x86 Assembly Tutorial

From 8086 to Intel Core Processors

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Contents

1 Introduction

1.1 Overview

The x86 architecture is a wide spread microprocessor architecture used today. From time to time it could be helpful to understand the architecture more in depth or even develop some parts of a program in assembly language because you either want to tune the performance or to reduce the space needed.

In this book I will go through the assembly language instructions found in modern x86 processors. I will start with the 8086 assembly language in chapter 3 and go on to the 8087 assembly language extensions in chapter 4, which is the first x87 floating point unit (FPU).

Further on I will visit the other CPUs in historical order. We go on with the 80286 in chapter 7, the 80386 in chapter 9 and the 80486 in chapter 11.

After that I will not go on with different processors but with features. This starts with the chapter Processor with CPUID which is the first feature I'll discuss. This is the base for all other features because with the `CPUID` you can determine all other features. This is because not every processor needs to implement all features.

I start with the 8086 and go on through all other successing processors because some of the idiosyncrasies of the modern processors can be easier understand if you have the history in mind.

I will look at the processors from the softwares view. If there are differences in the hardware I do not concern as long as it does not influence the software run on the processor.

1.2 Structure of this Book

This book has a certain structure that I want to explain in this section.

Each processor or feature has its own chapter and this chapter is divided into sections that show several associated instructions. In this sections the instructions are explained and also the according memory structures (if there are any).

Additionally this book has several appendices. The appendices have the following meaning:

A	Differences in AT&T syntax and Intel syntax
B	Main glossary
C	Acronyms
D	Instructions with a short description
E	List of code chunks defined
F	Licenses of the document and the code
G	Master index
H	Instruction index

When an instruction is used on a page this instruction in printed in the margin for easier reference.

All examples in this book are written in Intel syntax. To see the differences between AT&T syntax and Intel syntax please refer to the chapter A Assembly Syntax.

In examples I will write the instructions in lower case letters and registers in upper case letters. If I need to use a label then this will also be in lower case.

2 Environment

2.1 Introduction

To develop software, independent of the programming language used, you need some tools. I selected some tools that I will use in this tutorial.

We will not develop application software in this tutorial but will look at the instructions and therefore have special requirements on the tools. Also we have nothing that supports us with doing regular tasks such as printing a text to the screen. Therefore most of the time we will run our programs in an isolated environment and see the results directly in a debugger.

If you are used to work with Linux then please go on to section 2.2 Setup. There I list all software needed and give a short introduction to each of this tools.

If you do not know Linux or are not used to work with the command line interface (CLI) then it is best to continue with section 2.3 VM. In this section I will show a virtual machine (VM) that contains everything and also give an instruction on how to use everything with a step–by–step introduction.

In either case after setup you should go the section 2.4 Test Setup to make a short check of your setup.

2.2 Setup

If you already use a Linux system and know how to use the CLI then you need to ensure that some software is installed.

The following software is included in the standard repositories of most distributions, at least CentOS (with epel), debian and ubuntu have the software in the repositories.

- NASM
- GNU Debugger (GDB)
- QEMU (install the package qemu-system-x86)
- git

You additionally need to setup an additional repository to install git-lfs. The installation instructions for setting up the repository for CentOS, debian and ubuntu can be found at `https://github.com/git-lfs/git-lfs/wiki/Installation`.

Next is it advisable to clone the repository of this tutorial (from `https://github.com/osdevelopment-info/tutorial-x86`). This repository contains a subfolder `bootloader/`

wich contains a bootloader that helps us and also a shell script that creates a floppy disk for booting.

Additionally you can create a subfolder in your home that contains all tutorial code that you write. In the course of this book I expect the folder to be `tutorial/`.

Finally creating a file `~/.gdbinit` with the following content will help us during development.

```
set auto-load safe-path /home/<username>
```

You can restrict the path for autoloading further to the subfolder that you create for the tutorial code.

Now please check you setup with section 2.4 Test Setup.

2.3 VM

If you are not using Linux or not used to use the CLI on a daily base then the VM created for this tutorial is perhaps helpfull for you.

The link to download the VM can be found at the projects page[1].

I created the VM using VirtualBox. The software should also run with other virtualization software but this is not tested.

The VM is a debian installation with all additional software installed. The VM does not contain a graphical user interface (GUI) and is only installed with CLI.

To install the downloaded VM you have to follow the following steps. I explain these steps for VirtualBox.

To install the downloaded VM in VirtualBox start VirtualBox and select "Import Appliance..." in the menu "File". Select the downloaded file in the import settings and click "Next>" to go to the settings screen. There click "Import" to import the VM. After that the VM is ready to start.

So to help you with using this tutorial I created a toolset that may help you. Basically I created a VM that contains everything that you need to see the instructions work as explained in this book. The VM contains a basic debian and all tools needed to run the examples. The tools installed are NASM (used to assemble your programs), GDB (a debugger to view into your program) and QEMU (an emulator to run and debug your program). The use of QEMU is helpfull because it has a direct interface for the debugger and supports also 16-bit programs (with which we start). Additionally the git repository that hosts this tutorial is checked out (into `/home/tut/tutorial-x86`). This repository contains a simple bootloader which helps you loading you programs. We will not develop any applications in this book but program directly on the bare metal because then we do not need to obey any rules.

So after setting up the VM start the VM and log in with username `tut` and the password `tut`. If you execute any command with `sudo` then you have to repeat your password.

[1] https://osdevelopment-info.github.io/tutorial-x86/

First we should check that the network is working correctly (in some VM environments it must be adjusted) by issuing the following command

```
dmesg | grep "renamed from eth"
```

The output of the command is like

```
[    X.XXXXXX] eXXXX XXXX:XX:XX.X enp0s3: renamed from eth0
```

If the name is `enp0s3` then the network should be alright else you have to adjust the network settings.

To adjust the network settings open the file `/etc/network/interfaces` with `nano` or `vi` and change the occurences of `enp0s3` with the output of the command above. After the change reboote the VM with the command

```
sudo reboot
```

Before we start I suggest updating the operating system of the VM and the tutorial repository with the following commands

```
sudo apt-get update
sudo apt-get upgrade
cd tutorial-x86
git pull
cd
```

First create a folder that houses your code samples. I suggest the following structure:

tutorial
├─ 8086
├─ 8087
├─ 80186
├─ 80286
├─ 80287
├─ 80386
├─ 80387
├─ 80486
├─ cpuid
└─ ...

so having one folder and include a new folder specific to each processor/feature in this book.

Now go into the right folder and copy the `bootloader` and the `makebootfloppy.sh` from `/home/tut/tutorial-x86/bootloader` to the folder.

```
cp ~/tutorial-x86/bootloader/bootloader ~/tutorial-x86/bootloader/makebootflopy.sh .
```

The `bootloader` loads our code into the memory and the `makebootfloppy.sh` creates a boot floppy for us.

Next we start with coding for the 8086 so we create a file `.gdbinit` in the current folder with the following content (use either `vi` or `nano` for editing)

```
break *0x8000
set disassembly-flavor intel
set disassemble-next-line on
set architecture i8086
layout asm
layout regs
target remote localhost:1234
```

This file sets the correct breakpoint and program layout for GDB and tries to connect to QEMU which should already be running when calling GDB.

2.4 Test Setup

- qemu-system-i386 -s -S -drive format=raw,file=floppy,if=floppy
- gdbtui

```
git clone https://github.com/osdevelopment-info/tutorial-x86
cd tutorial-x86/bootloader
vi test.asm / nano test.asm / pico test.asm
nasm test.asm -o test
cat bootloader test > floppy
./makebootfloppy.sh floppy
qemu-system-i386 -s -S -drive format=raw,file=floppy,if=floppy \
-cpu 486 -display curses
```

Alt + F2

```
gdbtui
```

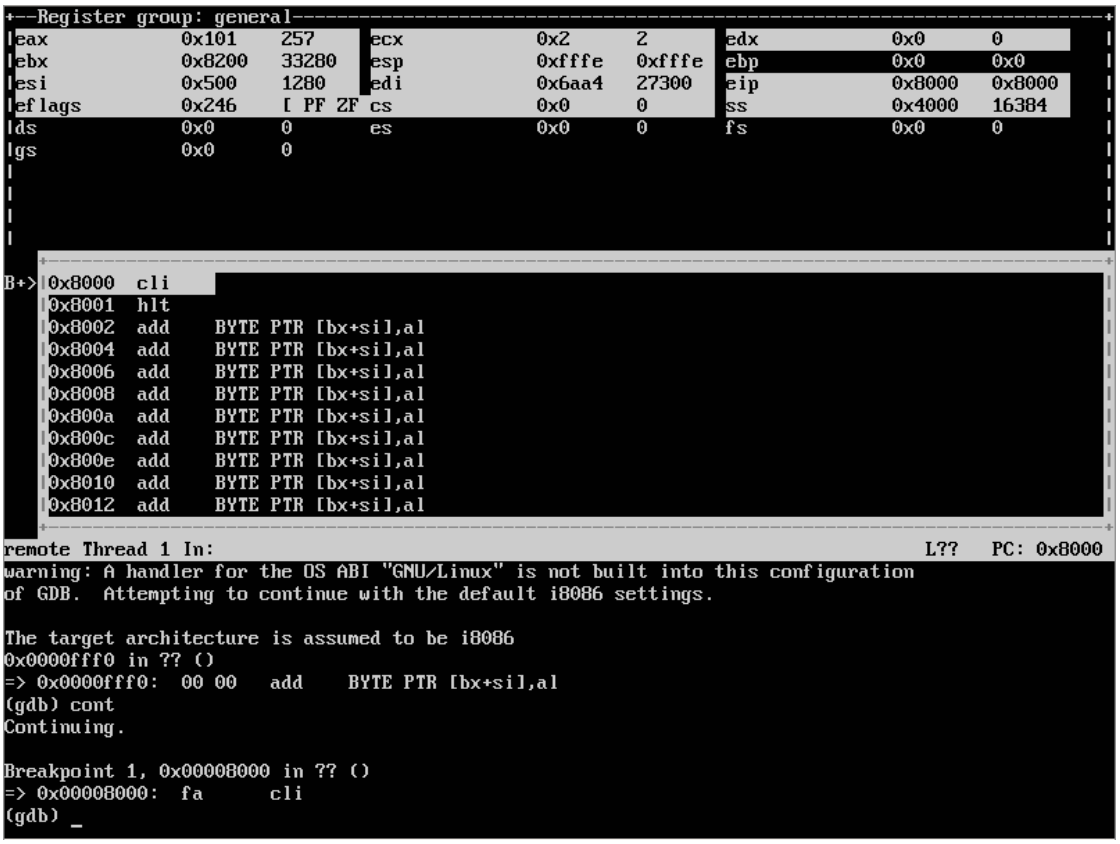

Figure 2.1: GDB TUI in action.

3 8086

3.1 Introduction

- released 1978 (Intel)
- Intel 8086
- Intel 8088
- AMD 8086
- AMD 8088

3.2 Special Commands

TBD	HLT
TBD	LOCK
TBD	NOP
TBD	WAIT

3.3 Moving Data Around

TBD	CBW
TBD	CWD
TBD	LAHF
TBD	MOV
TBD	SAHF
TBD	XCHG

3.4 Doing Arithmetic

TBD	AAA
TBD	AAD
TBD	AAM
TBD	AAS
TBD	ADC
TBD	ADD
TBD	DAA

DAS	TBD
DEC	TBD
DIV	TBD
IDIV	TBD
IMUL	TBD
INC	TBD
MUL	TBD
NEG	TBD
SBB	TBD
SUB	TBD
XCHG	TBD

3.5 Doing Boolean Arithmetic

AND	TBD
NOT	TBD
OR	TBD
XOR	TBD

3.6 Shifting and Rotating

RCL	TBD
RCR	TBD
ROL	TBD
ROR	TBD
SAL	TBD
SAR	TBD
SHL	TBD
SHR	TBD

3.7 Accessing Memory

LDS	TBD
LEA	TBD
LES	TBD
LODS	TBD
MOV	TBD
MOVS	TBD
SCAS	TBD
STOS	TBD
XCHG	TBD
XLAT	TBD

3.8 Conditions and Control Flow

TBD	CLC
TBD	CLD
TBD	CMC
TBD	CMP
TBD	CMPS
TBD	Jcc
TBD	JMP
TBD	LOOP/LOOPcc
TBD	REPcc
TBD	STC
TBD	STD
TBD	TEST

3.9 Using Subroutines

TBD	CALL
TBD	POP
TBD	POPF
TBD	PUSH
TBD	PUSHF
TBD	RET

3.10 Interrupting Work and Using System Subroutines

TBD	CLI
TBD	INT
TBD	INTO
TBD	IRET
TBD	STI

3.11 Communicating with Periphery

TBD	IN
TBD	OUT

4 8087

- released 1980 (Intel)
- Intel 8087

TBD	F2XM1
TBD	FABS
TBD	FADD
TBD	FADDP
TBD	FBLD
TBD	FBSTP
TBD	FCHS
TBD	FCLEX
TBD	FCOM
TBD	FCOMP
TBD	FCOMPP
TBD	FDECSTP
TBD	FDISI
TBD	FDIV
TBD	FDIVP
TBD	FDIVR
TBD	FDIVRP
TBD	FENI
TBD	FFREE
TBD	FIADD
TBD	FICOM
TBD	FICOMP
TBD	FIDIV
TBD	FIDIVR
TBD	FILD
TBD	FIMUL
TBD	FINCSTP
TBD	FINIT
TBD	FIST
TBD	FISTP
TBD	FISUB
TBD	FISUBR
TBD	FLD

FLD1	TBD
FLDCW	TBD
FLDENV	TBD
FLDL2E	TBD
FLDL2T	TBD
FLDLG2	TBD
FLDLN2	TBD
FLDPI	TBD
FLDZ	TBD
FMUL	TBD
FMULP	TBD
FNCLEX	TBD
FNDISI	TBD
FNENI	TBD
FNINIT	TBD
FNOP	TBD
FNSAVE	TBD
FNSTCW	TBD
FNSTENV	TBD
FNSTSW	TBD
FPATAN	TBD
FPREM	TBD
FPTAN	TBD
FRNDINT	TBD
FRSTOR	TBD
FSAVE	TBD
FSCALE	TBD
FST	TBD
FSTCW	TBD
FSTENV	TBD
FSTP	TBD
FSTSW	TBD
FSUB	TBD
FSUBP	TBD
FSUBR	TBD
FSUBP	TBD
FTST	TBD
FWAIT	TBD
FXAM	TBD
FXCH	TBD
FXTRACT	TBD
FYL2X	TBD
FYL2XP1	TBD

5 80186

- released 1982 (Intel)
- Intel 80186

TBD	BOUND
TBD	ENTER
TBD	INS
TBD	LEAVE
TBD	OUTS
TBD	POPA
TBD	PUSHA
TBD (immediate)	PUSH
TBD (immediate)	IMUL
TBD (immediate)	SHL
TBD (immediate)	SHR
TBD (immediate)	SAL
TBD (immediate)	SAR
TBD (immediate)	ROL
TBD (immediate)	ROR
TBD (immediate)	RCL
TBD (immediate)	RCR

6 80187

- released ??? (Intel)
- Intel 80187 (8087 interface/80387 core)

7 80286

- released 1982 (Intel)
- Intel 80286
- i286 (Intel)
- Am286 (AMD)

TBD	ARPL
TBD	CLTS
TBD	LAR
TBD	LGDT
TBD	LIDT
TBD	LLDT
TBD	LMSW
TBD	LSL
TBD	LTR
TBD	SGDT
TBD	SIDT
TBD	SLDT
TBD	SMSW
TBD	STR
TBD	VERR
TBD	VERW

8 80287

- released ??? (Intel)
- Intel 80287
- i287 (Intel)

TBD FSETPM

9 80386

- released 1985 (Intel)
- Intel 80386
- i386 (Intel)
- Am386 (AMD)

TBD (extend)	ADC
TBD (extend)	ADD
TBD (extend)	AND
TBD (extend)	BOUND
TBD	BSF
TBD	BSR
TBD	BT
TBD	BTC
TBD	BTR
TBD	BTS
TBD (extend)	CALL
TBD	CDQ
TBD (extend)	CMP
TBD (extend)	CMPS
TBD	CWDE
TBD (extend)	DEC
TBD (extend)	DIV
TBD (extend)	ENTER
TBD (extend)	IDIV
TBD (extend)	IMUL
TBD (extend)	IN
TBD (extend)	INC
TBD (extend)	INS
TBD (extend)	IRET
TBD (extend)	Jcc
TBD (extend)	JMP
TBD (extend)	LAR
TBD	LFS
TBD	LGS
TBD	LSS

LEA	TBD (extend)
LEAVE	TBD (extend)
LODS	TBD (extend)
LOOP/LOOPcc	TBD (extend)
LSL	TBD (extend)
MOV	TBD (extend)
MOVS	TBD (extend)
MOVSX	TBD
MOVZX	TBD
MUL	TBD (extend)
NEG	TBD (extend)
NOT	TBD (extend)
OR	TBD (extend)
OUT	TBD (extend)
OUTS	TBD (extend)
POP	TBD (extend)
POPA	TBD (extend)
POPF	TBD (extend)
PUSH	TBD (extend)
PUSHA	TBD (extend)
PUSHF	TBD (extend)
RCL	TBD (extend)
RCR	TBD (extend)
REPcc	TBD (extend)
ROL	TBD (extend)
ROR	TBD (extend)
SAL	TBD (extend)
SAR	TBD (extend)
SBB	TBD (extend)
SCAS	TBD (extend)
SETcc	TBD
SGDT	TBD (extend)
SHL	TBD (extend)
SHLD	TBD
SHR	TBD (extend)
SHRD	TBD
SIDT	TBD (extend)
SMSW	TBD (extend)
STOS	TBD (extend)
SUB	TBD (extend)
TEST	TBD (extend)
XCHG	TBD (extend)
XLAT	TBD (extend)
XOR	TBD (extend)

10 80387

- released 1987 (Intel)
- Intel 80387
- i387 (Intel)

TBD	FCOS
TBD (extend)	FNSAVE
TBD (extend)	FNSTENV
TBD (extend)	FNSTSW
TBD	FPREM1
TBD (extend)	FRSTOR
TBD (extend)	FSAVE
TBD (extend)	FSTENV
TBD (extend)	FSTSW
TBD	FSIN
TBD	FSINCOS
TBD	FUCOM
TBD	FUCOMP
TBD	FUCOMPP

11 80486

- released 1989 (Intel)
- i486 (Intel)
- Am486 (AMD)
- Am5x86 (AMD)

TBD	BSWAP
TBD	CMPXCHG
TBD	INVD
TBD	INVLPG
TBD	WBINVD
TBD	XADD

12 RSM

- released 1993 (Intel)

TBD

RSM

13 Processor with CPUID

- released 1993 (Intel)
- Intel Pentium (Intel)
- AMD K5 (AMD)

TBD CPUID

14 CX8

- released 1993 (Intel)

TBD CMPXCHG8B

15 MSR

- released 1993 (Intel)

TBD	RDMSR
TBD	WRMSR

16 TSC

- released 1993 (Intel)
- Invariant TSC

TBD

RDTSC

17 PMC

- released 1997 (Intel)

TBD RDPMC

18 MMX

- released 1997 (Intel)

TBD	EMMS
TBD	MOVD
TBD	MOVQ
TBD	PACKSSDW
TBD	PACKSSWB
TBD	PACKUSWB
TBD	PADDB
TBD	PADDW
TBD	PADDD
TBD	PADDQ
TBD	PADDSB
TBD	PADDSW
TBD	PADDUSB
TBD	PADDUSW
TBD	PAND
TBD	PANDN
TBD	PCMPEQB
TBD	PCMPEQW
TBD	PCMPEQD
TBD	PCMPGTB
TBD	PCMPGTW
TBD	PCMPGTD
TBD	PMADDWD
TBD	PMULHW
TBD	PMULLW
TBD	POR
TBD	PSLLW
TBD	PSLLD
TBD	PSLLQ
TBD	PDRAW
TBD	PDRAD
TBD	PDRAQ
TBD	PDRLW
TBD	PDRLD
TBD	PDRLQ

PSUBB	TBD
PSUBW	TBD
PSUBD	TBD
PSUBSB	TBD
PSUBSW	TBD
PSUBUSB	TBD
PSUBUSW	TBD
PUNPCKHBW	TBD
PUNPCKHDQ	TBD
PUNPCKHWD	TBD
PUNPCKLBW	TBD
PUNPCKLDQ	TBD
PUNPCKLWD	TBD
PXOR	TBD

19 Temp

This is a temporary chapter to help me organize this book.

- CLFSH
- CMPXCHG16B
- CMOV
- RDTSCP
- SEP
- SYSCALL/SYSRET in 64-bit Mode
- 3DNow (AMD)
- MMX ext (AMD)
- 3DNow ext (AMD)
- PREFETCHW (3DNow AMD)
- SSE
- SSE2
- SSE3
- SSSE3
- SSE4A (AMD)
- SSE4.2
- Intel 64 Architecture/Long Mode (AMD)
- MISCSELECT (SGX) (Intel)
- SGX1 (Intel)
- SGX2 (Intel)
- ENCLV (SGX) (Intel)

- ENCLS (SGX) (Intel)
- SVM (AMD)
- AVX
- AVX2
- XOP (AMD)
- AESNI (AES (AMD))
- FMA
- FMA4 (AMD)
- F16C
- RDRAND
- LZCNT (ABM (AMD))
- BMI1
- BMI2
- POPCNT
- TBM (AMD)
- MOVBE
- MONITOR
- MONITORX (AMD)
- PCMULQDQ
- FXSR
- SKINIT (AMD)
- LAHF/SAHF in 64-bit Mode
- FSGSBASE
- SHA
- CLFLUSHOPT (CLFLOPT (AMD))
- SMAP
- ADX

- RDSEED
- SME (AMD)
- SEV (AMD)
- PageFlushMgr (AMD)
- ES (AMD)
- CLZERO (AMD)
- Instruction Retired Counter (AMD)
- Error Pointer (AMD)
- XSAVEOPT
- XSAVEC
- XGETBV
- XSAVES
- XSAVE
- OSXSAVE
- HTT
- PSE-36
- PAT
- MCA
- PGE
- MTRR
- APIC
- MCE
- PAE
- PSE
- DE
- VME
- SMEP

- DTSE64 (Intel)
- MONITOR (Intel)
- DS-CPL (Intel)
- VMX (Intel)
- SMX (Intel)
- EIST (Intel)
- TM2 (Intel)
- CNXT-ID (Intel)
- SDBG (Intel)
- xTPR Update Control (Intel)
- PDCM (Intel)
- PCID (Intel)
- DCA (Intel)
- x2APIC (Intel)
- TSC-Deadline (Intel)
- PSN (Intel)
- DS (Intel)
- ACPI (Intel)
- SS (Intel)
- TM (Intel)
- PBE (Intel)
- Execute Disable Flag (Intel)
- IA32_TSC_ADJUST (Intel)
- HLE (Intel)
- INVPCID (Intel)
- RTM (Intel)
- RDT-M (Intel)

- MPX (Intel)
- RDT-A (Intel)
- AVX512F (Intel)
- AVX512DQ (Intel)
- AVX512_IFMA (Intel)
- CLWB (Intel)
- Intel Processor Trace (Intel)
- AVX512PF (Intel)
- AVX512ER (Intel)
- AVX512CD (Intel)
- AVX512BW (Intel)
- AVX512VL (Intel)

A Assembly Syntax

A.1 Introduction

There are two different syntaxes for assembly language for the x86 assembly language. One is the AT&T syntax and the other is the Intel syntax.

The difference looks like this:

AT&T Syntax	Intel Syntax
`movw %DX,%AX`	`mov AX,DX`

If you work with Linux or other Unix like systems you will most likely find the AT&T syntax. If you use material from Intel you will find the Intel syntax. I will use the Intel syntax in this book as I will reference Intel material for reference.

In the remaining section I will explain all differences between the syntaxes.

A.2 Register Naming

The registers have a plain name in Intel syntax, like `AX` or `RAX`. In AT&T syntax each register is prefixed with `%` so the registers would be named `%AX` or `%RAX`.

Example:

AT&T Syntax	Intel Syntax
`%AX`	`AX`

A.3 Immediate Value

If you use an immediate value (e.g. a constant) then you have to prefix this with `$` in AT&T syntax. In Intel syntax a prefix is not needed. When using binary immediates you have to prefix the value with `0b`, hexadecimal immediates must be prefixed with `0x`. If you start an immediate with `0` (the figure 0) then the value is interpreted as octal in AT&T syntax whereas in Intel syntax you prefix the immediate with `0o` or `0q`.

Example for moving a binary value to `BL`:

AT&T Syntax	Intel Syntax
`movb $0b00111100,%BL`	`mov BL,0b00111100`

Example for moving an octal value to `BL`:

AT&T Syntax	Intel Syntax
`movb $0123,%BL`	`mov BL,0o123`

Example for moving a decimal value to `BL`:

AT&T Syntax	Intel Syntax
`movb $15,%BL`	`mov BL,15`

Example for moving a hexadecimal value to `BL`:

AT&T Syntax	Intel Syntax
`movb $0xab,%BL`	`mov BL,0xab`

A.4 Order of Operands

The order of operands are reversed between AT&T syntax and Intel syntax. In AT&T syntax you name the source operand(s) first and the target last. In Intel syntax the target is named first and then the source operand(s).

Example to move a value from `AX` to `BX`:

AT&T Syntax	Intel Syntax
`movl %AX,%BX`	`mov BX,AX`

A.5 Data Size Determination

In AT&T syntax you usually append a suffix to the instruction to determine the data size. This is done by appending `b` for byte (8 bit integer) operands, `s` for short (16 bit integer/32 bit float) operands, `w` for word (16 bit integer) operands, `l` for long (32 bit integer/64 bit float) operands, `q` for quad (64 bit integer) operands and `t` for ten byte (80 bit float) operands.

In Intel sytax you only determine the operand size if it is not deferable by the operands directly. So you add `byte` for a byte (8 bit), `word` for a word (16 bit), `dword` for a double word (32 bit) and `qword` for a quad word (64 bit).

Example to move a byte to a register:

AT&T Syntax	Intel Syntax
`movb $0x80,%AL`	`mov AL,0x80`

Example to move a word into a memory location:

AT&T Syntax	Intel Syntax
`movw $0x8080,(%EAX)`	`mov word[EAX],0x8080`

A.6 Indirect Memory Access

When accessing the memory with an address in a register the syntax also differs. In AT&T syntax you enclose the register with round brackets (`()`). In Intel syntax you use square brackets for this (`[]`).

Example to load the byte from the address stored in `ESI` to `AH`:

AT&T Syntax	Intel Syntax
`movb (%ESI),%AH`	`mov AH,[ESI]`

B Glossary

bootloader a program that runs at the start of a computer and loads further code 8

CentOS a Linux distribution 7

clone coping the repository in a distibuted version control system (dVCS) 7

debian the Linux distribution used in this book for the VM 7, 8

debugger a program to execute and monitor another program and stop the execution of the monitored program for examination 7

git a dVCS 7, 8

git-lfs an extension to git for handling large files 7

Linux an operating system 7, 8, 53

NASM the assembler used in this book (The Netwide Assembler) 7, 8

QEMU the x86 emulator used in this book 7, 8, 10

ubuntu a Linux distribution 7

VirtualBox a virtualization software running on different operating system (OS) 8

x86 a microprocessor architecture based on the 8086/8088 from Intel 5, 53

x87 a mathematical coprocessor for the x86 5

C Acronyms

CLI command line interface 7, 8

FPU floating point unit 5

GDB GNU Debugger 7, 8, 10

GUI graphical user interface 8

VM virtual machine 7–9

D x86-Instructions

AAA ASCII adjust AL after addition, introduced with 8086 13

AAD ASCII adjust AX before division, introduced with 8086 13

AAM ASCII adjust AX after multiplication, introduced with 8086 13

AAS ASCII adjust AL after subtraction, introduced with 8086 13

ADC Add with carry, introduced with 8086, extended with 80386 13, 27

ADD Add, introduced with 8086, extended with 80386 13, 27

AND Logical AND, introduced with 8086, extended with 80386 14, 27

ARPL Adjust RPL field of selector, introduced with 80286 23

BOUND Check array index against bounds, introduced with 80186, extended with 80386 19, 27

BSF Bit scan forward, introduced with 80386 27

BSR Bit scan reverse, introduced with 80386 27

BSWAP Byte swap, introduced with 80486 31

BTC Bit test and complement, introduced with 80386 27

BTR Bit test and reset, introduced with 80386 27

BTS Bit test and set, introduced with 80386 27

BT Bit test, introduced with 80386 27

CALL Call procedure, introduced with 8086, extended with 80386 15, 27

CBW Convert byte to word, introduced with 8086 13

CDQ Convert double-word to quad-word, introduced with 80386 27

CLC Clear carry flag, introduced with 8086 15

CLD Clear direction flag, introduced with 8086 15

CLI Clear interrupt flag, introduced with 8086 15

CLTS Clear task-switched flag in CR0, introduced with 80286 23

CMC Complement carry flag, introduced with 8086 15

CMPS Compare string operands, introduced with 8086, extended with 80386 15, 27

CMPXCHG8B Compare and exchange bytes, introduced with CX8 37

CMPXCHG Compare and exchange, introduced with 80486 31

CMP Compare two operands, introduced with 8086, extended with 80386 15, 27

CPUID CPU identification, introduced with Processor with CPUID 5, 35

CWDE Convert word to double-word, introduced with 80386 27

CWD Convert word to doubleword, introduced with 8086 13

DAA Decimal adjust AL after addition, introduced with 8086 13

DAS Decimal adjust AL after subtraction, introduced with 8086 14

DEC Decrement by 1, introduced with 8086, extended with 80386 14, 27

DIV Unsigned divide, introduced with 8086, extended with 80386 14, 27

EMMS Empty MMX technology state, introduced with MMX 45

ENTER Make stack frame for procedure parameters, introduced with 80186, extended with 80386 19, 27

F2XM1 Computer $2^x - 1$, introduced with 8087 17

FABS Absolute value, introduced with 8087 17

FADDP Add and pop, introduced with 8087 17

FADD Add, introduced with 8087 17

FBLD Load binary coded decimal (BCD), introduced with 8087 17

FBSTP Store BCD integer and pop, introduced with 8087 17

FCHS Change sign, introduced with 8087 17

FCLEX Clear exceptions, introduced with 8087 17

FCOMPP Compare floating point values and pop twice, introduced with 8087 17

FCOMP Compare floating point values and pop, introduced with 8087 17

FCOM Compare floating point values, introduced with 8087 17

FCOS Cosine, introduced with 80387 29

FDECSTP Decrement stack-top pointer, introduced with 8087 17

FDISI Disable interrupts, introduced with 8087, **FNOP** on other FPUs 17

FDIVP Divide and pop, introduced with 8087 17

FDIVRP Reverse divide and pop, introduced with 8087 17

FDIVR Reverse divide, introduced with 8087 17

FDIV Divide, introduced with 8087 17

FENI Enable interrupts, introduced with 8087, **FNOP** on other FPUs 17

FFREE Free floating-pont register, introduced with 8087 17

FIADD Add integer, introduced with 8087 17

FICOMP Compare integer and pop, introduced with 8087 17

FICOM Compare integer, introduced with 8087 17

FIDIVR Reverse divide integer, introduced with 8087 17

FIDIV Divide integer, introduced with 8087 17

FILD Load integer, introduced with 8087 17

FIMUL Multiply integer, introduced with 8087 17

FINCSTP Increment stack-top pointer, introduced with 8087 17

FINIT Initialize floating point unit, introduced with 8087 17

FISTP Store integer and pop, introduced with 8087 17

FIST Store integer, introduced with 8087 17

FISUBR Reverse subtract integer, introduced with 8087 17

FISUB Subtract integer, introduced with 8087 17

FLD1 Load constant 1.0, introduced with 8087 18

FLDCW Load x87 FPU control word, introduced with 8087 18

FLDENV Load x87 FPU environment, introduced with 8087 18

FLDL2E Load constant $log_2(e)$, introduced with 8087 18

FLDL2T Load constant $log_2(10)$, introduced with 8087 18

FLDLG2 Load constant $log_10(2)$, introduced with 8087 18

FLDLN2 Load constant $ln(2)$, introduced with 8087 18

FLDPI Load constant π, introduced with 8087 18

FLDZ Load constant 0.0, introduced with 8087 18

FLD Load floating point value, introduced with 8087 17

FMULP Multiply and pop, introduced with 8087 18

FMUL Multiply, introduced with 8087 18

FNCLEX Clear exceptions, no wait, introduced with 8087 18

FNDISI Disable interrupts, no wait, introduced with 8087, `FNOP` on other FPUs 18

FNENI Enable interrupts, no wait, introduced with 8087, `FNOP` on other FPUs 18

FNINIT Initialize floating point unit, no wait, introduced with 8087 18

FNOP No operation, introduced with 8087 18

FNSAVE Save x87 FPU state, no wait, introduced with 8087, extended with 80387 18, 29

FNSTCW Store x87 FPU control word, no wait, introduced with 8087 18

FNSTENV Store x87 FPU environment, no wait, introduced with 8087, extended with 80387 18, 29

FNSTSW Store x87 FPU status word, no wait, introduced with 8087, extended with 80387 18, 29

FPATAN Partial arctangent, introduced with 8087 18

FPREM1 Partial remainder (IEEE), introduced with 80387 29

FPREM Partial remainder, introduced with 8087 18

FPTAN Partial tangent, introduced with 8087 18

FRNDINT Round to integer, introduced with 8087 18

FRSTOR Restore x87 FPU state, introduced with 8087, extended with 80387 18, 29

FSAVE Save x87 FPU state, introduced with 8087, extended with 80387 18, 29

FSCALE Scale, introduced with 8087 18

FSETPM Set protected mode, introduced with 80287, `FNOP` on other FPUs 25

FSINCOS Sine and cosine, introduced with 80387 29

FSIN Sine, introduced with 80387 29

FSTCW Store x87 FPU control word, introduced with 8087 18

FSTENV Store x87 FPU environment, introduced with 8087, extended with 80387 18, 29

FSTP Store floating point value and pop, introduced with 8087 18

FSTSW Store x87 FPU status word, introduced with 8087, extended with 80387 18, 29

FST Store floating point value, introduced with 8087 18

FSUBP Subtract and pop, introduced with 8087 18

FSUBR Reverse subtract, introduced with 8087 18

FSUB Subtract, introduced with 8087 18

FTST Test, introduced with 8087 18

FUCOMPP Unordered compare floating point values and pop twice, introduced with 80387 29

FUCOMP Unordered compare floating point values and pop, introduced with 80387 29

FUCOM Unordered compare floating point values, introduced with 80387 29

FWAIT Wait (opcode synonym for **WAIT**), introduced with 8087 18

FXAM Examine floating-point, introduced with 8087 18

FXCH Exchange register contents, introduced with 8087 18

FXTRACT Extract exponent and significand, introduced with 8087 18

FYL2XP1 Compute $y * log_2(x + 1)$, introduced with 8087 18

FYL2X Compute $y * log_2 x$, introduced with 8087 18

HLT Halt, introduced with 8086 13

IDIV Signed divide, introduced with 8086, extended with 80386 14, 27

IMUL Signed multiply, introduced with 8086, extended with 80186, 80386 14, 19, 27

INC Increment by 1, introduced with 8086, extended with 80386 14, 27

INS Input from port to string, introduced with 80186, extended with 80386 19, 27

INTO Call to interrupt procedure if overflow, introduced with 8086 15

INT Call to interrupt procedure, introduced with 8086 15

INVD Invalidate internal caches, introduced with 80486 31

INVLPG Invalidate translation lookaside buffer (TLB) entries, introduced with 80486 31

IN Input from port, introduced with 8086, extended with 80386 15, 27

IRET Interrupt return, introduced with 8086, extended with 80386 15, 27

JMP Jump, introduced with 8086, extended with 80386 15, 27

Jcc Jump if condition is met, introduced with 8086, extended with 80386 15, 27

LAHF Load status flags into AH register, introduced with 8086 13

LAR Load access rights byte, introduced with 80286, extended with 80386 23, 27

LDS Load DS with far pointer, introduced with 8086 14

LEAVE High level procedure exit, introduced with 80186, extended with 80386 19, 28

LEA Load effective address, introduced with 8086, extended with 80386 14, 28

LES Load ES with far pointer, introduced with 8086 14

LFS Load FS with far pointer, introduced with 80386 27

LGDT Load global descriptor table register, introduced with 80286 23

LGS Load GS with far pointer, introduced with 80386 27

LIDT Load interrupt descriptor table register, introduced with 80286 23

LLDT Load local descriptor table register, introduced with 80286 23

LMSW Load machine status word, introduced with 80286 23

LOCK Assert LOCK# signal prefix, introduced with 8086 13

LODS Load string, introduced with 8086, extended with 80386 14, 28

LOOP/LOOPcc Loop according to (E/R)CX counter, introduced with 8086, extended with 80386 15, 28

LSL Load segment limit, introduced with 80286, extended with 80386 23, 28

LSS Load SS with far pointer, introduced with 80386 27

LTR Load task register, introduced with 80286 23

MOVD Move doubleword, introduced with MMX 45

MOVQ Move quadword, introduced with MMX 45

MOVSX Move with sign-extension, introduced with 80386 28

MOVS Move data from string to string, introduced with 8086, extended with 80386 14, 28

MOVZX Move with zero-extend, introduced with 80386 28

MOV Move, introduced with 8086, extended with 80386 13, 14, 28

MUL Unsigned multiply, introduced with 8086, extended with 80386 14, 28

NEG Two's complement negation, introduced with 8086, extended with 80386 14, 28

NOP No operation, introduced with 8086 13

NOT One's complement negation, logical NOT, introduced with 8086, extended with 80386 14, 28

OR Logical inclusive OR, introduced with 8086, extended with 80386 14, 28

OUTS Output string to port, introduced with 80186, extended with 80386 19, 28

OUT Output to port, introduced with 8086, extended with 80386 15, 28

PACKSSDW Pack doublewords with signed saturation, introduced with MMX 45

PACKSSWB Pack words with signed saturation, introduced with MMX 45

PACKUSWB Pack words with unsigned saturation, introduced with MMX 45

PADDB Add packed byte integers, introduced with MMX 45

PADDD Add packed doubleword integers, introduced with MMX 45

PADDQ Add packed quadword integers, introduced with MMX 45

PADDSB Add packed signed byte integers with signed saturation, introduced with MMX 45

PADDSW Add packed signed word integers with signed saturation, introduced with MMX 45

PADDUSB Add packed unsigned byte integers with unsigned saturation, introduced with MMX 45

PADDUSW Add packed unsigned word integers with unsigned saturation, introduced with MMX 45

PADDW Add packed word integers, introduced with MMX 45

PANDN Logical AND NOT, introduced with MMX 45

PAND Logical AND, introduced with MMX 45

PCMPEQB Compare packed bytes for equal, introduced with MMX 45

PCMPEQD Compare packed doublewords for equal, introduced with MMX 45

PCMPEQW Compare packed words for equal, introduced with MMX 45

PCMPGTB Compare packed signed bytes for greater than, introduced with MMX 45

PCMPGTD Compare packed signed doublewords for greater than, introduced with MMX 45

PCMPGTW Compare packed signed words for greater than, introduced with MMX 45

PDRAD Shift packed doublewords right arithmetic, introduced with MMX 45

PDRAQ Shift packed quadwords right arithmetic, introduced with MMX 45

PDRAW Shift packed words right arithmetic, introduced with MMX 45

PDRLD Shift packed doublewords right logical, introduced with MMX 45

PDRLQ Shift packed quadwords right logical, introduced with MMX 45

PDRLW Shift packed words right logical, introduced with MMX 45

PMADDWD Multiply and add packed integers, introduced with MMX 45

PMULHW Multiply packed signed integers and store high result, introduced with MMX 45

PMULLW Multiply packed signed integers and store low result, introduced with MMX 45

POPA Pop all general-purpose registers, introduced with 80186, extended with 80386 19, 28

POPF Pop stack into FLAGS register, introduced with 8086, extended with 80386 15, 28

POP Pop a value from the stack, introduced with 8086, extended with 80386 15, 28

POR Bitwise logical OR, introduced with MMX 45

PSLLD Shift packed doublewords left logical, introduced with MMX 45

PSLLQ Shift packed quadwords left logical, introduced with MMX 45

PSLLW Shift packed words left logical, introduced with MMX 45

PSUBB Subtract packed byte integers, introduced with MMX 46

PSUBD Subtract packed doubleword integers, introduced with MMX 46

PSUBSB Subtract packed signed bytes with signed saturation, introduced with MMX 46

PSUBSW Subtract packed signed words with signed saturation, introduced with MMX 46

PSUBUSB Subtract packed unsigned bytes with unsigned saturation, introduced with MMX 46

PSUBUSW Subtract packed unsigned words with unsigned saturation, introduced with MMX 46

PSUBW Subtract packed word integers, introduced with MMX 46

PUNPCKHBW Unpack high bytes, introduced with MMX 46

PUNPCKHDQ Unpack high doublewords, introduced with MMX 46

PUNPCKHWD Unpack high words, introduced with MMX 46

PUNPCKLBW Unpack low bytes, introduced with MMX 46

PUNPCKLDQ Unpack low doublewords, introduced with MMX 46

PUNPCKLWD Unpack low words, introduced with MMX 46

PUSHA Push all general-purpose registers, introduced with 80186, extended with 80386 19, 28

PUSHF Push FLAGS register onto the stack, introduced with 8086, extended with 80386 15, 28

PUSH Push data onto the stack, introduced with 8086, extended with 80186, 80386 15, 19, 28

PXOR Logical exclusive OR, introduced with MMX 46

RCL Rotate left through carry, introduced with 8086, extended with 80186, 80386 14, 19, 28

RCR Rotate right through carry, introduced with 8086, extended with 80186, 80386 14, 19, 28

RDMSR Read from model specific register, introduced with MSR 39

RDPMC Read performance-monitoring counters, introduced with PMC 43

RDTSC Read time-stamp counter, introduced with TSC 41

REPcc Repeat string operation prefix, introduced with 8086, extended with 80386 15, 28

RET Return from procedure, introduced with 8086 15

ROL Rotate left, introduced with 8086, extended with 80186, 80386 14, 19, 28

ROR Rotate right, introduced with 8086, extended with 80186, 80386 14, 19, 28

RSM Resume from system management mode, introduced with RSM 33

SAHF Store AH into flags, introduced with 8086 13

SAL Shift arithmetically left, introduced with 8086, extended with 80186, 80386 14, 19, 28

SAR Shift arithmetically right, introduced with 8086, extended with 80186, 80386 14, 19, 28

SBB Integer subtraction with borrow, introduced with 8086, extended with 80386 14, 28

SCAS Scan string, introduced with 8086, extended with 80386 14, 28

SETcc Set byte on condition, introduced with 80386 28

SGDT Store global descriptor table register, introduced with 80286, extended with 80386 23, 28

SHLD Double precision shift left, introduced with 80386 28

SHL Shift left, introduced with 8086, extended with 80186, 80386 14, 19, 28

SHRD Double precision shift right, introduced with 80386 28

SHR Shift right, introduced with 8086, extended with 80186, 80386 14, 19, 28

SIDT Store interrupt descriptor table register, introduced with 80286, extended with 80386 23, 28

SLDT Store local descriptor table register, introduced with 80286 23

SMSW Store machine status word, introduced with 80286, extended with 80386 23, 28

STC Set carry flag, introduced with 8086 15

STD Set direction flag, introduced with 8086 15

STI Set interrupt flag, introduced with 8086 15

STOS Store string, introduced with 8086, extended with 80386 14, 28

STR Store task register, introduced with 80286 23

SUB Subtract, introduced with 8086, extended with 80386 14, 28

TEST Logical compare, introduced with 8086, extended with 80386 15, 28

VERR Verify a segment for reading, introduced with 80286 23

VERW Verify a segment for writing, introduced with 80286 23

WAIT Wait, introduced with 8086 13

WBINVD Write back and invalidate cache, introduced with 80486 31

WRMSR Write to model specific register, introduced with MSR 39

XADD Exchange and add, introduced with 80486 31

XCHG Exchange register/memory with register, introduced with 8086, extended with 80386 13, 14, 28

XLAT Table look-up translation, introduced with 8086, extended with 80386 14, 28

XOR Logical exclusive OR, introduced with 8086, extended with 80386 14, 28

E Code Chunks

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            How to Apply These Terms to Your New Programs

  If you develop a new program, and you want it to be of the greatest
possible use to the public, the best way to achieve this is to make it
free software which everyone can redistribute and change under these terms.

  To do so, attach the following notices to the program.  It is safest
to attach them to the start of each source file to most effectively
state the exclusion of warranty; and each file should have at least
the "copyright" line and a pointer to where the full notice is found.

    <one line to give the program's name and a brief idea of what it does.>
    Copyright (C) <year>  <name of author>

    This program is free software: you can redistribute it and/or modify
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  If the program does terminal interaction, make it output a short
notice like this when it starts in an interactive mode:

    <program>  Copyright (C) <year>  <name of author>
    This program comes with ABSOLUTELY NO WARRANTY; for details type `show w'.
    This is free software, and you are welcome to redistribute it
    under certain conditions; type `show c' for details.
```

```
The hypothetical commands `show w' and `show c' should show the appropriate
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```

F.2.2 Code Chunk of GPL

This is a code chunk to be included by the generated asm files.

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```
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```

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