Introduction to C
Part 3
Meet Your TAs!!

• Come to CIT 3rd-floor atrium on Thursday at 5
• Eat tasty cookies!
• Talk to the course staff!
• Talk to fellow students in the course!
Arrays and Parameters

```c
void func(int arg[]) {  
    /* arg points to the caller’s array */
    int local[7];        /* seven ints */
    arg++;                /* legal */
    arg = local;          /* legal */
    local++;              /* illegal */
    local = arg;          /* illegal */
}
```
```c
int main() {
    int *p; int a = 4;
p = &a;
    *p++;
    printf("%d %u\n", *p, p);
}
```

```
$ ./a.out
3221224360 3221224360
```
Dereferencing C Pointers

```c
int main() {
    int *p; int a = 4;
    p = &a;
    (*p)++;
    printf("%d %u\n", *p, p);
}
```

$ ./a.out
5 3221224356
Dereferencing C Pointers

```c
int main() {
    int *p; int a = 4;
    p = &a;
    ++*p;
    printf("%d %u\n", *p, p);
}
```

```
$ ./a.out
5 3221224356
```
Quiz 1

int proc(int arg[]) {
    arg++;
    return arg[1];
}

int main() {
    int A[3]={0, 1, 2};
    printf("%d\n", proc(A));
}

What’s printed?

a) 0  

b) 1  

c) 2  

d) indeterminate
Strings

• Strings are arrays of characters terminated by '\0' ("null")
  – the '\0' is included at the end of string constants
    » "Hello"

```
Hello \0
```
Strings

```c
int main() {
    printf("%s","Hello");
    return 0;
}
```

```
$ ./a.out
Hello$
```
int main() {
    printf("%s\n","Hello");
    return 0;
}

$ ./a.out
Hello
$
Strings

```c
void printString(char s[]) {
    int i;
    for(i=0; s[i]!='/0'; i++)
        printf("%c", s[i]);
}

int main() {
    printString("Hello");
    printf("\n");
    return 0;
}
```

Tells C that this function does not return a value
2-D Arrays

• Suppose $T$ is a datatype (such as `int`)
  • $T \ n[6]$
    – declares $n$ to be an array of (six) $T$
    – the type of $n$ is $T[6]$
  • Thus $T[6]$ is effectively a datatype
  • Thus we can have an array of $T[6]$
  • $T \ m[7][6]$
    – $m$ is an array of (seven) $T[6]$
    – $m[i]$ is of type $T[6]$
    – $m[i][j]$ is of type $T$
3-D Arrays

• How do we declare an array of eight $T[7][6]$?

\[
T \ p[8][7][6]
\]

- $p$ is an array of (eight) $T[7][6]$
- $p[i]$ is of type $T[7][6]$
- $p[i][j]$ is of type $T[6]$
- $p[i][j][k]$ is of type $T$
#define NUM_ROWS 3
#define NUM_COLS 4
...
int main() {
    int row, col;
    int m[NUM_ROWS][NUM_COLS];
    for(row=0; row<NUM_ROWS; row++)
        for(col=0; col<NUM_COLS; col++)
            m[row][col] = row*NUM_COLS+col;
    printMatrix(NUM_ROWS, NUM_COLS, m);
    return 0;
}"
2-D Arrays

It must be told the dimensions

```c
void printMatrix(int nr, int nc,
                 int m[nr][nc]) {
    int row, col;
    for (row=0; row<nr; row++) {
        for (col=0; col<nc; col++)
            printf("%6d", m[row][col]);
        printf("\n");
    }
}
```
Memory Layout

Row-Major Order

```
#define NUM_ROWS 3
#define NUM_COLS 3

m[0][0]  m[0][1]  m[0][2]

m[1][0]  m[1][1]  m[1][2]

m[2][0]  m[2][1]  m[2][2]
```

row 0  row 1  row 2
2-D Arrays

Alternatively ...

```c
void printMatrix(int nr, int nc, 
    int m[][nc]) {
    int row, col;
    for (row=0; row<nr; row++) {
        for (col=0; col<nc; col++)
            printf("%6d", m[row][col]);
        printf("\n");
    }
}
```
2-D Arrays

```c
void printMatrix(int nr, int nc,
                 int m[][nc]) {
    int i;
    for(i=0; i<nr; i++)
        printRow(nc, m[i]);
}

void printRow(int nc, int a[]) {
    int i;
    for(i=0; i<nc; i++)
        printf("%6d", a[i]);
    printf("\n");
}
```

Or …
2D as 1D

\[
\begin{array}{cccc}
0 & 1 & 2 & 3 \\
4 & 5 & 6 & 7 \\
\end{array}
= \begin{array}{cccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\end{array}
\]

```c
int A2D[2][4];
int A1D[8];

int AccessAs1D(int A[], int Row, int Col, int RowSize) {
    return A[Row*RowSize + Col];
}

int main(void) {
    int A2D[2][4] = {{0, 1, 2, 3}, {4, 5, 6, 7}};
    int *A1D = &A2D[0][0];
    int x = AccessAs1D(A1D, 1, 2, 4);
    printf("%d\n", x);
    return 0;
}
```

```
$ ./a.out
6
$ 
```
Quiz 2

Consider the array
int A[3][3];

which element is adjacent to A[0][0] in memory?

a) A[0][1]
b) A[1][0]
c) none of the above
Consider the array

```c
int A[3][3];
int *B = &A[0][0];
```

```c
B[8] = 8;
```

- which element of A was modified?
  a) A[0][3]
  b) A[2][2]
  c) A[3][0]
  d) none of the above
Number Representation

• Hindu-Arabic numerals
  – developed by Hindus starting in 5th century
    » positional notation
    » symbol for 0
  – adopted and modified somewhat later by Arabs
    » known by them as “Rakam Al-Hind” (Hindu numeral system)
  – 1999 rather than MCMXCIX
    » (try doing long division with Roman numerals!)
Which Base?

• 1999
  – base 10
    » $9 \cdot 10^0 + 9 \cdot 10^1 + 9 \cdot 10^2 + 1 \cdot 10^3$
  – base 2
    » 11111001111
      • $1 \cdot 2^0 + 1 \cdot 2^1 + 1 \cdot 2^2 + 1 \cdot 2^3 + 0 \cdot 2^4 + 0 \cdot 2^5 + 1 \cdot 2^6 + 1 \cdot 2^7 + 1 \cdot 2^8 + 1 \cdot 2^9 + 1 \cdot 2^{10}$
  – base 8
    » 3717
      • $7 \cdot 8^0 + 1 \cdot 8^1 + 7 \cdot 8^2 + 3 \cdot 8^3$
        » why are we interested?
  – base 16
    » 7CF
      • $15 \cdot 16^0 + 12 \cdot 16^1 + 7 \cdot 16^2$
        » why are we interested?
Words ...

12-bit computer word

01111110011111
3 7 1 7

16-bit computer word

000001111110011111
0 7 C F
Algorithm ...

```c
void baseX(unsigned int num, unsigned int base) {
    char digits[] = {'0', '1', '2', '3', '4', '5', '6', ... };
    char buf[8*sizeof(unsigned int)+1];
    int i;

    for (i = sizeof(buf) - 2; i >= 0; i--) {
        buf[i] = digits[num%base];
        num /= base;
        if (num == 0)
            break;
    }

    buf[sizeof(buf) - 1] = '\0';
    printf("%s\n", &buf[i]);
}
```
Or …

$ bc$
obase=16
1999
7CF
$

Quiz 4

• What’s the decimal (base 10) equivalent of $23_{16}$?
  a) 19
  b) 33
  c) 35
  d) 37
Encoding Byte Values

- **Byte = 8 bits**
  - binary $00000000_2$ to $11111111_2$
  - decimal: $0_{10}$ to $255_{10}$
  - hexadecimal $00_{16}$ to $FF_{16}$
    - base 16 number representation
    - use characters ‘0’ to ‘9’ and ‘A’ to ‘F’
    - write $FA1D37B_{16}$ in C as
      - `0xFA1D37B`
      - `0xfa1d37b`

<table>
<thead>
<tr>
<th>Hex</th>
<th>Decimal</th>
<th>Binary</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0000</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0010</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<tr>
<td>4</td>
<td>4</td>
<td>0100</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0101</td>
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<tr>
<td>6</td>
<td>6</td>
<td>0110</td>
</tr>
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<td>7</td>
<td>7</td>
<td>0111</td>
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<td>8</td>
<td>8</td>
<td>1000</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1001</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>1010</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>1011</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>1100</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>1101</td>
</tr>
<tr>
<td>E</td>
<td>14</td>
<td>1110</td>
</tr>
<tr>
<td>F</td>
<td>15</td>
<td>1111</td>
</tr>
</tbody>
</table>
## Unsigned 32-Bit Integers

<table>
<thead>
<tr>
<th>$b_{31}$</th>
<th>$b_{30}$</th>
<th>$b_{29}$</th>
<th>...</th>
<th>$b_{2}$</th>
<th>$b_{1}$</th>
<th>$b_{0}$</th>
</tr>
</thead>
</table>

value = $\sum_{i=0}^{31} b_i \cdot 2^i$

(we ignore negative integers for now)
Storing and Viewing Ints

```c
int main() {
    int n = 57;
    printf("binary: %b, decimal: %d, ",
          "hex: %x\n", n, n, n);
    return 0;
}
```

```
$ ./a.out
binary: 111001, decimal: 57, hex: 39
$
```
## Boolean Algebra

- **Developed by George Boole in 19th Century**
  - algebraic representation of logic
    » encode “true” as 1 and “false” as 0

### And
- \( A \& B = 1 \) when both \( A=1 \) and \( B=1 \)

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Or
- \( A \mid B = 1 \) when either \( A=1 \) or \( B=1 \)

<table>
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<tr>
<th></th>
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<td>1</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Not
- \( \neg A = 1 \) when \( A=0 \)

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>0</td>
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</tr>
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<td>1</td>
<td>0</td>
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</table>

### Exclusive-Or (Xor)
- \( A^B = 1 \) when either \( A=1 \) or \( B=1 \), but not both

<table>
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<tbody>
<tr>
<td>0</td>
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<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
General Boolean Algebras

• Operate on bit vectors
  – operations applied bitwise

  \[
  \begin{array}{c}
  01101001 \& 01010101 = 01000001 \\
  01101001 \mid 01010101 = 01111101 \\
  01101001 \wedge 01010101 = 00111100 \\
  \sim 01010101 = 10101010
  \end{array}
  \]

• All of the properties of boolean algebra apply
Example: Representing & Manipulating Sets

• Representation
  – width-\(w\) bit vector represents subsets of \(\{0, \ldots, w-1\}\)
  – \(a_j = 1\) iff \(j \in A\)

\[
\begin{align*}
01101001 & \quad \{0, 3, 5, 6\} \\
76543210 & \\
01010101 & \quad \{0, 2, 4, 6\} \\
76543210 & 
\end{align*}
\]

• Operations
  & intersection \quad 01000001 \quad \{0, 6\}
  \mid union \quad 01111101 \quad \{0, 2, 3, 4, 5, 6\}
  ^ symmetric difference \quad 00111100 \quad \{2, 3, 4, 5\}
  \sim complement \quad 10101010 \quad \{1, 3, 5, 7\}
Bit-Level Operations in C

• Operations &, |, ~, ^ available in C
  – apply to any “integral” data type
    » long, int, short, char
  – view arguments as bit vectors
  – arguments applied bit-wise

• Examples (char datatype)
  \(~0x41 \rightarrow 0xBE\)
    \(~01000001_2 \rightarrow 10111110_2\)
  \(~0x00 \rightarrow 0xFF\)
    \(~00000000_2 \rightarrow 11111111_2\)
  \(0x69 \& 0x55 \rightarrow 0x41\)
    \(01101001_2 \& 01010101_2 \rightarrow 01000001_2\)
  \(0x69 \mid 0x55 \rightarrow 0x7D\)
    \(01101001_2 \mid 01010101_2 \rightarrow 01111110_2\)
Contrast: Logic Operations in C

• Contrast to Logical Operators
  – &&, ||, !
    » view 0 as “false”
    » anything nonzero as “true”
    » always return 0 or 1
    » early termination/short-circuited execution

• Examples (char datatype)
  !0x41 → 0x00
  !0x00 → 0x01
  !!0x41 → 0x01
  0x69 && 0x55 → 0x01
  0x69 || 0x55 → 0x01
  p && *p (avoids null pointer access)
Contrast: Logic Operations in C

• Contrast to Logical Operators
  - `&&`, `||`, `!`
    » view 0 as “false”
    » anything nonzero as “true”
    » always return 0 or 1
    » early termination/short-circuited execution

• Examples (char `datatype`)
  - `!0x41` → 0x00
  - `!0x00` → 0x01
  - `!!0x41` → 0x01
  - `0x69 && 0x55` → 0x01
  - `0x69 || 0x55` → 0x01
  - `p && *p` (avoids null pointer access)

Watch out for `&&` vs. `&` (and `||` vs. `|`)… One of the more common oopsies in C programming
Quiz 5

• Which of the following would determine whether the next-to-the-rightmost bit of Y (declared as a char) is 1? (I.e., the expression evaluates to true if and only if that bit of Y is 1.)
  a) Y & 0x02
  b) !((~Y) & 0x02)
  c) both of the above
  d) none of the above
Shift Operations

• **Left Shift:** \( x \ll y \)
  - shift bit-vector \( x \) left \( y \) positions
    - throw away extra bits on left
      » fill with 0’s on right

• **Right Shift:** \( x \gg y \)
  - shift bit-vector \( x \) right \( y \) positions
    » throw away extra bits on right
  - logical shift
    » fill with 0’s on left
  - arithmetic shift
    » replicate most significant bit on left

• **Undefined Behavior**
  - shift amount < 0 or ≥ word size

<table>
<thead>
<tr>
<th>Argument ( x )</th>
<th>01100010</th>
</tr>
</thead>
<tbody>
<tr>
<td>( &lt;&lt; 3 )</td>
<td>00010000</td>
</tr>
<tr>
<td>Log. ( &gt;&gt; 2 )</td>
<td>00011000</td>
</tr>
<tr>
<td>Arith. ( &gt;&gt; 2 )</td>
<td>00011000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Argument ( x )</th>
<th>10100010</th>
</tr>
</thead>
<tbody>
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<td>( &lt;&lt; 3 )</td>
<td>00010000</td>
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<tr>
<td>Log. ( &gt;&gt; 2 )</td>
<td>00101000</td>
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<tr>
<td>Arith. ( &gt;&gt; 2 )</td>
<td>11101000</td>
</tr>
</tbody>
</table>