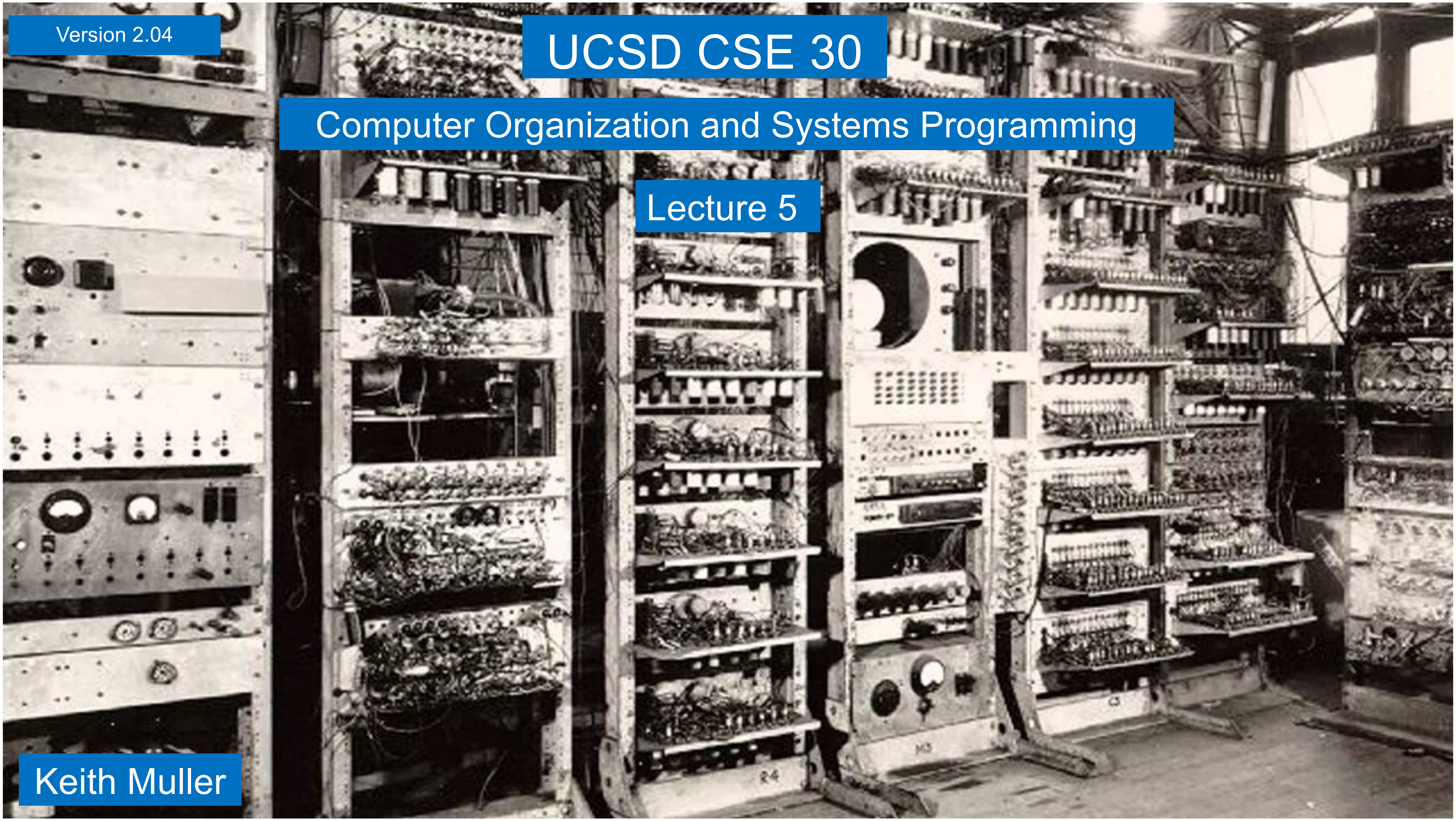
Version 2.04

UCSD CSE 30

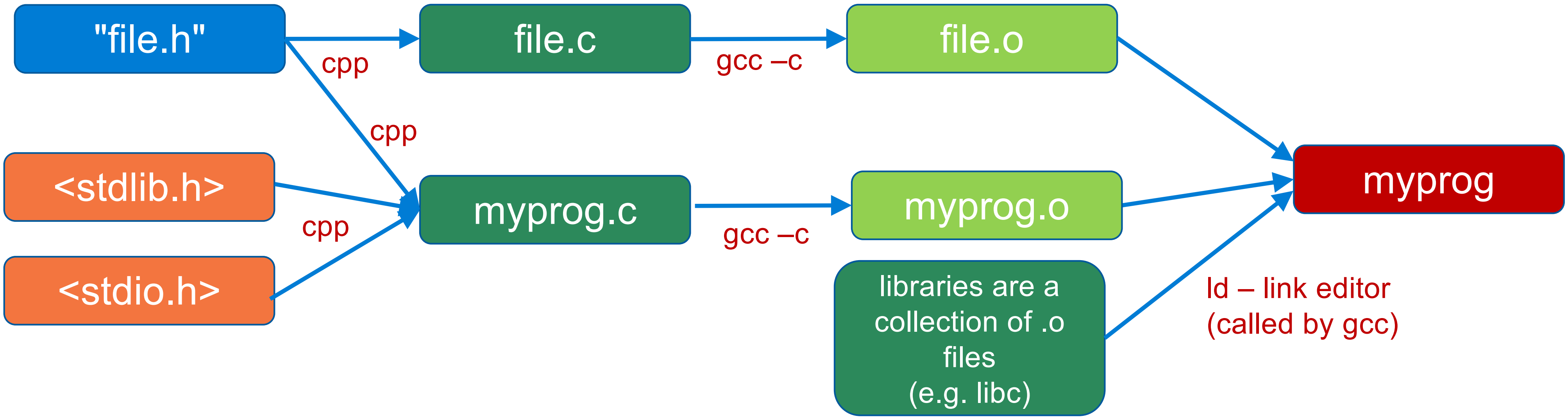
Computer Organization and Systems Programming

Lecture 5



Keith Muller

Compiling Multi-File Programs (assembly steps not shown)



1. compile each .c file independently to a .o object file this requires you use the –c flag to gcc to only compile and assemble and NOT to call the liner yet

```
gcc -Wall -Wextra -Werror -c file.c   # creates file.o
gcc -Wall -Wextra -Werror -c myprog.c   # creates myprog.o
```

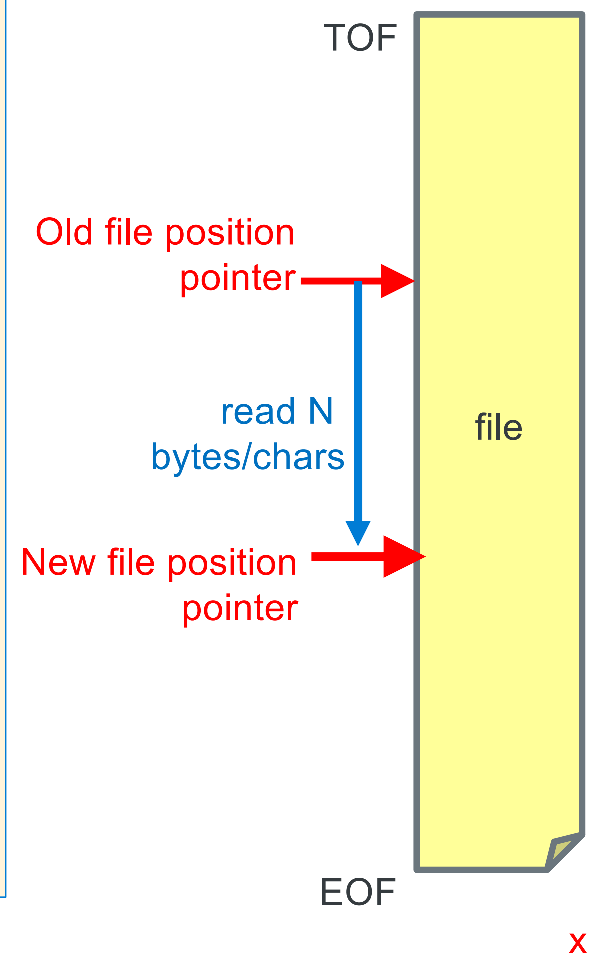
2. link all the .o objects files and libraries (aggregation of multiple .o files) to produce an executable file (gcc calls ld, the linker
   - The .o's in the libraries are automatically linked in as needed to produce an executable file

```
gcc -Wall -Wextra myprog.o file.o -o myprog
```


x

C standard I/O Library (stdio) File I/O
File Position Pointer and EOF

- Read/write functions in the standard I/O library *advances* the ***file position pointer*** from the ***top of a file*** (before the 1st byte if any) towards the ***end of the file*** **after each call** to a read/write function
  - **Side effect of call:** file position pointer moves towards the **end of file** by number of bytes read/written
- **standard I/O File position pointer** indicates where in the file (byte distance from the top of the file) the next read/write I/O will occur
- Performing a sequence of read/write operations (without using any other stdio functions to move the file pointer between the read/write calls) performs what is called **Sequential I/O** (sequential read & sequential write)
- EOF condition state may be set after a **read operation**
  - After the last byte is read in a file, additional reads results in a **function return value** of EOF
  - **EOF signals** no more data is available to be read
  - EOF is **NOT a character in the file**, but a condition state on the stream
  - EOF is usually a #define EOF -1 macro located in the file stdio.h (later in course)



C Library Function API : Simple Character I/O – Used in PA3

Operation	Usage Examples
Write a char	`int status; int c;` `status = putchar(c);          /* Writes to screen stdout */`
Read a char	`int c;` `c = getchar();                 /* Reads from keyboard stdin */`

```
#include <stdio.h>  // import the public interface
```

`int putchar(int c);`

- writes c (demoted to a char) **to** `stdout`
- returns either: c on success *OR* EOF (a macro often defined as -1) on failure
- see % man 3 putchar

`int getchar(void);`

- returns either: next input character **promoted to an int** read **from** `stdin` OR EOF
- see % man 3 getchar)

- Make sure you use int variables with putchar() and putchar()
- Both functions return an int because they must be able to return both valid chars **and** indicate the **EOF condition (**-1) which is outside the range of valid characters

x

Character I/O (Also the Primary loop in PA3)

```
// copy stdin to stdout one char at a time
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
   int c;


   while ((c = getchar()) != EOF) {
       (void)putchar(c);   // ignore return value
   }

   return EXIT_SUCCESS;
}
```

Always check return code to handle EOF
EOF is a macro integer in stdio.h

```
% ./a.out
thIS is a TeSt
thIS is a TeSt
^d
%
%./a.out < a > b
```

Typed on keyboard

Printed by program

Typed on keyboard

Copies file a to file b

Always check return codes unless you do not need it

Sometimes you may see a (void) cast which indicates ***ignoring the return value is deliberate*** this is often required by many coding standards (it is optional)

Make sure you use int variables with getchar() and putchar()!

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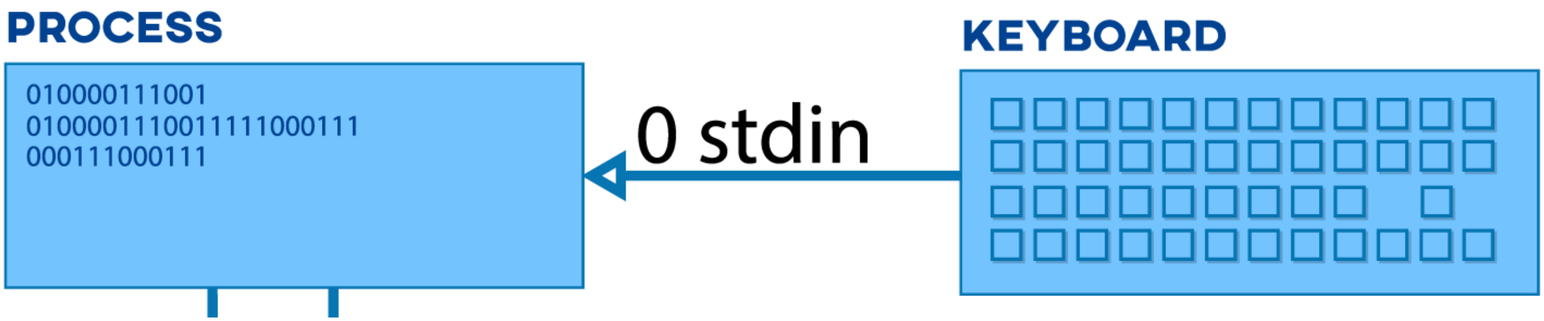
stdio File I/O – Working with a Keyboard



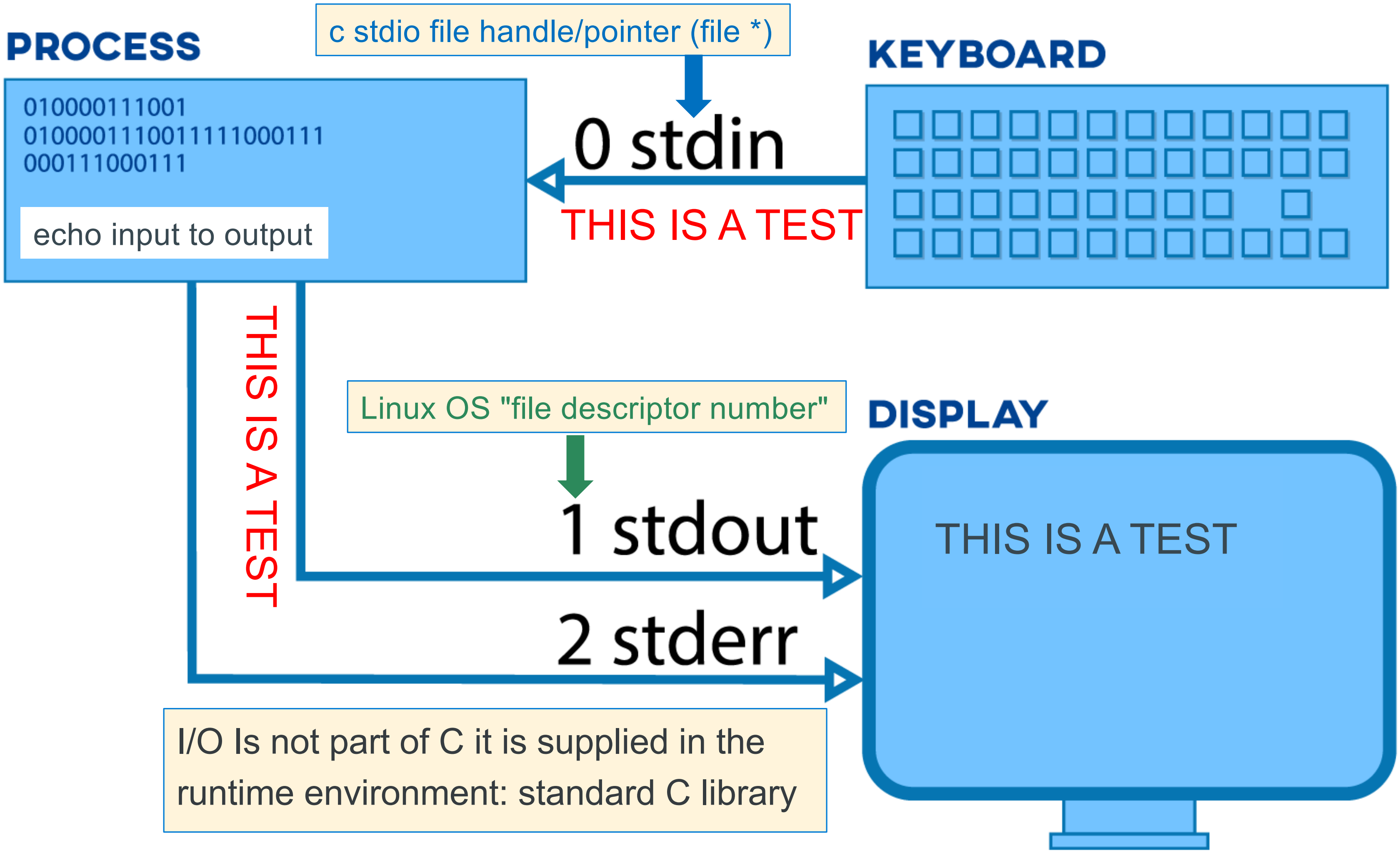
How do I signal EOF?

- How can you have an EOF **when reading from a keyboard**?
- stdio I/O library functions **designed** to work primarily on **files**
  - With keyboard devices the semantics of *file operations* needs to be *"simulated"*
- Example: when a program (or a shell) is reading the keyboard and is blocked waiting for input it is waiting for you to type a line
  - **This is NOT an EOF condition**
- To set an *EOF condition from the keyboard,* type on an input line all by itself:

  *two key combination (**ctrl key** and the **d key** at same time),* **followed by a return/enter**

  `ctrl-d` *`often shown in slides etc. as`* ***`^d`***

Linux/Unix Process and Standard I/O (CSE 15L)



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C Library Function: Simple Formatted Printing

Task	Example Function Calls

Write formatted data	`int status;`
	`status = fprintf(stderr, "%d\n", i);`
	`status = printf("%d\n", i);      /* Writes to stdout */`

```
#include <stdio.h>  // import the public interface

int fprintf(FILE *file, const char *format, ...);
```

- Write chars to the file identified by **file** (stdout, stderr are already open)
- Convert values to chars, as directed by **format**
- Return count of chars successfully written
- **Format** is the output specifications enclosed in a "string"
- Returns a negative value if an error occurs

```
int printf(const char *format, ...); // *format - later in course
```

- Equivalent to `fprintf(stdout, format, ...);`

- Type **%** `man 3 printf` for more information on *`format`*

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Some Formatted Output Conversion Examples

- Conversion specifications example
  - **%d** conversion specifier for **int** variables
  - **%c** conversion specifier for **char** variables
  - many more conversion specifiers (online manual: `% man printf` and the textbooks)

```
int i = 10;
char z = 'i';
char a[] = " Hello\n";

printf("%c = %d,%s", z, i, a); // write to stdout
fprintf(stderr, "This is an error message to stderr\n");
```

- Output

```
i = 10, Hello
This is an error message to stderr
```


X

Conditional Statements (`if`, `while`, `do...while`, `for`)

- **C conditional test expressions**: **0 (NULL) is FALSE**, **<u>any</u> non-0 value is TRUE**
- **C comparison operators (==, !=, >, etc.) evaluate to either 0 (false) or 1 (true)**
- Legal in Java and in C:

```
i = 0;
if (i == 5)
   statement1;
else
   statement2;
```

Which statement is executed after the if statement test?

- Illegal in Java, but **legal** in C (often a typo!):

```
i = 0;
if (i = 5)
   statement1;
else
   statement2;
```

Assignment operators evaluate to the value that is assigned, so…. Which statement is executed after the if statement test?

x

Program Flow – Short Circuit or Minimal Evaluation

- In evaluation of conditional guard expressions, C uses what is called **short circuit** or **minimal** evaluation

```
if ((x == 5) || (y > 3))  // if x == 5 then y > 3 is not evaluated
```

- **Each** expression argument is evaluated **in sequence** from left to right including any side effects (modified using parenthesis), **before** (optionally) evaluating the next expression argument
- If after evaluating an argument, the value of the entire expression can be determined, then the remaining arguments are NOT evaluated *(for performance)*

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Program Flow – Short Circuit or Minimal Evaluation

```
if ((a != 0) && func(b))      // if a is 0, func(b) is not called
    do_something();
```

```
// if (((x > 0) && (c == 'Q')) evaluates to non zero (true)
// then (b == 3) is not tested

while (((x > 0) && (c == 'Q')) || (b == 3)) {  // c short circuit
    x = x / 2;
    if (x == 0) {
       return 0;
    }
}
```


x

Be Careful with the comma , sequence operator

- Sequence Operator ,

  expr1,expr2

- Evaluates *expr1* first and then *expr2* evaluates to or returns *expr2*

```
for (i = 0, j = 0; i < 10; i++, j++)
   …
```

- Unexpected results with , operator (some compilers will warn)

```
    i = 64,323;         // i = 64 (assigns first)
    i = (64, 323);      // i = 323 (value of expression)
```


x

Review: Binary Numbering

- Binary is base 2
  - *adjective:* being in a state of one of two **mutually exclusive** conditions such as **on** or off, true or false, molten or frozen, presence or absence of a signal
  - From Late Latin *bīnārius* ("consisting of two")
- Two symbols:

  0 1
- Numbers in C that start with 0b are binary
- Example: What is 0b110 in base 10?
  - 0b110 = $110_2 = (1 \times 2^2) + (1 \times 2^1) + (0 \times 2^0) = 6_{10}$

powers of two

- A **bit** is a single binary digit
- A **byte** is an 8-bit value

$$Unsigned\ binary\ Number = \sum_{i=0}^{i=n-1} b_i\ x\ 2^i = b_{n-1}2^{N-1} + b_{n-2}2^{N-2} + \ldots + b_1 2^1 + b_0 2^0$$

x

Review: Hexadecimal Numbering

- hexadecimal is base 16
  - From “hexa” (Ancient Greek ἑξα-) ⇒ six
  - and from “decem” (Latin) ⇒ ten
- Sixteen symbols

  0 1 2 3 4 5 6 7 8 9 a b c d e f

- Numbers in C that start with 0x are hexadecimal numbers
  - **16_{10}** = $0x10_{16}$
- Example: What is 0xa5 in base 10?
  - 0xa5 = $a5_{16}$ = $(10 \times 16^{1}) + (5 \times 16^{0}) = 165_{10}$
- Hexadecimal numbers are very commonly used in programming to express binary values
  - Imagine the difficulty in correctly expressing a 64-bit binary value in your code

$$Unsigned\ Hex\ Number = \sum_{i=0}^{i=n-1} b_i\ x\ 16^i = b_{n-1}16^{N-1} + b_{n-2}16^{N-2} + \ldots + b_1 16^1 + b_0 16^0$$

x

Binary <---> Hexadecimal Equivalences

- Hex → Binary: $16^1 = 2^4$ 1 digit hex = 4 digits binary
  1. Replace hex digits with binary digits
  2. Drop leading zeros
  - Example: 0x2d to binary
    - 0x2 is 0b00**10,** 0xd is 0b1101
    - Drop two leading zeros, answer is 0b**10**1101
- Binary → Hex: $2^4 = 16^1$
  1. **Pad** with enough leading zeros until number of digits is a multiple of 4
  2. **Replace** each **group of 4** with the **HEX equivalent**
  - Example: 0b101101
    - **Pad on the left** to: 0b 0010 1101
    - Replace to get: 0x2d

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Number Base Overview (as written in C)

- Decimal is base 10 and Hexadecimal is base 16,
- **Hex digits** have 16 values 0 - 9 a - f (written in C as 0x0 – 0xf)
- No standard prefix in C for binary (most use hex)
  - gcc (compiler) allows 0b prefix others might not

Hex digit	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
Decimal value	0	1	2	3	4	5	6	7
Binary value	0b0000	0b0001	0b0010	0b0011	0b0100	0b0101	0b0110	0b0111

Hex digit	0x8	0x9	0xa	0xb	0xc	0xd	0xe	0xf
Decimal value	8	9	10	11	12	13	14	15
Binary value	0b1000	0b1001	0b1010	0b1011	0b1100	0b1101	0b1110	0b1111

x

Hex to Binary (group 4 bits per digit from the right)

- Each Hex digit is 4 bits in base 2 $16^1 = 2^4$

$$0x\ \ \underbrace{1111}_{f}\ \ \underbrace{1010}_{a}\ \ \underbrace{0101}_{5}\ \ \underbrace{0011}_{3}$$

$$\boxed{0b1111101001010011}$$

binary start with a 0b in C

x

Binary to Hex (group 4 bits per digit from the right)

- 4 binary bits is one Hex digit $2^4 = 16^1$

$$0b\ \underbrace{0110}_{6}\ \underbrace{1010}_{a}\ \underbrace{0011}_{3}\ \underbrace{1111}_{f}$$

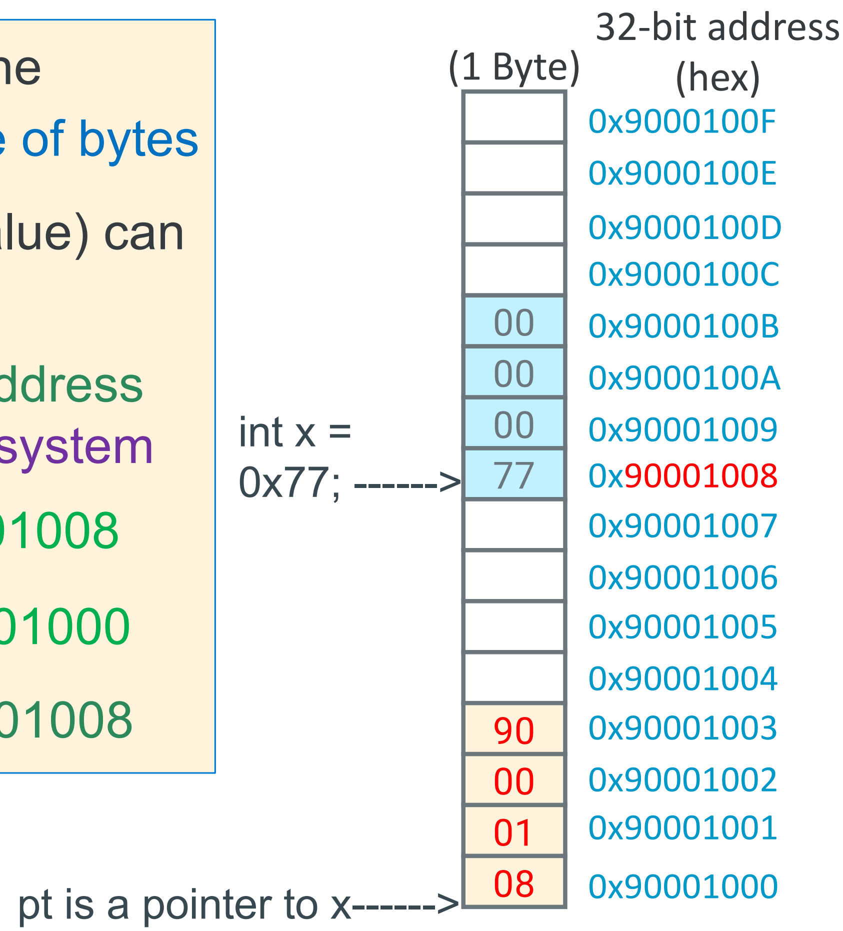
$$\boxed{0x6a3f}$$

hex start with 0x in C

x

Address and Pointers

- An address refers to a location in memory, the lowest or first byte in a contiguous sequence of bytes
- A pointer is a variable whose contents (or value) can be properly used as an address
  - The value in a pointer *should* be a valid address allocated to the process by the operating system
- The variable x is at memory address 0x90001008
- The variable pt is at memory location 0x90001000
- The contents of pt is the address of x 0x90001008



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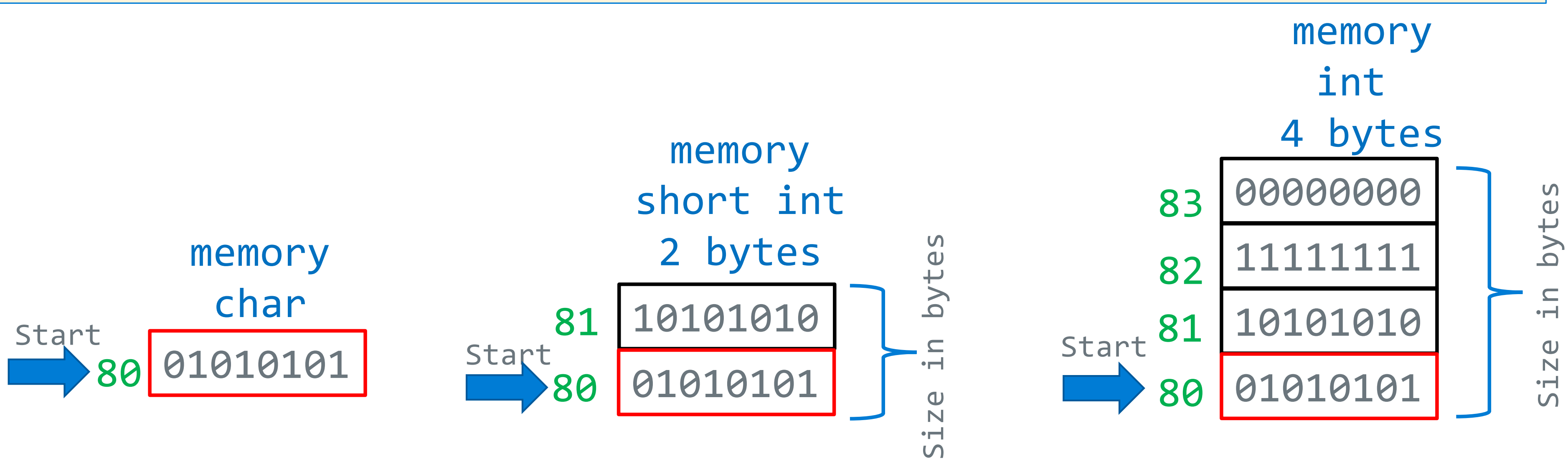
Variables in Memory: Size and Address

- The number of **contiguous bytes** a variable uses is based on the *type* of the variable
  - Different variable types require different numbers of contiguous bytes
- ***Variable names*** map to a *starting address in memory*
- Example Below: Variables all starting at address 0x80, each box is a byte



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Variables: Size

- **Integer types**
  - **`char`**, **`int`**
- **Floating Point**
  - **`float`**, **`double`**
- Modifiers for each base type
  - **`short`** [int]
  - **`long`** [int, double]
  - **`signed`** [char, int]
  - **`unsigned`** [char, int]
  - **`const`**: variable read only
- **char type**
  - One byte in a byte addressable memory
  - **Signed** vs **Unsigned** Char implementations
  - **Be careful** char is unsigned on arm and signed on other HW like intel

C Data Type	AArch-32 contiguous Bytes	AArch-64 contiguous Bytes	printf specification
char (arm unsigned)	1	1	%c
short int	2	2	%hd
unsigned short int	2	2	%hu
int	4	4	%d / %i
unsigned int	4	4	%u
long int	4	8	%ld
long long int	8	8	%lld
float	4	4	%f
double	8	8	%lf
long double	8	16	%Lf
pointer *	4	8	%p

size of a pointer is the word size

x

sizeof(): Variable Size (number of bytes) *Operator*

```
#include <stddef.h>
/* size_t type may vary by system but is always unsigned */
```

sizeof() operator returns a value of type size_t:

the number of bytes used to store a variable or variable type

```
size_t size = sizeof(variable_type);
                or
size_t size = sizeof(variable_name); // preferred!
```

- `sizeof()` is often used in an expression:

```
size = sizeof(int) * 10;
```

  - reads as:
    - number of bytes required to store **10 integers (an array of [10])**

x

Memory Addresses & Memory Content

Variable names in a C statement evaluation

```
x = x + 1;     // Lvalue = Rvalue
```

- **Lvalue:** when on the left side (Lside or Left value) of the = sign
  - address where it is stored in memory – a constant
  - **Address assigned to a variable cannot be changed at runtime**
  - Does not require a memory read
  - **Lside Must evaluate to an address**
- **Rvalue:** when on the right side (Rside or Right value) of an = sign
  - **contents or value stored** in the variable (at its memory address)
  - requires a memory read to obtain contents

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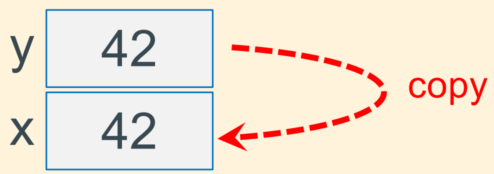
Memory Addresses & Memory Content

One memory write required

One memory read required

```
y = 42;
x = y;          // Lvalue = Rvalue
```



- **x** on left side (**Lside**) of the assignment operator = evaluates to:
  - **Address** of the memory assigned to the x – this is x's **Lvalue**
- **y** on right side (**Rside**) of the assignment operator = evaluates to:
  - **Contents** of the memory assigned to the variable y (type determines length – number of bytes) - this is y’s **Rvalue**
- So, x = y; is:

  Read memory at y (**Rvalue**); write it to memory at x's address (**Lvalue**)

x

Introduction: Address Operator: &

- Unary ***address operator*** (&) produces the **address** of where an identifier is in memory
  - Print g's assigned address

```
int main(void)
{
    int g = 42;

    printf("value of g is: %d\n", g);
    printf("address of g is: %p\n", &g);
    return EXIT_SUCCESS;
}
```

- Example this might print:

  value *of g is: 42*

  address *of g is: 0x71a0a0*

  (the address will vary)

- *Tip*: `printf()` format specifier to display an address/pointer (in hex) is "%p"

x

Introduction: Address Operator: &

- Requirement: **identifier must have a Lvalue**
  - Cannot be used with constants (e.g., 12) or expressions (e.g., x + y)
  - Example: **`&12`** does not have an *Lvalue*,
    - so, &12 is **not** a legal expression
- How can I get an address for use on the **Rside**?
  - **`&var`** (any variable identifier or name)
  - **function_name** (name of a function, not func());
    - &funct_name is equivalent
  - **array_name** (name of the array like array_name[5]);
    - &array_name is equivalent

x

Pointer Variables

- In C, there is a *variable* ***type*** for **storing an address**: a ***pointer***
  - **Contents** of a pointer is an **unsigned** (positive numbers) **memory address**

```
type *name;  // defines a pointer; name contains address of a variable of type
```

- A pointer is defined by placing a ***star (**or **asterisk) (*)*** ***before*** the identifier (name)
- You also must specify the type of variable to which the pointer points
- **Pointers are typed**! Why?
  - The compiler needs to know the size (sizeof()) of the data **you are pointing at** (number of consecutive bytes to access) to use (dereference) the pointer
- When the **Rside of a variable** contains a **memory address**, (it **evaluates** to an **address**) the variable is called a **pointer variable**

x

Pointer Variables - 2

- A pointer **cannot** point at itself, why?

```
int *p = &p; /* is not legal – type mismatch */
```

  - p is defined as (int *), a pointer to an int, **but**
  - the type of &p is (int **), a pointer to a pointer to an int
- Pointer variables all use the **same amount of memory** no matter what they point at (in all but very tiny, often old design, cpu's)

```
int *iptr;
char *cptr;

printf("iptr(%u) cptr(%u)\n", sizeof(iptr), sizeof(cptr));
```

- Above prints on a 32-raspberry pi

```
% ./example
iptr(4) cptr(4)
```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Defining Pointer Variables

- Assigning a value to a pointer:

```
int *p = &i;  /* p points at i (assign address i to p) */
```

- Is the same as writing the following definition and assignment statements

```
int *p;         /* p is defined (not initialized) */
p = &i;         /* p points at i (assign address of i to p */
```

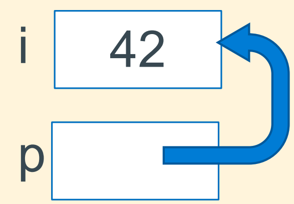
- The * is part of the definition of p and is not part of the variable name
  - The name of the variable is simply p, not *p
- C mostly ignores whitespace, so these three definitions are equivalent

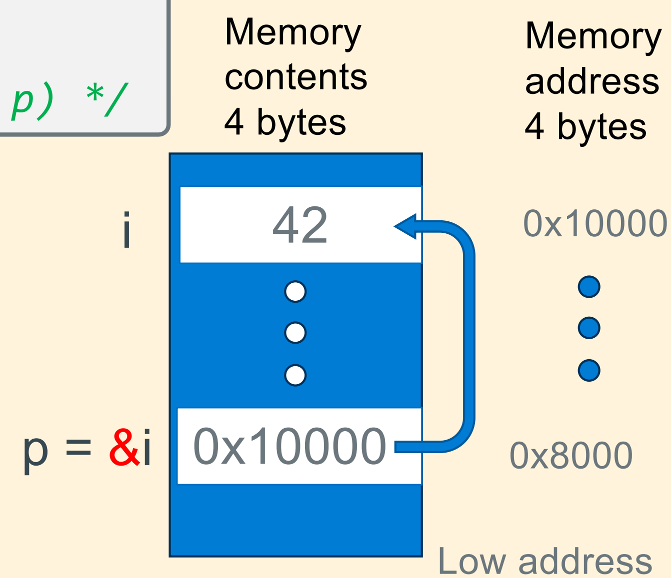
```
int  *p = &i;         /* Style A */
int * p = &i;         /* Style B */
int*  p = &i;         /* Style C */
```


X

Using Pointer Variables and the Address Operator & - 1

```
int i = 42;
int *p;  /* p contains the address of an integer */
p = &i;  /* p "points at" i (assign address of i to p) */
```





- Recommended: be careful when defining multiple pointers on the same line:

`int *p1, p2;` is not the same as: `int *p1, *p2;`

Some find this clearer instead:

```
int *p1;
int *p2;
```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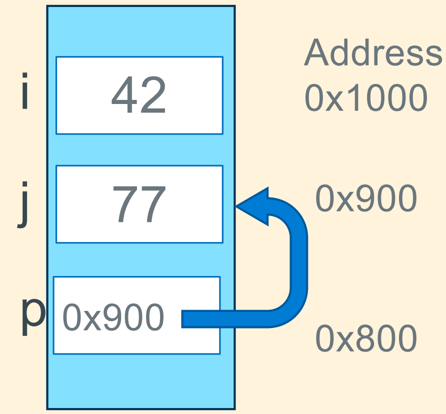
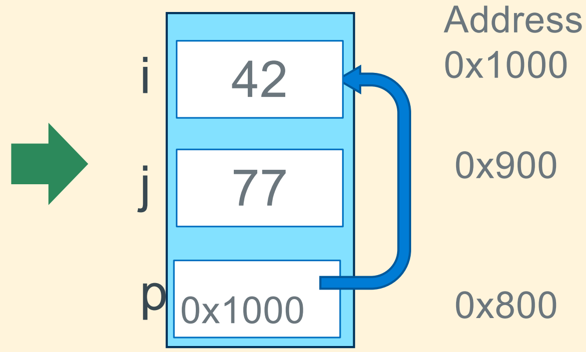
Using Pointer Variables and the Address Operator & - 2

- As with any variable, its value can be changed

```
p = &j;     /* p now points at j */
```




```
p = &i;     /* p now points at i */
```



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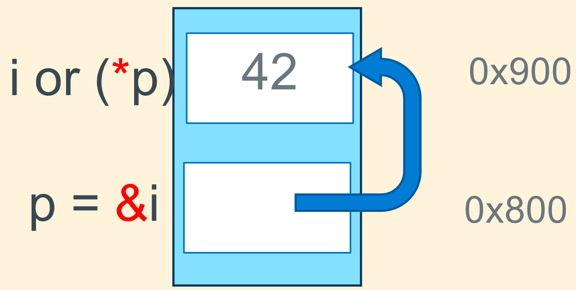
Indirection (or dereference) Operator: *

- The ***indirection operator*** (*) or the *dereference operator to a variable* is the **inverse** of the *address operator* (&)
- **address operator (&)** can be thought of as:

  "get the address of this box”"



- **indirection operator (*)** can be thought of as:

  "follow the arrow to the next box and get its contents”"

- **Indirection operator causes an additional read to occur**, when on either the Rside or Lside of a statement

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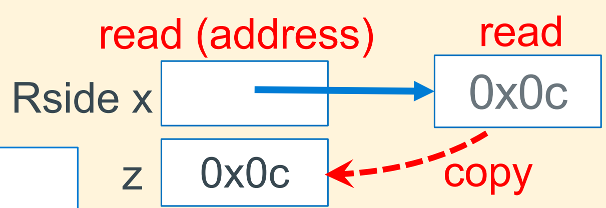
Rside Indirection (or dereference) Operator: *

- Performs the following steps when the * is on the Rside:

1. read the contents of the variable to get an address
2. **read** and return the contents at that address
   - (requires two reads of memory on the Rside)

```
z = *x; // copy the contents of memory pointed at by x to z
```



Two reads here
(1) read to get an address
(2) read the address to get
the value

x

Rside Indirection (or dereference) Operator: *

*Contents of **p** is the address of **i***

(p points at i)

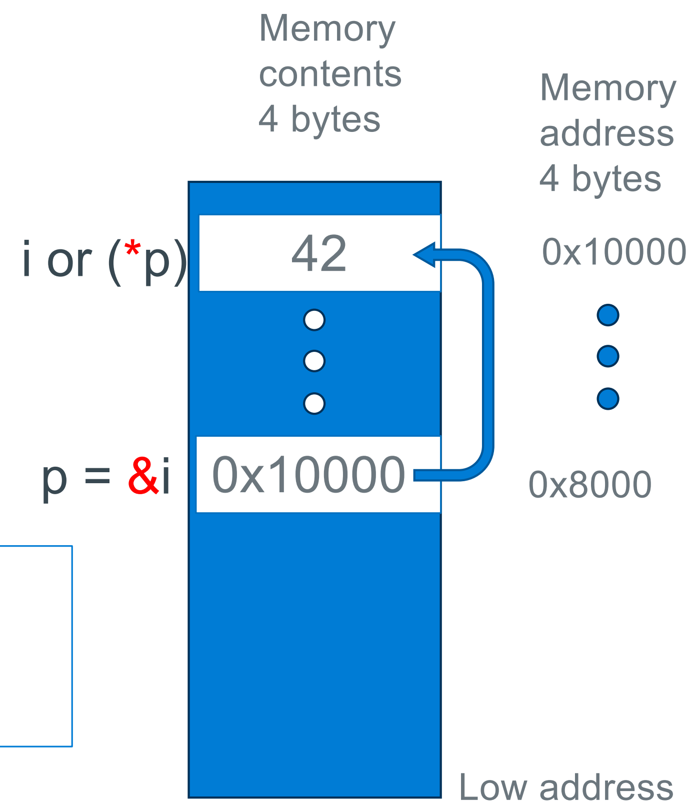
```
int i = 42;
int *p;
p = &i;
```

No reads here

```
printf("*p is %d\n", *p);
```

```
% ./a.out
*p is 42
```

Two reads here
(1) read to get an address
(2) read the address to get the value



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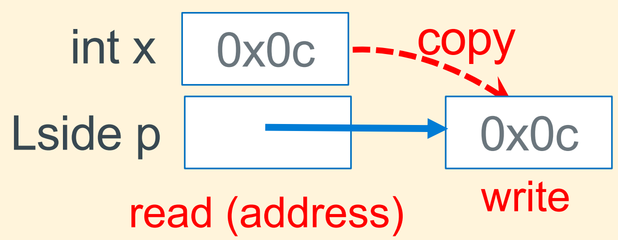
Lside Indirection Operator

Performs the following steps when the * is on the Lside:

1. read the contents of the variable to get an address
2. **write** the evaluation of the Rside expression to that address
   - (requires one read of memory and one write of memory on the Lside)

```
*p = x; // copy the value of x to the memory pointed at by p
```



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