Memory Indexing

Part 7

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Sizing Instructions

How many bytes are you using?

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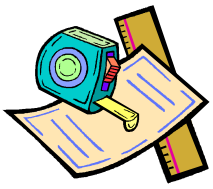
Sizing Instructions

- The Intel can load/store 1-byte, 2-byte, 4-byte or 8-byte values
- Whenever a processor accesses memory, the instruction specifies how many bytes to access



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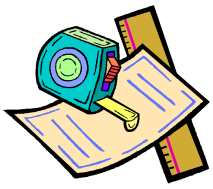
Sizing Instructions

- The assembler will automatically fill this information in for you.
- *How?* If a register is used, the assembly can assume it by looking at size of the register



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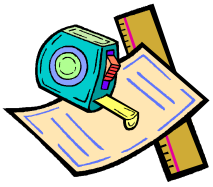
Sizing Instructions

- 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 Main
Main:
    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 Main
Main:
    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 Main
Main:
    movq total, 50
```

Note the q. Now the assembler knows you mean "move quad".

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Behind the Scenes of Arrays

All the mystery is revealed!

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Arrays

- Computers do not have an 'array' data type
- So, how do you have array variables?
- When you create an array…
  - you allocate a block of memory
  - each element is located sequentially in memory – one right after each other

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Arrays

- Every byte in memory has an address
- This is just like an array
- To get an array element
  - we merely need to compute the address
  - we must also remember that some values take multiple bytes – *so there is math*

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Array Math Example

- Let's again assume that our buffer starts at address 2000
- The first array element is located at address 2000
- Arrays consists of bytes…
  - the second is 2001
  - the third is 2002
  - the fourth 2003
  - etc…

2000	H
2001	e
2002	l
2003	l
2004	o

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Array Math Example – 16 bit

- First element uses 2000… 2001
- Since each array element is 2 bytes…
  - second address is 2002
  - third address is 2004
  - fourth address is 2006
  - etc…

2000	F0A3
2002	042B
2004	C1F1
2006	0D0B
2008	9C2A

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Array Math Example – 64 bit

- First element uses 2000 to 2007
- Second address is 2008
- Third address is 2016
- Fourth address is 2024
- etc…

2000	446576696E20436F
2008	6F6B000000000000
2016	53616372616D656E
2024	746F205374617465
2032	4353433335000000

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Behind the Scenes…

- So, when an array element is read, internally, a mathematical equation is used
- It uses the start of the first element, the array index, and the size of each element

```
start address + (index × size)
```


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Behind the Scenes…

- *This is why the C Programming Languages uses zero as the first array element*
- If zero is used with this formula, it gets the start of the buffer

```
start address + (index × size)
```


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Behind the Scenes…

- Java uses zero-indexing because C does
- … and C does so it can create efficient assembly!

```
start address + (index × size)
```


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Indexing on the x64

Grabbing any byte

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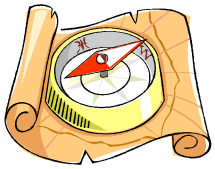
Indexing on the x64

- The Intel x64 supports direct, indirect, indexing and scaling
- So, the Intel is very versatile in how it can access memory
- This is typical of CISC-ish architectures



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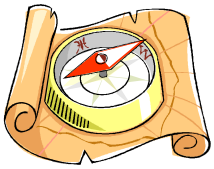
Effective Addresses

- Processors have the ability to create the *effective address* by combining data
- How it works:
  - starts with a base address
  - then adds a value (or values)
  - finally, uses this temporary value as the actual address



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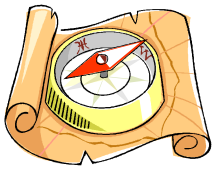
Effective Addresses

- Using the addresses stored in memory, registers, etc… is useful in programs
- Often programs contain *groups* of data
  - fields in an abstract data type
  - elements in an array
  - entries in a large table etc…



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Terminology

- *Base-address* is the initial address
- *Displacement (aka offset)* is a constant (immediate) that is added to the address
- *Index* is a register added to the address
- *Scale* used to multiply the index before adding it to the address

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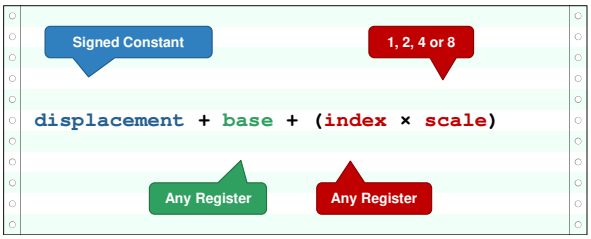
x64 Effective Address Formula



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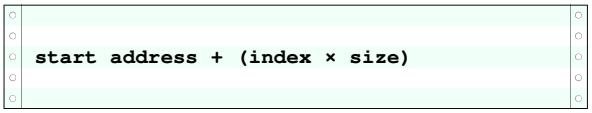
Behind the Scenes…

- But wait, doesn't that formula look familiar?
- The addressing term "scale" is basically equivalent to "size" in this example
- Addressing and arrays work together flawlessly



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Addressing Notation in Assembly

- Intel Notation *(Microsoft actually created it)* allows you to specify the full equation
- The notation is very straight forward and mimics the equation used to compute the effective address
- Parts of the equation can be omitted, and the assembler will understand

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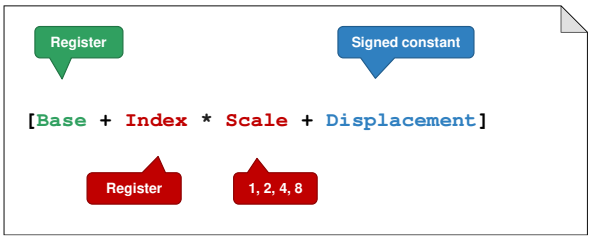
Intel Notation



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Notation (reg = register)

Mode	Syntax	Java Equivalent
Immediate	`value`	`value`
Register	`register`	`register`
Direct	`label`	`Memory[label]`
Direct Indexed	`[label + reg]`	`Memory[label + reg]`
Indirect	`[reg]`	`Memory[reg]`
Indirect Indexed	`[reg + reg]`	`Memory[reg + reg]`
Indirect Indexed Scale	`[reg + reg * scale]`	`Memory[reg + reg × scale]`

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Addressing Notation in Assembly

- When you write an assembly instruction…
  - you specify all 4 four addressing features
  - however, notation fills in the "missing" items
- For example: for direct addressing…
  - Displacement → Address of the data
  - Base → Not used
  - Index → Not used
  - Scale → 1, irrelevant without an Index

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Indexing Examples

- The following examples use addressing modes modify an ASCII buffer
- Let's assume that the start of the buffer **Talk** is **5000**

Talk = 5000

5000	48	H
5001	65	e
5002	6C	l
5003	6C	l
5004	6F	o

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Example: Direct Index

```
# Talk = 5000

mov  rdi, 1
movb [Talk + rdi], 33
```

Using the rsi register for indexing, but you can use any register

ASCII 33 → !

5000	48	H
5001	33	!
5002	6C	l
5003	6C	l
5004	6F	o

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Example: Direct Index (Scale 2)

```
# Talk = 5000

mov  rdi, 1
movb [Talk + rdi * 2], 33
```

5000	48	H
5001	65	e
5002	33	!
5003	6C	l
5004	6F	o

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Example: Direct Index (Scale 4)

```
# Talk = 5000

mov  rdi, 1
movb [Talk + rdi * 4], 33
```

5000	48	H
5001	65	e
5002	6C	l
5003	6C	l
5004	33	!

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Example: Register Indirect

```
# Talk = 5000

lea  rax, Talk
movb [rax], 33
```

Indirect. Base is rax

5000	33	!
5001	65	e
5002	6C	l
5003	6C	l
5004	6F	o

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Example: Register Indirect Index

```
# Talk = 5000

lea  rax, Talk
mov  rdi, 1
movb [rax + rdi], 33
```

Base Index

5000	48	H
5001	33	!
5002	6C	l
5003	6C	l
5004	6F	o

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Ex: Register Indirect Index (Scale 2)

```
# Talk = 5000

lea   rax, Talk
mov   rsi, 1
movb [rax + rsi * 2], 33
```

Scale

5000	48	H
5001	65	e
5002	33	!
5003	6C	l
5004	6F	o

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Ex: Register Indirect Index (Scale 4)

```
# Talk = 5000

lea   rax, Talk
mov   rsi, 1
movb [rax + rsi * 4], 33
```

5000	48	H
5001	65	e
5002	6C	l
5003	6C	l
5004	33	!

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Addressing & Loops

They were made for each other … *literally*

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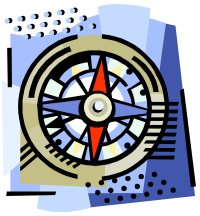
Addressing & Loops

- When you use arrays in Java, often the index is a variable
- This allows you to use a For Loop to analyze very element in the array
- This is more common than you think in assembly



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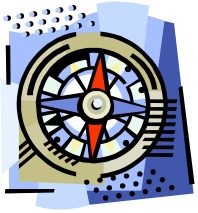
Addressing & Loops

- So, processors allow a register to be used as an index
- This allows you to:
  - copy strings (copying arrays)
  - search through a list
  - and much more…



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For Loop: 0 to 4 - Before

```
.intel_syntax noprefix
.data
Greet:
   .ascii "HELLO"

.text
.global Main

Main:
```

Greet		
	H	0
	E	1
	L	2
	L	3
	O	4

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For Loop: 0 to 4

```
        mov  rax, 0

    Loop:
        cmp  rax, 4
        jg   End

        movb [Greet + rax], 33
        add  rax, 1
        jmp  Loop
    End:
```

! character

Greet		
H	0	
E	1	
L	2	
L	3	
O	4	

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For Loop: 0 to 4 - After

```
        mov  rax, 0

    Loop:
        cmp  rax, 4
        jg   End

        movb [Greet + rax], 33
        add  rax, 1
        jmp  Loop
    End:
```

Greet		
!	0	
!	1	
!	2	
!	3	
!	4	

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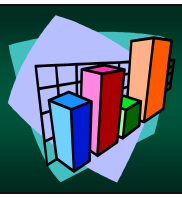

Tables

How to Organize Data

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Tables

- In assembly, you have full control of memory
- You can take advantage of these to create tables
- They can contain any data – from integers, to characters, to addresses

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Accessing Each element

Use register to hold table index

```
mov   rsi, 1
movb  ah, [Greet + rsi]
```

Greet		
H	0	
E	1	
L	2	
L	3	
O	4	

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Tables of Integers

- Tables can contain *anything!*
- Often, they are used to store integers & addresses (8 bytes on a 64-bit system)
- Just make sure to use the scale feature!

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Table of Long Integers

```
Years:
    .quad 1776
    .quad 1783
    .quad 1846
    .quad 1850
    .quad 1947
```

8 Bytes each

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Assuming Years is 6000

```
Years:
    .quad 1776
    .quad 1783
    .quad 1846
    .quad 1850
    .quad 1947
```

6000	1776
6008	1783
6016	1846
6024	1850
6032	1947

50

Assuming Years is 6000

Table index 1

```
mov  rsi, 1
mov  rcx, [Years + rsi * 8]
```

Note the scale!

6000	1776
6008	1783
6016	1846
6024	1850
6032	1947

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Table of Addresses. Assume Names is 3000

```
Sutter:
    .ascii "John Sutter\0"

Marshal:
    .ascii "James Marshal\0"

Names:
    .quad Sutter
    .quad Marshal
```

3000	Sutter *(address)*
3008	Marshal *(address)*

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Assuming Names is 3000

Note: mov is used. We want the data from the table (which is an address)

```
mov  rsi, 1
mov  rdx, [Names + rsi * 8]

call PrintString
```

3000	Sutter *(address)*
3008	Marshal *(address)*

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Buffer Overflow

With Great Power
Comes Great Responsibility

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Buffer Overflow

- Operating systems protect programs from having their memory / code damaged by *other* programs
- However…operating systems don't protect programs from damaging *themselves*

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Buffers & Programs

- In memory, a running program's data is often stored next to its instructions
- This means…
  - if the end of a buffer of exceeded, the program can be read/written
  - this is a common hacker technique to modify a program *while it is running!*

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Example Program

```
.data
Kitty:
   .ascii "Cat"

Puppy:
   .ascii "Dog"

.text
.global Main
Main:
```

Kitty	43	C
	61	a
	74	t
Puppy	44	D
	6F	o
	67	g
Main		
	...	

Start of program

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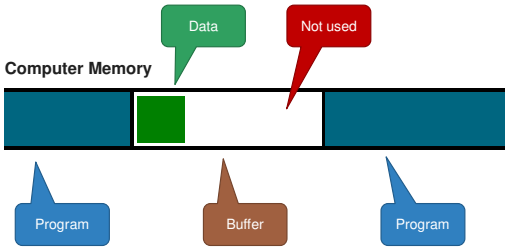
Buffer Overflow – How it Works



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Buffer Overflow

- It is possible to store too much information – resulting in a *buffer overflow*
- The extra bytes will overwrite part of the running program – changing it!

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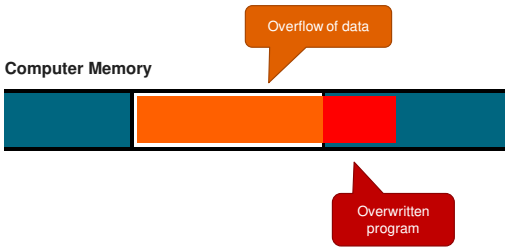
Buffer Overflow – How it Works



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Bad Indexing

- It is possible to accidentally change data stored in the different buffers
- In assembly, you have full control over your allocated memory
- *With great power comes great responsibility*

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Wrong Buffer Changed

```
.intel_syntax noprefix
.data
Kitty:
   .ascii "Cat\0"
Puppy:
   .ascii "Dog\0"

.text
.global Main
Main:
    mov  rdi, 4
    movb [Kitty + rdi], 72
```

4 bytes. Character indexes from 0 to 3

72 is ASCII 'H' In hex it's 48

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Wrong Buffer Changed

```
.intel_syntax noprefix
.data
Kitty:
   .ascii "Cat\0"
Puppy:
   .ascii "Dog\0"

.text
.global Main
Main:
    mov  rdi, 4
    movb [Kitty + rdi], 72
```

Kitty	43	C
	61	a
	74	t
	00	
Puppy	44	D
	6F	o
	67	g
	00	

63

Wrong Buffer Changed

```
.intel_syntax noprefix
.data
Kitty:
   .ascii "Cat\0"
Puppy:
   .ascii "Dog\0"

.text
.global Main
Main:
    mov  rdi, 4
    movb [Kitty + rdi], 72
```

Kitty	43	C
	61	a
	74	t
	00	
Puppy	48	H
	6F	o
	67	g
	00	

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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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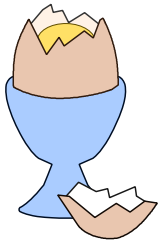
Big Endian vs. Little Endian

- 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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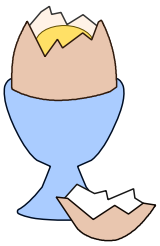
So… who is correct?

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



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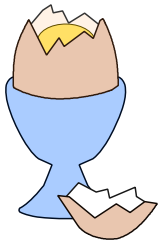
So… who is correct?

- 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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