15-122: Principles of Imperative Computation

Recitation 11

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Memory layout

So far in 122, we've been ignoring the details of how and where C0 stores things in memory. Today we're going to talk about how exactly that works.

On the machines we'll be talking about in this class (those that have an x86 architecture), memory is laid out as follows:



A key idea here is that everything in memory has an address. C0 doesn't let you get all of these addresses, though. (Being able to get every address can be useful, but also makes it much easier to write code that crashes or has security vulnerabilities.) In C0 the only way to get a pointer (an address of something) is to use the alloc or alloc_array functions.

The key sections of memory we'll be talking about are the *stack*, the *heap*, *text* (where code is stored—yes, it's a confusing name) and *data*, where constants and global variables are stored. We won't talk about the data section for now, since C0 doesn't have any constants or global variables.

The *text* section contains the instructions that tell the computer what to do (the compiled version of your programs, for instance). For this class you don't need to know much more about it than that, but if you take systems classes like 213 and courses that follow it you'll learn more about it.

The *heap* is where memory allocated when you call alloc or alloc_array is placed. For instance, if I say int[] a = alloc_array(int, 30); then the array a will be located on the heap. Similarly, if I write int* b = alloc(int); then b will be a pointer to an int and that int will be on the heap. b itself is stored on the stack (more on that in a moment).

The *stack* contains local variables that aren't allocated with alloc or alloc_array, arguments to functions (depending on your architecture, which you don't need to worry about for this class), and various information necessary for your functions to run and return. Whenever you call a new function, the stack grows (towards lower addresses) to make room for the *callee*'s variables and arguments.

Let's look at an example of how the stack grows when we call functions. (Credit for these diagrams goes to the 15-213 lecture slides. If you want to view them (you don't need to know the material until you take 213), they're at http://www.cs.cmu.edu/~213/lectures/07-machine-procedures.pdf)

Consider this code (someone in 213 chose strange names for functions) after a call to yoo.

```
1 int amI(int a, int b)
2 {
3
     if (b == 1) {
4
         // do some stuff
5
         return a;
6
     }
7
     return amI(a, 1) + b;
8 }
9 int who(int a, int b, int c)
10 {
11
     // do something
12
     return amI(a * tmp, c);
13 }
14 int yoo(int a, int b)
15 {
16
     int someLocalVariable = 2 * a + b;
17
     // do something
     return who(a, b, someLocalVariable);
18
19 }
```



The diagrams show how the stack changes as we call functions: The first diagram is before we call who, the second is after we call who, the third is after we call amI, the fourth is after amI calls itself, and then the rest are after functions start returning: the fifth is after amI returns, the sixth is after amI returns, and the seventh is after who returns.

In the stack frame for yoo we have someLocalVariable stored as well as necessary information for the function call to work.

Recursion

As we saw above, when a function calls itself it grows the stack. This is because each call of the function needs its own space for local variables and information that allows it to return to the function that called it. For more detail, see the section in this handout called "Recursion".

To prove correctness of a recursive function, we follow a somewhat similar process to the one we use to show that an iterative function is correct.

First, we show partial correctness (i.e., if the code terminates it is correct) and then we show termination, just as we do when we have loops. The way we do this is somewhat different, though.

We show partial correctness by induction: First, we show correctness for some kind of base case and then we show that if our function is correct for some fixed input it is true for a larger input. (In other words: we assume that the recursive call returns correctly and show that that means this function call returns correctly)

Then, we show that for any valid input, the function must eventually terminate.

Iterative vs. recursive factorial

Consider the following implementations of the factorial function, and try to prove that it satisfies its postcondition.

```
1 int factIter(int n)
2 //@requires n >= 0;
3 {
4
     // You can assume that this function is correctly implemented.
5
     // That is, you can assume factIter(n) is equal to n!
6 }
7
8 int factRec(int n)
9 //@requires n >= 0;
10 //@ensures \result == factIter(n);
11 {
     if (n == 0) {
12
13
        return 1;
14
     }
     else {
15
16
        return n * factRec(n - 1);
     }
17
18 }
```