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Vinny Palaniappan

http://xkcd.com/138/
Administrivia

- Lab 0 due today @ 11:59pm
  - You will be revisiting this program throughout this class!
- Homework 1 due Wednesday
  - Reminder: autograded, 20 tries, no late submissions
- Lab 1 released tomorrow
Review Questions

1) If the word size of a machine is 64-bits, which of the following is usually true? (pick all that apply)
   a) 64 bits is the size of a pointer
   b) 64 bits is the size of an integer
   c) 64 bits is the width of a register

2) (True/False) By looking at the bits stored in memory, I can tell if a particular 4-bytes is being used to represent an integer, floating point number, or instruction.

3) If the size of a pointer on a machine is 6 bits, the address space is how many bytes?
Memory, Data, and Addressing

- Representing information as bits and bytes
- Organizing and addressing data in memory
- **Manipulating data in memory using C**
- Boolean algebra and bit-level manipulations
Addresses and Pointers in C

- \& = “address of” operator
- \* = “value at address” or “dereference” operator

```c
int* ptr;
int x = 5;
int y = 2;
ptr = &x;
y = 1 + *ptr;
```

- Declares a variable, `ptr`, that is a pointer to (i.e. holds the address of) an `int` in memory
- Declares two variables, `x` and `y`, that hold ints, and initializes them to 5 and 2, respectively
- Sets `ptr` to the address of `x` (“`ptr` points to `x`”)
- Sets `y` to “1 plus the value stored at the address held by `ptr`. Because `ptr` points to `x`, this is equivalent to `y = 1 + x`;

What is \* (&y) ?

* is also used with variable declarations
Assignment in C

- A variable is represented by a memory location
- Declaration ≠ initialization (initially holds “garbage”)
- `int x, y;`
  - `x` is at address 0x04, `y` is at 0x18
Assignment in C

- A variable is represented by a memory location
- Declaration ≠ initialization (initially holds “garbage”)
- `int x, y;`
  - `x` is at address 0x04, `y` is at 0x18

32-bit example (pointers are 32-bits wide)

little-endian
Assignment in C

- left-hand side = right-hand side;
  - LHS must evaluate to a memory location
  - RHS must evaluate to a value (could be an address)
  - Store RHS value at LHS location

- int x, y;
- x = 0;

32-bit example
(pointers are 32-bits wide)

& = “address of”
* = “dereference”
Assignment in C

- **left-hand side = right-hand side;**
  - LHS must evaluate to a memory *location*
  - RHS must evaluate to a *value* (could be an address)
  - Store RHS value at LHS location

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`

32-bit example (pointers are 32-bits wide)

& = “address of”
* = “dereference”

little endian!
Assignment in C

- left-hand side = right-hand side;
  - LHS must evaluate to a memory location
  - RHS must evaluate to a value (could be an address)
  - Store RHS value at LHS location

```c
int x, y;
x = 0;
y = 0x3CD02700;
x = y + 3;
```

- Get value at \( y \), add 3, store in \( x \)

### 32-bit example (pointers are 32-bits wide)

\& = “address of”

\* = “dereference”

<table>
<thead>
<tr>
<th></th>
<th>0x00</th>
<th>0x01</th>
<th>0x02</th>
<th>0x03</th>
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<td>3C</td>
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<tr>
<td>0x24</td>
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</tr>
</tbody>
</table>

\( x \) = 0x3CD02700
\( y \) = 0x3CD02700

\& = “address of”

\* = “dereference”
Assignment in C

- left-hand side = right-hand side;
  - LHS must evaluate to a memory location
  - RHS must evaluate to a value (could be an address)
  - Store RHS value at LHS location

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at y, add 3, store in x
- `int* z;`
  - z is at address 0x20

32-bit example (pointers are 32-bits wide)

& = “address of”
* = “dereference”
Assignment in C

- left-hand side = right-hand side;
  - LHS must evaluate to a memory location
  - RHS must evaluate to a value (could be an address)
  - Store RHS value at LHS location

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z = &y + 3;`
  - Get address of `y`, “add 3”, store in `z`
Pointer Arithmetic

- Pointer arithmetic is scaled by the size of target type
  - In this example, `sizeof(int) = 4`

- `int* z = &y + 3;`
  - Get address of `y`, add `3 * sizeof(int)`, store in `z`
  - `&y = 0x18 = 1*16^1 + 8*16^0 = 24`
  - `24 + 3*(4) = 36 = 2*16^1 + 4*16^0 = 0x24`

- Pointer arithmetic can be dangerous!
  - Can easily lead to bad memory accesses
  - Be careful with data types and casting
Assignment in C

- `int x, y;`
- `x = 0;`
- `y = 0x3CD02700;`
- `x = y + 3;`
  - Get value at `y`, add 3, store in `x`
- `int* z = &y + 3;`
  - Get address of `y`, add 12, store in `z`
- `*z = y;`
  - What does this do?
Assignment in C

- \texttt{int x, y;}
- \texttt{x = 0;}
- \texttt{y = 0x3CD02700;}
- \texttt{x = y + 3;}
  - Get value at \texttt{y}, add 3, store in \texttt{x}
- \texttt{int* z = \&y + 3;}
  - Get address of \texttt{y}, add 12, store in \texttt{z}
- \texttt{*z = y;}
  - Get value of \texttt{y}, put in address stored in \texttt{z}

### 32-bit example
(pointers are 32-bits wide)

\& = “address of”
\* = “dereference”
Arrays in C

Declaration: `int a[6];`

- **element type**
- **name**
- **number of elements**

Arrays are adjacent locations in memory storing the same type of data object.

- `a` is a name for the array’s address.

64-bit example (pointers are 64-bits wide)
Arrays in C

Declaration: `int a[6];`

Indexing:  
- `a[0] = 0x015f;`
- `a[5] = a[0];`

Arrays are adjacent locations in memory storing the same type of data object.

- `a` is a name for the array’s address.
- The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes.

```
<p>| | | | | | | | |</p>
<table>
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<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>0x2</td>
<td>0x3</td>
<td>0x4</td>
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<td>---</td>
</tr>
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<td>0x9</td>
<td>0xA</td>
<td>0xB</td>
<td>0xC</td>
<td>0xD</td>
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<td>00</td>
<td>00</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>a[4]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

```
0x00
0x08
0x10
0x18
0x20
0x28
0x30
0x38
0x40
0x48
```
Arrays in C

Declaration:  `int a[6];`

Indexing:  `a[0] = 0x015f;`
  `a[5] = a[0];`

No bounds  `a[6] = 0xBAD;`
checking:  `a[-1] = 0xBAD;`

Arrays are adjacent locations in memory storing the same type of data object

- **a** is a name for the array’s address
- The address of `a[i]` is the address of `a[0]` plus `i` times the element size in bytes
Arrays in C

Declaration: \( \text{int a[6];} \)

Indexing: \( a[0] = 0x015f; \)
\( a[5] = a[0]; \)

No bounds \( a[6] = 0xBAD; \)
checking: \( a[-1] = 0xBAD; \)

Pointers: \( \text{int* p;} \)
\( p = a; \)
\( p = \&a[0]; \)
\( *p = 0xA; \)

Arrays are adjacent locations in memory storing the same type of data object
\( a \) is a name for the array’s address
The address of \( a[i] \) is the address of \( a[0] \) plus \( i \) times the element size in bytes
Arrays in C

Declaration: \texttt{int a[6];}

Indexing: \texttt{a[0] = 0x015f;}
\texttt{a[5] = a[0];}

No bounds \texttt{a[6] = 0xBAD;}
checking: \texttt{a[-1] = 0xBAD;}

Pointers: \texttt{int* p;}
\texttt{p = a;}
\texttt{p = &a[0];}
\texttt{*p = 0xA;}

The address of \texttt{a[i]} is the address of \texttt{a[0]} plus \texttt{i} times the element size in bytes

Array indexing = address arithmetic (both scaled by the size of the type)

\texttt{p[1] = 0xB;}
\texttt{*(p+1) = 0xB;}
\texttt{p = p + 2;}
Arrays in C

Declaration:  int a[6];

Indexing:  a[0] = 0x015f;
            a[5] = a[0];

No bounds  a[6] = 0xBAD;
checking:  a[-1] = 0xBAD;

Pointers:  int* p;
           p = a;
           p = &a[0];
           *p = 0xA;
           p[1] = 0xB;
           *(p+1) = 0xB;
           p = p + 2;
           *p = a[1] + 1;

Arrays are adjacent locations in memory storing the same type of data object

a is a name for the array’s address

The address of a[i] is the address of a[0] plus i times the element size in bytes

array indexing = address arithmetic (both scaled by the size of the type)

equivalent

\[
\begin{align*}
p[1] &= 0xB; \\
*(p+1) &= 0xB; \\
p &= p + 2; \\
*p &= a[1] + 1;
\end{align*}
\]
Question: The variable values after Line 3 executes are shown on the right. What are they after Line 4 & 5?

- Vote at http://PollEv.com/justinh

```
void main() {
    int a[] = {5,10};
    int *p = a;
    p = p + 1;
    *p = *p + 1;
}
```

(A) 101 10 5 10 then 101 11 5 11
(B) 104 10 5 10 then 104 11 5 11
(C) 100 6 6 10 then 101 6 6 10
(D) 100 6 6 10 then 104 6 6 10
Representing strings

- C-style string stored as an array of bytes (char *)
  - Elements are one-byte ASCII codes for each character
  - No “String” keyword, unlike Java

<table>
<thead>
<tr>
<th>ASCII</th>
<th>Character</th>
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<td>space</td>
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<td>!</td>
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<tr>
<td>34</td>
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<td>#</td>
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<td>36</td>
<td>$</td>
</tr>
<tr>
<td>37</td>
<td>%</td>
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<td>38</td>
<td>&amp;</td>
</tr>
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<td>(</td>
</tr>
<tr>
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<td>*</td>
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<tr>
<td>43</td>
<td>+</td>
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<td>,</td>
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<td>45</td>
<td>-</td>
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<tr>
<td>47</td>
<td>/</td>
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<td></td>
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<td>127</td>
<td>del</td>
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</table>

ASCII: American Standard Code for Information Interchange
Null-Terminated Strings

- **Example:** “Donald Trump” stored as a 13-byte array

<table>
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<th>Decimal</th>
<th>68</th>
<th>111</th>
<th>110</th>
<th>97</th>
<th>108</th>
<th>100</th>
<th>32</th>
<th>84</th>
<th>114</th>
<th>117</th>
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</tr>
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<tbody>
<tr>
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<td>0x6E</td>
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<td>0x6C</td>
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<td>0x20</td>
<td>0x54</td>
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</tr>
<tr>
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<td>Trump</td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Last character followed by a 0 byte (‘\0’) (a.k.a. “null terminator”)
  - Must take into account when allocating space in memory
  - Note that ‘0’ ≠ ‘\0’ (i.e. character 0 has non-zero value)

- How do we compute the length of a string?
  - Traverse array until null terminator encountered
Endianness and Strings

```c
char s[6] = "12345";
```

- **Byte ordering (endianness) is not an issue for 1-byte values**
  - The whole array does not constitute a single value
  - Individual elements are values; chars are single bytes

### String literal

<table>
<thead>
<tr>
<th>IA32, x86-64 (little-endian)</th>
<th>SPARC (big-endian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00 31</td>
<td>0x00 31</td>
</tr>
<tr>
<td>0x01 32</td>
<td>0x01 32</td>
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<tr>
<td>0x02 33</td>
<td>0x02 33</td>
</tr>
<tr>
<td>0x03 34</td>
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<tr>
<td>0x04 35</td>
<td>0x04 35</td>
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<tr>
<td>0x05 00</td>
<td>0x05 00</td>
</tr>
</tbody>
</table>

- 0x31 = 49 decimal = ASCII ‘1’
Examining Data Representations

- Code to print byte representation of data
  - Any data type can be treated as a byte array by casting it to char
  - C has unchecked casts  !! DANGER !!

```c
void show_bytes(char* start, int len) {
    int i;
    for (i = 0; i < len; i++)
        printf("%p\t0x%.2x\n", start+i, *(start+i));
    printf("\n");
}
```

`printf` directives:
- `%p` Print pointer
- `	` Tab
- `%x` Print value as hex
- `
` New line
Examining Data Representations

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  - C has **unchecked casts**  !! DANGER !!

```c
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    for (i = 0; i < len; i++)
        printf("%p\t0x%.2x\n", start+i, *(start+i));
    printf("\n");
}

void show_int(int x) {
    show_bytes((char*) &x, sizeof(int));
}
```
show_bytes Execution Example

```c
int x = 12345; // 0x00003039
printf("int x = %d;\n",x);
show_int(x); // show_bytes((char *) &x, sizeof(int));
```

- Result (Linux x86-64):
  - **Note:** The addresses will change on each run (try it!), but fall in same general range

```
int x = 12345;
0x7ffffff7f71dbc 0x39
0x7ffffff7f71dbd 0x30
0x7ffffff7f71dbe 0x00
0x7ffffff7f71dbf 0x00
```
Summary

- Assignment in C results in value being put in memory location
- Pointer is a C representation of a data address
  - `&` = “address of” operator
  - `*` = “value at address” or “dereference” operator
- Pointer arithmetic scales by size of target type
  - Convenient when accessing array-like structures in memory
  - Be careful when using – particularly when casting variables
- Arrays are adjacent locations in memory storing the same type of data object
  - Strings are null-terminated arrays of characters (ASCII)