Memory, Data, & Addressing II
CSE 351 Autumn 2021

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

❖ Lab 0 due today @ 11:59 pm
  ▪ You will revisit this concepts from program!

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

❖ Lab 1a released today, due next Monday (10/11)
  ▪ 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 20% 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

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

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

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 = &y + 3;`
  - Get address of y, “add 3”, store in z

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

& = “address of”
★ = “dereference”

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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;`

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;`
  - Get value of y, put in address stored in z

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

& = “address of”
* = “dereference”
Addresses and Pointers in C (Review)

❖ Draw out a box-and-arrow diagram for the result of the following C code:

```c
int* ptr;

int x = 5;

int y = 2;

ptr = &x;

y = 1 + *ptr;
```
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):
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

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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: `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)

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Adjustment by the element size in bytes

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

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

a (array name) returns the array’s address

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

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Adjustment by the element size in bytes
Arrays in C

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

Indexing: \begin{align*}
a[0] &= 0x015f; \\
a[5] &= a[0];
\end{align*}

No bounds \begin{align*}
a[6] &= 0xBAD;
\end{align*}
checking: \begin{align*}
a[-1] &= 0xBAD;
\end{align*}

Pointers: \begin{align*}
\texttt{int* p;}
\end{align*}

\begin{align*}
\text{equivalent } &p = a; \\
&\text{equivalent } p = \&a[0]; \\
&\text{equivalent } *p = 0xA;
\end{align*}

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

\begin{align*}
\text{equivalent } &p[1] = 0xB; \\
&\text{equivalent } *(p+1) = 0xB; \\
&p = p + 2;
\end{align*}

\begin{align*}
*p &= a[1] + 1;
\end{align*}
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      }

(A) 0x101  0x5  0x11
(B) 0x104  0x5  0x11
(C) 0x101  0x6  0x10
(D) 0x104  0x6  0x10
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>
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<td>&gt;</td>
<td>78</td>
<td>N</td>
<td>94</td>
<td>^</td>
<td>110</td>
<td>n</td>
</tr>
<tr>
<td>47</td>
<td>/</td>
<td>63</td>
<td>?</td>
<td>79</td>
<td>O</td>
<td>95</td>
<td>_</td>
<td>111</td>
<td>o</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></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>83</td>
<td>116</td>
<td>97</td>
<td>121</td>
<td>32</td>
<td>115</td>
<td>97</td>
<td>102</td>
<td>101</td>
<td>32</td>
<td>87</td>
<td>65</td>
</tr>
<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>
</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>
</tr>
</tbody>
</table>

Dec: 83 116 97 121 32 115 97 102 101 32 87 65 0
Hex: 0x53 0x74 0x61 0x79 0x20 0x73 0x61 0x66 0x65 0x20 0x57 0x41 0x00
Text: 'S' 't' 'a' 'y' ' ' 's' 'a' 'f' 'e' ' ' 'W' 'A' '\0'
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**

```c
0x31 = 49 decimal = ASCII '1'
```

<table>
<thead>
<tr>
<th>IA32, x86-64 (little-endian)</th>
<th>SPARC (big-endian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00 31</td>
<td>31 0x00 '1'</td>
</tr>
<tr>
<td>0x01 32</td>
<td>32 0x01 '2'</td>
</tr>
<tr>
<td>0x02 33</td>
<td>33 0x02 '3'</td>
</tr>
<tr>
<td>0x03 34</td>
<td>34 0x03 '4'</td>
</tr>
<tr>
<td>0x04 35</td>
<td>35 0x04 '5'</td>
</tr>
<tr>
<td>0x05 00</td>
<td>00 0x05 '\0'</td>
</tr>
</tbody>
</table>

C (char = 1 byte)
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");
}
```

❖ *printf* directives:
  ▪ %p Print pointer
  ▪ \t Tab
  ▪ %.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 !!

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    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)