CMPE-013/L

Introduction to “C” Programming

Maxwell James Dunne
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

```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

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 *:

\[ p = &x; \]

• 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. \( \text{int } x; \text{ int } \ast p; \))
Pointers

Dereferencing

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

\[ y = *p; \]

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

• `&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

Address of Mailbox

Bank of Mailboxes (memory locations)

\( p = \& x; \)
Pointers

Another view

Contents of the Mailbox

\((x, \ast p)\)

Address of Mailbox

\((\&x, p)\)

Bank of Mailboxes

(memory locations)

\(*p = 2;\)
Pointers
Dereferencing non-primitives

Example

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

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

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

Example

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

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0x08B8</th>
<th>0x08BC</th>
<th>0x08C0</th>
<th>0x08C4</th>
<th>0x08C8</th>
<th>0x08CC</th>
<th>0x08D0</th>
<th>0x08D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>y</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>0000 0000</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 0000</td>
<td>0000 0000</td>
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Pointers
How Pointers Work

Example

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

32-bit Data Memory (RAM)

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<tr>
<td>0x08B8</td>
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<td></td>
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<td>0000 0000</td>
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<td>0000 0000</td>
<td></td>
</tr>
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<td></td>
</tr>
<tr>
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<td>0000 0000</td>
<td></td>
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Pointers
How Pointers Work

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y = 0xBEEF;
p = &x;

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Pointers
How Pointers Work

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int *p;
x = 0xDEAD;
y = 0xBEEF;
p = &x;
*p = 0x0100;
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<th>y</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x08B8</td>
<td>0000</td>
<td>DEAD</td>
<td></td>
</tr>
<tr>
<td>0x08BC</td>
<td></td>
<td>BEEF</td>
<td>08BC</td>
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<tr>
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Pointers
How Pointers Work

Example

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    int x, y;
    int *p;
    x = 0xDEAD;
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<th>0000 0100</th>
<th>0000 BEEF</th>
<th>0000 08BC</th>
<th>0000 0000</th>
<th>0000 0000</th>
<th>0000 0000</th>
<th>0000 0000</th>
</tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0x08C0</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x08CC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x08D0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x08D4</td>
<td></td>
<td></td>
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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;
}
```

<table>
<thead>
<tr>
<th>Address</th>
<th>Variable at Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x08B8</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08BC</td>
<td>0000 0100 (x)</td>
</tr>
<tr>
<td>0x08C0</td>
<td>0000 BEEF (y)</td>
</tr>
<tr>
<td>0x08C4</td>
<td>0000 08C0 (p)</td>
</tr>
<tr>
<td>0x08C8</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08CC</td>
<td>0000 0000</td>
</tr>
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<td>0x08D0</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08D4</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>
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>0000 0000</th>
<th>0000 0100</th>
<th>0000 0200</th>
<th>0000 08C0</th>
<th>0000 0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x08B8</td>
<td>0000 0000</td>
<td>0000 0100</td>
<td>0000 0200</td>
<td>0000 08C0</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08BC</td>
<td>0000 0000</td>
<td>0000 0100</td>
<td>0000 0200</td>
<td>0000 08C0</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08C0</td>
<td>0000 0000</td>
<td>0000 0100</td>
<td>0000 0200</td>
<td>0000 08C0</td>
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</tr>
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<td>0000 0000</td>
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<tr>
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<td>0000 0000</td>
</tr>
<tr>
<td>0x08D0</td>
<td>0000 0000</td>
<td>0000 0100</td>
<td>0000 0200</td>
<td>0000 08C0</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08D4</td>
<td>0000 0000</td>
<td>0000 0100</td>
<td>0000 0200</td>
<td>0000 08C0</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>
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 (0th) element

If we declare the following array and pointer variable:

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

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0x07FC</th>
<th>0x0800</th>
<th>0x0804</th>
<th>0x0808</th>
<th>0x080C</th>
</tr>
</thead>
<tbody>
<tr>
<td>x[0]</td>
<td>0000 0001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[1]</td>
<td>0000 0002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[2]</td>
<td>0000 0003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>FFFF FFFF</td>
<td></td>
<td></td>
<td></td>
<td></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)

- 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;
```

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
char *ptr
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 = 0xBAD0000F00D1;
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>x[0]</th>
<th>x[1]</th>
<th>x[2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td>0000 0000</td>
<td>0000 0001</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0800</td>
<td>0000 0000</td>
<td>0000 0002</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0804</td>
<td>0000 0000</td>
<td>0000 0003</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0808</td>
<td>0000 0800</td>
<td>0000 0000</td>
<td>0000 0000</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 = 0xBAD0000F00D;
}
```

32-bit Data Memory (RAM)

Address

0x07FC  0x0800  0x0804  0x0808  0x080C  0x0810  0x0814  0x0818

0000 0000 0000 0000 0002 0000 0000 0003
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000

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Pointers

Pointer Arithmetic

Example

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32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0000 0000</th>
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<td>0x07FC</td>
<td>0000 0000</td>
<td>0000 0005</td>
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<td>0x0814</td>
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<tr>
<td>0x0818</td>
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Pointers

Pointer Arithmetic

Example

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

*p += 4;
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<td>0000 0000</td>
</tr>
<tr>
<td>0x0808</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x080C</td>
<td>1234 BEEF</td>
</tr>
<tr>
<td>0x0810</td>
<td>0000 0003</td>
</tr>
<tr>
<td>0x0814</td>
<td>0000 0000</td>
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Pointers

Pointer Arithmetic

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<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 DEAD</td>
</tr>
<tr>
<td>0x0810</td>
<td>4321 F00D</td>
</tr>
<tr>
<td>0x0814</td>
<td>0000 F1D0</td>
</tr>
<tr>
<td>0x0818</td>
<td>0000 0810</td>
</tr>
</tbody>
</table>

Maxwell James Dunne

CMPE-013/L: "C" Programming
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

Pointer Arithmetic

Example

```c
{  long long x[] = {1, 2, 3};  long long *p = x;
  *p += 4;
  ++p;
  *p = 0xDEAD1234BEEF;
  ++p;
  *p = 0x1F1D04321F00D;
  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><code>z = *(p++) ;</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td>is equivalent to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>z = *p ;</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>p = p + 1 ;</code></td>
</tr>
<tr>
<td>(*p)++</td>
<td>Post-Increment data pointed to by Pointer</td>
<td><code>z = (*p)++ ;</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td>is equivalent to:</td>
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<td></td>
<td><code>z = *p ;</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>*p = *p + 1 ;</code></td>
</tr>
</tbody>
</table>
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)

Address

0x07FC

0x0800

0x0804

0x0808

0x080C

0x0810

0x0814

0x0818

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)

```
0x07FC | 0000 0000
0x0800 | 0000 0001
0x0804 | 0000 0002
0x0808 | 0000 0003
0x080C | 0000 0800
0x0810 | 0000 0006
0x0814 | 0000 0000
0x0818 | 0000 0000
```

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

```
<table>
<thead>
<tr>
<th>Address</th>
<th>0x0000</th>
<th>0x0001</th>
<th>0x0002</th>
<th>0x0003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[0]</td>
<td>0000</td>
<td>0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[1]</td>
<td>0000</td>
<td>0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[2]</td>
<td>0000</td>
<td>0003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Remember:

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

- Address: 0x07FC
- 0000 0000
- 0000 0001
- 0000 0002
- 0000 0003
- 0000 0804
- 0000 0007
- 0000 0000
- 0000 0000

- Address: 0x0800
- 0000 0000
- 0000 0000
- 0000 0000
- 0000 0000
- 0000 0000
- 0000 0000
- 0000 0000

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)

- Address: 0x07FC
- 0000 0000
- 0000 0001
- 0000 0003
- 0000 0003
- 0000 0804
- 0000 0007
- 0000 0000
- 0000 0000

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:

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

Pre-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)

<table>
<thead>
<tr>
<th>Address</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>0x0800</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>0x0804</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>0x0808</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>0x080C</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>0x0810</td>
<td>0000</td>
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<tr>
<td>0x0814</td>
<td>0000</td>
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</tr>
<tr>
<td>0x0818</td>
<td>0000</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

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>0x07FC</th>
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</tr>
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<tr>
<td></td>
<td>0000 0000</td>
<td>0000 0001</td>
<td>0000 0002</td>
<td>0000 0003</td>
<td>0000 0804</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;  
  
  // Increment pointer and dereference it  
  y = 5 + *(++p);  
  
  // Increment the value it points to  
  y = 5 + ++(*p);  
}  
```

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x07FC</td>
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</tr>
<tr>
<td>0x0818</td>
<td>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)

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<th>0x0818</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000 0000</td>
<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>
<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>
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<th>0x07FC</th>
<th>0x0800</th>
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</tr>
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<tbody>
<tr>
<td></td>
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<td>0000</td>
</tr>
<tr>
<td>x[0]</td>
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<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>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>x[2]</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>p</td>
<td>0000</td>
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<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>y</td>
<td>0000</td>
<td>0008</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
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<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</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

\[ * (++p) \text{ or } +++p \text{ and } * (p++) \text{ or } *p++ \]

Modify the value pointed to by the pointer

\[ ++(*p) \text{ and } (*p)++ \]
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` \0 \0.
• This will prevent it from unintentionally corrupting a memory location if it is accidentally used before it is initialized.

Example

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

**NUL** is the character `\0` but **NULL** is the value of a pointer that points to nowhere.
Values

Values

Values + 3

*(Values + 3) = 13

↑

10
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 variables 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("%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 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

```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

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

![Memory diagram showing address and content of string]

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";
str += 4
```

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

```
Example: Character array
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>0x9D0008C0</td>
<td>0x9D0008C0</td>
</tr>
<tr>
<td>0xA0000FB0</td>
<td>0xA0000FB0</td>
</tr>
<tr>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>0xA0000FB4</td>
<td>0xA0000FB4</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>0xA0000FB5</td>
<td>0xA0000FB5</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>0xA0000FB6</td>
<td>0xA0000FB6</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0xA0000FB7</td>
<td>0xA0000FB7</td>
</tr>
</tbody>
</table>

```
```
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:  
  \[
  \text{if (} \text{str} == \text{"Microchip"})
  \]
  
- This is not correct, though it might appear to work sometimes

- This compares the address in \text{str} to the address of the string literal \text{"Microchip"}

- The correct way is to use the \text{strcmp}() function in the standard library which compares strings character by character
Arrays of Pointers

Declaration

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

\[
\text{char } *p[4];
\]

• This creates an array of 4 pointers to \text{char}
  – The array \text{p[]} itself is like any other array
  – The elements of \text{p[]} , such as \text{p[1]} , are pointers to \text{char}
Arrays of Pointers

Array Elements are Pointers Themselves

32-bit Data Memory (RAM)

\[ \begin{array}{c}
\text{p[0]} \\
9D00 \quad 3FC0 \\
\text{p[1]} \\
9D00 \quad 3FC3 \\
\text{p[2]} \\
9D00 \quad 3FC7 \\
\text{p[3]} \\
9D00 \quad 3FCC \\
\end{array} \]

- 3FC0: On \n- 3FC3: Off
- 3FC7: Main
- 3FCC: Aux
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][] = {
   "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>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3FA4-3FA8</td>
<td>On \0\0\0</td>
</tr>
<tr>
<td>3FA9-3FAD</td>
<td>Off \0\0</td>
</tr>
<tr>
<td>3FAE-3FB2</td>
<td>Main \0</td>
</tr>
<tr>
<td>3FB3-3FB7</td>
<td>Aux \0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Index</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>p[0]</td>
<td>0</td>
<td>0000 6E4F</td>
</tr>
<tr>
<td>p[1]</td>
<td>1</td>
<td>6666 4F00</td>
</tr>
<tr>
<td>p[2]</td>
<td>2</td>
<td>614D 0000</td>
</tr>
<tr>
<td>p[3]</td>
<td>3</td>
<td>4100 6E69</td>
</tr>
</tbody>
</table>

Maxwell James Dunne
Arrays of Pointers

Dereferencing

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

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

- Using \( *p[0] \) is the same as using the object it points to, such as \( x \) or the string literal "My String" from the previous slide.
Arrays of Pointers
Accessing Strings

Example

```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));
```
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

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

The Heap

Example

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

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

Heap (top)
Dynamic Memory

The Heap

Example

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

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 = NULL
    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!