Memory

Part 4

1

von Neumann Architecture

The Information Superhighway

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von Neumann Machine Architecture

- Modern computers are based on the design of John von Neumann
- His design greatly simplified the construction of (and use) computers

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Some von Neumann Attributes

1. Programs are stored and executed in memory
2. Separation of processing from memory
3. Different system components communicate over a shared bus

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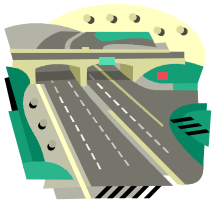
The Bus

- Electronic pathway that transports data between components
- Think of it as a "highway"
  - data moves on shared paths
  - otherwise, the computer would be very complex



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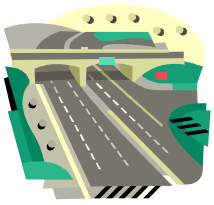
System Bus

- The information sent on the memory bus falls into 3 categories
- Three sets of signals
  - address bus
  - data bus
  - control bus



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Address Bus

- Used by the processor to access a specific piece of data
- This "address" can be
  - a specific byte in memory
  - unique IO port
  - etc…
- The more bits it has, the more memory can be accessed

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Address Bus Size Examples

- 8-bit → 2^8 = 256 bytes
- 16-bit → 2^{16} = 64 KB (65,536 bytes)
- 32-bit → 2^{32} = 4 GB (4,294,967,296 bytes)
- 64-bit → 2^{64} = 18 EB (18,446,744,073,709,551,616)

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Historic Address Sizes

- Intel 8086
  - original 1982 IBM PC
  - 20-bit address bus (1 MB)
  - only 640 KB usable for programs
- MOS 6502 computers
  - Commodore 64, Apple II, Nintendo, etc…
  - 16-bit address bus (64 KB)

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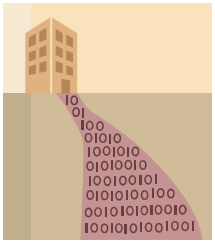
Data Bus

- The actual data travels over the *data bus*
- The number of bits that the processor uses – as its natural unit of data – is called a *word*



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Data Bus

- Typically we define a system by word size
- Example:
  - 8-bit system uses 8 bit words
  - 16-bit system uses 16 bits (2 bytes) words
  - 32-bit system uses 32 bits (4 bytes) words
  - etc…

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Control Bus

- The *control bus* controls the timing and synchronizes the subsystems
- Specifies what is happening
  - read data
  - write data
  - reset
  - etc…

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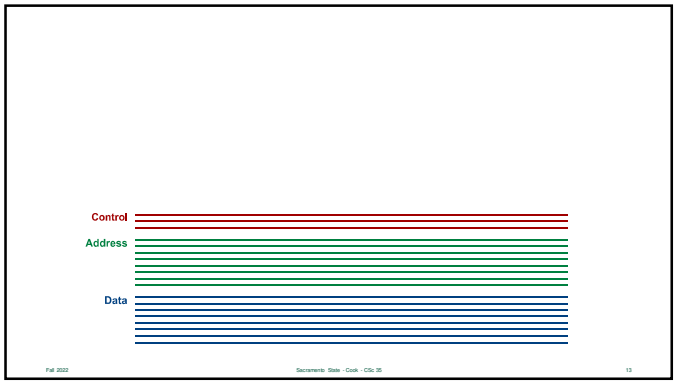

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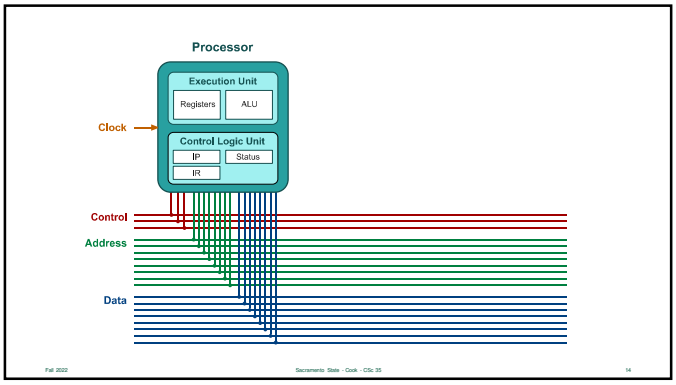

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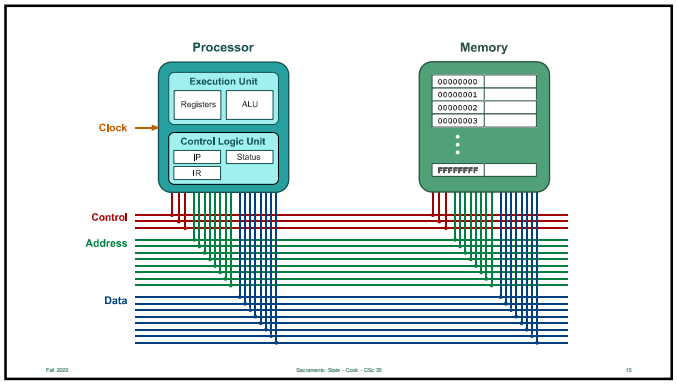

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von Neumann Architecture Today

- Because of the emphasis on memory, most real-world systems use a modified version of his design
- In particular, they have a special high-speed bus between the processor and memory

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von Neumann Architecture Today

- Think of it as a diamond-lane on a freeway
- … or as high-speed rail – which has a fixed source and destination and goes faster than the freeway

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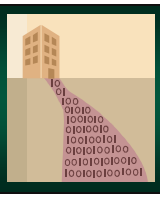

Accessing Data

Filling the registers

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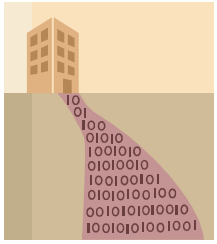
Accessing Data

- Processors use registers to hold data being computed
- So, how is data put into the registers to begin with?
- Data can come from two major sources



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Immediates

- In programming, it is common to assign a constant to a variable
- As you can imagine, this will also be quite common with instructions

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Immediates

- When a constant is stored as part of instruction, it is called an *immediate*
- Once the instruction is loaded by the processor, it is "immediately" available from the IR – hence, the name

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Load Immediate

- A *Load Immediate* instruction, stores a constant into a register
- The instruction must store the destination register and the immediate value

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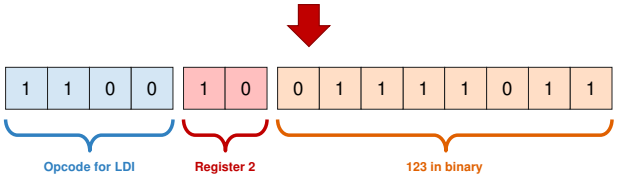
Load Immediate Example (not x86)

```
LDI r2, 123
```



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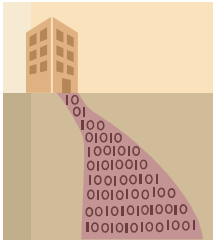
Copying Data



- Processors have a number of instructions that can copy data
- Each has a unique name –*not surprising since each does something different*

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Transfer

- A *Transfer* instruction, copies the contents of one instruction into another
- The instruction must store both the destination and source register

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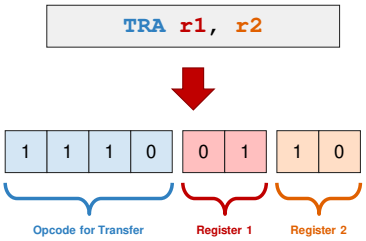
Transfer Example (not x86)



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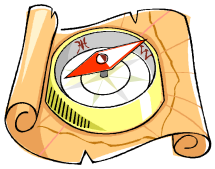
Effective Addresses

- Processors also have the ability to access memory
- Since memory is a massive array, the processor needs to know the address



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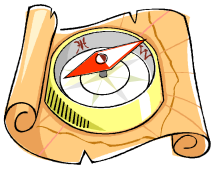
Effective Addresses

- The *effective address* is used to access memory
- Often it is created by combining multiple values
- … but we will cover that later in the semester



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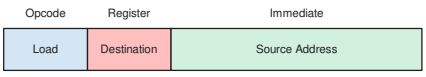
Load

- A *Load* instruction, reads data from memory (at a specified address)
- This data is then stored into the destination register



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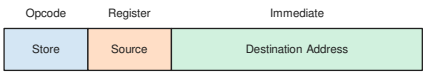
Store

- A *Store* instruction, writes data from a register into the specified address
- Note: the structure is identical to Load



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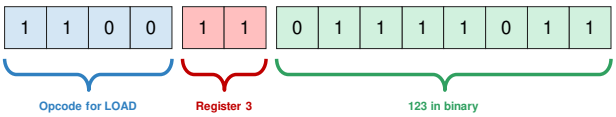
Load Example (not x86)

```
LDR r3, [123]
```



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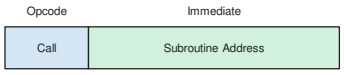
Call Instruction

- The *Call instruction* doesn't change any of the general-purpose registers
- It only stores an address – where execution will continue



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Buffers

Creating your own space

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Buffers

- A *buffer* is any allocated block of memory that contains data
- This can hold anything:
  - text
  - image
  - file
  - etc….

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Buffers

- There are several assembly *directives* which will allocate space
- We have covered a few of them, but there are many – all with a specific purpose

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A few directives that create space

Directive	What it does
`.ascii`	Allocate enough space to store an ASCII string
`.quad`	Allocate 8-byte blocks with initial value(s)
`.byte`	Allocate byte(s) with initial value(s)
`.space`	Allocate any ***size*** of empty bytes (with initial values).

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Labels are addresses

- Labels are used to keep track of memory locations
- They are stored, by the assembler, in a table
- Whenever a label is used in the program, the assembler substitutes the address

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Labels are addresses

- The table of labels is stored in the *object file*
- That way the linker can resolve any unknown labels
- After the program is linked into an executable, only addresses exist. No labels.

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Quad Directive

```
Value:
    .quad 74
```

Let's assume Value = 2000

2000	4A
2001	00
2002	00
2003	00
2004	00
2005	00
2006	00
2007	00

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ASCII Directive Creates a Buffer

```
Text:
    .ascii "Hello\0"
```

This label will store an address... once the assembler finds where to store it.

Creates 6 bytes to store Hello. They are stored consequently.

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Bytes are stored consecutively

```
Text:
    .ascii "Hello\0"
```

Let's assume Text = 2000

2000	48	H
2001	65	e
2002	6C	l
2003	6C	l
2004	6F	o
2005	00	\0

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Same Thing!

```
Text:
    .byte 'H'
    .byte 'e'
    .byte 'l'
    .byte 'l'
    .byte 'o'
    .byte 0
```

Created byte by byte

Null character. Marks the end of a string

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This works too!

```
Text:
    .ascii "Hello"
    .byte 0
```

Directives just create space. So, this creates a byte after the ASCII text.

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Create a Buffer of Any Size

```
Text:
    .space 30
```

Create 30 bytes (defaults to 0x20 which is a space)

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Create a Buffer of Any Size

```
Text:
    .space 30, 0
```

Create 30 bytes. All of which are 0.

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Direct Addressing

Using memory… finally

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Direct Addressing

- In *direct addressing*, the processor reads data directly from an address
- Commonly used to:
  - get a value from a "variable"
  - read items in an array
  - etc...

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Direct Addressing

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Direct in Java

- The following, for comparison, is the equivalent in Java
- The memory, at the address total, is loaded into rdx

```
// rdx = Memory[total];
mov rdx, total
```


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Example: Direct Load

```
.intel_syntax noprefix
.data
funds:
   .quad 100

.text
.global _start
_start:
    mov rdx, funds
```

64 bit integer with an initial value of 100.

Read 8 bytes at this address. Doesn't store the address in rdx.

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Example: Direct Store

```
.intel_syntax noprefix
.data
funds:
   .quad 100

.text
.global _start
_start:
    mov rdx, 5000
    mov funds, rdx
```

Store rdx into Address "funds"

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Example: Direct Store 2

```
.intel_syntax noprefix
.data
funds:
   .quad 100

.text
.global _start
_start:
    call ScanInt
    mov  funds, rdx
```

You can store inputted values.

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Direct in Java

- Note: this a shortcut notation
- The full notation would use square brackets
- The assembler recognizes the difference automatically

```
// rdx = Memory[total];
mov rdx, total
```


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Direct in Java

- You can use the square-brackets if you want
- This way it explicitly show *how* the label is being used – it's a matter of preference

```
// rdx = Memory[total];
mov rdx, [total]
```


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Example: Direct

```
.intel_syntax noprefix
.data
funds:
   .quad 100

.text
.global _start
_start:
    mov rdx, [funds]
```

A bit more descriptive

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Load Effective Address

- Load Effective Address stores the actual address into a register
- It doesn't access memory

```
// rdx = total;
lea rdx, total
```


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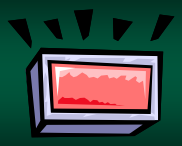

When to use `mov` and `lea`

The difference is huge!

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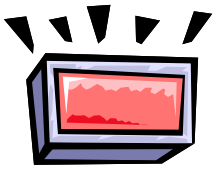
When to use `mov` and `lea`

- Knowing when to use an address **or** the data *located at that address* is vital
- Using the wrong one can cause your program to malfunction or crash



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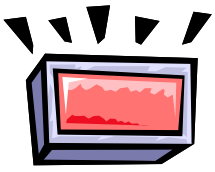
Cause of the Segmentation Fault

- This is one of the most common mistakes in assembly programming



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Using Move Correctly

```
.intel_syntax noprefix
.data
Year:
    .quad 1947

.text
.global _start
_start:
    mov  rdx, Year
    call PrintInt
```

Creates 8 bytes

mov loads the data located at the address Year

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Using move Correctly: Output

```
1947
```

Correct output. mov loaded the data from an address

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Using `lea` by accident

```
.intel_syntax noprefix
.data
Year:
   .quad 1947

.text
.global _start
_start:
   lea  rdx, Year
   call PrintInt
```

Creates 8 bytes

lea is going to store the address Year into rdx

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Using `lea` by accident

```
6293248
```

That's wrong… very, very wrong

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Why it Failed

```
.intel_syntax noprefix
.data
Year:
   .quad 1947

.text
.global _start
_start:
   lea  rdx, Year
   call PrintInt
```

6293232	
6293240	
6293248	1947
6293256	
6293264	

1947 was being stored at this address

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Sometimes, You Need the Address

- Of course, sometimes, you do need an address
- For example, PrintZString
  - needs to know where the string is located so it can print a series of characters
  - so, it requires an address
  - `lea` is necessary

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Using `lea` correctly

```
.intel_syntax noprefix
.data
Message:
    .ascii "Hello!!\0"

.text
.global _start
_start:
    lea  rdx, Message
    call PrintZString
```

Loads the effective address into rdx

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Using `lea` correctly: Output

```
Hello!!
```

Correct output. PrintZString went to the address and printed characters

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Cause of the Segmentation Fault

```
.intel_syntax noprefix
.data
Message:
    .ascii "Hello!!\0"

.text
.global _start
_start:
    mov  rdx, Message
    call PrintZString
```

Creates 8 bytes using ASCII values

Used mov rather than lea. rdx is 64-bit (8 bytes)

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Cause of the Segmentation Fault

```
.intel_syntax noprefix
.data
Message:
    .ascii "Hello!!\0"

.text
.global _start
_start:
    mov  rdx, Message
    call PrintZString
```

Message		
	48	H
	65	e
	6C	l
	6C	l
	6F	o
	21	!
	21	!
	00	\0

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Cause of the Segmentation Fault

```
.intel_syntax noprefix
.data
Message:
    .ascii "Hello!!\0"

.text
.global _start
_start:
    mov  rdx, Message
    call PrintZString
```

Grabs 8 bytes and creates a huge value

Message		
	48	H
	65	e
	6C	l
	6C	l
	6F	o
	21	!
	21	!
	00	\0

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Sizing Instructions

How many bytes are you using?

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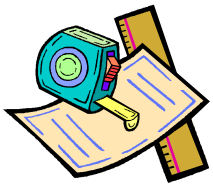
Sizing Instructions

- The Intel can load/store 1-byte, 2-byte, 4-byte or 8-byte values
- The assembler knows *(by looking at the size of the register)* how much many bytes you want to load/store



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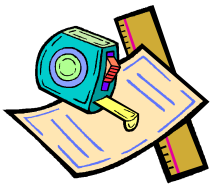
Sizing Instructions

- However, sometimes the number of bytes (1, 2, etc..) can't be determined
- In this case, the assembler will report an error
- … since it doesn't know how to encode the instruction



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Example: How Many Bytes?

```
.intel_syntax noprefix
.data
total:
    .quad 0

.text
.global _start
_start:
    mov  total, 50
```

total is a target address. It doesn't have any implied size.

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Example: How Many Bytes?

```
.intel_syntax noprefix
.data
total:
    .quad 0

.text
.global _start
_start:
    mov  total, 50
```

How many bytes is this? The value 50 can be stored in 1, 2, 4, or 8 bytes.

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How Many Bytes?

- If the assembler can't infer how many bytes to access, it'll will report *"ambiguous operand size"*
- To address this issue…
  - GAS assembly allows you places a single character after the instruction's mnemonic
  - this suffix will tell the assembler how many bytes will be accessed during the operation

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How Many Bytes

Suffix	Name	Size
b	byte	1 byte
s	short	2 bytes
l	long	4 bytes
q	quad	8 bytes

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Example: Suffix Used

```
.intel_syntax noprefix
.data
total:
    .quad 0

.text
.global _start
_start:
    movq total, 50
```

Now the assembler knows you mean "move quad".

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Endianness

The "proper" order of things

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So Many Bytes…

- On a 64-bit system, each word consists of 8 bytes
- So, when any 64-bit value is stored in memory, each of those 8 bytes must be stored
- However, question remains: *What order do we store them?*

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Example Unsigned Integer (4 Byte)

1,188,852,977

46	DC	74	F1

Most significant Byte (MSB)

Least significant Byte (LSB)

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So Many Bytes…

- Do we store the least-significant byte (LSB) first, or the most-significant (MSB)?
- As long as a system always follows the same format, then there are no problems
- … but different system use different approaches

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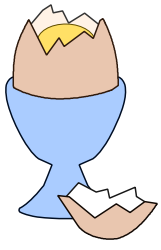
Big Endian vs. Little Endian

- Big-Endian approach
  - store the MSB first
  - used by Motorola & PowerPC
- Little-Endian approach
  - store the LSB first
  - used by Intel



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Big Endian vs. Little Endian

46	DC	74	F1

Big Endian	
0	46
1	DC
2	74
3	F1

Little Endian	
0	F1
1	74
2	DC
3	46

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Assuming Value is located at 2000

```
Value:
    .quad 74
```

2000	4A
2001	00
2002	00
2003	00
2004	00
2005	00
2006	00
2007	00

Least Significant Byte (LSB)

Little Endian

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No "End" to Problems

- *There is a problem...*
  if two systems use different formats, data will be interpreted incorrectly!
- If how the read differs from how it is stored, the data will be mangled

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No "End" to Problems

- For example:
  - a little-endian system reads a value stored in big-endian
  - a big-endian system reads a value stored in little-endian
- Programmers must be conscience of this whenever binary data is accessed

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No "End" to Problems

- So, whenever data is read from secondary storage, you cannot assume it will be in your processor's format
- This is compounded by file formats (gif, jpeg, mp3, etc…) which are also inconsistent

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Example File Format Endianness

File Format	Endianness
Adobe Photoshop	Big Endian
Windows Bitmap (.bmp)	Little Endian
GIF	Little Endian
JPEG	Big Endian
MP4	Big Endian
ZIP file	Little Endian

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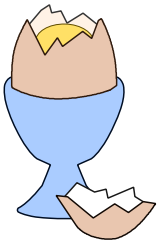
So… who is correct?

- So, what is the correct and superior format?
- Is it Intel (little endian)?
- …or the PowerPC (big endian) correct?



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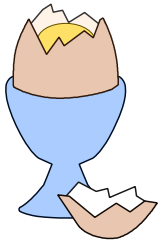
So… who is correct?

- In reality neither side is superior
- Both formats are equally correct
- Both have minor advantages in assembly… but nothing huge



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Gulliver's Travels

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