COMP310: Legacy Game Systems

1: Assembly language

Learning outcomes

- **Explain** the historical significance of the 6502 CPU
- **Identify** the key components of the 6502 architecture
- **Read** and **write** simple programs in 6502 assembly language

Module introduction

Why Legacy Game Systems?

- To better understand the **history** of videogame systems
- To study low-level **machine architecture** without diving straight into complex modern architectures
- To make something under **constraints**:
  - Inspires **creativity**
  - Requires creative **problem solving**
  - Makes you a **better programmer**

Assignment 1: Constrained Development Task

- Design and implement a **de-make** of a well-known game
- Your de-make must run on the **NES** and be written in **6502 assembly**
- **In week 3**: present a **proposal** and **Trello board**
- **Tip**: scope carefully! Assembly programming is hard — keep it simple

Assignment 2: Research Journal

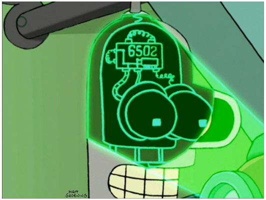
- As a **group**, make the ultimate **NES programming wiki**
- **Tip**: use the wiki to record what you're already learning for your project. Don't leave it until the last minute!!!

The 6502 CPU architecture

MOS Technology 6502

- Designed by Chuck Peddle and team at **MOS Technology**
- **8-bit** CPU, 16-bit addressing
- Clocked between **1MHz** and **3MHz**
- First produced in **1975**
- Still in production **today**

Uses of the 6502



Recap: hexadecimal notation

- We usually write numbers in **decimal** i.e. **base 10**
- Hexadecimal is **base 16**
- Uses extra digits:
  - `A`=10, `B`=11, …, `F`=15

Hex	**Dec**	**Hex**	**Dec**	**Hex**	**Dec**
`00`	0	`10`	16	`F0`	240
`01`	1	`11`	17	`F1`	241
⋮	⋮	⋮	⋮	⋮	⋮
`09`	9	`19`	25	`F9`	249
`0A`	10	`1A`	26	`FA`	250
`0B`	11	`1B`	27	`FB`	251
`0C`	12	`1C`	28	`FC`	252
`0D`	13	`1D`	29	`FD`	253
`0E`	14	`1E`	30	`FE`	254
`0F`	15	`1F`	31	`FF`	255

How a CPU works

- Executes a series of **instructions** stored in **memory**
- An instruction is stored as an **opcode** followed by 0 or more **arguments**
- CPU has several **registers**, each storing a single value
- Instructions can read and write values in **registers** and in **memory**, and can perform **arithmetic and logical** operations on them
- The **program counter (PC)** register stores the address of the next instruction to execute

Registers on the 6502

- 6502 is an **8-bit** CPU, meaning each register stores **8 bits** of data
  - 1 byte
  - A number between 0 and 255
- A = **accumulator**
- X, Y = **index** registers
- SP = **stack pointer** register
- PC = **program counter** register (16 bits)
- **Status** register, composed of seven 1-bit **flags**

Assembly language

- Translates **directly** to machine code
- I.e. 1 line of assembly = 1 CPU instruction
- An **assembler** translates assembly to machine code
  - I.e. an assembler is a “compiler” for assembly language
- Each CPU architecture has its own instruction set therefore its own assembly language

Our first assembly program

```
LDA #$01
STA $0200
LDA #$05
STA $0201
LDA #$08
STA $0202
```

Try it out! `http://skilldrick.github.io/easy6502/`

Our first assembly program

```
LDA #$01
```

- Store the value `01` (hexadecimal) into register A
- **`LDA`** (“load accumulator”) stores a value in register A
- `#` denotes a literal number (as opposed to a memory address)
- `$` denotes hexadecimal notation

Our first assembly program

```
STA $0200
```

- Write the value of register A into memory address `0200` (hex)
- `STA` ("store accumulator") copies the value of register A into main memory
- Note that address is a **16-bit** number (2 bytes, 4 hex digits)
- In this emulator the display is "memory mapped", with 1 byte per pixel, starting from address `0200`
    - This may **not** be the case on other 6502-based systems!

Assembly to machine code

```
LDA #$01
STA $0200
LDA #$05
STA $0201
LDA #$08
STA $0202
```

```
A9 01
8D 00 02
A9 05
8D 01 02
A9 08
8D 02 02
```

Note that the 6502 is **little endian**

- In 16-bit values, the “high” byte comes before the “low” byte
- Intel x86 is also little endian

Looping

- PC normally **advances** to the next instruction
- Some instructions **modify** the PC
- E.g. `JMP` (jump) sets the PC to the specified address

```
INC $0200 ; add 1 to the value at address 0200
JMP $0600 ; jump back to beginning of program
```

- In this emulator the program always starts at address `0600`
  - This may **not** be the case on other 6502-based systems!

Labels

- Don't use explicit jump locations in your code, it's not maintainable!
- Can add a **label** to a line of code, by giving a name followed by a colon
- Labels can then be used in instructions

```
start:
    INC $0200
    JMP start
```

- `start` is essentially a constant with value `$0600`
- The assembled code is exactly the same as for the previous slide

Conditional branching

```
  LDX #$08       ; set X=8
decrement:
  DEX            ; subtract 1 from X
  STX $0200      ; store X in top left pixel
  CPX #$03       ; compare X to 3
  BNE decrement  ; if not equal, jump
  STX $0201      ; store X in next pixel
  BRK            ; halt execution
```

$X = 8$
do
    $X = X - 1$
    memory[0200] $= X$
while $X \neq 3$
memory[0201] $= X$

Conditional branching

- Assembly language does not have **structured programming** constructs such as if/else, switch/case, for, while, etc.
- However all of these can be implemented using branch instructions
- ... which is exactly how compilers implement them

Subroutines

- `JSR` (jump to subroutine) works like `JMP`, but stores the current PC
- `RTS` (return from subroutine) jumps back to the instruction after the `JSR`
- These are used to implement **function calls**

Addressing modes

- Immediate: `LDA #$42`
  - Load the literal value 42 (hex) into register A
- Absolute: `LDA $42`
  - Load the value stored at memory address 42 (hex) into register A
- That `#` makes a big difference!
- Note that these actually assemble to **different** CPU instructions

Indexed addressing

```
LDA $0200,X
```

- Look up the value stored at memory address

  $$\texttt{0200} + \text{(value of X register)}$$

  and store it in A
- Can also do `LDA $0200,Y`
- ... but **only** `X` and `Y` registers can be used for indexed addressing

Indexed addressing

```
  LDX #0        ; X=0
loop:
  TXA           ; A=X
  STA $0200,X ; store A to 0200+X
  INX           ; X++
  JMP loop      ; loop forever
```

- Why does it stop $\frac{1}{4}$ of the way down?
- Hint: it stops after filling 256 pixels...

Next steps

- **Work through** the tutorials on `http://skilldrick.github.io/easy6502/`
- **Understand** and try to **modify** the Snake game code