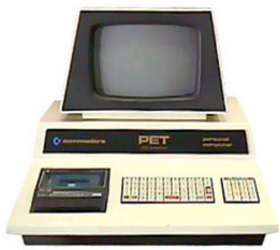
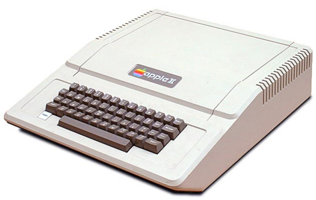
6502alan Machine Language Instruction Set





We will use an instruction set based on the operation codes of the classic 6502 microprocessor. It was the heart of the Commodore PET, Apple //, Atari 800, and many other ground-breaking computers, so we're in good company using it ourselves.

Test your code in the sample operating systems available on our class web site. Also, there is an excellent virtual 6502 simulator, assembler, and disassembler at http://e-tradition.net/bytes/6502. Feel free to use that tool as well.

There are only three registers: X, Y, and the Accumulator.

Code examples follow the op code descriptions, below.

Description	**Op Code**	**Mnemonic**	**Example Assembly**	**Example Disassembly**
Load the accumulator with a constant	A9	LDA	LDA #$07	A9 07
Load the accumulator from memory	AD	LDA	LDA $0010	AD 10 00
Store the accumulator in memory	8D	STA	STA $0010	8D 10 00
Add with carry Adds contents of an address to the contents of the accumulator and keeps the result in the accumulator	6D	ADC	ADC $0010	6D 10 00
Load the X register with a constant	A2	LDX	LDX #$01	A2 01
Load the X register from memory	AE	LDX	LDX $0010	AE 10 00
Load the Y register with a constant	A0	LDY	LDY #$04	A0 04
Load the Y register from memory	AC	LDY	LDY $0010	AC 10 00
No Operation	EA	NOP	EA	EA
Break (which is really a system call)	00	BRK	00	00
Compare a byte in memory to the X reg Sets the Z (zero) flag if equal	EC	CPX	EC $0010	EC 10 00
Branch *n* bytes if Z flag = 0	D0	BNE	D0 $EF	D0 EF
Increment the value of a byte	EE	INC	EE $0021	EE 21 00
System Call #$01 in X reg = print the integer stored in the Y register. #$02 in X reg = print the 00-terminated string stored at the address in the Y register.	FF	SYS		FF

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Example One

```
;
; Adds 3 and 4 and outputs result.
;
lda #$03    ; Load the accumulator (the "A register") with the constant 3.
sta $0000   ; Store A in location $0000;  (These are hex numbers.)
lda #$04    ; A <-- 4
adc $0000   ; Add the value in location $0000 to A and keep the result in A.
sta $0001   ; Store A (our result) in location $0001.
ldx #$01    ; Load the X register with the value 1 (for syscall)
ldy $0001   ; Load the Y register with our result.
sys         ; Make a system call to the OS (via a software interrupt)
brk         ; Software interrupt for normal termination
```

Assemble this into 6502 machine code at http://www.e-tradition.net/bytes/6502/assembler.html. Use only the assembly code. Comments will mess it up. You should get:

```
LDA #$03        A9 03
STA $0000       8D 00 00
LDA #$04        A9 04
ADC $0000       6D 00 00
STA $0001       8D 01 00  (Notice the low-order bytes are first ("little-endian"), so 0001 = address 01 00.)
LDX #$01        A2 01
LDY $0001       AC 01 00
SYS
BRK             00
```

Note that SYS does not cause an error (as the real 6502 did not have this), which is nice, but it also does not generate an op code. This is fine in the sample operating systems found on our class web site, but in order to make our code work in the e-tradition.net emulator, we'll use the op code for NOP (no operation) in place of SYS. That's EA. Inserting EA for SYS into the object code stream, we get:

```
A9 03 8D 00 00 A9 04 6D
00 00 8D 01 00 A2 01 AC
01 00 EA 00
```

Copy the object code and test it out at http://www.e-tradition.net/bytes/6502. You can see it run step by step. Be sure to set the start address to 0000. Also, once you load memory, click "show memory" to see the address-detailed display. You need to click "show memory" to see the updates as you step through the user program.

Test your code there so you can concentrate on getting your generator right. There are lots of cool things at that site, so check it all out.

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Example Two

In the first example we loaded the instructions beginning at location $0000. We also began storing our values at $0000. This might be a bad idea, as we'll write over our own code with data. Let's store our data in locations elsewhere:

```
;
;Adds 3 and 4 and outputs result; doesn't overwrite our code in memory.
;
lda #$03    ; Load the accumulator (the "A register") with the constant 3.
sta $0018   ; Store A in location $0018;  (These are hex numbers.)
lda #$04    ; A <-- #$04
adc $0018   ; Add the value in location $0018 to A and keep the result in A.
sta $0019   ; Store A (our result) in location $0019.
ldx #$01    ; Load the X register with the value 1 (Used by syscall to denote integer output.)
ldy $0019   ; Load the Y register with our result.
sys         ; Make a system call to the OS (via a software interrupt)
brk         ; Software interrupt for normal termination
```

Assembly and Op-codes:

```
LDA #$03        A9 03
STA $0018       8D 18 00
LDA #$04        A9 04
ADC $0018       6D 18 00
STA $0019       8D 19 00
LDX #$01        A2 01
LDY $0019       AC 19 00
SYS
BRK             00
```

Remembering to substitute EA (nop) for out SYScall when using the emulator, we get object code:

```
A9 03 8D 18 00 A9 04 6D
18 00 8D 19 00 A2 01 AC
19 00 EA 00
```

Copy the object code and test it out at http://www.e-tradition.net/bytes/6502.

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Example Three

`; Prints 1, 2 and DONE.`

lda #$3	*Acc = 3*	0000	LDA #$03	A9 03
sta $0041	*Mem[41] = 3*	0002	STA $0041	8D 41 00
lda #$1	*Acc = 1*	0005	LDA #$01	A9 01
sta $0040	*Mem[40] = 1*	0007	STA $0040	8D 40 00
loop ldy $0040	*Y = Mem[40]*	000A **LOOP**	LDY $0040	AC 40 00
ldx #$01	*X = 1*	000D	LDX #$01	A2 01
sys	*System Call*	000F	SYS	FF
inc $0040	*Mem[40]++*	0010	INC $0040	EE 40 00
ldx $0040	*X = Mem[40]*	0013	LDX $0040	AE 40 00
cpx $0041	*Z bit = (x == Mem[41])*	0016	CPX $0041	EC 41 00
bne loop	*if z == 0 goto loop*	0019	BNE **LOOP**	D0 **EF**
lda #$44	*Acc = $44 ("D")*	001B	LDA #$44	A9 44
sta $0042	*Mem[42] = $44*	001D	STA $0042	8D 42 00
lda #$4F	*Acc = $4F ("O")*	0020	LDA #$4F	A9 4F
sta $0043	*Mem[43] = $4F*	0022	STA $0043	8D 43 00
lda #$4E	*Acc = $4E ("N")*	0025	LDA #$4E	A9 4E
sta $0044	*Mem[44] = $4E*	0027	STA $0044	8D 44 00
lda #$45	*Acc = $45 ("E")*	002A	LDA #$45	A9 45
sta $0045	*Mem[45] = $45*	002C	STA $0045	8D 45 00
lda #$00	*Acc = $00 (null)*	002F	LDA #$00	A9 00
sta $0046	*Mem[46] = $00*	0031	STA $0046	8D 46 00
ldx #$02	*X = 2*	0034	LDX #$02	A2 02
ldy #$42	*Y = $42 (address)*	0036	LDY #$42	A0 42
sys	*System call*	0038	SYS	FF
brk	*Break*	0039	BRK	00

Remember, SYS does not cause an error (as the real 6502 did not have this), which is nice, but it also does not generate an op code. In order to make our code work in the e-tradition.net emulator, we use the op code for NOP in place of SYS. Thus the EA's in the op code stream below.

```
A9 03 8D 41 00 A9 01 8D 40 00 AC 40 00 A2 01 EA EE 40 00 AE 40 00 EC 41 00 D0
EF A9 44 8D 42 00 A9 4F 8D 43 00 A9 4E 8D 44 00 A9 45 8D 45 00 A9 00 8D 46 00
A2 02 A0 42 EA 00
```

In the OS simulations, the CPU object will generate a software interrupt when it sees the SYS op code (FF). Be sure that you generate FF for SYStem calls. Use the EA only for testing at http://www.e-tradition.net/bytes/6502.

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