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http://xkcd.com/138/
Relevant Course Information

- Lab 0 due today @ 11:59 pm
  - *You will revisit the concepts from this program in future labs!*

- hw2 due Wednesday, hw3 due Friday
  - Autograded, unlimited tries, no late submissions

- Lab 1a released today, due next Monday (10/10)
  - Pointers in C
  - Last submission graded, can optionally work with a partner
    - One student submits, then add their partner to the submission
  - Short answer “synthesis questions” for after the lab
Late Days

- You are given **5 late day tokens** for the whole quarter
  - Tokens can only apply to Labs
  - No benefit to having leftover tokens

- Count lateness in **days** (even if just by a second)
  - **Special**: weekends count as *one day*
  - No submissions accepted more than two days late

- Late penalty is 10% deduction of your score per day
  - Only late labs are eligible for penalties
  - Penalties applied at end of quarter to *maximize* your grade

- Use at own risk – don’t want to fall too far behind
  - Intended to allow for unexpected circumstances
Reading Review

❖ Terminology:
  - address-of operator (&), dereference operator (\*), NULL
  - box-and-arrow memory diagrams
  - pointer arithmetic, arrays
  - C string, null character, string literal

❖ Questions from the Reading?
Review Questions

❖ int x = 351;
char* p = &x;
int ar[3];

❖ How much space does the variable p take up?
A. 1 byte
B. 2 bytes
C. 4 bytes
D. 8 bytes

❖ Which of the following expressions evaluate to an address?
A. x + 10
B. p + 10
C. &x + 10
D. *(&p)
E. ar[1]
F. &ar[2]
Pointer Operators

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

Operator confusion

▪  The pointer operators are unary (i.e., take 1 operand)
▪  These operators both have binary forms
  •  \( x \& y \) is bitwise AND (we’ll talk about this next lecture)
  •  \( x \* y \) is multiplication
▪  \* is also used as part of the data type in pointer variable declarations – this is NOT an operator in this context!
Assignment in C

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>A7 00 32 00</td>
</tr>
<tr>
<td>0x04</td>
<td>00 01 29 F3</td>
</tr>
<tr>
<td>0x08</td>
<td>EE EE EE EE</td>
</tr>
<tr>
<td>0x0C</td>
<td>FA CE CA FE</td>
</tr>
<tr>
<td>0x10</td>
<td>26 00 00 00</td>
</tr>
<tr>
<td>0x14</td>
<td>00 00 10 00</td>
</tr>
<tr>
<td>0x18</td>
<td>01 00 00 00</td>
</tr>
<tr>
<td>0x1C</td>
<td>FF 00 F4 96</td>
</tr>
<tr>
<td>0x20</td>
<td>DE AD BE EF</td>
</tr>
<tr>
<td>0x24</td>
<td>00 00 00 00</td>
</tr>
</tbody>
</table>

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

little-endian
Assignment in C

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

- Left-hand side = right-hand side;
  - LHS must evaluate to a 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 *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 *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

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 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
Assignment in C

- left-hand side = right-hand side;
  - LHS must evaluate to a 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

32-bit example (pointers are 32-bits wide)
& = “address of”
* = “dereference”
### 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;`
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
  - The target of a pointer is also a location
- `*z = y;
  - Get value of y, put in address stored in z

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

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

Declaration: `int a[6];`

- **element type**: `int`
- **name**: `a`
- **number of elements**: 6

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

- `a` (array name) returns the array’s address

64-bit example (pointers are 64-bits wide)

- `a[0]` at 0x00
- `a[1]` at 0x08
- `a[2]` at 0x10
- `a[3]` at 0x18
- `a[4]` at 0x20
- `a[5]` at 0x28
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` (array name) returns the array’s address.
- `&a[i]` is the address of `a[0]` plus `i` times the element size in bytes.
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` (array name) returns the array’s address

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

- `0x00 0x08 0x10 0x18 0x20 0x28 0x30 0x38 0x40 0x48`
- `0x0 0x1 0x2 0x3 0x4 0x5 0x6 0x7 0x8 0x9 0xA 0xB 0xC 0xD 0xE 0xF`
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;`

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

`a` (array name) returns the array’s address

`&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;}

equivalent \texttt{p = a;}
\texttt{p = \&a[0];}
\texttt{*p = 0xA;}

array indexing = address arithmetic
(both scaled by the size of the type)
equivalent \texttt{p[1] = 0xB;}
\texttt{* (p+1) = 0xB;}
\texttt{p = p + 2;}

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

\begin{verbatim}
0x00 0x08 0x10 0x18 0x20 0x28 0x30 0x38 0x40 0x48
AD 0B 00 00 0A 00 00 00 0B 00 00 00 00 01 00 00 00
\end{verbatim}
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;`
- equivalent `[p = a; p = &a[0]; *p = 0xA;]

array indexing = address arithmetic (both scaled by the size of the type)
- equivalent `[p[1] = 0xB; *(p+1) = 0xB; p = p + 2;]

*p = a[1] + 1;`
Question: The variable values after Line 3 executes are shown on the right. What are they after Line 5?

- Vote in Ed Lessons

```
1    void main() {
2        int a[] = {0x5, 0x10};
3        int* p = a;
4        p = p + 1;
5        *p = *p + 1;
6    }
```

<table>
<thead>
<tr>
<th></th>
<th><strong>p</strong></th>
<th><strong>a[0]</strong></th>
<th><strong>a[1]</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>0x101</td>
<td>0x5</td>
<td>0x11</td>
</tr>
<tr>
<td>(B)</td>
<td>0x104</td>
<td>0x5</td>
<td>0x11</td>
</tr>
<tr>
<td>(C)</td>
<td>0x101</td>
<td>0x6</td>
<td>0x10</td>
</tr>
<tr>
<td>(D)</td>
<td>0x104</td>
<td>0x6</td>
<td>0x10</td>
</tr>
</tbody>
</table>
Representing strings (Review)

❖ C-style string stored as an array of bytes (char*)

▪ No “String” keyword, unlike Java
▪ Elements are one-byte ASCII codes for each character

<table>
<thead>
<tr>
<th>ASCII</th>
<th>Character</th>
</tr>
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<tbody>
<tr>
<td>32</td>
<td>space</td>
</tr>
<tr>
<td>33</td>
<td>!</td>
</tr>
<tr>
<td>34</td>
<td>&quot;</td>
</tr>
<tr>
<td>35</td>
<td>#</td>
</tr>
<tr>
<td>36</td>
<td>$</td>
</tr>
<tr>
<td>37</td>
<td>%</td>
</tr>
<tr>
<td>38</td>
<td>&amp;</td>
</tr>
<tr>
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<td>'</td>
</tr>
<tr>
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<td>(</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>43</td>
<td>+</td>
</tr>
<tr>
<td>44</td>
<td>,</td>
</tr>
<tr>
<td>45</td>
<td>-</td>
</tr>
<tr>
<td>46</td>
<td>.</td>
</tr>
<tr>
<td>47</td>
<td>/</td>
</tr>
<tr>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td>49</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
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<td>51</td>
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<td>8</td>
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<td>57</td>
<td>9</td>
</tr>
<tr>
<td>58</td>
<td>:</td>
</tr>
<tr>
<td>59</td>
<td>;</td>
</tr>
<tr>
<td>60</td>
<td>&lt;</td>
</tr>
<tr>
<td>61</td>
<td>=</td>
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<tr>
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<td>&gt;</td>
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<tr>
<td>63</td>
<td>?</td>
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<td>64</td>
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</tr>
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<td>A</td>
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<tr>
<td>66</td>
<td>B</td>
</tr>
<tr>
<td>67</td>
<td>C</td>
</tr>
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<td>68</td>
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</tr>
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<td>73</td>
<td>I</td>
</tr>
<tr>
<td>74</td>
<td>J</td>
</tr>
<tr>
<td>75</td>
<td>K</td>
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<td>92</td>
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<tr>
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</tr>
<tr>
<td>95</td>
<td>_</td>
</tr>
<tr>
<td>96</td>
<td>`</td>
</tr>
<tr>
<td>97</td>
<td>a</td>
</tr>
<tr>
<td>98</td>
<td>b</td>
</tr>
<tr>
<td>99</td>
<td>c</td>
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<td>100</td>
<td>d</td>
</tr>
<tr>
<td>101</td>
<td>e</td>
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<td>102</td>
<td>f</td>
</tr>
<tr>
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<td>g</td>
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<td>104</td>
<td>h</td>
</tr>
<tr>
<td>105</td>
<td>i</td>
</tr>
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<td>106</td>
<td>j</td>
</tr>
<tr>
<td>107</td>
<td>k</td>
</tr>
<tr>
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<td>l</td>
</tr>
<tr>
<td>109</td>
<td>m</td>
</tr>
<tr>
<td>110</td>
<td>n</td>
</tr>
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<td>111</td>
<td>o</td>
</tr>
<tr>
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<td>p</td>
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<td>q</td>
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<td>r</td>
</tr>
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<td>115</td>
<td>s</td>
</tr>
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</tr>
<tr>
<td>117</td>
<td>u</td>
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<tr>
<td>118</td>
<td>v</td>
</tr>
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<td>w</td>
</tr>
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<td>120</td>
<td>x</td>
</tr>
<tr>
<td>121</td>
<td>y</td>
</tr>
<tr>
<td>122</td>
<td>z</td>
</tr>
<tr>
<td>123</td>
<td>{</td>
</tr>
<tr>
<td>124</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>}</td>
</tr>
<tr>
<td>126</td>
<td>~</td>
</tr>
<tr>
<td>127</td>
<td>del</td>
</tr>
</tbody>
</table>

ASCII: American Standard Code for Information Interchange
Representing strings (Review)

- C-style string stored as an array of bytes (**char** *)
  - No “String” keyword, unlike Java
  - Elements are one-byte ASCII codes for each character
  - Last character followed by a 0 byte (**' \0 '**) (a.k.a. the **null character**)

<table>
<thead>
<tr>
<th>Decimal</th>
<th>83</th>
<th>116</th>
<th>97</th>
<th>121</th>
<th>32</th>
<th>115</th>
<th>97</th>
<th>102</th>
<th>101</th>
<th>32</th>
<th>87</th>
<th>65</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hex</td>
<td>0x53</td>
<td>0x74</td>
<td>0x61</td>
<td>0x79</td>
<td>0x20</td>
<td>0x73</td>
<td>0x61</td>
<td>0x66</td>
<td>0x65</td>
<td>0x20</td>
<td>0x57</td>
<td>0x41</td>
<td>0x00</td>
</tr>
<tr>
<td>Text</td>
<td>'S'</td>
<td>'t'</td>
<td>'a'</td>
<td>'y'</td>
<td>' '</td>
<td>'s'</td>
<td>'a'</td>
<td>'f'</td>
<td>'e'</td>
<td>' '</td>
<td>'W'</td>
<td>'A'</td>
<td>'\0'</td>
</tr>
</tbody>
</table>
Endianness and Strings

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

C (char = 1 byte)

IA32, x86-64 (little-endian)

<table>
<thead>
<tr>
<th>Address (Hex)</th>
<th>Value (Dec)</th>
<th>ASCII Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>31</td>
<td>'1'</td>
</tr>
<tr>
<td>0x01</td>
<td>32</td>
<td>'2'</td>
</tr>
<tr>
<td>0x02</td>
<td>33</td>
<td>'3'</td>
</tr>
<tr>
<td>0x03</td>
<td>34</td>
<td>'4'</td>
</tr>
<tr>
<td>0x04</td>
<td>35</td>
<td>'5'</td>
</tr>
<tr>
<td>0x05</td>
<td>00</td>
<td>'\0'</td>
</tr>
</tbody>
</table>

SPARC (big-endian)

<table>
<thead>
<tr>
<th>Address (Hex)</th>
<th>Value (Dec)</th>
<th>ASCII Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>31</td>
<td>'1'</td>
</tr>
<tr>
<td>0x01</td>
<td>32</td>
<td>'2'</td>
</tr>
<tr>
<td>0x02</td>
<td>33</td>
<td>'3'</td>
</tr>
<tr>
<td>0x03</td>
<td>34</td>
<td>'4'</td>
</tr>
<tr>
<td>0x04</td>
<td>35</td>
<td>'5'</td>
</tr>
<tr>
<td>0x05</td>
<td>00</td>
<td>'\0'</td>
</tr>
</tbody>
</table>

- 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
Examining Data Representations

❖ Code to print byte representation of data
  ▪ Treat any data type as a byte array by casting its address 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\t%0x%.2hhX\n", start+i, *(start+i));
    printf("\n");
}
```

❖ printf directives:
  ▪ %p       Print pointer
  ▪ \t       Tab
  ▪ %0x%.2hhX Print value as char (hh) in hex (X), padding to 2 digits (. 2)
  ▪ \n       New line
Examining Data Representations

❖ Code to print byte representation of data

- Treat any data type as a *byte array* by **casting** its address 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%.2hhX\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 = 123456; // 0x00 01 E2 40
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

```c
int x = 123456;
0x7fffb245549c  0x40
0x7fffb245549d  0xE2
0x7fffb245549e  0x01
0x7fffb245549f  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)