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;

- 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

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. \texttt{int } x; \texttt{ int } *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 \texttt{x})

Address of Mailbox
(\&x)

Bank of Mailboxes
(memory locations)

CMPE-013/L: “C” Programming
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

\((&x, p)\)

Bank of Mailboxes

(memory locations)

\(*p = 2;\)
**Pointers**

Dereferencing non-primitives

**Example**

```c
Complex x = {0.6, 1.2};
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

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

How Pointers Work

Example

```c
{ 
    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>0x08B8</th>
<th>0x08BC</th>
<th>0x08C0</th>
<th>0x08C4</th>
<th>0x08C8</th>
<th>0x08CC</th>
<th>0x08D0</th>
<th>0x08D4</th>
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</tr>
</tbody>
</table>

Variable at Address

- x
- y
- p

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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
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    int x, y;
    int *p;
    x = 0xDEAD;
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<tbody>
<tr>
<td>0x08B8</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x08BC</td>
<td>0000 DEAD</td>
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Pointers
How Pointers Work

Example

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{  
    int x, y;
    int *p;

    x = 0xDEAD;
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<tr>
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</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;
```

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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;
}
```
Pointers and Arrays
A Quick Reminder...

• Array elements occupy consecutive memory locations

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

int x[1] = &x[0];
```

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<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>

• Pointers can provide an alternate method for accessing array elements

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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};
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;

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>
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<tr>
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<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>x[1]</td>
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<td>0000</td>
<td>0800</td>
</tr>
<tr>
<td>x[2]</td>
<td>0000</td>
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<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)

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</tr>
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<tr>
<td>x[0]</td>
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<td>0000</td>
<td>0000</td>
<td>0003</td>
<td></td>
</tr>
<tr>
<td>x[1]</td>
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<td>0000</td>
<td>0804</td>
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</tr>
<tr>
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<td>0000</td>
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<td></td>
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</tr>
</tbody>
</table>

- 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;
++p;
```

We will the address of \( p \) incremented by 4 since a \textbf{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;
```
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 = 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 = 0xF1D04321F00D;
    p -= 2;
    *p = 0xBAD0000F00D;
}
```
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;
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<tr>
<td>0x0818</td>
<td>0000  0808</td>
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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 = 0xBAD0000F00D1;
```

32-bit Data Memory (RAM)

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Pointers

Pointer Arithmetic

Example

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long long x[] = {1, 2, 3};
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Pointers

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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>
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<tbody>
<tr>
<td>*p++</td>
<td>Post-Increment Pointer</td>
<td>$z = * (p++)$;</td>
</tr>
<tr>
<td>* (p++)</td>
<td>Post-Increment data pointed to by Pointer</td>
<td>$z = *p$;</td>
</tr>
<tr>
<td>(*p) ++</td>
<td>Post-Increment data pointed to by Pointer</td>
<td>$z = (*p) ++$;</td>
</tr>
</tbody>
</table>

$z = * (p++)$ is equivalent to:

$z = *p$;
$p = p + 1$;

$z = (*p) ++$ is equivalent to:

$z = *p$;
$p = p + 1$;
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>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>
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<tr>
<td>0x0818</td>
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<td></td>
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</tr>
</tbody>
</table>

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)

```
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</thead>
<tbody>
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<tr>
<td>0x0810</td>
<td>0000 0006</td>
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<td>0x0814</td>
<td>0000 0000</td>
</tr>
<tr>
<td>0x0818</td>
<td>0000 0000</td>
</tr>
</tbody>
</table>
```

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]: 0000 0001
- x[1]: 0000 0002
- x[2]: 0000 0003

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)

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<th>0x0814</th>
<th>0x0818</th>
</tr>
</thead>
<tbody>
<tr>
<td>x[0]</td>
<td>0000 0000</td>
<td>0000 0001</td>
<td>0000 0002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x[1]</td>
<td></td>
<td></td>
<td>0000 0002</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>x[2]</td>
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<tr>
<td>p</td>
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<tr>
<td>y</td>
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<td>0000 0007</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000</td>
</tr>
</tbody>
</table>
```

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)

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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0000 0000</td>
<td>0000 0001</td>
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<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 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>$z = <em>(</em>(++p))$; is equivalent to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$p = p + 1;$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$z = *p;$</td>
</tr>
<tr>
<td><code>*(++p)</code></td>
<td>Pointer</td>
<td>$z = <em>(</em>(++p))$; is equivalent to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$p = p + 1;$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$z = *p;$</td>
</tr>
<tr>
<td><code>++(*p)</code></td>
<td>Pre-Increment data pointed to by Pointer</td>
<td>$z = ++(*(p))$; is equivalent to:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$*p = *p + 1;$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$z = *p;$</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)

- Address 0x07FC: 0000 0000
- Address 0x0800: 0000 0001
- Address 0x0804: 0000 0002
- Address 0x0808: 0000 0003
- Address 0x080C: 0000 0800
- Address 0x0810: 0000 0000
- Address 0x0814: 0000 0000
- Address 0x0818: 0000 0000

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);  
}
```

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<tr>
<td>x[0]</td>
<td>0000</td>
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<tr>
<td>x[1]</td>
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<tr>
<td>x[2]</td>
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</tr>
</tbody>
</table>

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

Pre-Increment / Decrement Syntax

```
{ 
    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 0804</th>
<th>0000 0007</th>
<th>0000 0000</th>
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<td></td>
</tr>
</tbody>
</table>

Remember: *

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

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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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<td></td>
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<td>x[1]</td>
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<td>0804</td>
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<td>0000</td>
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<td></td>
<td></td>
<td></td>
<td>0000</td>
<td>0007</td>
<td>0000</td>
</tr>
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* *(++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 0000</td>
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<tr>
<td>0x0818</td>
<td>0000 0000</td>
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</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 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);
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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);
}
```
Wednesday: How stock ren work?

Thursday:

Friday:

Monday sections: problems code
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:
```
char *str = "PIC32MX"; str
```

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>str1</td>
<td>str2</td>
</tr>
<tr>
<td>0x9D0008C0</td>
<td>0x9D0008C0</td>
</tr>
<tr>
<td>P</td>
<td>C</td>
</tr>
<tr>
<td>0xA0000FB0</td>
<td>0xA0000FB6</td>
</tr>
<tr>
<td>I</td>
<td>0xA0000FB4</td>
</tr>
<tr>
<td></td>
<td>0xA0000FB5</td>
</tr>
<tr>
<td>\0</td>
<td>0xA0000FB7</td>
</tr>
</tbody>
</table>

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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";
```

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:
  ```c
  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

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

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

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

\[\text{4 bytes}\]
Arrays of Pointers

Array Elements are Pointers Themselves

32-bit Data Memory (RAM)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9D00 3FC0</td>
<td>9D00 3FC3</td>
<td>9D00 3FC7</td>
<td>9D00 3FCC</td>
</tr>
</tbody>
</table>

- 3FC0 \(\rightarrow\) On \(\rightarrow\) 0
- 3FC3 \(\rightarrow\) Off \(\rightarrow\) 0
- 3FC7 \(\rightarrow\) Main \(\rightarrow\) 0
- 3FCC \(\rightarrow\) Aux \(\rightarrow\) 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)

- `p[0]`: 0000 0000
- `p[1]`: 0000 6E4F
- `p[6]`: 0000 0000
- `p[7]`: 0000 0000

- 3FA4-3FA8: 0n 0 0 0
- 3FA9-3FAD: 0f f 0 0
- 3FAE-3FB2: Main 0
- 3FB3-3FB7: Aux 0 0

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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:

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

• 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

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

Complex *x = malloc(sizeof(Complex));
printf("Complex{re:%f im:%f}\n",
    x->re, x->im);
char f [12k];

char *f = malloc(12k);
free (f);
Dynamic Memory

malloc()d memory

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
The Heap

Example

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

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

0 or not 0
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\n\nComplex{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!

8 were
were
w: re = 3.4
CMPE-013/L

Introduction to “C” Programming

Maxwell James Dunne
Dynamic Memory

malloc()

free()
Dynamic Memory
Memory leaks

- If pointers returned by `malloc()` are lost, that memory is then "lost"
- Easy to do because this may not crash your program, possibly only causing errors over long periods of time

Example

```c
void MyFunc(void)
{
    Complex *x = malloc(sizeof(Complex));
    ...
}
```
Dynamic Memory

Memory leaks

- So for every pointer obtained from `malloc()`, there should be an equivalent `free()` at some point.

Example

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

    ...

    free(x);
}
```
Dynamic Memory
When to use the Heap

• For unknown amounts of data
  – Arrays are always fixed-length at compile time
• When data needs to be accessible outside of the scope it was created in
  – Pointers need to be passed around
Pointers

Pointers to pointers
Pointers

Pointers to pointers

• Since pointers can point to any valid datatype, they can also point to other pointers

• No limit on levels of indirection
Pointers

Pointers to pointers

Example

```c
{  
    int x = 6;
    int *y = &x;
    int **z = &y;
    printf("\%d\n", **z);
}
```

32-bit Data Memory
(RAM)

<table>
<thead>
<tr>
<th>Address</th>
<th>0x3F50</th>
<th>0x3F54</th>
<th>0x3F58</th>
<th>0x3F5C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>X</td>
<td>0000</td>
<td>0006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>0000</td>
<td>3F54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>0000</td>
<td>3F58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Output

6

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Pointers

Passing by reference, again

- Passing by reference only allows persistently changing the value 1 level of indirection from the pointer and further
  - If a pointer is passed to a function, the data it points to can be altered
  - If a pointer-to-a-pointer is passed, the pointer it points to and the data that pointer points to can be altered

\[ x \rightarrow y \rightarrow z \]

- \[ x \rightarrow y = 1 \]
Pointers
Passing by reference, again

Example interrupt

```c
void MyFunc(int *x)
{
    *x = 6;
}

int main(void)
{
    int myInt;
    int *myIntPtr = &myInt;
    MyFunc(*myIntPtr);
}
```

ADC60
Pointers
Passing by reference, again

Example interrupt

```c
void MyFunc(int **x)
{
    *x = malloc(sizeof(int));
    if (*x) {
        **x = 6;
    }
}

int main(void)
{
    int *myInt;
    MyFunc(&myInt);
}
```
Enums
Enumerations

Definition

Enumerations are integer data types that you can create with a limited range of values. Each value is represented by a symbolic constant that may be used in conjunction with variables of the same enumerated type.

- Enumerations:
  - Are unique integer data types
  - May only contain a specified list of values
  - Values are specified as symbolic constants
Enumerations

How to Create an Enumeration Type

- Creates an ordered list of constants
- If unspecified, each label's value is one greater than the previous label

**Syntax**

```c
enum typeName { label_0, label_1, ..., label_n }
```

Where compiler sets $label_0 = 0$, $label_1 = 1$, $label_n = n$

**Example**

```c
enum weekday { SUN, MON, TUE, WED, THR, FRI, SAT };
```

Label Values:

- $SUN = 0$, $MON = 1$, $TUE = 2$, $WED = 3$, $THR = 4$, $FRI = 5$, $SAT = 6$
Enumerations
How to Create an Enumeration Type

- Any label may be assigned a specific value
- The following labels will increment from that value

Syntax
```
enum typeName {label₀ = const₀,...,labelₙ}
```
Where compiler sets `label₀ = const₀, label₁ = (const₀ + 1),...`

Example
```
enum people {Rob, Steve, Paul = 7, Bill, Gary};
```
Label Values:
```
Rob = 0, Steve = 1, Paul = 7, Bill = 8, Gary = 9
```
Enumerations
How to Create an Enumeration Type

- Any label may be assigned a specific value
- The following labels will increment from that value

**Syntax**

```c
enum typeName {label_0 = const_0, ..., label_n}
```

Where compiler sets `label_0 = const_0, label_1 = (const_0 + 1), ...`

**Example**

```c
enum people {Rob = 'a', Steve, Paul, Bill, Gary};
```

Label Values:

Rob = 'a', Steve = 'b', Paul = 'c', Bill = 'd', Gary = 'e'
Enumerations
How to Create an Enumeration Type

- Any label may be assigned a specific value
- The following labels will increment from that value

**Syntax**

```c
enum typeName {label0 = const0, ..., labeln}
```

Where compiler sets `label0 = const0, label1 = (const0 + 1), ...`

**Example**

```c
enum people {Rob = -4, Steve, Paul, Bill, Gary};
```

Label Values:

```
Rob = -4, Steve = -3, Paul = -2, Bill = -1, Gary = 0
```
Enumerations
How to Declare an Enumeration Type Variable

- Declared along with type:

```
enum typeName {const-list} varname_1, ...;
```

- Declared independently:

```
enum typeName varName_1, ..., varName_n;
```

Example
```
enum weekday {SUN, MON, TUE, WED, THR, FRI, SAT} today;
enum weekday day; // day is a variable of type weekday
```
Enumerations
How to Declare a ‘Tagless’ Enumeration Variable

- No type name specified:

```
enum {const-list} varName1,...,varNameN;
```

- Only variables specified as part of the `enum` declaration may be of that type
- No type name is available to declare additional variables of the `enum` type later in code

```
enum {SUN, MON, TUE, WED, THR, FRI, SAT} Today;
```
Enumerations

How to Declare an Enumeration Type with `typedef`

- Variables may be declared as type `typeName` without needing the `enum` keyword

**Syntax**

```
typedef enum {const-list} typeName;
```

- The enumeration may now be used as an ordinary data type (compatible with `int`)

**Example**

```
typedef enum {SUN, MON, TUE, WED, THR, FRI, FRI, SAT} Weekday;

Weekday day;    // Variable of type weekday
```
Enumerations
How to Use an Enumeration Type Variable

If enumeration and variable have already been defined:

**Syntax**

```c
varName = label_n;
```

- The labels may be used as any other symbolic constant
- Variables defined as enumeration types must be used in conjunction with the type’s labels or equivalent integer

**Example**

```c
enum weekday {SUN, MON, TUE, WED, THR, FRI, SAT};
enum weekday day;

day = WED;
day = 6; // May only use values from 0 to 6
if (day == WED) {
    ...
```
Enumerations

Proper formatting

Example

typedef enum {
    SUN,
    MON,
    TUE,
    WED,
    THR,
    FRI,
    SAT
} Weekday;

Weekday day = WED;
Enumerations

Proper formatting

Example

typedef enum {
    SUN,
    MON,
    TUE,
    WED,
    THR,
    FRI,
    SAT
} Weekday;

Weekday day = 3;  // No compilation warning/error
Enumerations
Datatype usage

Example

typedef enum {  
    SUN,  
    MON,  
    TUE,  
    WED,  
    THR,  
    FRI,  
    SAT  
} Weekday;

void PrintDayName(Weekday d)  
{  
    if (d == SUN) {  
        printf("Sun\n");  
    } ...  
}

PrintDayName(WED);  // No compilation warning/error
Enumerations

Why enumerations?

• Enumerations are a proper datatype as well as the possible values for them
• Some compile-time checking
• Doesn't do text replacement, done during the compiler stage
• Use for a group of related values
Interrupts
Interrupts

• High-priority alerts that an event requires immediate attention
• Generally interrupts can be assigned priorities
• Event is handled by an Interrupt Service Routine (ISR)
Interrupts

- ISR is a special function that is written by the developer, but called directly by the processor.
- ISRs have no inputs or outputs:
  - All processing through global/module-level variables.
- ISRs are written a specific way and the processor is told they have been implemented by the compiler/developer.
Interrupts

Traps

- Software interrupts are generally referred to as exceptions or traps
- Examples:
  - Division by zero
  - Invalid address dereference
  - Debugging breakpoint
  - Stack overflow
Example interrupt

```c
void _ISR IsrName(void)
{
    // Process data from the interrupt
    // Store results in global/module variable
    // Clear interrupt flag
}
```
Example interrupt

```c
void _ISR Uart1TxInterrupt(void)
{
    // Stall until transmission finishes
    while (!U1STAbits.TRMT);

    // Continue transmitting next batch of data
    Uart1StartTransmission();

    // Clear interrupt flag
    IFS0bits.U1TXIF = 0;
}
```
Interrupts

Calling

Example program

```c
int main(void)
{
    int x = 20;
    int y;
    y = x / 2;
}
```

Interrupt: UART1 Post-transmission

```c
void _ISR_U1TXInt(void)
{
    IFS0bits.U1TXIF = 0;
}
```
Interrupts
Calling

Example program

```c
int main(void)
{
    int x = 20;
    int y;
    _U1TXInt();
    y = x / 2;
}
```

Interrupt: UART1 Post-transmission

```c
void __ISR __U1TXInt(void)
{
    IFS0bits.U1TXIF = 0;
}
```
Interrupts

- Interrupts are important events that happen in real-time
- ISRs are the functions that handle these events
- ISRs are called outside of regular program execution order
CMPE-013/L

Linked Lists

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Linked List

Theory

Doubly Linked List

a → b → c → d → e → a

a
b

c
b

a
b
θ
d

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Linked List
Struct Layout

typedef struct ListItem {
    struct ListItem *previousItem;
    struct ListItem *nextItem;
    char *data;
} ListItem;
Linked List

ListItem *LinkedListNew(char *data);

ListItem *x = malloc(sizeof(ListItem));
if (x) {
    x->data = data;
    return x;
}
Linked List

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

item \rightarrow N = x;

x \rightarrow r = item;
Linked List

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

Z \rightarrow N = item \rightarrow N;
Z \rightarrow N \rightarrow p = Z;
item \rightarrow N = Z;
Z \rightarrow p = item;
Linked List

char *LinkedListRemove(ListItem *item);

item \rightarrow N \rightarrow p = NULL;
Linked List

char *LinkedListRemove(ListItem *item);

item -> p -> N = NULL
free(item)
Linked List

char *LinkedListRemove(ListItem *item);
Linked List

char *LinkedListRemove(ListItem *item);
Linked List

cchar *LinkedListRemove(ListItem *item);
LinkedList

ListItem *LinkedListGetFirst(ListItem *list);

NULL

item -> p == NULL
Linked List

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

d = NULL

```c
printf("\%s", d);
```