# FIT1047 - Week 4

# Control, Memory and Indirect Addressing

# Overview

- Control
  - how to generate control signals
- Memory organisation
  - how to address different locations
- Instructions for accessing memory
  - indirect addressing
  - subroutines

# Control (the machine)

# Control what?

- Fetch - decode - execute cycle
- Implement the RTL code for each instruction
  - RTL = Register transfer language
- Generate control signals for individual circuits
  - opcode for the ALU
  - read/write register number for the register file
  - memory read/write

# Control Signals

Signals for Add X:

| | | |
|---|---|---|
| 1. MAR ← PC | P3 P1 | |
| 2. MBR ← M[MAR] | P4 P3 | Mr |
| 3. IR ← MBR | P5 P4 P3 P1 P0 | |
| 4. PC ← PC+1 | P4 P1 | A2 |
| 5. MAR ← X | P3 P2 P1 P0 | |
| 6. MBR ← M[MAR] | P4 P3 | Mr |
| 7. AC ← AC + MBR | P5 P2 | A1 |

# Timing

How do we generate that sequence of signals?

Add a cycle counter!

- n outputs $T_1$ to $T_n$
- Cycle through these outputs at each clock cycle.
- Has an input $C_r$ to reset to $T_1$.

# Cycle counter

# Control circuit (Add X)

# Hardwired Control

RTL for each instruction is implemented using gates.

- Very fast!
- But really complicated to design.
- What if we want to add instructions?
- What if we made a mistake?

# Microprogrammed Control

Break up instructions into microoperations.

- One microop per possible RTL instruction
  - Far fewer than instructions!
- Microops for each instruction stored in memory in the processor
- Execution slightly slower, but
  - Circuits for microops much simpler
  - Microcode can be updated

# MARIE Data Paths

# Memory

# Memory

For the programmer:

- A sequence of locations
- Each location has an address
  - an unsigned integer, starting from 0
- Each location stores one value
  - each value has a fixed width (number of bits)
- We can read and change the value stored at a location

# Memory

| Address | Hex value |
|---|---|
| 000 | 1004 |
| 001 | 3005 |
| 002 | 2006 |
| 003 | 7000 |
| 004 | 008E |
| 005 | 0D80 |
| 006 | 0000 |

(all values given in hexadecimal)

# What does it store?

| Address | Hex Value | Integer |
|---|---|---|
| 000 | 1004 | 4100 |
| 001 | 3005 | 12293 |
| 002 | 2006 | 8198 |
| 003 | 7000 | 28672 |
| 004 | 008E | 142 |
| 005 | 0D80 | 3456 |
| 006 | 0000 | 0 |

# What does it store?

| Address | Hex Value | Integer | Bit pattern |
|---|---|---|---|
| 000 | 1004 | 4100 | 0001000000010100 |
| 001 | 3005 | 12293 | 0011000000000101 |
| 002 | 2006 | 8198 | 0010000000000110 |
| 003 | 7000 | 28672 | 0111000000000000 |
| 004 | 008E | 142 | 0000000010001110 |
| 005 | 0D80 | 3456 | 0000110110000000 |
| 006 | 0000 | 0 | 0000000000000000 |

# What does it store?

| Address | Hex Value | Integer | Bit pattern | Instruction |
|---|---|---|---|---|
| 000 | 1004 | 4100 | 0001000000010100 | Load 004 |
| 001 | 3005 | 12293 | 0011000000000101 | Add 005 |
| 002 | 2006 | 8198 | 0010000000000110 | Store 006 |
| 003 | 7000 | 28672 | 0111000000000000 | Halt |
| 004 | 008E | 142 | 0000000010001110 | JnS 08E |
| 005 | 0D80 | 3456 | 0000110110000000 | JnS D80 |
| 006 | 0000 | 0 | 0000000000000000 | JnS 000 |

It stores bits!

What they mean depends on how we interpret them!

# Addressing

In most architectures,

one memory location stores one byte.

Consequently, each location, each byte, has its own address.

This is called byte-addressable.

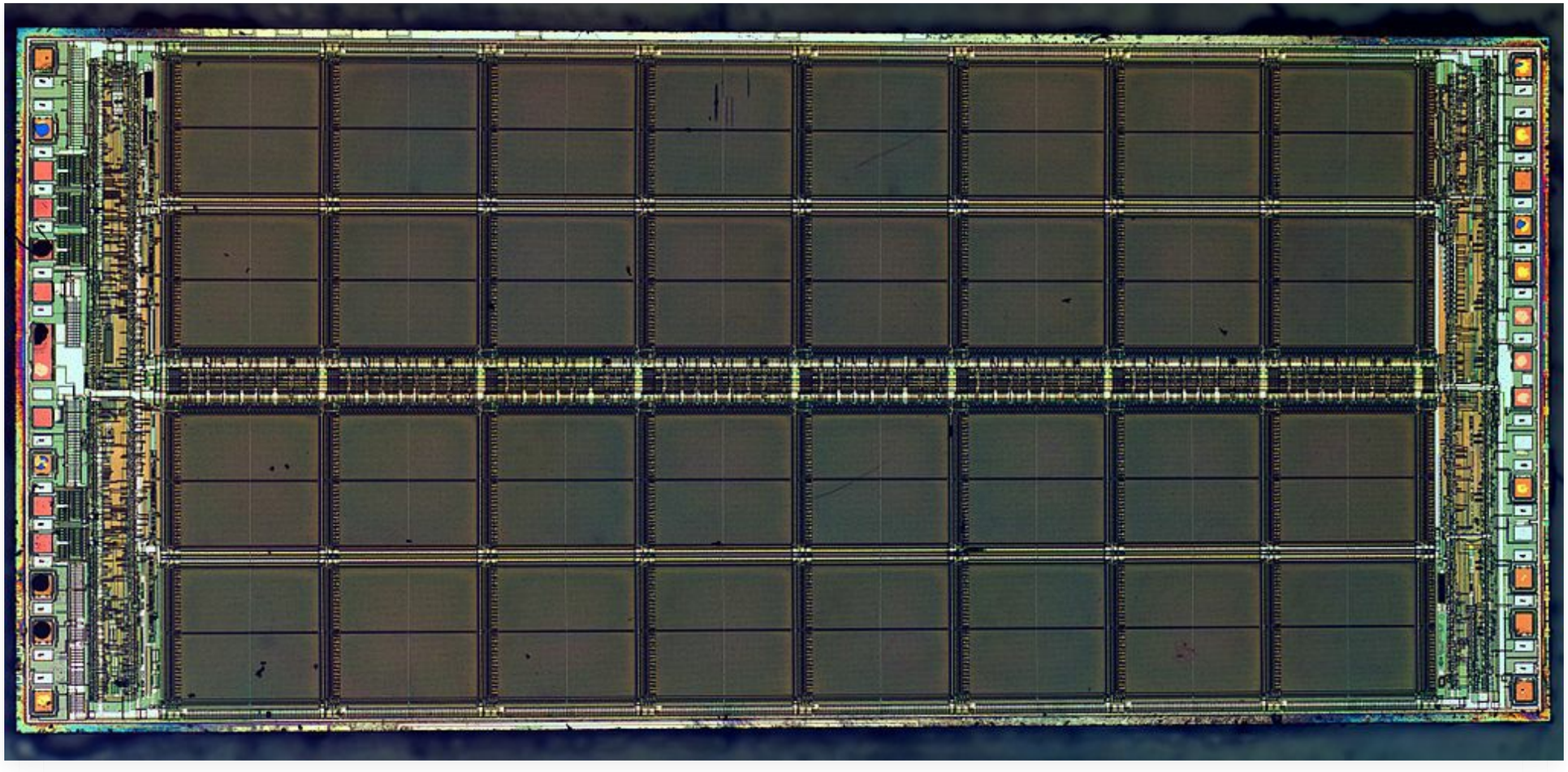
# Adressing in MARIE

In MARIE,

one memory location stores one word (two bytes, or 16 bits).

An address therefore references a whole word.

# RAM



A DRAM chip with 1 megabit capacity. Source: Wikipedia

# Memory Organisation

RAM is made up of multiple chips.

Each has a fixed size $L \times W$

- $L$ : number of locations
- $W$ : number of bits per location

E.g. $2K \times 8$ means $2 \times 2^{10}$ locations of 8 bits each.

# Memory Organisation

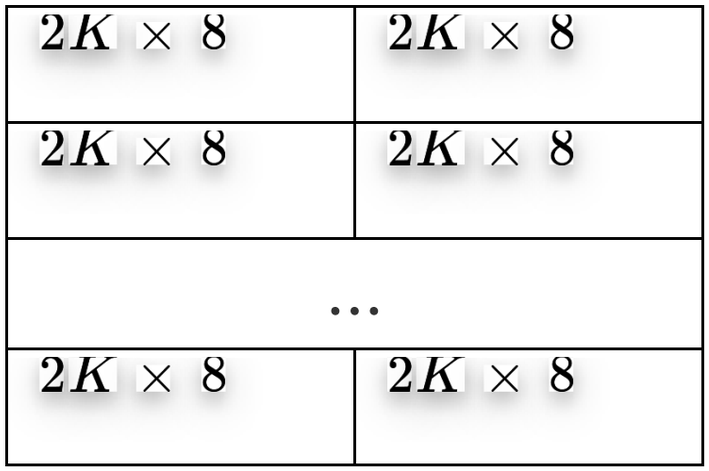
RAM chips are combined in rows and columns.

E.g. to build $32K \times 16$ memory out of $2K \times 8$ chips:

| | |
|---|---|
| $2K \times 8$ | $2K \times 8$ |
| $2K \times 8$ | $2K \times 8$ |
| ... | |
| $2K \times 8$ | $2K \times 8$ |

How do we address individual locations?

# Memory Organisation




$32K = 2^{15}$ words, so addresses need 15 bits.

- Use highest 4 bits to select the row
- Use low 11 bits to select the word in the row

# Indirect Addressing

# Accessing memory in MARIE

So far:

- Store X
- Load X
- Add X
- Jump X

All use the value stored at address X.

This is not very flexible!

# Indirect addressing

Add X:

Load the value stored at X and add it to the AC register.

AddI X:

Use the address stored at X, load the value from that address, and add it to AC.

("add indirect")

# Indirect addressing

Jump X:

Jump to address X.

JumpI X:

Use the address stored at X, and jump to that address.

("jump indirect")

# Indirect addressing

Advantages:

- addresses don't need to be hardcoded
- we can compute the address!
- e.g. loop through a list of values

# Adding up a list

```
000  Loop,   LoadI Addr
001          SkipCond 800
002          Jump End
003          Add Sum
004          Store Sum
005          Load Addr
006          Add One
007          Store Addr
008          Jump Loop
009  End,    Load Sum
00A          Output
00B          Halt
00C  One,    DEC 1
00D  Sum,    DEC 0
00E  Addr,   HEX 00F
00F          DEC 70
010          DEC 73
011          DEC 84
012          DEC 0
```

# Subroutines

AKA procedures, functions, methods

A piece of code that

- has a well-defined function
- needs to be executed often
- we can call, passing arguments to it
- returns to where it was called from, possibly with a return value

# Subroutines

ISAs provide support for subroutines.

In MARIE,

JnS X:

Stores the PC into X, then jumps to X+1

X holds the return address

JumpI X:

Jump to address stored at X

(returns to the calling code)

# Subroutines

MARIE example subroutine:

```
        Load  FortyTwo
        Store Print_Arg
        JnS   Print
        Halt

FortyTwo,  DEC 42

        / Subroutine that prints one number
Print_Arg, DEC 0            / put argument here
Print,     HEX 0            / return address
        Load Print_Arg
        Output
        JumpI Print         / return to caller
```

# Tutorials this week

- Programming MARIE
- Circuits for adding and subtracting