This is Week 4

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Agenda

- Resources + Announcements
- Review
  - Problem Set 2
- Memory, Part 1
  - Hexadecimal numbers
  - Stack
- Pointers
- Memory, Part 2
  - Heap
  - Dynamic memory allocation
  - Arrays
- Merge Sort

Resources + Announcements

- Problem Set 4 Walkthrough (Sun, 7pm, NW B103) – https://www.cs50.net/psets/
- Office Hours – https://www.cs50.net/ohs/
- Lecture videos, slides, source code, scribe notes – https://www.cs50.net/lectures/
- Bulletin Board – http://help.cs50.net
- Problem Set feedback and scores
  - pset1, pset2 – all ready sent out!
  - pset3 – Thursday
- Quiz 0 (Wed, 10/12) – https://www.cs50.net/quizzes/

Review

pset2 - Correctness

- Make sure your code compiles
  - Run a fresh `make` of each program before you submit
- Make sure your code works properly
  - Compare its results to the staff solution's results
  - Check corner cases

pset2 - Style

- Block comments at the beginning of each file

```
/*
 * caesar.c
 *
 * Computer Science 50
 * Jason Hirschhorn
 *
 * Encrypts a phrase using a Caesar cipher.
 */
```

pset2 - Style

```
int main(int argc, char *argv[])
{
    // validates user input
    if(argc != 2)
        return 1;

    // creates variables to store name and length
    char *name = argv[1];
    int length = strlen(name);

    // ensures each character is a valid letter
    for(int i = 0; i < length; i++)
    {
        if(!isalpha(name[i])
            return 1;
    }
}
```

Appropriately detailed inline comments

Consistent indentation

Self-explanatory variable names (smaller scope = shorter name)

Memory, Part 1

Memory

- Code and data for your program are stored in random-access memory (RAM)
- Memory is a huge array of 1 byte (8 bits) blocks
- Each block has a numerical address
- We use hexadecimal numbers to concisely represent the memory addresses of these blocks

Hexadecimal Numbers

- Hexadecimal = numbers are in base 16
  - 0 to 9 then A to F

0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7

8	9	10	11	12	13	14	15
8	9	A	B	C	D	E	F

Hexadecimal Numbers

- Every set of 4 bits (a “nibble,” or half a “byte”) can be represented by 1 hex digit
- To signal that we’re using hexadecimal, we start with “0x”

8s	4s	2s	1s
1	0	0	1
0x9			

8s	4s	2s	1s
1	1	1	0
0xE			

8s	4s	2s	1s
0	1	1	1
0x7			

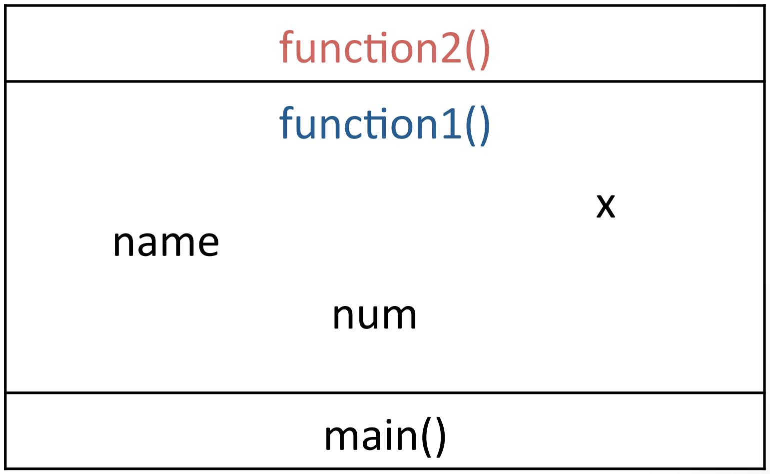
8s	4s	2s	1s
1	0	1	0
0xA			

Stack

- A part of memory
  - Need to store something? Put it on top
  - Done with something? Take it off
- Each function that's called gets its own block
  - "Frame"
  - It puts the variables it creates in its frame
- When a function returns, its frame becomes inaccessible

function1 creates

```
int num = 5;
string name = “cs50”;
char x = ‘a’;
```



Pointers

Pointers

- Data stored in memory has both a *value* and an *address*
- A pointer is a special type of variable
  - Its value *is* an address
- How big is a pointer?
  - Every memory address is 4 bytes (32 bits)
  - So a pointer is also 4 bytes
  - No matter what type it is

Quick Quiz

- What are the following hexadecimal numbers?

8s	4s	2s	1s
1	1	0	1

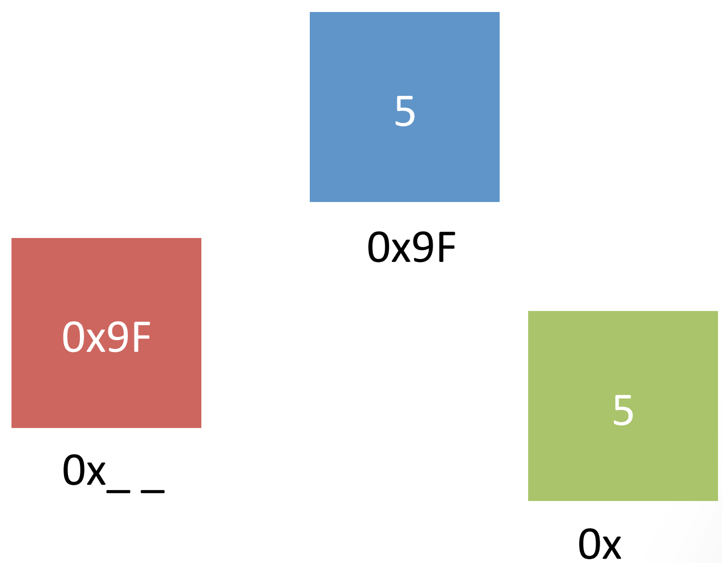
8s	4s	2s	1s
0	1	0	1

8s	4s	2s	1s
1	0	1	1

Using Pointers

- `<type>* <variable name>` declares a pointer
  - It will hold an address, not a value
- `&<variable name>` gets the address of a variable
- `*<variable name>` goes to the address stored in the variable and gets its value

```
int x = 5;
int* y = &x;
int copy = *y;
```



Examples

```
char m = ‘A’;
char* n = &m;
```

- What is m? What is n?
- If I want `char p` to be ‘A’, what two things can I set it equal to?

```
int x = 13;
int* y = &x;
*y = (*y) * 2;
```

- What is x?
- What is y?

```
int a = 3, b = 4, c = 5;
int *pa = &a, *pb = &b, *pc = &c;
```

- What happens after each statement?

```
a = b * c;
a *= c;
b = *pa;
pc = pa;
*pb = b * c;
c = (*pa) * (*pc);
```

Practice Problems

- address.c
  - Concepts to practice – pointers
- pointers.c
  - Concepts to practice – pointers (these take a ton of practice)


MAN, I SUCK AT THIS GAME. CAN YOU GIVE ME A FEW POINTERS?
0x3A28213A 0x6339392C, 0x7363682E.
I HATE YOU.

Memory, Part 2

Heap

- Sometimes we want our variables to stay in memory after a function returns
  - Remember, local variables are stored in the stack
  - Stack frames go away after a function returns
- So, we can store these variables on the heap
  - Another part of memory
  - Separate from the stack
- Data on the heap won't get overwritten
  - We get to choose when it gets created and destroyed
- However, we have to explicitly reserve this memory

Dynamic Memory Allocation

- Requesting memory on the fly
- `void* malloc(int <number of bytes>)`
  - Reserves a block of memory on the heap
  - Returns the address of this block
- `sizeof(<data type>)`
  - Returns the number of bytes a given type occupies
- `void free(void* <name of pointer>)`
  - Frees up the reserved memory

Quick Quiz

- How many bytes is an `int`? A `char`? An `int*`? A `char*`?

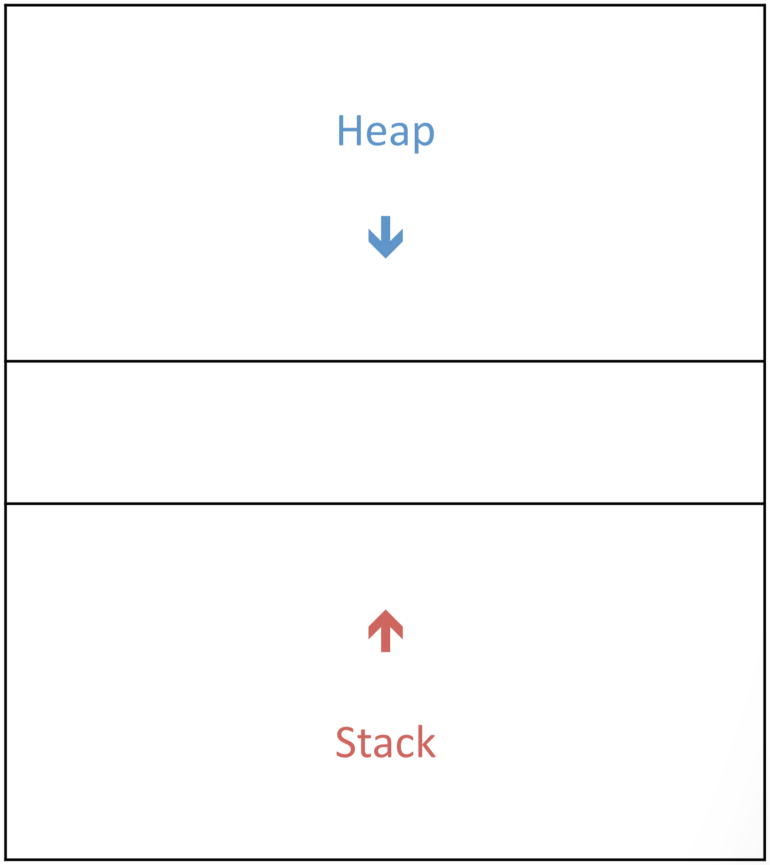
Dynamic Memory Allocation

```
// reserves enough space to store 10 chars
char* x = malloc(sizeof(char) * 10);

// frees this reserved block
free(x);
```

Stack vs. Heap

- Contains global variables
- Dynamically allocated memory



- Contains local variables
- Function calls create new frames

Heap.c

- Concepts to practice – pointers, dynamic memory allocation, the heap
- When using `malloc`, always remember to…
  - Check whether it returns null
  - Free the allocated memory exactly once
- Compare to stack.c

Pointer Arithmetic

- Adding an integer n to a pointer shifts the pointer over
- Shift = n * sizeof(<type of pointer>) bytes
- The address of x is 0x04

```
int x;
int* y = &x; // y has the value 0x04
y += 1; // y has the value 0x08
```

- Why?

Quick Quiz

- The address of x is 0xAA

```
char x;
char* y = &x; // what is the value of y?
y += 1; // what about now?
```

Arrays

- Arrays are pointers!

char array[4];

F	O	P	3
array[0]	array[1]	array[2]	array[3]
*array	*(array + 1)	*(array + 2)	*(array + 3)

Array.c

- Concepts to practice – command line arguments, dynamic memory allocation, pointers, pointer arithmetic

```
// counts up to a given number
#include <stdio.h>
#include <stdlib.h>

int
main(int argc, char* argv[])
{
    // ensure user enters an integer greater than 0
    // use malloc to initialize a new array of size = argv[1]
    /* use pointer arithmetic to store integers
       starting at 0 */
    // use index notation to add 1 to each element
    // print each element of final array
}
```

Merge Sort

Merge Sort

- Yet another sorting algorithm
  - Like bubble sort and selection sort, but way better!

Method

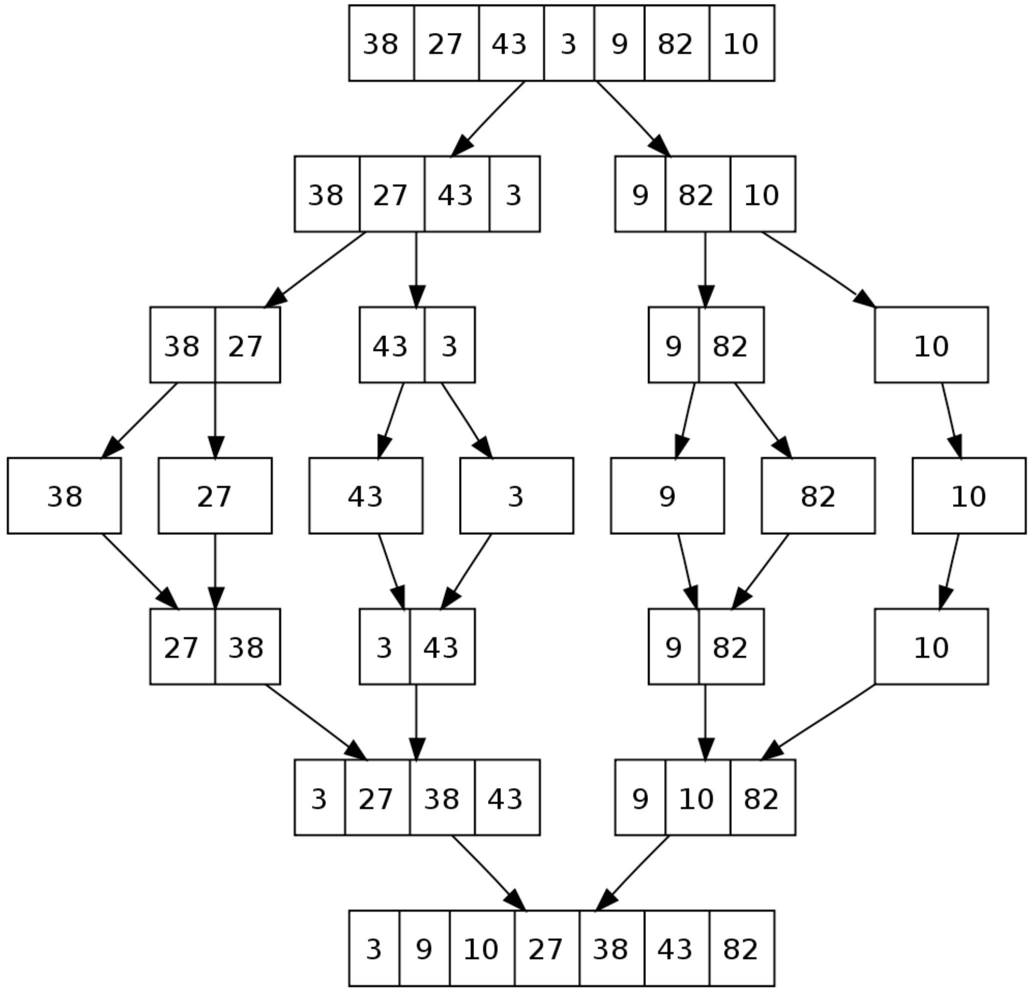
- If the list is length 0 or 1, it is already sorted
- Else divide the unsorted list into two halves
  - Sort each half
  - Merge the two halves into one sorted list
    - Compare first element of each half
    - Put lowest overall in front of new sorted list
    - Keep moving down each half until one runs out

Merge Sort

Unsorted list

Base cases

Sorted list



Running Time

Big O

- O(n log n)
- Breaking a list in half and rebuilding it = O(log n)
- Sorting each half = O(n)

That was Week 4

http://xkcd.com/179/