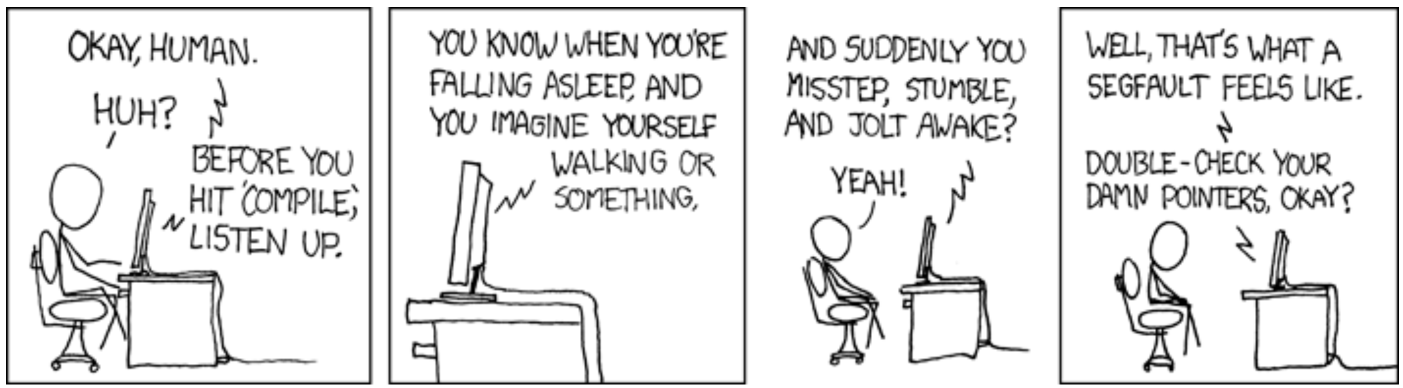
Memory, Data, & Addressing II

CSE 351 Winter 2017



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!

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

Review

- 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?

								Address
								0x00
00	00	00	00	00	00	01	5F	0x08
								0x10
								0x18
								0x20
								0x28
								0x30
00	00	00	00	00	00	00	08	0x38
								0x40
00	00	00	00	00	00	00	38	0x48

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

* is also used with variable declarations

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

```
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 ints, 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) ?

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

0x00	0x01	0x02	0x03		
A7	00	32	00	0x00	
00	01	29	F3	0x04	x
EE	EE	EE	EE	0x08	
FA	CE	CA	FE	0x0C	
26	00	00	00	0x10	
00	00	10	00	0x14	
01	00	00	00	0x18	y
FF	00	F4	96	0x1C	
DE	AD	BE	EF	0x20	
00	00	00	00	0x24	

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

0x00	0x01	0x02	0x03		
				0x00	
00	01	29	F3	0x04	x
				0x08	
				0x0C	
				0x10	
				0x14	
01	00	00	00	0x18	y
				0x1C	
				0x20	
				0x24	

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;`

0x00	0x01	0x02	0x03		
				0x00	
00	00	00	00	0x04	x
				0x08	
				0x0C	
				0x10	
				0x14	
01	00	00	00	0x18	y
				0x1C	
				0x20	
				0x24	

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(pointers are 32-bits wide)

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  - 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!

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

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`

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

Assignment in C

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- `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

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

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- `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`

Pointer arithmetic

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 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?

	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	

Assignment in C

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`*` = "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

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
00	27	D0	3C	0x24	

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

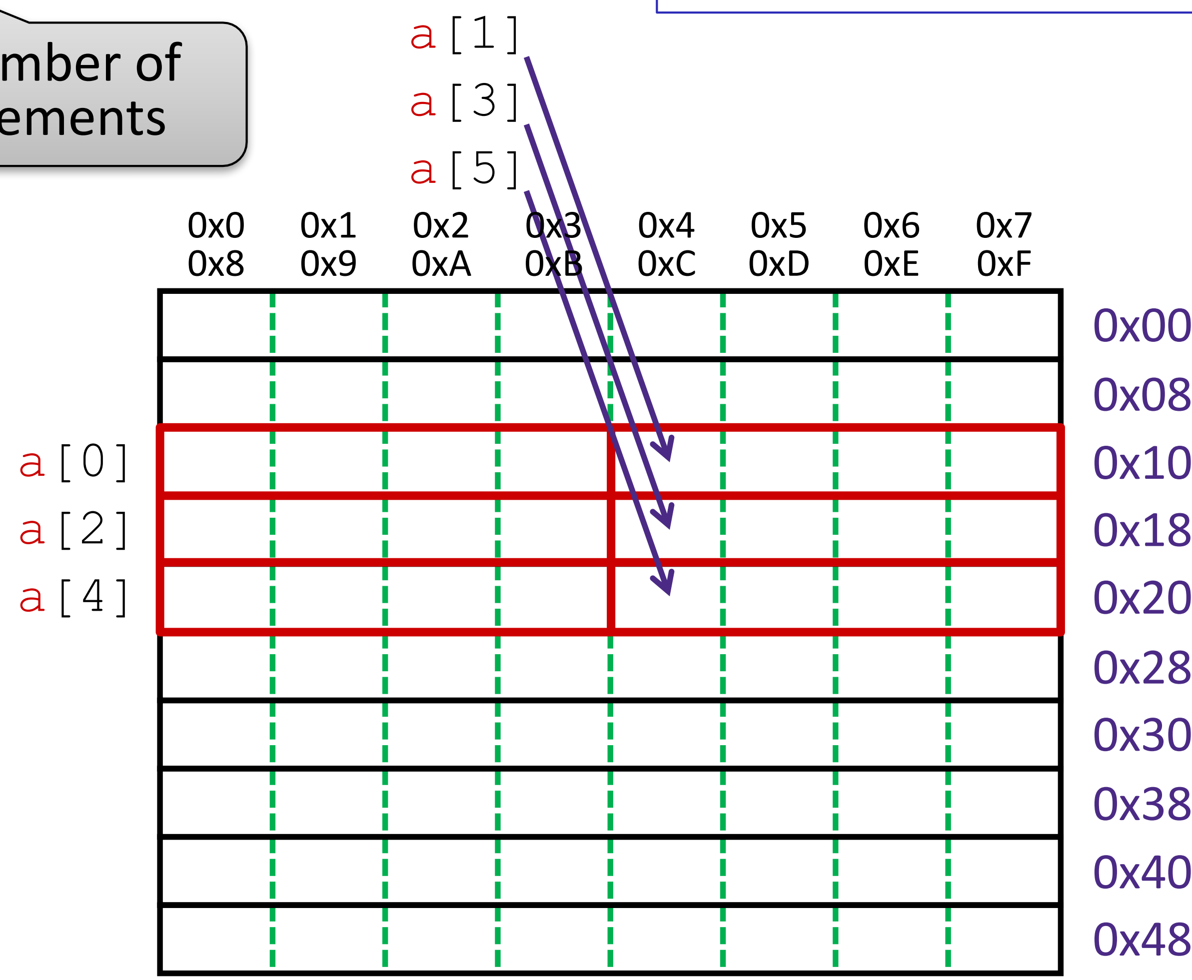
Declaration: `int a[6];`

element type

name

number of elements

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



Arrays in C

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];
```

	0x0 0x8	0x1 0x9	0x2 0xA	0x3 0xB	0x4 0xC	0x5 0xD	0x6 0xE	0x7 0xF	
									0x00
									0x08
a[0]	5F	01	00	00					0x10
a[2]									0x18
a[4]					5F	01	00	00	0x20
									0x28
									0x30
									0x38
									0x40
									0x48

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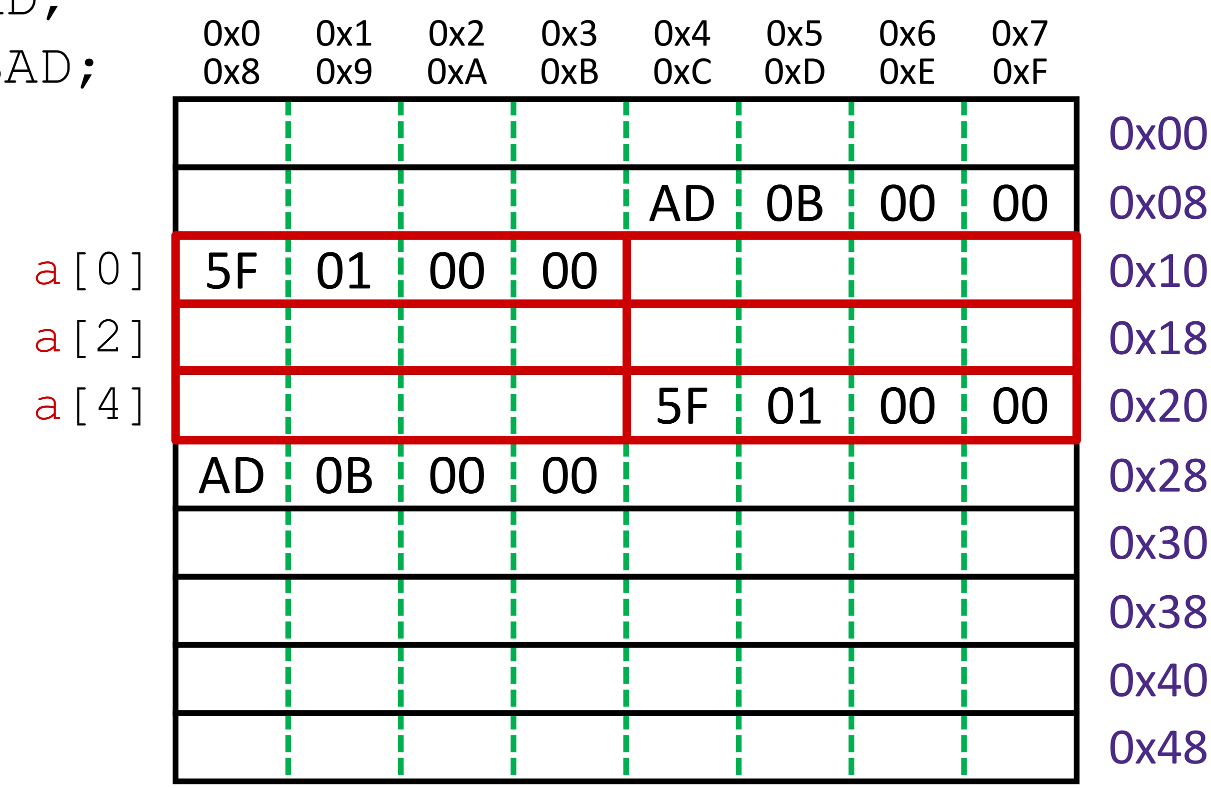
Declaration: `int a[6];`

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

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



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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;
```

	0x0 0x8	0x1 0x9	0x2 0xA	0x3 0xB	0x4 0xC	0x5 0xD	0x6 0xE	0x7 0xF	
									0x00
					AD	0B	00	00	0x08
a[0]	0A	00	00	00					0x10
a[2]									0x18
a[4]					5F	01	00	00	0x20
	AD	0B	00	00					0x28
									0x30
									0x38
p	10	00	00	00	00	00	00	00	0x40
									0x48

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a[0] = 0x015f;
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```

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;
```

	0x0 0x8	0x1 0x9	0x2 0xA	0x3 0xB	0x4 0xC	0x5 0xD	0x6 0xE	0x7 0xF	
									0x00
					AD	0B	00	00	0x08
a[0]	0A	00	00	00	0B	00	00	00	0x10
a[2]									0x18
a[4]					5F	01	00	00	0x20
	AD	0B	00	00					0x28
									0x30
									0x38
p	10	00	00	00	00	00	00	00	0x40
									0x48

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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;
```

	0x0 0x8	0x1 0x9	0x2 0xA	0x3 0xB	0x4 0xC	0x5 0xD	0x6 0xE	0x7 0xF	
									0x00
					AD	0B	00	00	0x08
a[0]	0A	00	00	00	0B	00	00	00	0x10
a[2]	0C	00	00	00					0x18
a[4]					5F	01	00	00	0x20
	AD	0B	00	00					0x28
									0x30
									0x38
p	18	00	00	00	00	00	00	00	0x40
									0x48

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

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

C (char = 1 byte)

Endianness and Strings

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

String literal

0x31 = 49 decimal = ASCII '1'

	IA32, x86-64 (little endian)	SPARC (big endian)		
0x00	31	31	0x00	'1'
0x01	32	32	0x01	'2'
0x02	33	33	0x02	'3'
0x03	34	34	0x03	'4'
0x04	35	35	0x04	'5'
0x05	00	00	0x05	'\0'

- 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

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   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)