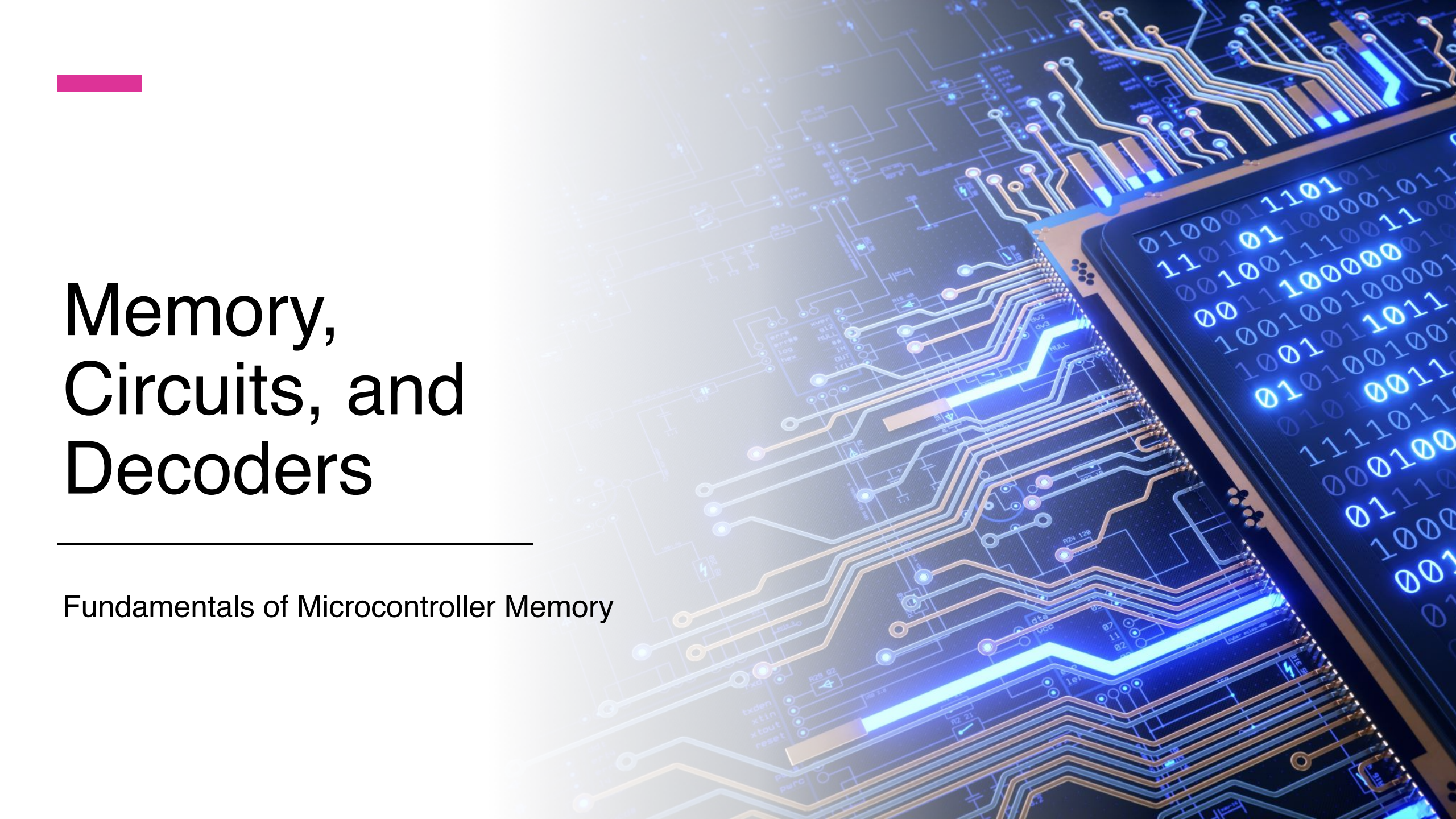
Memory, Circuits, and Decoders

Fundamentals of Microcontroller Memory

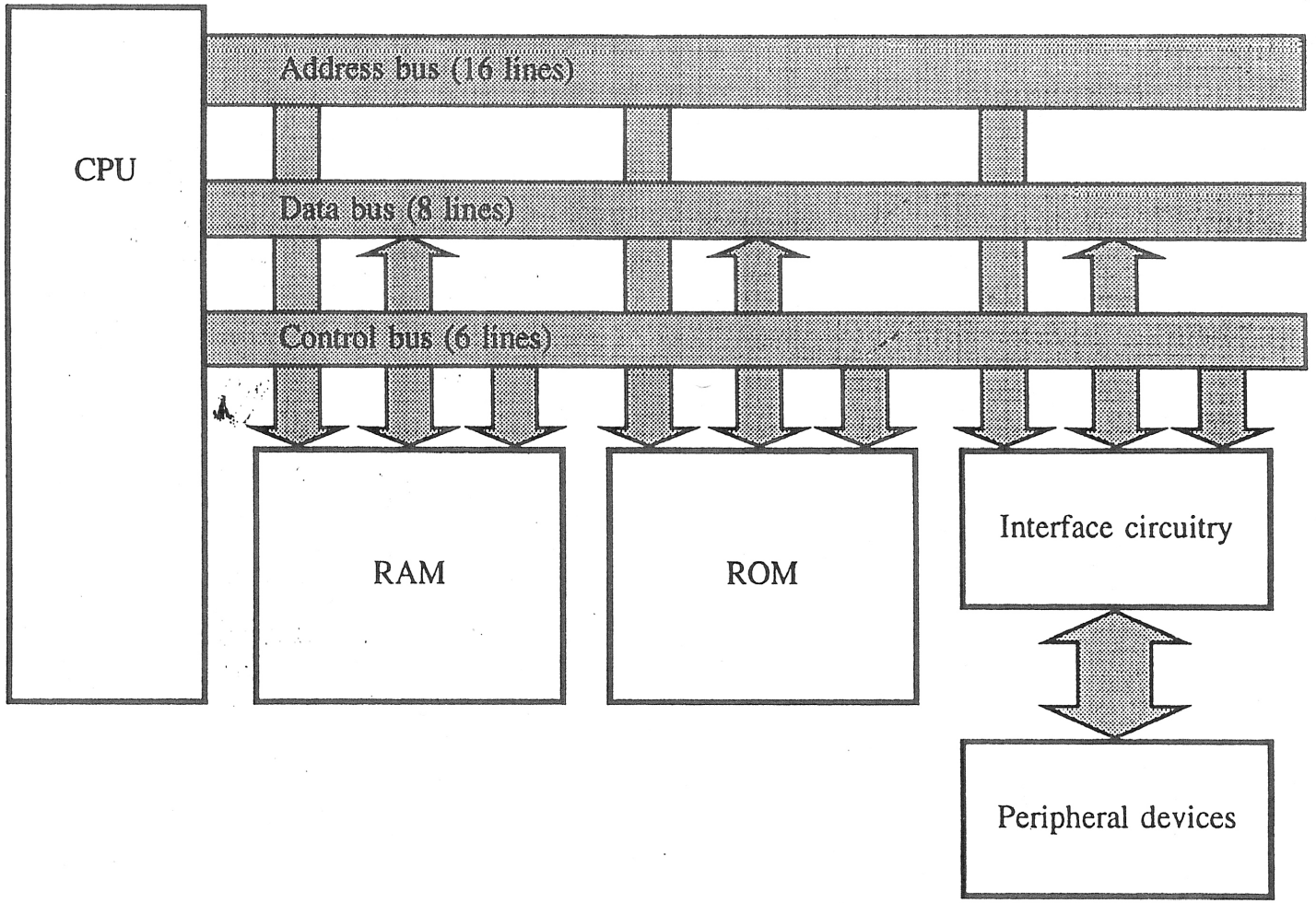


Objectives

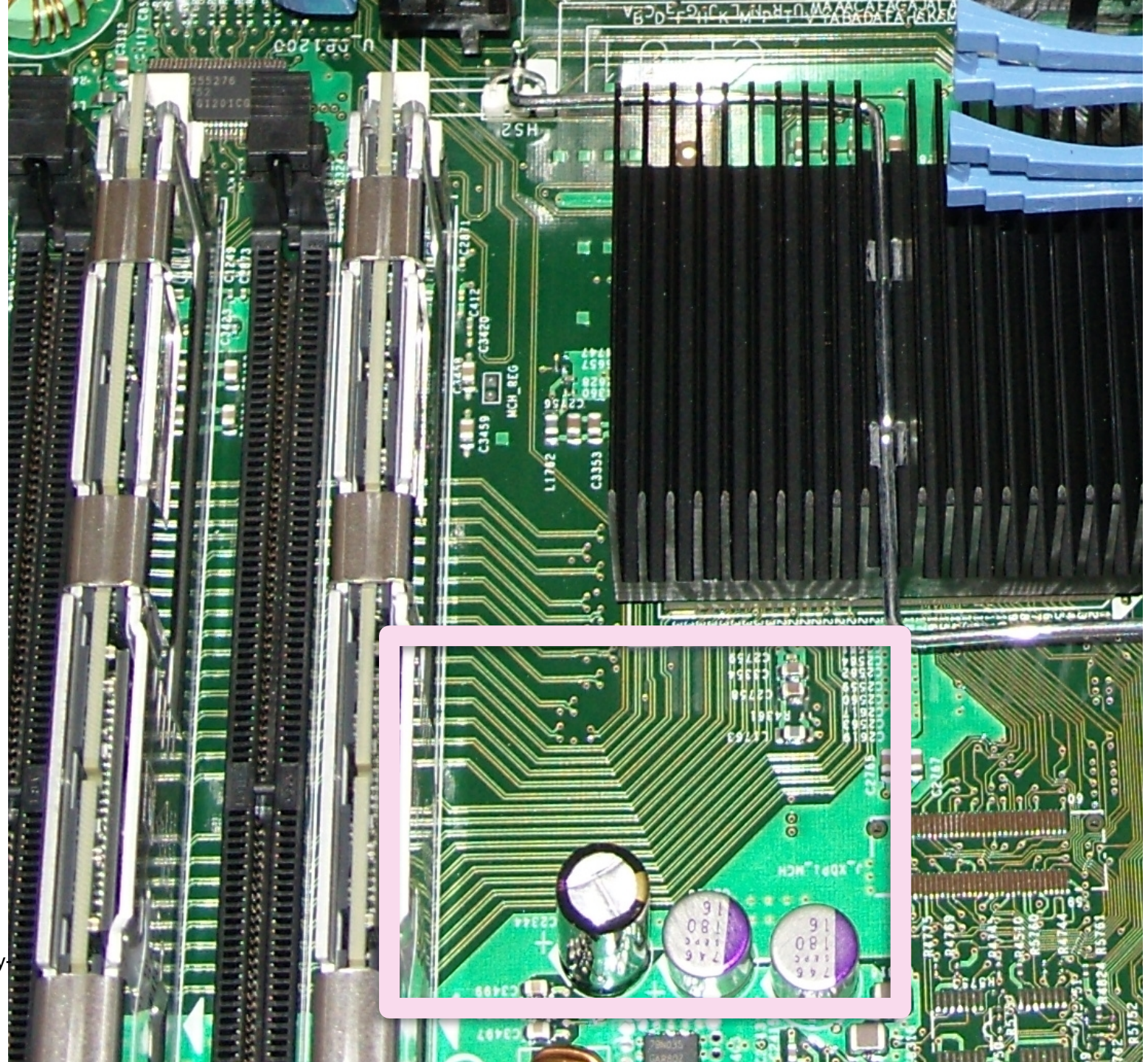
- Broad understanding of
  - memory access
  - busses, and
  - decoders
- Understand the role of memory mapping in a computer system

Microcomputer System Overview

- Communication occurs over busses
- A bus is a set of conductive *lines*
  - Address bus: carries the address to be recalled or written
  - Control bus: carries signals such as the clock, read/write lines, etc.
  - Data bus: carries data to and from external systems (bi-directional)



Example Bus Lines

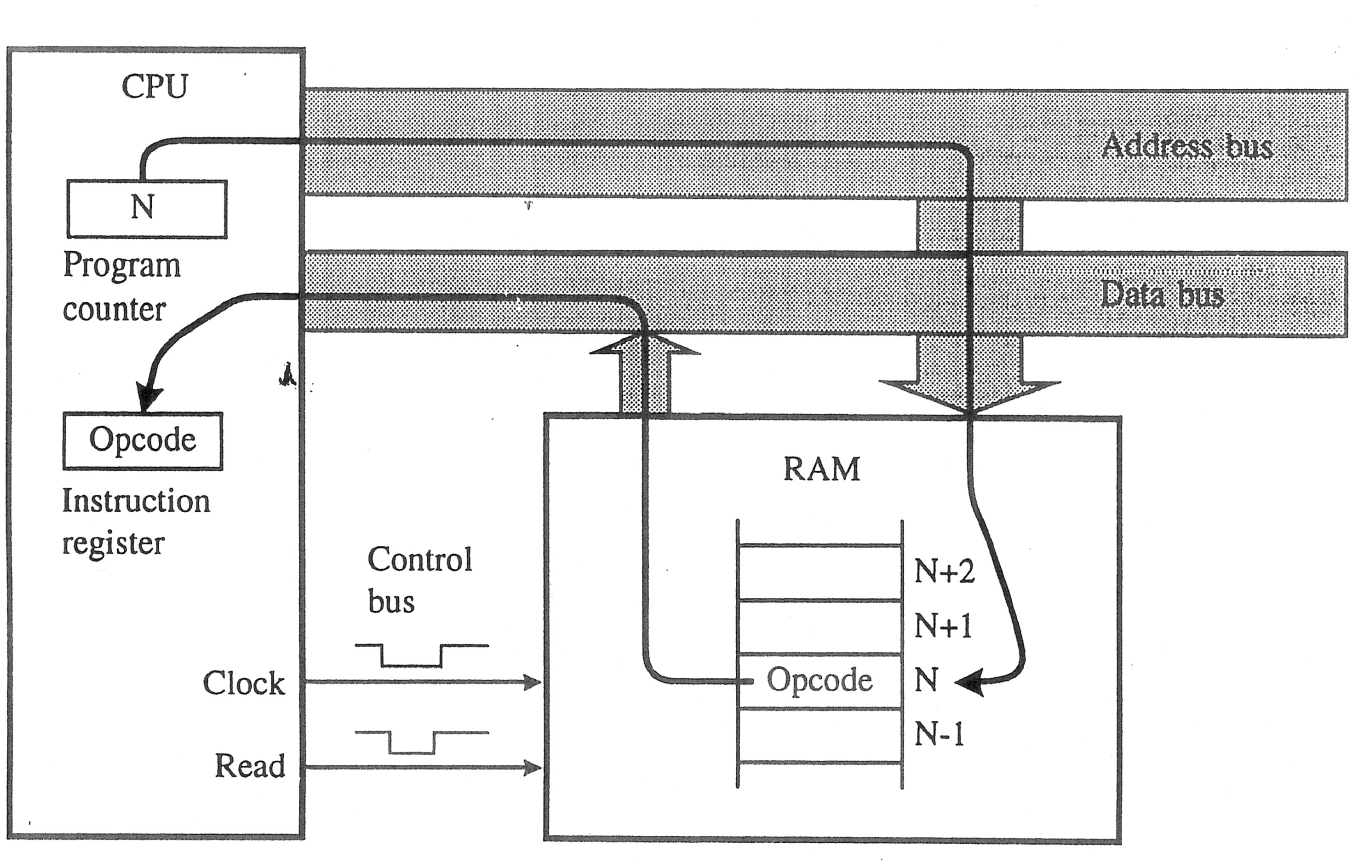


Example Bus Activity: Fetching an Opcode

- Opcodes are instructions executed by the CPU

1. CPU places address of next opcode on the address bus
2. RAM puts the opcode on the data bus
3. CPU reads the opcode into an instruction register and executes it

- Note that the Read and Clock lines are used to tell the RAM what operation is required and to synchronize the process, respectively



Example Opcode from AVR:

`ldi:` Load a value into a general purpose register

Example: Load register 16 with the value 31

```
ldi r16, 31
```

AVR Opcode Example

73. LDI – Load Immediate

73.1. Description

Loads an 8-bit constant directly to register 16 to 31.

Operation:

(i) Rd ← K

	Syntax:	Operands:	Program Counter:
(i)	LDI Rd,K	16 ≤ d ≤ 31, 0 ≤ K ≤ 255	PC ← PC + 1

16-bit Opcode:

1110	KKKK	dddd	KKKK

73.2. Status Register (SREG) and Boolean Formula

I	T	H	S	V	N	Z	C
–	–	–	–	–	–	–	–

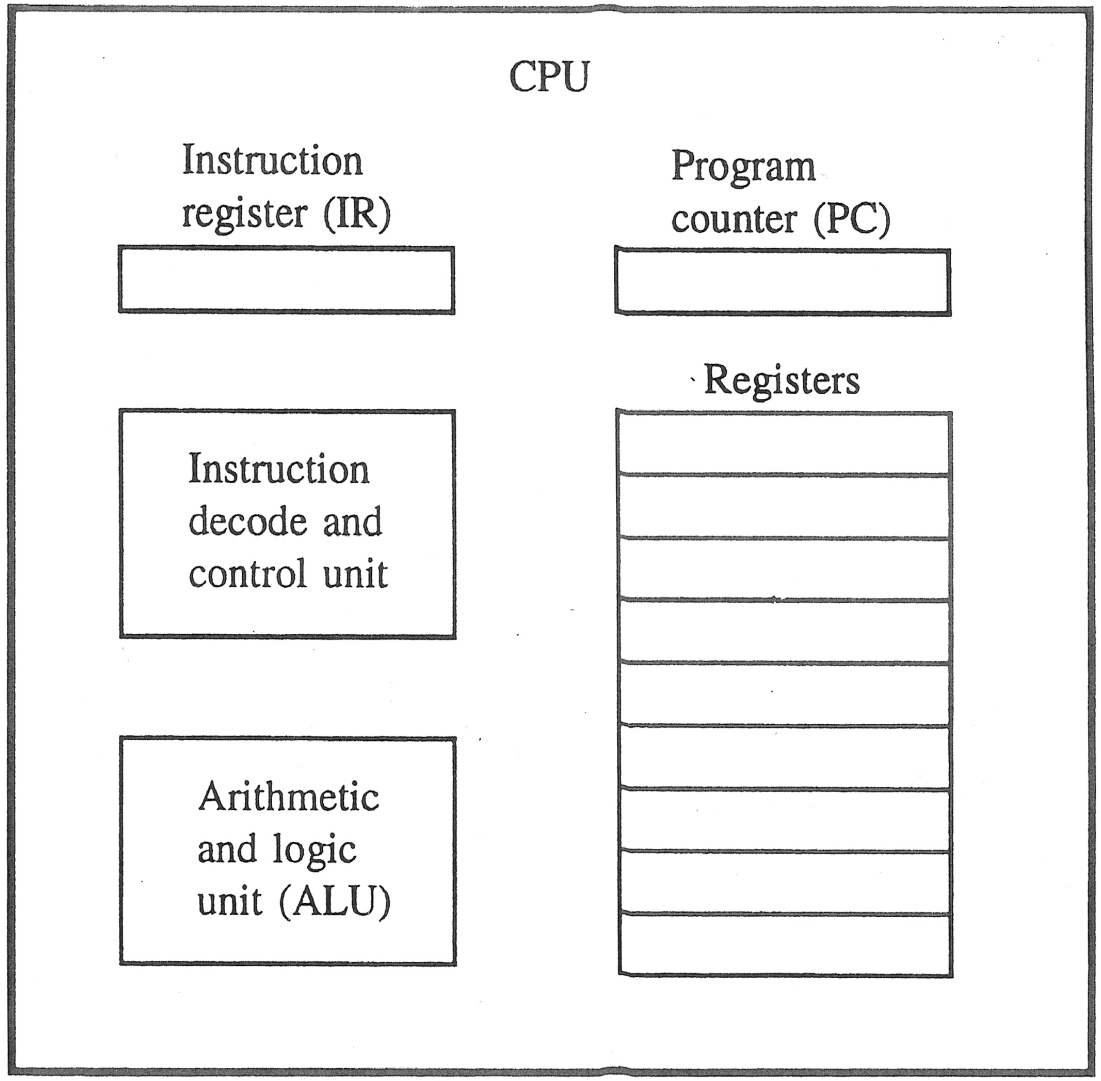
Example:

```
clr r31 ; Clear Z high byte
ldi r30,$F0 ; Set Z low byte to $F0
lpm ; Load constant from Program
; memory pointed to by Z
```

Words	1 (2 bytes)
Cycles	1

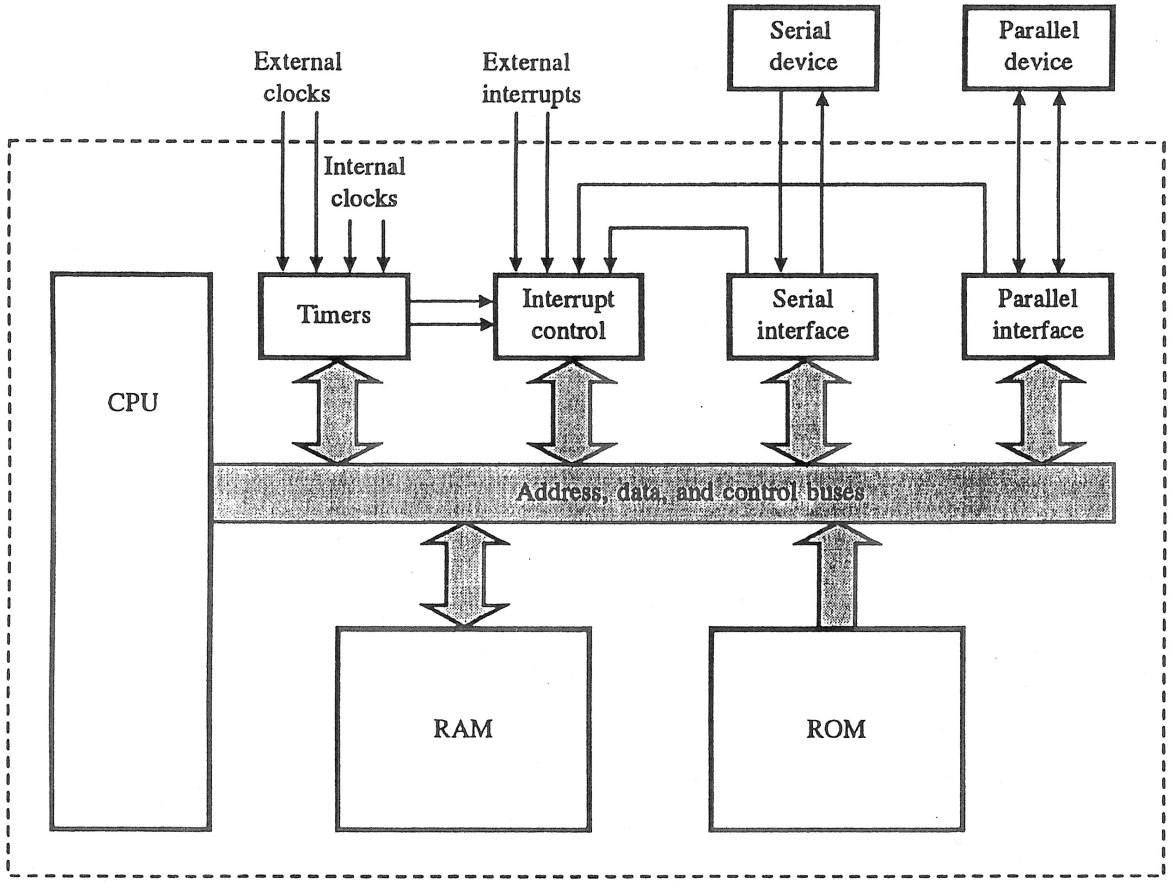
Inside the CPU

- Simplified view of CPU
  - Program counter holds address of next required instruction.
  - Instruction register holds the current instruction just fetched from the program counter address
  - Instr. decode unit analyzes the instruction in the IR to determine the type of operation and executes it
  - ALU performs any required math / logic for the instruction
  - Registers can be used for holding data required for operations



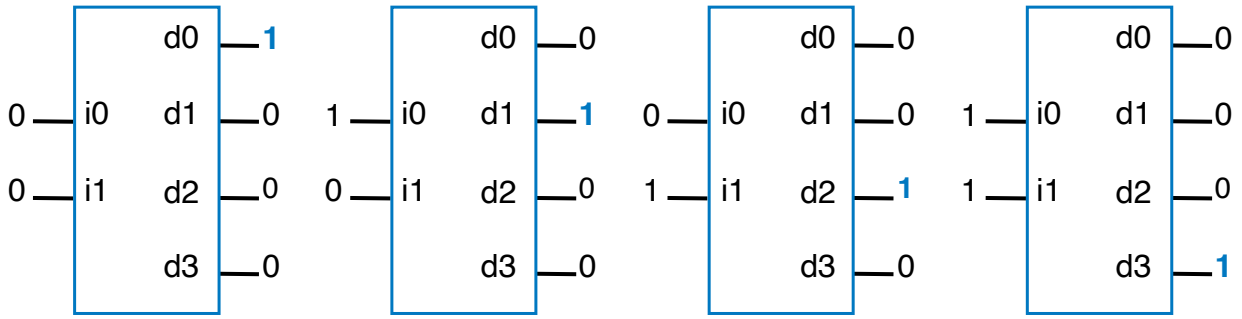
Everything has an Address

- To the CPU, everything is just an address that can be written to or read from
- Addresses are *mapped* to different physical components
- Writing to a serial device, for example, means
  - setting the appropriate control lines
  - setting its address on the address bus, and
  - writing data on the data bus



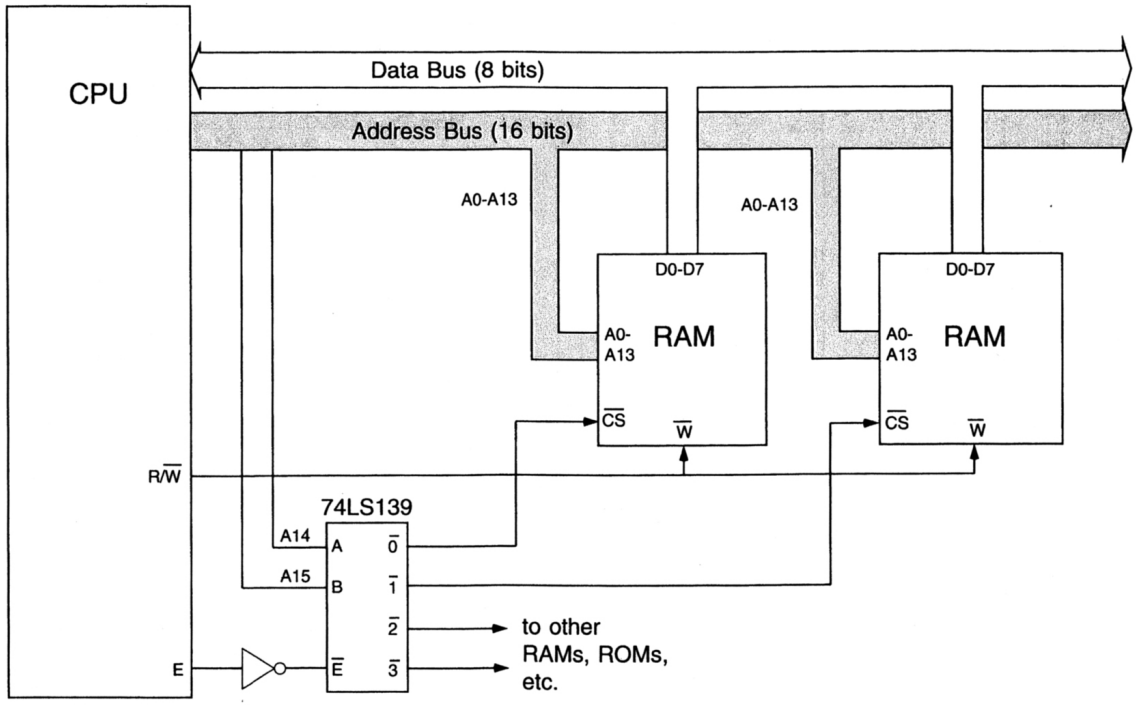
Quick Decoder Review

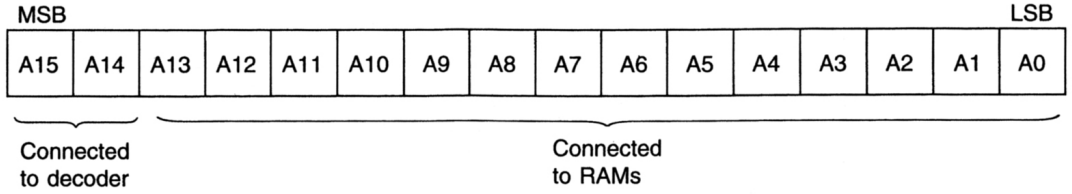
- Combinational logic building block that converts binary information from n input lines to a maximum of 2^n output lines
- Only one output line is 1 (its position is given by the input binary number)
- Also known as n-to-m line decoders where $m \leq 2^n$



Example of Accessing Physical Memory

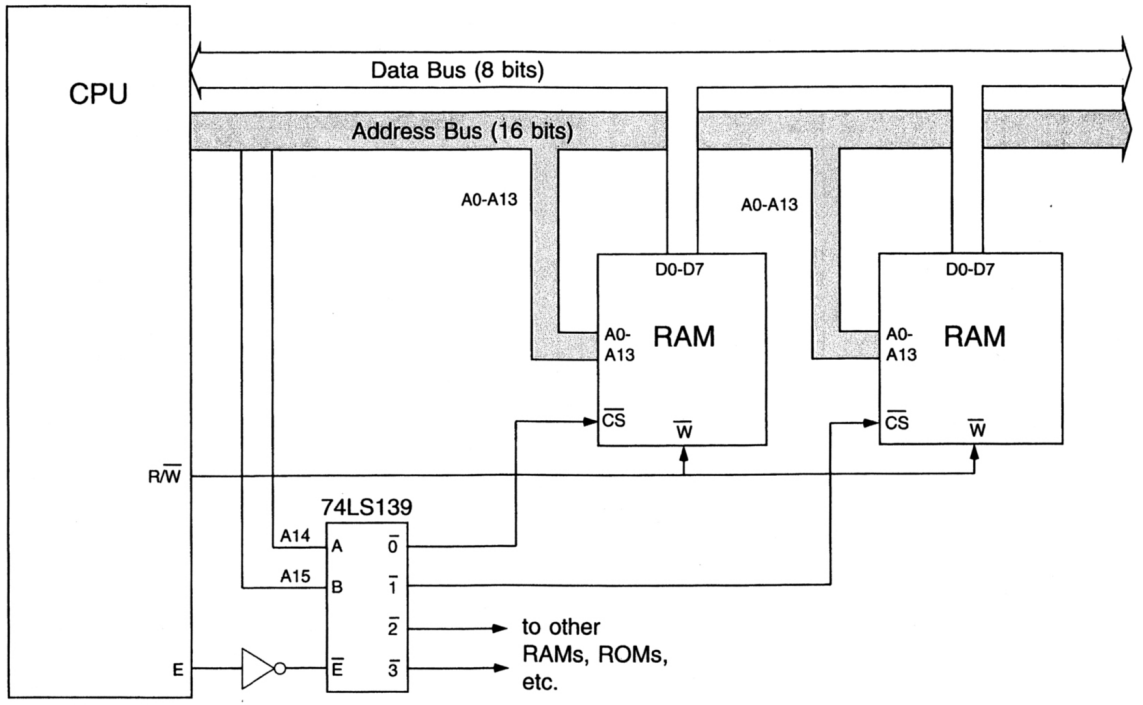
- RAM chips are connected to the data and address busses
- The two highest address bits are used to select the memory chips via a decoder
- Each output pin of the decoder can select one RAM chip

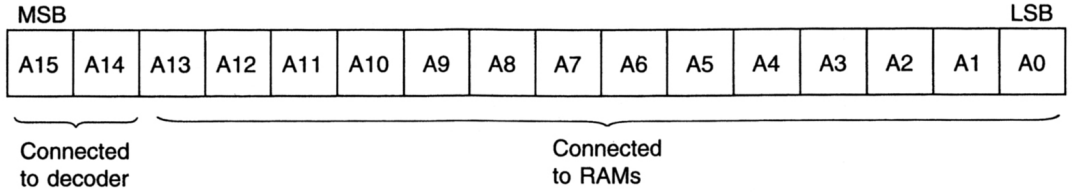




Example of Accessing Physical Memory (2)

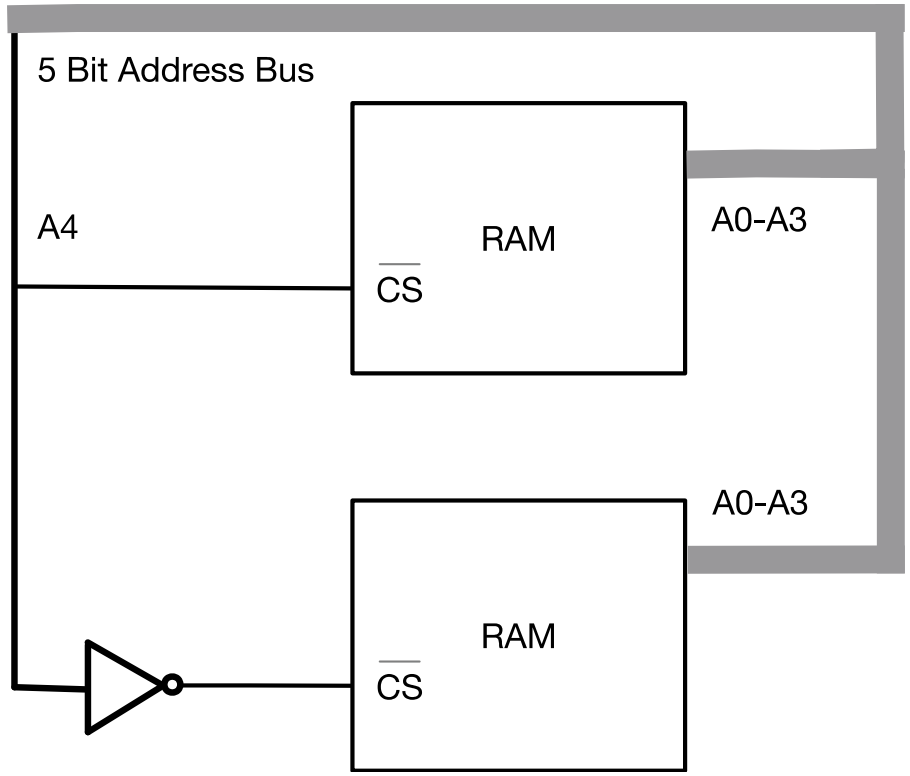
- In this configuration, the bit width (8 in this case) remains constant
- Every RAM chip adds more storage to the system
- Each chip is *mapped* to a range of memory
- The range is determined in this case by A14 and A15
- NOTE: The chip selected by A14 and A15 might be a peripheral and not a RAM chip





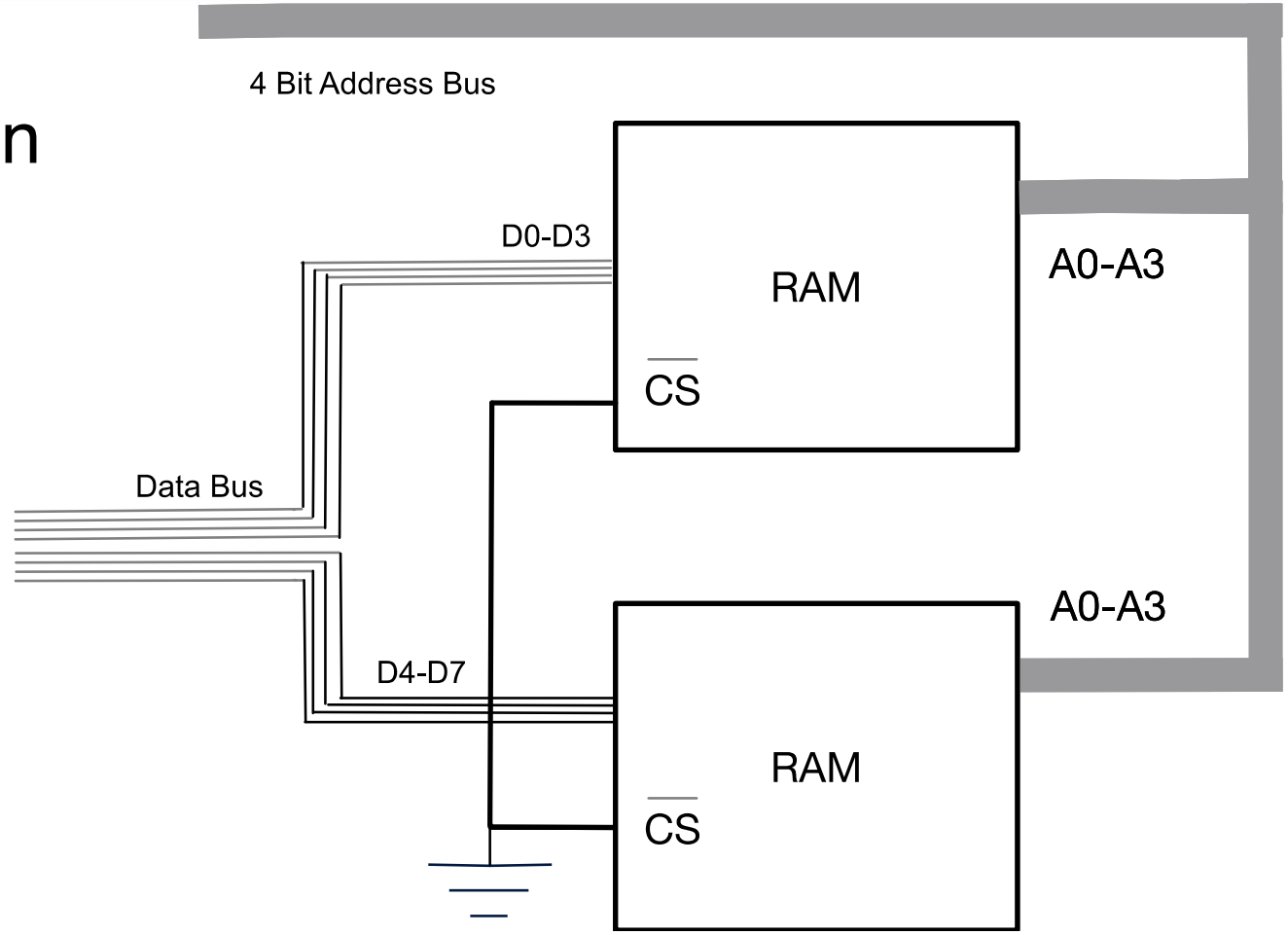
Using Combinational Logic for Chip Selection

- Instead of a decoder, combinational logic circuits can be used to enable / disable ICs
- Example:
  - 01100 retrieves data from address 1100 in the top chip
  - 11100 retrieves data from the bottom chip



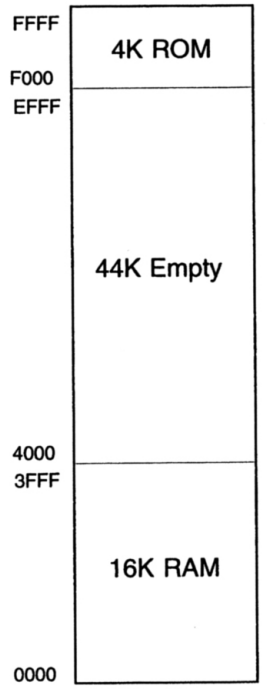
Increasing Word Size

- The same chipset can be configured to increase word size instead of total memory



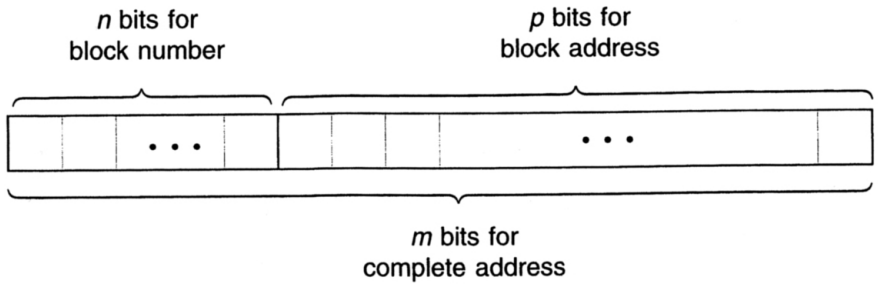
A Memory Map

- A simple memory map for 16 bit system:
  - General purpose RAM 0x0000-to 0x3FFF
  - ROM beginning at 0xF000 and extending to 0xFFFF



Determining Address Bit Allocation

The number of bits needed for block selection depends on the number of divisions required

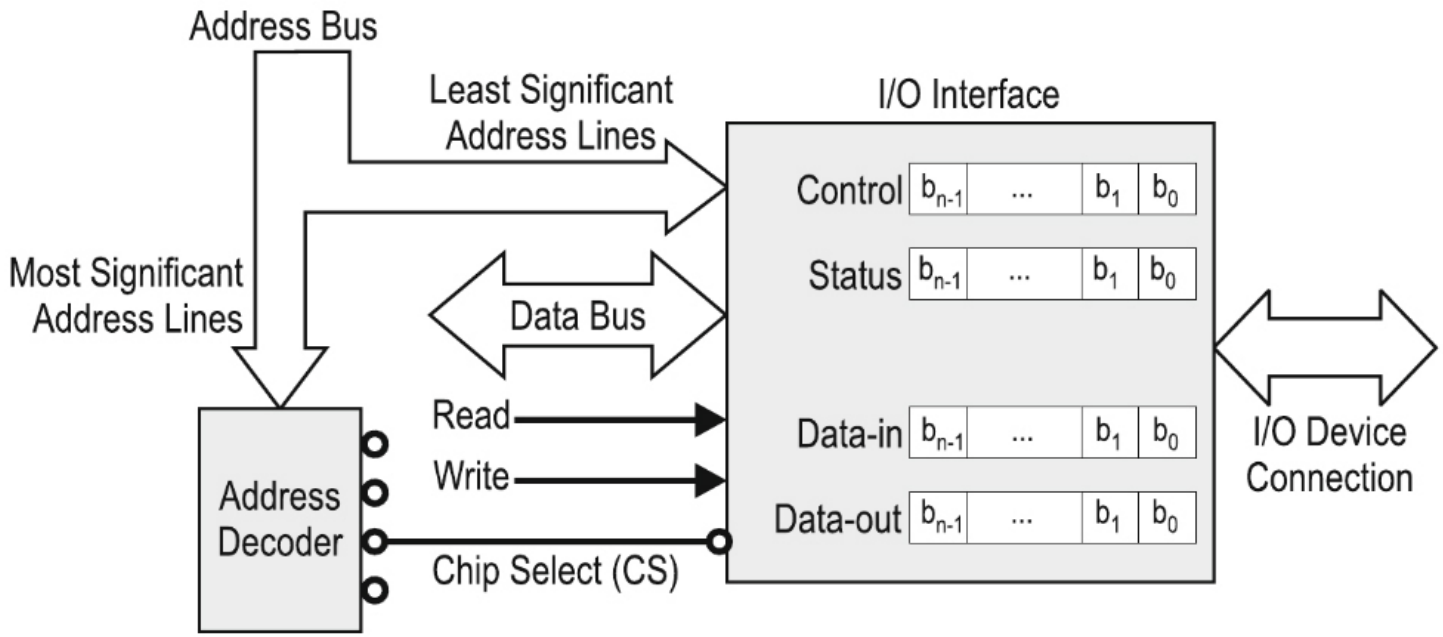


n	p	Number of Blocks (2^n)	Block Size (2^p)
0	16	1	65536
1	15	2	32768
2	14	4	16384
3	13	8	8192
4	12	16	4096
5	11	32	2048
6	10	64	1024
7	9	128	512
8	8	256	256
9	7	512	128
10	6	1024	64
11	5	2048	32
12	4	4096	16
13	3	8192	8
14	2	16384	4
15	1	32768	2
16	0	65536	1

Example for 64K Memory Space

Memory-mapped I/O

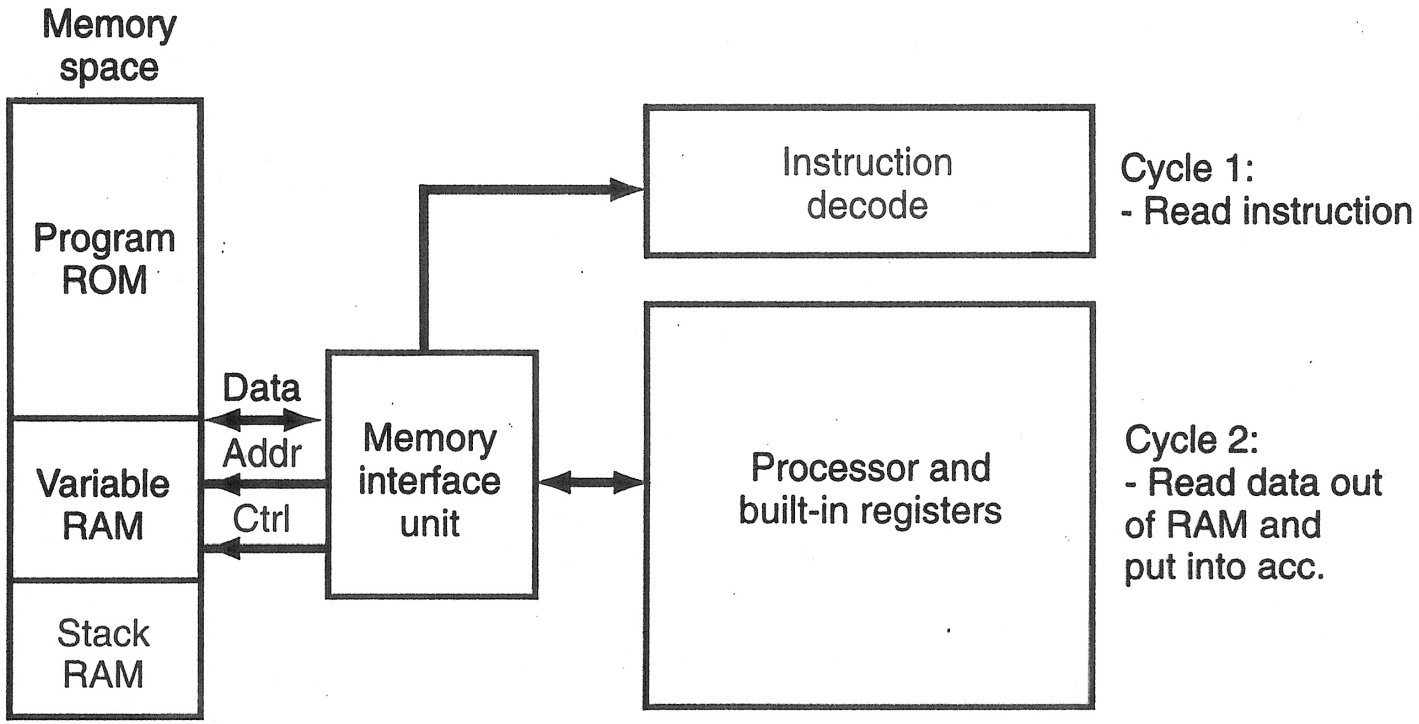
- The address decoder uses the MSB address lines to select the appropriate interface
- An interface is mapped to a range of addresses by the decoder
- Internal registers are access by putting the appropriate address on the bus
- Data is read from or written to the registers
- In general, each bit in the Control and Status registers has some specific meaning



Introduction to Embedded Systems, Jimenez et al

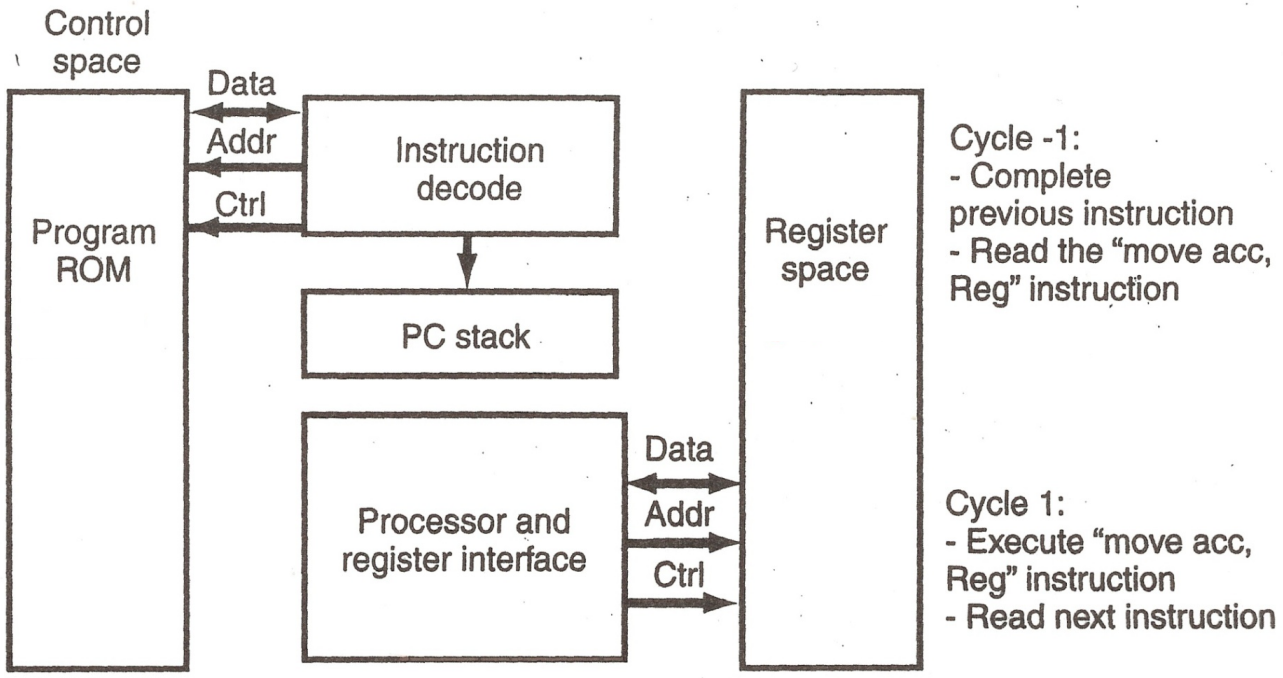
Dividing Program and Data Storage

- **Princeton Architecture**
  - Data and program memory share the same data and address busses
  - The CPU reads the instruction from a location in memory
  - Then the CPU reads/writes data to the appropriate memory location



Dividing Program and Data Storage (2)

- **Harvard Architecture**
  - Separate busses for instruction code and data
  - Operations can be completed in one cycle
- Harvard is faster, however the Princeton approach is simpler from a hardware perspective
- NOTE: The AVR chip on the Arduino uses the Harvard architecture

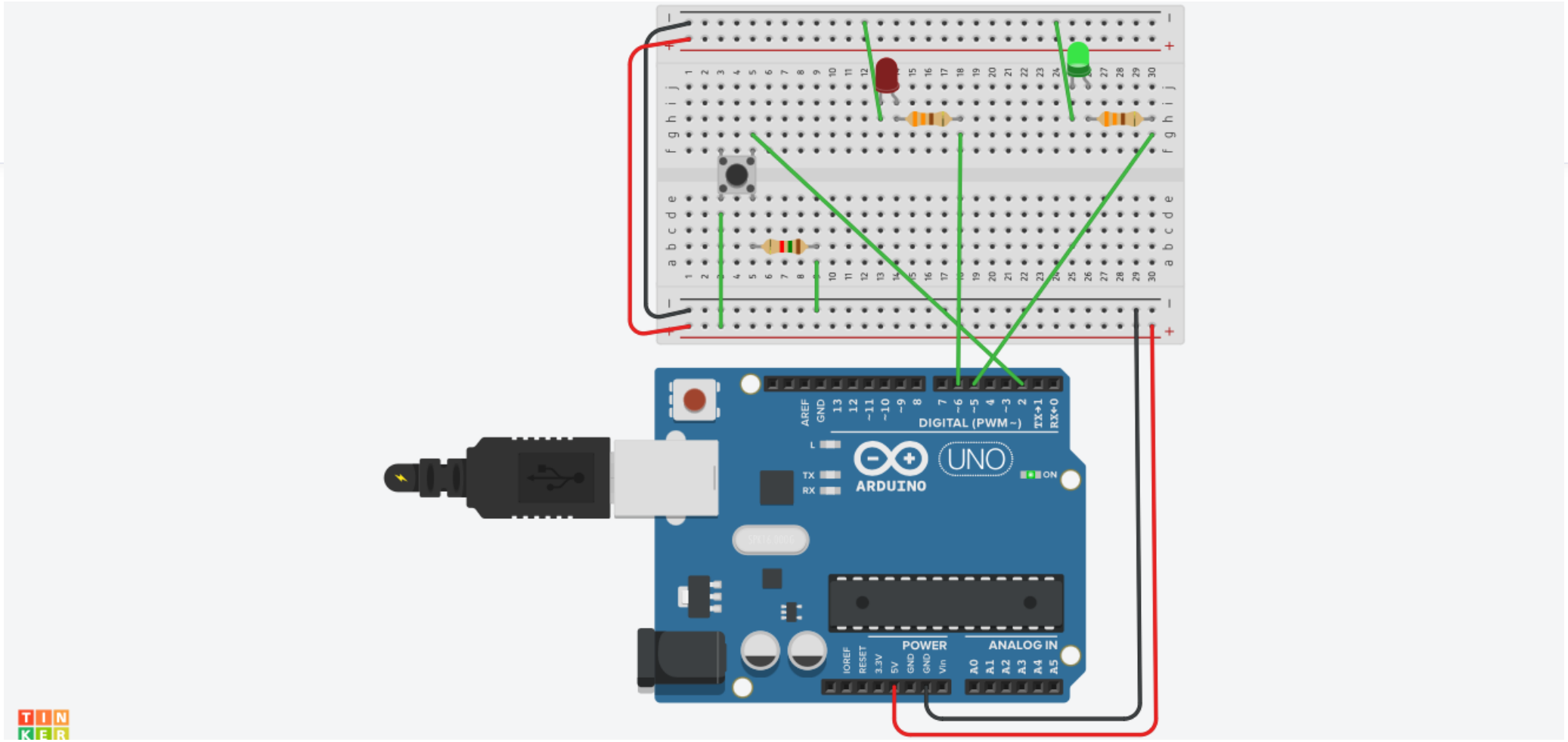


Computer Memory

- Types of memory
  - Static RAM (SRAM)
  - Dynamic RAM (DRAM)
  - Flash (NAND/NOR)
  - Erasable Programmable Read-Only Memory (EPROM)

Volatile - requires power to keep values

Involatile – retains values when power is off



https://www.tinkercad.com/things/2L9hSSEInHG-copy-of-lab-1-part2/editel?sharecode=Rsq5D7uMDx-qiL0slEX2jVKholQmmZFBkEHAilfSN1A

```
// C++ code
//
void setup() {
Serial.begin(9600);
Serial.println("Hello from the Serial monitor!");
pinMode(5, OUTPUT);
pinMode(6, OUTPUT);
pinMode(2, INPUT);
}
```

```
void loop() {
char input1 = digitalRead(2);
  if(input1 == LOW ){
            digitalWrite(5,HIGH);
    digitalWrite(6,LOW);
  }
  else if(input1 == HIGH){
            digitalWrite(6,HIGH);
    digitalWrite(5,LOW);
  }
}
```