
6502 Introduction

HW2 - due Friday 9/20

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~~28 February 2018~~

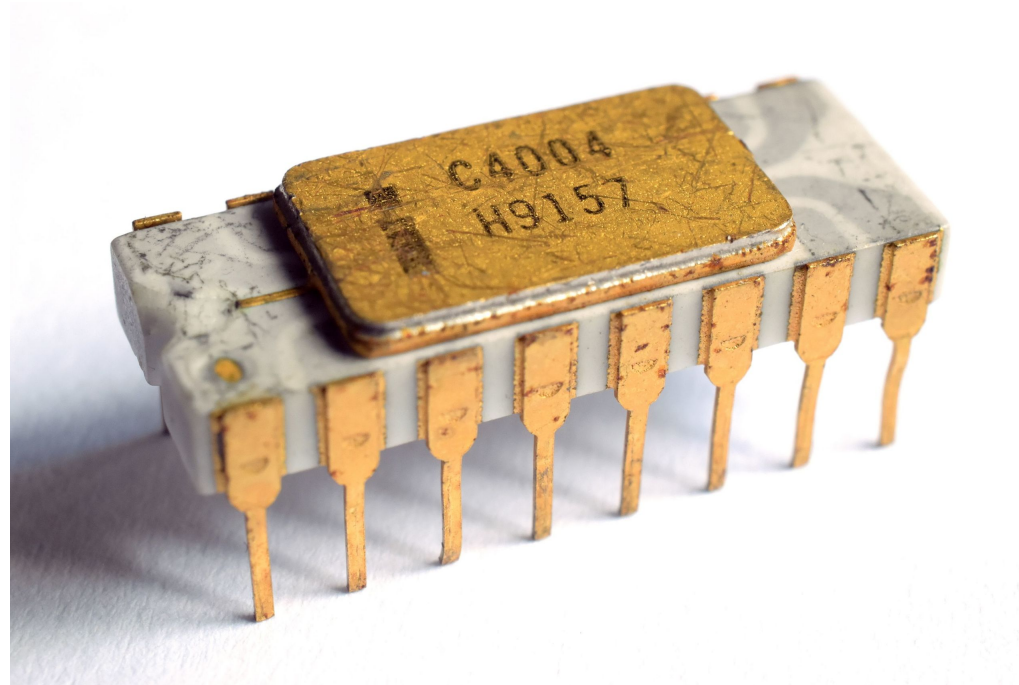
18 Sept 2019



some history

1971

- First microprocessor on an integrated circuit: Intel 4004



- 4-bit central processing unit, 12 bit address space (4KB)

1975



- MOS Technology 6502



- Dominant CPU in home computers for a decade
(Atari, Apple II, Nintendo Entertainment System, Commodore PET)

1977



- Atari 2600



- Video game console: Pong, Pac Man, ... connected to TV

- Commodore VIC20



- 1 MHz, 5KB RAM, BASIC, 3.5KB RAM, 176x184 3 bit color video

5120

1982



- Commodore C64



- 64KB RAM, 320x200 4 bit color video

Commodore C64



```
**** COMMODORE 64 BASIC V2 ****  
64K RAM SYSTEM 38911 BASIC BYTES FREE  
READY.
```

- BASIC programming language, but serious programs written in assembly
- No fancy stuff like multi-process, user accounts, virtual memory, etc.
- Machine itself had no mass storage - had to buy tape drive, then floppy disk drive, machine was obsolete once hard drives came around

BASIC Demo



- Commands get executed (just like Python interpreter)

```
PRINT "HELLO WORLD"  
HELLO WORLD
```

- Program with line numbers

```
10 PRINT "HELLO WORLD"  
20 GOTO 10
```

- List program

```
LIST
```

- Execute program

```
RUN
```

- Another example (takes about 1 second to run)

```
20 FOR I = 1 TO 1000  
30 NEXT
```

6502 specification

6502 Specification

- 8-bit processor, using 16 bit address space (up to 64KB RAM)
- 3 registers: accumulator, X register, Y register
- Status register: contains flags (*condition codes*)
- Operating system in ROM (read only memory)
- Stack -- more on that later
- Interrupts -- more on that later

Assembly Code Instructions

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- Load and store from A, X, and Y register
- Transfer between registers
- Arithmetic: add, subtract, increment, decrement
- Shift and rotate, e.g., 00001111 → 00011110
- Logic: AND and OR XOR
- Compare and test
- Branch (conditional jump)
- Set and clear flag values
- Jump and subroutines
- Interrupt: cause interrupt, return from interrupt
- Stack operations

Load $R \leftarrow \text{Mem}$
Store $\text{Mem} \leftarrow R$

} loops

a.k.a. "functions"

Memory Organization

- 0000-00ff** Zero page: used for variables
 - 0100-01ff** Stack
 - 0200-03ff** More variables [C64]
 - 0400-07ff** Screen memory (characters) [C64]
 - 0800-9fff** BASIC RAM [C64]
 - a000-bfff** BASIC ROM [C64]
 - c000-cfff** Upper RAM Area [C64]
 - d000-dfff** Character shape ROM / Video and audio RAM [C64]
 - e000-ffff** Kernel ROM [C64]
"OS"
- } always (any 6502 system)

Can switch to RAM under ROM

Load and Store

- 3 Registers: Accumulator, X, Y
- Load from memory: LDA, LDX, LDY
- Store to memory: STA, STX, STY

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- Zero page: as above, but for memory addresses 0000-00FF
LDA \$6A → accumulator has now value store in memory position \$006A

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- Absolute: load value from specified address
LDA \$D010 → accumulator has now value store in memory position \$D010
- Zero page: as above, but for memory addresses 0000-00FF
LDA \$6A → accumulator has now value store in memory position \$006A
- Relative: relative to current program counter
BCC \$06 → jump 6 memory positions forward, if carry flag clear

*8 bit signed
-128 .. 127*

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- Variants: Y register, zero page
- Zero Page Indexed Indirect
 - example: LDA (\$15,X) *pointer*
 - add value of register X to \$15 (say, X=\$02 → \$0017)
 - treat resulting memory position as pointer (say, \$0017 contains \$E0, \$0018 contains \$FF)
 - load value from that address (\$FFE0)

Transfer Between Registers

- 3 Registers: Accumulator, X, Y
- Transfer from Accumulator: TAX, TAY
- Transfer to Accumulator: TXA, TXY
- Note: no TXY, TYX

Arithmetic

All affect accumulator (A)
(unless they affect X/Y)

- Addition (to accumulator): ADC
 - ADC #\$02 → add 2 to accumulator
 - ADC \$4050 → add value in memory at address \$4050 to accumulator
- Subtraction (from accumulator): SBC
- Increment by 1: INC, INX, INY
- Decrement by 1: DEC, DEX, DEY
- Sets carry, overflow, zero flag

Flags

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- Other flags: Break, Interrupt, Decimal (more on these later)

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- Zero: set iff result of operation/load/transfer is 0
- Negative: set iff result of operation/load/transfer sets bit 7
- Other flags: Break, Interrupt, Decimal (more on these later)
- Clear flags: CLC, CLV, CLI, CLD *often done before ADD/subtract*
- Set flags: SEC, SED, SEI

Example Program



Address	Bytes	Command
4000	65 1C	(data: number 1)
4002	A0 9E	(data: number 2)
4004	00 00	(data: sum)
4006	AD 00 40	LDA 4000
4009	18	CLC
400A	6D 02 40	ADC 4002
400D	8D 04 40	STA 4004
4010	AD 01 40	LDA 4001
4013	6D 03 40	ADC 4003
4016	8D 05 40	STA 4005
4019	00	BRK

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add low bytes

add high bytes

affected by carry-in

16 bit addition

Branch

- Simple jump: `JMP`
- Flags can be used for conditional jump ("branch")

<code>BCC</code>	Branch if carry flag clear
<code>BCS</code>	Branch if carry flag set
<code>BEQ</code>	Branch if zero flag set
<code>BMI</code>	Branch if negative flag set
<code>BNE</code>	Branch if zero flag clear
<code>BPL</code>	Branch if negative flag clear
<code>BVC</code>	Branch if overflow flag clear
<code>BVS</code>	Branch if overflow flag set

Shift and Rotate



- Rotate bits by one position
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 - ROR: Rotate right, i.e., 11110000 → 01111000

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- ASL (Arithmetic Shift Left) /
LSR (Logical Shift Right) use carry bit
 - ASL: $11110000 (C=0) \rightarrow 11100000 (C=1)$
 - LSR: $11110000 (C=1) \rightarrow 11111000 (C=0)$

Example: Multiplication



- Elementary school multiplication:

$$10101 \times 1101$$

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$$\begin{array}{r} 10101 \times 1101 \\ \hline 10101 \end{array}$$

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(in decimal: $23 \times 13 = 299$)

Example: Multiplication

- Elementary school multiplication:

$$\begin{array}{r} 10101 \times 1101 \\ \hline 10101 \\ 0 \\ 10101 \\ 10101 \\ \hline 100010001 \end{array}$$

(in decimal: $23 \times 13 = 299$)

- Idea
 - shift second operand to right (get last bit)
 - if carry: add first operand to sum
 - rotate first operand to left (multiply with binary 10)

Code

Address	Bytes	Command
4100	03	(data: number 1)
4101	06	(data: number 2)
4102	00	(data: product)
4103	A9 00	LDA #00
4105	A2 08	LDX #08
4107	4E 01 41	LSR 4101
410A	90 04	BCC 4110
410C	18	CLC
410D	6D 00 41	ADC 4100
4110	2E 00 41	ROL 4100
4113	CA	DEX
4114	D0 F1	BNE 4107
4116	8D 02 41	STA 4102
4119	00	BRK