the number of leading zero bits in the 16-, 32-, or 64-bit general purpose register or memory source operand. Counting starts downward from the most significant bit and stops when the highest bit having a value of 1 is encountered or when the least significant bit is encountered. The count is written to the destination register.

If the input operand is zero, CF is set to 1 and the size (in bits) of the input operand is written to the destination register. Otherwise, CF is cleared.

If the most significant bit is a one, the ZF flag is set to 1, zero is written to the destination register. Otherwise, ZF is cleared.

Support for the LZCNT instruction is indicated by ECX bit 5 (LZCNT) as returned by CPUID function 8000_0001h. If the LZCNT instruction is not available, the encoding is treated as the BSR instruction. Software MUST check the CPUID bit once per program or library initialization before using the LZCNT instruction, or inconsistent behavior may result.

Mnemonic	Opcode	Description
LZCNT *reg16*, *reg/mem16*	F3 0F BD /r	Count the number of leading zeros in reg/mem16.
LZCNT *reg32*, *reg/mem32*	F3 0F BD /r	Count the number of leading zeros in reg/mem32.
LZCNT *reg64*, *reg/mem64*	F3 0F BD /r	Count the number of leading zeros in reg/mem64.

Related Instructions

BSF, BSR, POPCNT

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								U				U	M	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MFENCE Memory Fence

Acts as a barrier to force strong memory ordering (serialization) between load and store instructions preceding the MFENCE, and load and store instructions that follow the MFENCE. The processor may perform loads out of program order with respect to non-conflicting stores for certain memory types. The MFENCE instruction guarantees that the system completes all previous memory accesses before executing subsequent accesses.

The MFENCE instruction is weakly-ordered with respect to data and instruction prefetches. Speculative loads initiated by the processor, or specified explicitly using cache-prefetch instructions, can be reordered around an MFENCE.

In addition to load and store instructions, the MFENCE instruction is strongly ordered with respect to other MFENCE instructions, LFENCE instructions, SFENCE instructions, serializing instructions, and CLFLUSH instructions. Further details on the use of MFENCE to order accesses among differing memory types may be found in *AMD64 Architecture Programmer's Manual Volume 2: System Programming*, section 7.4 "Memory Types" on page 170.

Support for the MFENCE instruction is indicated when the SSE2 bit (bit 26) is set to 1 in EDX after executing CPUID with function 0000_0001h.

Mnemonic	Opcode	Description
MFENCE	0F AE F0	Force strong ordering of (serialized) load and store operations.

Related Instructions

LFENCE, SFENCE

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The MFENCE instruction is not supported as indicated by bit 26 of CPUID function 0000_0001h.

MOV Move

Copies an immediate value or the value in a general-purpose register, segment register, or memory location (second operand) to a general-purpose register, segment register, or memory location. The source and destination must be the same size (byte, word, doubleword, or quadword) and cannot both be memory locations.

In opcodes A0 through A3, the memory offsets (called *moffsets*) are address sized. In 64-bit mode, memory offsets default to 64 bits. Opcodes A0–A3, in 64-bit mode, are the only cases that support a 64-bit offset value. (In all other cases, offsets and displacements are a maximum of 32 bits.) The B8 through BF (B8 +*rq*) opcodes, in 64-bit mode, are the only cases that support a 64-bit immediate value (in all other cases, immediate values are a maximum of 32 bits).

When reading segment-registers with a 32-bit operand size, the processor zero-extends the 16-bit selector results to 32 bits. When reading segment-registers with a 64-bit operand size, the processor zero-extends the 16-bit selector to 64 bits. If the destination operand specifies a segment register (DS, ES, FS, GS, or SS), the source operand must be a valid segment selector.

It is possible to move a null segment selector value (0000–0003h) into the DS, ES, FS, or GS register. This action does not cause a general protection fault, but a subsequent reference to such a segment *does* cause a #GP exception. For more information about segment selectors, see "Segment Selectors and Registers" on page 67.

When the MOV instruction is used to load the SS register, the processor blocks external interrupts until after the execution of the following instruction. This action allows the following instruction to be a MOV instruction to load a stack pointer into the ESP register (`MOV ESP,val`) before an interrupt occurs. However, the LSS instruction provides a more efficient method of loading SS and ESP.

Attempting to use the MOV instruction to load the CS register generates an invalid opcode exception (#UD). Use the far JMP, CALL, or RET instructions to load the CS register.

To initialize a register to 0, rather than using a MOV instruction, it may be more efficient to use the XOR instruction with identical destination and source operands.

Mnemonic	Opcode	Description
MOV *reg/mem8*, *reg8*	88 */r*	Move the contents of an 8-bit register to an 8-bit destination register or memory operand.
MOV *reg/mem16*, *reg16*	89 */r*	Move the contents of a 16-bit register to a 16-bit destination register or memory operand.
MOV *reg/mem32*, *reg32*	89 */r*	Move the contents of a 32-bit register to a 32-bit destination register or memory operand.
MOV *reg/mem64*, *reg64*	89 */r*	Move the contents of a 64-bit register to a 64-bit destination register or memory operand.
MOV *reg8*, *reg/mem8*	8A */r*	Move the contents of an 8-bit register or memory operand to an 8-bit destination register.

Mnemonic	Opcode	Description
MOV *reg16*, *reg/mem16*	8B */r*	Move the contents of a 16-bit register or memory operand to a 16-bit destination register.
MOV *reg32*, *reg/mem32*	8B */r*	Move the contents of a 32-bit register or memory operand to a 32-bit destination register.
MOV *reg64*, *reg/mem64*	8B */r*	Move the contents of a 64-bit register or memory operand to a 64-bit destination register.
MOV *reg16/32/64/mem16*, *segReg*	8C */r*	Move the contents of a segment register to a 16-bit, 32-bit, or 64-bit destination register or to a 16-bit memory operand.
MOV *segReg, reg/mem16*	8E */r*	Move the contents of a 16-bit register or memory operand to a segment register.
MOV AL, *moffset8*	A0	Move 8-bit data at a specified memory offset to the AL register.
MOV AX, *moffset16*	A1	Move 16-bit data at a specified memory offset to the AX register.
MOV EAX, *moffset32*	A1	Move 32-bit data at a specified memory offset to the EAX register.
MOV RAX, *moffset64*	A1	Move 64-bit data at a specified memory offset to the RAX register.
MOV *moffset8*, AL	A2	Move the contents of the AL register to an 8-bit memory offset.
MOV *moffset16*, AX	A3	Move the contents of the AX register to a 16-bit memory offset.
MOV *moffset32*, EAX	A3	Move the contents of the EAX register to a 32-bit memory offset.
MOV *moffset64*, RAX	A3	Move the contents of the RAX register to a 64-bit memory offset.
MOV *reg8*, *imm8*	B0 *+rb ib*	Move an 8-bit immediate value into an 8-bit register.
MOV *reg16*, *imm16*	B8 *+rw iw*	Move a 16-bit immediate value into a 16-bit register.
MOV *reg32*, *imm32*	B8 *+rd id*	Move an 32-bit immediate value into a 32-bit register.
MOV *reg64*, *imm64*	B8 *+rq iq*	Move an 64-bit immediate value into a 64-bit register.
MOV *reg/mem8, imm8*	C6 /0 *ib*	Move an 8-bit immediate value to an 8-bit register or memory operand.
MOV *reg/mem16, imm16*	C7 /0 *iw*	Move a 16-bit immediate value to a 16-bit register or memory operand.
MOV *reg/mem32, imm32*	C7 /0 *id*	Move a 32-bit immediate value to a 32-bit register or memory operand.
MOV *reg/mem64, imm32*	C7 /0 *id*	Move a 32-bit signed immediate value to a 64-bit register or memory operand.

Related Instructions

MOV(CR*n*), MOV(DR*n*), MOVD, MOVSX, MOVZX, MOVSXD, MOVS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	An attempt was made to load the CS register.
Segment not present, #NP (selector)			X	The DS, ES, FS, or GS register was loaded with a non-null segment selector and the segment was marked not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)			X	The SS register was loaded with a non-null segment selector, and the segment was marked not present.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
General protection, #GP (selector)			X	A segment register was loaded, but the segment descriptor exceeded the descriptor table limit.
			X	A segment register was loaded and the segment selector's TI bit was set, but the LDT selector was a null selector.
			X	The SS register was loaded with a null segment selector in non-64-bit mode or while CPL = 3.
			X	The SS register was loaded and the segment selector RPL and the segment descriptor DPL were not equal to the CPL.
			X	The SS register was loaded and the segment pointed to was not a writable data segment.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was a data or non-conforming code segment, but the RPL or CPL was greater than the DPL.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was not a data segment or readable code segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MOVD — Move Doubleword or Quadword

Moves a 32-bit or 64-bit value in one of the following ways:

- from a 32-bit or 64-bit general-purpose register or memory location to the low-order 32 or 64 bits of an XMM register, with zero-extension to 128 bits
- from the low-order 32 or 64 bits of an XMM to a 32-bit or 64-bit general-purpose register or memory location
- from a 32-bit or 64-bit general-purpose register or memory location to the low-order 32 bits (with zero-extension to 64 bits) or the full 64 bits of an MMX register
- from the low-order 32 or the full 64 bits of an MMX register to a 32-bit or 64-bit general-purpose register or memory location

Mnemonic	Opcode	Description
MOVD *xmm*, *reg/mem32*	66 0F 6E */r*	Move 32-bit value from a general-purpose register or 32-bit memory location to an XMM register.
MOVD *xmm*, *reg/mem64*	66 0F 6E */r*	Move 64-bit value from a general-purpose register or 64-bit memory location to an XMM register.
MOVD *reg/mem32*, *xmm*	66 0F 7E */r*	Move 32-bit value from an XMM register to a 32-bit general-purpose register or memory location.
MOVD *reg/mem64*, *xmm*	66 0F 7E */r*	Move 64-bit value from an XMM register to a 64-bit general-purpose register or memory location.
MOVD *mmx*, *reg/mem32*	0F 6E */r*	Move 32-bit value from a general-purpose register or 32-bit memory location to an MMX register.
MOVD *mmx*, *reg/mem64*	0F 6E */r*	Move 64-bit value from a general-purpose register or 64-bit memory location to an MMX register.
MOVD *reg/mem32*, *mmx*	0F 7E */r*	Move 32-bit value from an MMX register to a 32-bit general-purpose register or memory location.
MOVD *reg/mem64*, *mmx*	0F 7E */r*	Move 64-bit value from an MMX register to a 64-bit general-purpose register or memory location.

The diagrams in Figure 3-1 on page 160 illustrate the operation of the MOVD instruction.

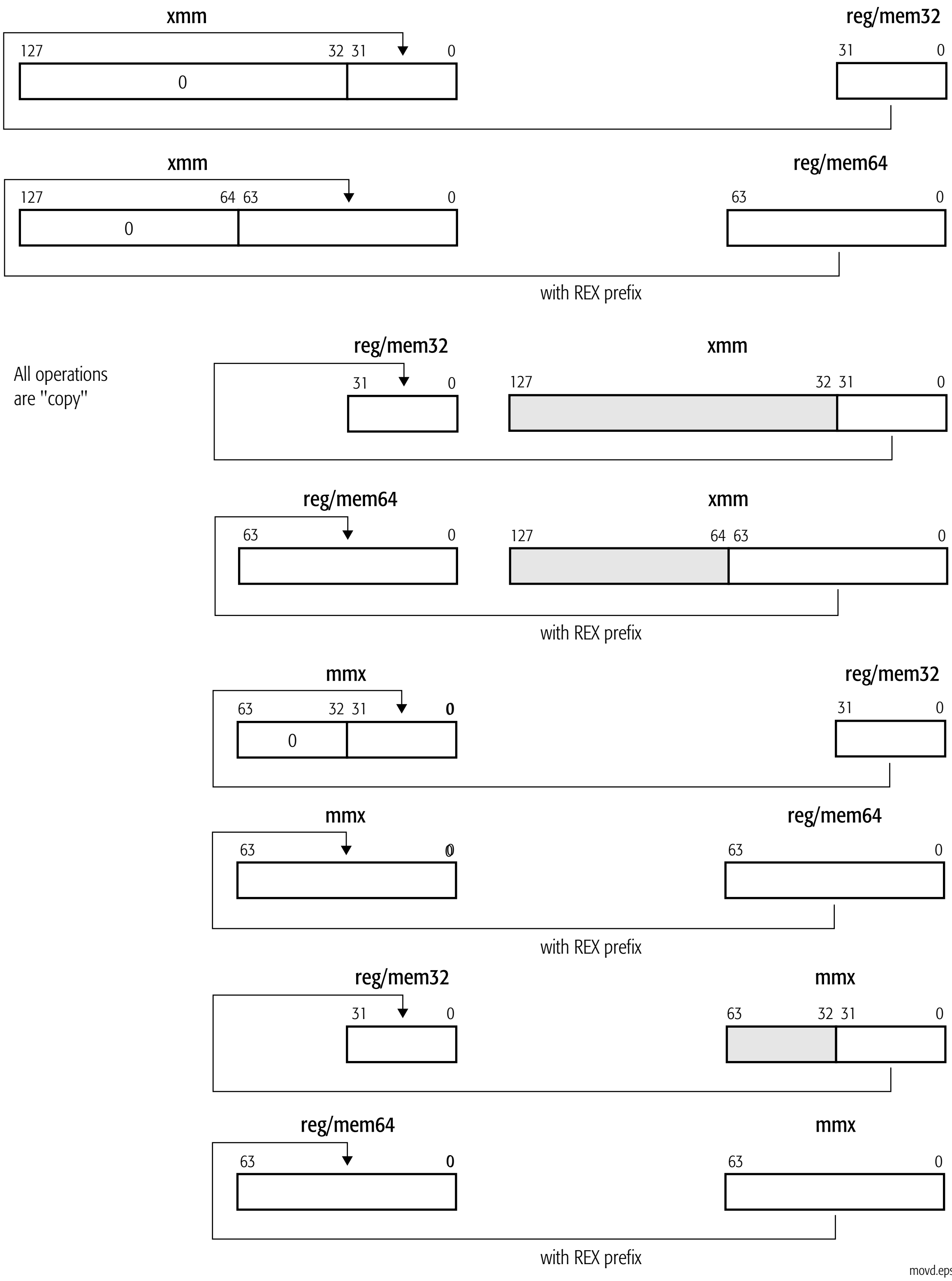


Figure 3-1. MOVD Instruction Operation

Related Instructions

MOVDQA, MOVDQU, MOVDQ2Q, MOVQ, MOVQ2DQ

rFLAGS Affected

None

MXCSR Flags Affected

None

Exceptions

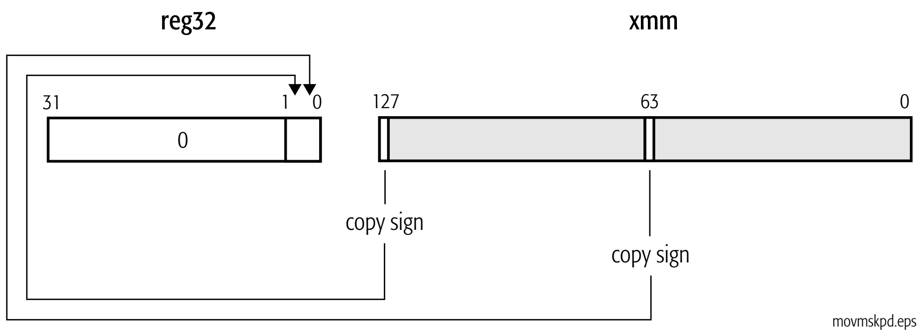
Exception	Real	Virtual 8086	Protected	Description
Invalid opcode, #UD	X	X	X	The MMX instructions are not supported, as indicated by EDX bit 23 of CPUID function 0000_0001h.
	X	X	X	The SSE2 instructions are not supported, as indicated by EDX bit 26 of CPUID function 0000_0001.
	X	X	X	The emulate bit (EM) of CR0 was set to 1.
	X	X	X	The instruction used XMM registers while CR4.OSFXSR=0.
Device not available, #NM	X	X	X	The task-switch bit (TS) of CR0 was set to 1.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
x87 floating-point exception pending, #MF	X	X	X	An x87 floating-point exception was pending and the instruction referenced an MMX register.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MOVMSKPD Extract Packed Double-Precision Floating-Point Sign Mask

Moves the sign bits of two packed double-precision floating-point values in an XMM register (second operand) to the two low-order bits of a general-purpose register (first operand) with zero-extension.

The MOVMSKPD instruction is an SSE2 instruction; Check the status of EDX bit 26 of CPUID function 0000_0001h to verify that the processor supports this function.

Mnemonic	Opcode	Description
MOVMSKPD *reg32*, *xmm*	66 0F 50 */r*	Move sign bits 127 and 63 in an XMM register to a 32-bit general-purpose register.



Related Instructions

MOVMSKPS, PMOVMSKB

rFLAGS Affected

None

MXCSR Flags Affected

None

Exceptions

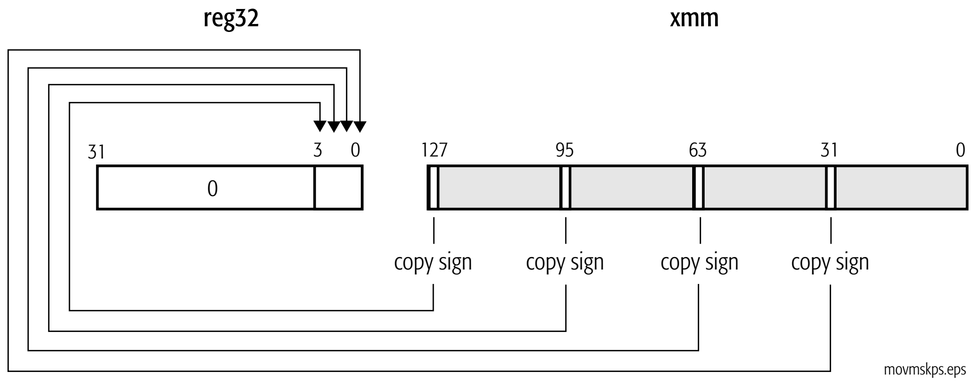
Exception (vector)	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SSE2 instructions are not supported, as indicated by EDX bit 26 of CPUID function 0000_0001h.
	X	X	X	The operating-system FXSAVE/FXRSTOR support bit (OSFXSR) of CR4 was cleared to 0.
	X	X	X	The emulate bit (EM) of CR0 was set to 1.
Device not available, #NM	X	X	X	The task-switch bit (TS) of CR0 was set to 1.

MOVMSKPS Extract Packed Single-Precision Floating-Point Sign Mask

Moves the sign bits of four packed single-precision floating-point values in an XMM register (second operand) to the four low-order bits of a general-purpose register (first operand) with zero-extension.

The MOVMSKPD instruction is an SSE2 instruction; Check the status of EDX bit 26 of CPUID function 0000_0001h to verify that the processor supports this function.

Mnemonic	Opcode	Description
MOVMSKPS *reg32*, *xmm*	0F 50 */r*	Move sign bits 127, 95, 63, 31 in an XMM register to a 32-bit general-purpose register.



Related Instructions

MOVMSKPD, PMOVMSKB

rFLAGS Affected

None

MXCSR Flags Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SSE2 instructions are not supported, as indicated by EDX bit 26 of CPUID function 1.
	X	X	X	The operating-system FXSAVE/FXRSTOR support bit (OSFXSR) of CR4 was cleared to 0.
	X	X	X	The emulate bit (EM) of CR0 was set to 1.
Device not available, #NM	X	X	X	The task-switch bit (TS) of CR0 was set to 1.

MOVNTI Move Non-Temporal Doubleword or Quadword

Stores a value in a 32-bit or 64-bit general-purpose register (second operand) in a memory location (first operand). This instruction indicates to the processor that the data is non-temporal and is unlikely to be used again soon. The processor treats the store as a write-combining (WC) memory write, which minimizes cache pollution. The exact method by which cache pollution is minimized depends on the hardware implementation of the instruction. For further information, see “Memory Optimization” in Volume 1.

The MOVNTI instruction is weakly-ordered with respect to other instructions that operate on memory. Software should use an SFENCE instruction to force strong memory ordering of MOVNTI with respect to other stores.

Support for the MOVNTI instruction is indicated when the SSE2 bit (bit 26) is set to 1 in EDX after executing CPUID function 0000_0001h.

Mnemonic	Opcode	Description
MOVNTI *mem32*, *reg32*	0F C3 */r*	Stores a 32-bit general-purpose register value into a 32-bit memory location, minimizing cache pollution.
MOVNTI *mem64*, *reg64*	0F C3 */r*	Stores a 64-bit general-purpose register value into a 64-bit memory location, minimizing cache pollution.

Related Instructions

MOVNTDQ, MOVNTPD, MOVNTPS, MOVNTQ

rFLAGS Affected

None

Exceptions

Exception (vector)	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SSE2 instructions are not supported, as indicated by EDX bit 26 of CPUID function 0000_0001h.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
			X	The destination operand was in a non-writable segment.

Exception (vector)	Real	Virtual 8086	Protected	Cause of Exception
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MOVS MOVSB MOVSW MOVSD MOVSQ — Move String

Moves a byte, word, doubleword, or quadword from the memory location pointed to by DS:rSI to the memory location pointed to by ES:rDI, and then increments or decrements the rSI and rDI registers according to the state of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments both pointers; otherwise, it decrements them. It increments or decrements the pointers by 1, 2, 4, or 8, depending on the size of the operands.

The forms of the MOVS*x* instruction with explicit operands address the first operand at *seg*:[rSI]. The value of *seg* defaults to the DS segment, but can be overridden by a segment prefix. These instructions always address the second operand at ES:[rDI] (ES may not be overridden). The explicit operands serve only to specify the type (size) of the value being moved.

The no-operands forms of the instruction use the DS:[rSI] and ES:[rDI] registers to point to the value to be moved (they do not allow a segment prefix). The mnemonic determines the size of the operands.

Do not confuse this MOVSD instruction with the same-mnemonic MOVSD (move scalar double-precision floating-point) instruction in the 128-bit media instruction set. Assemblers can distinguish the instructions by the number and type of operands.

The MOVS*x* instructions support the REP prefixes. For details about the REP prefixes, see “Repeat Prefixes” on page 9.

Mnemonic	Opcode	Description
MOVS *mem8*, *mem8*	A4	Move byte at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVS *mem16*, *mem16*	A5	Move word at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVS *mem32*, *mem32*	A5	Move doubleword at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVS *mem64*, *mem64*	A5	Move quadword at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVSB	A4	Move byte at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVSW	A5	Move word at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.

Mnemonic	Opcode	Description
MOVSD	A5	Move doubleword at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.
MOVSQ	A5	Move quadword at DS:rSI to ES:rDI, and then increment or decrement rSI and rDI.

Related Instructions

MOV, LODSx, STOS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MOVSX Move with Sign-Extension

Copies the value in a register or memory location (second operand) into a register (first operand), extending the most significant bit of an 8-bit or 16-bit value into all higher bits in a 16-bit, 32-bit, or 64-bit register.

Mnemonic	Opcode	Description
MOVSX *reg16*, *reg/mem8*	0F BE */r*	Move the contents of an 8-bit register or memory location to a 16-bit register with sign extension.
MOVSX *reg32*, *reg/mem8*	0F BE */r*	Move the contents of an 8-bit register or memory location to a 32-bit register with sign extension.
MOVSX *reg64*, *reg/mem8*	0F BE */r*	Move the contents of an 8-bit register or memory location to a 64-bit register with sign extension.
MOVSX *reg32*, *reg/mem16*	0F BF */r*	Move the contents of an 16-bit register or memory location to a 32-bit register with sign extension.
MOVSX *reg64*, *reg/mem16*	0F BF */r*	Move the contents of an 16-bit register or memory location to a 64-bit register with sign extension.

Related Instructions

MOVSXD, MOVZX

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MOVSXD Move with Sign-Extend Doubleword

Copies the 32-bit value in a register or memory location (second operand) into a 64-bit register (first operand), extending the most significant bit of the 32-bit value into all higher bits of the 64-bit register.

This instruction requires the REX prefix 64-bit operand size bit (REX.W) to be set to 1 to sign-extend a 32-bit source operand to a 64-bit result. Without the REX operand-size prefix, the operand size will be 32 bits, the default for 64-bit mode, and the source is zero-extended into a 64-bit register. With a 16-bit operand size, only 16 bits are copied, without modifying the upper 48 bits in the destination.

This instruction is available only in 64-bit mode. In legacy or compatibility mode this opcode is interpreted as ARPL.

Mnemonic	Opcode	Description
MOVSXD *reg64*, *reg/mem32*	63 */r*	Move the contents of a 32-bit register or memory operand to a 64-bit register with sign extension.

Related Instructions

MOVSX, MOVZX

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS			X	A memory address was non-canonical.
General protection, #GP			X	A memory address was non-canonical.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

MOVZX Move with Zero-Extension

Copies the value in a register or memory location (second operand) into a register (first operand), zero-extending the value to fit in the destination register. The operand-size attribute determines the size of the zero-extended value.

Mnemonic	Opcode	Description
MOVZX *reg16*, *reg/mem8*	0F B6 */r*	Move the contents of an 8-bit register or memory operand to a 16-bit register with zero-extension.
MOVZX *reg32*, *reg/mem8*	0F B6 */r*	Move the contents of an 8-bit register or memory operand to a 32-bit register with zero-extension.
MOVZX *reg64*, *reg/mem8*	0F B6 */r*	Move the contents of an 8-bit register or memory operand to a 64-bit register with zero-extension.
MOVZX *reg32*, *reg/mem16*	0F B7 */r*	Move the contents of a 16-bit register or memory operand to a 32-bit register with zero-extension.
MOVZX *reg64*, *reg/mem16*	0F B7 */r*	Move the contents of a 16-bit register or memory operand to a 64-bit register with zero-extension.

Related Instructions

MOVSXD, MOVSX

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

MUL Unsigned Multiply

Multiplies the unsigned byte, word, doubleword, or quadword value in the specified register or memory location by the value in AL, AX, EAX, or RAX and stores the result in AX, DX:AX, EDX:EAX, or RDX:RAX (depending on the operand size). It puts the high-order bits of the product in AH, DX, EDX, or RDX.

If the upper half of the product is non-zero, the instruction sets the carry flag (CF) and overflow flag (OF) both to 1. Otherwise, it clears CF and OF to 0. The other arithmetic flags (SF, ZF, AF, PF) are undefined.

Mnemonic	Opcode	Description
MUL *reg/mem8*	F6 /4	Multiplies an 8-bit register or memory operand by the contents of the AL register and stores the result in the AX register.
MUL *reg/mem16*	F7 /4	Multiplies a 16-bit register or memory operand by the contents of the AX register and stores the result in the DX:AX register.
MUL *reg/mem32*	F7 /4	Multiplies a 32-bit register or memory operand by the contents of the EAX register and stores the result in the EDX:EAX register.
MUL *reg/mem64*	F7 /4	Multiplies a 64-bit register or memory operand by the contents of the RAX register and stores the result in the RDX:RAX register.

Related Instructions

DIV

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				U	U	U	U	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference is performed while alignment checking was enabled.

NEG Two's Complement Negation

Performs the two's complement negation of the value in the specified register or memory location by subtracting the value from 0. Use this instruction only on signed integer numbers.

If the value is 0, the instruction clears the CF flag to 0; otherwise, it sets CF to 1. The OF, SF, ZF, AF, and PF flag settings depend on the result of the operation.

The forms of the NEG instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
NEG *reg/mem8*	F6 /3	Performs a two's complement negation on an 8-bit register or memory operand.
NEG *reg/mem16*	F7 /3	Performs a two's complement negation on a 16-bit register or memory operand.
NEG *reg/mem32*	F7 /3	Performs a two's complement negation on a 32-bit register or memory operand.
NEG *reg/mem64*	F7 /3	Performs a two's complement negation on a 64-bit register or memory operand.

Related Instructions

AND, NOT, OR, XOR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand is in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

NOP No Operation

Does nothing. This one-byte instruction increments the rIP to point to next instruction in the instruction stream, but does not affect the machine state in any other way.

The NOP instruction is an alias for `XCHG rAX,rAX`.

Mnemonic	Opcode	Description
NOP	90	Performs no operation.

Related Instructions

None

rFLAGS Affected

None

Exceptions

None

NOT One's Complement Negation

Performs the one's complement negation of the value in the specified register or memory location by inverting each bit of the value.

The memory-operand forms of the NOT instruction support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
NOT *reg/mem8*	F6 /2	Complements the bits in an 8-bit register or memory operand.
NOT *reg/mem16*	F7 /2	Complements the bits in a 16-bit register or memory operand.
NOT *reg/mem32*	F7 /2	Complements the bits in a 32-bit register or memory operand.
NOT *reg/mem64*	F7 /2	Compliments the bits in a 64-bit register or memory operand.

Related Instructions

AND, NEG, OR, XOR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference is performed while alignment checking was enabled.

OR Logical OR

Performs a logical OR on the bits in a register, memory location, or immediate value (second operand) and a register or memory location (first operand) and stores the result in the first operand location. The two operands cannot both be memory locations.

If both corresponding bits are 0, the corresponding bit of the result is 0; otherwise, the corresponding result bit is 1.

The forms of the OR instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
OR AL, *imm8*	0C *ib*	OR the contents of AL with an immediate 8-bit value.
OR AX, *imm16*	0D *iw*	OR the contents of AX with an immediate 16-bit value.
OR EAX, *imm32*	0D *id*	OR the contents of EAX with an immediate 32-bit value.
OR RAX, *imm32*	0D *id*	OR the contents of RAX with a sign-extended immediate 32-bit value.
OR *reg/mem8*, *imm8*	80 /1 *ib*	OR the contents of an 8-bit register or memory operand and an immediate 8-bit value.
OR *reg/mem16*, *imm16*	81 /1 *iw*	OR the contents of a 16-bit register or memory operand and an immediate 16-bit value.
OR *reg/mem32*, *imm32*	81 /1 *id*	OR the contents of a 32-bit register or memory operand and an immediate 32-bit value.
OR *reg/mem64*, *imm32*	81 /1 *id*	OR the contents of a 64-bit register or memory operand and sign-extended immediate 32-bit value.
OR *reg/mem16*, *imm8*	83 /1 *ib*	OR the contents of a 16-bit register or memory operand and a sign-extended immediate 8-bit value.
OR *reg/mem32*, *imm8*	83 /1 *ib*	OR the contents of a 32-bit register or memory operand and a sign-extended immediate 8-bit value.
OR *reg/mem64*, *imm8*	83 /1 *ib*	OR the contents of a 64-bit register or memory operand and a sign-extended immediate 8-bit value.
OR *reg/mem8*, reg8	08 */r*	OR the contents of an 8-bit register or memory operand with the contents of an 8-bit register.
OR *reg/mem16*, *reg16*	09 */r*	OR the contents of a 16-bit register or memory operand with the contents of a 16-bit register.
OR *reg/mem32*, *reg32*	09 */r*	OR the contents of a 32-bit register or memory operand with the contents of a 32-bit register.
OR *reg/mem64*, *reg64*	09 */r*	OR the contents of a 64-bit register or memory operand with the contents of a 64-bit register.
OR *reg8*, *reg/mem8*	0A */r*	OR the contents of an 8-bit register with the contents of an 8-bit register or memory operand.

Mnemonic	Opcode	Description
OR *reg16*, *reg/mem16*	0B */r*	OR the contents of a 16-bit register with the contents of a 16-bit register or memory operand.
OR *reg32*, *reg/mem32*	0B */r*	OR the contents of a 32-bit register with the contents of a 32-bit register or memory operand.
OR *reg64*, *reg/mem64*	0B */r*	OR the contents of a 64-bit register with the contents of a 64-bit register or memory operand.

The following chart summarizes the effect of this instruction:

X	Y	X OR Y
0	0	0
0	1	1
1	0	1
1	1	1

Related Instructions

AND, NEG, NOT, XOR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								0				M	M	U	M	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

OUT Output to Port

Copies the value from the AL, AX, or EAX register (second operand) to an I/O port (first operand). The port address can be a byte-immediate value (00h to FFh) or the value in the DX register (0000h to FFFFh). The source register used determines the size of the port (8, 16, or 32 bits).

If the operand size is 64 bits, OUT only writes to a 32-bit I/O port.

If the CPL is higher than the IOPL or the mode is virtual mode, OUT checks the I/O permission bitmap in the TSS before allowing access to the I/O port. See Volume 2 for details on the TSS I/O permission bitmap.

Mnemonic	Opcode	Description
OUT *imm8*, AL	E6 *ib*	Output the byte in the AL register to the port specified by an 8-bit immediate value.
OUT *imm8*, AX	E7 *ib*	Output the word in the AX register to the port specified by an 8-bit immediate value.
OUT *imm8*, EAX	E7 *ib*	Output the doubleword in the EAX register to the port specified by an 8-bit immediate value.
OUT DX, AL	EE	Output byte in AL to the output port specified in DX.
OUT DX, AX	EF	Output word in AX to the output port specified in DX.
OUT DX, EAX	EF	Output doubleword in EAX to the output port specified in DX.

Related Instructions

IN, INS*x*, OUTS*x*

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X		One or more I/O permission bits were set in the TSS for the accessed port.
			X	The CPL was greater than the IOPL and one or more I/O permission bits were set in the TSS for the accessed port.
Page fault (#PF)		X	X	A page fault resulted from the execution of the instruction.

OUTS OUTSB OUTSW OUTSD — Output String

Copies data from the memory location pointed to by DS:rSI to the I/O port address (0000h to FFFFh) specified in the DX register, and then increments or decrements the rSI register according to the setting of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments rSI; otherwise, it decrements rSI. It increments or decrements the pointer by 1, 2, or 4, depending on the size of the value being copied.

The OUTS*x* instruction uses an explicit memory operand (second operand) to determine the type (size) of the value being copied, but always uses DS:rSI for the location of the value to copy. The explicit register operand specifies the I/O port address and must always be DX.

The no-operands forms of the instruction use the DS:[rSI] register pair to point to the data to be copied and the DX register as the destination. The mnemonic specifies the size of the I/O port and the type (size) of the value being copied.

The OUTS*x* instruction supports the REP prefix. For details about the REP prefix, see “Repeat Prefixes” on page 9.

If the operand size is 64-bits, OUTS only writes to a 32-bit I/O port.

If the CPL is higher than the IOPL or the mode is virtual mode, OUTS*x* checks the I/O permission bitmap in the TSS before allowing access to the I/O port. See Volume 2 for details on the TSS I/O permission bitmap.

Mnemonic	Opcode	Description
OUTS DX, *mem8*	6E	Output the byte in DS:rSI to the port specified in DX, then increment or decrement rSI.
OUTS DX, *mem16*	6F	Output the word in DS:rSI to the port specified in DX, then increment or decrement rSI.
OUTS DX, *mem32*	6F	Output the doubleword in DS:rSI to the port specified in DX, then increment or decrement rSI.
OUTSB	6E	Output the byte in DS:rSI to the port specified in DX, then increment or decrement rSI.
OUTSW	6F	Output the word in DS:rSI to the port specified in DX, then increment or decrement rSI.
OUTSD	6F	Output the doubleword in DS:rSI to the port specified in DX, then increment or decrement rSI.

Related Instructions

IN, INS*x*, OUT

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
		X		One or more I/O permission bits were set in the TSS for the accessed port.
			X	The CPL was greater than the IOPL and one or more I/O permission bits were set in the TSS for the accessed port.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference is performed while alignment checking was enabled.

PAUSE Pause

Improves the performance of spin loops, by providing a hint to the processor that the current code is in a spin loop. The processor may use this to optimize power consumption while in the spin loop.

Architecturally, this instruction behaves like a NOP instruction.

Processors that do not support PAUSE treat this opcode as a NOP instruction.

Mnemonic	Opcode	Description
PAUSE	F3 90	Provides a hint to processor that a spin loop is being executed.

Related Instructions

None

rFLAGS Affected

None

Exceptions

None

POP Pop Stack

Copies the value pointed to by the stack pointer (SS:rSP) to the specified register or memory location and then increments the rSP by 2 for a 16-bit pop, 4 for a 32-bit pop, or 8 for a 64-bit pop.

The operand-size attribute determines the amount by which the stack pointer is incremented (2, 4 or 8 bytes). The stack-size attribute determines whether SP, ESP, or RSP is incremented.

For forms of the instruction that load a segment register (POP DS, POP ES, POP FS, POP GS, POP SS), the source operand must be a valid segment selector. When a segment selector is popped into a segment register, the processor also loads all associated descriptor information into the hidden part of the register and validates it.

It is possible to pop a null segment selector value (0000–0003h) into the DS, ES, FS, or GS register. This action does not cause a general protection fault, but a subsequent reference to such a segment *does* cause a #GP exception. For more information about segment selectors, see “Segment Selectors and Registers” on page 67.

In 64-bit mode, the POP operand size defaults to 64 bits and there is no prefix available to encode a 32-bit operand size. Using POP DS, POP ES, or POP SS instruction in 64-bit mode generates an invalid-opcode exception.

This instruction cannot pop a value into the CS register. The RET (Far) instruction performs this function.

Mnemonic	Opcode	Description
POP reg/*mem16*	8F /0	Pop the top of the stack into a 16-bit register or memory location.
POP reg/*mem32*	8F /0	Pop the top of the stack into a 32-bit register or memory location. (No prefix for encoding this in 64-bit mode.)
POP reg/*mem64*	8F /0	Pop the top of the stack into a 64-bit register or memory location.
POP *reg16*	58 *+rw*	Pop the top of the stack into a 16-bit register.
POP *reg32*	58 *+rd*	Pop the top of the stack into a 32-bit register. (No prefix for encoding this in 64-bit mode.)
POP *reg64*	58 *+rq*	Pop the top of the stack into a 64-bit register.
POP DS	1F	Pop the top of the stack into the DS register. (Invalid in 64-bit mode.)
POP ES	07	Pop the top of the stack into the ES register. (Invalid in 64-bit mode.)
POP SS	17	Pop the top of the stack into the SS register. (Invalid in 64-bit mode.)

Mnemonic	Opcode	Description
POP FS	0F A1	Pop the top of the stack into the FS register.
POP GS	0F A9	Pop the top of the stack into the GS register.

Related Instructions

PUSH

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	POP DS, POP ES, or POP SS was executed in 64-bit mode.
Segment not present, #NP (selector)			X	The DS, ES, FS, or GS register was loaded with a non-null segment selector and the segment was marked not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)			X	The SS register was loaded with a non-null segment selector and the segment was marked not present.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
General protection, #GP (selector)			X	A segment register was loaded and the segment descriptor exceeded the descriptor table limit.
			X	A segment register was loaded and the segment selector's TI bit was set, but the LDT selector was a null selector.
			X	The SS register was loaded with a null segment selector in non-64-bit mode or while CPL = 3.
			X	The SS register was loaded and the segment selector RPL and the segment descriptor DPL were not equal to the CPL.
			X	The SS register was loaded and the segment pointed to was not a writable data segment.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was a data or non-conforming code segment, but the RPL or the CPL was greater than the DPL.
			X	The DS, ES, FS, or GS register was loaded and the segment pointed to was not a data segment or readable code segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

POPA
POPAD

POP All GPRs

Pops words or doublewords from the stack into the general-purpose registers in the following order: eDI, eSI, eBP, eSP (image is popped and discarded), eBX, eDX, eCX, and eAX. The instruction increments the stack pointer by 16 or 32, depending on the operand size.

Using the POPA or POPAD instructions in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
POPA	61	Pop the DI, SI, BP, SP, BX, DX, CX, and AX registers. (Invalid in 64-bit mode.)
POPAD	61	Pop the EDI, ESI, EBP, ESP, EBX, EDX, ECX, and EAX registers. (Invalid in 64-bit mode.)

Related Instructions

PUSHA, PUSHAD

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode (#UD)			X	This instruction was executed in 64-bit mode.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

POPCNT Bit Population Count

Counts the number of bits having a value of 1 in the source operand and places the result in the destination register. The source operand is a 16-, 32-, or 64-bit general purpose register or memory operand; the destination operand is a general purpose register of the same size as the source operand register.

If the input operand is zero, the ZF flag is set to 1 and zero is written to the destination register. Otherwise, the ZF flag is cleared. The other flags are cleared.

Support for the POPCNT instruction is indicated by ECX bit 23 (POPCNT) as returned by CPUID function 0000_0001h. Software MUST check the CPUID bit once per program or library initialization before using the POPCNT instruction, or inconsistent behavior may result.

Mnemonic		Opcode	Description
POPCNT	*reg16*, *reg/mem16*	F3 0F B8 /r	Count the 1s in reg/mem16.
POPCNT	*reg32*, *reg/mem32*	F3 0F B8 /r	Count the 1s in reg/mem32.
POPCNT	*reg64*, *reg/mem64*	F3 0F B8 /r	Count the 1s in reg/mem64.

Related Instructions

BSF, BSR, LZCNT

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								0				0	M	0	0	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The POPCNT instruction is not supported, as indicated by ECX bit 23 as returned by CPUID function 0000_0001h.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

POPF POPFD POPFQ — POP to rFLAGS

Pops a word, doubleword, or quadword from the stack into the rFLAGS register and then increments the stack pointer by 2, 4, or 8, depending on the operand size.

In protected or real mode, all the non-reserved flags in the rFLAGS register can be modified, except the VIP, VIF, and VM flags, which are unchanged. In protected mode, at a privilege level greater than 0 the IOPL is also unchanged. The instruction alters the interrupt flag (IF) only when the CPL is less than or equal to the IOPL.

In virtual-8086 mode, if IOPL field is less than 3, attempting to execute a POPF*x or* PUSHF*x* instruction while VME is not enabled, or the operand size is not 16-bit, generates a #GP exception.

In 64-bit mode, this instruction defaults to a 64-bit operand size; there is no prefix available to encode a 32-bit operand size.

Mnemonic	Opcode	Description
POPF	9D	Pop a word from the stack into the FLAGS register.
POPFD	9D	Pop a double word from the stack into the EFLAGS register. (No prefix for encoding this in 64-bit mode.)
POPFQ	9D	Pop a quadword from the stack to the RFLAGS register.

Action

```
// See “Pseudocode Definitions” on page 41.

POPF_START:

IF (REAL_MODE)
    POPF_REAL
ELSIF (PROTECTED_MODE)
    POPF_PROTECTED
ELSE // (VIRTUAL_MODE)
    POPF_VIRTUAL


POPF_REAL:

    POP.v temp_RFLAGS
    RFLAGS.v = temp_RFLAGS          // VIF,VIP,VM unchanged
                                    // RF cleared
    EXIT
```

```
POPF_PROTECTED:

    POP.v temp_RFLAGS
    RFLAGS.v = temp_RFLAGS          // VIF,VIP,VM unchanged
                                    // IOPL changed only if (CPL=0)
                                    // IF changed only if (CPL<=old_RFLAGS.IOPL)
                                    // RF cleared
    EXIT


POPF_VIRTUAL:

    IF (RFLAGS.IOPL=3)
    {
        POP.v temp_RFLAGS
        RFLAGS.v = temp_RFLAGS      // VIF,VIP,VM,IOPL unchanged
                                    // RF cleared
        EXIT
    }
    ELSIF ((CR4.VME=1) && (OPERAND_SIZE=16))
    {
        POP.w temp_RFLAGS
        IF (((temp_RFLAGS.IF=1) && (RFLAGS.VIP=1)) || (temp_RFLAGS.TF=1))
            EXCEPTION [#GP(0)]
                                   // notify the virtual-mode-manager to deliver
                                    // the task's pending interrupts
        RFLAGS.w = temp_RFLAGS      // IF,IOPL unchanged
                                    // RFLAGS.VIF=temp_RFLAGS.IF
                                    // RF cleared
        EXIT
    }
    ELSE // ((RFLAGS.IOPL<3) && ((CR4.VME=0) || (OPERAND_SIZE!=16)))
        EXCEPTION [#GP(0)]
```

Related Instructions

PUSHF, PUSHFD, PUSHFQ

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
M		M	M		0	M	M	M	M	M	M	M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP		X		The I/O privilege level was less than 3 and one of the following conditions was true: • CR4.VME was 0. • The effective operand size was 32-bit. • Both the original EFLAGS.VIP and the new EFLAGS.IF bits were set. • The new EFLAGS.TF bit was set.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

PREFETCH PREFETCHW — Prefetch L1 Data-Cache Line

Loads the entire 64-byte aligned memory sequence *containing* the specified memory address into the L1 data cache. The position of the specified memory address within the 64-byte cache line is irrelevant. If a cache hit occurs, or if a memory fault is detected, no bus cycle is initiated and the instruction is treated as a NOP.

The PREFETCHW instruction loads the prefetched line and sets the cache-line state to Modified, in anticipation of subsequent data writes to the line. The PREFETCH instruction, by contrast, typically sets the cache-line state to Exclusive (depending on the hardware implementation).

The opcodes for the PREFETCH/PREFETCHW instructions include the ModRM byte; however, only the memory form of ModRM is valid. The register form of ModRM causes an invalid-opcode exception. Because there is no destination register, the three destination register field bits of the ModRM byte define the type of prefetch to be performed. The bit patterns 000b and 001b define the PREFETCH and PREFETCHW instructions, respectively. All other bit patterns are reserved for future use.

The *reserved* PREFETCH types do not result in an invalid-opcode exception if executed. Instead, for forward compatibility with future processors that may implement additional forms of the PREFETCH instruction, all reserved PREFETCH types are implemented as synonyms of the basic PREFETCH type (the PREFETCH instruction with type 000b).

The operation of these instructions is implementation-dependent. The processor implementation can ignore or change these instructions. The size of the cache line also depends on the implementation, with a minimum size of 32 bytes. For details on the use of this instruction, see the processor data sheets or other software-optimization documentation relating to particular hardware implementations.

Support for these instructions may be indicated by any of the following:

- EDX bit 31 as returned by CPUID function 8000_0001h
- EDX bit 29 as returned by CPUID function 8000_0001h
- ECX bit 8 as returned by CPUID function 8000_0001h

Mnemonic	Opcode	Description
PREFETCH *mem8*	0F 0D /0	Prefetch processor cache line into L1 data cache.
PREFETCHW *mem8*	0F 0D /1	Prefetch processor cache line into L1 data cache and mark it modified.

Related Instructions

PREFETCH*level*

rFLAGS Affected

None

Exceptions

<table>
<tr><th>Exception (vector)</th><th>Real</th><th>Virtual 8086</th><th>Protected</th><th>Cause of Exception</th></tr>
<tr><td rowspan="2">Invalid opcode, #UD</td><td>X</td><td>X</td><td>X</td><td>The PREFETCH/W instructions are not supported, as indicated when the following bits are all clear:
• PREFETCH/PREFETCHW are not supported, as indicated by ECX bit 8 of CPUID function 8000_0001h
• Long Mode is not supported, as indicated by EDX bit 29 of CPUID function 8000_0001h
• The 3DNow!™ instructions are not supported, as indicated by EDX bit 31 of CPUID function 8000_0001h.</td></tr>
<tr><td>X</td><td>X</td><td>X</td><td>The operand was a register.</td></tr>
</table>

PREFETCH*level* Prefetch Data to Cache Level *level*

Loads a cache line from the specified memory address into the data-cache level specified by the locality reference bits 5–3 of the ModRM byte. Table 3-3 on page 195 lists the locality reference options for the instruction.

This instruction loads a cache line even if the *mem8* address is not aligned with the start of the line. If the cache line is already contained in a cache level that is lower than the specified locality reference, or if a memory fault is detected, a bus cycle is not initiated and the instruction is treated as a NOP.

The operation of this instruction is implementation-dependent. The processor implementation can ignore or change this instruction. The size of the cache line also depends on the implementation, with a minimum size of 32 bytes. AMD processors alias PREFETCH1 and PREFETCH2 to PREFETCH0. For details on the use of this instruction, see the software-optimization documentation relating to particular hardware implementations.

Mnemonic	Opcode	Description
PREFETCHNTA *mem8*	0F 18 /0	Move data closer to the processor using the NTA reference.
PREFETCHT0 *mem8*	0F 18 /1	Move data closer to the processor using the T0 reference.
PREFETCHT1 *mem8*	0F 18 /2	Move data closer to the processor using the T1 reference.
PREFETCHT2 *mem8*	0F 18 /3	Move data closer to the processor using the T2 reference.

Table 3-3. Locality References for the Prefetch Instructions

Locality Reference	Description
NTA	Non-Temporal Access—Move the specified data into the processor with minimum cache pollution. This is intended for data that will be used only once, rather than repeatedly. The specific technique for minimizing cache pollution is implementation-dependent and may include such techniques as allocating space in a software-invisible buffer, allocating a cache line in only a single way, etc. For details, see the software-optimization documentation for a particular hardware implementation.
T0	All Cache Levels—Move the specified data into all cache levels.
T1	Level 2 and Higher—Move the specified data into all cache levels except 0th level (L1) cache.
T2	Level 3 and Higher—Move the specified data into all cache levels except 0th level (L1) and 1st level (L2) caches.

Related Instructions

PREFETCH, PREFETCHW

rFLAGS Affected

None

Exceptions

None

PUSH Push onto Stack

Decrements the stack pointer and then copies the specified immediate value or the value in the specified register or memory location to the top of the stack (the memory location pointed to by SS:rSP).

The operand-size attribute determines the number of bytes pushed to the stack. The stack-size attribute determines whether SP, ESP, or RSP is the stack pointer. The address-size attribute is used only to locate the memory operand when pushing a memory operand to the stack.

If the instruction pushes the stack pointer (rSP), the resulting value on the stack is that of rSP before execution of the instruction.

There is a PUSH CS instruction but no corresponding POP CS. The RET (Far) instruction pops a value from the top of stack into the CS register as part of its operation.

In 64-bit mode, the operand size of all PUSH instructions defaults to 64 bits, and there is no prefix available to encode a 32-bit operand size. Using the PUSH CS, PUSH DS, PUSH ES, or PUSH SS instructions in 64-bit mode generates an invalid-opcode exception.

Pushing an odd number of 16-bit operands when the stack address-size attribute is 32 results in a misaligned stack pointer.

Mnemonic	Opcode	Description
PUSH reg/*mem16*	FF /6	Push the contents of a 16-bit register or memory operand onto the stack.
PUSH reg/*mem32*	FF /6	Push the contents of a 32-bit register or memory operand onto the stack. (No prefix for encoding this in 64-bit mode.)
PUSH reg/*mem64*	FF /6	Push the contents of a 64-bit register or memory operand onto the stack.
PUSH *reg16*	50 *+rw*	Push the contents of a 16-bit register onto the stack.
PUSH *reg32*	50 *+rd*	Push the contents of a 32-bit register onto the stack. (No prefix for encoding this in 64-bit mode.)
PUSH *reg64*	50 *+rq*	Push the contents of a 64-bit register onto the stack.
PUSH *imm8*	6A *ib*	Push an 8-bit immediate value (sign-extended to 16, 32, or 64 bits) onto the stack.
PUSH *imm16*	68 *iw*	Push a 16-bit immediate value onto the stack.
PUSH *imm32*	68 *id*	Push a 32-bit immediate value onto the stack. (No prefix for encoding this in 64-bit mode.)
PUSH *imm64*	68 *id*	Push a sign-extended 32-bit immediate value onto the stack.
PUSH CS	0E	Push the CS selector onto the stack. (Invalid in 64-bit mode.)

Mnemonic	Opcode	Description
PUSH SS	16	Push the SS selector onto the stack. (Invalid in 64-bit mode.)
PUSH DS	1E	Push the DS selector onto the stack. (Invalid in 64-bit mode.)
PUSH ES	06	Push the ES selector onto the stack. (Invalid in 64-bit mode.)
PUSH FS	0F A0	Push the FS selector onto the stack.
PUSH GS	0F A8	Push the GS selector onto the stack.

Related Instructions

POP

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	PUSH CS, PUSH DS, PUSH ES, or PUSH SS was executed in 64-bit mode.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

PUSHA PUSHAD — Push All GPRs onto Stack

Pushes the contents of the eAX, eCX, eDX, eBX, eSP (original value), eBP, eSI, and eDI general-purpose registers onto the stack in that order. This instruction decrements the stack pointer by 16 or 32 depending on operand size.

Using the PUSHA or PUSHAD instruction in 64-bit mode generates an invalid-opcode exception.

Mnemonic	Opcode	Description
PUSHA	60	Push the contents of the AX, CX, DX, BX, original SP, BP, SI, and DI registers onto the stack. (Invalid in 64-bit mode.)
PUSHAD	60	Push the contents of the EAX, ECX, EDX, EBX, original ESP, EBP, ESI, and EDI registers onto the stack. (Invalid in 64-bit mode.)

Related Instructions

POPA, POPAD

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction was executed in 64-bit mode.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

PUSHF PUSHFD PUSHFQ — Push rFLAGS onto Stack

Decrements the rSP register and copies the rFLAGS register (except for the VM and RF flags) onto the stack. The instruction clears the VM and RF flags in the rFLAGS image before putting it on the stack.

The instruction pushes 2, 4, or 8 bytes, depending on the operand size.

In 64-bit mode, this instruction defaults to a 64-bit operand size and there is no prefix available to encode a 32-bit operand size.

In virtual-8086 mode, if system software has set the IOPL field to a value less than 3, a general-protection exception occurs if application software attempts to execute PUSHF*x* or POPF*x* while VME is not enabled or the operand size is not 16-bit.

Mnemonic	Opcode	Description
PUSHF	9C	Push the FLAGS word onto the stack.
PUSHFD	9C	Push the EFLAGS doubleword onto stack. (No prefix encoding this in 64-bit mode.)
PUSHFQ	9C	Push the RFLAGS quadword onto stack.

Action

```
// See "Pseudocode Definitions" on page 41.

PUSHF_START:
IF (REAL_MODE)
    PUSHF_REAL
ELSIF (PROTECTED_MODE)
    PUSHF_PROTECTED
ELSE // (VIRTUAL_MODE)
    PUSHF_VIRTUAL

PUSHF_REAL:
    PUSH.v old_RFLAGS     // Pushed with RF and VM cleared.
    EXIT

PUSHF_PROTECTED:
    PUSH.v old_RFLAGS   // Pushed with RF cleared.
    EXIT

PUSHF_VIRTUAL:
    IF (RFLAGS.IOPL=3)
    {
        PUSH.v old_RFLAGS // Pushed with RF,VM cleared.
        EXIT
    }
```

```
ELSIF ((CR4.VME=1) && (OPERAND_SIZE=16))
{
    PUSH.v old_RFLAGS // Pushed with VIF in the IF position.
                      // Pushed with IOPL=3.
    EXIT
}
ELSE // ((RFLAGS.IOPL<3) && ((CR4.VME=0) || (OPERAND_SIZE!=16)))
    EXCEPTION [#GP(0)]
```

Related Instructions

POPF, POPFD, POPFQ

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP		X		The I/O privilege level was less than 3 and either VME was not enabled or the operand size was not 16-bit.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

RCL Rotate Through Carry Left

Rotates the bits of a register or memory location (first operand) to the left (more significant bit positions) and through the carry flag by the number of bit positions in an unsigned immediate value or the CL register (second operand). The bits rotated through the carry flag are rotated back in at the right end (lsb) of the first operand location.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

For 1-bit rotates, the instruction sets the OF flag to the exclusive OR of the CF bit (after the rotate) and the most significant bit of the result. When the rotate count is greater than 1, the OF flag is undefined. When the rotate count is 0, no flags are affected.

Mnemonic	Opcode	Description
RCL *reg/mem8*,1	D0 /2	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location left 1 bit.
RCL *reg/mem8*, CL	D2 /2	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location left the number of bits specified in the CL register.
RCL *reg/mem8*, *imm8*	C0 /2 *ib*	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location left the number of bits specified by an 8-bit immediate value.
RCL *reg/mem16*, 1	D1 /2	Rotate the 17 bits consisting of the carry flag and a 16-bit register or memory location left 1 bit.
RCL *reg/mem16*, CL	D3 /2	Rotate the 17 bits consisting of the carry flag and a 16-bit register or memory location left the number of bits specified in the CL register.
RCL *reg/mem16*, *imm8*	C1 /2 *ib*	Rotate the 17 bits consisting of the carry flag and a 16-bit register or memory location left the number of bits specified by an 8-bit immediate value.
RCL *reg/mem32*, 1	D1 /2	Rotate the 33 bits consisting of the carry flag and a 32-bit register or memory location left 1 bit.
RCL *reg/mem32*, CL	D3 /2	Rotate 33 bits consisting of the carry flag and a 32-bit register or memory location left the number of bits specified in the CL register.
RCL *reg/mem32*, *imm8*	C1 /2 *ib*	Rotate the 33 bits consisting of the carry flag and a 32-bit register or memory location left the number of bits specified by an 8-bit immediate value.
RCL *reg/mem64*, 1	D1 /2	Rotate the 65 bits consisting of the carry flag and a 64-bit register or memory location left 1 bit.

Mnemonic	Opcode	Description
RCL *reg/mem64*, CL	D3 /2	Rotate the 65 bits consisting of the carry flag and a 64-bit register or memory location left the number of bits specified in the CL register.
RCL *reg/mem64*, *imm8*	C1 /2 *ib*	Rotates the 65 bits consisting of the carry flag and a 64-bit register or memory location left the number of bits specified by an 8-bit immediate value.

Related Instructions

RCR, ROL, ROR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M								M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

RCR Rotate Through Carry Right

Rotates the bits of a register or memory location (first operand) to the right (toward the less significant bit positions) and through the carry flag by the number of bit positions in an unsigned immediate value or the CL register (second operand). The bits rotated through the carry flag are rotated back in at the left end (msb) of the first operand location.

The processor masks the upper three bits in the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

For 1-bit rotates, the instruction sets the OF flag to the exclusive OR of the CF flag (before the rotate) and the most significant bit of the original value. When the rotate count is greater than 1, the OF flag is undefined. When the rotate count is 0, no flags are affected.

Mnemonic	Opcode	Description
RCR *reg/mem8*, 1	D0 /3	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location right 1 bit.
RCR *reg/mem8*,CL	D2 /3	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location right the number of bits specified in the CL register.
RCR *reg/mem8*,*imm8*	C0 /3 *ib*	Rotate the 9 bits consisting of the carry flag and an 8-bit register or memory location right the number of bits specified by an 8-bit immediate value.
RCR *reg/mem16*,1	D1 /3	Rotate the 17 bits consisting of the carry flag and a 16-bit register or memory location right 1 bit.
RCR *reg/mem16*,CL	D3 /3	Rotate the17 bits consisting of the carry flag and a 16-bit register or memory location right the number of bits specified in the CL register.
RCR *reg/mem16*, *imm8*	C1 /3 *ib*	Rotate the 17 bits consisting of the carry flag and a 16-bit register or memory location right the number of bits specified by an 8-bit immediate value.
RCR *reg/mem32*,1	D1 /3	Rotate the 33 bits consisting of the carry flag and a 32-bit register or memory location right 1 bit.
RCR *reg/mem32*,CL	D3 /3	Rotate 33 bits consisting of the carry flag and a 32-bit register or memory location right the number of bits specified in the CL register.
RCR *reg/mem32*, *imm8*	C1 /3 *ib*	Rotate the 33 bits consisting of the carry flag and a 32-bit register or memory location right the number of bits specified by an 8-bit immediate value.
RCR *reg/mem64*,1	D1 /3	Rotate the 65 bits consisting of the carry flag and a 64-bit register or memory location right 1 bit.

Mnemonic	Opcode	Description
RCR *reg/mem64*,CL	D3 /3	Rotate 65 bits consisting of the carry flag and a 64-bit register or memory location right the number of bits specified in the CL register.
RCR *reg/mem64*, *imm8*	C1 /3 *ib*	Rotate the 65 bits consisting of the carry flag and a 64-bit register or memory location right the number of bits specified by an 8-bit immediate value.

Related Instructions

RCL, ROR, ROL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M								M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

RET (Near) Near Return from Called Procedure

Returns from a procedure previously entered by a CALL near instruction. This form of the RET instruction returns to a calling procedure within the current code segment.

This instruction pops the rIP from the stack, with the size of the pop determined by the operand size. The new rIP is then zero-extended to 64 bits. The RET instruction can accept an immediate value operand that it adds to the rSP after it pops the target rIP. This action skips over any parameters previously passed back to the subroutine that are no longer needed.

In 64-bit mode, the operand size defaults to 64 bits (eight bytes) without the need for a REX prefix. No prefix is available to encode a 32-bit operand size in 64-bit mode.

See RET (Far) for information on far returns—returns to procedures located outside of the current code segment. For details about control-flow instructions, see "Control Transfers" in Volume 1, and "Control-Transfer Privilege Checks" in Volume 2.

Mnemonic	Opcode	Description
RET	C3	Near return to the calling procedure.
RET *imm16*	C2 *iw*	Near return to the calling procedure then pop the specified number of bytes from the stack.

Related Instructions

CALL (Near), CALL (Far), RET (Far)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

RET (Far) Far Return from Called Procedure

Returns from a procedure previously entered by a CALL Far instruction. This form of the RET instruction returns to a calling procedure in a different segment than the current code segment. It can return to the same CPL or to a less privileged CPL.

RET Far pops a target CS and rIP from the stack. If the new code segment is less privileged than the current code segment, the stack pointer is incremented by the number of bytes indicated by the immediate operand, if present; then a new SS and rSP are also popped from the stack.

The final value of rSP is incremented by the number of bytes indicated by the immediate operand, if present. This action skips over the parameters (previously passed to the subroutine) that are no longer needed.

All stack pops are determined by the operand size. If necessary, the target rIP is zero-extended to 64 bits before assuming program control.

If the CPL changes, the data segment selectors are set to NULL for any of the data segments (DS, ES, FS, GS) not accessible at the new CPL.

See RET (Near) for information on near returns—returns to procedures located inside the current code segment. For details about control-flow instructions, see “Control Transfers” in Volume 1, and “Control-Transfer Privilege Checks” in Volume 2.

Mnemonic	Opcode	Description
RETF	CB	Far return to the calling procedure.
RETF *imm16*	CA *iw*	Far return to the calling procedure, then pop the specified number of bytes from the stack.

Action

```
// Far returns (RETF)
// See "Pseudocode Definitions" on page 41.

RETF_START:

IF (REAL_MODE)
    RETF_REAL_OR_VIRTUAL
ELSIF (PROTECTED_MODE)
    RETF_PROTECTED
ELSE // (VIRTUAL_MODE)
    RETF_REAL_OR_VIRTUAL

RETF_REAL_OR_VIRTUAL:

    IF (OPCODE = retf imm16)
        temp_IMM = word-sized immediate specified in the instruction,
                   zero-extended to 64 bits
```

```
    ELSE // (OPCODE = retf)
        temp_IMM = 0

    POP.v temp_RIP
    POP.v temp_CS

    IF (temp_RIP > CS.limit)
        EXCEPTION [#GP(0)]

    CS.sel  = temp_CS
    CS.base = temp_CS SHL 4

    RSP.s = RSP + temp_IMM
    RIP = temp_RIP
    EXIT


RETF_PROTECTED:

    IF (OPCODE = retf imm16)
        temp_IMM = word-sized immediate specified in the instruction,
                   zero-extended to 64 bits
    ELSE // (OPCODE = retf)
        temp_IMM = 0

    POP.v temp_RIP
    POP.v temp_CS

    temp_CPL = temp_CS.rpl

    IF (CPL=temp_CPL)
    {
        CS = READ_DESCRIPTOR (temp_CS, iret_chk)

        RSP.s = RSP + temp_IMM

        IF ((64BIT_MODE) && (temp_RIP is non-canonical)
           || (!64BIT_MODE) && (temp_RIP > CS.limit))
            EXCEPTION [#GP(0)]

        RIP = temp_RIP
        EXIT
    }
    ELSE // (CPL!=temp_CPL)
    {
        RSP.s = RSP + temp_IMM

        POP.v temp_RSP
        POP.v temp_SS

        CS = READ_DESCRIPTOR (temp_CS, iret_chk)
```

```
        CPL = temp_CPL

        IF ((64BIT_MODE) && (temp_RIP is non-canonical)
           || (!64BIT_MODE) && (temp_RIP > CS.limit))
            EXCEPTION [#GP(0)]

        SS = READ_DESCRIPTOR (temp_SS, ss_chk)

        RSP.s = temp_RSP + temp_IMM

        IF (changing CPL)
        {
           FOR (seg = ES, DS, FS, GS)
               IF ((seg.attr.dpl < CPL) && ((seg.attr.type = 'data')
                  || (seg.attr.type = 'non-conforming-code')))
               {
                    seg = NULL  // can't use lower dpl data segment at higher cpl
               }
        }

        RIP = temp_RIP
        EXIT
    }
```

Related Instructions

CALL (Near), CALL (Far), RET (Near)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Segment not present, #NP (selector)			X	The return code segment was marked not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)			X	The return stack segment was marked not present.
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP (selector)			X	The return code selector was a null selector.
			X	The return stack selector was a null selector and the return mode was non-64-bit mode or CPL was 3.
			X	The return code or stack descriptor exceeded the descriptor table limit.
			X	The return code or stack selector's TI bit was set but the LDT selector was a null selector.
			X	The segment descriptor for the return code was not a code segment.
			X	The RPL of the return code segment selector was less than the CPL.
			X	The return code segment was non-conforming and the segment selector's DPL was not equal to the RPL of the code segment's segment selector.
			X	The return code segment was conforming and the segment selector's DPL was greater than the RPL of the code segment's segment selector.
			X	The segment descriptor for the return stack was not a writable data segment.
			X	The stack segment descriptor DPL was not equal to the RPL of the return code segment selector.
			X	The stack segment selector RPL was not equal to the RPL of the return code segment selector.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned-memory reference was performed while alignment checking was enabled.

ROL — Rotate Left

Rotates the bits of a register or memory location (first operand) to the left (toward the more significant bit positions) by the number of bit positions in an unsigned immediate value or the CL register (second operand). The bits rotated out left are rotated back in at the right end (lsb) of the first operand location.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, it masks the upper two bits of the count, providing a count in the range of 0 to 63.

After completing the rotation, the instruction sets the CF flag to the last bit rotated out (the lsb of the result). For 1-bit rotates, the instruction sets the OF flag to the exclusive OR of the CF bit (after the rotate) and the most significant bit of the result. When the rotate count is greater than 1, the OF flag is undefined. When the rotate count is 0, no flags are affected.

Mnemonic	Opcode	Description
ROL *reg/mem8*, 1	D0 /0	Rotate an 8-bit register or memory operand left 1 bit.
ROL *reg/mem8*, CL	D2 /0	Rotate an 8-bit register or memory operand left the number of bits specified in the CL register.
ROL *reg/mem8*, *imm8*	C0 /0 *ib*	Rotate an 8-bit register or memory operand left the number of bits specified by an 8-bit immediate value.
ROL *reg/mem16*, 1	D1 /0	Rotate a 16-bit register or memory operand left 1 bit.
ROL *reg/mem16*, CL	D3 /0	Rotate a 16-bit register or memory operand left the number of bits specified in the CL register.
ROL *reg/mem16*, *imm8*	C1 /0 *ib*	Rotate a 16-bit register or memory operand left the number of bits specified by an 8-bit immediate value.
ROL *reg/mem32*, 1	D1 /0	Rotate a 32-bit register or memory operand left 1 bit.
ROL *reg/mem32*, CL	D3 /0	Rotate a 32-bit register or memory operand left the number of bits specified in the CL register.
ROL *reg/mem32*, *imm8*	C1 /0 *ib*	Rotate a 32-bit register or memory operand left the number of bits specified by an 8-bit immediate value.
ROL *reg/mem64*, 1	D1 /0	Rotate a 64-bit register or memory operand left 1 bit.
ROL *reg/mem64*, CL	D3 /0	Rotate a 64-bit register or memory operand left the number of bits specified in the CL register.
ROL *reg/mem64*, *imm8*	C1 /0 *ib*	Rotate a 64-bit register or memory operand left the number of bits specified by an 8-bit immediate value.

Related Instructions

RCL, RCR, ROR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M								M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

ROR Rotate Right

Rotates the bits of a register or memory location (first operand) to the right (toward the less significant bit positions) by the number of bit positions in an unsigned immediate value or the CL register (second operand). The bits rotated out right are rotated back in at the left end (the most significant bit) of the first operand location.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

After completing the rotation, the instruction sets the CF flag to the last bit rotated out (the most significant bit of the result). For 1-bit rotates, the instruction sets the OF flag to the exclusive OR of the two most significant bits of the result. When the rotate count is greater than 1, the OF flag is undefined. When the rotate count is 0, no flags are affected.

Mnemonic	Opcode	Description
ROR *reg/mem8*, 1	D0 /1	Rotate an 8-bit register or memory location right 1 bit.
ROR *reg/mem8*, CL	D2 /1	Rotate an 8-bit register or memory location right the number of bits specified in the CL register.
ROR *reg/mem8*, *imm8*	C0 /1 *ib*	Rotate an 8-bit register or memory location right the number of bits specified by an 8-bit immediate value.
ROR *reg/mem16*, 1	D1 /1	Rotate a 16-bit register or memory location right 1 bit.
ROR *reg/mem16*, CL	D3 /1	Rotate a 16-bit register or memory location right the number of bits specified in the CL register.
ROR *reg/mem16*, *imm8*	C1 /1 *ib*	Rotate a 16-bit register or memory location right the number of bits specified by an 8-bit immediate value.
ROR *reg/mem32*, 1	D1 /1	Rotate a 32-bit register or memory location right 1 bit.
ROR *reg/mem32*, CL	D3 /1	Rotate a 32-bit register or memory location right the number of bits specified in the CL register.
ROR *reg/mem32*, *imm8*	C1 /1 *ib*	Rotate a 32-bit register or memory location right the number of bits specified by an 8-bit immediate value.
ROR *reg/mem64*, 1	D1 /1	Rotate a 64-bit register or memory location right 1 bit.
ROR *reg/mem64*, CL	D3 /1	Rotate a 64-bit register or memory operand right the number of bits specified in the CL register.
ROR *reg/mem64*, *imm8*	C1 /1 *ib*	Rotate a 64-bit register or memory operand right the number of bits specified by an 8-bit immediate value.

Related Instructions

RCL, RCR, ROL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M								M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SAHF Store AH into Flags

Loads the SF, ZF, AF, PF, and CF flags of the EFLAGS register with values from the corresponding bits in the AH register (bits 7, 6, 4, 2, and 0, respectively). The instruction ignores bits 1, 3, and 5 of register AH; it sets those bits in the EFLAGS register to 1, 0, and 0, respectively.

The SAHF instruction can only be executed in 64-bit mode if supported by the processor implementation. Check the status of ECX bit 0 returned by CPUID function 8000_0001h to verify that the processor supports SAHF in 64-bit mode.

Mnemonic	Opcode	Description
SAHF	9E	Loads the sign flag, the zero flag, the auxiliary flag, the parity flag, and the carry flag from the AH register into the lower 8 bits of the EFLAGS register.

Related Instructions

LAHF

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
												M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	This instruction is not supported in 64-bit mode, as indicated by ECX bit 0 returned by CPUID function 8000_0001h.

SAL
SHL
Shift Left

Shifts the bits of a register or memory location (first operand) to the left through the CF bit by the number of bit positions in an unsigned immediate value or the CL register (second operand). The instruction discards bits shifted out of the CF flag. For each bit shift, the SAL instruction clears the least-significant bit to 0. At the end of the shift operation, the CF flag contains the last bit shifted out of the first operand.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

The effect of this instruction is multiplication by powers of two.

For 1-bit shifts, the instruction sets the OF flag to the exclusive OR of the CF bit (after the shift) and the most significant bit of the result. When the shift count is greater than 1, the OF flag is undefined.

If the shift count is 0, no flags are modified.

SHL is an alias to the SAL instruction.

Mnemonic	Opcode	Description
SAL *reg/mem8*, 1	D0 /4	Shift an 8-bit register or memory location left 1 bit.
SAL *reg/mem8*, CL	D2 /4	Shift an 8-bit register or memory location left the number of bits specified in the CL register.
SAL *reg/mem8*, *imm8*	C0 /4 *ib*	Shift an 8-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SAL *reg/mem16*, 1	D1 /4	Shift a 16-bit register or memory location left 1 bit.
SAL *reg/mem16*, CL	D3 /4	Shift a 16-bit register or memory location left the number of bits specified in the CL register.
SAL *reg/mem16*, *imm8*	C1 /4 *ib*	Shift a 16-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SAL *reg/mem32*, 1	D1 /4	Shift a 32-bit register or memory location left 1 bit.
SAL *reg/mem32*, CL	D3 /4	Shift a 32-bit register or memory location left the number of bits specified in the CL register.
SAL *reg/mem32*, *imm8*	C1 /4 *ib*	Shift a 32-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SAL *reg/mem64*, 1	D1 /4	Shift a 64-bit register or memory location left 1 bit.
SAL *reg/mem64*, CL	D3 /4	Shift a 64-bit register or memory location left the number of bits specified in the CL register.
SAL *reg/mem64*, *imm8*	C1 /4 *ib*	Shift a 64-bit register or memory location left the number of bits specified by an 8-bit immediate value.

Mnemonic	Opcode	Description
SHL *reg/mem8*, 1	D0 /4	Shift an 8-bit register or memory location by 1 bit.
SHL *reg/mem8*, CL	D2 /4	Shift an 8-bit register or memory location left the number of bits specified in the CL register.
SHL *reg/mem8*, *imm8*	C0 /4 *ib*	Shift an 8-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SHL *reg/mem16*, 1	D1 /4	Shift a 16-bit register or memory location left 1 bit.
SHL *reg/mem16*, CL	D3 /4	Shift a 16-bit register or memory location left the number of bits specified in the CL register.
SHL *reg/mem16*, *imm8*	C1 /4 *ib*	Shift a 16-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SHL *reg/mem32*, 1	D1 /4	Shift a 32-bit register or memory location left 1 bit.
SHL *reg/mem32*, CL	D3 /4	Shift a 32-bit register or memory location left the number of bits specified in the CL register.
SHL *reg/mem32*, *imm8*	C1 /4 *ib*	Shift a 32-bit register or memory location left the number of bits specified by an 8-bit immediate value.
SHL *reg/mem64*, 1	D1 /4	Shift a 64-bit register or memory location left 1 bit.
SHL *reg/mem64*, CL	D3 /4	Shift a 64-bit register or memory location left the number of bits specified in the CL register.
SHL *reg/mem64*, *imm8*	C1 /4 *ib*	Shift a 64-bit register or memory location left the number of bits specified by an 8-bit immediate value.

Related Instructions

SAR, SHR, SHLD, SHRD

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	U	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS		X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SAR Shift Arithmetic Right

Shifts the bits of a register or memory location (first operand) to the right through the CF bit by the number of bit positions in an unsigned immediate value or the CL register (second operand). The instruction discards bits shifted out of the CF flag. At the end of the shift operation, the CF flag contains the last bit shifted out of the first operand.

The SAR instruction does not change the sign bit of the target operand. For each bit shift, it copies the sign bit to the next bit, preserving the sign of the result.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

For 1-bit shifts, the instruction clears the OF flag to 0. When the shift count is greater than 1, the OF flag is undefined.

If the shift count is 0, no flags are modified.

Although the SAR instruction effectively divides the operand by a power of 2, the behavior is different from the IDIV instruction. For example, shifting –11 (FFFFFFF5h) by two bits to the right (that is, divide –11 by 4), gives a result of FFFFFFFDh, or –3, whereas the IDIV instruction for dividing –11 by 4 gives a result of –2. This is because the IDIV instruction rounds off the quotient to zero, whereas the SAR instruction rounds off the remainder to zero for positive dividends and to negative infinity for negative dividends. So, for positive operands, SAR behaves like the corresponding IDIV instruction. For negative operands, it gives the same result if and only if all the shifted-out bits are zeroes; otherwise, the result is smaller by 1.

Mnemonic	Opcode	Description
SAR *reg/mem8*, 1	D0 /7	Shift a signed 8-bit register or memory operand right 1 bit.
SAR *reg/mem8*, CL	D2 /7	Shift a signed 8-bit register or memory operand right the number of bits specified in the CL register.
SAR *reg/mem8*, *imm8*	C0 /7 *ib*	Shift a signed 8-bit register or memory operand right the number of bits specified by an 8-bit immediate value.
SAR *reg/mem16*, 1	D1 /7	Shift a signed 16-bit register or memory operand right 1 bit.
SAR *reg/mem16*, CL	D3 /7	Shift a signed 16-bit register or memory operand right the number of bits specified in the CL register.
SAR *reg/mem16*, *imm8*	C1 /7 *ib*	Shift a signed 16-bit register or memory operand right the number of bits specified by an 8-bit immediate value.
SAR *reg/mem32*, 1	D1 /7	Shift a signed 32-bit register or memory location 1 bit.
SAR *reg/mem32*, CL	D3 /7	Shift a signed 32-bit register or memory location right the number of bits specified in the CL register.

Mnemonic	Opcode	Description
SAR *reg/mem32*, *imm8*	C1 /7 *ib*	Shift a signed 32-bit register or memory location right the number of bits specified by an 8-bit immediate value.
SAR *reg/mem64*, 1	D1 /7	Shift a signed 64-bit register or memory location right 1 bit.
SAR *reg/mem64*, CL	D3 /7	Shift a signed 64-bit register or memory location right the number of bits specified in the CL register.
SAR *reg/mem64*, *imm8*	C1 /7 *ib*	Shift a signed 64-bit register or memory location right the number of bits specified by an 8-bit immediate value.

Related Instructions

SAL, SHL, SHR, SHLD, SHRD

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	U	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SBB Subtract with Borrow

Subtracts an immediate value or the value in a register or a memory location (second operand) from a register or a memory location (first operand), and stores the result in the first operand location. If the carry flag (CF) is 1, the instruction subtracts 1 from the result. Otherwise, it operates like SUB.

The SBB instruction sign-extends immediate value operands to the length of the first operand size.

This instruction evaluates the result for both signed and unsigned data types and sets the OF and CF flags to indicate a borrow in a signed or unsigned result, respectively. It sets the SF flag to indicate the sign of a signed result.

This instruction is useful for multibyte (multiword) numbers because it takes into account the borrow from a previous SUB instruction.

The forms of the SBB instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
SBB AL, *imm8*	1C *ib*	Subtract an immediate 8-bit value from the AL register with borrow.
SBB AX, *imm16*	1D *iw*	Subtract an immediate 16-bit value from the AX register with borrow.
SBB EAX, *imm32*	1D *id*	Subtract an immediate 32-bit value from the EAX register with borrow.
SBB RAX, *imm32*	1D *id*	Subtract a sign-extended immediate 32-bit value from the RAX register with borrow.
SBB *reg/mem8*, *imm8*	80 /3 *ib*	Subtract an immediate 8-bit value from an 8-bit register or memory location with borrow.
SBB *reg/mem16*, *imm16*	81 /3 *iw*	Subtract an immediate 16-bit value from a 16-bit register or memory location with borrow.
SBB *reg/mem32*, *imm32*	81 /3 *id*	Subtract an immediate 32-bit value from a 32-bit register or memory location with borrow.
SBB *reg/mem64*, *imm32*	81 /3 *id*	Subtract a sign-extended immediate 32-bit value from a 64-bit register or memory location with borrow.
SBB *reg/mem16*, *imm8*	83 /3 *ib*	Subtract a sign-extended 8-bit immediate value from a 16-bit register or memory location with borrow.
SBB *reg/mem32*, *imm8*	83 /3 *ib*	Subtract a sign-extended 8-bit immediate value from a 32-bit register or memory location with borrow.
SBB *reg/mem64*, *imm8*	83 /3 *ib*	Subtract a sign-extended 8-bit immediate value from a 64-bit register or memory location with borrow.
SBB *reg/mem8*, *reg8*	18 */r*	Subtract the contents of an 8-bit register from an 8-bit register or memory location with borrow.
SBB *reg/mem16*, *reg16*	19 */r*	Subtract the contents of a 16-bit register from a 16-bit register or memory location with borrow.

Mnemonic	Opcode	Description
SBB *reg/mem32*, *reg32*	19 */r*	Subtract the contents of a 32-bit register from a 32-bit register or memory location with borrow.
SBB *reg/mem64*, *reg64*	19 */r*	Subtract the contents of a 64-bit register from a 64-bit register or memory location with borrow.
SBB *reg8*, *reg/mem8*	1A */r*	Subtract the contents of an 8-bit register or memory location from the contents of an 8-bit register with borrow.
SBB *reg16*, *reg/mem16*	1B */r*	Subtract the contents of a 16-bit register or memory location from the contents of a 16-bit register with borrow.
SBB *reg32*, *reg/mem32*	1B */r*	Subtract the contents of a 32-bit register or memory location from the contents of a 32-bit register with borrow.
SBB *reg64*, *reg/mem64*	1B */r*	Subtract the contents of a 64-bit register or memory location from the contents of a 64-bit register with borrow.

Related Instructions

SUB, ADD, ADC

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SCAS SCASB SCASW SCASD SCASQ — Scan String

Compares the AL, AX, EAX, or RAX register with the byte, word, doubleword, or quadword pointed to by ES:rDI, sets the status flags in the rFLAGS register according to the results, and then increments or decrements the rDI register according to the state of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments the rDI register; otherwise, it decrements it. The instruction increments or decrements the rDI register by 1, 2, 4, or 8, depending on the size of the operands.

The forms of the SCASx instruction with an explicit operand address the operand at ES:rDI. The explicit operand serves only to specify the size of the values being compared.

The no-operands forms of the instruction use the ES:rDI registers to point to the value to be compared. The mnemonic determines the size of the operands and the specific register containing the other comparison value.

For block comparisons, the SCASx instructions support the REPE or REPZ prefixes (they are synonyms) and the REPNE or REPNZ prefixes (they are synonyms). For details about the REP prefixes, see “Repeat Prefixes” on page 9. A SCAS*x* instruction can also operate inside a loop controlled by the LOOP*cc* instruction.

Mnemonic	Opcode	Description
SCAS *mem8*	AE	Compare the contents of the AL register with the byte at ES:rDI, and then increment or decrement rDI.
SCAS *mem16*	AF	Compare the contents of the AX register with the word at ES:rDI, and then increment or decrement rDI.
SCAS *mem32*	AF	Compare the contents of the EAX register with the doubleword at ES:rDI, and then increment or decrement rDI.
SCAS *mem64*	AF	Compare the contents of the RAX register with the quadword at ES:rDI, and then increment or decrement rDI.
SCASB	AE	Compare the contents of the AL register with the byte at ES:rDI, and then increment or decrement rDI.
SCASW	AF	Compare the contents of the AX register with the word at ES:rDI, and then increment or decrement rDI.

Mnemonic	Opcode	Description
SCASD	AF	Compare the contents of the EAX register with the doubleword at ES:rDI, and then increment or decrement rDI.
SCASQ	AF	Compare the contents of the RAX register with the quadword at ES:rDI, and then increment or decrement rDI.

Related Instructions

CMP, CMPS*x*

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP			X	A null ES segment was used to reference memory.
	X	X	X	A memory address exceeded the ES segment limit or was non-canonical.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SET*cc* Set Byte on Condition

Checks the status flags in the rFLAGS register and, if the flags meet the condition specified in the mnemonic (*cc*), sets the value in the specified 8-bit memory location or register to 1. If the flags do not meet the specified condition, SET*cc* clears the memory location or register to 0.

Mnemonics with the A (above) and B (below) tags are intended for use when performing unsigned integer comparisons; those with G (greater) and L (less) tags are intended for use with signed integer comparisons.

Software typically uses the SET*cc* instructions to set logical indicators. Like the CMOV*cc* instructions (page 91), the SET*cc* instructions can replace two instructions—a conditional jump and a move. Replacing conditional jumps with conditional sets can help avoid branch-prediction penalties that may result from conditional jumps.

If the logical value "true" (logical one) is represented in a high-level language as an integer with all bits set to 1, software can accomplish such representation by first executing the opposite SET*cc* instruction—for example, the opposite of SETZ is SETNZ—and then decrementing the result.

A ModR/M byte is used to identify the operand. The *reg* field in the ModR/M byte is unused.

Mnemonic	Opcode	Description
SETO *reg/mem8*	0F 90 /0	Set byte if overflow (OF = 1).
SETNO *reg/mem8*	0F 91 /0	Set byte if not overflow (OF = 0).
SETB *reg/mem8* SETC *reg/mem8* SETNAE *reg/mem8*	0F 92 /0	Set byte if below (CF = 1). Set byte if carry (CF = 1). Set byte if not above or equal (CF = 1).
SETNB *reg/mem8* SETNC *reg/mem8* SETAE *reg/mem8*	0F 93 /0	Set byte if not below (CF = 0). Set byte if not carry (CF = 0). Set byte if above or equal (CF = 0).
SETZ *reg/mem8* SETE *reg/mem8*	0F 94 /0	Set byte if zero (ZF = 1). Set byte if equal (ZF = 1).
SETNZ *reg/mem8* SETNE *reg/mem8*	0F 95 /0	Set byte if not zero (ZF = 0). Set byte if not equal (ZF = 0).
SETBE *reg/mem8* SETNA *reg/mem8*	0F 96 /0	Set byte if below or equal (CF = 1 or ZF = 1). Set byte if not above (CF = 1 or ZF = 1).
SETNBE *reg/mem8* SETA *reg/mem8*	0F 97 /0	Set byte if not below or equal (CF = 0 and ZF = 0). Set byte if above (CF = 0 and ZF = 0).
SETS *reg/mem8*	0F 98 /0	Set byte if sign (SF = 1).
SETNS *reg/mem8*	0F 99 /0	Set byte if not sign (SF = 0).
SETP *reg/mem8* SETPE *reg/mem8*	0F 9A /0	Set byte if parity (PF = 1). Set byte if parity even (PF = 1).
SETNP *reg/mem8* SETPO *reg/mem8*	0F 9B /0	Set byte if not parity (PF = 0). Set byte if parity odd (PF = 0).

Mnemonic	Opcode	Description
SETL *reg/mem8* SETNGE *reg/mem8*	0F 9C /0	Set byte if less (SF <> OF). Set byte if not greater or equal (SF <> OF).
SETNL *reg/mem8* SETGE *reg/mem8*	0F 9D /0	Set byte if not less (SF = OF). Set byte if greater or equal (SF = OF).
SETLE *reg/mem8* SETNG *reg/mem8*	0F 9E /0	Set byte if less or equal (ZF = 1 or SF <> OF). Set byte if not greater (ZF = 1 or SF <> OF).
SETNLE *reg/mem8* SETG *reg/mem8*	0F 9F /0	Set byte if not less or equal (ZF = 0 and SF = OF). Set byte if greater (ZF = 0 and SF = OF).

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.

SFENCE Store Fence

Acts as a barrier to force strong memory ordering (serialization) between store instructions preceding the SFENCE and store instructions that follow the SFENCE. Stores to differing memory types, or within the WC memory type, may become visible out of program order; the SFENCE instruction ensures that the system completes all previous stores in such a way that they are globally visible before executing subsequent stores. This includes emptying the store buffer and all write-combining buffers.

The SFENCE instruction is weakly-ordered with respect to load instructions, data and instruction prefetches, and the LFENCE instruction. Speculative loads initiated by the processor, or specified explicitly using cache-prefetch instructions, can be reordered around an SFENCE.

In addition to store instructions, SFENCE is strongly ordered with respect to other SFENCE instructions, MFENCE instructions, and serializing instructions. Further details on the use of MFENCE to order accesses among differing memory types may be found in *AMD64 Architecture Programmer's Manual Volume 2: System Programming*, section 7.4 "Memory Types" on page 170.

Support for the SFENCE instruction is indicated when the SSE bit (bit 25) is set to 1 in EDX after executing CPUID function 0000_0001h.

Mnemonic	Opcode	Description
SFENCE	0F AE F8	Force strong ordering of (serialized) store operations.

Related Instructions

LFENCE, MFENCE

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid Opcode, #UD	X	X	X	The SSE instructions are not supported, as indicated by EDX bit 25 of CPUID function 0000_0001h; and the AMD extensions to MMX are not supported, as indicated by EDX bit 22 of CPUID function 8000_0001h.

SHL Shift Left

This instruction is synonymous with the SAL instruction. For information, see "SAL SHL" on page 216.

SHLD Shift Left Double

Shifts the bits of a register or memory location (first operand) to the left by the number of bit positions in an unsigned immediate value or the CL register (third operand), and shifts in a bit pattern (second operand) from the right. At the end of the shift operation, the CF flag contains the last bit shifted out of the first operand.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63. If the masked count is greater than the operand size, the result in the destination register is undefined.

If the shift count is 0, no flags are modified.

If the count is 1 and the sign of the operand being shifted changes, the instruction sets the OF flag to 1. If the count is greater than 1, OF is undefined.

Mnemonic	Opcode	Description
SHLD *reg/mem16*, *reg16*, *imm8*	0F A4 */r ib*	Shift bits of a 16-bit destination register or memory operand to the left the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHLD *reg/mem16*, *reg16*, CL	0F A5 */r*	Shift bits of a 16-bit destination register or memory operand to the left the number of bits specified in the CL register, while shifting in bits from the second operand.
SHLD *reg/mem32*, *reg32*, *imm8*	0F A4 */r ib*	Shift bits of a 32-bit destination register or memory operand to the left the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHLD *reg/mem32*, *reg32*, CL	0F A5 */r*	Shift bits of a 32-bit destination register or memory operand to the left the number of bits specified in the CL register, while shifting in bits from the second operand.
SHLD *reg/mem64*, *reg64*, *imm8*	0F A4 */r ib*	Shift bits of a 64-bit destination register or memory operand to the left the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHLD *reg/mem64*, *reg64*, CL	0F A5 */r*	Shift bits of a 64-bit destination register or memory operand to the left the number of bits specified in the CL register, while shifting in bits from the second operand.

Related Instructions

SHRD, SAL, SAR, SHR, SHL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	U	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SHR Shift Right

Shifts the bits of a register or memory location (first operand) to the right through the CF bit by the number of bit positions in an unsigned immediate value or the CL register (second operand). The instruction discards bits shifted out of the CF flag. At the end of the shift operation, the CF flag contains the last bit shifted out of the first operand.

For each bit shift, the instruction clears the most-significant bit to 0.

The effect of this instruction is unsigned division by powers of two.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63.

For 1-bit shifts, the instruction sets the OF flag to the most-significant bit of the original value. If the count is greater than 1, the OF flag is undefined.

If the shift count is 0, no flags are modified.

Mnemonic	Opcode	Description
SHR *reg/mem8*, 1	D0 /5	Shift an 8-bit register or memory operand right 1 bit.
SHR *reg/mem8*, CL	D2 /5	Shift an 8-bit register or memory operand right the number of bits specified in the CL register.
SHR *reg/mem8*, *imm8*	C0 /5 *ib*	Shift an 8-bit register or memory operand right the number of bits specified by an 8-bit immediate value.
SHR *reg/mem16*, 1	D1 /5	Shift a 16-bit register or memory operand right 1 bit.
SHR *reg/mem16*, CL	D3 /5	Shift a 16-bit register or memory operand right the number of bits specified in the CL register.
SHR *reg/mem16*, *imm8*	C1 /5 *ib*	Shift a 16-bit register or memory operand right the number of bits specified by an 8-bit immediate value.
SHR *reg/mem32*, 1	D1 /5	Shift a 32-bit register or memory operand right 1 bit.
SHR *reg/mem32*, CL	D3 /5	Shift a 32-bit register or memory operand right the number of bits specified in the CL register.
SHR *reg/mem32*, *imm8*	C1 /5 *ib*	Shift a 32-bit register or memory operand right the number of bits specified by an 8-bit immediate value.
SHR *reg/mem64*, 1	D1 /5	Shift a 64-bit register or memory operand right 1 bit.
SHR *reg/mem64*, CL	D3 /5	Shift a 64-bit register or memory operand right the number of bits specified in the CL register.
SHR *reg/mem64*, *imm8*	C1 /5 *ib*	Shift a 64-bit register or memory operand right the number of bits specified by an 8-bit immediate value.

Related Instructions

SHL, SAL, SAR, SHLD, SHRD

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	U	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SHRD Shift Right Double

Shifts the bits of a register or memory location (first operand) to the right by the number of bit positions in an unsigned immediate value or the CL register (third operand), and shifts in a bit pattern (second operand) from the left. At the end of the shift operation, the CF flag contains the last bit shifted out of the first operand.

The processor masks the upper three bits of the count operand, thus restricting the count to a number between 0 and 31. When the destination is 64 bits wide, the processor masks the upper two bits of the count, providing a count in the range of 0 to 63. If the masked count is greater than the operand size, the result in the destination register is undefined.

If the shift count is 0, no flags are modified.

If the count is 1 and the sign of the value being shifted changes, the instruction sets the OF flag to 1. If the count is greater than 1, the OF flag is undefined.

Mnemonic	Opcode	Description
SHRD *reg/mem16*, *reg16*, *imm8*	0F AC */r ib*	Shift bits of a 16-bit destination register or memory operand to the right the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHRD *reg/mem16*, *reg16*, CL	0F AD */r*	Shift bits of a 16-bit destination register or memory operand to the right the number of bits specified in the CL register, while shifting in bits from the second operand.
SHRD *reg/mem32*, *reg32*, *imm8*	0F AC */r ib*	Shift bits of a 32-bit destination register or memory operand to the right the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHRD *reg/mem32*, *reg32*, CL	0F AD */r*	Shift bits of a 32-bit destination register or memory operand to the right the number of bits specified in the CL register, while shifting in bits from the second operand.
SHRD *reg/mem64*, *reg64*, *imm8*	0F AC */r ib*	Shift bits of a 64-bit destination register or memory operand to the right the number of bits specified in an 8-bit immediate value, while shifting in bits from the second operand.
SHRD *reg/mem64*, *reg64*, CL	0F AD */r*	Shift bits of a 64-bit destination register or memory operand to the right the number of bits specified in the CL register, while shifting in bits from the second operand.

Related Instructions

SHLD, SHR, SHL, SAR, SAL

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	U	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

STC Set Carry Flag

Sets the carry flag (CF) in the rFLAGS register to one.

Mnemonic	Opcode	Description
STC	F9	Set the carry flag (CF) to one.

Related Instructions

CLC, CMC

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
																1
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

None

STD Set Direction Flag

Set the direction flag (DF) in the rFLAGS register to 1. If the DF flag is 0, each iteration of a string instruction increments the data pointer (index registers rSI or rDI). If the DF flag is 1, the string instruction decrements the pointer. Use the CLD instruction before a string instruction to make the data pointer increment.

Mnemonic	Opcode	Description
STD	FD	Set the direction flag (DF) to one.

Related Instructions

CLD, INSx, LODSx, MOVSx, OUTSx, SCASx, STOSx, CMPS*x*

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
									1							
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

None

STOS STOSB STOSW STOSD STOSQ

Store String

Copies a byte, word, doubleword, or quadword from the AL, AX, EAX, or RAX registers to the memory location pointed to by ES:rDI and increments or decrements the rDI register according to the state of the DF flag in the rFLAGS register.

If the DF flag is 0, the instruction increments the pointer; otherwise, it decrements the pointer. It increments or decrements the pointer by 1, 2, 4, or 8, depending on the size of the value being copied.

The forms of the STOS*x* instruction with an explicit operand use the operand only to specify the type (size) of the value being copied.

The no-operands forms specify the type (size) of the value being copied with the mnemonic.

The STOS*x* instructions support the REP prefixes. For details about the REP prefixes, see "Repeat Prefixes" on page 9. The STOS*x* instructions can also operate inside a LOOP*cc* instruction.

Mnemonic	Opcode	Description
STOS *mem8*	AA	Store the contents of the AL register to ES:rDI, and then increment or decrement rDI.
STOS *mem16*	AB	Store the contents of the AX register to ES:rDI, and then increment or decrement rDI.
STOS *mem32*	AB	Store the contents of the EAX register to ES:rDI, and then increment or decrement rDI.
STOS *mem64*	AB	Store the contents of the RAX register to ES:rDI, and then increment or decrement rDI.
STOSB	AA	Store the contents of the AL register to ES:rDI, and then increment or decrement rDI.
STOSW	AB	Store the contents of the AX register to ES:rDI, and then increment or decrement rDI.
STOSD	AB	Store the contents of the EAX register to ES:rDI, and then increment or decrement rDI.
STOSQ	AB	Store the contents of the RAX register to ES:rDI, and then increment or decrement rDI.

Related Instructions

LODSx, MOVSx

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X	X	X	A memory address exceeded the ES segment limit or was non-canonical.
			X	The ES segment was a non-writable segment.
			X	A null ES segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SUB Subtract

Subtracts an immediate value or the value in a register or memory location (second operand) from a register or a memory location (first operand) and stores the result in the first operand location. An immediate value is sign-extended to the length of the first operand.

This instruction evaluates the result for both signed and unsigned data types and sets the OF and CF flags to indicate a borrow in a signed or unsigned result, respectively. It sets the SF flag to indicate the sign of a signed result.

The forms of the SUB instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

Mnemonic	Opcode	Description
SUB AL, *imm8*	2C *ib*	Subtract an immediate 8-bit value from the AL register and store the result in AL.
SUB AX, *imm16*	2D *iw*	Subtract an immediate 16-bit value from the AX register and store the result in AX.
SUB EAX, *imm32*	2D *id*	Subtract an immediate 32-bit value from the EAX register and store the result in EAX.
SUB RAX, *imm32*	2D *id*	Subtract a sign-extended immediate 32-bit value from the RAX register and store the result in RAX.
SUB *reg/mem8*, *imm8*	80 /5 *ib*	Subtract an immediate 8-bit value from an 8-bit destination register or memory location.
SUB *reg/mem16*, *imm16*	81 /5 *iw*	Subtract an immediate 16-bit value from a 16-bit destination register or memory location.
SUB *reg/mem32*, *imm32*	81 /5 *id*	Subtract an immediate 32-bit value from a 32-bit destination register or memory location.
SUB *reg/mem64*, *imm32*	81 /5 *id*	Subtract a sign-extended immediate 32-bit value from a 64-bit destination register or memory location.
SUB *reg/mem16*, *imm8*	83 /5 *ib*	Subtract a sign-extended immediate 8-bit value from a 16-bit register or memory location.
SUB *reg/mem32*, *imm8*	83 /5 *ib*	Subtract a sign-extended immediate 8-bit value from a 32-bit register or memory location.
SUB *reg/mem64*, *imm8*	83 /5 *ib*	Subtract a sign-extended immediate 8-bit value from a 64-bit register or memory location.
SUB *reg/mem8*, *reg8*	28 */r*	Subtract the contents of an 8-bit register from an 8-bit destination register or memory location.
SUB *reg/mem16*, *reg16*	29 */r*	Subtract the contents of a 16-bit register from a 16-bit destination register or memory location.
SUB *reg/mem32*, *reg32*	29 */r*	Subtract the contents of a 32-bit register from a 32-bit destination register or memory location.
SUB *reg/mem64*, *reg64*	29 */r*	Subtract the contents of a 64-bit register from a 64-bit destination register or memory location.

Mnemonic	Opcode	Description
SUB *reg8*, *reg/mem8*	2A */r*	Subtract the contents of an 8-bit register or memory operand from an 8-bit destination register.
SUB *reg16*, *reg/mem16*	2B */r*	Subtract the contents of a 16-bit register or memory operand from a 16-bit destination register.
SUB *reg32*, *reg/mem32*	2B */r*	Subtract the contents of a 32-bit register or memory operand from a 32-bit destination register.
SUB *reg64*, *reg/mem64*	2B */r*	Subtract the contents of a 64-bit register or memory operand from a 64-bit destination register.

Related Instructions

ADC, ADD, SBB

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

TEST — Test Bits

Performs a bit-wise logical AND on the value in a register or memory location (first operand) with an immediate value or the value in a register (second operand) and sets the flags in the rFLAGS register based on the result. While the AND instruction changes the contents of the destination and the flag bits, the TEST instruction changes only the flag bits.

Mnemonic	Opcode	Description
TEST AL, *imm8*	A8 *ib*	AND an immediate 8-bit value with the contents of the AL register and set rFLAGS to reflect the result.
TEST AX, *imm16*	A9 *iw*	AND an immediate 16-bit value with the contents of the AX register and set rFLAGS to reflect the result.
TEST EAX, *imm32*	A9 *id*	AND an immediate 32-bit value with the contents of the EAX register and set rFLAGS to reflect the result.
TEST RAX, *imm32*	A9 *id*	AND a sign-extended immediate 32-bit value with the contents of the RAX register and set rFLAGS to reflect the result.
TEST *reg/mem8*, *imm8*	F6 /0 *ib*	AND an immediate 8-bit value with the contents of an 8-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem16*, *imm16*	F7 /0 *iw*	AND an immediate 16-bit value with the contents of a 16-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem32*, *imm32*	F7 /0 *id*	AND an immediate 32-bit value with the contents of a 32-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem64*, *imm32*	F7 /0 *id*	AND a sign-extended immediate32-bit value with the contents of a 64-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem8*, *reg8*	84 */r*	AND the contents of an 8-bit register with the contents of an 8-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem16*, *reg16*	85 */r*	AND the contents of a 16-bit register with the contents of a 16-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem32*, *reg32*	85 */r*	AND the contents of a 32-bit register with the contents of a 32-bit register or memory operand and set rFLAGS to reflect the result.
TEST *reg/mem64*, *reg64*	85 */r*	AND the contents of a 64-bit register with the contents of a 64-bit register or memory operand and set rFLAGS to reflect the result.

Related Instructions

AND, CMP

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								0				M	M	U	M	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

XADD Exchange and Add

Exchanges the contents of a register (second operand) with the contents of a register or memory location (first operand), computes the sum of the two values, and stores the result in the first operand location.

The forms of the XADD instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see "Lock Prefix" on page 8.

Mnemonic	Opcode	Description
XADD *reg/mem8*, *reg8*	0F C0 */r*	Exchange the contents of an 8-bit register with the contents of an 8-bit destination register or memory operand and load their sum into the destination.
XADD *reg/mem16*, *reg16*	0F C1 */r*	Exchange the contents of a 16-bit register with the contents of a 16-bit destination register or memory operand and load their sum into the destination.
XADD *reg/mem32*, *reg32*	0F C1 */r*	Exchange the contents of a 32-bit register with the contents of a 32-bit destination register or memory operand and load their sum into the destination.
XADD *reg/mem64*, *reg64*	0F C1 */r*	Exchange the contents of a 64-bit register with the contents of a 64-bit destination register or memory operand and load their sum into the destination.

Related Instructions

None

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								M				M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

XCHG Exchange

Exchanges the contents of the two operands. The operands can be two general-purpose registers or a register and a memory location. If either operand references memory, the processor locks automatically, whether or not the LOCK prefix is used and independently of the value of IOPL. For details about the LOCK prefix, see "Lock Prefix" on page 8.

The x86 architecture commonly uses the XCHG EAX, EAX instruction (opcode 90h) as a one-byte NOP. In 64-bit mode, the processor treats opcode 90h as a true NOP only if it would exchange rAX with itself. Without this special handling, the instruction would zero-extend the upper 32 bits of RAX, and thus it would not be a true no-operation. Opcode 90h can still be used to exchange rAX and r8 if the appropriate REX prefix is used.

This special handling does not apply to the two-byte ModRM form of the XCHG instruction.

Mnemonic	Opcode	Description
XCHG AX, *reg16*	90 *+rw*	Exchange the contents of the AX register with the contents of a 16-bit register.
XCHG *reg16*, AX	90 *+rw*	Exchange the contents of a 16-bit register with the contents of the AX register.
XCHG EAX, *reg32*	90 *+rd*	Exchange the contents of the EAX register with the contents of a 32-bit register.
XCHG *reg32*, EAX	90 *+rd*	Exchange the contents of a 32-bit register with the contents of the EAX register.
XCHG RAX, *reg64*	90 *+rq*	Exchange the contents of the RAX register with the contents of a 64-bit register.
XCHG *reg64*, RAX	90 *+rq*	Exchange the contents of a 64-bit register with the contents of the RAX register.
XCHG *reg/mem8*, *reg8*	86 */r*	Exchange the contents of an 8-bit register with the contents of an 8-bit register or memory operand.
XCHG *reg8*, *reg/mem8*	86 */r*	Exchange the contents of an 8-bit register or memory operand with the contents of an 8-bit register.
XCHG *reg/mem16*, *reg16*	87 */r*	Exchange the contents of a 16-bit register with the contents of a 16-bit register or memory operand.
XCHG *reg16*, *reg/mem16*	87 */r*	Exchange the contents of a 16-bit register or memory operand with the contents of a 16-bit register.
XCHG *reg/mem32*, *reg32*	87 */r*	Exchange the contents of a 32-bit register with the contents of a 32-bit register or memory operand.
XCHG *reg32*, *reg/mem32*	87 */r*	Exchange the contents of a 32-bit register or memory operand with the contents of a 32-bit register.
XCHG *reg/mem64*, *reg64*	87 */r*	Exchange the contents of a 64-bit register with the contents of a 64-bit register or memory operand.
XCHG *reg64*, *reg/mem64*	87 */r*	Exchange the contents of a 64-bit register or memory operand with the contents of a 64-bit register.

Related Instructions

BSWAP, XADD

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The source or destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

XLAT
XLATB
Translate Table Index

Uses the unsigned integer in the AL register as an offset into a table and copies the contents of the table entry at that location to the AL register.

The instruction uses *seg*:[rBX] as the base address of the table. The value of *seg* defaults to the DS segment, but may be overridden by a segment prefix.

This instruction writes AL without changing RAX[63:8]. This instruction ignores operand size.

The single-operand form of the XLAT instruction uses the operand to document the segment and address size attribute, but it uses the base address specified by the rBX register.

This instruction is often used to translate data from one format (such as ASCII) to another (such as EBCDIC).

Mnemonic	Opcode	Description
XLAT *mem8*	D7	Set AL to the contents of DS:[rBX + unsigned AL].
XLATB	D7	Set AL to the contents of DS:[rBX + unsigned AL].

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.

XOR Logical Exclusive OR

Performs a bitwise exclusive OR operation on both operands and stores the result in the first operand location. The first operand can be a register or memory location. The second operand can be an immediate value, a register, or a memory location. XOR-ing a register with itself clears the register.

The forms of the XOR instruction that write to memory support the LOCK prefix. For details about the LOCK prefix, see “Lock Prefix” on page 8.

The instruction performs the following operation for each bit:

X	Y	X XOR Y
0	0	0
0	1	1
1	0	1
1	1	0

Mnemonic	Opcode	Description
XOR AL, *imm8*	34 *ib*	XOR the contents of AL with an immediate 8-bit operand and store the result in AL.
XOR AX, *imm16*	35 *iw*	XOR the contents of AX with an immediate 16-bit operand and store the result in AX.
XOR EAX, *imm32*	35 *id*	XOR the contents of EAX with an immediate 32-bit operand and store the result in EAX.
XOR RAX, *imm32*	35 *id*	XOR the contents of RAX with a sign-extended immediate 32-bit operand and store the result in RAX.
XOR *reg/mem8*, *imm8*	80 /6 *ib*	XOR the contents of an 8-bit destination register or memory operand with an 8-bit immediate value and store the result in the destination.
XOR *reg/mem16*, *imm16*	81 /6 *iw*	XOR the contents of a 16-bit destination register or memory operand with a 16-bit immediate value and store the result in the destination.
XOR *reg/mem32*, *imm32*	81 /6 *id*	XOR the contents of a 32-bit destination register or memory operand with a 32-bit immediate value and store the result in the destination.
XOR *reg/mem64*, *imm32*	81 /6 *id*	XOR the contents of a 64-bit destination register or memory operand with a sign-extended 32-bit immediate value and store the result in the destination.
XOR *reg/mem16*, *imm8*	83 /6 *ib*	XOR the contents of a 16-bit destination register or memory operand with a sign-extended 8-bit immediate value and store the result in the destination.

Mnemonic	Opcode	Description
XOR *reg/mem32*, *imm8*	83 /6 *ib*	XOR the contents of a 32-bit destination register or memory operand with a sign-extended 8-bit immediate value and store the result in the destination.
XOR *reg/mem64*, *imm8*	83 /6 *ib*	XOR the contents of a 64-bit destination register or memory operand with a sign-extended 8-bit immediate value and store the result in the destination.
XOR *reg/mem8*, *reg8*	30 */r*	XOR the contents of an 8-bit destination register or memory operand with the contents of an 8-bit register and store the result in the destination.
XOR *reg/mem16*, *reg16*	31 */r*	XOR the contents of a 16-bit destination register or memory operand with the contents of a 16-bit register and store the result in the destination.
XOR *reg/mem32*, *reg32*	31 */r*	XOR the contents of a 32-bit destination register or memory operand with the contents of a 32-bit register and store the result in the destination.
XOR *reg/mem64*, *reg64*	31 */r*	XOR the contents of a 64-bit destination register or memory operand with the contents of a 64-bit register and store the result in the destination.
XOR *reg8*, *reg/mem8*	32 */r*	XOR the contents of an 8-bit destination register with the contents of an 8-bit register or memory operand and store the results in the destination.
XOR *reg16*, *reg/mem16*	33 */r*	XOR the contents of a 16-bit destination register with the contents of a 16-bit register or memory operand and store the results in the destination.
XOR *reg32*, *reg/mem32*	33 */r*	XOR the contents of a 32-bit destination register with the contents of a 32-bit register or memory operand and store the results in the destination.
XOR *reg64*, *reg/mem64*	33 */r*	XOR the contents of a 64-bit destination register with the contents of a 64-bit register or memory operand and store the results in the destination.

Related Instructions

OR, AND, NOT, NEG

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
								0				M	M	U	M	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

4 System Instruction Reference

This chapter describes the function, mnemonic syntax, opcodes, affected flags, and possible exceptions generated by the system instructions. The system instructions are used to establish the operating mode, access processor resources, handle program and system errors, and manage memory. Many of these instructions can only be executed by privileged software, such as the operating system kernel and interrupt handlers, that run at the highest privilege level. Only system instructions can access certain processor resources, such as the control registers, model-specific registers, and debug registers.

System instructions are supported in all hardware implementations of the AMD64 architecture, except that the following system instructions are implemented only if their associated CPUID function bits are set:

- RDMSR and WRMSR, indicated by bit 5 of CPUID function 0000_0001h or function 8000_0001h.
- SYSENTER and SYSEXIT, indicated by bit 11 of CPUID function 0000_0001h.
- SYSCALL and SYSRET, indicated by bit 11 of CPUID function 8000_0001h.
- Long Mode instructions, indicated by bit 29 of CPUID function 8000_0001h.
- There are also several other CPUID function bits that control the use of system resources and functions, such as paging functions, virtual-mode extensions, machine-check exceptions, advanced programmable interrupt control (APIC), memory-type range registers (MTRRs), etc. For details, see “Processor Feature Identification” in Volume 2.

For further information about the system instructions and register resources, see:

- “System-Management Instructions” in Volume 2.
- “Summary of Registers and Data Types” on page 24.
- “Notation” on page 37.
- “Instruction Prefixes” on page 3.

ARPL Adjust Requestor Privilege Level

Compares the requestor privilege level (RPL) fields of two segment selectors in the source and destination operands of the instruction. If the RPL field of the destination operand is less than the RPL field of the segment selector in the source register, then the zero flag is set and the RPL field of the destination operand is increased to match that of the source operand. Otherwise, the destination operand remains unchanged and the zero flag is cleared.

The destination operand can be either a 16-bit register or memory location; the source operand must be a 16-bit register.

The ARPL instruction is intended for use by operating-system procedures to adjust the RPL of a segment selector that has been passed to the operating system by an application program to match the privilege level of the application program. The segment selector passed to the operating system is placed in the destination operand and the segment selector for the code segment of the application program is placed in the source operand. The RPL field in the source operand represents the privilege level of the application program. The ARPL instruction then insures that the RPL of the segment selector received by the operating system is no lower than the privilege level of the application program.

See “Adjusting Access Rights” in Volume 2, for more information on access rights.

In 64-bit mode, this opcode (63H) is used for the MOVSXD instruction.

Mnemonic	Opcode	Description
ARPL *reg/mem16*, *reg16*	63 */r*	Adjust the RPL of a destination segment selector to a level not less than the RPL of the segment selector specified in the 16-bit source register. (Invalid in 64-bit mode.)

Related Instructions

LAR, LSL, VERR, VERW

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected legacy and compatibility mode.
Stack, #SS			X	A memory address exceeded the stack segment limit.
General protection, #GP			X	A memory address exceeded a data segment limit.
			X	The destination operand was in a non-writable segment.
			X	A null segment selector was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

CLGI Clear Global Interrupt Flag

Clears the global interrupt flag (GIF). While GIF is zero, all external interrupts are disabled.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See "Enabling SVM" on page 369 in *AMD64 Architecture Programmer's Manual Volume-2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
CLGI	0F 01 DD	Clears the global interrupt flag (GIF).

Related Instructions

STGI

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
			X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X		Instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.

CLI Clear Interrupt Flag

Clears the interrupt flag (IF) in the rFLAGS register to zero, thereby masking external interrupts received on the INTR input. Interrupts received on the non-maskable interrupt (NMI) input are not affected by this instruction.

In real mode, this instruction clears IF to 0.

In protected mode and virtual-8086-mode, this instruction is IOPL-sensitive. If the CPL is less than or equal to the rFLAGS.IOPL field, the instruction clears IF to 0.

In protected mode, if IOPL < 3, CPL = 3, and protected mode virtual interrupts are enabled (CR4.PVI = 1), then the instruction instead clears rFLAGS.VIF to 0. If none of these conditions apply, the processor raises a general-purpose exception (#GP). For more information, see "Protected Mode Virtual Interrupts" in Volume 2.

In virtual-8086 mode, if IOPL < 3 and the virtual-8086-mode extensions are enabled (CR4.VME = 1), the CLI instruction clears the virtual interrupt flag (rFLAGS.VIF) to 0 instead.

See "Virtual-8086 Mode Extensions" in Volume 2 for more information about IOPL-sensitive instructions.

Mnemonic	Opcode	Description
CLI	FA	Clear the interrupt flag (IF) to zero.

Action

```
IF (CPL <= IOPL)
      RFLAGS.IF = 0

ELSEIF (((VIRTUAL_MODE) && (CR4.VME = 1))
        || ((PROTECTED_MODE) && (CR4.PVI = 1) && (CPL == 3)))
      RFLAGS.VIF = 0;

ELSE
      EXCEPTION[#GP(0)]
```

Related Instructions

STI

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
		M								M						
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X		The CPL was greater than the IOPL and virtual mode extensions are not enabled (CR4.VME = 0).
			X	The CPL was greater than the IOPL and either the CPL was not 3 or protected mode virtual interrupts were not enabled (CR4.PVI = 0).

CLTS Clear Task-Switched Flag in CR0

Clears the task-switched (TS) flag in the CR0 register to 0. The processor sets the TS flag on each task switch. The CLTS instruction is intended to facilitate the synchronization of FPU context saves during multitasking operations.

This instruction can only be used if the current privilege level is 0.

See "System-Control Registers" in Volume 2 for more information on FPU synchronization and the TS flag.

Mnemonic	Opcode	Description
CLTS	0F 06	Clear the task-switched (TS) flag in CR0 to 0.

Related Instructions

LMSW, MOV (CR*n*)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X	X	CPL was not 0.

HLT Halt

Causes the microprocessor to halt instruction execution and enter the HALT state. Entering the HALT state puts the processor in low-power mode. Execution resumes when an unmasked hardware interrupt (INTR), non-maskable interrupt (NMI), system management interrupt (SMI), RESET, or INIT occurs.

If an INTR, NMI, or SMI is used to resume execution after a HLT instruction, the saved instruction pointer points to the instruction following the HLT instruction.

Before executing a HLT instruction, hardware interrupts should be enabled. If rFLAGS.IF = 0, the system will remain in a HALT state until an NMI, SMI, RESET, or INIT occurs.

If an SMI brings the processor out of the HALT state, the SMI handler can decide whether to return to the HALT state or not. See Volume 2: System Programming, for information on SMIs.

Current privilege level must be 0 to execute this instruction.

Mnemonic	Opcode	Description
HLT	F4	Halt instruction execution.

Related Instructions

STI, CLI

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X	X	CPL was not 0.

INT 3 Interrupt to Debug Vector

Calls the debug exception handler. This instruction maps to a 1-byte opcode (CC) that raises a #BP exception. The INT 3 instruction is normally used by debug software to set instruction breakpoints by replacing the first byte of the instruction opcode bytes with the INT 3 opcode.

This one-byte INT 3 instruction behaves differently from the two-byte INT 3 instruction (opcode CD 03) (see "INT" in Chapter 3 "General Purpose Instructions" for further information) in two ways:

The #BP exception is handled without any IOPL checking in virtual x86 mode. (IOPL mismatches will not trigger an exception.)

- In VME mode, the #BP exception is not redirected via the interrupt redirection table. (Instead, it is handled by a protected mode handler.)

Mnemonic	Opcode	Description
INT 3	CC	Trap to debugger at Interrupt 3.

For complete descriptions of the steps performed by INT instructions, see the following:

- *Legacy-Mode Interrupts:* "Legacy Protected-Mode Interrupt Control Transfers" in Volume 2.
- *Long-Mode Interrupts:* "Long-Mode Interrupt Control Transfers" in Volume 2.

Action

```
// Refer to INT instruction's Action section for the details on INT_N_REAL,
// INT_N_PROTECTED, and INT_N_VIRTUAL_TO_PROTECTED.
INT3_START:

If (REAL_MODE)
    INT_N_REAL                 //N = 3

ELSEIF (PROTECTED_MODE)
    INT_N_PROTECTED            //N = 3

ELSE // VIRTUAL_MODE
    INT_N_VIRTUAL_TO_PROTECTED  //N = 3
```

Related Instructions

INT, INTO, IRET

rFLAGS Affected

If a task switch occurs, all flags are modified; otherwise, setting are as follows:

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
			M	0	0	M				M	0					
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Breakpoint, #BP	X	X	X	INT 3 instruction was executed.
Invalid TSS, #TS (selector)		X	X	As part of a stack switch, the target stack segment selector or rSP in the TSS that was beyond the TSS limit.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was beyond the limit of the GDT or LDT descriptor table.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was a null selector.
		X	X	As part of a stack switch, the target stack segment selector's TI bit was set, but the LDT selector was a null selector.
		X	X	As part of a stack switch, the target stack segment selector in the TSS contained a RPL that was not equal to its DPL.
		X	X	As part of a stack switch, the target stack segment selector in the TSS contained a DPL that was not equal to the CPL of the code segment selector.
		X	X	As part of a stack switch, the target stack segment selector in the TSS was not a writable segment.
Segment not present, #NP (selector)		X	X	The accessed code segment, interrupt gate, trap gate, task gate, or TSS was not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)		X	X	After a stack switch, a memory address exceeded the stack segment limit or was non-canonical and a stack switch occurred.
		X	X	As part of a stack switch, the SS register was loaded with a non-null segment selector and the segment was marked not present.
General protection, #GP	X	X	X	A memory address exceeded the data segment limit or was non-canonical.
	X	X	X	The target offset exceeded the code segment limit or was non-canonical.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP (selector)	X	X	X	The interrupt vector was beyond the limit of IDT.
		X	X	The descriptor in the IDT was not an interrupt, trap, or task gate in legacy mode or not a 64-bit interrupt or trap gate in long mode.
		X	X	The DPL of the interrupt, trap, or task gate descriptor was less than the CPL.
		X	X	The segment selector specified by the interrupt or trap gate had its TI bit set, but the LDT selector was a null selector.
		X	X	The segment descriptor specified by the interrupt or trap gate exceeded the descriptor table limit or was a null selector.
		X	X	The segment descriptor specified by the interrupt or trap gate was not a code segment in legacy mode, or not a 64-bit code segment in long mode.
			X	The DPL of the segment specified by the interrupt or trap gate was greater than the CPL.
		X		The DPL of the segment specified by the interrupt or trap gate pointed was not 0 or it was a conforming segment.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

INVD Invalidate Caches

Invalidates internal caches (data cache, instruction cache, and on-chip L2 cache) and triggers a bus cycle that causes external caches to invalidate themselves as well.

No data is written back to main memory from invalidating internal caches. After invalidating internal caches, the processor proceeds immediately with the execution of the next instruction without waiting for external hardware to invalidate its caches.

This is a privileged instruction. The current privilege level (CPL) of a procedure invalidating the processor's internal caches must be 0.

To insure that data is written back to memory prior to invalidating caches, use the WBINVD instruction.

This instruction does not invalidate TLB caches.

INVD is a serializing instruction.

Mnemonic	Opcode	Description
INVD	0F 08	Invalidate internal caches and trigger external cache invalidations.

Related Instructions

WBINVD, CLFLUSH

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X	X	CPL was not 0.

INVLPG Invalidate TLB Entry

Invalidates the TLB entry that would be used for the 1-byte memory operand.

This instruction invalidates the TLB entry, regardless of the G (Global) bit setting in the associated PDE or PTE entry and regardless of the page size (4 Kbytes, 2 Mbytes, or 4 Mbytes). It may invalidate any number of additional TLB entries, in addition to the targeted entry.

INVLPG is a serializing instruction and a privileged instruction. The current privilege level must be 0 to execute this instruction.

See “Page Translation and Protection” in Volume 2 for more information on page translation.

Mnemonic	Opcode	Description
INVLPG *mem8*	0F 01 /7	Invalidate the TLB entry for the page containing a specified memory location.

Related Instructions

INVLPGA, MOV CR*n* (CR3 and CR4)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X	X	CPL was not 0.

INVLPGA Invalidate TLB Entry in a Specified ASID

Invalidates the TLB mapping for a given virtual page and a given ASID. The virtual address is specified in the implicit register operand rAX. The portion of RAX used to form the address is determined by the effective address size. The ASID is taken from ECX.

The INVLPGA instruction may invalidate any number of additional TLB entries, in addition to the targeted entry.

The INVLPGA instruction is a serializing instruction and a privileged instruction. The current privilege level must be 0 to execute this instruction.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See "Enabling SVM" on page 369 in *AMD64 Architecture Programmer's Manual Volume-2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
INVLPGA rAX, ECX	0F 01 DF	Invalidates the TLB mapping for the virtual page specified in rAX and the ASID specified in ECX.

Related Instructions

INVLPG.

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
			X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X		Instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.

IRET
IRETD
IRETQ
Return from Interrupt

Returns program control from an exception or interrupt handler to a program or procedure previously interrupted by an exception, an external interrupt, or a software-generated interrupt. These instructions also perform a return from a nested task. All flags, CS, and rIP are restored to the values they had before the interrupt so that execution may continue at the next instruction following the interrupt or exception. In 64-bit mode or if the CPL changes, SS and RSP are also restored.

IRET, IRETD, and IRETQ are synonyms mapping to the same opcode. They are intended to provide semantically distinct forms for various opcode sizes. The IRET instruction is used for 16-bit operand size; IRETD is used for 32-bit operand sizes; IRETQ is used for 64-bit operands. The latter form is only meaningful in 64-bit mode.

IRET, IRETD, or IRETQ must be used to terminate the exception or interrupt handler associated with the exception, external interrupt, or software-generated interrupt.

IRET*x* is a serializing instruction.

For detailed descriptions of the steps performed by IRET*x* instructions, see the following:

- *Legacy-Mode Interrupts:* "Legacy Protected-Mode Interrupt Control Transfers" in Volume 2.
- *Long-Mode Interrupts:* "Long-Mode Interrupt Control Transfers" in Volume 2.

Mnemonic	Opcode	Description
IRET	CF	Return from interrupt (16-bit operand size).
IRETD	CF	Return from interrupt (32-bit operand size).
IRETQ	CF	Return from interrupt (64-bit operand size).

Action

```
IRET_START:

IF (REAL_MODE)
    IRET_REAL
ELSIF (PROTECTED_MODE)
    IRET_PROTECTED
ELSE // (VIRTUAL_MODE)
    IRET_VIRTUAL

IRET_REAL:

    POP.v temp_RIP
    POP.v temp_CS
    POP.v temp_RFLAGS
```

```
    IF (temp_RIP > CS.limit)
        EXCEPTION [#GP(0)]

    CS.sel  = temp_CS
    CS.base = temp_CS SHL 4

    RFLAGS.v = temp_RFLAGS // VIF,VIP,VM unchanged
    RIP = temp_RIP
    EXIT


IRET_PROTECTED:

    IF (RFLAGS.NT=1)             // iret does a task-switch to a previous task
        IF (LEGACY_MODE)
            TASK_SWITCH          // using the 'back link' field in the tss
        ELSE                     // (LONG_MODE)
            EXCEPTION [#GP(0)]   // task switches aren't supported in long mode

    POP.v temp_RIP
    POP.v temp_CS
    POP.v temp_RFLAGS

    IF ((temp_RFLAGS.VM=1) && (CPL=0) && (LEGACY_MODE))
        IRET_FROM_PROTECTED_TO_VIRTUAL

    temp_CPL = temp_CS.rpl

    IF ((64BIT_MODE) || (temp_CPL!=CPL))
    {
        POP.v temp_RSP            // in 64-bit mode, iret always pops ss:rsp
        POP.v temp_SS
    }

    CS = READ_DESCRIPTOR (temp_CS, iret_chk)

    IF ((64BIT_MODE) && (temp_RIP is non-canonical)
       || (!64BIT_MODE) && (temp_RIP > CS.limit))
    {
        EXCEPTION [#GP(0)]
    }

    CPL = temp_CPL

    IF ((started in 64-bit mode) || (changing CPL))
                        // ss:rsp were popped, so load them into the registers
    {
        SS = READ_DESCRIPTOR (temp_SS, ss_chk)
        RSP.s = temp_RSP
    }
```

```
    IF (changing CPL)
    {
       FOR (seg = ES, DS, FS, GS)
           IF ((seg.attr.dpl < CPL) && ((seg.attr.type = 'data')
              || (seg.attr.type = 'non-conforming-code')))
           {
               seg = NULL       // can't use lower dpl data segment at higher cpl
           }
    }
    RFLAGS.v = temp_RFLAGS      // VIF,VIP,IOPL only changed if (old_CPL=0)
                                // IF only changed if (old_CPL<=old_RFLAGS.IOPL)
                                // VM unchanged
                                // RF cleared
    RIP = temp_RIP
    EXIT


IRET_VIRTUAL:

    IF ((RFLAGS.IOPL<3) && (CR4.VME=0))
        EXCEPTION [#GP(0)]

    POP.v temp_RIP
    POP.v temp_CS
    POP.v temp_RFLAGS

    IF (temp_RIP > CS.limit)
        EXCEPTION [#GP(0)]

    IF (RFLAGS.IOPL=3)
    {
        RFLAGS.v = temp_RFLAGS  // VIF,VIP,VM,IOPL unchanged
                                // RF cleared
        CS.sel  = temp_CS
        CS.base = temp_CS SHL 4

        RIP = temp_RIP
        EXIT
    }

    // now ((IOPL<3) && (CR4.VME=1)

    ELSIF ((OPERAND_SIZE=16)
          && !((temp_RFLAGS.IF=1) && (RFLAGS.VIP=1))
          && (temp_RFLAGS.TF=0))
    {
        RFLAGS.w = temp_RFLAGS  // RFLAGS.VIF=temp_RFLAGS.IF
                                // IF,IOPL unchanged
                                // RF cleared
        CS.sel  = temp_CS
        CS.base = temp_CS SHL 4
```

```
        RIP = temp_RIP
        EXIT
    }
    ELSE // ((RFLAGS.IOPL<3) && (CR4.VME=1) && ((OPERAND_SIZE=32) ||
         // ((temp_RFLAGS.IF=1) && (RFLAGS.VIP=1)) || (temp_RFLAGS.TF=1)))
        EXCEPTION [#GP(0)]


IRET_FROM_PROTECTED_TO_VIRTUAL:

    // temp_RIP already popped
    // temp_CS  already popped
    // temp_RFLAGS already popped, temp_RFLAGS.VM=1

    POP.d temp_RSP
    POP.d temp_SS
    POP.d temp_ES
    POP.d temp_DS
    POP.d temp_FS
    POP.d temp_GS

    CS.sel  = temp_CS          // force the segments to have virtual-mode values
    CS.base = temp_CS SHL 4
    CS.limit= 0x0000FFFF
    CS.attr = 16-bit dpl3 code

    SS.sel  = temp_SS
    SS.base = temp_SS SHL 4
    SS.limit= 0x0000FFFF
    SS.attr = 16-bit dpl3 stack

    DS.sel  = temp_DS
    DS.base = temp_DS SHL 4
    DS.limit= 0x0000FFFF
    DS.attr = 16-bit dpl3 data

    ES.sel  = temp_ES
    ES.base = temp_ES SHL 4
    ES.limit= 0x0000FFFF
    ES.attr = 16-bit dpl3 data

    FS.sel  = temp_FS
    FS.base = temp_FS SHL 4
    FS.limit= 0x0000FFFF
    FS.attr = 16-bit dpl3 data

    GS.sel  = temp_GS
    GS.base = temp_GS SHL 4
    GS.limit= 0x0000FFFF
    GS.attr = 16-bit dpl3 data
```

```
RSP.d = temp_RSP
RFLAGS.d = temp_RFLAGS
CPL = 3

RIP = temp_RIP AND 0x0000FFFF
EXIT
```

Related Instructions

INT, INTO, INT3

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Segment not present, #NP (selector)			X	The return code segment was marked not present.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
Stack, #SS (selector)			X	The SS register was loaded with a non-null segment selector and the segment was marked not present.
General protection, #GP	X	X	X	The target offset exceeded the code segment limit or was non-canonical.
		X		IOPL was less than 3 and one of the following conditions was true: • CR4.VME was 0. • The effective operand size was 32-bit. • Both the original EFLAGS.VIP and the new EFLAGS.IF were set. • The new EFLAGS.TF was set.
			X	IRET*x* was executed in long mode while EFLAGS.NT=1.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP (selector)			X	The return code selector was a null selector.
			X	The return stack selector was a null selector and the return mode was non-64-bit mode or CPL was 3.
			X	The return code or stack descriptor exceeded the descriptor table limit.
			X	The return code or stack selector's TI bit was set but the LDT selector was a null selector.
			X	The segment descriptor for the return code was not a code segment.
			X	The RPL of the return code segment selector was less than the CPL.
			X	The return code segment was non-conforming and the segment selector's DPL was not equal to the RPL of the code segment's segment selector.
			X	The return code segment was conforming and the segment selector's DPL was greater than the RPL of the code segment's segment selector.
			X	The segment descriptor for the return stack was not a writable data segment.
			X	The stack segment descriptor DPL was not equal to the RPL of the return code segment selector.
			X	The stack segment selector RPL was not equal to the RPL of the return code segment selector.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

LAR Load Access Rights Byte

Loads the access rights from the segment descriptor specified by a 16-bit source register or memory operand into a specified 16-bit, 32-bit, or 64-bit general-purpose register and sets the zero (ZF) flag in the rFLAGS register if successful. LAR clears the zero flag if the descriptor is invalid for any reason.

The LAR instruction checks that:

- the segment selector is not a null selector.
- the descriptor is within the GDT or LDT limit.
- the descriptor DPL is greater than or equal to both the CPL and RPL, or the segment is a conforming code segment.
- the descriptor type is valid for the LAR instruction. Valid descriptor types are shown in the following table. LDT and TSS descriptors in 64-bit mode, and call-gate descriptors in long mode, are only valid if bits 12–8 of doubleword +12 are zero, as shown on page 111 of vol. 2 in Figure 4-22.

Valid Descriptor Type		Description
Legacy Mode	**Long Mode**	
All	All	All code and data descriptors
1	—	Available 16-bit TSS
2	2	LDT
3	—	Busy 16-bit TSS
4	—	16-bit call gate
5	—	Task gate
9	9	Available 32-bit or 64-bit TSS
B	B	Busy 32-bit or 64-bit TSS
C	C	32-bit or 64-bit call gate

If the segment descriptor passes these checks, the attributes are loaded into the destination general-purpose register. If it does not, then the zero flag is cleared and the destination register is not modified.

When the operand size is 16 bits, access rights include the DPL and Type fields located in bytes 4 and 5 of the descriptor table entry. Before loading the access rights into the destination operand, the low order word is masked with FF00H.

When the operand size is 32 or 64 bits, access rights include the DPL and type as well as the descriptor type (S field), segment present (P flag), available to system (AVL flag), default operation size (D/B flag), and granularity flags located in bytes 4–7 of the descriptor. Before being loaded into the destination operand, the doubleword is masked with 00FF_FF00H.

In 64-bit mode, for both 32-bit and 64-bit operand sizes, 32-bit register results are zero-extended to 64 bits.

This instruction can only be executed in protected mode.

Mnemonic	Opcode	Description
LAR *reg16*, *reg/mem16*	0F 02 */r*	Reads the GDT/LDT descriptor referenced by the 16-bit source operand, masks the attributes with FF00h and saves the result in the 16-bit destination register.
LAR *reg32*, *reg/mem16*	0F 02 */r*	Reads the GDT/LDT descriptor referenced by the 16-bit source operand, masks the attributes with 00FFFF00h and saves the result in the 32-bit destination register.
LAR *reg64*, *reg/mem16*	0F 02 */r*	Reads the GDT/LDT descriptor referenced by the 16-bit source operand, masks the attributes with 00FFFF00h and saves the result in the 64-bit destination register.

Related Instructions

ARPL, LSL, VERR, VERW

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded the data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
			X	The extended attribute bits of a system descriptor was not zero in 64-bit mode.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

LGDT Load Global Descriptor Table Register

Loads the pseudo-descriptor specified by the source operand into the global descriptor table register (GDTR). The pseudo-descriptor is a memory location containing the GDTR base and limit. In legacy and compatibility mode, the pseudo-descriptor is 6 bytes; in 64-bit mode, it is 10 bytes.

If the operand size is 16 bits, the high-order byte of the 6-byte pseudo-descriptor is not used. The lower two bytes specify the 16-bit limit and the third, fourth, and fifth bytes specify the 24-bit base address. The high-order byte of the GDTR is filled with zeros.

If the operand size is 32 bits, the lower two bytes specify the 16-bit limit and the upper four bytes specify a 32-bit base address.

In 64-bit mode, the lower two bytes specify the 16-bit limit and the upper eight bytes specify a 64-bit base address. In 64-bit mode, operand-size prefixes are ignored and the operand size is forced to 64-bits; therefore, the pseudo-descriptor is always 10 bytes.

This instruction is only used in operating system software and must be executed at CPL 0. It is typically executed once in real mode to initialize the processor before switching to protected mode.

LGDT is a serializing instruction.

Mnemonic	Opcode	Description
LGDT *mem16:32*	0F 01 /2	Loads *mem16:32* into the global descriptor table register.
LGDT *mem16:64*	0F 01 /2	Loads *mem16:64* into the global descriptor table register.

Related Instructions

LIDT, LLDT, LTR, SGDT, SIDT, SLDT, STR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The operand was a register.
Stack, #SS	X		X	A memory address exceeded the stack segment limit or was non-canonical.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X		X	A memory address exceeded the data segment limit or was non-canonical.
		X	X	CPL was not 0.
			X	The new GDT base address was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.

LIDT — Load Interrupt Descriptor Table Register

Loads the pseudo-descriptor specified by the source operand into the interrupt descriptor table register (IDTR). The pseudo-descriptor is a memory location containing the IDTR base and limit. In legacy and compatibility mode, the pseudo-descriptor is six bytes; in 64-bit mode, it is 10 bytes.

If the operand size is 16 bits, the high-order byte of the 6-byte pseudo-descriptor is not used. The lower two bytes specify the 16-bit limit and the third, fourth, and fifth bytes specify the 24-bit base address. The high-order byte of the IDTR is filled with zeros.

If the operand size is 32 bits, the lower two bytes specify the 16-bit limit and the upper four bytes specify a 32-bit base address.

In 64-bit mode, the lower two bytes specify the 16-bit limit, and the upper eight bytes specify a 64-bit base address. In 64-bit mode, operand-size prefixes are ignored and the operand size is forced to 64-bits; therefore, the pseudo-descriptor is always 10 bytes.

This instruction is only used in operating system software and must be executed at CPL 0. It is normally executed once in real mode to initialize the processor before switching to protected mode.

LIDT is a serializing instruction.

Mnemonic	Opcode	Description
LIDT *mem16:32*	0F 01 /3	Loads *mem16:32* into the interrupt descriptor table register.
LIDT *mem16:64*	0F 01 /3	Loads *mem16:64* into the interrupt descriptor table register.

Related Instructions

LGDT, LLDT, LTR, SGDT, SIDT, SLDT, STR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The operand was a register.
Stack, #SS	X		X	A memory address exceeded the stack segment limit or was non-canonical.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP	X		X	A memory address exceeded the data segment limit or was non-canonical.
		X	X	CPL was not 0.
			X	The new IDT base address was non-canonical.
			X	A null data segment was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.

LLDT Load Local Descriptor Table Register

Loads the specified segment selector into the visible portion of the local descriptor table (LDT). The processor uses the selector to locate the descriptor for the LDT in the global descriptor table. It then loads this descriptor into the hidden portion of the LDTR.

If the source operand is a null selector, the LDTR is marked invalid and all references to descriptors in the LDT will generate a general protection exception (#GP), except for the LAR, VERR, VERW or LSL instructions.

In legacy and compatibility modes, the LDT descriptor is 8 bytes long and contains a 32-bit base address.

In 64-bit mode, the LDT descriptor is 16-bytes long and contains a 64-bit base address. The LDT descriptor type (02h) is redefined in 64-bit mode for use as the 16-byte LDT descriptor.

This instruction must be executed in protected mode. It is only provided for use by operating system software at CPL 0.

LLDT is a serializing instruction.

Mnemonic	Opcode	Description
LLDT *reg/mem16*	0F 00 /2	Load the 16-bit segment selector into the local descriptor table register and load the LDT descriptor from the GDT.

Related Instructions

LGDT, LIDT, LTR, SGDT, SIDT, SLDT, STR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Segment not present, #NP (selector)			X	The LDT descriptor was marked not present.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	CPL was not 0.
			X	A null data segment was used to reference memory.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP (selector)			X	The source selector did not point into the GDT.
			X	The descriptor was beyond the GDT limit.
			X	The descriptor was not an LDT descriptor.
			X	The descriptor's extended attribute bits were not zero in 64-bit mode.
			X	The new LDT base address was non-canonical.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.

LMSW Load Machine Status Word

Loads the lower four bits of the 16-bit register or memory operand into bits 3–0 of the machine status word in register CR0. Only the protection enabled (PE), monitor coprocessor (MP), emulation (EM), and task switched (TS) bits of CR0 are modified. Additionally, LMSW can set CR0.PE, but cannot clear it.

The LMSW instruction can be used only when the current privilege level is 0. It is only provided for compatibility with early processors.

Use the MOV CR0 instruction to load all 32 or 64 bits of CR0.

Mnemonic	Opcode	Description
LMSW *reg/mem16*	0F 01 /6	Load the lower 4 bits of the source into the lower 4 bits of CR0.

Related Instructions

MOV (CRn), SMSW

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X		X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X		X	A memory address exceeded a data segment limit or was non-canonical.
		X	X	CPL was not 0.
			X	A null data segment was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.

LSL Load Segment Limit

Loads the segment limit from the segment descriptor specified by a 16-bit source register or memory operand into a specified 16-bit, 32-bit, or 64-bit general-purpose register and sets the zero (ZF) flag in the rFLAGS register if successful. LSL clears the zero flag if the descriptor is invalid for any reason.

In 64-bit mode, for both 32-bit and 64-bit operand sizes, 32-bit register results are zero-extended to 64 bits.

The LSL instruction checks that:

- the segment selector is not a null selector.
- the descriptor is within the GDT or LDT limit.
- the descriptor DPL is greater than or equal to both the CPL and RPL, or the segment is a conforming code segment.
- the descriptor type is valid for the LAR instruction. Valid descriptor types are shown in the following table. LDT and TSS descriptors in 64-bit mode are only valid if bits 12–8 of doubleword +12 are zero, as shown on Figure 4-22 on page 89 of Volume 2: System Programming.

Valid Descriptor Type		Description
Legacy Mode	**Long Mode**	
—	—	All code and data descriptors
1	—	Available 16-bit TSS
2	2	LDT
3	—	Busy 16-bit TSS
9	9	Available 32-bit or 64-bit TSS
B	B	Busy 32-bit or 64-bit TSS

If the segment selector passes these checks and the segment limit is loaded into the destination general-purpose register, the instruction sets the zero flag of the rFLAGS register to 1. If the selector does not pass the checks, then LSL clears the zero flag to 0 and does not modify the destination.

The instruction calculates the segment limit to 32 bits, taking the 20-bit limit and the granularity bit into account. When the operand size is 16 bits, it truncates the upper 16 bits of the 32-bit adjusted segment limit and loads the lower 16-bits into the target register.

Mnemonic	Opcode	Description
LSL *reg16*, *reg/mem16*	0F 03 */r*	Loads a 16-bit general-purpose register with the segment limit for a selector specified in a 16-bit memory or register operand.

LSL *reg32*, *reg/mem16*	0F 03 */r*	Loads a 32-bit general-purpose register with the segment limit for a selector specified in a 16-bit memory or register operand.
LSL *reg64*, *reg/mem16*	0F 03 */r*	Loads a 64-bit general-purpose register with the segment limit for a selector specified in a 16-bit memory or register operand.

Related Instructions

ARPL, LAR, VERR, VERW

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.
			X	The extended attribute bits of a system descriptor was not zero in 64-bit mode.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

LTR Load Task Register

Loads the specified segment selector into the visible portion of the task register (TR). The processor uses the selector to locate the descriptor for the TSS in the global descriptor table. It then loads this descriptor into the hidden portion of TR. The TSS descriptor in the GDT is marked busy, but no task switch is made.

If the source operand is null, a general protection exception (#GP) is generated.

In legacy and compatibility modes, the TSS descriptor is 8 bytes long and contains a 32-bit base address.

In 64-bit mode, the instruction references a 64-bit descriptor to load a 64-bit base address. The TSS type (09H) is redefined in 64-bit mode for use as the 16-byte TSS descriptor.

This instruction must be executed in protected mode when the current privilege level is 0. It is only provided for use by operating system software.

The operand size attribute has no effect on this instruction.

LTR is a serializing instruction.

Mnemonic	Opcode	Description
LTR *reg/mem16*	0F 00 /3	Load the 16-bit segment selector into the task register and load the TSS descriptor from the GDT.

Related Instructions

LGDT, LIDT, LLDT, STR, SGDT, SIDT, SLDT

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Segment not present, #NP (selector)			X	The TSS descriptor was marked not present.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	CPL was not 0.
			X	A null data segment was used to reference memory.
			X	The new TSS selector was a null selector.
General protection, #GP (selector)			X	The source selector did not point into the GDT.
			X	The descriptor was beyond the GDT limit.
			X	The descriptor was not an available TSS descriptor.
			X	The descriptor's extended attribute bits were not zero in 64-bit mode.
			X	The new TSS base address was non-canonical.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.

MONITOR Setup Monitor Address

Establishes a linear address range of memory for hardware to monitor and puts the processor in the monitor event pending state. When in the monitor event pending state, the monitoring hardware detects stores to the specified linear address range and causes the processor to exit the monitor event pending state. The MWAIT instruction uses the state of the monitor hardware.

The address range should be a write-back memory type. Executing MONITOR on an address range for a non-write-back memory type is not guaranteed to cause the processor to enter the monitor event pending state. The size of the linear address range that is established by the MONITOR instruction can be determined by CPUID function 0000_0005h.

The [rAX] register provides the effective address. The DS segment is the default segment used to create the linear address. Segment overrides may be used with the MONITOR instruction.

The ECX register specifies optional extensions for the MONITOR instruction. There are currently no extensions defined and setting any bits in ECX will result in a #GP exception. The ECX register operand is implicitly 32-bits.

The EDX register specifies optional hints for the MONITOR instruction. There are currently no hints defined and EDX is ignored by the processor. The EDX register operand is implicitly 32-bits.

The MONITOR instruction can be executed at CPL 0 and is allowed at CPL > 0
only if MSR C001_0015h[MonMwaitUserEn] = 1. When MSR C001_0015h[MonMwaitUserEn] = 0, MONITOR generates #UD at CPL > 0. (See the appropriate version of the *BIOS and Kernel Developer's Guide* for specific details on MSR C001_0015h.)

MONITOR performs the same segmentation and paging checks as a 1-byte read.

Support for the MONITOR instruction is indicated by ECX bit 3 (Monitor) as returned by CPUID function 0000_0001h. Software must check the CPUID bit once per program or library initialization before using the MONITOR instruction, or inconsistent behavior may result. Software designed to run at CPL greater than 0 must also check for availability by testing whether executing MONITOR causes a #UD exception.

The following pseudo-code shows typical usage of a MONITOR/MWAIT pair:

```
EAX = Linear_Address_to_Monitor;
ECX = 0;  // Extensions
EDX = 0;  // Hints

while (!matching_store_done){
      MONITOR EAX, ECX, EDX
      IF (!matching_store_done) {
           MWAIT EAX, ECX
  }
}
```

Mnemonic	Opcode	Description
MONITOR	0F 01 C8	Establishes a linear address range to be monitored by hardware and activates the monitor hardware.

Related Instructions

MWAIT

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The MONITOR/MWAIT instructions are not supported, as indicated by ECX bit 3 (Monitor) as returned by CPUID function 0000_0001h.
		X	X	CPL was not zero and MSR C001_0015[MonMwaitUserEn] = 0.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
	X	X	X	ECX was non-zero.
			X	A null data segment was used to reference memory.
Page Fault, #PF		X	X	A page fault resulted from the execution of the instruction.

MOV (CR*n*) Move to/from Control Registers

Moves the contents of a 32-bit or 64-bit general-purpose register to a control register or vice versa.

In 64-bit mode, the operand size is fixed at 64 bits without the need for a REX prefix. In non-64-bit mode, the operand size is fixed at 32 bits and the upper 32 bits of the destination are forced to 0.

CR0 maintains the state of various control bits. CR2 and CR3 are used for page translation. CR4 holds various feature enable bits. CR8 is used to prioritize external interrupts. CR1, CR5, CR6, CR7, and CR9 through CR15 are all reserved and raise an undefined opcode exception (#UD) if referenced.

CR8 can be read and written in 64-bit mode, using a REX prefix. CR8 can be read and written in all modes using a LOCK prefix instead of a REX prefix to specify the additional opcode bit. To verify whether the LOCK prefix can be used in this way, check the status of ECX bit 4 returned by CPUID function 8000_0001h.

CR8 can also be read and modified using the task priority register described in "System-Control Registers" in Volume 2.

This instruction is always treated as a register-to-register (MOD = 11) instruction, regardless of the encoding of the MOD field in the MODR/M byte.

MOV(CRn) is a privileged instruction and must always be executed at CPL = 0.

MOV (CRn) is a serializing instruction.

Mnemonic	Opcode	Description
MOV CR*n*, *reg32*	0F 22 /r	Move the contents of a 32-bit register to CR*n*
MOV CR*n*, *reg64*	0F 22 /r	Move the contents of a 64-bit register to CR*n*
MOV *reg32*, CR*n*	0F 20 /r	Move the contents of CR*n* to a 32-bit register.
MOV *reg64*, CR*n*	0F 20 /r	Move the contents of CR*n* to a 64-bit register.
MOV CR8, *reg32*	F0 0F 22/r	Move the contents of a 32-bit register to CR8.
MOV CR8, *reg64*	F0 0F 22/r	Move the contents of a 64-bit register to CR8.
MOV reg32, CR8	F0 0F 20/r	Move the contents of CR8 into a 32-bit register.
MOV reg64, CR8	F0 0F 20/r	Move the contents of CR8 into a 64-bit register.

Related Instructions

CLTS, LMSW, SMSW

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid Instruction, #UD	X	X	X	An illegal control register was referenced (CR1, CR5–CR7, CR9–CR15).
	X	X	X	The use of the LOCK prefix to read CR8 is not supported, as indicated by ECX bit 4 as returned by CPUID function 8000_0001h.
General protection, #GP		X	X	CPL was not 0.
	X		X	An attempt was made to set CR0.PG = 1 and CR0.PE = 0.
	X		X	An attempt was made to set CR0.CD = 0 and CR0.NW = 1.
	X		X	Reserved bits were set in the page-directory pointers table (used in the legacy extended physical addressing mode) and the instruction modified CR0, CR3, or CR4.
	X		X	An attempt was made to write 1 to any reserved bit in CR0, CR3, CR4 or CR8.
	X		X	An attempt was made to set CR0.PG while long mode was enabled (EFER.LME = 1), but paging address extensions were disabled (CR4.PAE = 0).
			X	An attempt was made to clear CR4.PAE while long mode was active (EFER.LMA = 1).

MOV(DR*n*) Move to/from Debug Registers

Moves the contents of a debug register into a 32-bit or 64-bit general-purpose register or vice versa.

In 64-bit mode, the operand size is fixed at 64 bits without the need for a REX prefix. In non-64-bit mode, the operand size is fixed at 32-bits and the upper 32 bits of the destination are forced to 0.

DR0 through DR3 are linear breakpoint address registers. DR6 is the debug status register and DR7 is the debug control register. DR4 and DR5 are aliased to DR6 and DR7 if CR4.DE = 0, and are reserved if CR4.DE = 1.

DR8 through DR15 are reserved and generate an undefined opcode exception if referenced.

These instructions are privileged and must be executed at CPL 0.

The `MOV DRn,reg32` and `MOV DRn,reg64` instructions are serializing instructions.

The MOV(DR) instruction is always treated as a register-to-register (MOD = 11) instruction, regardless of the encoding of the MOD field in the MODR/M byte.

See "Debug and Performance Resources" in Volume 2 for details.

Mnemonic	Opcode	Description
MOV *reg32*, DR*n*	0F 21 /r	Move the contents of DR*n* to a 32-bit register.
MOV *reg64*, DR*n*	0F 21 /r	Move the contents of DR*n* to a 64-bit register.
MOV DR*n*, *reg32*	0F 23 */r*	Move the contents of a 32-bit register to DR*n*.
MOV DR*n*, *reg64*	0F 23 */r*	Move the contents of a 64-bit register to DR*n*.

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Debug, #DB	X		X	A debug register was referenced while the general detect (GD) bit in DR7 was set.
Invalid opcode, #UD	X		X	DR4 or DR5 was referenced while the debug extensions (DE) bit in CR4 was set.
			X	An illegal debug register (DR8–DR15) was referenced.
General protection, #GP		X	X	CPL was not 0.
			X	A 1 was written to any of the upper 32 bits of DR6 or DR7 in 64-bit mode.

MWAIT Monitor Wait

Used in conjunction with the MONITOR instruction to cause a processor to wait until a store occurs to a specific linear address range from another processor. The previously executed MONITOR instruction causes the processor to enter the monitor event pending state. The MWAIT instruction may enter an implementation dependent power state until the monitor event pending state is exited. The MWAIT instruction has the same effect on architectural state as the NOP instruction.

Events that cause an exit from the monitor event pending state include:

- A store from another processor matches the address range established by the MONITOR instruction.
- Any unmasked interrupt, including INTR, NMI, SMI, INIT.
- RESET.
- Any far control transfer that occurs between the MONITOR and the MWAIT.

EAX specifies optional hints for the MWAIT instruction. There are currently no hints defined and all bits should be 0. Setting a reserved bit in EAX is ignored by the processor.

ECX specifies optional extensions for the MWAIT instruction. The only extension currently defined is ECX bit 0, which allows interrupts to wake MWAIT, even when eFLAGS.IF=0. Support for this extension is indicated by CPUID. Setting any unsupported bit in ECX results in a #GP exception.

CPUID function 5 indicates support for extended features of MONITOR/MWAIT in ECX:

- ECX[0] indicates support for enumeration of MONITOR/MWAIT extensions.
- ECX[1] indicates that MWAIT can use ECX bit 0 to allow interrupts to cause an exit from the monitor event pending state even when eFLAGS.IF=0.

The MWAIT instruction can be executed at CPL 0 and is allowed at CPL > 0 only if MSR C001_0015h[MonMwaitUserEn] =1. When MSR C001_0015h[MonMwaitUserEn] is 0, MWAIT generates #UD at CPL > 0. (See the appropriate version of the BIOS and Kernel Developer's Guide for specific details on MSR C001_0015h.)

Support for the MWAIT instruction is indicated by ECX bit 3 (Monitor) as returned by CPUID function 0000_0001h. Software MUST check the CPUID bit once per program or library initialization before using the MWAIT instruction, or inconsistent behavior may result. Software designed to run at CPL greater than 0 must also check for availability by testing whether executing MWAIT causes a #UD exception.

The use of the MWAIT instruction is contingent upon the satisfaction of the following coding requirements:

- MONITOR must precede the MWAIT and occur in the same loop.
- MWAIT must be conditionally executed only if the awaited store has not already occurred. (This prevents a race condition between the MONITOR instruction arming the monitoring hardware and the store intended to trigger the monitoring hardware.)

The following pseudo-code shows typical usage of a MONITOR/MWAIT pair:

```
EAX = Linear_Address_to_Monitor;
ECX = 0;  // Extensions
EDX = 0;  // Hints

while (!matching_store_done ){
     MONITOR EAX, ECX, EDX
     IF ( !matching_store_done ) {
          MWAIT EAX, ECX
     }
}
```

Mnemonic	Opcode	Description
MWAIT	0F 01 C9	Causes the processor to stop instruction execution and enter an implementation-dependent optimized state until occurrence of a class of events.

Related Instructions

MONITOR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The MONITOR/MWAIT instructions are not supported, as indicated by ECX bit 3 (Monitor) as returned by CPUID function 0000_0001h.
		X	X	CPL was not zero and MSRC001_0015[MonMwaitUserEn] = 0.
General protection, #GP	X	X	X	Unsupported extension bits were set in ECX

RDMSR Read Model-Specific Register

Loads the contents of a 64-bit model-specific register (MSR) specified in the ECX register into registers EDX:EAX. The EDX register receives the high-order 32 bits and the EAX register receives the low order bits. The RDMSR instruction ignores operand size; ECX always holds the MSR number, and EDX:EAX holds the data. If a model-specific register has fewer than 64 bits, the unimplemented bit positions loaded into the destination registers are undefined.

This instruction must be executed at a privilege level of 0 or a general protection exception (#GP) will be raised. This exception is also generated if a reserved or unimplemented model-specific register is specified in ECX.

Use the CPUID instruction to determine if this instruction is supported.

For more information about model-specific registers, see the documentation for various hardware implementations and Volume 2: System Programming.

Mnemonic	Opcode	Description
RDMSR	0F 32	Copy MSR specified by ECX into EDX:EAX.

Related Instructions

WRMSR, RDTSC, RDPMC

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The RDMSR instruction is not supported, as indicated by EDX bit 5 returned by CPUID function 0000_0001h or function 8000_0001h.
General protection, #GP		X	X	CPL was not 0.
	X		X	The value in ECX specifies a reserved or unimplemented MSR address.

RDPMC Read Performance-Monitoring Counter

Loads the contents of a 64-bit performance counter register (PerfCtr*n)* specified in the ECX register into registers EDX:EAX. The EDX register receives the high-order 32 bits and the EAX register receives the low order 32 bits. The RDPMC instruction ignores operand size; ECX always holds the number of the PerfCtr, and EDX:EAX holds the data.

The AMD64 architecture currently supports four performance counters: PerfCtr0 through PerfCtr3. To specify the performance counter number in ECX, specify the counter number (0000_0000h–0000_0003h), rather than the performance counter MSR address (C001_0004h–C001_0007h).

Programs running at any privilege level can read performance monitor counters if the PCE flag in CR4 is set to 1; otherwise this instruction must be executed at a privilege level of 0.

This instruction is not serializing. Therefore, there is no guarantee that all instructions have completed at the time the performance counter is read.

For more information about performance-counter registers, see the documentation for various hardware implementations and "Performance Counters" in Volume 2.

Mnemonic	Opcode	Description
RDPMC	0F 33	Copy the performance monitor counter specified by ECX into EDX:EAX.

Related Instructions

RDMSR, WRMSR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General Protection, #GP	X	X	X	The value in ECX specified an unimplemented performance counter number.
		X	X	CPL was not 0 and CR4.PCE = 0.

RDTSC Read Time-Stamp Counter

Loads the value of the processor's 64-bit time-stamp counter into registers EDX:EAX.

The time-stamp counter (TSC) is contained in a 64-bit model-specific register (MSR). The processor sets the counter to 0 upon reset and increments the counter every clock cycle. INIT does not modify the TSC.

The high-order 32 bits are loaded into EDX, and the low-order 32 bits are loaded into the EAX register. This instruction ignores operand size.

When the time-stamp disable flag (TSD) in CR4 is set to 1, the RDTSC instruction can only be used at privilege level 0. If the TSD flag is 0, this instruction can be used at any privilege level.

This instruction is not serializing. Therefore, there is no guarantee that all instructions have completed at the time the time-stamp counter is read.

The behavior of the RDTSC instruction is implementation dependent. The TSC counts at a constant rate, but may be affected by power management events (such as frequency changes), depending on the processor implementation. If CPUID 8000_0007.edx[8] = 1, then the TSC rate is ensured to be invariant across all P-States, C-States, and stop-grant transitions (such as STPCLK Throttling); therefore, the TSC is suitable for use as a source of time. Consult the BIOS and kernel developer's guide for your AMD processor implementation for information concerning the effect of power management on the TSC.

Mnemonic	Opcode	Description
RDTSC	0F 31	Copy the time-stamp counter into EDX:EAX.

Related Instructions

RDTSCP, RDMSR, WRMSR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The RDTSC instruction is not supported, as indicated by EDX bit 4 returned by CPUID function 0000_0001h or function 8000_0001h.
General protection, #GP		X	X	CPL was not 0 and CR4.TSD = 1.

RDTSCP Read Time-Stamp Counter and Processor ID

Loads the value of the processor's 64-bit time-stamp counter into registers EDX:EAX, and loads the value of TSC_AUX into ECX. This instruction ignores operand size.

The time-stamp counter is contained in a 64-bit model-specific register (MSR). The processor sets the counter to 0 upon reset and increments the counter every clock cycle. INIT does not modify the TSC.

The high-order 32 bits are loaded into EDX, and the low-order 32 bits are loaded into the EAX register.

The TSC_AUX value is contained in the low-order 32 bits of the TSC_AUX register (MSR address C000_0103h). This MSR is initialized by privileged software to any meaningful value, such as a processor ID, that software wants to associate with the returned TSC value.

When the time-stamp disable flag (TSD) in CR4 is set to 1, the RDTSCP instruction can only be used at privilege level 0. If the TSD flag is 0, this instruction can be used at any privilege level.

Unlike the RDTSC instruction, RDTSCP forces all older instructions to retire before reading the time-stamp counter.

The behavior of the RDTSCP instruction is implementation dependent. The TSC counts at a constant rate, but may be affected by power management events (such as frequency changes), depending on the processor implementation. If CPUID 8000_0007.edx[8] = 1, then the TSC rate is ensured to be invariant across all P-States, C-States, and stop-grant transitions (such as STPCLK Throttling); therefore, the TSC is suitable for use as a source of time. Consult the BIOS and kernel developer's guide for your AMD processor implementation for information concerning the effect of power management on the TSC.

Use the CPUID instruction to verify support for this instruction.

Mnemonic	Opcode	Description
RDTSCP	0F 01 F9	Copy the time-stamp counter into EDX:EAX and the TSC_AUX register into ECX.

Related Instructions

RDTSC

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The RDTSCP instruction is not supported, as indicated by EDX bit 27 returned by CPUID function 8000_0001h.
General protection, #GP		X	X	CPL was not 0 and CR4.TSD = 1.

RSM Resume from System Management Mode

Resumes an operating system or application procedure previously interrupted by a system management interrupt (SMI). The processor state is restored from the information saved when the SMI was taken. If the processor detects invalid state information in the system management mode (SMM) save area during RSM, it goes into a shutdown state.

RSM will shutdown if any of the following conditions are found in the save map (SSM):

- An illegal combination of flags in CR0 (CR0.PG = 1 and CR0.PE = 0, or CR0.NW = 1 and CR0.CD = 0).
- A reserved bit in CR0, CR3, CR4, DR6, DR7, or the extended feature enable register (EFER) is set to 1.
- The following bit combination occurs: EFER.LME = 1, CR0.PG = 1, CR4.PAE = 0.
- The following bit combination occurs: EFER.LME = 1, CR0.PG = 1, CR4.PAE = 1, CS.D = 1, CS.L = 1.
- SMM revision field has been modified.

RSM cannot modify EFER.SVME. Attempts to do so are ignored.

When EFER.SVME is 1, RSM reloads the four PDPEs (through the incoming CR3) when returning to a mode that has legacy PAE mode paging enabled.

When EFER.SVME is 1, the RSM instruction is permitted to return to paged real mode (i.e., CR0.PE=0 and CR0.PG=1).

The AMD64 architecture uses a new 64-bit SMM state-save memory image. This 64-bit save-state map is used in all modes, regardless of mode. See “System-Management Mode” in Volume 2 for details.

Mnemonic	Opcode	Description
RSM	0F AA	Resume operation of an interrupted program.

Related Instructions

None

rFLAGS Affected

All flags are restored from the state-save map (SSM).

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The processor was not in System Management Mode (SMM).

SGDT Store Global Descriptor Table Register

Stores the global descriptor table register (GDTR) into the destination operand. In legacy and compatibility mode, the destination operand is 6 bytes; in 64-bit mode, it is 10 bytes. In all modes, operand-size prefixes are ignored.

In non-64-bit mode, the lower two bytes of the operand specify the 16-bit limit and the upper 4 bytes specify the 32-bit base address.

In 64-bit mode, the lower two bytes of the operand specify the 16-bit limit and the upper 8 bytes specify the 64-bit base address.

This instruction is intended for use in operating system software, but it can be used at any privilege level.

Mnemonic	Opcode	Description
SGDT *mem16:32*	0F 01 /0	Store global descriptor table register to memory.
SGDT *mem16:64*	0F 01 /0	Store global descriptor table register to memory.

Related Instructions

SIDT, SLDT, STR, LGDT, LIDT, LLDT, LTR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The operand was a register.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SIDT Store Interrupt Descriptor Table Register

Stores the interrupt descriptor table register (IDTR) in the destination operand. In legacy and compatibility mode, the destination operand is 6 bytes; in 64-bit mode it is 10 bytes. In all modes, operand-size prefixes are ignored.

In non-64-bit mode, the lower two bytes of the operand specify the 16-bit limit and the upper 4 bytes specify the 32-bit base address.

In 64-bit mode, the lower two bytes of the operand specify the 16-bit limit and the upper 8 bytes specify the 64-bit base address.

This instruction is intended for use in operating system software, but it can be used at any privilege level.

Mnemonic	Opcode	Description
SIDT *mem16:32*	0F 01 /1	Store interrupt descriptor table register to memory.
SIDT *mem16:64*	0F 01 /1	Store interrupt descriptor table register to memory.

Related Instructions

SGDT, SLDT, STR, LGDT, LIDT, LLDT, LTR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The operand was a register.
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

SKINIT Secure Init and Jump with Attestation

Securely reinitializes the cpu, allowing for the startup of trusted software (such as a VMM). The code to be executed after reinitialization can be verified based on a secure hash comparison. SKINIT takes the physical base address of the SLB as its only input operand, in EAX. The SLB must be structured as described in “Secure Loader Block” on page 415 of the *AMD64 Architecture Programmer’s Manual Volume 2: System Programming*, order# 24593, and is assumed to contain the code for a Secure Loader (SL).

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume 2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
SKINIT EAX	0F 01 DE	Secure initialization and jump, with attestation.

Action

```
IF ((EFER.SVMEN == 0) && !(CPUID 8000_0001.ECX[SKINIT]) || (!PROTECTED_MODE))

     EXCEPTION [#UD]        // This instruction can only be executed
                            //  in protected mode with SVM enabled.

IF (CPL != 0)               // This instruction is only allowed at CPL 0.
    EXCEPTION [#GP]

Initialize processor state as for an INIT signal
CR0.PE = 1

CS.sel = 0x0008
CS.attr = 32-bit code, read/execute
CS.base = 0
CS.limit = 0xFFFFFFFF

SS.sel = 0x0010
SS.attr = 32-bit stack, read/write, expand up
SS.base = 0
SS.limit = 0xFFFFFFFF

EAX = EAX & 0xFFFF0000 // Form SLB base address.
EDX = family/model/stepping
ESP = EAX + 0x00010000  // Initial SL stack.
Clear GPRs other than EAX, EDX, ESP

EFER = 0
VM_CR.DPD = 1
VM_CR.R_INIT = 1
VM_CR.DIS_A20M = 1
```

```
Enable SL_DEV, to protect 64Kbyte of physical memory starting at
the physical address in EAX

GIF = 0

Read the SL length from offset 0x0002 in the SLB
Copy the SL image to the TPM for attestation

Read the SL entrypoint offset from offset 0x0000 in the SLB
Jump to the SL entrypoint, at EIP = EAX+entrypoint offset
```

Related Instructions

None.

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to 1 or cleared to 0 is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	Secure Virtual Machine was not enabled (EFER.SVME=0) and both of the following conditions were true: • SVM-Lock is not available, as indicated by EDX bit 2 returned by CPUID function 8000_000Ah. • DEV is not available, as indicated by ECX bit 12 returned by CPUID function 8000_0001h.
	X	X		Instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.

SLDT Store Local Descriptor Table Register

Stores the local descriptor table (LDT) selector to a register or memory destination operand.

If the destination is a register, the selector is zero-extended into a 16-, 32-, or 64-bit general purpose register, depending on operand size.

If the destination operand is a memory location, the segment selector is written to memory as a 16-bit value, regardless of operand size.

This SLDT instruction can only be used in protected mode, but it can be executed at any privilege level.

Mnemonic	Opcode	Description
SLDT *reg16*	0F 00 /0	Store the segment selector from the local descriptor table register to a 16-bit register.
SLDT *reg32*	0F 00 /0	Store the segment selector from the local descriptor table register to a 32-bit register.
SLDT *reg64*	0F 00 /0	Store the segment selector from the local descriptor table register to a 64-bit register.
SLDT *mem16*	0F 00 /0	Store the segment selector from the local descriptor table register to a 16-bit memory location.

Related Instructions

SIDT, SGDT, STR, LIDT, LGDT, LLDT, LTR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

SMSW Store Machine Status Word

Stores the lower bits of the machine status word (CR0). The target can be a 16-, 32-, or 64-bit register or a 16-bit memory operand.

This instruction is provided for compatibility with early processors.

This instruction can be used at any privilege level (CPL).

Mnemonic	Opcode	Description
SMSW *reg16*	0F 01 /4	Store the low 16 bits of CR0 to a 16-bit register.
SMSW *reg32*	0F 01 /4	Store the low 32 bits of CR0 to a 32-bit register.
SMSW *reg64*	0F 01 /4	Store the entire 64-bit CR0 to a 64-bit register.
SMSW *mem16*	0F 01 /4	Store the low 16 bits of CR0 to memory.

Related Instructions

LMSW, MOV(CR*n*)

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Stack, #SS	X	X	X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP	X	X	X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF		X	X	A page fault resulted from the execution of the instruction.
Alignment check, #AC		X	X	An unaligned memory reference was performed while alignment checking was enabled.

STI Set Interrupt Flag

Sets the interrupt flag (IF) in the rFLAGS register to 1, thereby allowing external interrupts received on the INTR input. Interrupts received on the non-maskable interrupt (NMI) input are not affected by this instruction.

In real mode, this instruction sets IF to 1.

In protected mode and virtual-8086-mode, this instruction is IOPL-sensitive. If the CPL is less than or equal to the rFLAGS.IOPL field, the instruction sets IF to 1.

In protected mode, if IOPL < 3, CPL = 3, and protected mode virtual interrupts are enabled (CR4.PVI = 1), then the instruction instead sets rFLAGS.VIF to 1. If none of these conditions apply, the processor raises a general protection exception (#GP). For more information, see “Protected Mode Virtual Interrupts” in Volume 2.

In virtual-8086 mode, if IOPL < 3 and the virtual-8086-mode extensions are enabled (CR4.VME = 1), the STI instruction instead sets the virtual interrupt flag (rFLAGS.VIF) to 1.

If STI sets the IF flag and IF was initially clear, then interrupts are not enabled until after the instruction following STI. Thus, if IF is 0, this code will not allow an INTR to happen:

```
STI
CLI
```

In the following sequence, INTR will be allowed to happen only after the NOP.

```
STI
NOP
CLI
```

If STI sets the VIF flag and VIP is already set, a #GP fault will be generated.

See “Virtual-8086 Mode Extensions” in Volume 2 for more information about IOPL-sensitive instructions.

Mnemonic	Opcode	Description
STI	FB	Set interrupt flag (IF) to 1.

Action

```
IF (CPL <= IOPL)
      RFLAGS.IF = 1

ELSIF (((VIRTUAL_MODE) && (CR4.VME = 1))
        || ((PROTECTED_MODE) && (CR4.PVI = 1) && (CPL = 3)))
       {
         IF (RFLAGS.VIP = 1)
             EXCEPTION[#GP(0)]
         RFLAGS.VIF = 1
       }
ELSE
       EXCEPTION[#GP(0)]
```

Related Instructions

CLI

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
		M								M						
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. M (modified) is either set to one or cleared to zero. Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X		The CPL was greater than the IOPL and virtual-mode extensions were not enabled (CR4.VME = 0).
			X	The CPL was greater than the IOPL and either the CPL was not 3 or protected-mode virtual interrupts were not enabled (CR4.PVI = 0).
		X	X	This instruction would set RFLAGS.VIF to 1 and RFLAGS.VIP was already 1.

STGI Set Global Interrupt Flag

Sets the global interrupt flag (GIF) to 1. While GIF is zero, all external interrupts are disabled.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled and ECX.SKINIT as returned by CPUID function 8000_0001 is cleared to 0. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume-2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
STGI	0F 01 DC	Sets the global interrupt flag (GIF).

Related Instructions

CLGI

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD			X	Secure Virtual Machine was not enabled (EFER.SVME=0) and both of the following conditions were true: • SVM-Lock is not available, as indicated by EDX bit 2 returned by CPUID function 8000_000Ah. • DEV is not available, as indicated by ECX bit 12 returned by CPUID function 8000_0001h.
	X	X		Instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.

STR Store Task Register

Stores the task register (TR) selector to a register or memory destination operand.

If the destination is a register, the selector is zero-extended into a 16-, 32-, or 64-bit general purpose register, depending on the operand size.

If the destination is a memory location, the segment selector is written to memory as a 16-bit value, regardless of operand size.

The STR instruction can only be used in protected mode, but it can be used at any privilege level.

Mnemonic	Opcode	Description
STR *reg16*	0F 00 /1	Store the segment selector from the task register to a 16-bit general-purpose register.
STR *reg32*	0F 00 /1	Store the segment selector from the task register to a 32-bit general-purpose register.
STR *reg64*	0F 00 /1	Store the segment selector from the task register to a 64-bit general-purpose register.
STR *mem16*	0F 00 /1	Store the segment selector from the task register to a 16-bit memory location.

Related Instructions

LGDT, LIDT, LLDT, LTR, SIDT, SGDT, SLDT

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	The destination operand was in a non-writable segment.
			X	A null data segment was used to reference memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

SWAPGS Swap GS Register with KernelGSbase MSR

Provides a fast method for system software to load a pointer to system data structures. SWAPGS can be used upon entering system-software routines as a result of a SYSCALL instruction, an interrupt or an exception. Prior to returning to application software, SWAPGS can be used to restore the application data pointer that was replaced by the system data-structure pointer.

This instruction can only be executed in 64-bit mode. Executing SWAPGS in any other mode generates an undefined opcode exception.

The SWAPGS instruction only exchanges the base-address value located in the KernelGSbase model-specific register (MSR address C000_0102h) with the base-address value located in the hidden-portion of the GS selector register (GS.base). This allows the system-kernel software to access kernel data structures by using the GS segment-override prefix during memory references.

The address stored in the KernelGSbase MSR must be in canonical form. The WRMSR instruction used to load the KernelGSbase MSR causes a general-protection exception if the address loaded is not in canonical form. The SWAPGS instruction itself does not perform a canonical check.

This instruction is only valid in 64-bit mode at CPL 0. A general protection exception (#GP) is generated if this instruction is executed at any other privilege level.

For additional information about this instruction, refer to “System-Management Instructions” in Volume 2.

Examples

At a kernel entry point, the OS uses SwapGS to obtain a pointer to kernel data structures and simultaneously save the user's GS base. Upon exit, it uses SwapGS to restore the user's GS base:

```
SystemCallEntryPoint:
SwapGS                          ; get kernel pointer, save user GSbase
mov gs:[SavedUserRSP], rsp     ; save user's stack pointer
mov rsp, gs:[KernelStackPtr]   ; set up kernel stack
push rax                       ; now save user GPRs on kernel stack
              .                ; perform system service
              .
SwapGS                          ; restore user GS, save kernel pointer
```

Mnemonic	Opcode	Description
SWAPGS	0F 01 F8	Exchange GS base with KernelGSBase MSR. (Invalid in legacy and compatibility modes.)

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	This instruction was executed in legacy or compatibility mode.
General protection, #GP			X	CPL was not 0.

SYSCALL Fast System Call

Transfers control to a fixed entry point in an operating system. It is designed for use by system and application software implementing a flat-segment memory model.

The SYSCALL and SYSRET instructions are low-latency system call and return control-transfer instructions, which assume that the operating system implements a flat-segment memory model. By eliminating unneeded checks, and by loading pre-determined values into the CS and SS segment registers (both visible and hidden portions), calls to and returns from the operating system are greatly simplified. These instructions can be used in protected mode and are particularly well-suited for use in 64-bit mode, which requires implementation of a paged, flat-segment memory model.

This instruction has been optimized by reducing the number of checks and memory references that are normally made so that a call or return takes considerably fewer clock cycles than the CALL FAR /RET FAR instruction method.

It is assumed that the base, limit, and attributes of the Code Segment will remain flat for all processes and for the operating system, and that only the current privilege level for the selector of the calling process should be changed from a current privilege level of 3 to a new privilege level of 0. It is also assumed (but not checked) that the RPL of the SYSCALL and SYSRET target selectors are set to 0 and 3, respectively.

SYSCALL sets the CPL to 0, regardless of the values of bits 33–32 of the STAR register. There are no permission checks based on the CPL, real mode, or virtual-8086 mode. SYSCALL and SYSRET must be enabled by setting EFER.SCE to 1.

It is the responsibility of the operating system to keep the descriptors in memory that correspond to the CS and SS selectors loaded by the SYSCALL and SYSRET instructions consistent with the segment base, limit, and attribute values forced by these instructions.

Legacy x86 Mode. In legacy x86 mode, when SYSCALL is executed, the EIP of the instruction following the SYSCALL is copied into the ECX register. Bits 31–0 of the SYSCALL/SYSRET target address register (STAR) are copied into the EIP register. (The STAR register is model-specific register C000_0081h.)

New selectors are loaded, without permission checking (see above), as follows:

- Bits 47–32 of the STAR register specify the selector that is copied into the CS register.
- Bits 47–32 of the STAR register + 8 specify the selector that is copied into the SS register.
- The CS_base and the SS_base are both forced to zero.
- The CS_limit and the SS_limit are both forced to 4 Gbyte.
- The CS segment attributes are set to execute/read 32-bit code with a CPL of zero.
- The SS segment attributes are set to read/write and expand-up with a 32-bit stack referenced by ESP.

Long Mode. When long mode is activated, the behavior of the SYSCALL instruction depends on whether the calling software is in 64-bit mode or compatibility mode. In 64-bit mode, SYSCALL saves the RIP of the instruction following the SYSCALL into RCX and loads the new RIP from LSTAR bits 63–0. (The LSTAR register is model-specific register C000_0082h.) In compatibility mode, SYSCALL saves the RIP of the instruction following the SYSCALL into RCX and loads the new RIP from CSTAR bits 63–0. (The CSTAR register is model-specific register C000_0083h.)

New selectors are loaded, without permission checking (see above), as follows:

- Bits 47–32 of the STAR register specify the selector that is copied into the CS register.
- Bits 47–32 of the STAR register + 8 specify the selector that is copied into the SS register.
- The CS_base and the SS_base are both forced to zero.
- The CS_limit and the SS_limit are both forced to 4 Gbyte.
- The CS segment attributes are set to execute/read 64-bit code with a CPL of zero.
- The SS segment attributes are set to read/write and expand-up with a 64-bit stack referenced by RSP.

The WRMSR instruction loads the target RIP into the LSTAR and CSTAR registers. If an RIP written by WRMSR is not in canonical form, a general-protection exception (#GP) occurs.

How SYSCALL and SYSRET handle rFLAGS, depends on the processor's operating mode.

In legacy mode, SYSCALL treats EFLAGS as follows:

- EFLAGS.IF is cleared to 0.
- EFLAGS.RF is cleared to 0.
- EFLAGS.VM is cleared to 0.

In long mode, SYSCALL treats RFLAGS as follows:

- The current value of RFLAGS is saved in R11.
- RFLAGS is masked using the value stored in SYSCALL_FLAG_MASK.
- RFLAGS.RF is cleared to 0.

For further details on the SYSCALL and SYSRET instructions and their associated MSR registers (STAR, LSTAR, CSTAR, and SYSCALL_FLAG_MASK), see "Fast System Call and Return" in Volume 2.

Mnemonic	Opcode	Description
SYSCALL	0F 05	Call operating system.

Action

```
// See "Pseudocode Definitions" on page 41.

SYSCALL_START:

    IF (MSR_EFER.SCE = 0)          // Check if syscall/sysret are enabled.
        EXCEPTION [#UD]

    IF (LONG_MODE)
        SYSCALL_LONG_MODE
    ELSE // (LEGACY_MODE)
        SYSCALL_LEGACY_MODE


SYSCALL_LONG_MODE:

    RCX.q = next_RIP
    R11.q = RFLAGS    // with rf cleared

    IF (64BIT_MODE)
        temp_RIP.q = MSR_LSTAR
    ELSE // (COMPATIBILITY_MODE)
        temp_RIP.q = MSR_CSTAR

    CS.sel   = MSR_STAR.SYSCALL_CS AND 0xFFFC
    CS.attr  = 64-bit code,dpl0  // Always switch to 64-bit mode in long mode.
    CS.base  = 0x00000000
    CS.limit = 0xFFFFFFFF

    SS.sel   = MSR_STAR.SYSCALL_CS + 8
    SS.attr  = 64-bit stack,dpl0
    SS.base  = 0x00000000
    SS.limit = 0xFFFFFFFF

    RFLAGS = RFLAGS AND ~MSR_SFMASK
    RFLAGS.RF = 0

    CPL = 0

    RIP = temp_RIP
    EXIT


SYSCALL_LEGACY_MODE:

    RCX.d = next_RIP

    temp_RIP.d = MSR_STAR.EIP

    CS.sel   = MSR_STAR.SYSCALL_CS AND 0xFFFC
    CS.attr  = 32-bit code,dpl0  // Always switch to 32-bit mode in legacy mode.
```

```
CS.base  = 0x00000000
CS.limit = 0xFFFFFFFF

SS.sel   = MSR_STAR.SYSCALL_CS + 8
SS.attr  = 32-bit stack,dpl0
SS.base  = 0x00000000
SS.limit = 0xFFFFFFFF

RFLAGS.VM,IF,RF=0

CPL = 0

RIP = temp_RIP
EXIT
```

Related Instructions

SYSRET, SYSENTER, SYSEXIT

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
M	M	M	M	0	0	M	M	M	M	M	M	M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SYSCALL and SYSRET instructions are not supported, as indicated by EDX bit 11 returned by CPUID function 8000_0001h.
	X	X	X	The system call extension bit (SCE) of the extended feature enable register (EFER) is set to 0. (The EFER register is MSR C000_0080h.)

SYSENTER System Call

Transfers control to a fixed entry point in an operating system. It is designed for use by system and application software implementing a flat-segment memory model. This instruction is valid only in legacy mode.

Three model-specific registers (MSRs) are used to specify the target address and stack pointers for the SYSENTER instruction, as well as the CS and SS selectors of the called and returned procedures:

- MSR_SYSENTER_CS: Contains the CS selector of the called procedure. The SS selector is set to MSR_SYSENTER_CS + 8.
- MSR_SYSENTER_ESP: Contains the called procedure's stack pointer.
- MSR_SYSENTER_EIP: Contains the offset into the CS of the called procedure.

The hidden portions of the CS and SS segment registers are not loaded from the descriptor table as they would be using a legacy x86 CALL instruction. Instead, the hidden portions are forced by the processor to the following values:

- The CS and SS base values are forced to 0.
- The CS and SS limit values are forced to 4 Gbytes.
- The CS segment attributes are set to execute/read 32-bit code with a CPL of zero.
- The SS segment attributes are set to read/write and expand-up with a 32-bit stack referenced by ESP.

System software must create corresponding descriptor-table entries referenced by the new CS and SS selectors that match the values described above.

The return EIP and application stack are not saved by this instruction. System software must explicitly save that information.

An invalid-opcode exception occurs if this instruction is used in long mode. Software should use the SYSCALL (and SYSRET) instructions in long mode. If SYSENTER is used in real mode, a #GP is raised.

For additional information on this instruction, see "SYSENTER and SYSEXIT (Legacy Mode Only)" in Volume 2.

Mnemonic	Opcode	Description
SYSENTER	0F 34	Call operating system.

Related Instructions

SYSCALL, SYSEXIT, SYSRET

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
				0						0						
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SYSENTER and SYSEXIT instructions are not supported, as indicated by EDX bit 11 returned by CPUID function 0000_0001h.
			X	This instruction is not recognized in long mode.
General protection, #GP	X			This instruction is not recognized in real mode.
		X	X	MSR_SYSENTER_CS was a null selector.

SYSEXIT System Return

Returns from the operating system to an application. It is a low-latency system return instruction designed for use by system and application software implementing a flat-segment memory model.

This is a privileged instruction. The current privilege level must be zero to execute this instruction. An invalid-opcode exception occurs if this instruction is used in long mode. Software should use the SYSRET (and SYSCALL) instructions when running in long mode.

When a system procedure performs a SYSEXIT back to application software, the CS selector is updated to point to the second descriptor entry after the SYSENTER CS value (MSR SYSENTER_CS+16). The SS selector is updated to point to the third descriptor entry after the SYSENTER CS value (MSR SYSENTER_CS+24). The CPL is forced to 3, as are the descriptor privilege levels.

The hidden portions of the CS and SS segment registers are not loaded from the descriptor table as they would be using a legacy x86 RET instruction. Instead, the hidden portions are forced by the processor to the following values:

- The CS and SS base values are forced to 0.
- The CS and SS limit values are forced to 4 Gbytes.
- The CS segment attributes are set to 32-bit read/execute at CPL 3.
- The SS segment attributes are set to read/write and expand-up with a 32-bit stack referenced by ESP.

System software must create corresponding descriptor-table entries referenced by the new CS and SS selectors that match the values described above.

The following additional actions result from executing SYSEXIT:

- EIP is loaded from EDX.
- ESP is loaded from ECX.

System software must explicitly load the return address and application software-stack pointer into the EDX and ECX registers prior to executing SYSEXIT.

For additional information on this instruction, see “SYSENTER and SYSEXIT (Legacy Mode Only)” in Volume 2.

Mnemonic	Opcode	Description
SYSEXIT	0F 35	Return from operating system to application.

Related Instructions

SYSCALL, SYSENTER, SYSRET

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
					0											
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SYSENTER and SYSEXIT instructions are not supported, as indicated by EDX bit 11 returned by CPUID function 0000_0001h.
			X	This instruction is not recognized in long mode.
General protection, #GP	X	X		This instruction is only recognized in protected mode.
			X	CPL was not 0.
			X	MSR_SYSENTER_CS was a null selector.

SYSRET Fast System Return

Returns from the operating system to an application. It is a low-latency system return instruction designed for use by system and application software implementing a flat segmentation memory model.

The SYSCALL and SYSRET instructions are low-latency system call and return control-transfer instructions that assume that the operating system implements a flat-segment memory model. By eliminating unneeded checks, and by loading pre-determined values into the CS and SS segment registers (both visible and hidden portions), calls to and returns from the operating system are greatly simplified. These instructions can be used in protected mode and are particularly well-suited for use in 64-bit mode, which requires implementation of a paged, flat-segment memory model.

This instruction has been optimized by reducing the number of checks and memory references that are normally made so that a call or return takes substantially fewer internal clock cycles when compared to the CALL/RET instruction method.

It is assumed that the base, limit, and attributes of the Code Segment will remain flat for all processes and for the operating system, and that only the current privilege level for the selector of the calling process should be changed from a current privilege level of 0 to a new privilege level of 3. It is also assumed (but not checked) that the RPL of the SYSCALL and SYSRET target selectors are set to 0 and 3, respectively.

SYSRET sets the CPL to 3, regardless of the values of bits 49–48 of the star register. SYSRET can only be executed in protected mode at CPL 0. SYSCALL and SYSRET must be enabled by setting EFER.SCE to 1.

It is the responsibility of the operating system to keep the descriptors in memory that correspond to the CS and SS selectors loaded by the SYSCALL and SYSRET instructions consistent with the segment base, limit, and attribute values forced by these instructions.

When a system procedure performs a SYSRET back to application software, the CS selector is updated from bits 63–50 of the STAR register (STAR.SYSRET_CS) as follows:

- If the return is to 32-bit mode (legacy or compatibility), CS is updated with the value of STAR.SYSRET_CS.
- If the return is to 64-bit mode, CS is updated with the value of STAR.SYSRET_CS + 16.

In both cases, the CPL is forced to 3, effectively ignoring STAR bits 49–48. The SS selector is updated to point to the next descriptor-table entry after the CS descriptor (STAR.SYSRET_CS + 8), and its RPL is not forced to 3.

The hidden portions of the CS and SS segment registers are not loaded from the descriptor table as they would be using a legacy x86 RET instruction. Instead, the hidden portions are forced by the processor to the following values:

- The CS base value is forced to 0.
- The CS limit value is forced to 4 Gbytes.

- The CS segment attributes are set to execute-read 32 bits or 64 bits (see below).
- The SS segment base, limit, and attributes are not modified.

When SYSCALLed system software is running in 64-bit mode, it has been entered from either 64-bit mode or compatibility mode. The corresponding SYSRET needs to know the mode to which it must return. Executing SYSRET in non-64-bit mode or with a 16- or 32-bit operand size returns to 32-bit mode with a 32-bit stack pointer. Executing SYSRET in 64-bit mode with a 64-bit operand size returns to 64-bit mode with a 64-bit stack pointer.

The instruction pointer is updated with the return address based on the operating mode in which SYSRET is executed:

- If returning to 64-bit mode, SYSRET loads RIP with the value of RCX.
- If returning to 32-bit mode, SYSRET loads EIP with the value of ECX.

How SYSRET handles RFLAGS depends on the processor's operating mode:

- If executed in 64-bit mode, SYSRET loads the lower-32 RFLAGS bits from R11[31:0] and clears the upper 32 RFLAGS bits.
- If executed in legacy mode or compatibility mode, SYSRET sets EFLAGS.IF.

For further details on the SYSCALL and SYSRET instructions and their associated MSR registers (STAR, LSTAR, and CSTAR), see "Fast System Call and Return" in Volume 2.

Mnemonic	Opcode	Description
SYSRET	0F 07	Return from operating system.

Action

```
// See "Pseudocode Definitions" on page 41.

SYSRET_START:

    IF (MSR_EFER.SCE = 0)          // Check if syscall/sysret are enabled.
        EXCEPTION [#UD]


    IF ((!PROTECTED_MODE) || (CPL != 0))
        EXCEPTION [#GP(0)]              // SYSRET requires protected mode, cpl0

   IF (64BIT_MODE)
        SYSRET_64BIT_MODE
    ELSE // (!64BIT_MODE)
        SYSRET_NON_64BIT_MODE

SYSRET_64BIT_MODE:

    IF (OPERAND_SIZE = 64)              // Return to 64-bit mode.
    {
```

```
        CS.sel   = (MSR_STAR.SYSRET_CS + 16) OR 3
        CS.base  = 0x00000000
        CS.limit = 0xFFFFFFFF
        CS.attr  = 64-bit code,dpl3

        temp_RIP.q = RCX
    }
    ELSE                              // Return to 32-bit compatibility mode.
    {
        CS.sel   = MSR_STAR.SYSRET_CS OR 3
        CS.base  = 0x00000000
        CS.limit = 0xFFFFFFFF
        CS.attr  = 32-bit code,dpl3

        temp_RIP.d = RCX
    }

    SS.sel = MSR_STAR.SYSRET_CS + 8     // SS selector is changed,
                                      // SS base, limit, attributes unchanged.

    RFLAGS.q = R11       // RF=0,VM=0
    CPL = 3

    RIP = temp_RIP
    EXIT

SYSRET_NON_64BIT_MODE:

     CS.sel   = MSR_STAR.SYSRET_CS OR 3 // Return to 32-bit legacy protected mode.
     CS.base  = 0x00000000
     CS.limit = 0xFFFFFFFF
     CS.attr  = 32-bit code,dpl3

     temp_RIP.d = RCX

     SS.sel = MSR_STAR.SYSRET_CS + 8    // SS selector is changed.
                                      // SS base, limit, attributes unchanged.
     RFLAGS.IF = 1
     CPL = 3

     RIP = temp_RIP
     EXIT
```

Related Instructions

SYSCALL, SYSENTER, SYSEXIT

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
M	M	M	M		0	M	M	M	M	M	M	M	M	M	M	M
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SYSCALL and SYSRET instructions are not supported, as indicated by EDX bit 11 returned by CPUID function 8000_0001h.
	X	X	X	The system call extension bit (SCE) of the extended feature enable register (EFER) is set to 0. (The EFER register is MSR C000_0080h.)
General protection, #GP	X	X		This instruction is only recognized in protected mode.
			X	CPL was not 0.

UD2 Undefined Operation

Generates an invalid opcode exception. Unlike other undefined opcodes that may be defined as legal instructions in the future, UD2 is guaranteed to stay undefined.

Mnemonic	Opcode	Description
UD2	0F 0B	Raise an invalid opcode exception.

Related Instructions

None

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	This instruction is not recognized.

VERR Verify Segment for Reads

Verifies whether a code or data segment specified by the segment selector in the 16-bit register or memory operand is readable from the current privilege level. The zero flag (ZF) is set to 1 if the specified segment is readable. Otherwise, ZF is cleared.

A segment is readable if all of the following apply:

- the selector is not a null selector.
- the descriptor is within the GDT or LDT limit.
- the segment is a data segment or readable code segment.
- the descriptor DPL is greater than or equal to both the CPL and RPL, or the segment is a conforming code segment.

The processor does not recognize the VERR instruction in real or virtual-8086 mode.

Mnemonic	Opcode	Description
VERR *reg/mem16*	0F 00 /4	Set the zero flag (ZF) to 1 if the segment selected can be read.

Related Instructions

ARPL, LAR, LSL, VERW

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or is non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to reference memory.

Exception	Real	Virtual 8086	Protected	Cause of Exception
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

VERW Verify Segment for Write

Verifies whether a data segment specified by the segment selector in the 16-bit register or memory operand is writable from the current privilege level. The zero flag (ZF) is set to 1 if the specified segment is writable. Otherwise, ZF is cleared.

A segment is writable if all of the following apply:

- the selector is not a null selector.
- the descriptor is within the GDT or LDT limit.
- the segment is a writable data segment.
- the descriptor DPL is greater than or equal to both the CPL and RPL.

The processor does not recognize the VERW instruction in real or virtual-8086 mode.

Mnemonic	Opcode	Description
VERW *reg/mem16*	0F 00 /5	Set the zero flag (ZF) to 1 if the segment selected can be written.

Related Instructions

ARPL, LAR, LSL, VERR

rFLAGS Affected

ID	VIP	VIF	AC	VM	RF	NT	IOPL	OF	DF	IF	TF	SF	ZF	AF	PF	CF
													M			
21	20	19	18	17	16	14	13–12	11	10	9	8	7	6	4	2	0

Note: *Bits 31–22, 15, 5, 3, and 1 are reserved. A flag set to one or cleared to zero is M (modified). Unaffected flags are blank. Undefined flags are U.*

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X		This instruction is only recognized in protected mode.
Stack, #SS			X	A memory address exceeded the stack segment limit or was non-canonical.
General protection, #GP			X	A memory address exceeded a data segment limit or was non-canonical.
			X	A null data segment was used to access memory.
Page fault, #PF			X	A page fault resulted from the execution of the instruction.
Alignment check, #AC			X	An unaligned memory reference was performed while alignment checking was enabled.

VMLOAD Load State from VMCB

Loads a subset of processor state from the VMCB specified by the physical address in the rAX register. The portion of RAX used to form the address is determined by the effective address size.

The VMSAVE and VMLOAD instructions complement the state save/restore abilities of VMRUN and #VMEXIT, providing access to hidden state that software is otherwise unable to access, plus some additional commonly-used state.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume 2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
VMLOAD rAX	0F 01 DA	Load additional state from VMCB.

Action

```
IF ((MSR_EFER.SVME = 0) || (!PROTECTED_MODE))
    EXCEPTION [#UD]        //  This instruction can only be executed in protected
                             //  mode with SVM enabled

IF (CPL != 0)                //  This instruction is only allowed at CPL 0
    EXCEPTION [#GP]

IF (rAX contains an unsupported physical address)
    EXCEPTION [#GP]

Load from a VMCB at physical address rAX:
      FS, GS, TR, LDTR (including all hidden state)
      KernelGsBase
      STAR, LSTAR, CSTAR, SFMASK
      SYSENTER_CS, SYSENTER_ESP, SYSENTER_EIP
```

Related Instructions

VMSAVE

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
			X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X		The instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.
			X	rAX referenced a physical address above the maximum supported physical address.
			X	The address in rAX was not aligned on a 4Kbyte boundary.

VMMCALL Call VMM

Provides a mechanism for a guest to explicitly communicate with the VMM by generating a #VMEXIT.

A non-intercepted VMMCALL unconditionally raises a #UD exception.

VMMCALL is not restricted to either protected mode or CPL zero.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume 2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
VMMCALL	0F 01 D9	Explicit communication with the VMM.

Related Instructions

None.

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
	X	X	X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X	X	VMMCALL was not intercepted.

VMRUN Run Virtual Machine

Starts execution of a guest instruction stream. The physical address of the *virtual machine control block* (VMCB) describing the guest is taken from the rAX register (the portion of RAX used to form the address is determined by the effective address size).

VMRUN saves a subset of host processor state to the host state-save area specified by the physical address in the VM_HSAVE_PA MSR. VMRUN then loads guest processor state (and control information) from the VMCB at the physical address specified in rAX. The processor then executes guest instructions until one of several *intercept* events (specified in the VMCB) is triggered. When an intercept event occurs, the processor stores a snapshot of the guest state back into the VMCB, reloads the host state, and continues execution of host code at the instruction following the VMRUN instruction.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume 2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
VMRUN rAX	0F 01 D8	Performs a world-switch to guest.

Action

```
IF ((MSR_EFER.SVME = 0) || (!PROTECTED_MODE))
     EXCEPTION [#UD]       //  This instruction can only be executed in protected
                            //  mode with SVM enabled

IF (CPL != 0)               //  This instruction is only allowed at CPL 0
    EXCEPTION [#GP]

IF (rAX contains an unsupported physical address)
    EXCEPTION [#GP]

if (intercepted(VMRUN))
    #VMEXIT (VMRUN)
remember VMCB address (delivered in rAX) for next #VMEXIT
save host state to physical memory indicated in the VM_HSAVE_PA MSR:
      ES.sel
      CS.sel
      SS.sel
      DS.sel
      GDTR.{base,limit}
      IDTR.{base,limit}
      EFER
      CR0
      CR4
      CR3
      // host CR2 is not saved
      RFLAGS
```

```
      RIP
      RSP
      RAX

from the VMCB at physical address rAX, load control information:
       intercept vector
       TSC_OFFSET
       interrupt control (v_irq, v_intr_*, v_tpr)
       EVENTINJ field
       ASID

if (nested paging supported)
    NP_ENABLE
    if (NP_ENABLE = 1)
       nCR3

from the VMCB at physical address rAX, load guest state:
             ES.{base,limit,attr,sel}
             CS.{base,limit,attr,sel}
             SS.{base,limit,attr,sel}
             DS.{base,limit,attr,sel}
             GDTR.{base,limit}
             IDTR.{base,limit}
             EFER
             CR0
             CR4
             CR3
             CR2
      if (NP_ENABLE = 1)
            gPAT            //  Leaves host hPAT register unchanged.
             RFLAGS
             RIP
             RSP
             RAX
             DR7
             DR6
             CPL            //  0 for real mode, 3 for v86 mode, else as loaded.
      INTERRUPT_SHADOW

if (LBR virtualization supported)
    LBR_VIRTUALIZATION_ENABLE
    if (LBR_VIRTUALIZATION_ENABLE=1)
        save LBR state to the host save area
             DBGCTL
             BR_FROM
             BR_TO
             LASTEXCP_FROM
             LASTEXCP_TO
        load LBR state from the VMCB
             DBGCTL
             BR_FROM
```

```
             BR_TO
             LASTEXCP_FROM
             LASTEXCP_TO

if (guest state consistency checks fail)
    #VMEXIT(INVALID)

Execute command stored in TLB_CONTROL.

GIF = 1           // allow interrupts in the guest
if (EVENTINJ.V)
      cause exception/interrupt in guest
else
      jump to first guest instruction
```

Upon #VMEXIT, the processor performs the following actions in order to return to the host execution context:

```
GIF = 0
save guest state to VMCB:
      ES.{base,limit,attr,sel}
      CS.{base,limit,attr,sel}
      SS.{base,limit,attr,sel}
      DS.{base,limit,attr,sel}
      GDTR.{base,limit}
      IDTR.{base,limit}
      EFER
      CR4
      CR3
      CR2
      CR0
      if (nested paging enabled)
          gPAT
      RFLAGS
      RIP
      RSP
      RAX
      DR7
      DR6
      CPL
      INTERRUPT_SHADOW
save additional state and intercept information:
      V_IRQ, V_TPR
      EXITCODE
      EXITINFO1
      EXITINFO2
      EXITINTINFO
clear EVENTINJ field in VMCB

prepare for host mode by clearing internal processor state bits:
      clear intercepts
      clear v_irq
```

```
      clear v_intr_masking
      clear tsc_offset
      disable nested paging
      clear ASID to zero

reload host state
      GDTR.{base,limit}
      IDTR.{base,limit}
      EFER
      CR0
      CR0.PE = 1  // saved copy of CR0.PE is ignored
      CR4
      CR3
      if (host is in PAE paging mode)
           reloaded host PDPEs
      // Do not reload host CR2 or PAT
      RFLAGS
      RIP
      RSP
      RAX
      DR7 = "all disabled"
      CPL = 0
      ES.sel; reload segment descriptor from GDT
      CS.sel; reload segment descriptor from GDT
      SS.sel; reload segment descriptor from GDT
      DS.sel; reload segment descriptor from GDT

if (LBR virtualization supported)
    LBR_VIRTUALIZATION_ENABLE
    if (LBR_VIRTUALIZATION_ENABLE=1)
        save LBR state to the VMCB:
            DBGCTL
            BR_FROM
            BR_TO
            LASTEXCP_FROM
            LASTEXCP_TO
        load LBR state from the host save area:
            DBGCTL
            BR_FROM
            BR_TO
            LASTEXCP_FROM
            LASTEXCP_TO

if (illegal host state loaded, or exception while loading host state)
      shutdown
else
      execute first host instruction following the VMRUN
```

Related Instructions

VMLOAD, VMSAVE.

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
			X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X		The instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.
			X	rAX referenced a physical address above the maximum supported physical address.
			X	The address in rAX was not aligned on a 4Kbyte boundary.

VMSAVE Save State to VMCB

Stores a subset of the processor state into the VMCB specified by the physical address in the rAX register (the portion of RAX used to form the address is determined by the effective address size).

The VMSAVE and VMLOAD instructions complement the state save/restore abilities of VMRUN and #VMEXIT, providing access to hidden state that software is otherwise unable to access, plus some additional commonly-used state.

This is a Secure Virtual Machine instruction. This instruction generates a #UD exception if SVM is not enabled. See “Enabling SVM” on page 369 in *AMD64 Architecture Programmer’s Manual Volume 2: System Instructions*, order# 24593.

Mnemonic	Opcode	Description
VMSAVE rAX	0F 01 DB	Save additional guest state to VMCB.

Action

```
IF ((MSR_EFER.SVME = 0) || (!PROTECTED_MODE))
     EXCEPTION [#UD]      // This instruction can only be executed in protected
                            //  mode with SVM enabled

IF (CPL != 0)               // This instruction is only allowed at CPL 0
    EXCEPTION [#GP]

IF (rAX contains an unsupported physical address)
    EXCEPTION [#GP]

Store to a VMCB at physical address rAX:
      FS, GS, TR, LDTR (including all hidden state)
      KernelGsBase
      STAR, LSTAR, CSTAR, SFMASK
      SYSENTER_CS, SYSENTER_ESP, SYSENTER_EIP
```

Related Instructions

VMLOAD

rFLAGS Affected

None.

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The SVM instructions are not supported as indicated by ECX bit 2 as returned by CPUID function 8000_0001h.
			X	Secure Virtual Machine was not enabled (EFER.SVME=0).
	X	X		The instruction is only recognized in protected mode.
General protection, #GP			X	CPL was not zero.
			X	rAX referenced a physical address above the maximum supported physical address.
			X	The address in rAX was not aligned on a 4Kbyte boundary.

WBINVD Writeback and Invalidate Caches

Writes all modified cache lines in the internal caches back to main memory and invalidates (flushes) internal caches. It then causes external caches to write back modified data to main memory; the external caches are subsequently invalidated. After invalidating internal caches, the processor proceeds immediately with the execution of the next instruction without waiting for external hardware to invalidate its caches.

The INVD instruction can be used when cache coherence with memory is not important.

This instruction does not invalidate TLB caches.

This is a privileged instruction. The current privilege level of a procedure invalidating the processor's internal caches must be zero.

WBINVD is a serializing instruction.

Mnemonic	Opcode	Description
WBINVD	0F 09	Write modified cache lines to main memory, invalidate internal caches, and trigger external cache flushes.

Related Instructions

CLFLUSH, INVD

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
General protection, #GP		X	X	CPL was not 0.

WRMSR Write to Model-Specific Register

Writes data to 64-bit model-specific registers (MSRs). These registers are widely used in performance-monitoring and debugging applications, as well as testability and program execution tracing.

This instruction writes the contents of the EDX:EAX register pair into a 64-bit model-specific register specified in the ECX register. The 32 bits in the EDX register are mapped into the high-order bits of the model-specific register and the 32 bits in EAX form the low-order 32 bits.

This instruction must be executed at a privilege level of 0 or a general protection fault #GP(0) will be raised. This exception is also generated if an attempt is made to specify a reserved or unimplemented model-specific register in ECX.

WRMSR is a serializing instruction.

The CPUID instruction can provide model information useful in determining the existence of a particular MSR.

See Volume 2: System Programming, for more information about model-specific registers, machine check architecture, performance monitoring and debug registers.

Mnemonic	Opcode	Description
WRMSR	0F 30	Write EDX:EAX to the MSR specified by ECX.

Related Instructions

RDMSR

rFLAGS Affected

None

Exceptions

Exception	Real	Virtual 8086	Protected	Cause of Exception
Invalid opcode, #UD	X	X	X	The WRMSR instruction is not supported, as indicated by EDX bit 5 returned by CPUID function 1 or 8000_0001h.
General protection, #GP		X	X	CPL was not 0.
	X		X	The value in ECX specifies a reserved or unimplemented MSR address.
	X		X	Writing 1 to any bit that must be zero (MBZ) in the MSR.
	X		X	Writing a non-canonical value to a MSR that can only be written with canonical values.

Appendix A Opcode and Operand Encodings

This section specifies the hexadecimal and/or binary encodings for the opcodes and the implicit operand references used in the AMD64 instruction set. For an overview of the instruction formats to which these encodings apply, see Chapter 1, "Instruction Formats."

A.1 Opcode-Syntax Notation

The following notation is used in this section to specify opcodes and their operands:

A Far pointer is encoded in the instruction.

C Control register specified by the ModRM *reg* field.

D Debug register specified by the ModRM *reg* field.

E General purpose register or memory operand specified by the ModRM byte. Memory addresses can be computed from a segment register, SIB byte, and/or displacement.

F rFLAGS register.

G General purpose register specified by the ModRM *reg* field.

I Immediate value.

J The instruction includes a relative offset that is added to the rIP.

M A memory operand specified by the ModRM byte.

O The offset of an operand is encoded in the instruction. There is no ModRM byte in the instruction. Complex addressing using the SIB byte cannot be done.

P 64-bit MMX register specified by the ModRM *reg* field.

PR 64-bit MMX register specified by the ModRM *r/m* field. The ModRM *mod* field must be 11b.

Q 64-bit MMX-register or memory operand specified by the ModRM byte. Memory addresses can be computed from a segment register, SIB byte, and/or displacement.

R General purpose register specified by the ModRM *r/m* field. The ModRM *mod* field must be 11b.

S Segment register specified by the ModRM *reg* field.

V 128-bit XMM register specified by the ModRM *reg* field.

VR 128-bit XMM register specified by the ModRM *r/m* field. The ModRM *mod* field must be 11b.

W A 128-bit XMM register or memory operand specified by the ModRM byte. Memory addresses can be computed from a segment register, SIB byte, and/or displacement.

X A memory operand addressed by the DS.rSI registers. Used in string instructions.

Y A memory operand addressed by the ES.rDI registers. Used in string instructions.

a Two 16-bit or 32-bit memory operands, depending on the effective operand size. Used in the BOUND instruction.

b A byte, irrespective of the effective operand size.

d A doubleword (32 bits), irrespective of the effective operand size.

dq A double-quadword (128 bits), irrespective of the effective operand size.

p A 32-bit or 48-bit far pointer, depending on the effective operand size.

pd A 128-bit double-precision floating-point vector operand (packed double).

pi A 64-bit MMX operand (packed integer).

ps A 128-bit single-precision floating-point vector operand (packed single).

q A quadword, irrespective of the effective operand size.

s A 6-byte or 10-byte pseudo-descriptor.

sd A scalar double-precision floating-point operand (scalar double).

si A scalar doubleword (32-bit) integer operand (scalar integer).

ss A scalar single-precision floating-point operand (scalar single).

v A word, doubleword, or quadword, depending on the effective operand size.

w A word, irrespective of the effective operand size.

z A word if the effective operand size is 16 bits, or a doubleword if the effective operand size is 32 or 64 bits.

/n A ModRM-byte *reg* field or SIB-byte *base* field that contains a value (*n*) between zero (binary 000) and 7 (binary 111).

For definitions of the mnemonics used to name registers, see “Summary of Registers and Data Types” on page 24.

A.2 Opcode Encodings

A.2.1 One-Byte Opcodes

Table A-1 on page 341 shows the one-byte opcodes in which the low nibble is in the range 0–7h. Table A-2 on page 342 shows those opcodes in which the low nibble is in the range 8–Fh. In both tables, the rows show the full range (0–Fh) of the high nibble, and the columns show the specified range of the low nibble.

Table A-1. One-Byte Opcodes, Low Nibble 0–7h

Nibble[1]	0	1	2	3	4	5	6	7
0	ADD						PUSH	POP
	Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	ES[3]	ES[3]
1	ADC						PUSH	POP
	Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	SS[3]	SS[3]
2	AND						seg ES[6]	DAA[3]
	Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz		
3	XOR						seg SS[6]	AAA[3]
	Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz		
4	INC[5]							
	eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI
5	PUSH							
	rAX/r8	rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
6	PUSHA/D[3]	POPA/D[3]	BOUND [3] Gv, Ma	ARPL[3] Ew, Gw MOVSXD[4] Gv, Ed	seg FS	seg GS	operand size	address size
7	JO Jb	JNO Jb	JB Jb	JNB Jb	JZ Jb	JNZ Jb	JBE Jb	JNBE Jb
8	Group 1[2]				TEST		XCHG	
	Eb, Ib	Ev, Iz	Eb, Ib[3]	Ev, Ib	Eb, Gb	Ev, Gv	Eb, Gb	Ev, Gv
9	XCHG							
	r8, rAX NOP,PAUSE	rCX/r9, rAX	rDX/r10, rAX	rBX/r11, rAX	rSP/r12, rAX	rBP/r13, rAX	rSI/r14, rAX	rDI/r15, rAX
A	MOV				MOVSB	MOVSW/D/Q	CMPSB	CMPSW/D/Q
	AL, Ob	rAX, Ov	Ob, AL	Ov, rAX	Yb, Xb	Yv, Xv	Xb, Yb	Xv, Yv
B	MOV							
	AL, Ib r8b, Ib	CL, Ib r9b, Ib	DL, Ib r10b, Ib	BL, Ib r11b, Ib	AH, Ib r12b, Ib	CH, Ib r13b, Ib	DH, Ib r14b, Ib	BH, Ib r15b, Ib
C	Group 2[2]		RET near		LES[3]	LDS[3]	Group 11[2]	
	Eb, Ib	Ev, Ib	Iw		Gz, Mp	Gz, Mp	Eb, Ib	Ev, Iz
D	Group 2[2]				AAM[3]	AAD[3]	SALC[3]	XLAT
	Eb, 1	Ev, 1	Eb, CL	Ev, CL				
E	LOOPNE/NZ	LOOPE/Z	LOOP	JrCXZ	IN		OUT	
	Jb	Jb	Jb	Jb	AL, Ib	eAX, Ib	Ib, AL	Ib, eAX
F	LOCK:	INT1 ICE Bkpt	REPNE:	REP: REPE:	HLT	CMC	Group 3[2]	

Notes:

1. *Rows in this table show the high opcode nibble, columns show the low opcode nibble.*
2. *An opcode extension is specified in bits 5–3 of the ModRM byte. See "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 for details.*
3. *Invalid in 64-bit mode.*
4. *Valid only in 64-bit mode.*
5. *Used as REX prefixes in 64-bit mode.*
6. *This is a null prefix in 64-bit mode.*

Table A-2. One-Byte Opcodes, Low Nibble 8–Fh

Nibble[1]	8	9	A	B	C	D	E	F
0	OR Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH CS[3]	2-byte opcodes
1	SBB Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	PUSH DS[3]	POP DS[3]
2	SUB Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	seg CS[6]	DAS[3]
3	CMP Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	rAX, Iz	seg DS[6]	AAS[3]
4	DEC[5] eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI
5	POP rAX/r8	rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
6	PUSH Iz	IMUL Gv, Ev, Iz	PUSH Ib	IMUL Gv, Ev, Ib	INSB Yb, DX	INSW/D Yz, DX	OUTSB DX, Xb	OUTSW/D DX, Xz
7	JS Jb	JNS Jb	JP Jb	JNP Jb	JL Jb	JNL Jb	JLE Jb	JNLE Jb
8	MOV Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	Mw/Rv, Sw	LEA Gv, M	MOV Sw, Ew	Group 1a[2] Ev
9	CBW, CWDE CDQE	CWD, CDQ, CQO	CALL[3] Ap	WAIT FWAIT	PUSHF/D/Q Fv	POPF/D/Q Fv	SAHF	LAHF
A	TEST AL, Ib	rAX, Iz	STOSB Yb, AL	STOSW/D/Q Yv, rAX	LODSB AL, Xb	LODSW/D/Q rAX, Xv	SCASB AL, Yb	SCASW/D/Q rAX, Yv
B	MOV rAX, Iv r8, Iv	rCX, Iv r9, Iv	rDX, Iv r10, Iv	rBX, Iv r11, Iv	rSP, Iv r12, Iv	rBP, Iv r13, Iv	rSI, Iv r14, Iv	rDI, Iv r15, Iv
C	ENTER Iw, Ib	LEAVE	RET far Iw		INT3	INT Ib	INTO[3]	IRET, IRETD IRETQ
D	x87 see Table A-10 on page 355							
E	CALL Jz	JMP Jz	Ap[3]	Jb	IN AL, DX	eAX, DX	OUT DX, AL	DX, eAX
F	CLC	STC	CLI	STI	CLD	STD	Group 4[2] Eb	Group 5[2]

Note:

1. *Rows in this table show the high opcode nibble, columns show the low opcode nibble.*
2. *An opcode extension is specified in bits 5–3 of the ModRM byte. See "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 for details.*
3. *Invalid in 64-bit mode.*
4. *Valid only in 64-bit mode.*
5. *Used as REX prefixes in 64-bit mode.*
6. *This is a null prefix in 64-bit mode.*

A.2.2 Two-Byte Opcodes

All two-byte opcodes have 0Fh as their first byte. Table A-3 below shows the second byte of the two-byte opcodes in which the second byte's low nibble is in the range 0–7h. Table A-4 on page 345 shows those opcodes in which the second byte's low nibble is in the range 8–Fh. In both tables, the rows show the full range (0–Fh) of the high nibble, and the columns show the low nibble of the opcode. The left-most column shows special-purpose prefix bytes used in many 128-bit and 64-bit instructions to modify the opcode.

Table A-3. Second Byte of Two-Byte Opcodes, Low Nibble 0–7h

Prefix	Nibble[1]	0	1	2	3	4	5	6	7
n/a	0	Group 6[2]	Group 7[2]	LAR Gv, Ew	LSL Gv, Ew	invalid	SYSCALL	CLTS	SYSRET
none	1	MOVUPS Vps, Wps	Wps, Vps	MOVLPS Vps, Mq MOVHLPS Vps, VRq	MOVLPS Mq, Vps	UNPCKLPS Vps, Wq	UNPCKHPS Vps, Wq	MOVHPS Vps, Mq MOVLHPS Vps, VRq	MOVHPS Mq, Vps
F3	1	MOVSS Vdq/ss, Wss	Wss, Vss	MOVSLDUP Vps, Wps	invalid	invalid	invalid	MOVSHDUP Vps, Wps	invalid
66	1	MOVUPD Vpd, Wpd	Wpd, Vpd	MOVLPD Vsd, Mq	Mq, Vsd	UNPCKLPD Vpd, Wq	UNPCKHPD Vpd, Wq	MOVHPD Vsd, Mq	Mq, Vsd
F2	1	MOVSD Vdq/sd, Wsd	Wsd, Vsd	MOVDDUP Vpd,Wsd	invalid	invalid	invalid	invalid	invalid
n/a	2	MOV Rd/q, Cd/q	Rd/q, Dd/q	Cd/q, Rd/q	Dd/q, Rd/q	invalid	invalid	invalid	invalid
n/a	3	WRMSR	RDTSC	RDMSR	RDPMC	SYSENTER[3]	SYSEXIT[3]	invalid	invalid
n/a	4	CMOVO Gv, Ev	CMOVNO Gv, Ev	CMOVB Gv, Ev	CMOVNB Gv, Ev	CMOVZ Gv, Ev	CMOVNZ Gv, Ev	CMOVBE Gv, Ev	CMOVNBE Gv, Ev
none	5	MOVMSKPS Gd, VRps	SQRTPS Vps, Wps	RSQRTPS Vps, Wps	RCPPS Vps, Wps	ANDPS Vps, Wps	ANDNPS Vps, Wps	ORPS Vps, Wps	XORPS Vps, Wps
F3	5	invalid	SQRTSS Vss, Wss	RSQRTSS Vss, Wss	RCPSS Vss, Wss	invalid	invalid	invalid	invalid
66	5	MOVMSKPD Gd, VRpd	SQRTPD Vpd, Wpd	invalid	invalid	ANDPD Vpd, Wpd	ANDNPD Vpd, Wpd	ORPD Vpd, Wpd	XORPD Vpd, Wpd
F2	5	invalid	SQRTSD Vsd, Wsd	invalid	invalid	invalid	invalid	invalid	invalid

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows in the table show the high nibble of the second opcode bytes, columns show the low nibble of this byte.*
2. *An opcode extension is specified in bits 5–3 of the ModRM byte. See "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 for details.*
3. *Invalid in long mode.*

Table A-3. Second Byte of Two-Byte Opcodes, Low Nibble 0–7h (continued)

Prefix	Nibble[1]	0	1	2	3	4	5	6	7
none	6	PUNPCK-LBW Pq, Qd	PUNPCK-LWD Pq, Qd	PUN-PCKLDQ Pq, Qd	PACKSSWB Pq, Qq	PCMPGTB Pq, Qq	PCMPGTW Pq, Qq	PCMPGTD Pq, Qq	PACKUSWB Pq, Qq
F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66		PUNPCK-LBW Vdq, Wq	PUNPCK-LWD Vdq, Wq	PUN-PCKLDQ Vdq, Wq	PACKSSWB Vdq, Wdq	PCMPGTB Vdq, Wdq	PCMPGTW Vdq, Wdq	PCMPGTD Vdq, Wdq	PACKUSWB Vdq, Wdq
F2		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
none	7	PSHUFW Pq, Qq, Ib	Group 12[2]	Group 13[2]	Group 14[2]	PCMPEQB Pq, Qq	PCMPEQW Pq, Qq	PCMPEQD Pq, Qq	EMMS
F3		PSHUFHW Vq, Wq, Ib	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66		PSHUFD Vdq, Wdq, Ib	Group 12[2]	Group 13[2]	Group 14[2]	PCMPEQB Vdq, Wdq	PCMPEQW Vdq, Wdq	PCMPEQD Vdq, Wdq	invalid
F2		PSHUFLW Vq, Wq, Ib	invalid	invalid	invalid	invalid	invalid	invalid	invalid
n/a	8	JO Jz	JNO Jz	JB Jz	JNB Jz	JZ Jz	JNZ Jz	JBE Jz	JNBE Jz
n/a	9	SETO Eb	SETNO Eb	SETB Eb	SETNB Eb	SETZ Eb	SETNZ Eb	SETBE Eb	SETNBE Eb
n/a	A	PUSH FS	POP FS	CPUID	BT Ev, Gv	SHLD Ev, Gv, Ib	Ev, Gv, CL	invalid	invalid
n/a	B	CMPXCHG Eb, Gb	Ev, Gv	LSS Gz, Mp	BTR Ev, Gv	LFS Gz, Mp	LGS Gz, Mp	MOVZX Gv, Eb	Gv, Ew
none	C	XADD Eb, Gb	Ev, Gv	CMPPS Vps, Wps, Ib	MOVNTI Md/q, Gd/q	PINSRW Pq, Ew, Ib	PEXTRW Gd, PRq, Ib	SHUFPS Vps, Wps, Ib	Group 9[2] Mq
F3				CMPSS Vss, Wss, Ib	invalid	invalid	invalid	invalid	
66				CMPPD Vpd, Wpd, Ib	invalid	PINSRW Vdq, Ew, Ib	PEXTRW Gd, VRdq, Ib	SHUFPD Vpd, Wpd, Ib	
F2				CMPSD Vsd, Wsd, Ib	invalid	invalid	invalid	invalid	
none	D	invalid	PSRLW Pq, Qq	PSRLD Pq, Qq	PSRLQ Pq, Qq	PADDQ Pq, Qq	PMULLW Pq, Qq	invalid	PMOVMSKB Gd, PRq
F3		invalid	invalid	invalid	invalid	invalid	invalid	MOVQ2DQ Vdq, PRq	invalid
66		ADDSUBPD Vpd, Wpd	PSRLW Vdq, Wdq	PSRLD Vdq, Wdq	PSRLQ Vdq, Wdq	PADDQ Vdq, Wdq	PMULLW Vdq, Wdq	MOVQ Wq, Vq	PMOVMSKB Gd, VRdq
F2		ADDSUBPS Vps, Wps	invalid	invalid	invalid	invalid	invalid	MOVDQ2Q Pq, VRq	invalid

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows in the table show the high nibble of the second opcode bytes, columns show the low nibble of this byte.*
2. *An opcode extension is specified in bits 5–3 of the ModRM byte. See “ModRM Extensions to One-Byte and Two-Byte Opcodes” on page 348 for details.*
3. *Invalid in long mode.*

Table A-3. Second Byte of Two-Byte Opcodes, Low Nibble 0–7h (continued)

Prefix	Nibble[1]	0	1	2	3	4	5	6	7
none	E	PAVGB Pq, Qq	PSRAW Pq, Qq	PSRAD Pq, Qq	PAVGW Pq, Qq	PMULHUW Pq, Qq	PMULHW Pq, Qq	invalid	MOVNTQ Mq, Pq
F3		invalid	invalid	invalid	invalid	invalid	invalid	CVTDQ2PD Vpd, Wq	invalid
66		PAVGB Vdq, Wdq	PSRAW Vdq, Wdq	PSRAD Vdq, Wdq	PAVGW Vdq, Wdq	PMULHUW Vdq, Wdq	PMULHW Vdq, Wdq	CVTTPD2DQ Vq, Wpd	MOVNTDQ Mdq, Vdq
F2		invalid	invalid	invalid	invalid	invalid	invalid	CVTPD2DQ Vq, Wpd	invalid
none	F	invalid	PSLLW Pq, Qq	PSLLD Pq, Qq	PSLLQ Pq, Qq	PMULUDQ Pq, Qq	PMADDWD Pq, Qq	PSADBW Pq, Qq	MASKMOVQ Pq, PRq
F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66		invalid	PSLLW Vdq, Wdq	PSLLD Vdq, Wdq	PSLLQ Vdq, Wdq	PMULUDQ Vdq, Wdq	PMADDWD Vdq, Wdq	PSADBW Vdq, Wdq	MASK-MOVDQU Vdq, VRdq
F2		LDDQU Vpd,Mdq	invalid	invalid	invalid	invalid	invalid	invalid	invalid

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows in the table show the high nibble of the second opcode bytes, columns show the low nibble of this byte.*
2. *An opcode extension is specified in bits 5–3 of the ModRM byte. See "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 for details.*
3. *Invalid in long mode.*

Table A-4. Second Byte of Two-Byte Opcodes, Low Nibble 8–Fh

Prefix	Nibble[1]	8	9	A	B	C	D	E	F
n/a	0	INVD	WBINVD	invalid	UD2	invalid	Group P[2] PREFETCH	FEMMS	3DNow! See "3DNow!™ Opcodes" on page 351
n/a	1	Group 16[2]	NOP[3]	NOP[3]	NOP[3]	NOP[3]	NOP[3]	NOP[3]	NOP[3]
none	2	MOVAPS Vps, Wps	Wps, Vps	CVTPI2PS Vps, Qq	MOVNTPS Mdq, Vps	CVTTPS2PI Pq, Wps	CVTPS2PI Pq, Wps	UCOMISS Vss, Wss	COMISS Vps, Wps
F3		invalid	invalid	CVTSI2SS Vss, Ed/q	MOVNTSS Md, Vss	CVTTSS2SI Gd/q, Wss	CVTSS2SI Gd/q, Wss	invalid	invalid
66		MOVAPD Vpd, Wpd	Wpd, Vpd	CVTPI2PD Vpd, Qq	MOVNTPD Mdq, Vpd	CVTTPD2PI Pq, Wpd	CVTPD2PI Pq, Wpd	UCOMISD Vsd, Wsd	COMISD Vpd, Wsd
F2		invalid	invalid	CVTSI2SD Vsd, Ed/q	MOVNTSD Mq, Vsd	CVTTSD2SI Gd/q, Wsd	CVTSD2SI Gd/q, Wsd	invalid	invalid

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows show high opcode nibble (hex), columns show low opcode nibble in hex.*
2. *An opcode extension is specified in the ModRM reg field (bits 5–3). See "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 for details.*
3. *This instruction takes a ModRM byte.*

Table A-4. Second Byte of Two-Byte Opcodes, Low Nibble 8–Fh (continued)

Prefix	Nibble[1]	8	9	A	B	C	D	E	F
n/a	3	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
n/a	4	CMOVS Gv, Ev	CMOVNS Gv, Ev	CMOVP Gv, Ev	CMOVNP Gv, Ev	CMOVL Gv, Ev	CMOVNL Gv, Ev	CMOVLE Gv, Ev	CMOVNLE Gv, Ev
none	5	ADDPS Vps, Wps	MULPS Vps, Wps	CVTPS2PD Vpd, Wps	CVTDQ2PS Vps, Wdq	SUBPS Vps, Wps	MINPS Vps, Wps	DIVPS Vps, Wps	MAXPS Vps, Wps
F3		ADDSS Vss, Wss	MULSS Vss, Wss	CVTSS2SD Vsd, Wss	CVTTPS2DQ Vdq, Wps	SUBSS Vss, Wss	MINSS Vss, Wss	DIVSS Vss, Wss	MAXSS Vss, Wss
66		ADDPD Vpd, Wpd	MULPD Vpd, Wpd	CVTPD2PS Vps, Wpd	CVTPS2DQ Vdq, Wps	SUBPD Vpd, Wpd	MINPD Vpd, Wpd	DIVPD Vpd, Wpd	MAXPD Vpd, Wpd
F2		ADDSD Vsd, Wsd	MULSD Vsd, Wsd	CVTSD2SS Vss, Wsd	invalid	SUBSD Vsd, Wsd	MINSD Vsd, Wsd	DIVSD Vsd, Wsd	MAXSD Vsd, Wsd
none	6	PUNPCK-HBW Pq, Qd	PUNPCK-HWD Pq, Qd	PUNPCK-HDQ Pq, Qd	PACKSSDW Pq, Qq	invalid	invalid	MOVD Pq, Ed/q	MOVQ Pq, Qq
F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	MOVDQU Vdq, Wdq
66		PUNPCK-HBW Vdq, Wq	PUNPCK-HWD Vdq, Wq	PUNPCK-HDQ Vdq, Wq	PACKSSDW Vdq, Wdq	PUNPCK-LQDQ Vdq, Wq	PUNPCK-HQDQ Vdq, Wq	MOVD Vdq, Ed/q	MOVDQA Vdq, Wdq
F2		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
none	7	invalid	invalid	invalid	invalid	invalid	invalid	MOVD Ed/q, Pd/q	MOVQ Qq, Pq
F3		invalid	invalid	invalid	invalid	invalid	invalid	MOVQ Vq, Wq	MOVDQU Wdq, Vdq
66		Group 17[2]	EXTRQ Vdq, VRq	invalid	invalid	HADDPD Vpd,Wpd	HSUBPD Vpd,Wpd	MOVD Ed/q, Vd/q	MOVDQA Wdq, Vdq
F2		INSERTQ Vdq,VRq,Ib,Ib	INSERTQ Vdq, VRdq	invalid	invalid	HADDPS Vps,Wps	HSUBPS Vps,Wps	invalid	invalid
n/a	8	JS Jz	JNS Jz	JP Jz	JNP Jz	JL Jz	JNL Jz	JLE Jz	JNLE Jz
n/a	9	SETS Eb	SETNS Eb	SETP Eb	SETNP Eb	SETL Eb	SETNL Eb	SETLE Eb	SETNLE Eb
n/a	A	PUSH GS	POP GS	RSM	BTS Ev, Gv	SHRD Ev, Gv, Ib	Ev, Gv, CL	Group 15[2]	IMUL Gv, Ev
none	B	reserved	Group 10[2]	Group 8[2] Ev, Ib	BTC Ev, Gv	BSF Gv, Ev	BSR Gv, Ev	MOVSX Gv, Eb	Gv, Ew
F3		POPCNT Gv, Ev	reserved	reserved	reserved	reserved	LZCNT Gv, Ev	reserved	reserved
F2		reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows show high opcode nibble (hex), columns show low opcode nibble in hex.*
2. *An opcode extension is specified in the ModRM reg field (bits 5–3). See “ModRM Extensions to One-Byte and Two-Byte Opcodes” on page 348 for details.*
3. *This instruction takes a ModRM byte.*

Table A-4. Second Byte of Two-Byte Opcodes, Low Nibble 8–Fh (continued)

Prefix	Nibble[1]	8	9	A	B	C	D	E	F
n/a	C	BSWAP rAX/r8	rCX/r9	rDX/r10	rBX/r11	rSP/r12	rBP/r13	rSI/r14	rDI/r15
none	D	PSUBUSB Pq, Qq	PSUBUSW Pq, Qq	PMINUB Pq, Qq	PAND Pq, Qq	PADDUSB Pq, Qq	PADDUSW Pq, Qq	PMAXUB Pq, Qq	PANDN Pq, Qq
F3	D	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66	D	PSUBUSB Vdq, Wdq	PSUBUSW Vdq, Wdq	PMINUB Vdq, Wdq	PAND Vdq, Wdq	PADDUSB Vdq, Wdq	PADDUSW Vdq, Wdq	PMAXUB Vdq, Wdq	PANDN Vdq, Wdq
F2	D	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
none	E	PSUBSB Pq, Qq	PSUBSW Pq, Qq	PMINSW Pq, Qq	POR Pq, Qq	PADDSB Pq, Qq	PADDSW Pq, Qq	PMAXSW Pq, Qq	PXOR Pq, Qq
F3	E	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66	E	PSUBSB Vdq, Wdq	PSUBSW Vdq, Wdq	PMINSW Vdq, Wdq	POR Vdq, Wdq	PADDSB Vdq, Wdq	PADDSW Vdq, Wdq	PMAXSW Vdq, Wdq	PXOR Vdq, Wdq
F2	E	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
none	F	PSUBB Pq, Qq	PSUBW Pq, Qq	PSUBD Pq, Qq	PSUBQ Pq, Qq	PADDB Pq, Qq	PADDW Pq, Qq	PADDD Pq, Qq	invalid
F3	F	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
66	F	PSUBB Vdq, Wdq	PSUBW Vdq, Wdq	PSUBD Vdq, Wdq	PSUBQ Vdq, Wdq	PADDB Vdq, Wdq	PADDW Vdq, Wdq	PADDD Vdq, Wdq	invalid
F2	F	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid

Note:

1. *All two-byte opcodes begin with an 0Fh byte. Rows show high opcode nibble (hex), columns show low opcode nibble in hex.*
2. *An opcode extension is specified in the ModRM reg field (bits 5–3). See “ModRM Extensions to One-Byte and Two-Byte Opcodes” on page 348 for details.*
3. *This instruction takes a ModRM byte.*

A.2.3 rFLAGS Condition Codes for Two-Byte Opcodes

Table A-5 shows the rFLAGS condition codes specified by the low nibble in the second opcode byte of the CMOV*cc*, J*cc*, and SET*cc* instructions.

Table A-5. rFLAGS Condition Codes for CMOV*cc*, J*cc*, and SET*cc*

Low Nibble of Second Opcode Byte (hex)	rFLAGS Value	*cc* Mnemonic	Arithmetic Type	Condition(s)
0	OF = 1	O	Signed	Overflow
1	OF = 0	NO		No Overflow
2	CF = 1	B, C, NAE	Unsigned	Below, Carry, Not Above or Equal
3	CF = 0	NB, NC, AE		Not Below, No Carry, Above or Equal
4	ZF = 1	Z, E		Zero, Equal
5	ZF = 0	NZ, NE		Not Zero, Not Equal
6	CF = 1 or ZF = 1	BE, NA		Below or Equal, Not Above
7	CF = 0 and ZF = 0	NBE, A		Not Below or Equal, Above
8	SF = 1	S	Signed	Sign
9	SF = 0	NS		Not Sign
A	PF = 1	P, PE	n/a	Parity, Parity Even
B	PF = 0	NP, PO		Not Parity, Parity Odd
C	(SF xor OF) = 1	L, NGE	Signed	Less than, Not Greater than or Equal to
D	(SF xor OF) = 0	NL, GE		Not Less than, Greater than or Equal to
E	(SF xor OF) = 1 or ZF = 1	LE, NG		Less than or Equal to, Not Greater than
F	(SF xor OF) = 0 and ZF = 0	NLE, G		Not Less than or Equal to, Greater than

A.2.4 ModRM Extensions to One-Byte and Two-Byte Opcodes

The ModRM byte, which immediately follows the last opcode byte, is used in certain instruction encodings to provide additional opcode bits with which to define the function of the instruction. ModRM bytes have three fields—*mod, reg*, and *r/m*, as shown in Figure A-1.

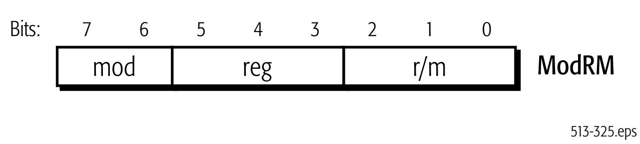


Figure A-1. ModRM-Byte Fields

In most cases, the *reg* field (bits 5–3) provides the additional bits with which to extend the encodings of the first one or two opcode bytes. In the case of the x87 floating-point instructions, the entire ModRM byte is used to extend the opcode encodings.

Table A-6 on page 349 shows how the ModRM *reg* field is used to extend the range of one-byte and two-byte opcodes. The opcode ranges are organized into *groups* of opcode extensions. The group number is shown in the left-most column of Table A-6. These groups are referenced in the opcodes shown in Table A-1 on page 341 through Table A-4 on page 345. An entry of “n.a.” in the Prefix column means that prefixes are not applicable to the opcodes in that row. Prefixes only apply to certain 128-bit media, 64-bit media, and a few other instructions introduced with the SSE or SSE2 technologies.

The /0 through /7 notation for the ModRM *reg* field (bits 5–3) means that the three-bit field contains a value from zero (binary 000) to 7 (binary 111).

Table A-6. One-Byte and Two-Byte Opcode ModRM Extensions

Group Number	Prefix	Opcode	ModRM *reg* Field							
			/0	/1	/2	/3	/4	/5	/6	/7
Group 1	n/a	80	ADD Eb, Ib	OR Eb, Ib	ADC Eb, Ib	SBB Eb, Ib	AND Eb, Ib	SUB Eb, Ib	XOR Eb, Ib	CMP Eb, Ib
		81	ADD Ev, Iz	OR Ev, Iz	ADC Ev, Iz	SBB Ev, Iz	AND Ev, Iz	SUB Ev, Iz	XOR Ev, Iz	CMP Ev, Iz
		82	ADD Eb, Ib[2]	OR Eb, Ib[2]	ADC Eb, Ib[2]	SBB Eb, Ib[2]	AND Eb, Ib[2]	SUB Eb, Ib[2]	XOR Eb, Ib[2]	CMP Eb, Ib[2]
		83	ADD Ev, Ib	OR Ev, Ib	ADC Ev, Ib	SBB Ev, Ib	AND Ev, Ib	SUB Ev, Ib	XOR Ev, Ib	CMP Ev, Ib
Group 1a	n/a	8F	POP Ev	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 2	n/a	C0	ROL Eb, Ib	ROR Eb, Ib	RCL Eb, Ib	RCR Eb, Ib	SHL/SAL Eb, Ib	SHR Eb, Ib	SHL/SAL Eb, Ib	SAR Eb, Ib
		C1	ROL Ev, Ib	ROR Ev, Ib	RCL Ev, Ib	RCR Ev, Ib	SHL/SAL Ev, Ib	SHR Ev, Ib	SHL/SAL Ev, Ib	SAR Ev, Ib
		D0	ROL Eb, 1	ROR Eb, 1	RCL Eb, 1	RCR Eb, 1	SHL/SAL Eb, 1	SHR Eb, 1	SHL/SAL Eb, 1	SAR Eb, 1
		D1	ROL Ev, 1	ROR Ev, 1	RCL Ev, 1	RCR Ev, 1	SHL/SAL Ev, 1	SHR Ev, 1	SHL/SAL Ev, 1	SAR Ev, 1
		D2	ROL Eb, CL	ROR Eb, CL	RCL Eb, CL	RCR Eb, CL	SHL/SAL Eb, CL	SHR Eb, CL	SHL/SAL Eb, CL	SAR Eb, CL
		D3	ROL Ev, CL	ROR Ev, CL	RCL Ev, CL	RCR Ev, CL	SHL/SAL Ev, CL	SHR Ev, CL	SHL/SAL Ev, CL	SAR Ev, CL
Group 3	n/a	F6	TEST Eb,Ib		NOT Eb	NEG Eb	MUL Eb	IMUL Eb	DIV Eb	IDIV Eb
		F7	TEST Ev,Iz		NOT Ev	NEG Ev	MUL Ev	IMUL Ev	DIV Ev	IDIV Ev
Group 4	n/a	FE	INC Eb	DEC Eb	invalid	invalid	invalid	invalid	invalid	invalid
Group 5	n/a	FF	INC Ev	DEC Ev	CALL Ev	CALL Mp	JMP Ev	JMP Mp	PUSH Ev	invalid

Note:
1. *See Table A-7 on page 351 for ModRM extensions of this two-byte opcode.*
2. *Invalid in 64-bit mode.*
3. *This instruction takes a ModRM byte.*
4. *Reserved prefetch encodings are aliased to the /0 encoding (PREFETCH Exclusive) for future compatibility.*

Table A-6. One-Byte and Two-Byte Opcode ModRM Extensions (continued)

Group Number	Prefix	Opcode	ModRM *reg* Field							
			/0	/1	/2	/3	/4	/5	/6	/7
Group 6	n/a	0F 00	SLDT Mw/Rv	STR Mw/Rv	LLDT Ew	LTR Ew	VERR Ew	VERW Ew	invalid	invalid
Group 7	n/a	0F 01	SGDT Ms	SIDT Ms MONITOR[1] MWAIT	LGDT Ms	LIDT Ms SVM[1]	SMSW Mw/Rv	invalid	LMSW Ew	INVLPG Mb SWAPGS[1] RDTSCP
Group 8	n/a	0F BA	invalid	invalid	invalid	invalid	BT Ev, Ib	BTS Ev, Ib	BTR Ev, Ib	BTC Ev, Ib
Group 9	n/a	0F C7	invalid	CMPXCH G8B Mq CMPXCH G16Mdq	invalid	invalid	invalid	invalid	invalid	invalid
Group 10	n/a	0F B9	invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 11	n/a	C6	MOV Eb,Ib	invalid	invalid	invalid	invalid	invalid	invalid	invalid
	n/a	C7	MOV Ev,Iz	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 12	none	0F 71	invalid	invalid	PSRLW PRq, Ib	invalid	PSRAW PRq, Ib	invalid	PSLLW PRq, Ib	invalid
	66		invalid	invalid	PSRLW VRdq, Ib	invalid	PSRAW VRdq, Ib	invalid	PSLLW VRdq, Ib	invalid
	F2, F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 13	none	0F 72	invalid	invalid	PSRLD PRq, Ib	invalid	PSRAD PRq, Ib	invalid	PSLLD PRq, Ib	invalid
	66		invalid	invalid	PSRLD VRdq, Ib	invalid	PSRAD VRdq, Ib	invalid	PSLLD VRdq, Ib	invalid
	F2, F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 14	none	0F 73	invalid	invalid	PSRLQ PRq, Ib	invalid	invalid	invalid	PSLLQ PRq, Ib	invalid
	66		invalid	invalid	PSRLQ VRdq, Ib	PSRLDQ VRdq, Ib	invalid	invalid	PSLLQ VRdq, Ib	PSLLDQ VRdq, Ib
	F2, F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 15	none	0F AE	FXSAVE M	FXRSTOR M	LDMXCSR Md	STMXCSR Md	invalid	LFENCE[1]	MFENCE[1]	SFENCE[1] CLFLUSH Mb
	66, F2, F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group 16	n/a.	0F 18	PREFETCH NTA	PREFETCH T0	PREFETCH T1	PREFETCH T2	NOP[4]	NOP[4]	NOP[4]	NOP[4]

Note:

1. *See Table A-7 on page 351 for ModRM extensions of this two-byte opcode.*
2. *Invalid in 64-bit mode.*
3. *This instruction takes a ModRM byte.*
4. *Reserved prefetch encodings are aliased to the /0 encoding (PREFETCH Exclusive) for future compatibility.*

Table A-6. One-Byte and Two-Byte Opcode ModRM Extensions (continued)

Group Number	Prefix	Opcode	ModRM *reg* Field							
			/0	/1	/2	/3	/4	/5	/6	/7
Group 17	66	0F 78	EXTRQ Vdq, Ib, Ib	invalid	invalid	invalid	invalid	invalid	invalid	invalid
	none, F2, F3		invalid	invalid	invalid	invalid	invalid	invalid	invalid	invalid
Group P	n/a.	0F 0D	PREFETCH Exclusive	PREFETCH Modified	Prefetch Reserved[4]	PREFETCH Modified	Prefetch Reserved[4]	Prefetch Reserved[4]	Prefetch Reserved[4]	Prefetch Reserved[4]

Note:
1. *See Table A-7 on page 351 for ModRM extensions of this two-byte opcode.*
2. *Invalid in 64-bit mode.*
3. *This instruction takes a ModRM byte.*
4. *Reserved prefetch encodings are aliased to the /0 encoding (PREFETCH Exclusive) for future compatibility.*

A.2.5 ModRM Extensions to Opcodes 0F 01 and 0F AE

Table A-7 shows the ModRM r/m field encodings for the 0F 01 and 0F AE opcodes, shown in Table A-6 on page 349. The 0F 01 opcode is shared by several system instructions, and the 0F AE opcode is shared by several media and fence instructions. The opcodes are differentiated by the fact that the binary value of the ModRM *mod* field is always 11 for these instructions. The ModRM *mod* field can be any value *except* 11 for the instructions having an explicit memory operand.

Table A-7. Opcode 0F 01 and 0F AE ModRM Extensions

Opcode	ModRM *r/m* Field							
	0	1	2	3	4	5	6	7
0F 01 /7 mod=11	0F 01 F8 SWAPGS	0F 01 F9 RDTSCP	invalid	invalid	invalid	invalid	invalid	invalid
0F 01 /3 mod=11	0F 01 D8 VMRUN	0F 01 D9 VMMCALL	0F 01 DA VMLOAD	0F 01 DB VMSAVE	0F 01 DC STGI	0F 01 DD CLGI	0F 01 DE SKINIT	0F 01 DF INVLPGA
0F 01 /1 mod=11	0F 01 C8 MONITOR	0F 01 C9 MWAIT	invalid	invalid	invalid	invalid	invalid	invalid
0F AE /5 mod=11	LFENCE							
0F AE /6 mod=11	MFENCE							
0F AE /7 mod=11	SFENCE							

A.2.6 3DNow!™ Opcodes

The 64-bit media instructions include the MMX™ instructions and the AMD 3DNow!™ instructions. The MMX instructions are encoded using two opcode bytes, as described in “Two-Byte Opcodes” on page 343.

The 3DNow! instructions are encoded using two 0Fh opcode bytes and an immediate byte that is located at the last byte position of the instruction encoding. Thus, the format for 3DNow! instructions is:

```
0Fh 0Fh [ModRM] [SIB] [displacement] imm8_opcode
```

Table A-8 and Table A-9 on page 353 show the immediate byte following the opcode bytes for 3DNow! instructions. In these tables, rows show the high nibble of the immediate byte, and columns show the low nibble of the immediate byte. Table A-8 shows the immediate bytes whose low nibble is in the range 0–7h. Table A-9 shows the same for immediate bytes whose low nibble is in the range 8–Fh.

Byte values shown as *reserved* in these tables have implementation-specific functions, which can include an invalid-opcode exception.

Table A-8. Immediate Byte for 3DNow!™ Opcodes, Low Nibble 0–7h

Nibble[1]	0	1	2	3	4	5	6	7
0	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
1	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
2	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
3	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
4	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
5	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
6	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
7	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
8	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
9	PFCMPGE Pq, Qq	reserved	reserved	reserved	PFMIN Pq, Qq	reserved	PFRCP Pq, Qq	PFRSQRT Pq, Qq
A	PFCMPGT Pq, Qq	reserved	reserved	reserved	PFMAX Pq, Qq	reserved	PFRCPIT1 Pq, Qq	PFRSQIT1 Pq, Qq
B	PFCMPEQ Pq, Qq	reserved	reserved	reserved	PFMUL Pq, Qq	reserved	PFRCPIT2 Pq, Qq	PMULHRW Pq, Qq
C	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
D	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
E	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
F	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved

Note:
1. *All 3DNow!™ opcodes consist of two 0Fh bytes. This table shows the immediate byte for 3DNow! opcodes. Rows show the high nibble of the immediate byte. Columns show the low nibble of the immediate byte.*

Table A-9. Immediate Byte for 3DNow!™ Opcodes, Low Nibble 8–Fh

Nibble[1]	8	9	A	B	C	D	E	F
0	reserved	reserved	reserved	reserved	PI2FW Pq, Qq	PI2FD Pq, Qq	reserved	reserved
1	reserved	reserved	reserved	reserved	PF2IW Pq, Qq	PF2ID Pq, Qq	reserved	reserved
2	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
3	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
4	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
5	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
6	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
7	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
8	reserved	reserved	PFNACC Pq, Qq	reserved	reserved	reserved	PFPNACC Pq, Qq	reserved
9	reserved	reserved	PFSUB Pq, Qq	reserved	reserved	reserved	PFADD Pq, Qq	reserved
A	reserved	reserved	PFSUBR Pq, Qq	reserved	reserved	reserved	PFACC Pq, Qq	reserved
B	reserved	reserved	reserved	PSWAPD Pq, Qq	reserved	reserved	reserved	PAVGUSB Pq, Qq
C	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
D	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
E	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
F	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved

Note:

1. *All 3DNow!™ opcodes consist of two 0Fh bytes. This table shows the immediate byte for 3DNow! opcodes. Rows show the high nibble of the immediate byte. Columns show the low nibble of the immediate byte.*

A.2.7 x87 Encodings

All x87 instructions begin with an opcode byte in the range D8h to DFh, as shown in Table A-2 on page 342. These opcodes are followed by a ModRM byte that further defines the opcode. Table A-10 shows both the opcode byte and the ModRM byte for each x87 instruction.

There are two significant ranges for the ModRM byte for x87 opcodes: 00–BFh and C0–FFh. When the value of the ModRM byte falls within the first range, 00–BFh, the opcode uses only the *reg* field to further define the opcode. When the value of the ModRM byte falls within the second range, C0–FFh, the opcode uses the entire ModRM byte to further define the opcode.

Byte values shown as *reserved* or *invalid* in Table A-10 have implementation-specific functions, which can include an invalid-opcode exception.

The basic instructions FNSTENV, FNSTCW, FNCLEX, FNINIT, FNSAVE, FNSTSW, and FNSTSW do not check for possible floating point exceptions before operating. Utility versions of these mnemonics are provided that insert an FWAIT (opcode 9B) before the corresponding non-waiting instruction. These are FSTENV, FSTCW, FCLEX, FINIT, FSAVE, and FSTSW. For further information on wait and non-waiting versions of these instructions, see their corresponding pages in Volume 5.

Table A-10. x87 Opcodes and ModRM Extensions

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
D8	!11	00–BF							
		FADD mem32real	FMUL mem32real	FCOM mem32real	FCOMP mem32real	FSUB mem32real	FSUBR mem32real	FDIV mem32real	FDIVR mem32real
	11	**C0** FADD ST(0), ST(0)	**C8** FMUL ST(0), ST(0)	**D0** FCOM ST(0), ST(0)	**D8** FCOMP ST(0), ST(0)	**E0** FSUB ST(0), ST(0)	**E8** FSUBR ST(0), ST(0)	**F0** FDIV ST(0), ST(0)	**F8** FDIVR ST(0), ST(0)
		C1 FADD ST(0), ST(1)	**C9** FMUL ST(0), ST(1)	**D1** FCOM ST(0), ST(1)	**D9** FCOMP ST(0), ST(1)	**E1** FSUB ST(0), ST(1)	**E9** FSUBR ST(0), ST(1)	**F1** FDIV ST(0), ST(1)	**F9** FDIVR ST(0), ST(1)
		C2 FADD ST(0), ST(2)	**CA** FMUL ST(0), ST(2)	**D2** FCOM ST(0), ST(2)	**DA** FCOMP ST(0), ST(2)	**E2** FSUB ST(0), ST(2)	**EA** FSUBR ST(0), ST(2)	**F2** FDIV ST(0), ST(2)	**FA** FDIVR ST(0), ST(2)
		C3 FADD ST(0), ST(3)	**CB** FMUL ST(0), ST(3)	**D3** FCOM ST(0), ST(3)	**DB** FCOMP ST(0), ST(3)	**E3** FSUB ST(0), ST(3)	**EB** FSUBR ST(0), ST(3)	**F3** FDIV ST(0), ST(3)	**FB** FDIVR ST(0), ST(3)
		C4 FADD ST(0), ST(4)	**CC** FMUL ST(0), ST(4)	**D4** FCOM ST(0), ST(4)	**DC** FCOMP ST(0), ST(4)	**E4** FSUB ST(0), ST(4)	**EC** FSUBR ST(0), ST(4)	**F4** FDIV ST(0), ST(4)	**FC** FDIVR ST(0), ST(4)
		C5 FADD ST(0), ST(5)	**CD** FMUL ST(0), ST(5)	**D5** FCOM ST(0), ST(5)	**DD** FCOMP ST(0), ST(5)	**E5** FSUB ST(0), ST(5)	**ED** FSUBR ST(0), ST(5)	**F5** FDIV ST(0), ST(5)	**FD** FDIVR ST(0), ST(5)
		C6 FADD ST(0), ST(6)	**CE** FMUL ST(0), ST(6)	**D6** FCOM ST(0), ST(6)	**DE** FCOMP ST(0), ST(6)	**E6** FSUB ST(0), ST(6)	**EE** FSUBR ST(0), ST(6)	**F6** FDIV ST(0), ST(6)	**FE** FDIVR ST(0), ST(6)
		C7 FADD ST(0), ST(7)	**CF** FMUL ST(0), ST(7)	**D7** FCOM ST(0), ST(7)	**DF** FCOMP ST(0), ST(7)	**E7** FSUB ST(0), ST(7)	**EF** FSUBR ST(0), ST(7)	**F7** FDIV ST(0), ST(7)	**FF** FDIVR ST(0), ST(7)

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
D9	!11	00–BF							
		FLD mem32real	invalid	FST mem32real	FSTP mem32real	FLDENV mem14/28env	FLDCW mem16	FNSTENV mem14/28env	FNSTCW mem16
	11	**C0** FLD ST(0), ST(0)	**C8** FXCH ST(0), ST(0)	**D0** FNOP	**D8** reserved	**E0** FCHS	**E8** FLD1	**F0** F2XM1	**F8** FPREM
		C1 FLD ST(0), ST(1)	**C9** FXCH ST(0), ST(1)	**D1** invalid	**D9** reserved	**E1** FABS	**E9** FLDL2T	**F1** FYL2X	**F9** FYL2XP1
		C2 FLD ST(0), ST(2)	**CA** FXCH ST(0), ST(2)	**D2** invalid	**DA** reserved	**E2** invalid	**EA** FLDL2E	**F2** FPTAN	**FA** FSQRT
		C3 FLD ST(0), ST(3)	**CB** FXCH ST(0), ST(3)	**D3** invalid	**DB** reserved	**E3** invalid	**EB** FLDPI	**F3** FPATAN	**FB** FSINCOS
		C4 FLD ST(0), ST(4)	**CC** FXCH ST(0), ST(4)	**D4** invalid	**DC** reserved	**E4** FTST	**EC** FLDLG2	**F4** FXTRACT	**FC** FRNDINT
		C5 FLD ST(0), ST(5)	**CD** FXCH ST(0), ST(5)	**D5** invalid	**DD** reserved	**E5** FXAM	**ED** FLDLN2	**F5** FPREM1	**FD** FSCALE
		C6 FLD ST(0), ST(6)	**CE** FXCH ST(0), ST(6)	**D6** invalid	**DE** reserved	**E6** invalid	**EE** FLDZ	**F6** FDECSTP	**FE** FSIN
		C7 FLD ST(0), ST(7)	**CF** FXCH ST(0), ST(7)	**D7** invalid	**DF** reserved	**E7** invalid	**EF** invalid	**F7** FINCSTP	**FF** FCOS

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
DA	!11	**00–BF** FIADD mem32int	FIMUL mem32int	FICOM mem32int	FICOMP mem32int	FISUB mem32int	FISUBR mem32int	FIDIV mem32int	FIDIVR mem32int
	11	**C0** FCMOVB ST(0), ST(0)	**C8** FCMOVE ST(0), ST(0)	**D0** FCMOVBE ST(0), ST(0)	**D8** FCMOVU ST(0), ST(0)	**E0** invalid	**E8** invalid	**F0** invalid	**F8** invalid
		C1 FCMOVB ST(0), ST(1)	**C9** FCMOVE ST(0), ST(1)	**D1** FCMOVBE ST(0), ST(1)	**D9** FCMOVU ST(0), ST(1)	**E1** invalid	**E9** FUCOMPP	**F1** invalid	**F9** invalid
		C2 FCMOVB ST(0), ST(2)	**CA** FCMOVE ST(0), ST(2)	**D2** FCMOVBE ST(0), ST(2)	**DA** FCMOVU ST(0), ST(2)	**E2** invalid	**EA** invalid	**F2** invalid	**FA** invalid
		C3 FCMOVB ST(0), ST(3)	**CB** FCMOVE ST(0), ST(3)	**D3** FCMOVBE ST(0), ST(3)	**DB** FCMOVU ST(0), ST(3)	**E3** invalid	**EB** invalid	**F3** invalid	**FB** invalid
		C4 FCMOVB ST(0), ST(4)	**CC** FCMOVE ST(0), ST(4)	**D4** FCMOVBE ST(0), ST(4)	**DC** FCMOVU ST(0), ST(4)	**E4** invalid	**EC** invalid	**F4** invalid	**FC** invalid
		C5 FCMOVB ST(0), ST(5)	**CD** FCMOVE ST(0), ST(5)	**D5** FCMOVBE ST(0), ST(5)	**DD** FCMOVU ST(0), ST(5)	**E5** invalid	**ED** invalid	**F5** invalid	**FD** invalid
		C6 FCMOVB ST(0), ST(6)	**CE** FCMOVE ST(0), ST(6)	**D6** FCMOVBE ST(0), ST(6)	**DE** FCMOVU ST(0), ST(6)	**E6** invalid	**EE** invalid	**F6** invalid	**FE** invalid
		C7 FCMOVB ST(0), ST(7)	**CF** FCMOVE ST(0), ST(7)	**D7** FCMOVBE ST(0), ST(7)	**DF** FCMOVU ST(0), ST(7)	**E7** invalid	**EF** invalid	**F7** invalid	**FF** invalid

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	/0	/1	/2	/3	/4	/5	/6	/7
DB	!11	00–BF							
		FILD mem32int	FISTTP mem32int	FIST mem32int	FISTP mem32int	invalid	FLD mem80real	invalid	FSTP mem80real
	11	**C0** FCMOVNB ST(0), ST(0)	**C8** FCMOVNE ST(0), ST(0)	**D0** FCMOVNBE ST(0), ST(0)	**D8** FCMOVNU ST(0), ST(0)	**E0** reserved	**E8** FUCOMI ST(0), ST(0)	**F0** FCOMI ST(0), ST(0)	**F8** invalid
		C1 FCMOVNB ST(0), ST(1)	**C9** FCMOVNE ST(0), ST(1)	**D1** FCMOVNBE ST(0), ST(1)	**D9** FCMOVNU ST(0), ST(1)	**E1** reserved	**E9** FUCOMI ST(0), ST(1)	**F1** FCOMI ST(0), ST(1)	**F9** invalid
		C2 FCMOVNB ST(0), ST(2)	**CA** FCMOVNE ST(0), ST(2)	**D2** FCMOVNBE ST(0), ST(2)	**DA** FCMOVNU ST(0), ST(2)	**E2** FNCLEX	**EA** FUCOMI ST(0), ST(2)	**F2** FCOMI ST(0), ST(2)	**FA** invalid
		C3 FCMOVNB ST(0), ST(3)	**CB** FCMOVNE ST(0), ST(3)	**D3** FCMOVNBE ST(0), ST(3)	**DB** FCMOVNU ST(0), ST(3)	**E3** FNINIT	**EB** FUCOMI ST(0), ST(3)	**F3** FCOMI ST(0), ST(3)	**FB** invalid
		C4 FCMOVNB ST(0), ST(4)	**CC** FCMOVNE ST(0), ST(4)	**D4** FCMOVNBE ST(0), ST(4)	**DC** FCMOVNU ST(0), ST(4)	**E4** reserved	**EC** FUCOMI ST(0), ST(4)	**F4** FCOMI ST(0), ST(4)	**FC** invalid
		C5 FCMOVNB ST(0), ST(5)	**CD** FCMOVNE ST(0), ST(5)	**D5** FCMOVNBE ST(0), ST(5)	**DD** FCMOVNU ST(0), ST(5)	**E5** invalid	**ED** FUCOMI ST(0), ST(5)	**F5** FCOMI ST(0), ST(5)	**FD** invalid
		C6 FCMOVNB ST(0), ST(6)	**CE** FCMOVNE ST(0), ST(6)	**D6** FCMOVNBE ST(0), ST(6)	**DE** FCMOVNU ST(0), ST(6)	**E6** invalid	**EE** FUCOMI ST(0), ST(6)	**F6** FCOMI ST(0), ST(6)	**FE** invalid
		C7 FCMOVNB ST(0), ST(7)	**CF** FCMOVNE ST(0), ST(7)	**D7** FCMOVNBE ST(0), ST(7)	**DF** FCMOVNU ST(0), ST(7)	**E7** invalid	**EF** FUCOMI ST(0), ST(7)	**F7** FCOMI ST(0), ST(7)	**FF** invalid

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
DC	!11	00–BF FADD mem64real	FMUL mem64real	FCOM mem64real	FCOMP mem64real	FSUB mem64real	FSUBR mem64real	FDIV mem64real	FDIVR mem64real
	11	**C0** FADD ST(0), ST(0)	**C8** FMUL ST(0), ST(0)	**D0** reserved	**D8** reserved	**E0** FSUBR ST(0), ST(0)	**E8** FSUB ST(0), ST(0)	**F0** FDIVR ST(0), ST(0)	**F8** FDIV ST(0), ST(0)
		C1 FADD ST(1), ST(0)	**C9** FMUL ST(1), ST(0)	**D1** reserved	**D9** reserved	**E1** FSUBR ST(1), ST(0)	**E9** FSUB ST(1), ST(0)	**F1** FDIVR ST(1), ST(0)	**F9** FDIV ST(1), ST(0)
		C2 FADD ST(2), ST(0)	**CA** FMUL ST(2), ST(0)	**D2** reserved	**DA** reserved	**E2** FSUBR ST(2), ST(0)	**EA** FSUB ST(2), ST(0)	**F2** FDIVR ST(2), ST(0)	**FA** FDIV ST(2), ST(0)
		C3 FADD ST(3), ST(0)	**CB** FMUL ST(3), ST(0)	**D3** reserved	**DB** reserved	**E3** FSUBR ST(3), ST(0)	**EB** FSUB ST(3), ST(0)	**F3** FDIVR ST(3), ST(0)	**FB** FDIV ST(3), ST(0)
		C4 FADD ST(4), ST(0)	**CC** FMUL ST(4), ST(0)	**D4** reserved	**DC** reserved	**E4** FSUBR ST(4), ST(0)	**EC** FSUB ST(4), ST(0)	**F4** FDIVR ST(4), ST(0)	**FC** FDIV ST(4), ST(0)
		C5 FADD ST(5), ST(0)	**CD** FMUL ST(5), ST(0)	**D5** reserved	**DD** reserved	**E5** FSUBR ST(5), ST(0)	**ED** FSUB ST(5), ST(0)	**F5** FDIVR ST(5), ST(0)	**FD** FDIV ST(5), ST(0)
		C6 FADD ST(6), ST(0)	**CE** FMUL ST(6), ST(0)	**D6** reserved	**DE** reserved	**E6** FSUBR ST(6), ST(0)	**EE** FSUB ST(6), ST(0)	**F6** FDIVR ST(6), ST(0)	**FE** FDIV ST(6), ST(0)
		C7 FADD ST(7), ST(0)	**CF** FMUL ST(7), ST(0)	**D7** reserved	**DF** reserved	**E7** FSUBR ST(7), ST(0)	**EF** FSUB ST(7), ST(0)	**F7** FDIVR ST(7), ST(0)	**FF** FDIV ST(7), ST(0)

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
DD	!11	00–BF FLD mem64real	FISTTP mem64int	FST mem64real	FSTP mem64real	FRSTOR mem98/108env	invalid	FNSAVE mem98/108env	FNSTSW mem16
	11	**C0** FFREE ST(0)	**C8** reserved	**D0** FST ST(0)	**D8** FSTP ST(0)	**E0** FUCOM ST(0), ST(0)	**E8** FUCOMP ST(0)	**F0** invalid	**F8** invalid
		C1 FFREE ST(1)	**C9** reserved	**D1** FST ST(1)	**D9** FSTP ST(1)	**E1** FUCOM ST(1), ST(0)	**E9** FUCOMP ST(1)	**F1** invalid	**F9** invalid
		C2 FFREE ST(2)	**CA** reserved	**D2** FST ST(2)	**DA** FSTP ST(2)	**E2** FUCOM ST(2), ST(0)	**EA** FUCOMP ST(2)	**F2** invalid	**FA** invalid
		C3 FFREE ST(3)	**CB** reserved	**D3** FST ST(3)	**DB** FSTP ST(3)	**E3** FUCOM ST(3), ST(0)	**EB** FUCOMP ST(3)	**F3** invalid	**FB** invalid
		C4 FFREE ST(4)	**CC** reserved	**D4** FST ST(4)	**DC** FSTP ST(4)	**E4** FUCOM ST(4), ST(0)	**EC** FUCOMP ST(4)	**F4** invalid	**FC** invalid
		C5 FFREE ST(5)	**CD** reserved	**D5** FST ST(5)	**DD** FSTP ST(5)	**E5** FUCOM ST(5), ST(0)	**ED** FUCOMP ST(5)	**F5** invalid	**FD** invalid
		C6 FFREE ST(6)	**CE** reserved	**D6** FST ST(6)	**DE** FSTP ST(6)	**E6** FUCOM ST(6), ST(0)	**EE** FUCOMP ST(6)	**F6** invalid	**FE** invalid
		C7 FFREE ST(7)	**CF** reserved	**D7** FST ST(7)	**DF** FSTP ST(7)	**E7** FUCOM ST(7), ST(0)	**EF** FUCOMP ST(7)	**F7** invalid	**FF** invalid

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field /0	/1	/2	/3	/4	/5	/6	/7
DE	!11	00–BF							
		FIADD mem16int	FIMUL mem16int	FICOM mem16int	FICOMP mem16int	FISUB mem16int	FISUBR mem16int	FIDIV mem16int	FIDIVR mem16int
	11	**C0** FADDP ST(0), ST(0)	**C8** FMULP ST(0), ST(0)	**D0** reserved	**D8** invalid	**E0** FSUBRP ST(0), ST(0)	**E8** FSUBP ST(0), ST(0)	**F0** FDIVRP ST(0), ST(0)	**F8** FDIVP ST(0), ST(0)
		C1 FADDP ST(1), ST(0)	**C9** FMULP ST(1), ST(0)	**D1** reserved	**D9** FCOMPP	**E1** FSUBRP ST(1), ST(0)	**E9** FSUBP ST(1), ST(0)	**F1** FDIVRP ST(1), ST(0)	**F9** FDIVP ST(1), ST(0)
		C2 FADDP ST(2), ST(0)	**CA** FMULP ST(2), ST(0)	**D2** reserved	**DA** invalid	**E2** FSUBRP ST(2), ST(0)	**EA** FSUBP ST(2), ST(0)	**F2** FDIVRP ST(2), ST(0)	**FA** FDIVP ST(2), ST(0)
		C3 FADDP ST(3), ST(0)	**CB** FMULP ST(3), ST(0)	**D3** reserved	**DB** invalid	**E3** FSUBRP ST(3), ST(0)	**EB** FSUBP ST(3), ST(0)	**F3** FDIVRP ST(3), ST(0)	**FB** FDIVP ST(3), ST(0)
		C4 FADDP ST(4), ST(0)	**CC** FMULP ST(4), ST(0)	**D4** reserved	**DC** invalid	**E4** FSUBRP ST(4), ST(0)	**EC** FSUBP ST(4), ST(0)	**F4** FDIVRP ST(4), ST(0)	**FC** FDIVP ST(4), ST(0)
		C5 FADDP ST(5), ST(0)	**CD** FMULP ST(5), ST(0)	**D5** reserved	**DD** invalid	**E5** FSUBRP ST(5), ST(0)	**ED** FSUBP ST(5), ST(0)	**F5** FDIVRP ST(5), ST(0)	**FD** FDIVP ST(5), ST(0)
		C6 FADDP ST(6), ST(0)	**CE** FMULP ST(6), ST(0)	**D6** reserved	**DE** invalid	**E6** FSUBRP ST(6), ST(0)	**EE** FSUBP ST(6), ST(0)	**F6** FDIVRP ST(6), ST(0)	**FE** FDIVP ST(6), ST(0)
		C7 FADDP ST(7), ST(0)	**CF** FMULP ST(7), ST(0)	**D7** reserved	**DF** invalid	**E7** FSUBRP ST(7), ST(0)	**EF** FSUBP ST(7), ST(0)	**F7** FDIVRP ST(7), ST(0)	**FF** FDIVP ST(7), ST(0)

Table A-10. x87 Opcodes and ModRM Extensions (continued)

Opcode	ModRM *mod* Field	ModRM *reg* Field							
		/0	/1	/2	/3	/4	/5	/6	/7
DF	!11	00–BF							
		FILD mem16int	FISTTP mem16int	FIST mem16int	FISTP mem16int	FBLD mem80dec	FILD mem64int	FBSTP mem80dec	FISTP mem64int
	11	**C0** reserved	**C8** reserved	**D0** reserved	**D8** reserved	**E0** FNSTSW AX	**E8** FUCOMIP ST(0), ST(0)	**F0** FCOMIP ST(0), ST(0)	**F8** invalid
		C1 reserved	**C9** reserved	**D1** reserved	**D9** reserved	**E1** invalid	**E9** FUCOMIP ST(0), ST(1)	**F1** FCOMIP ST(0), ST(1)	**F9** invalid
		C2 reserved	**CA** reserved	**D2** reserved	**DA** reserved	**E2** invalid	**EA** FUCOMIP ST(0), ST(2)	**F2** FCOMIP ST(0), ST(2)	**FA** invalid
		C3 reserved	**CB** reserved	**D3** reserved	**DB** reserved	**E3** invalid	**EB** FUCOMIP ST(0), ST(3)	**F3** FCOMIP ST(0), ST(3)	**FB** invalid
		C4 reserved	**CC** reserved	**D4** reserved	**DC** reserved	**E4** invalid	**EC** FUCOMIP ST(0), ST(4)	**F4** FCOMIP ST(0), ST(4)	**FC** invalid
		C5 reserved	**CD** reserved	**D5** reserved	**DD** reserved	**E5** invalid	**ED** FUCOMIP ST(0), ST(5)	**F5** FCOMIP ST(0), ST(5)	**FD** invalid
		C6 reserved	**CE** reserved	**D6** reserved	**DE** reserved	**E6** invalid	**EE** FUCOMIP ST(0), ST(6)	**F6** FCOMIP ST(0), ST(6)	**FE** invalid
		C7 reserved	**CF** reserved	**D7** reserved	**DF** reserved	**E7** invalid	**EF** FUCOMIP ST(0), ST(7)	**F7** FCOMIP ST(0), ST(7)	**FF** invalid

A.2.8 rFLAGS Condition Codes for x87 Opcodes

Table A-11 shows the rFLAGS condition codes specified by the opcode and ModRM bytes of the FCMOV*cc* instructions.

Table A-11. rFLAGS Condition Codes for FCMOV*cc*

Opcode (hex)	ModRM *mod* Field	ModRM *reg* Field	rFLAGS Value	cc Mnemonic	Condition
DA	11	000	CF = 1	B	Below
		001	ZF = 1	E	Equal
		010	CF = 1 or ZF = 1	BE	Below or Equal
		011	PF = 1	U	Unordered
DB		000	CF = 0	NB	Not Below
		001	ZF = 0	NE	Not Equal
		010	CF = 0 and ZF = 0	NBE	Not Below or Equal
		011	PF = 0	NU	Not Unordered

A.3 Operand Encodings

Register and memory operands are encoded using the *mode-register-memory* (ModRM) and the *scale-index-base* (SIB) bytes that follow the opcodes. In some instructions, the ModRM byte is followed by an SIB byte, which defines the instruction's memory-addressing mode for the complex-addressing modes.

A.3.1 ModRM Operand References

Figure A-2 on page 364 shows the format of a ModRM byte. There are three fields—*mod, reg*, and *r/m*. The *reg* field not only provides additional opcode bits—as described above beginning with "ModRM Extensions to One-Byte and Two-Byte Opcodes" on page 348 and ending with "x87 Encodings" on page 354—but is also used with the other two fields to specify operands. The *mod* and *r/m* fields are used together with each other and, in 64-bit mode, with the REX.R and REX.B bits of the REX prefix, to specify the location of the instruction's operands and certain of the possible addressing modes (specifically, the non-complex modes).

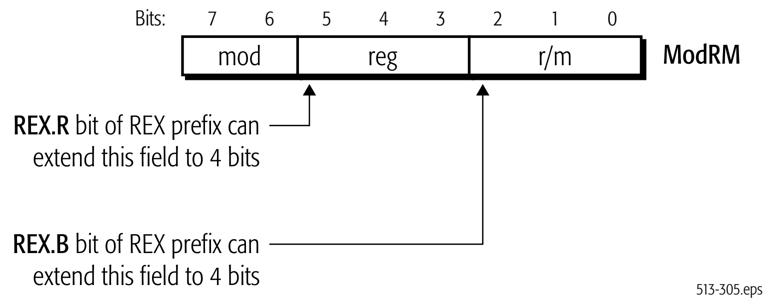


Figure A-2. ModRM-Byte Format

The two sections below describe the ModRM operand encodings, first for 16-bit references and then for 32-bit and 64-bit references.

16-Bit Register and Memory References. Table A-12 shows the notation and encoding conventions for register references using the ModRM *reg* field. This table is comparable to Table A-14 on page 367 but applies only when the address-size is 16-bit. Table A-13 on page 365 shows the notation and encoding conventions for 16-bit memory references using the ModRM byte. This table is comparable to Table A-15 on page 368.

Table A-12. ModRM Register References, 16-Bit Addressing

Mnemonic Notation	ModRM *reg* Field							
	/0	/1	/2	/3	/4	/5	/6	/7
reg8	AL	CL	DL	BL	AH	CH	DH	BH
reg16	AX	CX	DX	BX	SP	BP	SI	DI
reg32	EAX	ECX	EDX	EBX	ESP	EBP	ESI	EDI
mmx	MMX0	MMX1	MMX2	MMX3	MMX4	MMX5	MMX6	MMX7
xmm	XMM0	XMM1	XMM2	XMM3	XMM4	XMM5	XMM6	XMM7
sReg	ES	CS	SS	DS	FS	GS	invalid	invalid
cReg	CR0	CR1	CR2	CR3	CR4	CR5	CR6	CR7
dReg	DR0	DR1	DR2	DR3	DR4	DR5	DR6	DR7

Table A-13. ModRM Memory References, 16-Bit Addressing

Effective Address[1]	ModRM *mod* Field (binary)	ModRM *reg* Field[2]								ModRM *r/m* Field (binary)
		/0	/1	/2	/3	/4	/5	/6	/7	
		Complete ModRM Byte (hex)								
[BX+SI]	00	00	08	10	18	20	28	30	38	000
[BX+DI]		01	09	11	19	21	29	31	39	001
[BP+SI]		02	0A	12	1A	22	2A	32	3A	010
[BP+DI]		03	0B	13	1B	23	2B	33	3B	011
[SI]		04	0C	14	1C	24	2C	34	3C	100
[DI]		05	0D	15	1D	25	2D	35	3D	101
[*disp16*]		06	0E	16	1E	26	2E	36	3E	110
[BX]		07	0F	17	1F	27	2F	37	3F	111
[BX+SI+*disp8*]	01	40	48	50	58	60	68	70	78	000
[BX+DI+*disp8*]		41	49	51	59	61	69	71	79	001
[BP+SI+*disp8*]		42	4A	52	5A	62	6A	72	7A	010
[BP+DI+*disp8*]		43	4B	53	5B	63	6B	73	7B	011
[SI+*disp8*]		44	4C	54	5C	64	6C	74	7C	100
[DI+*disp8*]		45	4D	55	5D	65	6D	75	7D	101
[BP+*disp8*]		46	4E	56	5E	66	6E	76	7E	110
[BX+*disp8*]		47	4F	57	5F	67	6F	77	7F	111
[BX+SI+*disp16*]	10	80	88	90	98	A0	A8	B0	B8	000
[BX+DI+*disp16*]		81	89	91	99	A1	A9	B1	B9	001
[BP+SI+*disp16*]		82	8A	92	9A	A2	AA	B2	BA	010
[BP+DI+*disp16*]		83	8B	93	9B	A3	AB	B3	BB	011
[SI+*disp16*]		84	8C	94	9C	A4	AC	B4	BC	100
[DI+*disp16*]		85	8D	95	9D	A5	AD	B5	BD	101
[BP+*disp16*]		86	8E	96	9E	A6	AE	B6	BE	110
[BX+*disp16*]		87	8F	97	9F	A7	AF	B7	BF	111

Note:

1. *In these combinations, "disp8" and "disp16" indicate an 8-bit or 16-bit signed displacement.*
2. *See Table A-12 for complete specification of ModRM "reg" field.*

Table A-13. ModRM Memory References, 16-Bit Addressing (continued)

Effective Address[1]	ModRM mod Field (binary)	ModRM reg Field[2] /0	/1	/2	/3	/4	/5	/6	/7	ModRM r/m Field (binary)
		Complete ModRM Byte (hex)								
AL/AX/EAX/MMX0/XMM0	11	C0	C8	D0	D8	E0	E8	F0	F8	000
CL/CX/ECX/MMX1/XMM1		C1	C9	D1	D9	E1	E9	F1	F9	001
DL/DX/EDX/MMX2/XMM2		C2	CA	D2	DA	E2	EA	F2	FA	010
BL/BX/EBX/MMX3/XMM3		C3	CB	D3	DB	E3	EB	F3	FB	011
AH/SP/ESP/MMX4/XMM4		C4	CC	D4	DC	E4	EC	F4	FC	100
CH/BP/EBP/MMX5/XMM5		C5	CD	D5	DD	E5	ED	F5	FD	101
DH/SI/ESI/MMX6/XMM6		C6	CE	D6	DE	E6	EE	F6	FE	110
BH/DI/EDI/MMX7/XMM7		C7	CF	D7	DF	E7	EF	F7	FF	111

Note:

1. *In these combinations, "disp8" and "disp16" indicate an 8-bit or 16-bit signed displacement.*
2. *See Table A-12 for complete specification of ModRM "reg" field.*

Register and Memory References for 32-Bit and 64-Bit Addressing. Table A-14 on page 367 shows the encoding for 32-bit and 64-bit register references using the ModRM *reg* field. The first nine rows of Table A-14 show references when the REX.R bit is cleared to 0, and the last nine rows show references when the REX.R bit is set to 1. In this table, *Mnemonic Notation* means the syntax notation shown in "Mnemonic Syntax" on page 37 for a register, and *ModRM Notation (/r)* means the opcode-syntax notation shown in "Opcode Syntax" on page 39 for the register.

Table A-15 on page 368 shows the encoding for 32-bit and 64-bit memory references using the ModRM byte. This table describes 32-bit and 64-bit addressing, with the REX.B bit set or cleared. The *Effective Address* is shown in the two left-most columns, followed by the binary encoding of the ModRM-byte *mod* field, followed by the eight possible hex values of the complete ModRM byte (one value for each binary encoding of the ModRM-byte *reg* field), followed by the binary encoding of the ModRM *r/m* field.

The /0 through /7 notation for the ModRM *reg* field (bits 5–3) means that the three-bit field contains a value from zero (binary 000) to 7 (binary 111).

Table A-14. ModRM Register References, 32-Bit and 64-Bit Addressing

Mnemonic Notation	REX.R Bit	ModRM *reg* Field							
		/0	/1	/2	/3	/4	/5	/6	/7
reg8	0	AL	CL	DL	BL	AH/SPL	CH/BPL	DH/SIL	BH/DIL
reg16		AX	CX	DX	BX	SP	BP	SI	DI
reg32		EAX	ECX	EDX	EBX	ESP	EBP	ESI	EDI
reg64		RAX	RCX	RDX	RBX	RSP	RBP	RSI	RDI
mmx		MMX0	MMX1	MMX2	MMX3	MMX4	MMX5	MMX6	MMX7
xmm		XMM0	XMM1	XMM2	XMM3	XMM4	XMM5	XMM6	XMM7
sReg		ES	CS	SS	DS	FS	GS	invalid	invalid
cReg		CR0	CR1	CR2	CR3	CR4	CR5	CR6	CR7
dReg		DR0	DR1	DR2	DR3	DR4	DR5	DR6	DR7
reg8	1	R8B	R9B	R10B	R11B	R12B	R13B	R14B	R15B
reg16		R8W	R9W	R10W	R11W	R12W	R13W	R14W	R15W
reg32		R8D	R9D	R10D	R11D	R12D	R13D	R14D	R15D
reg64		R8	R9	R10	R11	R12	R13	R14	R15
mmx		MMX0	MMX1	MMX2	MMX3	MMX4	MMX5	MMX6	MMX7
xmm		XMM8	XMM9	XMM10	XMM11	XMM12	XMM13	XMM14	XMM15
sReg		ES	CS	SS	DS	FS	GS	invalid	invalid
cReg		CR8	CR9	CR10	CR11	CR12	CR13	CR14	CR15
dReg		DR8	DR9	DR10	DR11	DR12	DR13	DR14	DR15

Table A-15. ModRM Memory References, 32-Bit and 64-Bit Addressing

Effective Address[1]		ModRM mod Field (binary)	ModRM reg Field[3]								ModRM r/m Field (binary)
			/0	/1	/2	/3	/4	/5	/6	/7	
REX.B = 0	REX.B = 1		Complete ModRM Byte (hex)								
[rAX]	[r8]	00	00	08	10	18	20	28	30	38	000
[rCX]	[r9]		01	09	11	19	21	29	31	39	001
[rDX]	[r10]		02	0A	12	1A	22	2A	32	3A	010
[rBX]	[r11]		03	0B	13	1B	23	2B	33	3B	011
[SIB][4]	[SIB][4]		04	0C	14	1C	24	2C	34	3C	100
[rIP+*disp32*] or [*disp32*][2]	[rIP+*disp32*] or [*disp32*][2]		05	0D	15	1D	25	2D	35	3D	101
[rSI]	[r14]		06	0E	16	1E	26	2E	36	3E	110
[rDI]	[r15]		07	0F	17	1F	27	2F	37	3F	111
[rAX+*disp8*]	[r8+*disp8*]	01	40	48	50	58	60	68	70	78	000
[rCX+*disp8*]	[r9+*disp8*]		41	49	51	59	61	69	71	79	001
[rDX+*disp8*]	[r10+*disp8*]		42	4A	52	5A	62	6A	72	7A	010
[rBX+*disp8*]	[r11+*disp8*]		43	4B	53	5B	63	6B	73	7B	011
[SIB+*disp8*][4]	[SIB+*disp8*][4]		44	4C	54	5C	64	6C	74	7C	100
[rBP+*disp8*]	[r13+*disp8*]		45	4D	55	5D	65	6D	75	7D	101
[rSI+*disp8*]	[r14+*disp8*]		46	4E	56	5E	66	6E	76	7E	110
[rDI+*disp8*]	[r15+*disp8*]		47	4F	57	5F	67	6F	77	7F	111
[rAX+*disp32*]	[r8+*disp32*]	10	80	88	90	98	A0	A8	B0	B8	000
[rCX+*disp32*]	[r9+*disp32*]		81	89	91	99	A1	A9	B1	B9	001
[rDX+*disp32*]	[r10+*disp32*]		82	8A	92	9A	A2	AA	B2	BA	010
[rBX+*disp32*]	[r11+*disp32*]		83	8B	93	9B	A3	AB	B3	BB	011
[SIB+*disp32*][4]	[SIB+*disp32*][4]		84	8C	94	9C	A4	AC	B4	BC	100
[rBP+*disp32*]	[r13+*disp32*]		85	8D	95	9D	A5	AD	B5	BD	101
[rSI+*disp32*]	[r14+*disp32*]		86	8E	96	9E	A6	AE	B6	BE	110
[rDI+*disp32*]	[r15+*disp32*]		87	8F	97	9F	A7	AF	B7	BF	111

Note:

1. *In these combinations, "disp8" and "disp32" indicate an 8-bit or 32-bit signed displacement.*
2. *In 64-bit mode, the effective address is [rIP+disp32]. In all other modes, the effective address is [disp32]. If the address-size prefix is used in 64-bit mode to override 64-bit addressing, the [RIP+disp32] effective address is truncated after computation to 64 bits.*
3. *See Table A-14 for complete specification of ModRM "reg" field.*
4. *An SIB byte follows the ModRM byte to identify the memory operand.*

Table A-15. ModRM Memory References, 32-Bit and 64-Bit Addressing (continued)

Effective Address[1]		ModRM *mod* Field (binary)	ModRM *reg* Field[3]								ModRM *r/m* Field (binary)
			/0	/1	/2	/3	/4	/5	/6	/7	
REX.B = 0	REX.B = 1		Complete ModRM Byte (hex)								
AL/rAX/MMX0/XMM0	r8/MMX0/XMM8	11	C0	C8	D0	D8	E0	E8	F0	F8	000
CL/rCX/MMX1/XMM1	r9/MMX1/XMM9		C1	C9	D1	D9	E1	E9	F1	F9	001
DL/rDX/MMX2/XMM2	r10/MMX2/XMM10		C2	CA	D2	DA	E2	EA	F2	FA	010
BL/rBX/MMX3/XMM3	r11/MMX3/XMM11		C3	CB	D3	DB	E3	EB	F3	FB	011
AH/SPL/rSP/MMX4/XMM4	r12/MMX4/XMM12		C4	CC	D4	DC	E4	EC	F4	FC	100
CH/BPL/rBP/MMX5/XMM5	r13/MMX5/XMM13		C5	CD	D5	DD	E5	ED	F5	FD	101
DH/SIL/rSI/MMX6/XMM6	r14/MMX6/XMM14		C6	CE	D6	DE	E6	EE	F6	FE	110
BH/DIL/rDI/MMX7/XMM7	r15/MMX7/XMM15		C7	CF	D7	DF	E7	EF	F7	FF	111

Note:

1. *In these combinations, “disp8” and “disp32” indicate an 8-bit or 32-bit signed displacement.*
2. *In 64-bit mode, the effective address is [rIP+disp32]. In all other modes, the effective address is [disp32]. If the address-size prefix is used in 64-bit mode to override 64-bit addressing, the [RIP+disp32] effective address is truncated after computation to 64 bits.*
3. *See Table A-14 for complete specification of ModRM “reg” field.*
4. *An SIB byte follows the ModRM byte to identify the memory operand.*

A.3.2 SIB Operand References

Figure A-3 on page 370 shows the format of a scale-index-base (SIB) byte. Some instructions have an SIB byte following their ModRM byte to define memory addressing for the complex-addressing modes described in “Effective Addresses” in Volume 1. The SIB byte has three fields—*scale, index*, and *base*—that define the scale factor, index-register number, and base-register number for 32-bit and 64-bit complex addressing modes. In 64-bit mode, the REX.B and REX.X bits extend the encoding of the SIB byte’s *base* and *index* fields.

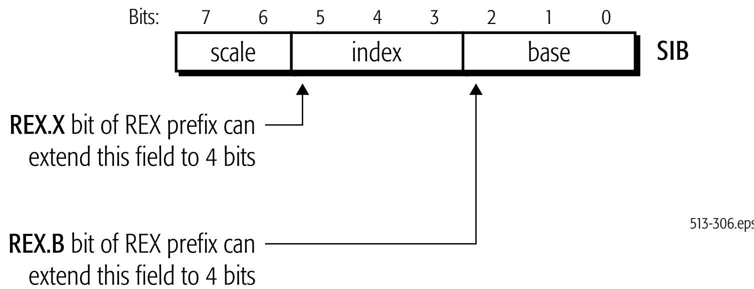


Figure A-3. SIB Byte Format

Table A-16 shows the encodings for the SIB byte's *base* field, which specifies the base register for addressing. Table A-17 on page 371 shows the encodings for the effective address referenced by a complete SIB byte, including its *scale* and *index* fields. The /0 through /7 notation for the SIB *base* field means that the three-bit field contains a value between zero (binary 000) and 7 (binary 111).

Table A-16. SIB *base* Field References

REX.B Bit	ModRM *mod* Field	SIB *base* Field							
		/0	/1	/2	/3	/4	/5	/6	/7
	00						*disp32*		
0	01	rAX	rCX	rDX	rBX	rSP	rBP+*disp8*	rSI	rDI
	10						rBP+*disp32*		
	00						disp32		
1	01	r8	r9	r10	r11	r12	r13+*disp8*	r14	r15
	10						r13+*disp32*		

Table A-17. SIB Memory References

Effective Address		SIB *scale* Field	SIB *index* Field	SIB *base* Field[1]								
				REX.B = 0:	rAX	rCX	rDX	rBX	rSP	note 1	rSI	rDI
				REX.B = 1:	r8	r9	r10	r11	r12	note 1	r14	r15
					/0	/1	/2	/3	/4	/5	/6	/7
REX.X = 0	REX.X = 1				Complete SIB Byte (hex)							
[rAX+base]	[r8+base]	00	000		00	01	02	03	04	05	06	07
[rCX+base]	[r9+base]		001		08	09	0A	0B	0C	0D	0E	0F
[rDX+base]	[r10+base]		010		10	11	12	13	14	15	16	17
[rBX+base]	[r11+base]		011		18	19	1A	1B	1C	1D	1E	1F
[base]	[r12+base]		100		20	21	22	23	24	25	26	27
[rBP+base]	[r13+base]		101		28	29	2A	2B	2C	2D	2E	2F
[rSI+base]	[r14+base]		110		30	31	32	33	34	35	36	37
[rDI+base]	[r15+base]		111		38	39	3A	3B	3C	3D	3E	3F
[rAX*2+base]	[r8*2+base]	01	000		40	41	42	43	44	45	46	47
[rCX*2+base]	[r9*2+base]		001		48	49	4A	4B	4C	4D	4E	4F
[rDX*2+base]	[r10*2+base]		010		50	51	52	53	54	55	56	57
[rBX*2+base]	[r11*2+base]		011		58	59	5A	5B	5C	5D	5E	5F
[base]	[r12*2+base]		100		60	61	62	63	64	65	66	67
[rBP*2+base]	[r13*2+base]		101		68	69	6A	6B	6C	6D	6E	6F
[rSI*2+base]	[r14*2+base]		110		70	71	72	73	74	75	76	77
[rDI*2+base]	[r15*2+base]		111		78	79	7A	7B	7C	7D	7E	7F
[rAX*4+base]	[r8*4+base]	10	000		80	81	82	83	84	85	86	87
[rCX*4+base]	[r9*4+base]		001		88	89	8A	8B	8C	8D	8E	8F
[rDX*4+base]	[r10*4+base]		010		90	91	92	93	94	95	96	97
[rBX*4+base]	[r11*4+base]		011		98	99	9A	9B	9C	9D	9E	9F
[base]	[r12*4+base]		100		A0	A1	A2	A3	A4	A5	A6	A7
[rBP*4+base]	[r13*4+base]		101		A8	A9	AA	AB	AC	AD	AE	AF
[rSI*4+base]	[r14*4+base]		110		B0	B1	B2	B3	B4	B5	B6	B7
[rDI*4+base]	[r15*4+base]		111		B8	B9	BA	BB	BC	BD	BE	BF

Note:

1. *See Table A-16 on page 370 for complete specification of SIB "base" field.*

Table A-17. SIB Memory References (continued)

Effective Address		SIB *scale* Field	SIB *index* Field	SIB *base* Field[1]								
				REX.B = 0:	rAX	rCX	rDX	rBX	rSP	note 1	rSI	rDI
				REX.B = 1:	r8	r9	r10	r11	r12	note 1	r14	r15
					/0	/1	/2	/3	/4	/5	/6	/7
REX.X = 0	REX.X = 1				Complete SIB Byte (hex)							
[rAX*8+base]	[r8*8+base]	11	000		C0	C1	C2	C3	C4	C5	C6	C7
[rCX*8+base]	[r9*8+base]		001		C8	C9	CA	CB	CC	CD	CE	CF
[rDX*8+base]	[r10*8+base]		010		D0	D1	D2	D3	D4	D5	D6	D7
[rBX*8+base]	[r11*8+base]		011		D8	D9	DA	DB	DC	DD	DE	DF
[base]	[r12*8+base]		100		E0	E1	E2	E3	E4	E5	E6	E7
[rBP*8+base]	[r13*8+base]		101		E8	E9	EA	EB	EC	ED	EE	EF
[rSI*8+base]	[r14*8+base]		110		F0	F1	F2	F3	F4	F5	F6	F7
[rDI*8+base]	[r15*8+base]		111		F8	F9	FA	FB	FC	FD	FE	FF

Note:

1. *See Table A-16 on page 370 for complete specification of SIB "base" field.*

Appendix B General-Purpose Instructions in 64-Bit Mode

This appendix provides details of the general-purpose instructions in 64-bit mode and its differences from legacy and compatibility modes. The appendix covers only the general-purpose instructions (those described in *Chapter 3, "General-Purpose Instruction Reference"*). It does not cover the 128-bit media, 64-bit media, or x87 floating-point instructions because those instructions are not affected by 64-bit mode, other than in the access by such instructions to extended GPR and XMM registers when using a REX prefix.

B.1 General Rules for 64-Bit Mode

In 64-bit mode, the following general rules apply to instructions and their operands:

- **"Promoted to 64 Bit"**: If an instruction's operand size (16-bit or 32-bit) in legacy and compatibility modes depends on the CS.D bit and the operand-size override prefix, then the operand-size choices in 64-bit mode are extended from 16-bit and 32-bit to include 64 bits (with a REX prefix), or the operand size is fixed at 64 bits. Such instructions are said to be "*Promoted to 64 bits"* in Table B-1. However, byte-operand opcodes of such instructions are not promoted.
- **Byte-Operand Opcodes Not Promoted**: As stated above in "Promoted to 64 Bit", byte-operand opcodes of promoted instructions are not promoted. Those opcodes continue to operate only on bytes.
- **Fixed Operand Size**: If an instruction's operand size is fixed in legacy mode (thus, independent of CS.D and prefix overrides), that operand size is usually fixed at the same size in 64-bit mode. For example, CPUID operates on 32-bit operands, irrespective of attempts to override the operand size.
- **Default Operand Size**: The default operand size for most instructions is 32 bits, and a REX prefix must be used to change the operand size to 64 bits. However, two groups of instructions default to 64-bit operand size and do not need a REX prefix: (1) near branches and (2) all instructions, except far branches, that implicitly reference the RSP. See Table B-5 on page 400 for a list of all instructions that default to 64-bit operand size.
- **Zero-Extension of 32-Bit Results**: Operations on 32-bit operands in 64-bit mode zero-extend the high 32 bits of 64-bit GPR destination registers.
- **No Extension of 8-Bit and 16-Bit Results**: Operations on 8-bit and 16-bit operands in 64-bit mode leave the high 56 or 48 bits, respectively, of 64-bit GPR destination registers unchanged.
- **Shift and Rotate Counts**: When the operand size is 64 bits, shifts and rotates use one additional bit (6 bits total) to specify shift-count or rotate-count, allowing 64-bit shifts and rotates.
- **Immediates**: The maximum size of immediate operands is 32 bits, except that 64-bit immediates can be MOVed into 64-bit GPRs. Immediates that are less than 64 bits are a maximum of 32 bits, and are sign-extended to 64 bits during use.

- **Displacements and Offsets**: The maximum size of an address displacement or offset is 32 bits, except that 64-bit offsets can be used by specific MOV opcodes that read or write AL or rAX. Displacements and offsets that are less than 64 bits are a maximum of 32 bits, and are sign-extended to 64 bits during use.
- **Undefined High 32 Bits After Mode Change**: The processor does not preserve the upper 32 bits of the 64-bit GPRs across switches from 64-bit mode to compatibility or legacy modes. In compatibility or legacy mode, the upper 32 bits of the GPRs are undefined and not accessible to software.

B.2 Operation and Operand Size in 64-Bit Mode

Table B-1 on page 374 lists the integer instructions, showing operand size in 64-bit mode and the state of the high 32 bits of destination registers when 32-bit operands are used. Opcodes, such as byte-operand versions of several instructions, that do not appear in Table B-1 are covered by the general rules described in "General Rules for 64-Bit Mode" on page 373.

Table B-1. Operations and Operands in 64-Bit Mode

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
AAA - ASCII Adjust after Addition 37	INVALID IN 64-BIT MODE (invalid-opcode exception)			
AAD - ASCII Adjust AX before Division D5	INVALID IN 64-BIT MODE (invalid-opcode exception)			
AAM - ASCII Adjust AX after Multiply D4	INVALID IN 64-BIT MODE (invalid-opcode exception)			
AAS - ASCII Adjust AL after Subtraction 3F	INVALID IN 64-BIT MODE (invalid-opcode exception)			

Note:
1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
ADC—Add with Carry 11 13 15 81 /2 83 /2	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
ADD—Signed or Unsigned Add 01 03 05 81 /0 83 /0	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
AND—Logical AND 21 23 25 81 /4 83 /4	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
ARPL - Adjust Requestor Privilege Level 63	OPCODE USED as MOVSXD in 64-BIT MODE			
BOUND - Check Array Against Bounds 62	INVALID IN 64-BIT MODE (invalid-opcode exception)			
BSF—Bit Scan Forward 0F BC	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
BSR—Bit Scan Reverse 0F BD	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
BSWAP—Byte Swap 0F C8 through 0F CF	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Swap all 8 bytes of a 64-bit GPR.
BT—Bit Test 0F A3 0F BA /4	Promoted to 64 bits.	32 bits	No GPR register results.	
BTC—Bit Test and Complement 0F BB 0F BA /7	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
BTR—Bit Test and Reset 0F B3 0F BA /6	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
BTS—Bit Test and Set 0F AB 0F BA /5	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
CALL—Procedure Call Near	See "Near Branches in 64-Bit Mode" in Volume 1.			
E8	Promoted to 64 bits.	64 bits	Can't encode.[6]	RIP = RIP + 32-bit displacement sign-extended to 64 bits.
FF /2	Promoted to 64 bits.	64 bits	Can't encode.[6]	RIP = 64-bit offset from register or memory.

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
CALL—Procedure Call Far	See “Branches to 64-Bit Offsets” in Volume 1.			
9A	INVALID IN 64-BIT MODE (invalid-opcode exception)			
FF /3	Promoted to 64 bits.	32 bits	If selector points to a gate, then RIP = 64-bit offset from gate, else RIP = zero-extended 32-bit offset from far pointer referenced in instruction.	
CBW, CWDE, CDQE—Convert Byte to Word, Convert Word to Doubleword, Convert Doubleword to Quadword 98	Promoted to 64 bits.	32 bits (size of destination register)	CWDE: Converts word to doubleword. Zero-extends EAX to RAX.	CDQE (new mnemonic): Converts doubleword to quadword. RAX = sign-extended EAX.
CDQ	see **CWD, CDQ, CQO**			
CDQE (new mnemonic)	see **CBW, CWDE, CDQE**			
CDWE	see **CBW, CWDE, CDQE**			
CLC—Clear Carry Flag F8	Same as legacy mode.	Not relevant.	No GPR register results.	
CLD—Clear Direction Flag FC	Same as legacy mode.	Not relevant.	No GPR register results.	
CLFLUSH—Cache Line Invalidate 0F AE /7	Same as legacy mode.	Not relevant.	No GPR register results.	
CLGI—Clear Global Interrupt 0F 01 DD	Same as legacy mode	Not relevant	No GPR register results.	
CLI—Clear Interrupt Flag FA	Same as legacy mode.	Not relevant.	No GPR register results.	

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
CLTS—Clear Task-Switched Flag in CR0 0F 06	Same as legacy mode.	Not relevant.	No GPR register results.	
CMC—Complement Carry Flag F5	Same as legacy mode.	Not relevant.	No GPR register results.	
CMOV*cc*—Conditional Move 0F 40 through 0F 4F	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits. This occurs even if the condition is false.	
CMP—Compare 39 3B 3D 81 /7 83 /7	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
CMPS, **CMPSW**, **CMPSD, CMPSQ**—Compare Strings A7	Promoted to 64 bits.	32 bits	CMPSD: Compare String Doublewords. See footnote[5]	CMPSQ (new mnemonic): Compare String Quadwords See footnote[5]
CMPXCHG—Compare and Exchange 0F B1	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
CMPXCHG8B—Compare and Exchange Eight Bytes 0F C7 /1	Same as legacy mode.	32 bits.	Zero-extends EDX and EAX to 64 bits.	CMPXCHG16B (new mnemonic): Compare and Exchange 16 Bytes.
CPUID—Processor Identification 0F A2	Same as legacy mode.	Operand size fixed at 32 bits.	Zero-extends 32-bit register results to 64 bits.	
CQO (new mnemonic)	see **CWD, CDQ, CQO**			
CWD, CDQ, CQO—Convert Word to Doubleword, Convert Doubleword to Quadword, Convert Quadword to Double Quadword 99	Promoted to 64 bits.	32 bits (size of destination register)	CDQ: Converts doubleword to quadword. Sign-extends EAX to EDX. Zero-extends EDX to RDX. RAX is unchanged.	CQO (new mnemonic): Converts quadword to double quadword. Sign-extends RAX to RDX. RAX is unchanged.
DAA - Decimal Adjust AL after Addition 27	INVALID IN 64-BIT MODE (invalid-opcode exception)			
DAS - Decimal Adjust AL after Subtraction 2F	INVALID IN 64-BIT MODE (invalid-opcode exception)			

Note:
1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
DEC—Decrement by 1 FF /1	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
48 through 4F	OPCODE USED as REX PREFIX in 64-BIT MODE			
DIV—Unsigned Divide F7 /6	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	RDX:RAX contain a 64-bit quotient (RAX) and 64-bit remainder (RDX).
ENTER—Create Procedure Stack Frame C8	Promoted to 64 bits.	64 bits	Can't encode[6]	
HLT—Halt F4	Same as legacy mode.	Not relevant.	No GPR register results.	
IDIV—Signed Divide F7 /7	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	RDX:RAX contain a 64-bit quotient (RAX) and 64-bit remainder (RDX).

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
IMUL - Signed Multiply				
F7 /5	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	RDX:RAX = RAX * reg/mem64 (i.e., 128-bit result)
0F AF				reg64 = reg64 * reg/mem64
69				reg64 = reg/mem64 * imm32
6B				reg64 = reg/mem64 * imm8
IN—Input From Port E5 ED	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
INC—Increment by 1				
FF /0	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
40 through 47	OPCODE USED as REX PREFIX in 64-BIT MODE			
INS, INSW, INSD—Input String 6D	Same as legacy mode.	32 bits	INSD: Input String Doublewords. No GPR register results. See footnote[5]	
INT n—Interrupt to Vector CD	Promoted to 64 bits.	Not relevant.	See “Long-Mode Interrupt Control Transfers” in Volume 2.	
INT3—Interrupt to Debug Vector CC				
INTO - Interrupt to Overflow Vector CE	INVALID IN 64-BIT MODE (invalid-opcode exception)			

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
INVD—Invalidate Internal Caches 0F 08	Same as legacy mode.	Not relevant.	No GPR register results.	
INVLPG—Invalidate TLB Entry 0F 01 /7	Promoted to 64 bits.	Not relevant.	No GPR register results.	
INVLPGA—Invalidate TLB Entry in a Specified ASID	Same as legacy mode.	Not relevant.	No GPR register results.	
IRET, **IRETD, IRETQ**—Interrupt Return CF	Promoted to 64 bits.	32 bits	IRETD: Interrupt Return Doubleword. See “Long-Mode Interrupt Control Transfers” in Volume 2.	IRETQ (new mnemonic): Interrupt Return Quadword. See “Long-Mode Interrupt Control Transfers” in Volume 2.
J*cc*—Jump Conditional	See “Near Branches in 64-Bit Mode” in Volume 1.			
70 through 7F	Promoted to 64 bits.	64 bits	Can’t encode.[6]	RIP = RIP + 8-bit displacement sign-extended to 64 bits.
0F 80 through 0F 8F				RIP = RIP + 32-bit displacement sign-extended to 64 bits.
JCXZ, **JECXZ, JRCXZ**—Jump on CX/ECX/RCX Zero E3	Promoted to 64 bits.	64 bits	Can’t encode.[6]	RIP = RIP + 8-bit displacement sign-extended to 64 bits. See footnote[5]

Note:

1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
JMP—Jump Near	See “Near Branches in 64-Bit Mode” in Volume 1.			
EB	Promoted to 64 bits.	64 bits	Can’t encode.[6]	RIP = RIP + 8-bit displacement sign-extended to 64 bits.
E9				RIP = RIP + 32-bit displacement sign-extended to 64 bits.
FF /4				RIP = 64-bit offset from register or memory.
JMP—Jump Far	See “Branches to 64-Bit Offsets” in Volume 1.			
EA	INVALID IN 64-BIT MODE (invalid-opcode exception)			
FF /5	Promoted to 64 bits.	32 bits	If selector points to a gate, then RIP = 64-bit offset from gate, else RIP = zero-extended 32-bit offset from far pointer referenced in instruction.	
LAHF - Load Status Flags into AH Register 9F	Same as legacy mode.	Not relevant.		
LAR—Load Access Rights Byte 0F 02	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LDS - Load DS Far Pointer C5	INVALID IN 64-BIT MODE (invalid-opcode exception)			

Note:

1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
LEA—Load Effective Address 8D	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LEAVE—Delete Procedure Stack Frame C9	Promoted to 64 bits.	64 bits	Can't encode[6]	
LES - Load ES Far Pointer C4	INVALID IN 64-BIT MODE (invalid-opcode exception)			
LFENCE—Load Fence 0F AE /5	Same as legacy mode.	Not relevant.	No GPR register results.	
LFS—Load FS Far Pointer 0F B4	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LGDT—Load Global Descriptor Table Register 0F 01 /2	Promoted to 64 bits.	Operand size fixed at 64 bits.	No GPR register results. Loads 8-byte base and 2-byte limit.	
LGS—Load GS Far Pointer 0F B5	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LIDT—Load Interrupt Descriptor Table Register 0F 01 /3	Promoted to 64 bits.	Operand size fixed at 64 bits.	No GPR register results. Loads 8-byte base and 2-byte limit.	
LLDT—Load Local Descriptor Table Register 0F 00 /2	Promoted to 64 bits.	Operand size fixed at 16 bits.	No GPR register results. References 16-byte descriptor to load 64-bit base.	
LMSW—Load Machine Status Word 0F 01 /6	Same as legacy mode.	Operand size fixed at 16 bits.	No GPR register results.	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
LODS, **LODSW**, **LODSD, LODSQ**—Load String AD	Promoted to 64 bits.	32 bits	LODSD: Load String Doublewords. Zero-extends 32-bit register results to 64 bits. See footnote[5]	LODSQ (new mnemonic): Load String Quadwords. See footnote[5]
LOOP—Loop E2	Promoted to 64 bits.	64 bits	Can't encode.[6]	RIP = RIP + 8-bit displacement sign-extended to 64 bits. See footnote[5]
LOOPZ, **LOOPE**—Loop if Zero/Equal E1				
LOOPNZ, **LOOPNE**—Loop if Not Zero/Equal E0				
LSL—Load Segment Limit 0F 03	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LSS —Load SS Segment Register 0F B2	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
LTR—Load Task Register 0F 00 /3	Promoted to 64 bits.	Operand size fixed at 16 bits.	No GPR register results. References 16-byte descriptor to load 64-bit base.	
LZCNT—Count Leading Zeros F3 0F BD	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
MFENCE—Memory Fence 0F AE /6	Same as legacy mode.	Not relevant.	No GPR register results.	
MONITOR—Setup Monitor Address 0F 01 C8	Same as legacy mode.	Operand size fixed at 32 bits.	No GPR register results.	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
MOV—Move				
89	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
8B	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
C7	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	32-bit immediate is sign-extended to 64 bits.
B8 through BF	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	64-bit immediate.
A1 (moffset)	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Memory offsets are address-sized and default to 64 bits.
A3 (moffset)	Promoted to 64 bits.	32 bits	Memory offsets are address-sized and default to 64 bits.	Memory offsets are address-sized and default to 64 bits.
MOV—Move to/from Segment Registers				
8C	Same as legacy mode.	32 bits	Zero-extends 32-bit register results to 64 bits.	
8E	Same as legacy mode.	Operand size fixed at 16 bits.	No GPR register results.	
MOV(CR*n*)—Move to/from Control Registers				
0F 22 0F 20	Promoted to 64 bits.	Operand size fixed at 64 bits.	The high 32 bits of control registers differ in their writability and reserved status. See “System Resources” in Volume 2 for details.	
MOV(DR*n*)—Move to/from Debug Registers				
0F 21 0F 23	Promoted to 64 bits.	Operand size fixed at 64 bits.	The high 32 bits of debug registers differ in their writability and reserved status. See “Debug and Performance Resources” in Volume 2 for details.	

Note:

1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
MOVD—Move Doubleword or Quadword 0F 6E 0F 7E	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
66 0F 6E 66 0F 7E			Zero-extends 32-bit register results to 128 bits.	Zero-extends 64-bit register results to 128 bits.
MOVNTI—Move Non-Temporal Doubleword 0F C3	Promoted to 64 bits.	32 bits	No GPR register results.	
MOVS, **MOVSW**, **MOVSD, MOVSQ**—Move String A5	Promoted to 64 bits.	32 bits	MOVSD: Move String Doublewords. See footnote[5]	MOVSQ (new mnemonic): Move String Quadwords. See footnote[5]
MOVSX—Move with Sign-Extend 0F BE	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Sign-extends byte to quadword.
0F BF				Sign-extends word to quadword.

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
MOVSXD—Move with Sign-Extend Doubleword 63	New instruction, available only in 64-bit mode. (In other modes, this opcode is ARPL instruction.)	32 bits	Zero-extends 32-bit register results to 64 bits.	Sign-extends doubleword to quadword.
MOVZX—Move with Zero-Extend 0F B6	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Zero-extends byte to quadword.
0F B7				Zero-extends word to quadword.
MUL—Multiply Unsigned F7 /4	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	RDX:RAX=RAX * quadword in register or memory.
MWAIT—Monitor Wait 0F 01 C9	Same as legacy mode.	Operand size fixed at 32 bits.	No GPR register results.	
NEG—Negate Two's Complement F7 /3	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
NOP—No Operation 90	Same as legacy mode.	Not relevant.	No GPR register results.	
NOT—Negate One's Complement F7 /2	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
OR—Logical OR 09 0B 0D 81 /1 83 /1	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
OUT—Output to Port E7 EF	Same as legacy mode.	32 bits	No GPR register results.	
OUTS, OUTSW, OUTSD—Output String 6F	Same as legacy mode.	32 bits	Writes doubleword to I/O port. No GPR register results. See footnote[5]	
PAUSE—Pause F3 90	Same as legacy mode.	Not relevant.	No GPR register results.	
POP—Pop Stack 8F /0 58 through 5F	Promoted to 64 bits.	64 bits	Cannot encode[6]	No GPR register results.
POP—Pop (segment register from) Stack 0F A1 (POP FS) 0F A9 (POP GS)	Same as legacy mode.	64 bits	Cannot encode[6]	No GPR register results.
1F (POP DS) 07 (POP ES) 17 (POP SS)	INVALID IN 64-BIT MODE (invalid-opcode exception)			

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
POPA, POPAD—Pop All to GPR Words or Doublewords 61	INVALID IN 64-BIT MODE (invalid-opcode exception)			
POPCNT—Bit Population Count F3 0F B8	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
POPF, **POPFD, POPFQ**—Pop to rFLAGS Word, Doublword, or Quadword 9D	Promoted to 64 bits.	64 bits	Cannot encode[6]	POPFQ (new mnemonic): Pops 64 bits off stack, writes low 32 bits into EFLAGS and zero-extends the high 32 bits of RFLAGS.
PREFETCH—Prefetch L1 Data-Cache Line 0F 0D /0	Same as legacy mode.	Not relevant.	No GPR register results.	
PREFETCH*level*—Prefetch Data to Cache Level *level* 0F 18 /0-3	Same as legacy mode.	Not relevant.	No GPR register results.	
PREFETCHW—Prefetch L1 Data-Cache Line for Write 0F 0D /1	Same as legacy mode.	Not relevant.	No GPR register results.	
PUSH—Push onto Stack FF /6 50 through 57 6A 68	Promoted to 64 bits.	64 bits	Cannot encode[6]	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
PUSH—Push (segment register) onto Stack 0F A0 (PUSH FS) 0F A8 (PUSH GS)	Promoted to 64 bits.	64 bits	Cannot encode[6]	
0E (PUSH CS) 1E (PUSH DS) 06 (PUSH ES) 16 (PUSH SS)	INVALID IN 64-BIT MODE (invalid-opcode exception)			
PUSHA, PUSHAD - Push All to GPR Words or Doublewords 60	INVALID IN 64-BIT MODE (invalid-opcode exception)			
PUSHF, **PUSHFD, PUSHFQ**—Push rFLAGS Word, Doubleword, or Quadword onto Stack 9C	Promoted to 64 bits.	64 bits	Cannot encode[6]	PUSHFQ (new mnemonic): Pushes the 64-bit RFLAGS register.
RCL—Rotate Through Carry Left D1 /2 D3 /2 C1 /2	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
RCR—Rotate Through Carry Right D1 /3 D3 /3 C1 /3	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
RDMSR—Read Model-Specific Register 0F 32	Same as legacy mode.	Not relevant.	RDX[31:0] contains MSR[63:32], RAX[31:0] contains MSR[31:0]. Zero-extends 32-bit register results to 64 bits.	

Note:
1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
RDPMC—Read Performance-Monitoring Counters 0F 33	Same as legacy mode.	Not relevant.	RDX[31:0] contains PMC[63:32], RAX[31:0] contains PMC[31:0]. Zero-extends 32-bit register results to 64 bits.	
RDTSC—Read Time-Stamp Counter 0F 31	Same as legacy mode.	Not relevant.	RDX[31:0] contains TSC[63:32], RAX[31:0] contains TSC[31:0]. Zero-extends 32-bit register results to 64 bits.	
RDTSCP—Read Time-Stamp Counter and Processor ID 0F 01 F9	Same as legacy mode.	Not relevant.	RDX[31:0] contains TSC[63:32], RAX[31:0] contains TSC[31:0]. RCX[31:0] contains the TSC_AUX MSR C000_0103h[31:0]. Zero-extends 32-bit register results to 64 bits.	
REP INS—Repeat Input String F3 6D	Same as legacy mode.	32 bits	Reads doubleword I/O port. See footnote[5]	
REP LODS—Repeat Load String F3 AD	Promoted to 64 bits.	32 bits	Zero-extends EAX to 64 bits. See footnote[5]	See footnote[5]
REP MOVS—Repeat Move String F3 A5	Promoted to 64 bits.	32 bits	No GPR register results. See footnote[5]	
REP OUTS—Repeat Output String to Port F3 6F	Same as legacy mode.	32 bits	Writes doubleword to I/O port. No GPR register results. See footnote[5]	
REP STOS—Repeat Store String F3 AB	Promoted to 64 bits.	32 bits	No GPR register results. See footnote[5]	
REPx CMPS —Repeat Compare String F3 A7	Promoted to 64 bits.	32 bits	No GPR register results. See footnote[5]	

Note:

1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
REPx SCAS —Repeat Scan String F3 AF	Promoted to 64 bits.	32 bits	No GPR register results. See footnote[5]	
RET—Return from Call Near	See "Near Branches in 64-Bit Mode" in Volume 1.			
C2 C3	Promoted to 64 bits.	64 bits	Cannot encode.[6]	No GPR register results.
RET—Return from Call Far CB CA	Promoted to 64 bits.	32 bits	See "Control Transfers" in Volume 1 and "Control-Transfer Privilege Checks" in Volume 2.	
ROL—Rotate Left D1 /0 D3 /0 C1 /0	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
ROR—Rotate Right D1 /1 D3 /1 C1 /1	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
RSM—Resume from System Management Mode 0F AA	New SMM state-save area.	Not relevant.	See "System-Management Mode" in Volume 2.	
SAHF - Store AH into Flags 9E	Same as legacy mode.	Not relevant.	No GPR register results.	
SAL—Shift Arithmetic Left D1 /4 D3 /4 C1 /4	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
SAR—Shift Arithmetic Right D1 /7 D3 /7 C1 /7	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
SBB—Subtract with Borrow 19 1B 1D 81 /3 83 /3	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
SCAS, **SCASW**, **SCASD, SCASQ**—Scan String AF	Promoted to 64 bits.	32 bits	SCASD: Scan String Doublewords. Zero-extends 32-bit register results to 64 bits. See footnote[5]	SCASQ (new mnemonic): Scan String Quadwords. See footnote[5]
SFENCE—Store Fence 0F AE /7	Same as legacy mode.	Not relevant.	No GPR register results.	
SGDT—Store Global Descriptor Table Register 0F 01 /0	Promoted to 64 bits.	Operand size fixed at 64 bits.	No GPR register results. Stores 8-byte base and 2-byte limit.	
SHL—Shift Left D1 /4 D3 /4 C1 /4	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
SHLD—Shift Left Double 0F A4 0F A5	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
SHR—Shift Right D1 /5 D3 /5 C1 /5	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
SHRD—Shift Right Double 0F AC 0F AD	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	Uses 6-bit count.
SIDT—Store Interrupt Descriptor Table Register 0F 01 /1	Promoted to 64 bits.	Operand size fixed at 64 bits.	No GPR register results. Stores 8-byte base and 2-byte limit.	
SKINIT—Secure Init and Jump with Attestation 0F 01 DE	Same as legacy mode.	Not relevant	Zero-extends 32-bit register results to 64 bits.	
SLDT—Store Local Descriptor Table Register 0F 00 /0	Same as legacy mode.	32	Zero-extends 2-byte LDT selector to 64 bits.	
SMSW—Store Machine Status Word 0F 01 /4	Same as legacy mode.	32	Zero-extends 32-bit register results to 64 bits.	Stores 64-bit machine status word (CR0).
STC—Set Carry Flag F9	Same as legacy mode.	Not relevant.	No GPR register results.	
STD—Set Direction Flag FD	Same as legacy mode.	Not relevant.	No GPR register results.	

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
STGI—Set Global Interrupt Flag 0F 01 DC	Same as legacy mode.	Not relevant.	No GPR register results.	
STI - Set Interrupt Flag FB	Same as legacy mode.	Not relevant.	No GPR register results.	
STOS, **STOSW**, **STOSD, STOSQ**- Store String AB	Promoted to 64 bits.	32 bits	STOSD: Store String Doublewords. See footnote[5]	STOSQ (new mnemonic): Store String Quadwords. See footnote[5]
STR—Store Task Register 0F 00 /1	Same as legacy mode.	32	Zero-extends 2-byte TR selector to 64 bits.	
SUB—Subtract 29 2B 2D 81 /5 83 /5	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
SWAPGS—Swap GS Register with KernelGSbase MSR 0F 01 /7	New instruction, available only in 64-bit mode. (In other modes, this opcode is invalid.)	Not relevant.	See “SWAPGS Instruction” in Volume 2.	
SYSCALL—Fast System Call 0F 05	Promoted to 64 bits.	Not relevant.	See “SYSCALL and SYSRET Instructions” in Volume 2 for details.	

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
SYSENTER—System Call 0F 34	INVALID IN LONG MODE (invalid-opcode exception)			
SYSEXIT—System Return 0F 35	INVALID IN LONG MODE (invalid-opcode exception)			
SYSRET—Fast System Return 0F 07	Promoted to 64 bits.	32 bits	See “SYSCALL and SYSRET Instructions” in Volume 2 for details.	
TEST—Test Bits 85 A9 F7 /0	Promoted to 64 bits.	32 bits	No GPR register results.	
UD2—Undefined Operation 0F 0B	Same as legacy mode.	Not relevant.	No GPR register results.	
VERR—Verify Segment for Reads 0F 00 /4	Same as legacy mode.	Operand size fixed at 16 bits	No GPR register results.	
VERW—Verify Segment for Writes 0F 00 /5	Same as legacy mode.	Operand size fixed at 16 bits	No GPR register results.	
VMLOAD—Load State from VMCB 0F 01 DA	Same as legacy mode.	Not relevant.	No GPR register results.	
VMMCALL—Call VMM 0F 01 D9	Same as legacy mode.	Not relevant.	No GPR register results.	
VMRUN—Run Virtual Machine 0F 01 D8	Same as legacy mode.	Not relevant.	No GPR register results.	
VMSAVE—Save State to VMCB 0F 01 DB	Same as legacy mode.	Not relevant.	No GPR register results.	

Note:
1. *See “General Rules for 64-Bit Mode” on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See “General Rules for 64-Bit Mode” on page 373 for definitions of “Promoted to 64 bits” and related topics.*
3. *If “Type of Operation” is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

Table B-1. Operations and Operands in 64-Bit Mode (continued)

Instruction and Opcode (hex)[1]	Type of Operation[2]	Default Operand Size[3]	For 32-Bit Operand Size[4]	For 64-Bit Operand Size[4]
WAIT—Wait for Interrupt 9B	Same as legacy mode.	Not relevant.	No GPR register results.	
WBINVD—Writeback and Invalidate All Caches 0F 09	Same as legacy mode.	Not relevant.	No GPR register results.	
WRMSR—Write to Model-Specific Register 0F 30	Same as legacy mode.	Not relevant.	No GPR register results. MSR[63:32] = RDX[31:0] MSR[31:0] = RAX[31:0]	
XADD—Exchange and Add 0F C1	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
XCHG—Exchange Register/Memory with Register 87 90	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	
XOR—Logical Exclusive OR 31 33 35 81 /6 83 /6	Promoted to 64 bits.	32 bits	Zero-extends 32-bit register results to 64 bits.	

Note:

1. *See "General Rules for 64-Bit Mode" on page 373, for opcodes that do not appear in this table.*
2. *The type of operation, excluding considerations of operand size or extension of results. See "General Rules for 64-Bit Mode" on page 373 for definitions of "Promoted to 64 bits" and related topics.*
3. *If "Type of Operation" is 64 bits, a REX prefix is needed for 64-bit operand size, unless the instruction size defaults to 64 bits. If the operand size is fixed, operand-size overrides are silently ignored.*
4. *Special actions in 64-bit mode, in addition to legacy-mode actions. Zero or sign extensions apply only to result operands, not source operands. Unless otherwise stated, 8-bit and 16-bit results leave the high 56 or 48 bits, respectively, of 64-bit destination registers unchanged. Immediates and branch displacements are sign-extended to 64 bits.*
5. *Any pointer registers (rDI, rSI) or count registers (rCX) are address-sized and default to 64 bits. For 32-bit address size, any pointer and count registers are zero-extended to 64 bits.*
6. *The default operand size can be overridden to 16 bits with 66h prefix, but there is no 32-bit operand-size override in 64-bit mode.*

B.3 Invalid and Reassigned Instructions in 64-Bit Mode

Table B-2 lists instructions that are illegal in 64-bit mode. Attempted use of these instructions generates an invalid-opcode exception (#UD).

Table B-2. Invalid Instructions in 64-Bit Mode

Mnemonic	Opcode (hex)	Description
AAA	37	ASCII Adjust After Addition
AAD	D5	ASCII Adjust Before Division
AAM	D4	ASCII Adjust After Multiply
AAS	3F	ASCII Adjust After Subtraction
BOUND	62	Check Array Bounds
CALL (far)	9A	Procedure Call Far (far absolute)
DAA	27	Decimal Adjust after Addition
DAS	2F	Decimal Adjust after Subtraction
INTO	CE	Interrupt to Overflow Vector
JMP (far)	EA	Jump Far (absolute)
LDS	C5	Load DS Far Pointer
LES	C4	Load ES Far Pointer
POP DS	1F	Pop Stack into DS Segment
POP ES	07	Pop Stack into ES Segment
POP SS	17	Pop Stack into SS Segment
POPA, POPAD	61	Pop All to GPR Words or Doublewords
PUSH CS	0E	Push CS Segment Selector onto Stack
PUSH DS	1E	Push DS Segment Selector onto Stack
PUSH ES	06	Push ES Segment Selector onto Stack
PUSH SS	16	Push SS Segment Selector onto Stack
PUSHA, PUSHAD	60	Push All to GPR Words or Doublewords
Redundant Grp1	82 /2	Redundant encoding of group1 Eb,Ib opcodes
SALC	D6	Set AL According to CF

Table B-3 lists instructions that are reassigned to different functions in 64-bit mode. Attempted use of these instructions generates the reassigned function.

Table B-3. Reassigned Instructions in 64-Bit Mode

Mnemonic	Opcode (hex)	Description
ARPL	63	Opcode for MOVSXD instruction in 64-bit mode. In all other modes, this is the Adjust Requestor Privilege Level instruction opcode.
DEC and INC	40-4F	REX prefixes in 64-bit mode. In all other modes, decrement by 1 and increment by 1.

Table B-4 lists instructions that are illegal in long mode. Attempted use of these instructions generates an invalid-opcode exception (#UD).

Table B-4. Invalid Instructions in Long Mode

Mnemonic	Opcode (hex)	Description
SYSENTER	0F 34	System Call
SYSEXIT	0F 35	System Return

B.4 Instructions with 64-Bit Default Operand Size

In 64-bit mode, two groups of instructions default to 64-bit operand size without the need for a REX prefix:

- *Near branches* —CALL, J*cc*, JrCX, JMP, LOOP, and RET.
- *All instructions, except far branches, that implicitly reference the RSP*—CALL, ENTER, LEAVE, POP, PUSH, and RET (CALL and RET are in both groups of instructions).

Table B-5 lists these instructions.

Table B-5. Instructions Defaulting to 64-Bit Operand Size

Mnemonic	Opcode (hex)	Implicitly Reference RSP	Description
CALL	E8, FF /2	yes	Call Procedure Near
ENTER	C8	yes	Create Procedure Stack Frame
J*cc*	many	no	Jump Conditional Near
JMP	E9, EB, FF /4	no	Jump Near
LEAVE	C9	yes	Delete Procedure Stack Frame
LOOP	E2	no	Loop

Table B-5. Instructions Defaulting to 64-Bit Operand Size (continued)

Mnemonic	Opcode (hex)	Implicitly Reference RSP	Description
LOOP*cc*	E0, E1	no	Loop Conditional
POP reg/mem	8F /0	yes	Pop Stack (register or memory)
POP reg	58-5F	yes	Pop Stack (register)
POP FS	0F A1	yes	Pop Stack into FS Segment Register
POP GS	0F A9	yes	Pop Stack into GS Segment Register
POPF, POPFD, POPFQ	9D	yes	Pop to rFLAGS Word, Doubleword, or Quadword
PUSH imm8	6A	yes	Push onto Stack (sign-extended byte)
PUSH imm32	68	yes	Push onto Stack (sign-extended doubleword)
PUSH reg/mem	FF /6	yes	Push onto Stack (register or memory)
PUSH reg	50-57	yes	Push onto Stack (register)
PUSH FS	0F A0	yes	Push FS Segment Register onto Stack
PUSH GS	0F A8	yes	Push GS Segment Register onto Stack
PUSHF, PUSHFD, PUSHFQ	9C	yes	Push rFLAGS Word, Doubleword, or Quadword onto Stack
RET	C2, C3	yes	Return From Call (near)

The 64-bit default operand size can be overridden to 16 bits using the 66h operand-size override. However, it is not possible to override the operand size to 32 bits because there is no 32-bit operand-size override prefix for 64-bit mode. See “Operand-Size Override Prefix” on page 4 for details.

B.5 Single-Byte INC and DEC Instructions in 64-Bit Mode

In 64-bit mode, the legacy encodings for the 16 single-byte INC and DEC instructions (one for each of the eight GPRs) are used to encode the REX prefix values, as described in “REX Prefixes” on page 11. Therefore, these single-byte opcodes for INC and DEC are not available in 64-bit mode, although they are available in legacy and compatibility modes. The functionality of these INC and DEC instructions is still available in 64-bit mode, however, using the ModRM forms of those instructions (opcodes FF/0 and FF/1).

B.6 NOP in 64-Bit Mode

Programs written for the legacy x86 architecture commonly use opcode 90h (the XCHG EAX, EAX instruction) as a one-byte NOP. In 64-bit mode, the processor treats opcode 90h specially in order to preserve this legacy NOP use. Without special handling in 64-bit mode, the instruction would not be a true no-operation. Therefore, in 64-bit mode the processor treats XCHG EAX, EAX as a true NOP, regardless of operand size.

This special handling does not apply to the two-byte ModRM form of the XCHG instruction. Unless a 64-bit operand size is specified using a REX prefix byte, using the two byte form of XCHG to exchange a register with itself will not result in a no-operation because the default operation size is 32 bits in 64-bit mode.

B.7 Segment Override Prefixes in 64-Bit Mode

In 64-bit mode, the CS, DS, ES, SS segment-override prefixes have no effect. These four prefixes are no longer treated as segment-override prefixes in the context of multiple-prefix rules. Instead, they are treated as null prefixes.

The FS and GS segment-override prefixes are treated as true segment-override prefixes in 64-bit mode. Use of the FS and GS prefixes cause their respective segment bases to be added to the effective address calculation. See “FS and GS Registers in 64-Bit Mode” in Volume 2 for details.

Appendix C Differences Between Long Mode and Legacy Mode

Table C-1 summarizes the major differences between 64-bit mode and legacy protected mode. The third column indicates differences between 64-bit mode and legacy mode. The fourth column indicates whether that difference also applies to compatibility mode.

Table C-1. Differences Between Long Mode and Legacy Mode

Type	Subject	64-Bit Mode Difference	Applies To Compatibility Mode?
Application Programming	Addressing	RIP-relative addressing available	no
	Data and Address Sizes	Default data size is 32 bits	
		REX Prefix toggles data size to 64 bits	
		Default address size is 64 bits	
		Address size prefix toggles address size to 32 bits	
	Instruction Differences	Various opcodes are invalid or changed in 64-bit mode (see Table B-2 on page 399 and Table B-3 on page 400)	
		Various opcodes are invalid in long mode (see Table B-4 on page 400)	yes
		MOV reg,imm32 becomes MOV reg,imm64 (with REX operand size prefix)	no
		REX is always enabled	
		Direct-offset forms of MOV to or from accumulator become 64-bit offsets	
		MOVD extended to MOV 64 bits between MMX registers and long GPRs (with REX operand-size prefix)	

Table C-1. Differences Between Long Mode and Legacy Mode (continued)

Type	Subject	64-Bit Mode Difference	Applies To Compatibility Mode?
System Programming	x86 Modes	Real and virtual-8086 modes not supported	yes
	Task Switching	Task switching not supported	yes
	Addressing	64-bit virtual addresses	yes
		4-level paging structures	
		PAE must always be enabled	
	Segmentation	CS, DS, ES, SS segment bases are ignored	no
		CS, DS, ES, FS, GS, SS segment limits are ignored	
		CS, DS, ES, SS Segment prefixes are ignored	
	Exception and Interrupt Handling	All pushes are 8 bytes	yes
		16-bit interrupt and trap gates are illegal	
		32-bit interrupt and trap gates are redefined as 64-bit gates and are expanded to 16 bytes	
		SS is set to null on stack switch	
		SS:RSP is pushed unconditionally	
	Call Gates	All pushes are 8 bytes	yes
		16-bit call gates are illegal	
		32-bit call gate type is redefined as 64-bit call gate and is expanded to 16 bytes.	
		SS is set to null on stack switch	
	System-Descriptor Registers	GDT, IDT, LDT, TR base registers expanded to 64 bits	yes
	System-Descriptor Table Entries and Pseudo-descriptors	LGDT and LIDT use expanded 10-byte pseudo-descriptors.	no
		LLDT and LTR use expanded 16-byte table entries.	

Appendix D Instruction Subsets and CPUID Feature Sets

Table D-1 is an alphabetical list of the AMD64 instruction set, including the instructions from all five of the instruction subsets that make up the entire AMD64 instruction-set architecture:

- Chapter 3, "General-Purpose Instruction Reference."
- Chapter 4, "System Instruction Reference."
- "128-Bit Media Instruction Reference" in Volume 4.
- "64-Bit Media Instruction Reference" in Volume 5.
- "x87 Floating-Point Instruction Reference" in Volume 5.

Several instructions belong to—and are described in—multiple instruction subsets. Table D-1 shows the minimum current privilege level (CPL) required to execute each instruction and the instruction subset(s) to which the instruction belongs. For each instruction subset, the CPUID feature set(s) that enables the instruction is shown.

D.1 Instruction Subsets

Figure D-1 on page 406 shows the relationship between the five instruction subsets and the CPUID feature sets. Dashed-line polygons represent the instruction subsets. Circles represent the major CPUID feature sets that enable various classes of instructions. (There are a few additional CPUID feature sets, not shown, each of which apply to only a few instructions.)

The overlapping of the 128-bit and 64-bit media instruction subsets indicates that these subsets share some common mnemonics. However, these common mnemonics either have distinct opcodes for each subset or they take operands in both the MMX and XMM register sets.

The horizontal axis of Figure D-1 shows how the subsets and CPUID feature sets have evolved over time.

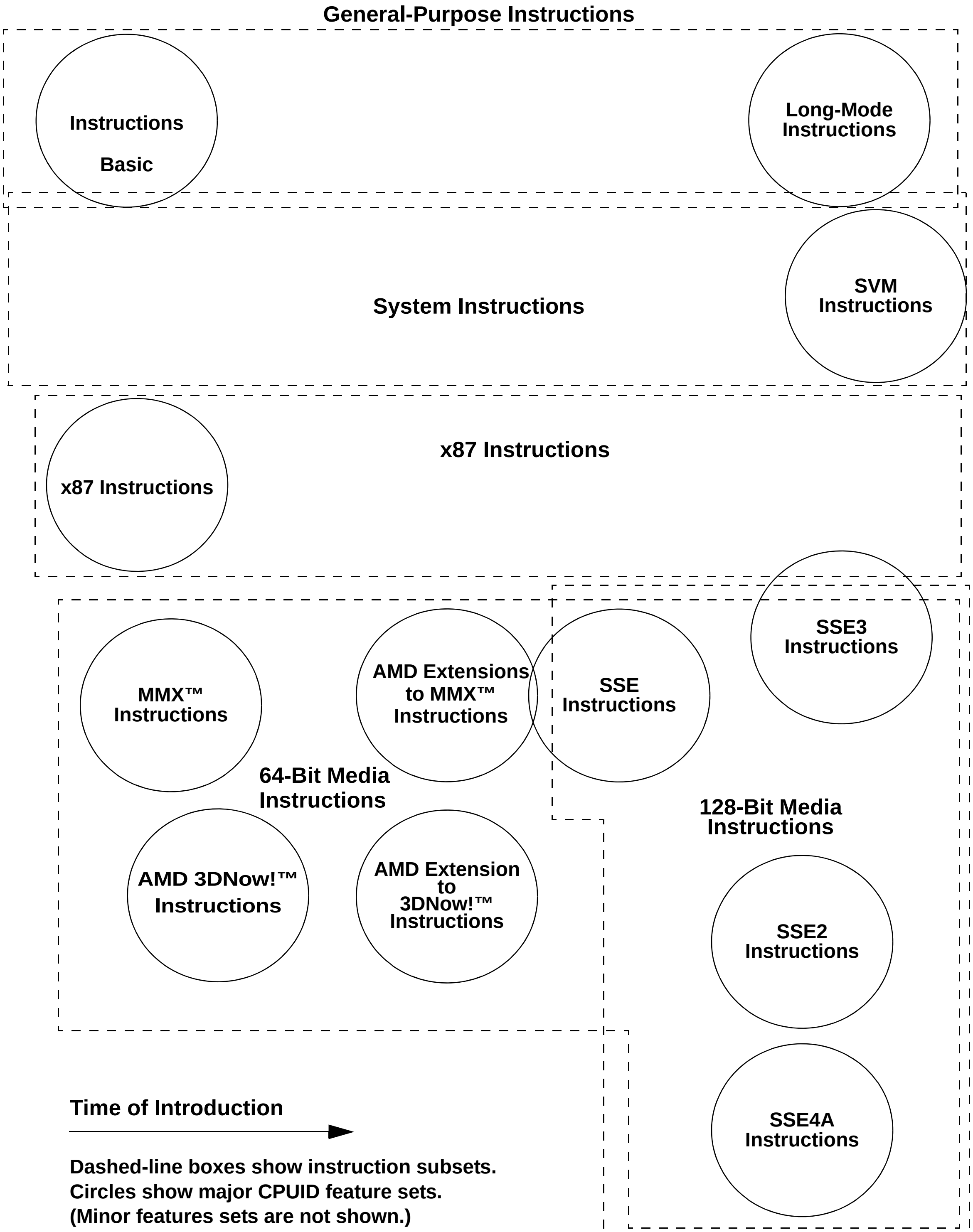


Figure D-1. Instruction Subsets vs. CPUID Feature Sets

D.2 CPUID Feature Sets

The CPUID feature sets shown in Figure D-1 and listed in Table D-1 on page 409 include:

- *Basic Instructions*—Instructions that are supported in all hardware implementations of the AMD64 architecture, except that the following instructions are implemented only if their associated CPUID function bit is set:
  - CLFLUSH, indicated by EDX bit 19 of CPUID function 0000_0001h.
  - CMPXCHG8B, indicated by EDX bit 8 of CPUID function 0000_0001h and function 8000_0001h.
  - CMPXCHG16B, indicated by ECX bit 13 of CPUID function 0000_0001h.
  - CMOV*cc* (conditional moves), indicated by EDX bit 15 of CPUID function 0000_0001h and function 8000_0001h.
  - RDMSR and WRMSR, indicated by EDX bit 5 of CPUID function 0000_0001h and function 8000_0001h.
  - RDTSC, indicated by EDX bit 4 of CPUID function 0000_0001h and function 8000_0001h.
  - RDTSCP, indicated by EDX bit 27 of CPUID function 8000_0001h.
  - SYSCALL and SYSRET, indicated by EDX bit 11 of CPUID function 8000_0001h.
  - SYSENTER and SYSEXIT, indicated by EDX bit 11 of CPUID function 0000_0001h.
- *x87 Instructions*—Legacy floating-point instructions that use the ST(0)–ST(7) stack registers (FPR0–FPR7 physical registers) and are supported if the following bits are set:
  - On-chip floating-point unit, indicated by EDX bit 0 of CPUID function 0000_0001h and function 8000_0001h.
  - FCMOV*cc* (conditional moves), indicated by EDX bit 15 of CPUID function 0000_0001h and function 8000_0001h. This bit indicates support for x87 floating-point conditional moves (FCMOV*cc*) whenever the On-Chip Floating-Point Unit bit (bit 0) is also set.
- *MMX™ Instructions*—Vector integer instructions that are implemented in the MMX instruction set, use the MMX logical registers (FPR0–FPR7 physical registers), and are supported if the following bit is set:
  - MMX instructions, indicated by EDX bit 23 of CPUID function 0000_0001h and function 8000_0001h.
- *AMD 3DNow!™ Instructions*—Vector floating-point instructions that comprise the AMD 3DNow! technology, use the MMX logical registers (FPR0–FPR7 physical registers), and are supported if the following bit is set:
  - AMD 3DNow! instructions, indicated by EDX bit 31 of CPUID function 8000_0001h.
- *AMD Extensions to MMX™ Instructions*—Vector integer instructions that use the MMX registers and are supported if the following bit is set:
  - AMD extensions to MMX instructions, indicated by EDX bit 22 of CPUID function 8000_0001h.

- *AMD Extensions to 3DNow!™ Instructions*—Vector floating-point instructions that use the MMX registers and are supported if the following bit is set:
  - AMD extensions to 3DNow! instructions, indicated by EDX bit 30 of CPUID function 8000_0001h.
- *SSE Instructions*—Vector integer instructions that use the MMX registers, single-precision vector and scalar floating-point instructions that use the XMM registers, plus other instructions for data-type conversion, prefetching, cache control, and memory-access ordering. These instructions are supported if the following bits are set:
  - SSE, indicated by EDX bit 25 of CPUID function 0000_0001h.
  - FXSAVE and FXRSTOR, indicated by EDX bit 24 of CPUID function 0000_0001h and function 8000_0001h.

  Several SSE opcodes are also implemented by the AMD Extensions to MMX™ Instructions.
- *SSE2 Instructions*—Vector and scalar integer and double-precision floating-point instructions that use the XMM registers, plus other instructions for data-type conversion, cache control, and memory-access ordering. These instructions are supported if the following bit is set:
  - SSE2, indicated by EDX bit 26 of CPUID function 0000_0001h.

  Several instructions originally implemented as MMX™ instructions are extended in the SSE2 instruction set to include opcodes that use XMM registers.
- *SSE3 Instructions*—Horizontal addition and subtraction of packed single-precision and double-precision floating point values, simultaneous addition and subtraction of packed single-precision and double-precision values, move with duplication, and floating-point-to-integer conversion. These instructions are supported if the following bit is set:
  - SSE3, indicated by ECX bit 0 of CPUID function 0000_0001h.
- *SSE4A Instructions*—The SSE4A instructions are EXTRQ, INSERTQ, MOVNTSD, and MOVNTSS.
  - SSE4A, indicated by ECX bit 6 of CPUID function 8000_0001h.
- *Long-Mode Instructions*—Instructions introduced by AMD with the AMD64 architecture. These instructions are supported if the following bit is set:
  - Long mode, indicated by EDX bit 29 of CPUID function 8000_0001h.
- *SVM Instructions*—Instructions introduced by AMD with the Secure Virtual Machine feature. These instructions are supported if the following bit is set:
  - SVM, indicated by ECX bit 2 of CPUID function 8000_0001h.

For complete details on the CPUID feature sets listed in Table D-1, see the *AMD CPUID Specification*, order# 25481.

D.3 Instruction List

Table D-1. Instruction Subsets and CPUID Feature Sets

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
AAA	ASCII Adjust After Addition	3	Basic				
AAD	ASCII Adjust Before Division	3	Basic				
AAM	ASCII Adjust After Multiply	3	Basic				
AAS	ASCII Adjust After Subtraction	3	Basic				
ADC	Add with Carry	3	Basic				
ADD	Signed or Unsigned Add	3	Basic				
ADDPD	Add Packed Double-Precision Floating-Point	3		SSE2			
ADDPS	Add Packed Single-Precision Floating-Point	3		SSE			
ADDSD	Add Scalar Double-Precision Floating-Point	3		SSE2			
ADDSS	Add Scalar Single-Precision Floating-Point	3		SSE			
ADDSUBPD	Add and Subtract Double-Precision	3		SSE3			
ADDSUBPS	Add and Subtract Single-Precision	3		SSE3			
AND	Logical AND	3	Basic				
ANDNPD	Logical Bitwise AND NOT Packed Double-Precision Floating-Point	3		SSE2			
ANDNPS	Logical Bitwise AND NOT Packed Single-Precision Floating-Point	3		SSE			
ANDPD	Logical Bitwise AND Packed Double-Precision Floating-Point	3		SSE2			
ANDPS	Logical Bitwise AND Packed Single-Precision Floating-Point	3		SSE			
ARPL	Adjust Requestor Privilege Level	3					Basic
BOUND	Check Array Bounds	3	Basic				

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
BSF	Bit Scan Forward	3	Basic				
BSR	Bit Scan Reverse	3	Basic				
BSWAP	Byte Swap	3	Basic				
BT	Bit Test	3	Basic				
BTC	Bit Test and Complement	3	Basic				
BTR	Bit Test and Reset	3	Basic				
BTS	Bit Test and Set	3	Basic				
CALL	Procedure Call	3	Basic				
CBW	Convert Byte to Word	3	Basic				
CDQ	Convert Doubleword to Quadword	3	Basic				
CDQE	Convert Doubleword to Quadword	3	Long Mode				
CLC	Clear Carry Flag	3	Basic				
CLD	Clear Direction Flag	3	Basic				
CLFLUSH	Cache Line Flush	3	CLFLUSH				
CLGI	Clear Global Interrupt Flag	0					SVM
CLI	Clear Interrupt Flag	3					Basic
CLTS	Clear Task-Switched Flag in CR0	0					Basic
CMC	Complement Carry Flag	3	Basic				
CMOVcc	Conditional Move	3	CMOV*cc*				
CMP	Compare	3	Basic				
CMPPD	Compare Packed Double-Precision Floating-Point	3		SSE2			
CMPPS	Compare Packed Single-Precision Floating-Point	3		SSE			
CMPS	Compare Strings	3	Basic				
CMPSB	Compare Strings by Byte	3	Basic				
CMPSD	Compare Strings by Doubleword	3	Basic[2]				
CMPSD	Compare Scalar Double-Precision Floating-Point	3		SSE2[2]			
CMPSQ	Compare Strings by Quadword	3	Long Mode				
CMPSS	Compare Scalar Single-Precision Floating-Point	3		SSE			

Note:

1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
CMPSW	Compare Strings by Word	3	Basic				
CMPXCHG	Compare and Exchange	3	Basic				
CMPXCHG8B	Compare and Exchange Eight Bytes	3	CMPXCHG8B				
CMPXCHG16B	Compare and Exchange Sixteen Bytes	3	CMPXCHG16B				
COMISD	Compare Ordered Scalar Double-Precision Floating-Point	3		SSE2			
COMISS	Compare Ordered Scalar Single-Precision Floating-Point	3		SSE			
CPUID	Processor Identification	3	Basic				
CQO	Convert Quadword to Double Quadword	3	Long Mode				
CVTDQ2PD	Convert Packed Doubleword Integers to Packed Double-Precision Floating-Point	3		SSE2			
CVTDQ2PS	Convert Packed Doubleword Integers to Packed Single-Precision Floating-Point	3		SSE2			
CVTPD2DQ	Convert Packed Double-Precision Floating-Point to Packed Doubleword Integers	3		SSE2			
CVTPD2PI	Convert Packed Double-Precision Floating-Point to Packed Doubleword Integers	3		SSE2	SSE2		
CVTPD2PS	Convert Packed Double-Precision Floating-Point to Packed Single-Precision Floating-Point	3		SSE2			
CVTPI2PD	Convert Packed Doubleword Integers to Packed Double-Precision Floating-Point	3		SSE2	SSE2		

Note:

1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
CVTPI2PS	Convert Packed Doubleword Integers to Packed Single-Precision Floating-Point	3		SSE	SSE		
CVTPS2DQ	Convert Packed Single-Precision Floating-Point to Packed Doubleword Integers	3		SSE2			
CVTPS2PD	Convert Packed Single-Precision Floating-Point to Packed Double-Precision Floating-Point	3		SSE2			
CVTPS2PI	Convert Packed Single-Precision Floating-Point to Packed Doubleword Integers	3		SSE	SSE		
CVTSD2SI	Convert Scalar Double-Precision Floating-Point to Signed Doubleword or Quadword Integer	3		SSE2			
CVTSD2SS	Convert Scalar Double-Precision Floating-Point to Scalar Single-Precision Floating-Point	3		SSE2			
CVTSI2SD	Convert Signed Doubleword or Quadword Integer to Scalar Double-Precision Floating-Point	3		SSE2			
CVTSI2SS	Convert Signed Doubleword or Quadword Integer to Scalar Single-Precision Floating-Point	3		SSE			
CVTSS2SD	Convert Scalar Single-Precision Floating-Point to Scalar Double-Precision Floating-Point	3		SSE2			
CVTSS2SI	Convert Scalar Single-Precision Floating-Point to Signed Doubleword or Quadword Integer	3		SSE			

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
CVTTPD2DQ	Convert Packed Double-Precision Floating-Point to Packed Doubleword Integers, Truncated	3		SSE2			
CVTTPD2PI	Convert Packed Double-Precision Floating-Point to Packed Doubleword Integers, Truncated	3		SSE2	SSE2		
CVTTPS2DQ	Convert Packed Single-Precision Floating-Point to Packed Doubleword Integers, Truncated	3		SSE2			
CVTTPS2PI	Convert Packed Single-Precision Floating-Point to Packed Doubleword Integers, Truncated	3		SSE	SSE		
CVTTSD2SI	Convert Scalar Double-Precision Floating-Point to Signed Doubleword or Quadword Integer, Truncated	3		SSE2			
CVTTSS2SI	Convert Scalar Single-Precision Floating-Point to Signed Doubleword or Quadword Integer, Truncated	3		SSE			
CWD	Convert Word to Doubleword	3	Basic				
CWDE	Convert Word to Doubleword	3	Basic				
DAA	Decimal Adjust after Addition	3	Basic				
DAS	Decimal Adjust after Subtraction	3	Basic				
DEC	Decrement by 1	3	Basic				
DIV	Unsigned Divide	3	Basic				
DIVPD	Divide Packed Double-Precision Floating-Point	3		SSE2			

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
DIVPS	Divide Packed Single-Precision Floating-Point	3		SSE			
DIVSD	Divide Scalar Double-Precision Floating-Point	3		SSE2			
DIVSS	Divide Scalar Single-Precision Floating-Point	3		SSE			
EMMS	Enter/Exit Multimedia State	3			MMX™	MMX	
ENTER	Create Procedure Stack Frame	3	Basic				
EXTRQ	Extract Field From Register	3		SSE4A			
F2XM1	Floating-Point Compute 2x–1	3				X87	
FABS	Floating-Point Absolute Value	3				X87	
FADD	Floating-Point Add	3				X87	
FADDP	Floating-Point Add and Pop	3				X87	
FBLD	Floating-Point Load Binary-Coded Decimal	3				X87	
FBSTP	Floating-Point Store Binary-Coded Decimal Integer and Pop	3				X87	
FCHS	Floating-Point Change Sign	3				X87	
FCLEX	Floating-Point Clear Flags	3				X87	
FCMOVB	Floating-Point Conditional Move If Below	3				X87, CMOV*cc*	
FCMOVBE	Floating-Point Conditional Move If Below or Equal	3				X87, CMOV*cc*	
FCMOVE	Floating-Point Conditional Move If Equal	3				X87, CMOV*cc*	
FCMOVNB	Floating-Point Conditional Move If Not Below	3				X87, CMOV*cc*	
FCMOVNBE	Floating-Point Conditional Move If Not Below or Equal	3				X87, CMOV*cc*	
FCMOVNE	Floating-Point Conditional Move If Not Equal	3				X87, CMOV*cc*	
FCMOVNU	Floating-Point Conditional Move If Not Unordered	3				X87, CMOV*cc*	

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
FCMOVU	Floating-Point Conditional Move If Unordered	3				X87, CMOV*cc*	
FCOM	Floating-Point Compare	3				X87	
FCOMI	Floating-Point Compare and Set Flags	3				X87	
FCOMIP	Floating-Point Compare and Set Flags and Pop	3				X87	
FCOMP	Floating-Point Compare and Pop	3				X87	
FCOMPP	Floating-Point Compare and Pop Twice	3				X87	
FCOS	Floating-Point Cosine	3				X87	
FDECSTP	Floating-Point Decrement Stack-Top Pointer	3				X87	
FDIV	Floating-Point Divide	3				X87	
FDIVP	Floating-Point Divide and Pop	3				X87	
FDIVR	Floating-Point Divide Reverse	3				X87	
FDIVRP	Floating-Point Divide Reverse and Pop	3				X87	
FEMMS	Fast Enter/Exit Multimedia State	3			3DNow!™	3DNow!	
FFREE	Free Floating-Point Register	3				X87	
FIADD	Floating-Point Add Integer to Stack Top	3				X87	
FICOM	Floating-Point Integer Compare	3				X87	
FICOMP	Floating-Point Integer Compare and Pop	3				X87	
FIDIV	Floating-Point Integer Divide	3				X87	
FIDIVR	Floating-Point Integer Divide Reverse	3				X87	
FILD	Floating-Point Load Integer	3				X87	
FIMUL	Floating-Point Integer Multiply	3				X87	

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
FINCSTP	Floating-Point Increment Stack-Top Pointer	3				X87	
FINIT	Floating-Point Initialize	3				X87	
FIST	Floating-Point Integer Store	3				X87	
FISTP	Floating-Point Integer Store and Pop	3				X87	
FISTTP	Floating-Point Integer Truncate and Store	3				SSE3	
FISUB	Floating-Point Integer Subtract	3				X87	
FISUBR	Floating-Point Integer Subtract Reverse	3				X87	
FLD	Floating-Point Load	3				X87	
FLD1	Floating-Point Load +1.0	3				X87	
FLDCW	Floating-Point Load x87 Control Word	3				X87	
FLDENV	Floating-Point Load x87 Environment	3				X87	
FLDL2E	Floating-Point Load Log_2 e	3				X87	
FLDL2T	Floating-Point Load Log_2 10	3				X87	
FLDLG2	Floating-Point Load Log_{10} 2	3				X87	
FLDLN2	Floating-Point Load Ln 2	3				X87	
FLDPI	Floating-Point Load Pi	3				X87	
FLDZ	Floating-Point Load +0.0	3				X87	
FMUL	Floating-Point Multiply	3				X87	
FMULP	Floating-Point Multiply and Pop	3				X87	
FNCLEX	Floating-Point No-Wait Clear Flags	3				X87	
FNINIT	Floating-Point No-Wait Initialize	3				X87	
FNOP	Floating-Point No Operation	3				X87	

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
FNSAVE	Save No-Wait x87 and MMX State	3			X87	X87	
FNSTCW	Floating-Point No-Wait Store x87 Control Word	3				X87	
FNSTENV	Floating-Point No-Wait Store x87 Environment	3				X87	
FNSTSW	Floating-Point No-Wait Store x87 Status Word	3				X87	
FPATAN	Floating-Point Partial Arctangent	3				X87	
FPREM	Floating-Point Partial Remainder	3				X87	
FPREM1	Floating-Point Partial Remainder	3				X87	
FPTAN	Floating-Point Partial Tangent	3				X87	
FRNDINT	Floating-Point Round to Integer	3				X87	
FRSTOR	Restore x87 and MMX State	3			X87	X87	
FSAVE	Save x87 and MMX State	3			X87	X87	
FSCALE	Floating-Point Scale	3				X87	
FSIN	Floating-Point Sine	3				X87	
FSINCOS	Floating-Point Sine and Cosine	3				X87	
FSQRT	Floating-Point Square Root	3				X87	
FST	Floating-Point Store Stack Top	3				X87	
FSTCW	Floating-Point Store x87 Control Word	3				X87	
FSTENV	Floating-Point Store x87 Environment	3				X87	
FSTP	Floating-Point Store Stack Top and Pop	3				X87	
FSTSW	Floating-Point Store x87 Status Word	3				X87	
FSUB	Floating-Point Subtract	3				X87	

Note:

1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
FSUBP	Floating-Point Subtract and Pop	3				X87	
FSUBR	Floating-Point Subtract Reverse	3				X87	
FSUBRP	Floating-Point Subtract Reverse and Pop	3				X87	
FTST	Floating-Point Test with Zero	3				X87	
FUCOM	Floating-Point Unordered Compare	3				X87	
FUCOMI	Floating-Point Unordered Compare and Set Flags	3				X87	
FUCOMIP	Floating-Point Unordered Compare and Set Flags and Pop	3				X87	
FUCOMP	Floating-Point Unordered Compare and Pop	3				X87	
FUCOMPP	Floating-Point Unordered Compare and Pop Twice	3				X87	
FWAIT	Wait for x87 Floating-Point Exceptions	3				X87	
FXAM	Floating-Point Examine	3				X87	
FXCH	Floating-Point Exchange	3				X87	
FXRSTOR	Restore XMM, MMX, and x87 State	3		FXSAVE, FXRSTOR	FXSAVE, FXRSTOR	FXSAVE, FXRSTOR	
FXSAVE	Save XMM, MMX, and x87 State	3		FXSAVE, FXRSTOR	FXSAVE, FXRSTOR	FXSAVE, FXRSTOR	
FXTRACT	Floating-Point Extract Exponent and Significand	3				X87	
FYL2X	Floating-Point y * log2x	3				X87	
FYL2XP1	Floating-Point y * log2(x +1)	3				X87	
HADDPD	Horizontal Add Packed Double	3		SSE3			
HADDPS	Horizontal Add Packed Single	3		SSE3			
HLT	Halt	0					Basic

Note:

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
HSUBPD	Horizontal Subtract Packed Double	3		SSE3			
HSUBPS	Horizontal Subtract Packed Single	3		SSE3			
IDIV	Signed Divide	3	Basic				
IMUL	Signed Multiply	3	Basic				
IN	Input from Port	3	Basic				
INC	Increment by 1	3	Basic				
INS	Input String	3	Basic				
INSB	Input String Byte	3	Basic				
INSD	Input String Doubleword	3	Basic				
INSERTQ	Insert Field	3		SSE4A			
INSW	Input String Word	3	Basic				
INT	Interrupt to Vector	3	Basic				
INT 3	Interrupt to Debug Vector	3					Basic
INTO	Interrupt to Overflow Vector	3	Basic				
INVD	Invalidate Caches	0					Basic
INVLPG	Invalidate TLB Entry	0					Basic
INVLPGA	Invalidate TLB Entry in a Specified ASID	0					SVM
IRET	Interrupt Return Word	3					Basic
IRETD	Interrupt Return Doubleword	3					Basic
IRETQ	Interrupt Return Quadword	3					Long Mode
Jcc	Jump Condition	3	Basic				
JCXZ	Jump if CX Zero	3	Basic				
JECXZ	Jump if ECX Zero	3	Basic				
JMP	Jump	3	Basic				
JRCXZ	Jump if RCX Zero	3	Basic				
LAHF	Load Status Flags into AH Register	3	Basic				
LAR	Load Access Rights Byte	3					Basic
LDDQU	Load Unaligned Double Quadword	3		SSE3			
LDMXCSR	Load MXCSR Control/Status Register	3		SSE			

Note:

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
LDS	Load DS Far Pointer	3	Basic				
LEA	Load Effective Address	3	Basic				
LEAVE	Delete Procedure Stack Frame	3	Basic				
LES	Load ES Far Pointer	3	Basic				
LFENCE	Load Fence	3	SSE2				
LFS	Load FS Far Pointer	3	Basic				
LGDT	Load Global Descriptor Table Register	0					Basic
LGS	Load GS Far Pointer	3	Basic				
LIDT	Load Interrupt Descriptor Table Register	0					Basic
LLDT	Load Local Descriptor Table Register	0					Basic
LMSW	Load Machine Status Word	0					Basic
LODS	Load String	3	Basic				
LODSB	Load String Byte	3	Basic				
LODSD	Load String Doubleword	3	Basic				
LODSQ	Load String Quadword	3	Long Mode				
LODSW	Load String Word	3	Basic				
LOOP	Loop	3	Basic				
LOOPE	Loop if Equal	3	Basic				
LOOPNE	Loop if Not Equal	3	Basic				
LOOPNZ	Loop if Not Zero	3	Basic				
LOOPZ	Loop if Zero	3	Basic				
LSL	Load Segment Limit	3	Basic				
LSS	Load SS Segment Register	3	Basic				
LTR	Load Task Register	0					Basic
LZCNT	Count Leading Zeros	3	Basic				
MASKMOVDQU	Masked Move Double Quadword Unaligned	3		SSE2			
MASKMOVQ	Masked Move Quadword	3			SSE, MMX Extensions		
MAXPD	Maximum Packed Double-Precision Floating-Point	3		SSE2			

Note:

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
MAXPS	Maximum Packed Single-Precision Floating-Point	3		SSE			
MAXSD	Maximum Scalar Double-Precision Floating-Point	3		SSE2			
MAXSS	Maximum Scalar Single-Precision Floating-Point	3		SSE			
MFENCE	Memory Fence	3	SSE2				
MINPD	Minimum Packed Double-Precision Floating-Point	3		SSE2			
MINPS	Minimum Packed Single-Precision Floating-Point	3		SSE			
MINSD	Minimum Scalar Double-Precision Floating-Point	3		SSE2			
MINSS	Minimum Scalar Single-Precision Floating-Point	3		SSE			
MONITOR	Setup Monitor Address	0					Basic
MOV	Move	3	Basic				
MOV CRn	Move to/from Control Registers	0					Basic
MOV DRn	Move to/from Debug Registers	0					Basic
MOVAPD	Move Aligned Packed Double-Precision Floating-Point	3		SSE2			
MOVAPS	Move Aligned Packed Single-Precision Floating-Point	3		SSE			
MOVD	Move Doubleword or Quadword	3	MMX, SSE2	SSE2	MMX		
MOVDDUP	Move Double-Precision and Duplicate	3		SSE3			
MOVDQ2Q	Move Quadword to Quadword	3		SSE2	SSE2		
MOVDQA	Move Aligned Double Quadword	3		SSE2			
MOVDQU	Move Unaligned Double Quadword	3		SSE2			

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
MOVHLPS	Move Packed Single-Precision Floating-Point High to Low	3		SSE			
MOVHPD	Move High Packed Double-Precision Floating-Point	3		SSE2			
MOVHPS	Move High Packed Single-Precision Floating-Point	3		SSE			
MOVLHPS	Move Packed Single-Precision Floating-Point Low to High	3		SSE			
MOVLPD	Move Low Packed Double-Precision Floating-Point	3		SSE2			
MOVLPS	Move Low Packed Single-Precision Floating-Point	3		SSE			
MOVMSKPD	Extract Packed Double-Precision Floating-Point Sign Mask	3	SSE2	SSE2			
MOVMSKPS	Extract Packed Single-Precision Floating-Point Sign Mask	3	SSE	SSE			
MOVNTDQ	Move Non-Temporal Double Quadword	3		SSE2			
MOVNTI	Move Non-Temporal Doubleword or Quadword	3	SSE2				
MOVNTPD	Move Non-Temporal Packed Double-Precision Floating-Point	3		SSE2			
MOVNTPS	Move Non-Temporal Packed Single-Precision Floating-Point	3		SSE			
MOVNTSD	Move Non-Temporal Scalar Double-Precision Floating-Point	3		SSE4A			
MOVNTSS	Move Non-Temporal Scalar Single-Precision Floating-Point	3		SSE4A			
MOVNTQ	Move Non-Temporal Quadword	3			SSE, MMX Extensions		
MOVQ	Move Quadword	3		SSE2	MMX		

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
MOVQ2DQ	Move Quadword to Quadword	3		SSE2	SSE2		
MOVS	Move String	3	Basic				
MOVSB	Move String Byte	3	Basic				
MOVSD	Move String Doubleword	3	Basic[2]				
MOVSD	Move Scalar Double-Precision Floating-Point	3		SSE2[2]			
MOVSHDUP	Move Single-Precision High and Duplicate	3		SSE3			
MOVSLDUP	Move Single-Precision Low and Duplicate	3		SSE3			
MOVSQ	Move String Quadword	3	Long Mode				
MOVSS	Move Scalar Single-Precision Floating-Point	3		SSE			
MOVSW	Move String Word	3	Basic				
MOVSX	Move with Sign-Extend	3	Basic				
MOVSXD	Move with Sign-Extend Doubleword	3	Long Mode				
MOVUPD	Move Unaligned Packed Double-Precision Floating-Point	3		SSE2			
MOVUPS	Move Unaligned Packed Single-Precision Floating-Point	3		SSE			
MOVZX	Move with Zero-Extend	3	Basic				
MUL	Multiply Unsigned	3	Basic				
MULPD	Multiply Packed Double-Precision Floating-Point	3		SSE2			
MULPS	Multiply Packed Single-Precision Floating-Point	3		SSE			
MULSD	Multiply Scalar Double-Precision Floating-Point	3		SSE2			
MULSS	Multiply Scalar Single-Precision Floating-Point	3		SSE			
MWAIT	Monitor Wait	0					Basic
NEG	Two's Complement Negation	3	Basic				

Note:
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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
NOP	No Operation	3	Basic				
NOT	One's Complement Negation	3	Basic				
OR	Logical OR	3	Basic				
ORPD	Logical Bitwise OR Packed Double-Precision Floating-Point	3		SSE2			
ORPS	Logical Bitwise OR Packed Single-Precision Floating-Point	3		SSE			
OUT	Output to Port	3	Basic				
OUTS	Output String	3	Basic				
OUTSB	Output String Byte	3	Basic				
OUTSD	Output String Doubleword	3	Basic				
OUTSW	Output String Word	3	Basic				
PACKSSDW	Pack with Saturation Signed Doubleword to Word	3		SSE2	MMX		
PACKSSWB	Pack with Saturation Signed Word to Byte	3		SSE2	MMX		
PACKUSWB	Pack with Saturation Signed Word to Unsigned Byte	3		SSE2	MMX		
PADDB	Packed Add Bytes	3		SSE2	MMX		
PADDD	Packed Add Doublewords	3		SSE2	MMX		
PADDQ	Packed Add Quadwords	3		SSE2	SSE2		
PADDSB	Packed Add Signed with Saturation Bytes	3		SSE2	MMX		
PADDSW	Packed Add Signed with Saturation Words	3		SSE2	MMX		
PADDUSB	Packed Add Unsigned with Saturation Bytes	3		SSE2	MMX		
PADDUSW	Packed Add Unsigned with Saturation Words	3		SSE2	MMX		
PADDW	Packed Add Words	3		SSE2	MMX		
PAND	Packed Logical Bitwise AND	3		SSE2	MMX		

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
PANDN	Packed Logical Bitwise AND NOT	3		SSE2	MMX		
PAVGB	Packed Average Unsigned Bytes	3		SSE2	SSE, MMX Extensions		
PAVGUSB	Packed Average Unsigned Bytes	3			3DNow!		
PAVGW	Packed Average Unsigned Words	3		SSE2	SSE, MMX Extensions		
PCMPEQB	Packed Compare Equal Bytes	3		SSE2	MMX		
PCMPEQD	Packed Compare Equal Doublewords	3		SSE2	MMX		
PCMPEQW	Packed Compare Equal Words	3		SSE2	MMX		
PCMPGTB	Packed Compare Greater Than Signed Bytes	3		SSE2	MMX		
PCMPGTD	Packed Compare Greater Than Signed Doublewords	3		SSE2	MMX		
PCMPGTW	Packed Compare Greater Than Signed Words	3		SSE2	MMX		
PEXTRW	Packed Extract Word	3		SSE2	SSE, MMX Extensions		
PF2ID	Packed Floating-Point to Integer Doubleword Conversion	3			3DNow!		
PF2IW	Packed Floating-Point to Integer Word Conversion	3			3DNow! Extensions		
PFACC	Packed Floating-Point Accumulate	3			3DNow!		
PFADD	Packed Floating-Point Add	3			3DNow!		
PFCMPEQ	Packed Floating-Point Compare Equal	3			3DNow!		
PFCMPGE	Packed Floating-Point Compare Greater or Equal	3			3DNow!		
PFCMPGT	Packed Floating-Point Compare Greater Than	3			3DNow!		
PFMAX	Packed Floating-Point Maximum	3			3DNow!		

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Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
PFMIN	Packed Floating-Point Minimum	3			3DNow!		
PFMUL	Packed Floating-Point Multiply	3			3DNow!		
PFNACC	Packed Floating-Point Negative Accumulate	3			3DNow! Extensions		
PFPNACC	Packed Floating-Point Positive-Negative Accumulate	3			3DNow! Extensions		
PFRCP	Packed Floating-Point Reciprocal Approximation	3			3DNow!		
PFRCPIT1	Packed Floating-Point Reciprocal, Iteration 1	3			3DNow!		
PFRCPIT2	Packed Floating-Point Reciprocal or Reciprocal Square Root, Iteration 2	3			3DNow!		
PFRSQIT1	Packed Floating-Point Reciprocal Square Root, Iteration 1	3			3DNow!		
PFRSQRT	Packed Floating-Point Reciprocal Square Root Approximation	3			3DNow!		
PFSUB	Packed Floating-Point Subtract	3			3DNow!		
PFSUBR	Packed Floating-Point Subtract Reverse	3			3DNow!		
PI2FD	Packed Integer to Floating-Point Doubleword Conversion	3			3DNow!		
PI2FW	Packed Integer To Floating-Point Word Conversion	3			3DNow! Extensions		
PINSRW	Packed Insert Word	3		SSE2	SSE, MMX Extensions		
PMADDWD	Packed Multiply Words and Add Doublewords	3		SSE2	MMX		
PMAXSW	Packed Maximum Signed Words	3		SSE2	SSE, MMX Extensions		

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	**Description**	**CPL**	**General-Purpose**	**128-Bit Media**	**64-Bit Media**	**x87**	**System**
PMAXUB	Packed Maximum Unsigned Bytes	3		SSE2	SSE, MMX Extensions		
PMINSW	Packed Minimum Signed Words	3		SSE2	SSE, MMX Extensions		
PMINUB	Packed Minimum Unsigned Bytes	3		SSE2	SSE, MMX Extensions		
PMOVMSKB	Packed Move Mask Byte	3		SSE2	SSE, MMX Extensions		
PMULHRW	Packed Multiply High Rounded Word	3			3DNow!		
PMULHUW	Packed Multiply High Unsigned Word	3		SSE2	SSE, MMX Extensions		
PMULHW	Packed Multiply High Signed Word	3		SSE2	MMX		
PMULLW	Packed Multiply Low Signed Word	3		SSE2	MMX		
PMULUDQ	Packed Multiply Unsigned Doubleword and Store Quadword	3		SSE2	SSE2		
POP	Pop Stack	3	Basic				
POPA	Pop All to GPR Words	3	Basic				
POPAD	Pop All to GPR Doublewords	3	Basic				
POPCNT	Bit Population Count	3	Basic				
POPF	Pop to FLAGS Word	3	Basic				
POPFD	Pop to EFLAGS Doubleword	3	Basic				
POPFQ	Pop to RFLAGS Quadword	3	Long Mode				
POR	Packed Logical Bitwise OR	3		SSE2	MMX		
PREFETCH	Prefetch L1 Data-Cache Line	3	3DNow!™, Long Mode				
PREFETCH*level*	Prefetch Data to Cache Level *level*	3	SSE, MMX Extensions				
PREFETCHW	Prefetch L1 Data-Cache Line for Write	3	3DNow!, Long Mode				
PSADBW	Packed Sum of Absolute Differences of Bytes into a Word	3		SSE2	SSE, MMX Extensions		

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
PSHUFD	Packed Shuffle Doublewords	3		SSE2			
PSHUFHW	Packed Shuffle High Words	3		SSE2			
PSHUFLW	Packed Shuffle Low Words	3		SSE2			
PSHUFW	Packed Shuffle Words	3			SSE, MMX Extensions		
PSLLD	Packed Shift Left Logical Doublewords	3		SSE2	MMX		
PSLLDQ	Packed Shift Left Logical Double Quadword	3		SSE2			
PSLLQ	Packed Shift Left Logical Quadwords	3		SSE2	MMX		
PSLLW	Packed Shift Left Logical Words	3		SSE2	MMX		
PSRAD	Packed Shift Right Arithmetic Doublewords	3		SSE2	MMX		
PSRAW	Packed Shift Right Arithmetic Words	3		SSE2	MMX		
PSRLD	Packed Shift Right Logical Doublewords	3		SSE2	MMX		
PSRLDQ	Packed Shift Right Logical Double Quadword	3		SSE2			
PSRLQ	Packed Shift Right Logical Quadwords	3		SSE2	MMX		
PSRLW	Packed Shift Right Logical Words	3		SSE2	MMX		
PSUBB	Packed Subtract Bytes	3		SSE2	MMX		
PSUBD	Packed Subtract Doublewords	3		SSE2	MMX		
PSUBQ	Packed Subtract Quadword	3		SSE2	SSE2		
PSUBSB	Packed Subtract Signed With Saturation Bytes	3		SSE2	MMX		
PSUBSW	Packed Subtract Signed with Saturation Words	3		SSE2	MMX		
PSUBUSB	Packed Subtract Unsigned and Saturate Bytes	3		SSE2	MMX		
PSUBUSW	Packed Subtract Unsigned and Saturate Words	3		SSE2	MMX		

Note:

1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
PSUBW	Packed Subtract Words	3		SSE2	MMX		
PSWAPD	Packed Swap Doubleword	3			3DNow! Extensions		
PUNPCKHBW	Unpack and Interleave High Bytes	3		SSE2	MMX		
PUNPCKHDQ	Unpack and Interleave High Doublewords	3		SSE2	MMX		
PUNPCKHQDQ	Unpack and Interleave High Quadwords	3		SSE2			
PUNPCKHWD	Unpack and Interleave High Words	3		SSE2	MMX		
PUNPCKLBW	Unpack and Interleave Low Bytes	3		SSE2	MMX		
PUNPCKLDQ	Unpack and Interleave Low Doublewords	3		SSE2	MMX		
PUNPCKLQDQ	Unpack and Interleave Low Quadwords	3		SSE2			
PUNPCKLWD	Unpack and Interleave Low Words	3		SSE2	3DNow!		
PUSH	Push onto Stack	3	Basic				
PUSHA	Push All GPR Words onto Stack	3	Basic				
PUSHAD	Push All GPR Doublewords onto Stack	3	Basic				
PUSHF	Push EFLAGS Word onto Stack	3	Basic				
PUSHFD	Push EFLAGS Doubleword onto Stack	3	Basic				
PUSHFQ	Push RFLAGS Quadword onto Stack	3	Long Mode				
PXOR	Packed Logical Bitwise Exclusive OR	3		SSE2	MMX		
RCL	Rotate Through Carry Left	3	Basic				
RCPPS	Reciprocal Packed Single-Precision Floating-Point	3		SSE			
RCPSS	Reciprocal Scalar Single-Precision Floating-Point	3		SSE			

Note:

1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
RCR	Rotate Through Carry Right	3	Basic				
RDMSR	Read Model-Specific Register	0					RDMSR, WRMSR
RDPMC	Read Performance-Monitoring Counter	3					Basic
RDTSC	Read Time-Stamp Counter	3					TSC
RDTSCP	Read Time-Stamp Counter and Processor ID	3					RDTSCP
RET	Return from Call	3	Basic				
ROL	Rotate Left	3	Basic				
ROR	Rotate Right	3	Basic				
RSM	Resume from System Management Mode	3					Basic
RSQRTPS	Reciprocal Square Root Packed Single-Precision Floating-Point	3		SSE			
RSQRTSS	Reciprocal Square Root Scalar Single-Precision Floating-Point	3		SSE			
SAHF	Store AH into Flags	3	Basic				
SAL	Shift Arithmetic Left	3	Basic				
SAR	Shift Arithmetic Right	3	Basic				
SBB	Subtract with Borrow	3	Basic				
SCAS	Scan String	3	Basic				
SCASB	Scan String as Bytes	3	Basic				
SCASD	Scan String as Doubleword	3	Basic				
SCASQ	Scan String as Quadword	3	Long Mode				
SCASW	Scan String as Words	3	Basic				
SETcc	Set Byte if Condition	3	Basic				
SFENCE	Store Fence	3	SSE, MMX™ Extensions				
SGDT	Store Global Descriptor Table Register	3					Basic
SHL	Shift Left	3	Basic				
SHLD	Shift Left Double	3	Basic				

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
SHR	Shift Right	3	Basic				
SHRD	Shift Right Double	3	Basic				
SHUFPD	Shuffle Packed Double-Precision Floating-Point	3		SSE2			
SHUFPS	Shuffle Packed Single-Precision Floating-Point	3		SSE			
SIDT	Store Interrupt Descriptor Table Register	3					Basic
SKINIT	Secure Init and Jump with Attestation	0					SVM
SLDT	Store Local Descriptor Table Register	3					Basic
SMSW	Store Machine Status Word	3					Basic
SQRTPD	Square Root Packed Double-Precision Floating-Point	3		SSE2			
SQRTPS	Square Root Packed Single-Precision Floating-Point	3		SSE			
SQRTSD	Square Root Scalar Double-Precision Floating-Point	3		SSE2			
SQRTSS	Square Root Scalar Single-Precision Floating-Point	3		SSE			
STC	Set Carry Flag	3	Basic				
STD	Set Direction Flag	3	Basic				
STGI	Set Global Interrupt Flag	0					SVM
STI	Set Interrupt Flag	3					Basic
STMXCSR	Store MXCSR Control/Status Register	3		SSE			
STOS	Store String	3	Basic				
STOSB	Store String Bytes	3	Basic				
STOSD	Store String Doublewords	3	Basic				
STOSQ	Store String Quadwords	3	Long Mode				
STOSW	Store String Words	3	Basic				
STR	Store Task Register	3					Basic

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
SUB	Subtract	3	Basic				
SUBPD	Subtract Packed Double-Precision Floating-Point	3		SSE2			
SUBPS	Subtract Packed Single-Precision Floating-Point	3		SSE			
SUBSD	Subtract Scalar Double-Precision Floating-Point	3		SSE2			
SUBSS	Subtract Scalar Single-Precision Floating-Point	3		SSE			
SWAPGS	Swap GS Register with KernelGSbase MSR	0					Long Mode
SYSCALL	Fast System Call	3					SYSCALL, SYSRET
SYSENTER	System Call	3					SYSENTER, SYSEXIT
SYSEXIT	System Return	0					SYSENTER, SYSEXIT
SYSRET	Fast System Return	0					SYSCALL, SYSRET
TEST	Test Bits	3	Basic				
UCOMISD	Unordered Compare Scalar Double-Precision Floating-Point	3		SSE2			
UCOMISS	Unordered Compare Scalar Single-Precision Floating-Point	3		SSE			
UD2	Undefined Operation	3					Basic
UNPCKHPD	Unpack High Double-Precision Floating-Point	3		SSE2			
UNPCKHPS	Unpack High Single-Precision Floating-Point	3		SSE			
UNPCKLPD	Unpack Low Double-Precision Floating-Point	3		SSE2			
UNPCKLPS	Unpack Low Single-Precision Floating-Point	3		SSE			
VERR	Verify Segment for Reads	3					Basic
VERW	Verify Segment for Writes	3					Basic
VMLOAD	Load State from VMCB	0					SVM

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Table D-1. Instruction Subsets and CPUID Feature Sets (continued)

Instruction			Instruction Subset and CPUID Feature Set(s)[1]				
Mnemonic	Description	CPL	General-Purpose	128-Bit Media	64-Bit Media	x87	System
VMMCALL	Call VMM	0					SVM
VMRUN	Run Virtual Machine	0					SVM
VMSAVE	Save State to VMCB	0					SVM
WAIT	Wait for x87 Floating-Point Exceptions	3				X87	
WBINVD	Writeback and Invalidate Caches	0					Basic
WRMSR	Write to Model-Specific Register	0					RDMSR, WRMSR
XADD	Exchange and Add	3	Basic				
XCHG	Exchange	3	Basic				
XLAT	Translate Table Index	3	Basic				
XLATB	Translate Table Index (No Operands)	3	Basic				
XOR	Exclusive OR	3	Basic				
XORPD	Logical Bitwise Exclusive OR Packed Double-Precision Floating-Point	3		SSE2			
XORPS	Logical Bitwise Exclusive OR Packed Single-Precision Floating-Point	3		SSE			

Note:
1. *Columns indicate the instruction subsets. Entries indicate the CPUID feature set(s) to which the instruction belongs.*
2. *Mnemonic is used for two different instructions. Assemblers can distinguish them by the number and type of operands.*

Appendix E Instruction Effects on RFLAGS

The flags in the RFLAGS register are described in “Flags Register” in Volume 1 and “RFLAGS Register” in Volume 2. Table E-1 summarizes the effect that instructions have on these flags. The table includes all instructions that affect the flags. Instructions not shown have no effect on RFLAGS.

The following codes are used within the table:

- 0—The flag is always cleared to 0.
- 1—The flag is always set to 1.
- AH—The flag is loaded with value from AH register.
- Mod—The flag is modified, depending on the results of the instruction.
- Pop—The flag is loaded with value popped off of the stack.
- Tst—The flag is tested.
- U—The effect on the flag is undefined.
- Gray shaded cells indicate that the flag is not affected by the instruction.

Table E-1. Instruction Effects on RFLAGS

Instruction Mnemonic	RFLAGS Mnemonic and Bit Number																
	ID 21	VIP 20	VIF 19	AC 18	VM 17	RF 16	NT 14	IOPL 13-12	OF 11	DF 10	IF 9	TF 8	SF 7	ZF 6	AF 4	PF 2	CF 0
AAA AAS									U				U	U	Tst Mod	U	Mod
AAD AAM									U				Mod	Mod	U	Mod	U
ADC									Mod				Mod	Mod	Mod	Mod	Tst Mod
ADD									Mod				Mod	Mod	Mod	Mod	Mod
AND									0				Mod	Mod	U	Mod	0
ARPL														Mod			
BSF BSR									U				U	Mod	U	U	U
BT BTC BTR BTS									U				U	U	U	U	Mod
CLC																	0
CLD										0							
CLI			Mod					TST			Mod						
CMC																	Mod
CMOV*cc*									Tst				Tst	Tst		Tst	Tst
CMP									Mod				Mod	Mod	Mod	Mod	Mod
CMPS*x*									Mod	Tst			Mod	Mod	Mod	Mod	Mod

Table E-1. Instruction Effects on RFLAGS (continued)

Instruction Mnemonic	RFLAGS Mnemonic and Bit Number																
	ID 21	VIP 20	VIF 19	AC 18	VM 17	RF 16	NT 14	IOPL 13-12	OF 11	DF 10	IF 9	TF 8	SF 7	ZF 6	AF 4	PF 2	CF 0
CMPXCHG									Mod				Mod	Mod	Mod	Mod	Mod
CMPXCHG8B														Mod			
CMPXCHG16B														Mod			
COMISD COMISS									0				0	Mod	0	Mod	Mod
DAA DAS									U				Mod	Mod	Tst Mod	Mod	Tst Mod
DEC									Mod				Mod	Mod	Mod	Mod	
DIV									U				U	U	U	U	U
FCMOV*cc*														Tst		Tst	Tst
FCOMI FCOMIP FUCOMI FUCOMIP														Mod		Mod	Mod
IDIV									U				U	U	U	U	U
IMUL									Mod				U	U	U	U	Mod
INC									Mod				Mod	Mod	Mod	Mod	
IN								Tst									
INS*x*								Tst		Tst							
INT INT 3			Mod	Mod	Tst Mod	0	Mod	Tst			Mod	0					
INTO				Mod	Tst Mod	0	Mod	Tst	Tst		Mod	Mod					
IRET*x*	Pop	Pop	Pop	Pop	Tst Pop	Pop	Tst Pop	Tst Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop
Jcc									Tst				Tst	Tst		Tst	Tst
LAR														Mod			
LODS*x*										Tst							
LOOPE LOOPNE														Tst			
LSL														Mod			
LZCNT									U				U	Mod	U	U	Mod
MOVS*x*										Tst							
MUL									Mod				U	U	U	U	Mod
NEG									Mod				Mod	Mod	Mod	Mod	Mod
OR									0				Mod	Mod	U	Mod	0
OUT								Tst									
OUTS*x*								Tst		Tst							
POPCNT									0				0	Mod	0	0	0
POPF*x*	Pop	Tst	Mod	Pop	Tst	0	Pop	Tst Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop	Pop

Table E-1. Instruction Effects on RFLAGS (continued)

Instruction Mnemonic	RFLAGS Mnemonic and Bit Number																
	ID 21	VIP 20	VIF 19	AC 18	VM 17	RF 16	NT 14	IOPL 13-12	OF 11	DF 10	IF 9	TF 8	SF 7	ZF 6	AF 4	PF 2	CF 0
RCL 1									Mod								Tst Mod
RCL *count*									U								Tst Mod
RCR 1									Mod								Tst Mod
RCR *count*									U								Tst Mod
ROL 1									Mod								Mod
ROL *count*									U								Mod
ROR 1									Mod								Mod
ROR *count*									U								Mod
RSM	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
SAHF													AH	AH	AH	AH	AH
SAL 1									Mod				Mod	Mod	U	Mod	Mod
SAL *count*									U				Mod	Mod	U	Mod	Mod
SAR 1									Mod				Mod	Mod	U	Mod	Mod
SAR *count*									U				Mod	Mod	U	Mod	Mod
SBB									Mod				Mod	Mod	Mod	Mod	Tst Mod
SCAS*x*									Mod	Tst			Mod	Mod	Mod	Mod	Mod
SETcc									Tst				Tst	Tst		Tst	Tst
SHLD 1 SHRD 1									Mod				Mod	Mod	U	Mod	Mod
SHLD count SHRD count									U				Mod	Mod	U	Mod	Mod
SHR 1									Mod				Mod	Mod	U	Mod	Mod
SHR count									U				Mod	Mod	U	Mod	Mod
STC																	1
STD										1							
STI			Mod					Tst			Mod						
STOS*x*										Tst							
SUB									Mod				Mod	Mod	Mod	Mod	Mod
SYSCALL	Mod	Mod	Mod	Mod	0	0	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
SYSENTER					0	0					0						
SYSRET	Mod	Mod	Mod	Mod		0	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod
TEST									0				Mod	Mod	U	Mod	0
UCOMISD UCOMISS									0				0	Mod	0	Mod	Mod

Table E-1. Instruction Effects on RFLAGS (continued)

Instruction Mnemonic	RFLAGS Mnemonic and Bit Number																
	ID 21	**VIP 20**	**VIF 19**	**AC 18**	**VM 17**	**RF 16**	**NT 14**	**IOPL 13-12**	**OF 11**	**DF 10**	**IF 9**	**TF 8**	**SF 7**	**ZF 6**	**AF 4**	**PF 2**	**CF 0**
VERR VERW														Mod			
XADD									Mod				Mod	Mod	Mod	Mod	Mod
XOR									0				Mod	Mod	U	Mod	0

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