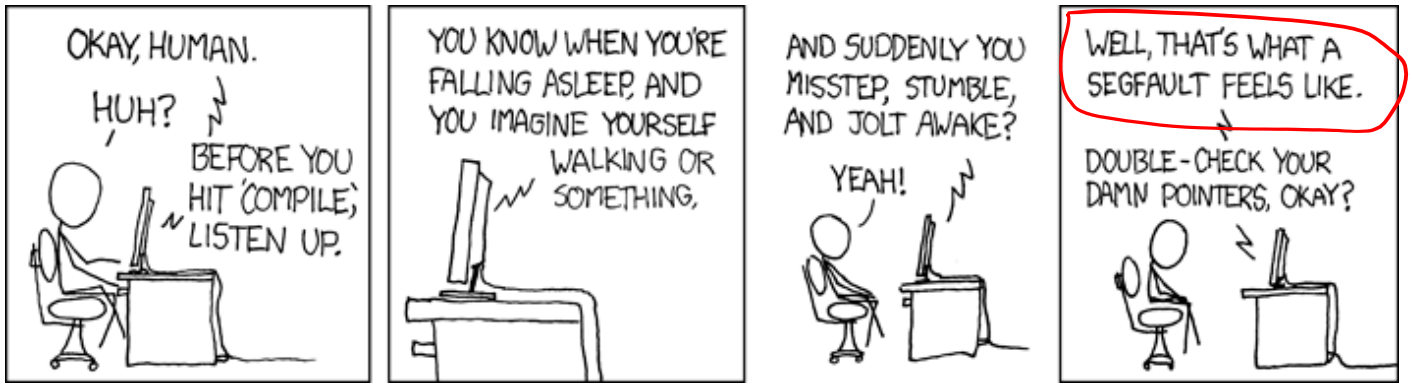
Memory, Data, & Addressing II

CSE 351 Winter 2017

hi! happy Monday!



http://xkcd.com/371/

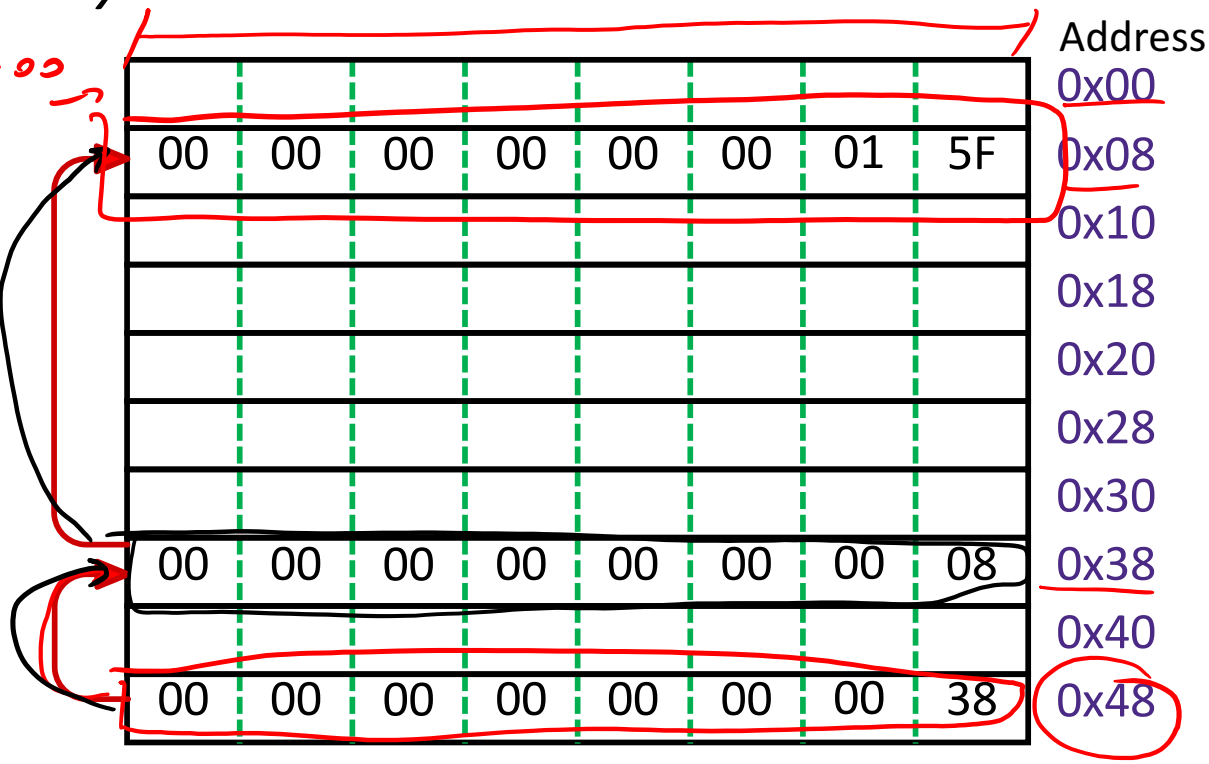
Administrivia

- Lab 0 due tomorrow @ 5pm
  - Credit/no credit – we'll talk about topics in depth later
- Lab 1 released later today @ 5pm
- Survey results:
  - More detail how computers work, learn C, get a CE/CS major ☺
  - People from most continents!

Review

64-bit example
(pointers are 64-bits wide)

- An *address* is a location in memory
- A *pointer* is a data object that holds an address
  - Address can point to *any* data
- Pointer stored at 0x48 points to address 0x38
  - Pointer to a pointer!
- Is the data stored at 0x08 a pointer?



Memory, Data, and Addressing

- Representing information as bits and bytes
- Organizing and addressing data in memory
- Manipulating data in memory using C
- Boolean algebra and bit-level manipulations

Addresses and Pointers in C

- `&` = "address of" operator
- `*` = "value at address" or "dereference" operator

`*` is also used with variable declarations

```
int* ptr;
```

Declares a variable, `ptr`, that is a pointer to (i.e. holds the address of) an `int` in memory

```
int x = 5;
int y = 2;
```

Declares two variables, `x` and `y`, that hold `int`s, and sets them to 5 and 2, respectively

```
ptr = &x;
```

Sets `ptr` to the address of `x` ("`ptr` points to `x`")

```
y = 1 + *ptr;
```

"Dereference `ptr`"

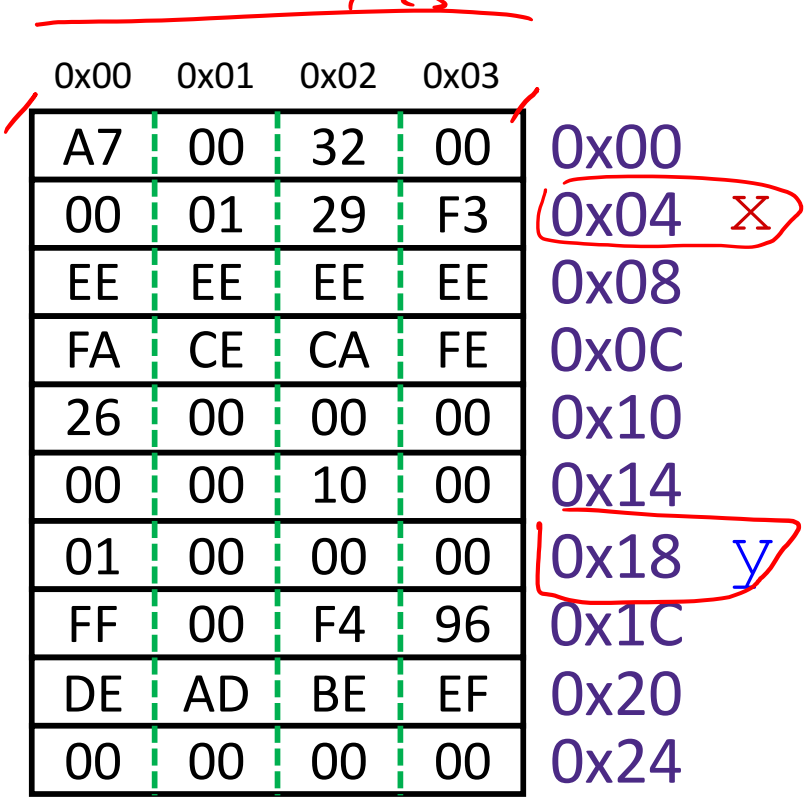
Sets `y` to "1 plus the value stored at the address held by `ptr`. Because `ptr` points to `x`, this is equivalent to `y=1+x;`

What is `*(&y)` ?

y

Assignment in C

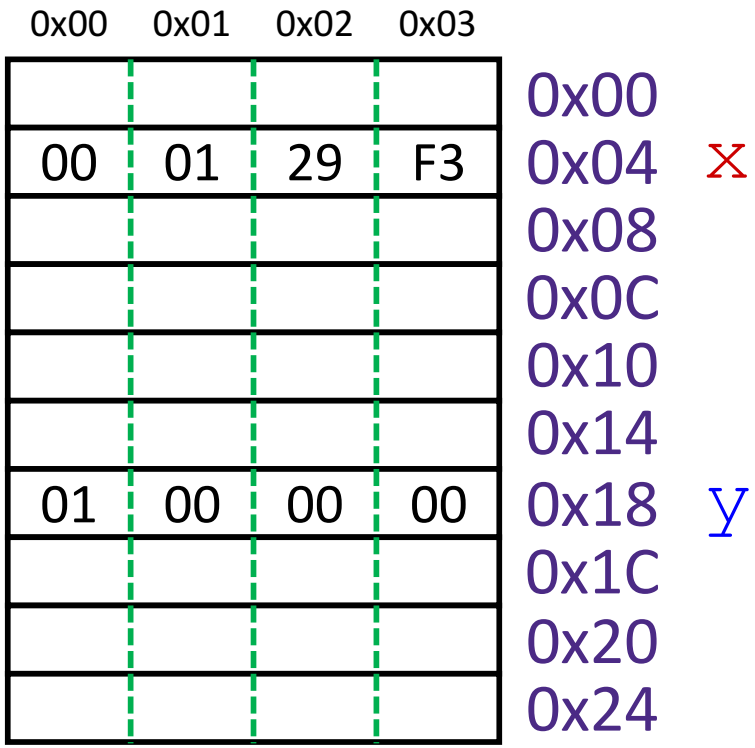
- A variable is represented by a memory location
- Declaration ≠ initialization (initially holds "garbage")
- `int x, y;`
  - `x` is at address 0x04, `y` is at 0x18



Assignment in C

32-bit example
(pointers are 32-bits wide)

- A variable is represented by a memory location
- Declaration ≠ initialization (initially holds "garbage")
- `int x, y;`
  - `x` is at address 0x04, `y` is at 0x18



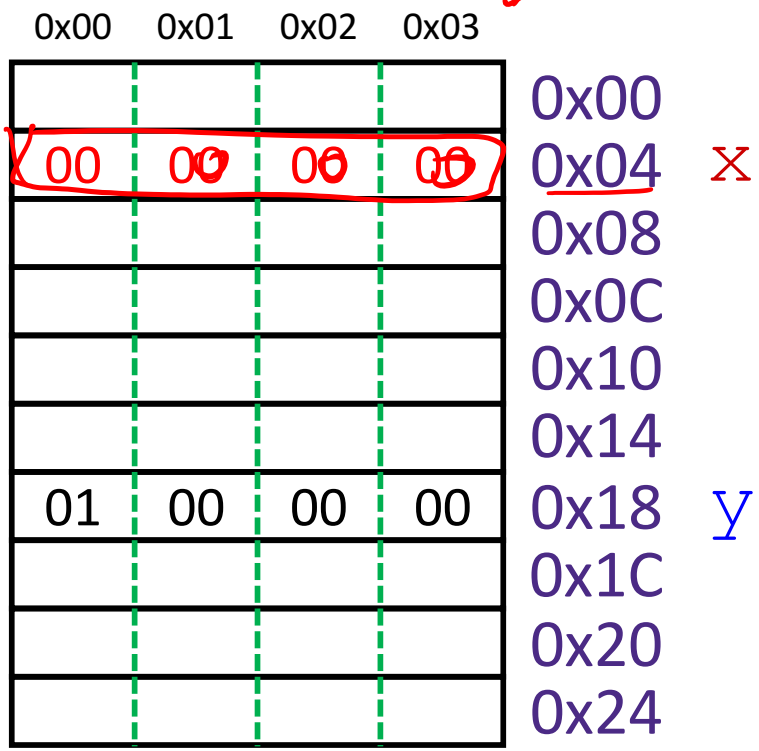
Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- left-hand side = right-hand side;
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location

- `int x, y;`
- `x = 0;`



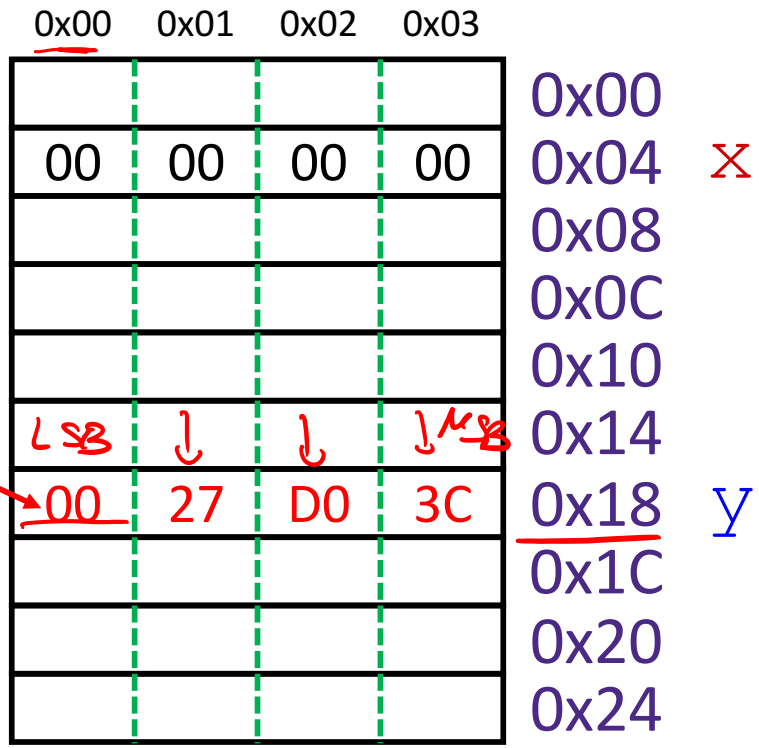
Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- left-hand side = right-hand side;
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location
- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`

little endian!

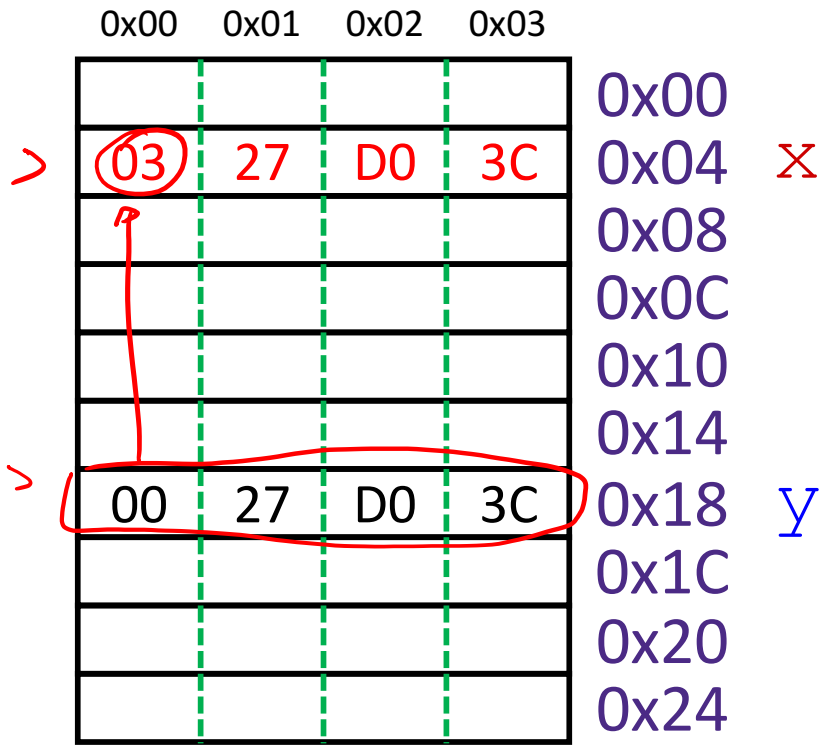


Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- left-hand side = right-hand side;
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location
- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`

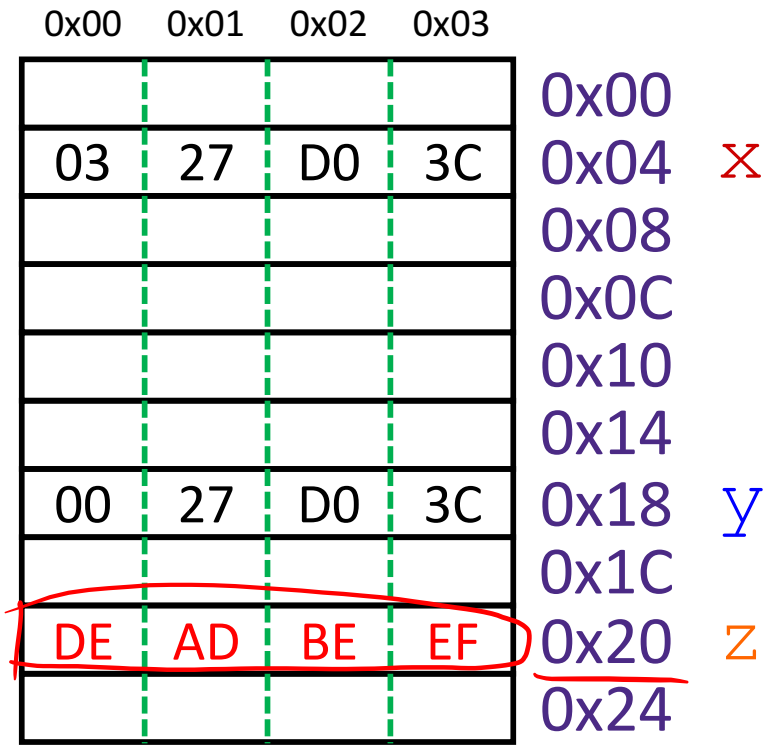


Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- left-hand side = right-hand side;
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location
- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z;`
  - `z` is at address 0x20



Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- left-hand side = right-hand side;
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location
- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z = &y + 3;`
  - Get address of `y`, "add 3", store in `z`

sizeof(int) = 4

0x00	0x01	0x02	0x03		
				0x00	
03	27	D0	3C	0x04	x
				0x08	
				0x0C	
				0x10	
				0x14	
00	27	D0	3C	0x18	y
				0x1C	
24	00	00	00	0x20	z
				0x24	

Pointer arithmetic

Pointer Arithmetic

- Pointer arithmetic is scaled by the size of target type
  - In this example, `sizeof(int)` = 4
- `int* z = &y + 3;`
  - Get address of `y`, add `3*sizeof(int)`, store in `z`
  - `&y = 0x18 = 1*16^1 + 8*16^0 = 24`
  - `24 + 3*(4) = 36 = 2*16^1 + 4*16^0 = 0x24`

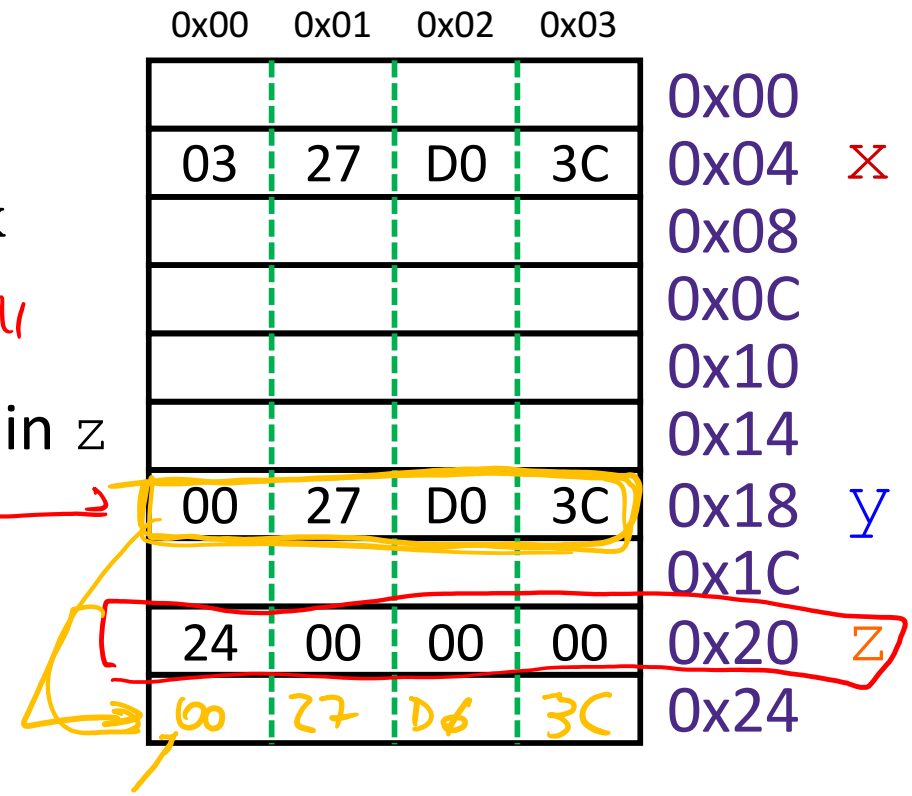
- Pointer arithmetic can be dangerous!
  - Can easily lead to bad memory accesses
  - Be careful with data types and *casting*

Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z = &y + 3;`
  - Get address of `y`, add **12**, store in `z`
- `*z = y;`
  - What does this do?



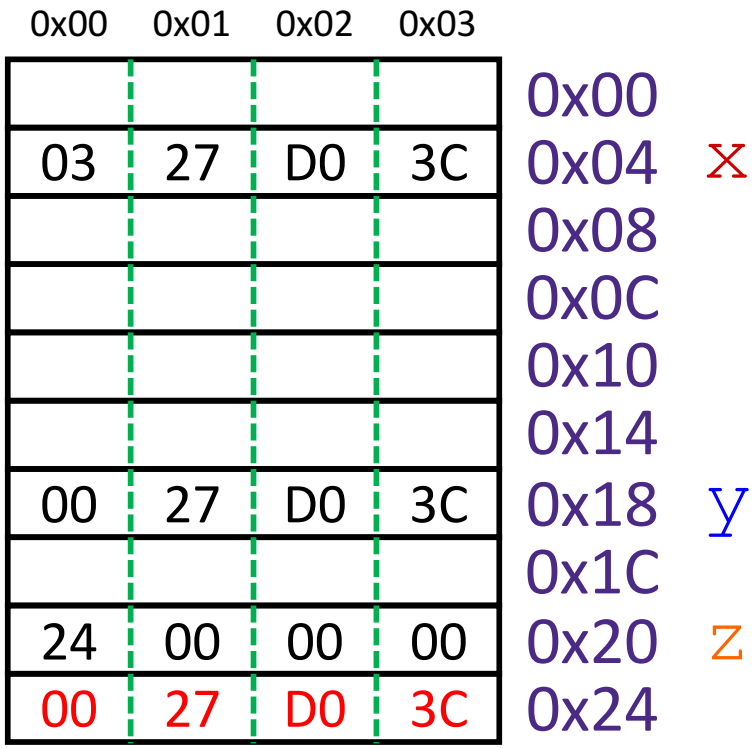
Assignment in C

32-bit example
(pointers are 32-bits wide)

& = "address of"
* = "dereference"

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z = &y + 3;`
  - Get address of `y`, add **12**, store in `z`
- `*z = y;`
  - Get value of `y`, put in address stored in `z`

The target of a pointer is also a memory location



Arrays in C

Arrays are adjacent locations in memory storing the same type of data object

a is a name for the array's address

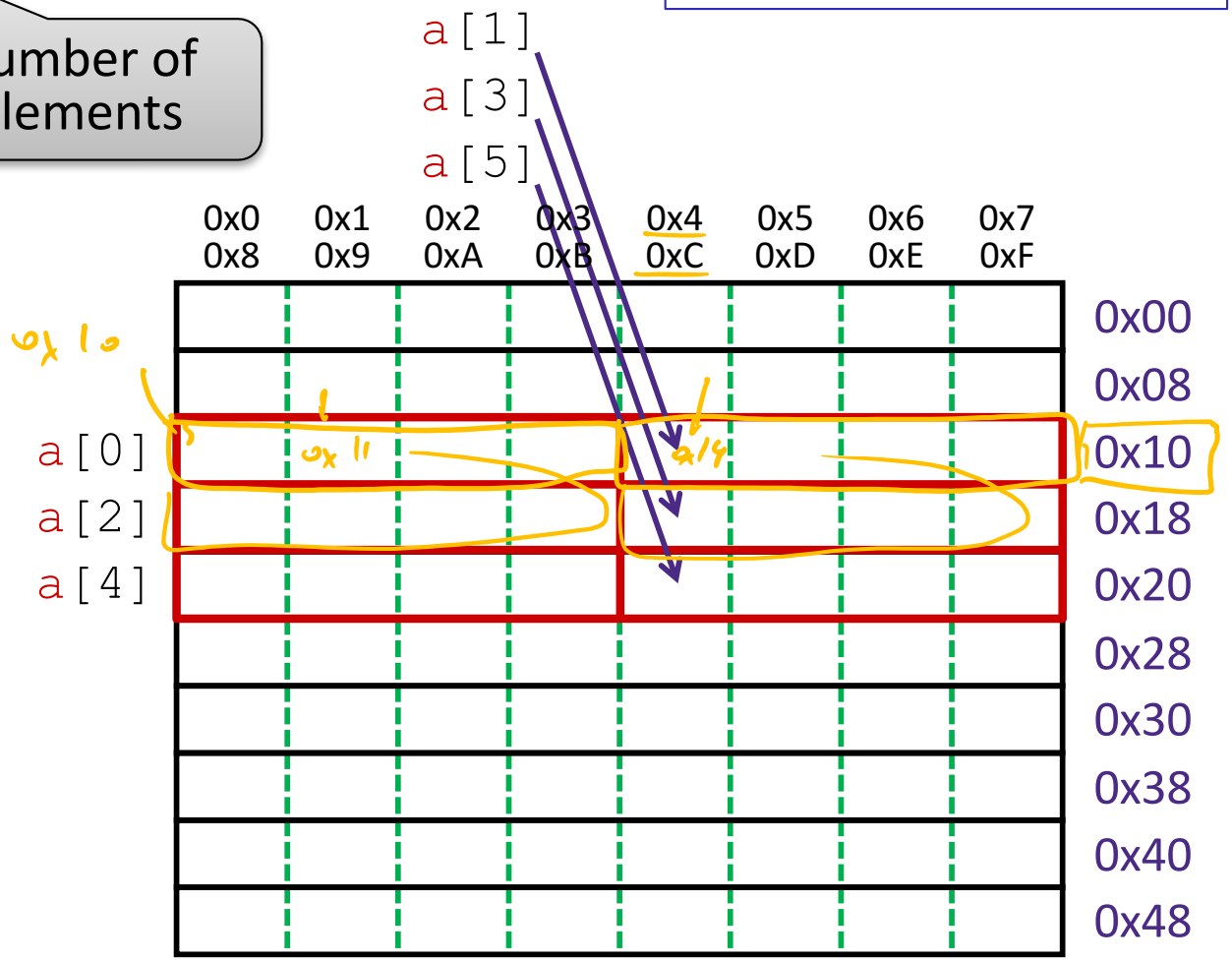
Declaration: `int a[6];`

element type

name

number of elements

64-bit example
(pointers are 64-bits wide)



Arrays in C

Declaration: `int a[6];`

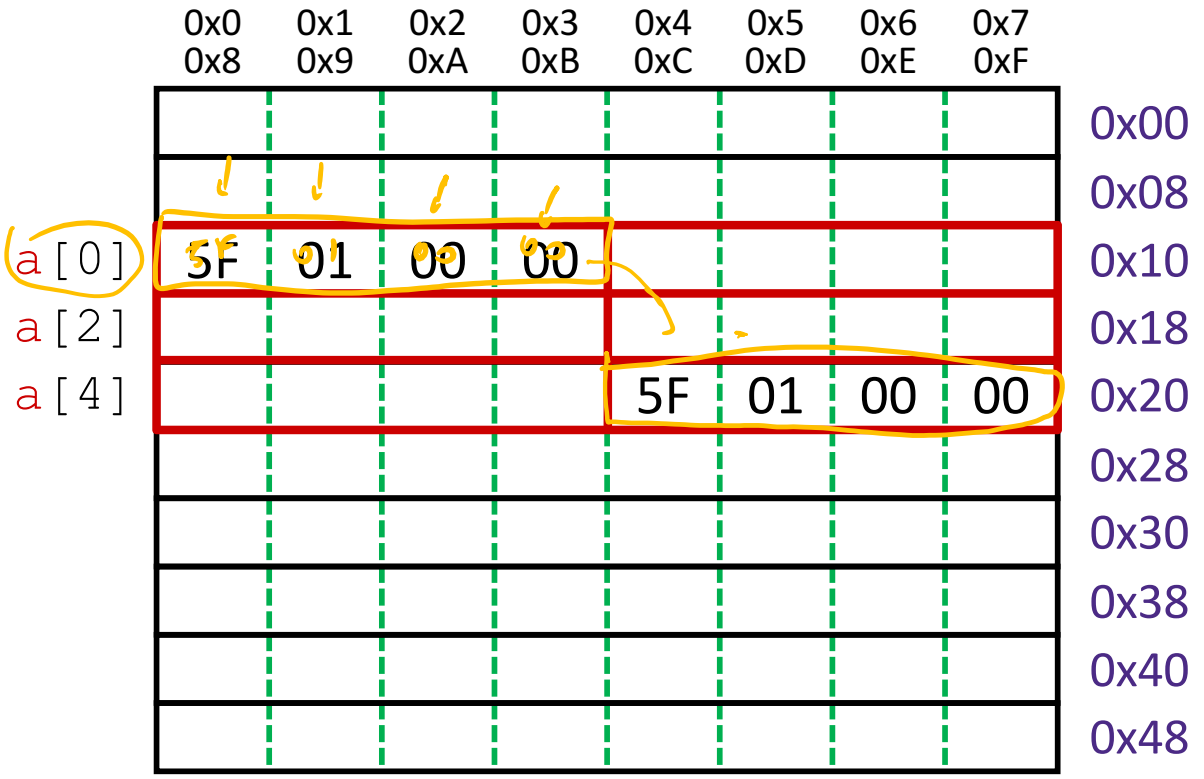
Indexing:

```
a[0] = 0x015f;
a[5] = a[0];
```

Arrays are adjacent locations in memory storing the same type of data object

`a` is a name for the array's address

The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes



Arrays in C

Declaration: `int a[6];`

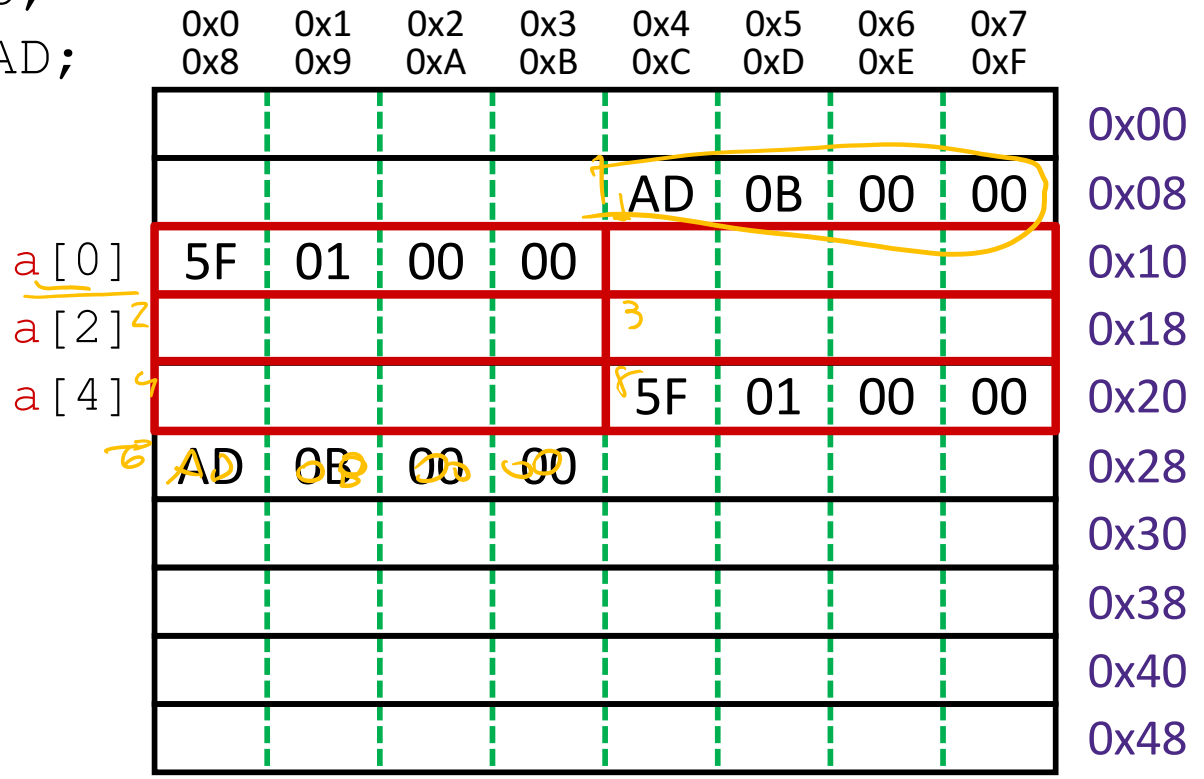
Indexing:
```
a[0] = 0x015f;
a[5] = a[0];
```

No bounds checking:
```
a[6] = 0xBAD;
a[-1] = 0xBAD;
```

Arrays are adjacent locations in memory storing the same type of data object

`a` is a name for the array's address

The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes



Arrays in C

Arrays are adjacent locations in memory storing the same type of data object

`a` is a name for the array's address

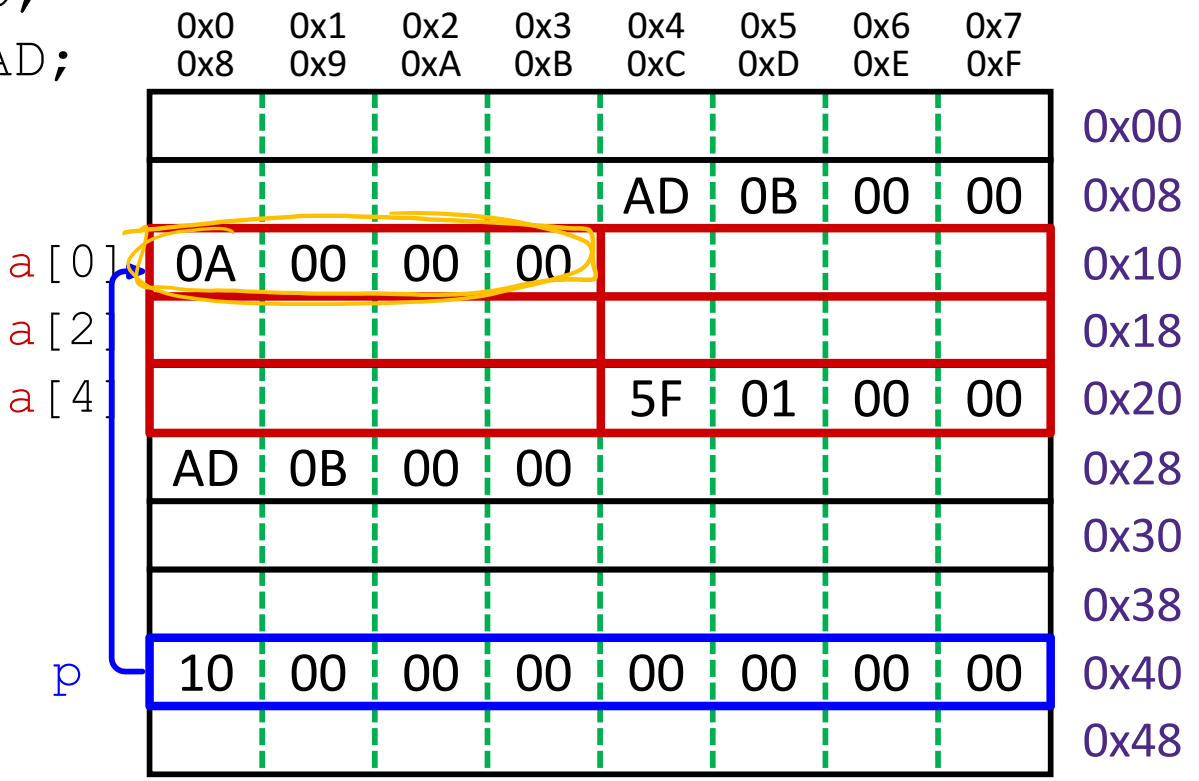
The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes

Declaration: `int a[6];`

Indexing:
```
a[0] = 0x015f;
a[5] = a[0];
```

No bounds checking:
```
a[6] = 0xBAD;
a[-1] = 0xBAD;
```

Pointers:
```
int* p;
p = a;          // equivalent
p = &a[0];      // equivalent
*p = 0xA;
```



Arrays in C

Arrays are adjacent locations in memory storing the same type of data object

`a` is a name for the array's address

The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes

Declaration: `int a[6];`

Indexing:
```
a[0] = 0x015f;
a[5] = a[0];
```

No bounds checking:
```
a[6] = 0xBAD;
a[-1] = 0xBAD;
```

Pointers: `int* p;`

equivalent:
```
p = a;
p = &a[0];
```

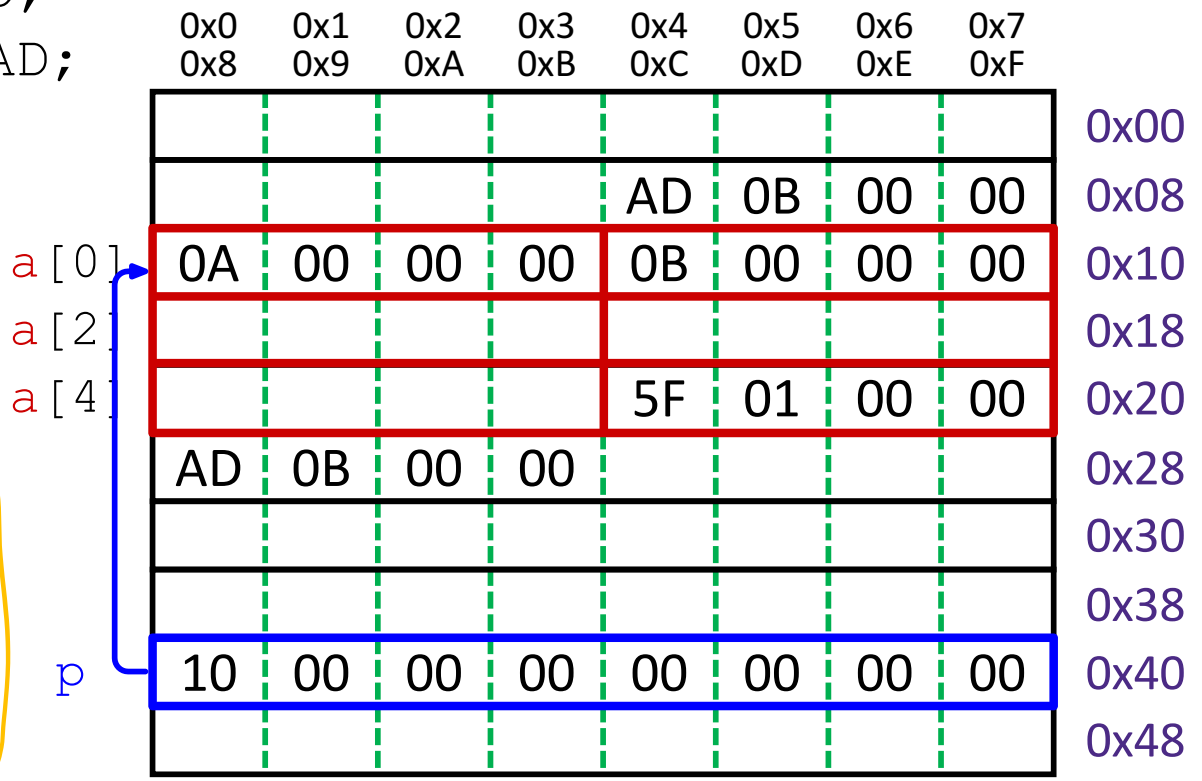
```
*p = 0xA;
```

array indexing = address arithmetic
(both scaled by the size of the type)

equivalent:
```
p[1] = 0xB;
*(p+1) = 0xB;
```

```
p = p + 2;
```

p = &a[2]



Arrays in C

Arrays are adjacent locations in memory storing the same type of data object

`a` is a name for the array's address

The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes

Declaration: `int a[6];`

Indexing:
```
a[0] = 0x015f;
a[5] = a[0];
```

No bounds checking:
```
a[6] = 0xBAD;
a[-1] = 0xBAD;
```

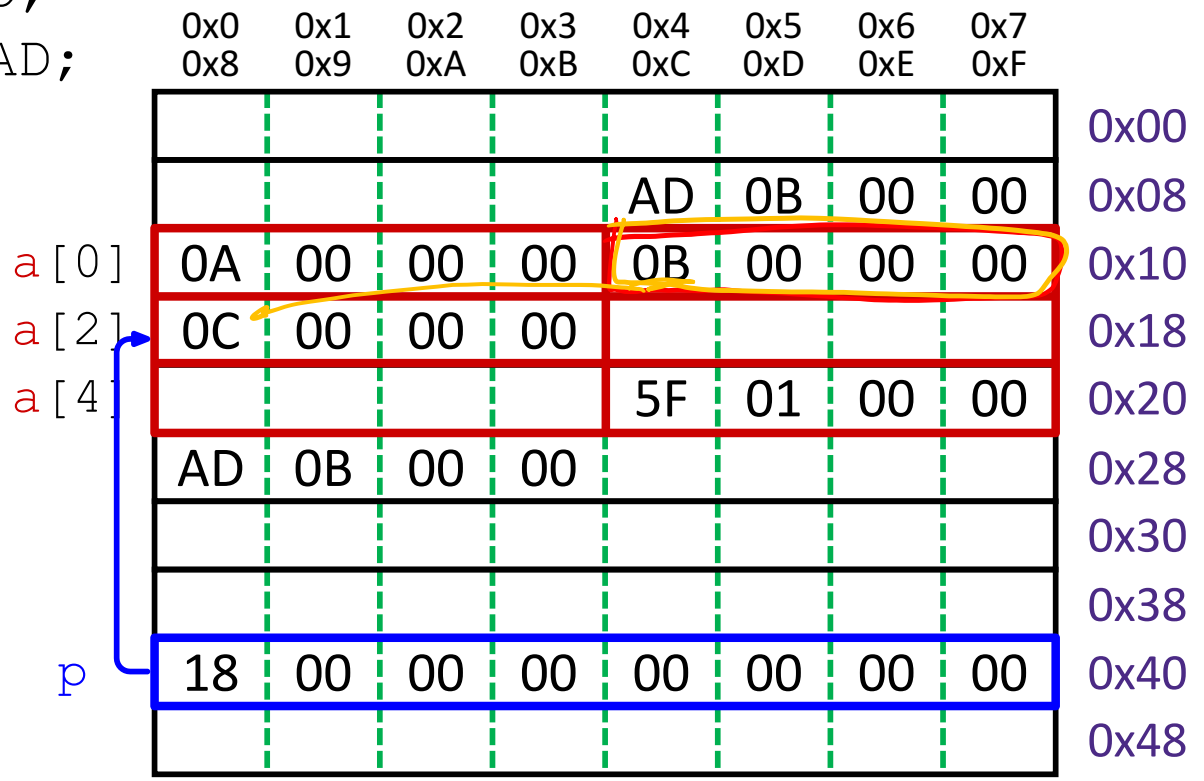
Pointers:
```
int* p;
```

equivalent:
```
p = a;
p = &a[0];
```
```
*p = 0xA;
```

array indexing = address arithmetic
(both scaled by the size of the type)

equivalent:
```
p[1] = 0xB;
*(p+1) = 0xB;
```
```
p = p + 2;
```

```
*p = a[1] + 1;
```



Representing strings

- C-style string stored as an array of bytes (`char *`)
  - Elements are one-byte ASCII codes for each character
  - No "String" keyword, unlike Java

32	space	48	0	64	@	80	P	96	`	112	p
33	!	49	1	65	A	81	Q	97	a	113	q
34	"	50	2	66	B	82	R	98	b	114	r
35	#	51	3	67	C	83	S	99	c	115	s
36	$	52	4	68	D	84	T	100	d	116	t
37	%	53	5	69	E	85	U	101	e	117	u
38	&	54	6	70	F	86	V	102	f	118	v
39	'	55	7	71	G	87	W	103	g	119	w
40	(	56	8	72	H	88	X	104	h	120	x
41	)	57	9	73	I	89	Y	105	i	121	y
42	*	58	:	74	J	90	Z	106	j	122	z
43	+	59	;	75	K	91	[	107	k	123	{
44	,	60	<	76	L	92	\	108	l	124	|
45	-	61	=	77	M	93	]	109	m	125	}
46	.	62	>	78	N	94	^	110	n	126	~
47	/	63	?	79	O	95	_	111	o	127	del

ASCII: American Standard Code for Information Interchange

Null-Terminated Strings

- **Example:** "Life is good" stored as a 13-byte array

	0	1	2	3	4	5	6	7	8	9	10	11	12
Decimal:	76	105	102	101	32	105	115	32	103	111	111	100	0
Hex:	0x4c	0x69	0x66	0x65	0x20	0x69	0x73	0x20	0x67	0x6f	0x6f	0x64	0x00
Text:	L	i	f	e		i	s		g	o	o	d	\0

- Last character followed by a 0 byte (`'\0'`) (a.k.a. "null terminator")
  - Must take into account when allocating space in memory
  - Note that `'0'` ≠ `'\0'` (i.e. character 0 has non-zero value)
- How do we compute the length of a string?
  - Traverse array until null terminator encountered

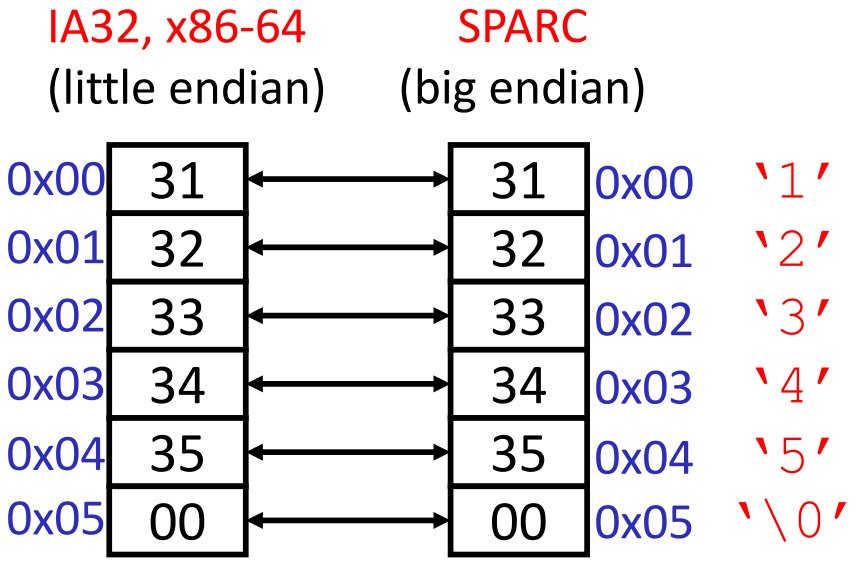
Endianness and Strings

C (char = 1 byte)

```
char s[6] = "12345";
```

String literal

0x31 = 49 decimal = ASCII '1'



- Byte ordering (endianness) is not an issue for 1-byte values
  - The whole array does not constitute a single value
  - Individual elements are values; chars are single bytes
- Unicode characters – up to 4 bytes/character
  - ASCII codes still work (just add leading zeros)
  - Unicode can support the many characters in all languages in the world
  - Java and C have libraries for Unicode (Java commonly uses 2 bytes/char)

Examining Data Representations

- Code to print byte representation of data
  - Any data type can be treated as a *byte array* by **casting** it to `char`
  - C has unchecked casts !! DANGER !!

```
void show_bytes(char* start, int len) {
   int i;
   for (i = 0; i < len; i++)
      printf("%p\t0x%.2x\n", start+i, *(start+i));
   printf("\n");
}
```

`printf` directives:

`%p`	Print pointer
`\t`	Tab
`%x`	Print value as hex
`\n`	New line

Examining Data Representations

- Code to print byte representation of data
  - Any data type can be treated as a *byte array* by **casting** it to `char`
  - C has unchecked casts !! DANGER !!

```
void show_bytes(char* start, int len) {
   int i;
   for (i = 0; i < len; i++)
      printf("%p\t0x%.2x\n", start+i, *(start+i));
   printf("\n");
}
```

```
void show_int(int x) {
   show_bytes( (char *) &x, sizeof(int));
}
```

show_bytes Execution Example

```
int a = 12345; // 0x00003039
printf("int a = 12345;\n");
show_int(a);   // show_bytes((char *) &a, sizeof(int));
```

- Result (Linux x86-64):
  - **Note:** The addresses will change on each run (try it!), but fall in same general range

```
int a = 12345;
0x7fffb7f71dbc      0x39
0x7fffb7f71dbd      0x30
0x7fffb7f71dbe      0x00
0x7fffb7f71dbf      0x00
```

Summary

- Assignment in C results in value being put in memory location
- Pointer is a C representation of a data address
  - & = "address of" operator
  - * = "value at address" or "dereference" operator
- Pointer arithmetic scales by size of target type
  - Convenient when accessing array-like structures in memory
  - Be careful when using – particularly when *casting* variables
- Arrays are adjacent locations in memory storing the same type of data object
  - Strings are null-terminated arrays of characters (ASCII)