CMPE-013/L

Introduction to “C” Programming

Maxwell James Dunne
Text I/O
Text I/O

- Within `<stdio.h>`:
  - Formatted text: `scanf()`/`printf()`
  - Characters: `getchar()`/`putchar()`
  - Strings/Lines: `fgets()`/`puts()`

  • NEVER EVER EVER USE `gets()`
Text I/O
fgets()

Syntax
char *fgets(char *str, int count, FILE *stream);

- **str** is where received data is stored
  - Needs to be an array
- **count** is how many characters to process
  - Stops when `\n` or `(count-1)` chars are received
- **stream** is `stdin`
Text I/O
fgets() example

Example

```c
#include <stdio.h>

int main(void)
{
    // Create enough memory for a 50 char string
    char inputData[50 + 1];

    fgets(inputData, sizeof(inputData), stdin);
}
```
String Processing
String Processing

- Within `<string.h>`:
  - Examination
    - Length: `strlen()`
    - Comparing: `strcmp() / strncmp()`
    - Splitting: `strtok()`
  - Manipulation
    - Copying: `strncpy()` (Don't use `strcpy()`!)
    - Appending: `strncat()`
String Processing

`strlen()`

**Syntax**

```c
size_t strlen(const char *str);
```

- `str` is the string to calculate the length of
- `size_t` can be treated as an `int`

**Examples**

```c
int x = strlen("My string"); // x = 9

char str[] = "asdf";
int y = strlen(str); // y = 4
```
String Processing

`strcmp()`

**Syntax**

```c
int strcmp(const char *s1, const char *s2);
```

- Ignores size of the strings, purely alphabetical comparison
- Return value is > 0 if `s1` alphabetically before `s2`, 0 if they're equal, < 0 if `s2` alphabetically before `s1`

**Examples**

```c
char *s1 = "apple", *s2 = "zed";
int cmpResult = strcmp(s1, s2);
if (cmpResult > 0) {
    printf("apple > zed\n");
} else if (cmpResult == 0) {
    printf("apple == zed\n");
} else {
    printf("apple < zed\n");
}
```
String Processing

strtok()

**Syntax**

```c
char *strtok(char *s1, const char *s2);
```

- **s1** (input/output), string to be tokenized
  - Will be modified!
- **s2** (input) – Delimiters

**Examples**

```c
char s1[] = "This is an example!";
char *firstToken = strtok(s1, " "); // firstToken = "This"
char *secondToken = strtok(NULL, " "); // secondToken = "is"
char *thirdToken = strtok(NULL, " "); // thirdToken = "an"
char *fourthToken = strtok(NULL, " "); // fourthToken = "example!"
```
Example

char s1[] = "This is an example!";
String Processing
strtok() Details

Example

```c
char s1[] = "This is an example!";
char *firstToken = strtok(s1, " ");

firstToken
s1
```

```
This is\0is an example!\0
```

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String Processing

strtok() Details

Example

```c
char s1[] = "This is an example!";
char *firstToken = strtok(s1, " ");
char *secondToken = strtok(NULL, " ");
```

```
firstToken
s1

This is an example!
```

```
secondToken
```
String Processing

strtok() Details

Example

```c
char s1[] = "This is an example!";
char *firstToken = strtok(s1, " ");
char *secondToken = strtok(NULL, " ");
char *thirdToken = strtok(NULL, " ");
```

```
This is \0 is \0 an \0 example \0
```

```
firstToken
s1
```

```
thirdToken
```

```
secondToken
```

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String Processing

`strtok()` Details

Example

```c
char s1[] = "This is an example!";
char *firstToken = strtok(s1, " ");
char *secondToken = strtok(NULL, " ");
char *thirdToken = strtok(NULL, " ");
char *fourthToken = strtok(NULL, " ");
```

```
This is an example!
```

```
This
```

```
is
```

```
\0 is \0 an \0 example
```

```
\0 e x a m p l e
```

```
! \0
```

```
secondToken
```

```
firstToken
```

```
thirdToken
```

```
fourthToken
```
String Processing

`strncpy()`

**Syntax**

```
char *strncpy(char *s1, const char *s2, size_t n);
```

- **s1** (output) – where the string will be copied to
- **s2** (input) - the string that to be copied
- **n** - how many characters can be copied
- Undefined if s1 and s2 overlap!

**Examples**

```c
char s1[50];
strncpy(s1, "asdf", 4); // s1 = "asdf\0"
strncpy(s1 + strlen(s1), "asdf", 4); // s1 = "asdfasdf\0"
```
String Processing

strncat()

Syntax

`char *strncat(char *s1, const char *s2, size_t n);`

- `s1` (input/output) - is the base string
- `s2` (input) - the string that will be appended
- `n` - how many characters can be appended
- Undefined if `s1` and `s2` overlap!

Examples

```c
char s1[50] = "This is an example!";
strncat(s1, "asdf", 4);
```
String Processing

• Within `<stdlib.h>`:
  – Conversion
    • Integer: `atoi()`, `xtoi()`
    • Floats: `atof()`

• Within `<stdio.h>`:
  – Conversion
    • Any: `sscanf()`
String Processing

`atof()`

**Syntax**

```c
double atof(const char *s);
```

- `s` (input) – The string to parse
- Returns the converted value or 0.0

**Examples**

```c
char s1[] = "1.03";
double x = atof(s); // y = 1.03

char s2[] = "efg";
double y = atof(s); // y = 0.0
```
4 + 9.11 + 3.14 / *

char * token = strtok("\n", "");
if (token)
    token = strtok(NULL);
Pointers

Pointers and memory
Pointer/array equivalency
Pointer arithmetic
Pointers and the stack
Pointers and strings
Arrays of pointers
Pointers
Address versus value

- In some situations, we will want to work with a variable's address in memory, rather than the value it contains...

Variable name from C code: `int x;`

Value of variable: $0x0123$

Address of variable $x$: $0x0804$
Pointers
What are pointers?

- A pointer holds the address of another variable or function
Pointers

What do they do?

- A pointer allows us to indirectly access a variable (just like indirect addressing in assembly language)
Pointers

Why would I want to do that?

• Pointers make it possible to write a very short loop that performs the same task on a range of memory locations / variables.

Example: Data Buffer

```c
// Point to RAM buffer starting address
char *bufPtr = &buffer;

while ((DataAvailable()) && (receivedCharacter != '\0')) {
    // Read byte from UART and write it to RAM buffer
    ReadUart(bufPtr);
    // Point to next available byte in RAM buffer
    bufPtr++;
}
```
Pointers
Why would I want to do that?

Example: Data Buffer

RAM buffer allocated over a range of addresses (perhaps an array)

Pseudo-code:
(1) Point arrow to first address of buffer
(2) Write data from UART to location pointed to by arrow
(3) Move arrow to point to next address in buffer
(4) Repeat until data from UART is 0, or buffer is full (arrow points to last address of buffer)
Pointers
Where else are they used?

- Provide method to pass arguments \textit{by reference} to functions
- Provide method to pass more than one piece of information out of a function
- Another means of accessing arrays and dealing with strings
- Used in conjunction with dynamic memory allocation (creating variables at runtime)
Pointers

How to Create a Pointer Variable

Syntax

```c
type *ptrName;
```

- In the context of a declaration, the * merely indicates that the variable is a pointer
- **type** is the type of data the pointer may point to
- Pointer usually described as “a pointer to **type**”

Example

```c
int *iPtr; // Create a pointer to int
int *iPtr, x; // Create a pointer to int and an int
float *fPtr1, *fPtr2; // Create 2 float pointers
```
Pointers

Pointers and memory
Pointer/array equivalency
Pointer arithmetic
Pointers and the stack
Pointers and strings
Arrays of pointers
Pointers
How to Create a Pointer Variable

Syntax

```
type *ptrName;
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Example

```
int *iPtr; // Create a pointer to int
int *iPtr, x; // Create a pointer to int and an int
float *fPtr1, *fPtr2; // Create 2 float pointers
```
Pointers

Initialization

- To set a pointer to point to another variable, we use the \& operator (address of), and the pointer variable is used without the dereference operator *:

\[
\text{p} = \&x;
\]

- This assigns the address of the variable \(x\) to the pointer \(p\) (\(p\) now points to \(x\))

Note: \(p\) must be declared to point to the type of \(x\) (e.g., \text{int } x; \text{ int } *p;\)
Pointers
Dereferencing

- When accessing the data pointed to by a pointer, we use the pointer with the dereference operator `*`:

\[ y = \ast p; \]

- This assigns to the variable `y`, the value of what `p` is pointing to (\( x \) from the last slide)
- Using `\( \ast p \)` is the same as using the variable it points to (e.g. `x`)
**Pointers**

Dereferencing example

```
int x = 6, *p; // int and a pointer to int
p = &x;       // Assign p the address of x
*p = 5;       // Same as x = 5;
```

- `&x` is a constant memory value
  - It represents the address of `x`
  - The address of `x` will never change

- `p` is a variable pointer to int
  - It can be assigned the address of any int
  - It may be assigned a new address any time
Pointers
Dereferencing example

Example

```c
int x = 6, *p;   // int and a pointer to int
p = &x;          // Assign p the address of x
*p = 5;          // Same as x = 5;
```

- \*p represents the data pointed to by \( p \)
  - \*p may be used anywhere you would use \( x \)
  - \* is the dereference operator, also called the indirection operator
  - In the pointer declaration, the only significance of \* is to indicate that the variable is a pointer rather than an ordinary variable
Pointers

Another view

Contents of the Mailbox
(variable \( x \))

Address of Mailbox
(\&x)

Bank of Mailboxes
(memory locations)
Pointers

Another view

Contents of the Mailbox

\((x, \,*p)\)

Address of Mailbox

\((&x, \, p)\)

Bank of Mailboxes

(memory locations)

\(p = &x;\)
Pointers

Another view

Contents of the Mailbox

\((x, \*p)\)

Address of Mailbox

\((&x, p)\)

*\(p = 2;\)

Bank of Mailboxes

(memory locations)
Pointers
Dereferencing non-primitives

Example

```c
Complex x = {0.6, 1.2}, *p;
p = &x;
p->re = 5;
```

- `p->re` represents the data pointed to by `p`
  - `p->re` may be used anywhere you would use `x.re`
  - `->` is the structure dereference operator, equivalent to `(*p).re`
  - In the pointer declaration, the only significance of `*` is to indicate that the variable is a pointer rather than an ordinary variable
Pointers
Dereferencing non-primitives

Example

```c
void MyFunc(Complex *x)
{
    Complex t = *x;

    x->re /= t.re * t.re + t.im * t.im;
    x->im /= t.re * t.re + t.im * t.im;
}
```
Pointers

Dereferencing non-primitives

```
void MyFunc(Complex *x)
{
    Complex t = *x;
}
```
Pointers
Dereferencing non-primitives

void MyFunc(Complex *x)
{
  Complex t = *x;
}
Pointers
How Pointers Work

Example

```
{ int x, y; int *p; x = 0xDEAD; y = 0xBEEF; p = &x; *p = 0x0100; p = &y; *p = 0x0200; }
```
Pointers
How Pointers Work

Example

```c
{ 
    int x, y;
    int *p;
    x = 0xDEAD;
    y = 0xBEEF;
    p = &x;

    *p = 0x0100;
    p = &y;
    *p = 0x0200;
}
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x08B8</td>
<td>0000</td>
</tr>
<tr>
<td>0x08BC</td>
<td>0000</td>
</tr>
<tr>
<td>0x08C0</td>
<td>0000</td>
</tr>
<tr>
<td>0x08C4</td>
<td>0000</td>
</tr>
<tr>
<td>0x08C8</td>
<td>0000</td>
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<tr>
<td>0x08CC</td>
<td>0000</td>
</tr>
<tr>
<td>0x08D0</td>
<td>0000</td>
</tr>
<tr>
<td>0x08D4</td>
<td>0000</td>
</tr>
</tbody>
</table>

x: 0000 DEAD
y: 0000 0000
p: 0000 0000

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Pointers

How Pointers Work

Example

```c
{  
    int x, y;
    int *p;

    x = 0xDEAD;
    y = 0xBEEF;
    p = &x;

    *p = 0x0100;
    p = &y;
    *p = 0x0200;
}
```

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</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>y</td>
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</tr>
<tr>
<td>p</td>
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<td></td>
</tr>
</tbody>
</table>
```
Pointers

How Pointers Work

Example

```c
{  
    int  x, y;
    int *p;
    
    x = 0xDEADB;
    y = 0xBEEF;
    p = &x;
    
    *p = 0x0100;
    p = &y;
    *p = 0x0200;
}
```

32-bit Data Memory (RAM)

- **Address 0x08B8**: Variable `x`, value 0x0000 DEAD
- **Address 0x08BC**: Variable `y`, value 0x0000 BEEF
- **Address 0x08C0**: Pointer `p`, value 0x0000 08BC

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Example

```c
int x, y;
int *p;
x = 0xDEAD;
y = 0xBEFE;
p = &x;
*p = 0x0100;
p = &y;
*p = 0x0200;
```

32-bit Data Memory (RAM)

<table>
<thead>
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<th>y</th>
<th>p</th>
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<td>BEEF</td>
<td></td>
</tr>
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<tr>
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<td>0000</td>
<td></td>
</tr>
</tbody>
</table>

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Pointers
How Pointers Work

Example

```c
{  
    int x, y;
    int *p;
    
    x = 0xDEAD;
    y = 0xBEFEF;
    p = &x;
    
    *p = 0x0100;
    p = &y;
    *p = 0x0200;
}
```

32-bit Data Memory (RAM)

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<td>0x08D4</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>

Variable at Address
Pointers
How Pointers Work

Example

```c
{  
  int x, y;
  int *p;
  
x = 0xDEAD;
y = 0xBEER;
p = &x;
  
  *p = 0x0100;
p = &y;
  
  *p = 0x0200;
}
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0000 0000</th>
<th>0000 0100</th>
<th>0000 0200</th>
<th>0000 08C0</th>
</tr>
</thead>
<tbody>
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<td>0x08B8</td>
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<td>0000 0100</td>
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<td>0000 0000</td>
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</tbody>
</table>

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Pointers and Arrays
A Quick Reminder...

• Array elements occupy consecutive memory locations

```c
int x[3] = {1, 2, 3};
```

- Pointers can provide an alternate method for accessing array elements
Pointers and Arrays

Initializing a Pointer to an Array

- The array name evaluates to the address of its first \( 0^{th} \) element

If we declare the following array and pointer variable:

```c
int x[5] = {1, 2, 3, 4, 5};
ext *p;
```

We can initialize the pointer to point to the array using either of these methods:

```c
p = x; // Works only for arrays
p = &x[0]; // Same as the above
```
Pointers and Arrays

A Preview of Pointer Arithmetic

- Incrementing a pointer will move it to the next element of the array

```c
int x[3] = {1, 2, 3};
int *p;
p = x;
p++; // Move pointer to next element
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td>FFFF FFFF</td>
</tr>
<tr>
<td>0x0800</td>
<td>0000 0001</td>
</tr>
<tr>
<td>0x0804</td>
<td>0000 0002</td>
</tr>
<tr>
<td>0x0808</td>
<td>0000 0003</td>
</tr>
<tr>
<td>0x080C</td>
<td>FFFF FFFF</td>
</tr>
</tbody>
</table>

- More on this in just a bit...
Pointers and Arrays
A Preview of Pointer Arithmetic

- Incrementing a pointer will move it to the next element of the array

```c
int x[3] = {1, 2, 3};
int *p;
p = x;
++p;
```

32-bit Data Memory (RAM)

```
<table>
<thead>
<tr>
<th>Address</th>
<th>Data Memory</th>
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<td>0x07FC</td>
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- More on this in just a bit...
Pointers and Arrays
A Preview of Pointer Arithmetic

• Incrementing a pointer will move it to the next element of the array

```c
int x[3] = {1, 2, 3};
int *p;
p = x;
++p;
```

32-bit Data Memory (RAM)

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<tr>
<td>0x080C</td>
<td></td>
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• More on this in just a bit...
Pointer Arithmetic

Incrementing Pointers

- Incrementing or decrementing a pointer will add or subtract a multiple of the number of bytes of its base type
- If we have:

```c
float x;
float *p = &x;
++p;
```

We will the address of p incremented by 4 since a `float` occupies 4 bytes
Pointer Arithmetic

Incrementing Pointers

Example

```c
float *ptr;
ptr = &a;
++ptr;
```

Incrementing `ptr` moves it to the next sequential `float` array element (4 bytes ahead)

32-bit Data Memory Words
Pointer Arithmetic

Larger Jumps

- Adding or subtracting any other number with the pointer will change it by a multiple of the number of bytes of its type
- If we have

```c
short int x;
short int *p = &x;
p += 3;
```

We will get the address of `p` incremented by 6 since a `short int` variable occupies 2 bytes of memory.
**Pointer Arithmetic**

Larger Jumps

**Example**

```c
float *ptr;
ptr = a;
```

Adding 6 to `ptr` moves it 6 float array elements ahead (24 bytes ahead)

```c
ptr += 6;
```

16-bit Data Memory Words
Pointers

Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0.BAD0000F00D1;
```
Pointers

Pointer Arithmetic

Example

```c
{ 
    long long x[] = {1, 2, 3};
    long long *p = x;

    *p += 4;
    ++p;
    *p = 0xDEAD1234BEEF;
    ++p;
    *p = 0xF1D04321F00D;
    p -= 2;
    *p = 0.BAD0000F00D1;
}
```
Pointers

Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0.BAD0000F00D1;
```
Pointers

Pointer Arithmetic

Example

```c
{ long long x[] = {1, 2, 3};
    long long *p = x;

    *p += 4;
    ++p;
    *p = 0xDEAD1234BEEF;
    ++p;
    *p = 0xF1D04321F00D;
    p -= 2;
    *p = 0xBAD0000F00D1;
}
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0800</td>
<td>0000 0005</td>
</tr>
<tr>
<td>0x0804</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0808</td>
<td>1234 BEEF</td>
</tr>
<tr>
<td>0x080C</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0810</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0814</td>
<td>0000 0003</td>
</tr>
<tr>
<td>0x0818</td>
<td>0000 0808</td>
</tr>
</tbody>
</table>

Maxwell James Dunne
Pointers

Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0.BAD0000F00D1;
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32-bit Data Memory (RAM)

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<th>0x0810</th>
<th>0x0814</th>
<th>0x0818</th>
</tr>
</thead>
<tbody>
<tr>
<td>x[0]</td>
<td>0000 0000</td>
<td>0000 0005</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0x1234</td>
<td>BEEF</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>x[1]</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>1234</td>
<td>BEEF</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>x[2]</td>
<td>0000 0003</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000</td>
<td>0810</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>
```

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Pointers

Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0.BAD0000F00D1;
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32-bit Data Memory (RAM)

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</tr>
</thead>
<tbody>
<tr>
<td>x[0]</td>
<td>0000 0000</td>
<td>0000 0005</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>1234 BEEF</td>
<td>0000 DEAD</td>
<td>4321 F00D</td>
<td>0000 F1D0</td>
</tr>
<tr>
<td>x[1]</td>
<td></td>
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<tr>
<td>x[2]</td>
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<tr>
<td>p</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0810</td>
</tr>
</tbody>
</table>
```
Pointers
Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0.BAD0000F00D1;
```
Pointers

Pointer Arithmetic

Example

```c
long long x[] = {1, 2, 3};
long long *p = x;

*p += 4;
++p;
*p = 0xDEAD1234BEEF;
++p;
*p = 0xF1D04321F00D;
p -= 2;
*p = 0xBAD0000F00D1;
```
Pointers

Post-Increment/Decrement Syntax Rule

- Care must be taken with respect to operator precedence when doing pointer arithmetic:

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Operation</th>
<th>Description by Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>*p++</td>
<td>Post-Increment Pointer</td>
<td>( z = *(p++) ); is equivalent to: ( z = *p; ) ( p = p + 1; )</td>
</tr>
<tr>
<td>*(p++)</td>
<td>Post-Increment data pointed to by Pointer</td>
<td>( z = (*p)++; ) is equivalent to: ( z = *p; ) ( *p = *p + 1; )</td>
</tr>
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<td>Post-Increment data pointed to by Pointer</td>
<td>( z = (*p)++; ) is equivalent to: ( z = *p; ) ( *p = *p + 1; )</td>
</tr>
</tbody>
</table>
Pointers

Post-Increment / Decrement Syntax

Example

```c
{  
    int x[3] = {1, 2, 3};
    int y;
    int *p = x;
    y = 5 + *(p++);
    y = 5 + (*p)++;
}
```

32-bit Data Memory (RAM)

Remember: *(p++) is the same as *p++
Pointers

Post-Increment / Decrement Syntax

Example

```c
{  
  int x[3] = {1, 2, 3};
  int y;
  int *p = x;
  y = 5 + *(p++);
  y = 5 + (*p)++;
}
```

32-bit Data Memory (RAM)

- `x[0]` at address `0x07FC` contains `0000 0001`
- `x[1]` at address `0x0800` contains `0000 0002`
- `x[2]` at address `0x0804` contains `0000 0003`
- `p` at address `0x0808` contains `0000 0800`
- `y` at address `0x0810` contains `0000 0006`

Remember: *(p++) is the same as *p++
Pointers

Post-Increment / Decrement Syntax

Example

```c
{  
    int x[3] = {1, 2, 3};  
    int y;  
    int *p = x;  

    y = 5 + *(p++);  
    y = 5 + (*p)++;  
}
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0800</td>
<td>0000 0001</td>
</tr>
<tr>
<td>0x0804</td>
<td>0000 0002</td>
</tr>
<tr>
<td>0x0808</td>
<td>0000 0003</td>
</tr>
<tr>
<td>0x081C</td>
<td>0000 0804</td>
</tr>
</tbody>
</table>

Remember: *(p++) is the same as *p++
Pointers
Post-Increment / Decrement Syntax

Example

```c
#include <stdio.h>

int main() {
    int x[3] = {1, 2, 3};
    int y;
    int *p = x;

    y = 5 + *(p++);
    printf("x[0] = %d\n", x[0]);
    printf("x[1] = %d\n", x[1]);
    printf("x[2] = %d\n", x[2]);

    y = 5 + (*p)++;
    printf("y = %d\n", y);
    return 0;
}
```

Remember:
* (p++) is the same as *p++

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0x07FC</th>
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<th>0x0804</th>
<th>0x0808</th>
<th>0x080C</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>0000 0000</td>
<td>0000 0001</td>
<td>0000 0002</td>
<td>0000 0003</td>
<td>0000 0007</td>
</tr>
<tr>
<td>x[0]</td>
<td>0000 0000</td>
<td>0000 0001</td>
<td>0000 0002</td>
<td>0000 0003</td>
<td>0000 0000</td>
</tr>
<tr>
<td>x[1]</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>x[2]</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>p</td>
<td>0000 0804</td>
<td>0000 0804</td>
<td>0000 0804</td>
<td>0000 0804</td>
<td>0000 0804</td>
</tr>
</tbody>
</table>

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Pointers
Post-Increment / Decrement Syntax

Example

```
{ 
    int x[3] = {1, 2, 3};
    int y;
    int *p = x;
    y = 5 + *(p++);
    y = 5 + (*p)++;
}
```

32-bit Data Memory (RAM)

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<th>0x080C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>x[0]</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>x[1]</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
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<td>0000</td>
</tr>
<tr>
<td>x[2]</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
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<td>0000</td>
</tr>
<tr>
<td>p</td>
<td>0000</td>
<td>0804</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>y</td>
<td>0000</td>
<td>0007</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
</tbody>
</table>

Remember: *(p++) is the same as *p++
## Pointers

**Pre-Increment/Decrement Syntax Rule**

- Care must be taken with respect to operator precedence when doing pointer arithmetic:

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</thead>
<tbody>
<tr>
<td><code>++*p</code></td>
<td>Pre-Increment Pointer</td>
<td><code>z = * (++p);</code> is equivalent to:</td>
</tr>
<tr>
<td><code>* (++p)</code></td>
<td>Pointer</td>
<td><code>p = p + 1;</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>z = *p;</code></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td><code>z = *p;</code></td>
</tr>
</tbody>
</table>
Pointers

Pre-Increment / Decrement Syntax

Example

```c
{ 
    int x[3] = {1, 2, 3};
    int y;
    int *p = x;
    y = 5 + *(++p);
    y = 5 + +++(*p);
}
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0000 0000</th>
<th>0000 0001</th>
<th>0000 0002</th>
<th>0000 0003</th>
<th>0000 0800</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x0800</td>
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<tr>
<td>0x0804</td>
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<td>0x0810</td>
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<td>0x0814</td>
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</tr>
<tr>
<td>0x0818</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remember:

* (++p) is the same as +++p
Pointers

Pre-Increment / Decrement Syntax

Example

```c
{  int x[3] = {1, 2, 3};  int y;
   int *p = x;
   y = 5 + *(++p);  // P points to x[1]
   y = 5 + ++(*p);  // P points to x[2]
}
```

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</tr>
<tr>
<td>0x0818</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>

Remember: * (++p) is the same as **(p)
Pointers

Pre-Increment / Decrement Syntax

```c
{  
    int x[3] = {1, 2, 3};  
    int y;  
    int *p = x;  
    y = 5 + *(++p);  
    y = 5 + ++(*p);  
}
```

Remember:  

\* (++p) is the same as **p
Pointers

Pre-Increment / Decrement Syntax

Example

```c
{  
    int x[3] = {1, 2, 3};  
    int y;  
    int *p = x;  
    y = 5 + *(++p);  
    y = 5 + ++(*p);  
}
```

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<td>0000 0001</td>
<td>0000 0003</td>
<td>0000 0003</td>
<td>0000 0804</td>
<td>0000 0007</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>

Remember: *(++p)* is the same as *+++p*
Pointers
Pre-Increment / Decrement Syntax

Example

```c
{  
    int x[3] = {1, 2, 3};  
    int y;  
    int *p = x;  
    y = 5 + *(++p);  
    // y = 5 + +*(p);  
}  
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0000 0000</th>
<th>0000 0001</th>
<th>0000 0003</th>
<th>0000 0003</th>
<th>0000 0804</th>
<th>0000 0008</th>
<th>0000 0000</th>
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</tr>
</thead>
<tbody>
<tr>
<td>x[0]</td>
<td></td>
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<td></td>
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</tr>
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<td>x[1]</td>
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</tr>
<tr>
<td>y</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remember: 
* (++p) is the same as +++p
Pointers

Pre- and Post- Increment/Decrement Summary

• The parentheses determine what gets incremented/decremented:

Modify the pointer itself

\( * (++p) \) or \( +++p \) and \( *(p++) \) or \( *p++ \)

Modify the value pointed to by the pointer

\( ++(*p) \) and \( (*p)++ \)
Pointers

Initialization Tip

• If a pointer isn't initialized to a specific address when it is created, it is a good idea to initialize it as NULL

• This will prevent it from unintentionally corrupting a memory location if it is accidentally used before it is initialized

Example

```c
int *p = NULL;
```

**NULL** is the character '\0' but **NULL** is the value of a pointer that points to nowhere
Pointers and the Stack

Beware the stack

- Memory addresses may not always be valid
- Addresses referring to the stack have a lifetime tied to that variable's scope
- Only global, static, and pointers returned by malloc() will always be valid
- You should almost never use the memory addresses of variables on the stack
Pointers and the Stack

Beware the stack

Example function

```c
int *foo(int x, int y)
{
    int z = x + (++y);
    return &z;
}
```

Example caller

```c
int *main(void)
{
    int a = 6, b = 19;
    int *c = foo(a, b);
    printf("8d\n", *c);
}
```
Pointers and the Stack

Beware the stack

Example function

```
int *foo(int x, int y)
{
    int z = x + (++y);
    return &z;
}
```

Example caller

```
int main(void)
{
    int a = 6, b = 19;
    int *c = foo(a, b);
    printf("%d\n", *c);
}
```
Pointers and the Stack

Beware the stack

Example function

```c
int *foo(int x, int y)
{
    int z = x + (++y);
    return &z;
}
```

Example caller

```c
{
    int a = 6, b = 19;
    int *c = foo(a, b);
    puts("Hey!");
    printf("%d\n", *c);
}
```
Pointers and Strings

- So far, we have worked with strings strictly as arrays of `char`
- Strings may be created and used with pointers much more elegantly

String declaration with a pointer:

```c
char *str = "PIC32MX";
```

Implementation varies depending on compiler and architecture used.
Pointers and Strings

- When initialized, a pointer to a string points to the first character:

```c
char *str = "Microchip";
```

- Increment or add an offset to the pointer to access subsequent characters.
Pointers and Strings

- Pointers may also be used to access characters via an offset:

```c
char *str = "Microchip";
*str == 'M'
*(str + 4) == 'o'
```

- Pointer always points to "base address"
  Offsets used to access subsequent chars
Pointers and Strings

Pointer versus Array: Initialization at Declaration

- Depending on variable type, part of the variable is constant

**Example: Pointer to String Constant**

```c
char *str = "PIC";
```

**Example: Character array**

```c
char str[] = "PIC";
```

The NULL character '\0' is automatically appended to strings in both cases (array must be large enough).
Pointers and Strings

Pointer versus Array: Initialization at Declaration

Example: Pointer Variable

```c
char *str1 = "PIC";
char str2[] = "PIC";
```

<table>
<thead>
<tr>
<th>RAM</th>
<th>ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>str1</td>
<td>str1</td>
</tr>
<tr>
<td>0x9D0008C0</td>
<td>0x9D0008C0</td>
</tr>
<tr>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>0xA0000FB0</td>
<td>0xA0000FB0</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>0xA0000FB4</td>
<td>0xA0000FB4</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>0xA0000FB5</td>
<td>0xA0000FB5</td>
</tr>
<tr>
<td>\0</td>
<td>\0</td>
</tr>
<tr>
<td>0xA0000FB6</td>
<td>0xA0000FB6</td>
</tr>
<tr>
<td>0xA0000FB7</td>
<td>0xA0000FB7</td>
</tr>
</tbody>
</table>

80%
Pointers and Strings

Pointer versus Array: Assignment in Code

- An entire string may be assigned to a pointer
- A character array must be assigned character by character

Example: Pointer Variable

```c
char *str;
str = "PIC";
str = "FOO";
```

Example: Array Variable

```c
char str[4];
str[0] = 'P';
str[1] = 'I';
str[2] = 'C';
str[3] = '\0';
```

Must explicitly add NUL character '\0' to array.
Pointers and Strings

Comparing Strings

• If you want to test a string for equivalence, the natural thing to do is:
  \[
  \text{if (str == "Microchip")}
  \]
  
• This is **not** correct, though it might appear to work sometimes

• This compares the address in `str` to the address of the string literal `"Microchip"

• The correct way is to use the `strcmp()` function in the standard library which compares strings character by character
Arrays of Pointers

- **Declaration**
  \[ \text{size of (char*)} = 4 \text{ bytes} \]

- An array of pointers is an ordinary array variable whose elements happen to all be pointers.

```
char *p[4];
```

- This creates an array of 4 pointers to char
  - The array `p[]` itself is like any other array
  - The elements of `p[]`, such as `p[1]`, are pointers to char
Arrays of Pointers

Array Elements are Pointers Themselves

32-bit Data Memory (RAM)

```
  p[0]  9D00 3FC0
  p[1]  9D00 3FC3
  p[2]  9D00 3FC7
  p[3]  9D00 3FCC

  0000 0000
  0000 0000
  0000 0000
  0000 0000
```

- 3FC0
  - On \0
- 3FC3
  - Off \0
- 3FC7
  - Main \0
- 3FCC
  - Aux \0
Arrays of Pointers

Initialization

• A pointer array element may be initialized just like its ordinary variable counterpart:

\[ p[0] = &x; \]

• Or, when working with strings:

\[ p[0] = "My string"; \]
Arrays of Pointers
Different from Two-dimensional Array

```
char p[4][4] = {
    "On",
    "Off",
    "Main",
    "Aux"
};
```

- This creates an two-dimensional array of chars
  - Amount of memory for every string the same
Arrays of Pointers

Array Elements are Sequential

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Memory Address</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000 0000</td>
<td>0000 6E4F</td>
</tr>
<tr>
<td>0000 6E4F</td>
<td>6666 4F00</td>
</tr>
<tr>
<td>6666 4F00</td>
<td>614D 0000</td>
</tr>
<tr>
<td>614D 0000</td>
<td>4100 6E69</td>
</tr>
<tr>
<td>4100 6E69</td>
<td>0000 7875</td>
</tr>
<tr>
<td>0000 7875</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>

Pointers:
- p[0] points to On
- p[1] points to Off
- p[2] points to Main
- p[3] points to Aux

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Arrays of Pointers

Dereferencing

• To use the value pointed to by a pointer array element, just dereference it like you would an ordinary variable:

\[ y = \ast p[0]; \]

• Using \( \ast p[0] \) is the same as using the object it points to, such as \( x \) or the string literal "My String" from the previous slide.
```c
int i = 0;
char *str[] = {"Zero", "One", "Two", "Three", "Four", "\0"};

int main(void)
{
    while(*str[i] != '\0') {
        printf("%s\n", str[i++]);
    }
    while(1);
}
```
Dynamic Memory

`malloc()`

`free()`
Dynamic Memory

Rationale

- Memory needs not known at compile time
- Memory needs to persist outside of current scope
Dynamic Memory

malloc()

Syntax

```c
void *malloc(size_t size);
```

- Request memory of **size** bytes
  - Usually returned by **sizeof** operator
- Returns valid pointer or **NULL**

Example

```c
typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
```
Stack

↓

Heap you
Dynamic Memory

malloc()'d memory

Example

typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
printf("Complex{re:%f im:%f}\n",
        x->re, x->im);
Dynamic Memory

malloc()d memory

```c
typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
x->re = 0.0;
x->im = 0.0;
printf("Complex{re:%f im:%f}\n",
      x->re, x->im);
```
Dynamic Memory

The Heap

Example

typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
Complex *x = malloc(sizeof(Complex));
Complex *x = malloc(sizeof(Complex));
Complex *x = malloc(sizeof(Complex));
Complex *x = malloc(sizeof(Complex));
Complex *x = malloc(sizeof(Complex));

NULL
Dynamic Memory
NULL pointers

Example

```c
typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
x->re = 0.0;
x->im = 0.0;
printf("Complex{re:%f im:%f}\n", x->re, x->im);
```
Dynamic Memory

NULL pointers

Example

typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
Complex y = *x;
Dynamic Memory

NULL pointers

Example

typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
if (x) {
    x->re = 0.0;
}

x->im = 0.0;
printf("Complex{re:%f im:%f}\n", x->re, x->im);
Dynamic Memory

NULL pointers

Example

typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
if (x) {
    x->re = 0.0;
    x->im = 0.0;
    printf("Complex{re:%f im:%f}\n", x->re, x->im);
}
Dynamic Memory

free()

Syntax

```c
void free(void *ptr);
```

- Frees memory pointed to by `ptr`
  - Must have been returned by `malloc()`

Example

```c
typedef struct {
    float re;
    float im;
} Complex;

Complex *x = malloc(sizeof(Complex));
free(x);
```
Dynamic Memory

Invalid free()ing

Example

// Non-initialized pointers
Complex *x;
free(x); // Invalid!

// NULL pointers
Complex *y = NULL;
free(y); // Invalid!

// Non-heap pointers
char *z = "Hey!";
free(z); // Invalid!

// Heap pointers not returned by malloc()
Complex *w = malloc(sizeof(Complex));
free(&w->re); // Invalid!
```c
char * p = malloc(1);
char * q = malloc(1);
free(p);
```

\[ a[i] = q[i+1] \]
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Linked Lists

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Linked List
Theory

[Diagram of a linked list with nodes labeled from top to bottom: first, second, third, and fourth nodes, each with a value. The diagram shows arrows connecting the nodes.]
typedef struct ListItem {
    struct ListItem *previousItem;
    struct ListItem *nextItem;
    char *data;
} ListItem;
Linked List

ListItem *LinkedListNew(char *data);
Linked List

ListItem *LinkedListCreateAfter(ListItem *item, char *data);
Linked List

ListItem *LinkedListCreateAfter(ListItem *item, char *data);

I → N → p = G;

I → N

I → N = G
Linked List

char *LinkedListRemove(ListItem *item);
Linked List

char *LinkedListRemove(ListItem *item);

\[ I \rightarrow p \rightarrow N = I \rightarrow N; \]
\[ I \rightarrow N \rightarrow p = I \rightarrow p; \]
Linked List

char *LinkedListRemove(ListItem *item);

\[ I \rightarrow P \rightarrow N = 0; \]

free()
Linked List

char *LinkedListRemove(ListItem *item);
Linked List

ListItem *LinkedListGetFirst(ListItem *list);
Linked List

int LinkedListSize(ListItem *list); / * int LinkedListPrint(ListItem *list); */