CSE 333

Lecture 2 - arrays, memory, pointers

Hal Perkins
Department of Computer Science & Engineering
University of Washington

Administrivia 1

ex0 was due 30 minutes ago! Solution posted after class

- let us know if you had any logistical problems with it

ex1 out now, due before class Friday

hw0 out soon - once we're happy with the setup

- Logistics and infrastructure - should be quick
- Demos in sections tomorrow
- **Please log in to CSE gitlab if you've never done that**

Reference system (grading, etc.) is CSE lab/VM Linux

Administrivia 2

Communications

- Use discussion board when possible
  - Contribute & read - help each other out
  - **Everyone** ~~should~~ **must** post a followup to the "welcome" message - get gopost to track new messages for you
- Mail to cse333-staff@cs when needed (not individual staff if possible)

If you're not registered…

- Please fill out the signup sheet after class if you didn't before
- We should be able to fit most CSE majors, but probably not non-majors
- One alternative: CSE 333 will be offered this summer

Today’s agenda

More C details

- functions
- arrays
- refresher on C’s memory model
  - address spaces
  - the stack
  - brief reminder of pointers

Defining a function

returnType name(type name, ..., type name) {
statements;
}

sum_fragment.c

```
// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i=1; i<=max; i++) {
    sum += i;
  }
  return sum;
}
```

Problem: ordering

You shouldn't call a function that hasn't been declared yet

sum_badorder.c

```
#include <stdio.h>

int main(int argc, char **argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}

// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i=1; i<=max; i++) {
    sum += i;
  }
  return sum;
}
```

Problem: ordering

Solution 1: reverse order of definition

sum_betterorder.c

```
#include <stdio.h>

// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i=1; i<=max; i++) {
    sum += i;
  }
  return sum;
}

int main(int argc, char **argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}
```

Problem: ordering

Solution 2: provide a declaration of the function

- teaches the compiler the argument and return types of the function
- then definitions can be in a logical order, not who-calls-what

```
#include <stdio.h>

// this function prototype is
// a declaration of sumTo
int sumTo(int);

int main(int argc, char **argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}

// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i=1; i<=max; i++) {
    sum += i;
  }
  return sum;
}
```

sum_declared.c

Declaration vs Definition

C/C++ make a careful distinction between these

Definition: The thing itself

- Code for function; a global variable definition that creates storage
- Must be **exactly one** actual definition of each thing (no dups)

Declaration: Description of a thing, repeated in all files that use it

- Function prototype or external variable declaration
  - Often in header files and incorporated via #include
  - Should also #include declaration in the file with the actual definition to check consistency
- Should occur before first use

Arrays

type name[size];

```
int scores[100];
```

example allocates 100 ints' worth of memory

- initially, each array element contains garbage data

an array does not know its own size

- sizeof(scores) is not reliable; only works in some situations
- recent versions of C allow the array size to be an expression
  - But not good practice to put large data in local stack frames (performance)

```
int n=100;
int scores[n];   // OK in C99
```

Initializing and using arrays

type name[size] = {value, value, ..., value};

- allocates an array and fills it with supplied values
- if fewer values are given than the array size, fills rest with 0
- only works for initialization - can't assign whole array values later

name[index] = expression;

- sets the value of an array element

```
int primes[6] = {2, 3, 5, 6, 11, 13};
primes[3] = 7;
primes[100] = 0;    // smash!
```

```
// 1000 zeroes
int allZeroes[1000] = {0};
```

Multi-dimensional arrays

type name[rows][columns] = {{values}, ..., {values}};

- allocates a 2D array and fills it with predefined values

```
// a 2 row, 3 column array of doubles
double grid[2][3];

// a 3 row, 5 column array of ints
int matrix[3][5] = {
  {0, 1, 2, 3, 4},
  {0, 2, 4, 6, 8},
  {1, 3, 5, 7, 9}
};
```

matrix.c

Parameters: reference vs value

Two fundamental parameter-passing schemes

Call-by-value

- Parameter is a local variable initialized when the function is called, but has no connection with the calling argument after that [C: almost everything, Java: everything (primitive types, references values)]

Call-by-reference

- Parameter is an alias for the actual argument supplied in the call (which must be a variable); it is not a separate local variable in the function [C/C++ arrays, C++ references]

Arrays as parameters

It's tricky to use arrays as parameters

- arrays are effectively passed by reference (not copied)
  - "array promotion" - array name treated as pointer to first element
- arrays do not know their own size

```
int sumAll(int a[]);  // prototype declaration

int main(int argc, char **argv) {
  int numbers[5] = {3, 4, 1, 7, 4};
  int sum = sumAll(numbers);
  return 0;
}

int sumAll(int a[]) {
  int i, sum = 0;
  for (i = 0; i < ...???
}
```

Arrays as parameters

Solution 1: declare the array size in the function

- problem: code isn't very flexible

```
int sumAll(int a[5]);

int main(int argc, char **argv) {
  int numbers[5] = {3, 4, 1, 7, 4};
  int sum = sumAll(numbers);
  printf("sum is: %d\n", sum);
  return 0;
}

int sumAll(int a[5]) {
  int i, sum = 0;

  for (i = 0; i < 5; i++) {
    sum += a[i];
  }
  return sum;
}
```

Arrays as parameters

Solution 2: pass the size as a parameter

```
int sumAll(int a[], int size);

int main(int argc, char **argv) {
  int numbers[5] = {3, 4, 1, 7, 4};
  int sum = sumAll(numbers, 5);
  printf("sum is: %d\n", sum);
  return 0;
}

int sumAll(int a[], int size) {
  int i, sum = 0;

  for (i = 0; i <= size; i++) {    //  CAN YOU SPOT THE BUG?
    sum += a[i];
  }
  return sum;
}
```

arraysum.c

Returning an array

Local variables, including arrays, are stack allocated

- they disappear when a function returns
- therefore, local arrays can't be safely returned from functions (can't assign/return whole arrays as values)

```
int *copyarray(int src[], int size) {
  int i, dst[size];   // OK in C99

  for (i = 0; i < size; i++) {
    dst[i] = src[i];
  }
  return dst;   // no -- buggy
}
```

buggy_copyarray.c

Solution: an output parameter

Create the "returned" array in the caller

- pass it as an ***output parameter*** to copyarray
- works because arrays are effectively passed by reference

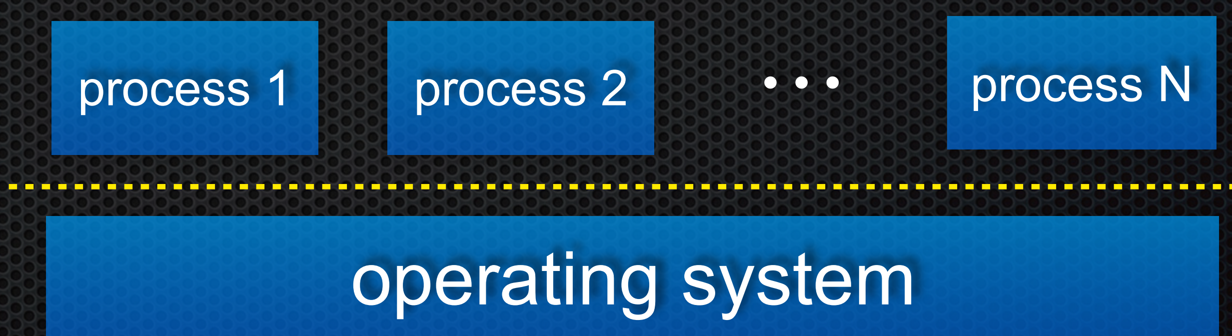
```
void copyarray(int src[], int dst[], int size) {
  int i;

  for (i = 0; i < size; i++) {
    dst[i] = src[i];
  }
}
```

copyarray.c

OS and processes

The OS lets you run multiple applications at once

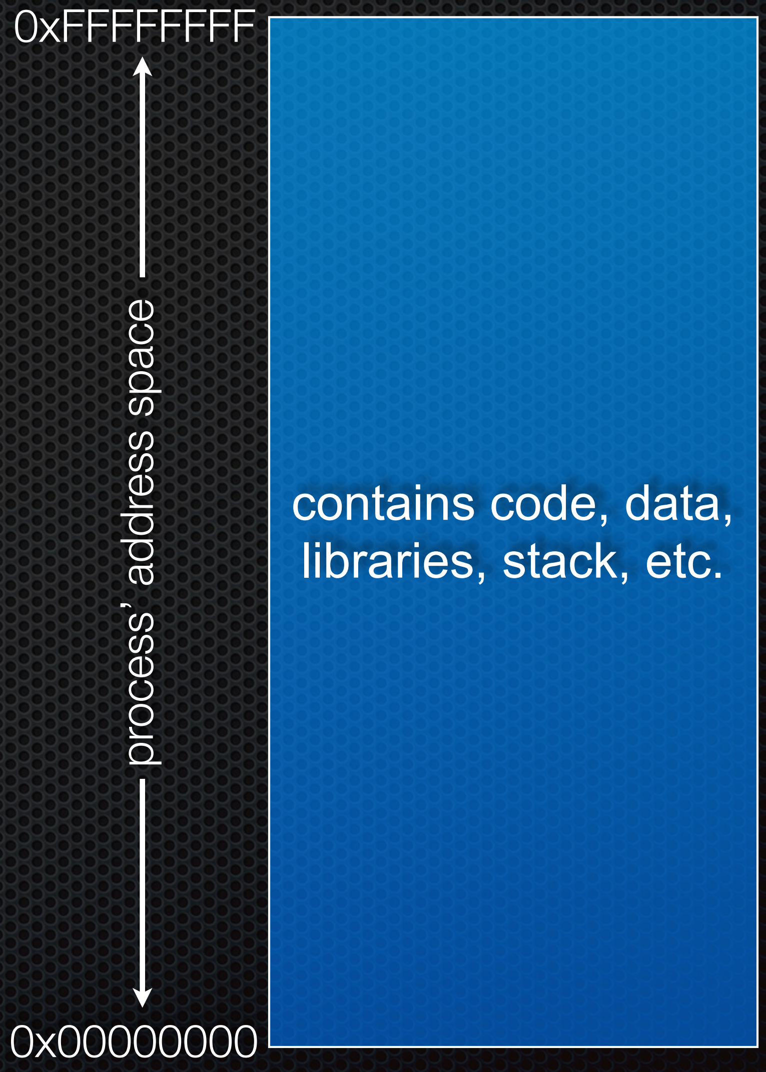
- an application runs within an OS "process"
- the OS timeslices each CPU between runnable processes
  - happens very fast; ~100 times per second!



Processes and virtual memory

OS gives each process the illusion of its own, private memory

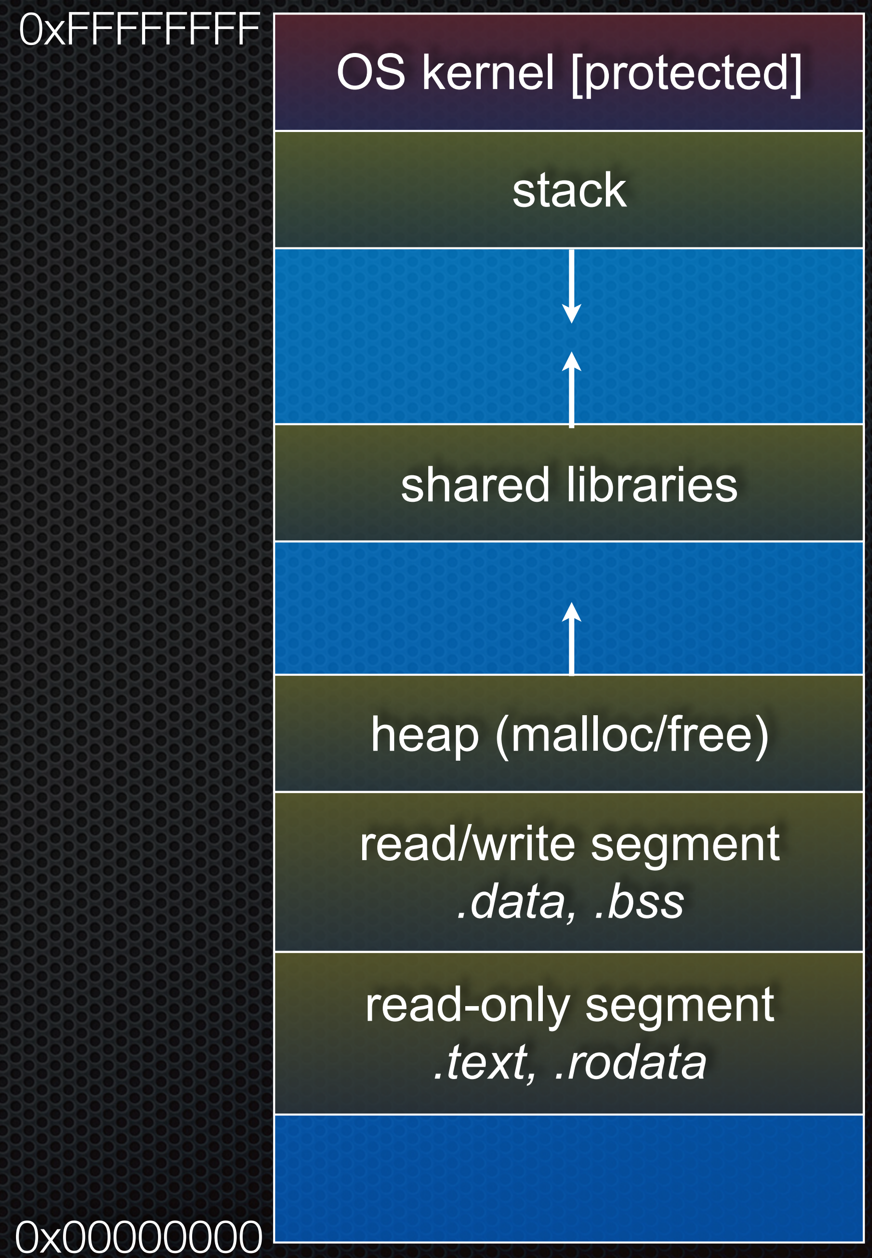
- this is called the process' ***address space***
- contains the process' virtual memory, visible only to it
- 2^{32} bytes on 32 bit host
- 2^{64} bytes on 64 bit host



Loading

When the OS loads a program, it:

- creates an address space
- inspects the executable file to see what's in it
- (lazily) copies regions of the file into the right place in the address space
- does any final linking, relocation, or other needed preparation



The stack

```
int f(int p1, int p2) {
 int x;
 int a[3];
 ...
 return x;
}
```

Used to store data associated with function calls

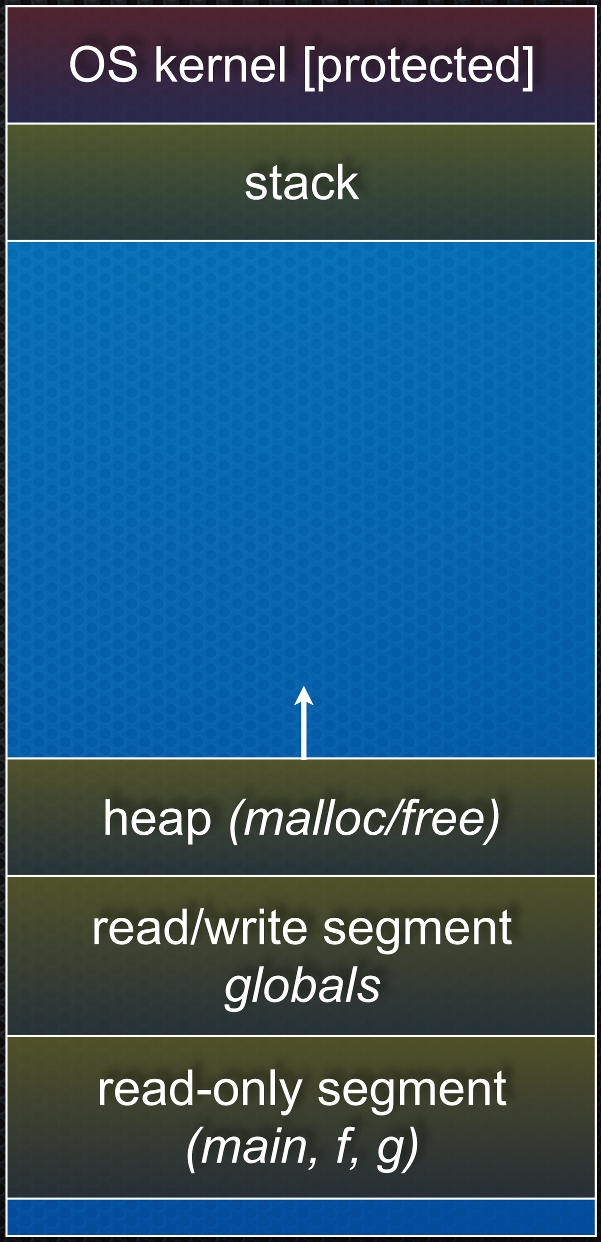
- when you call a function, compiler-inserted code will allocate a stack frame to store:
  - the function call arguments
    - (x86-64 args passed in registers, but copies often saved in frame)
  - the address to return to
  - local variables used by the function
  - a few other pieces of bookkeeping

offset	contents
24	p2
20	p1
16	return address
12	a[2]
8	a[1]
4	a[0]
0	x

a stack frame

The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



The stack in action

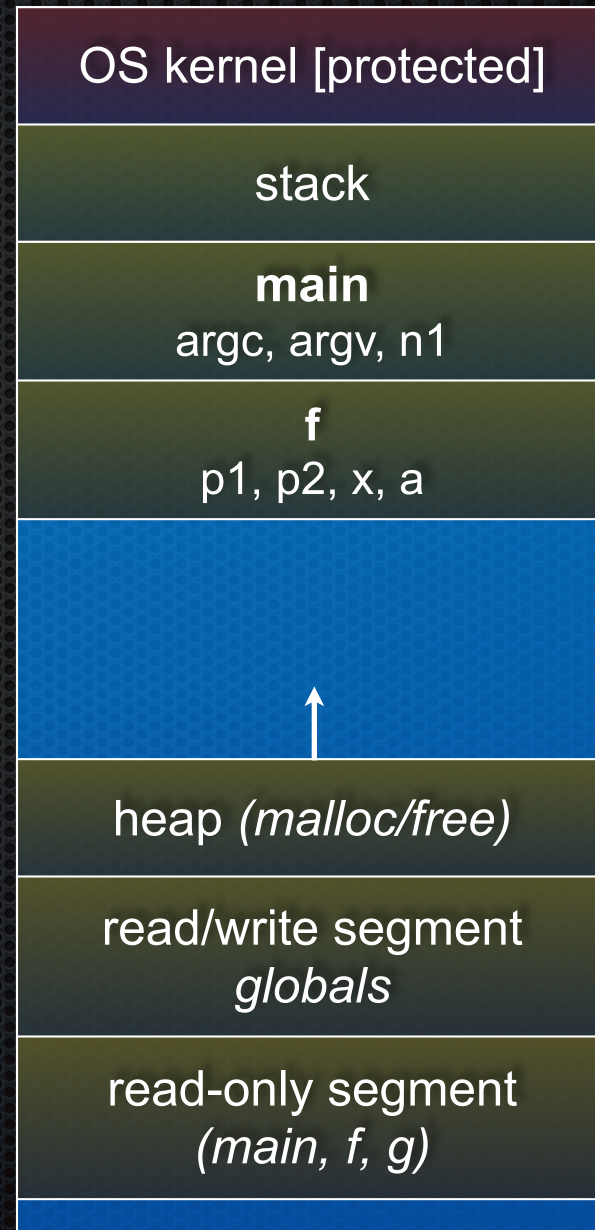
```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```

The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```

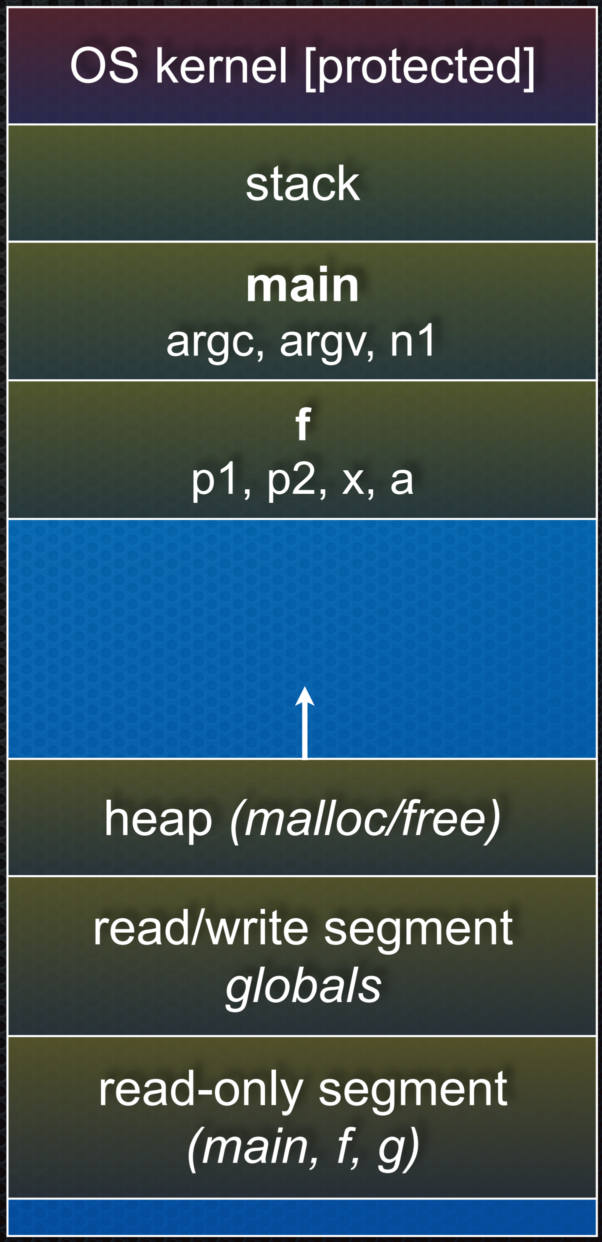
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



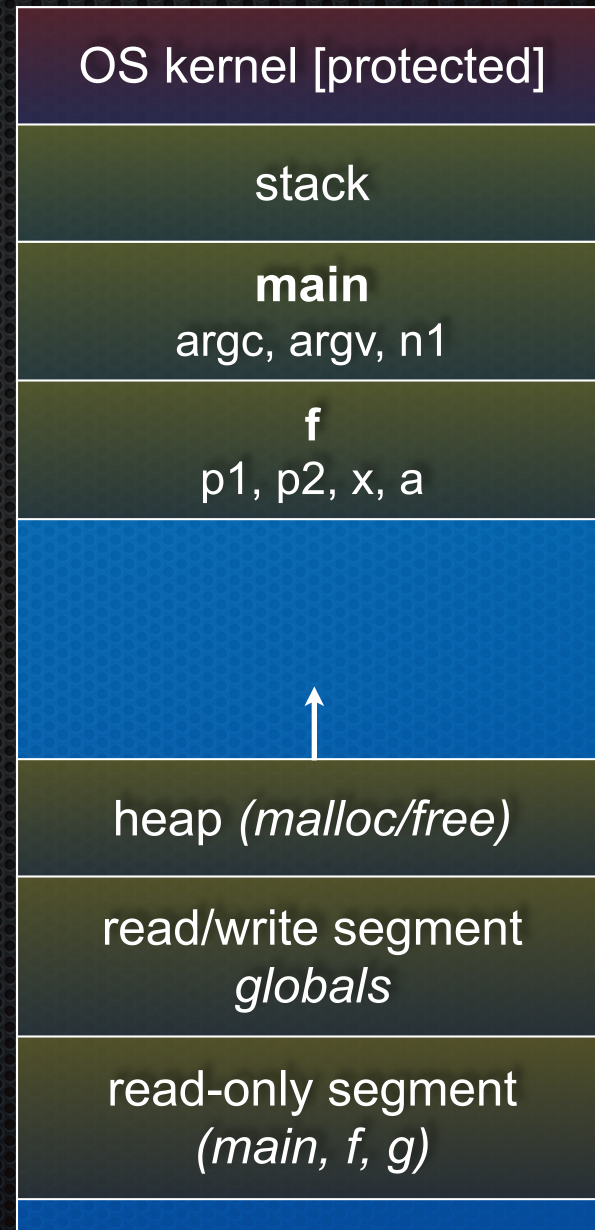
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



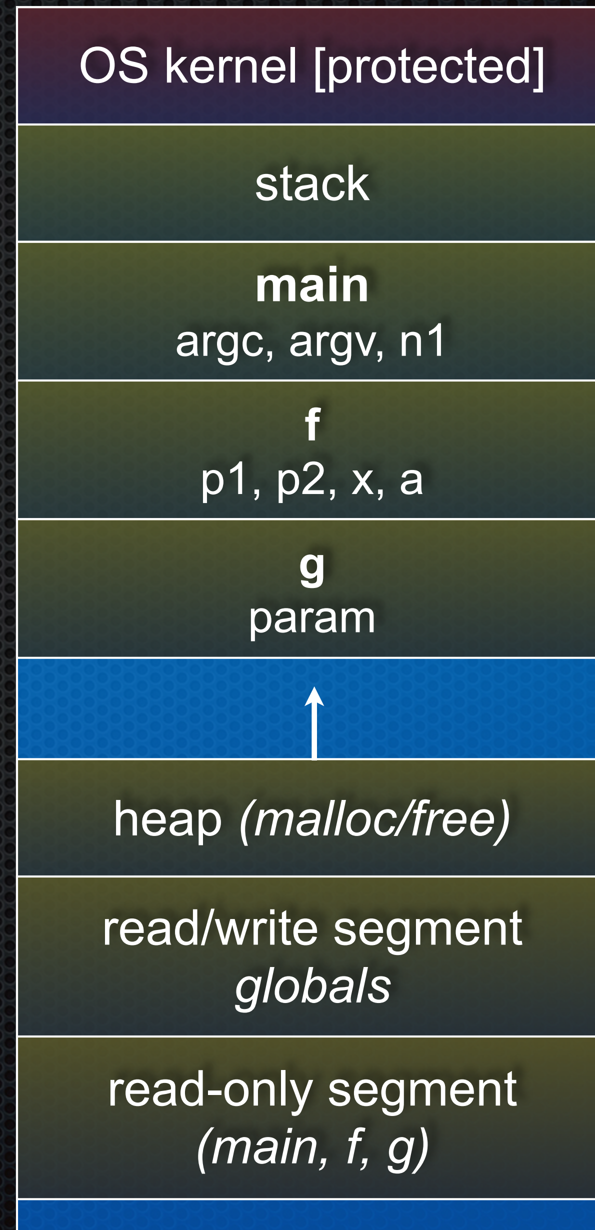
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



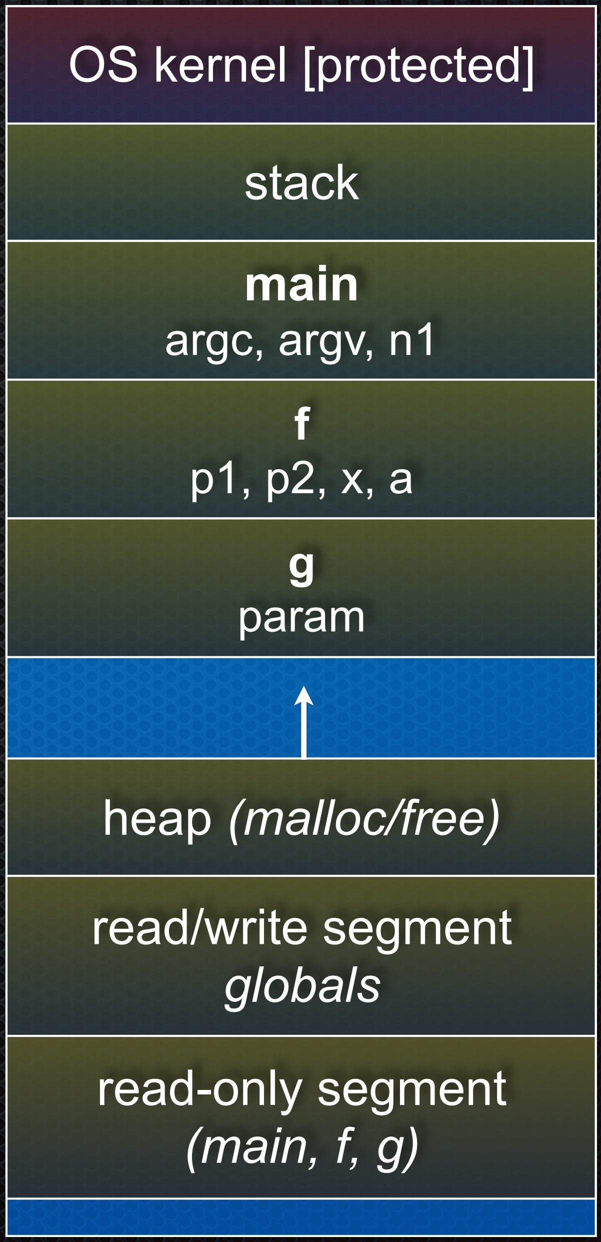
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



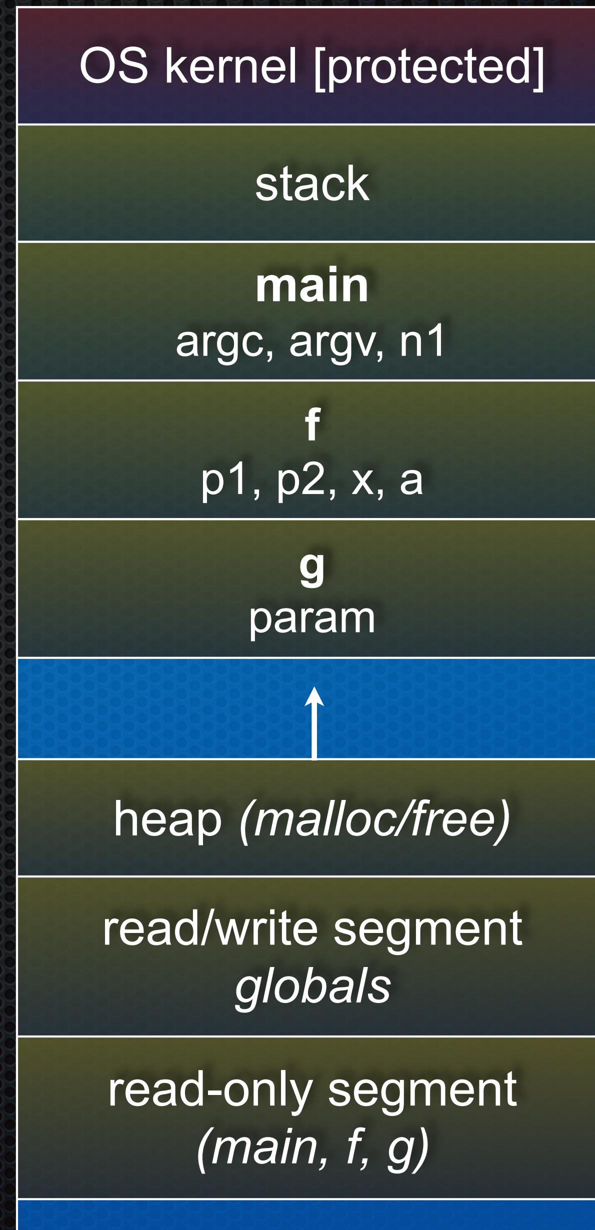
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



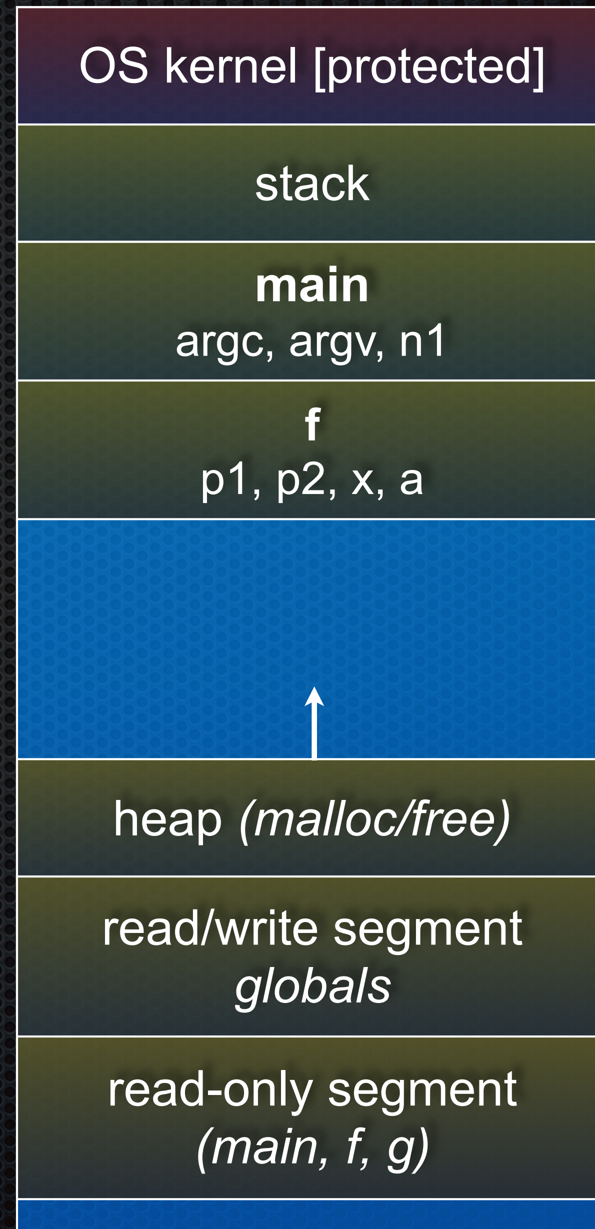
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



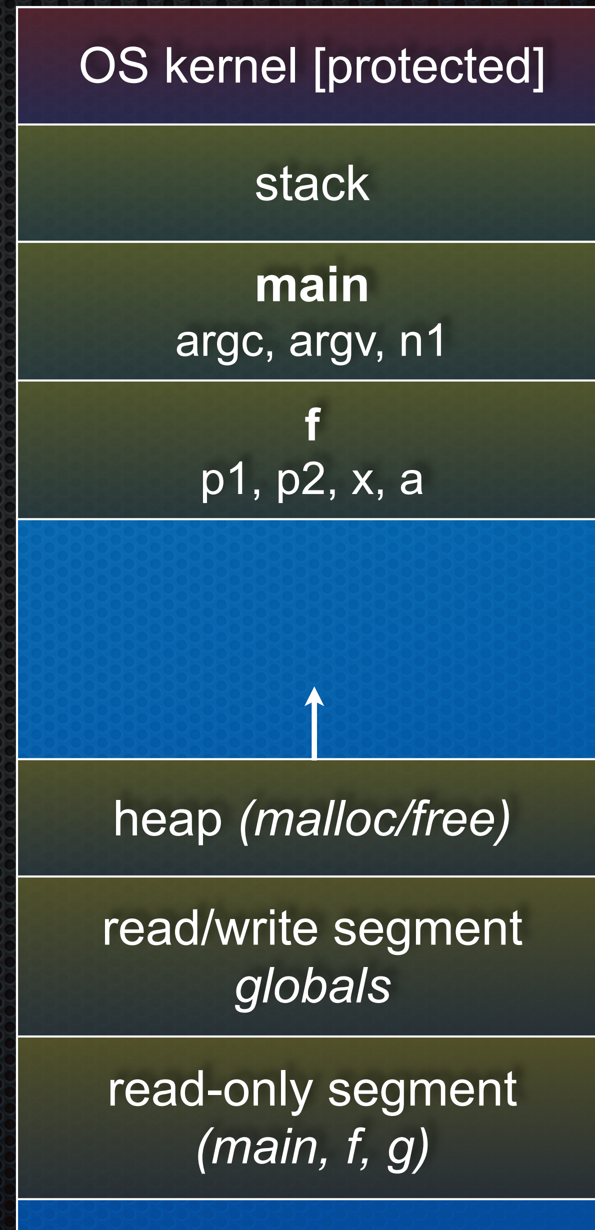
The stack in action

```c
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



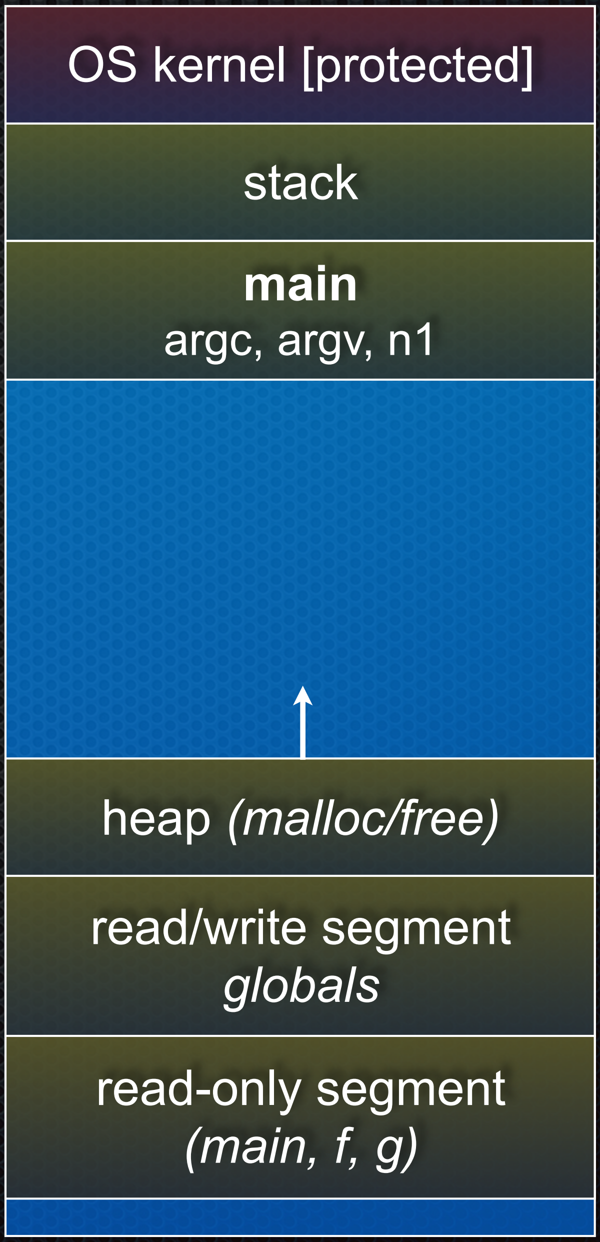
The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```

The stack in action

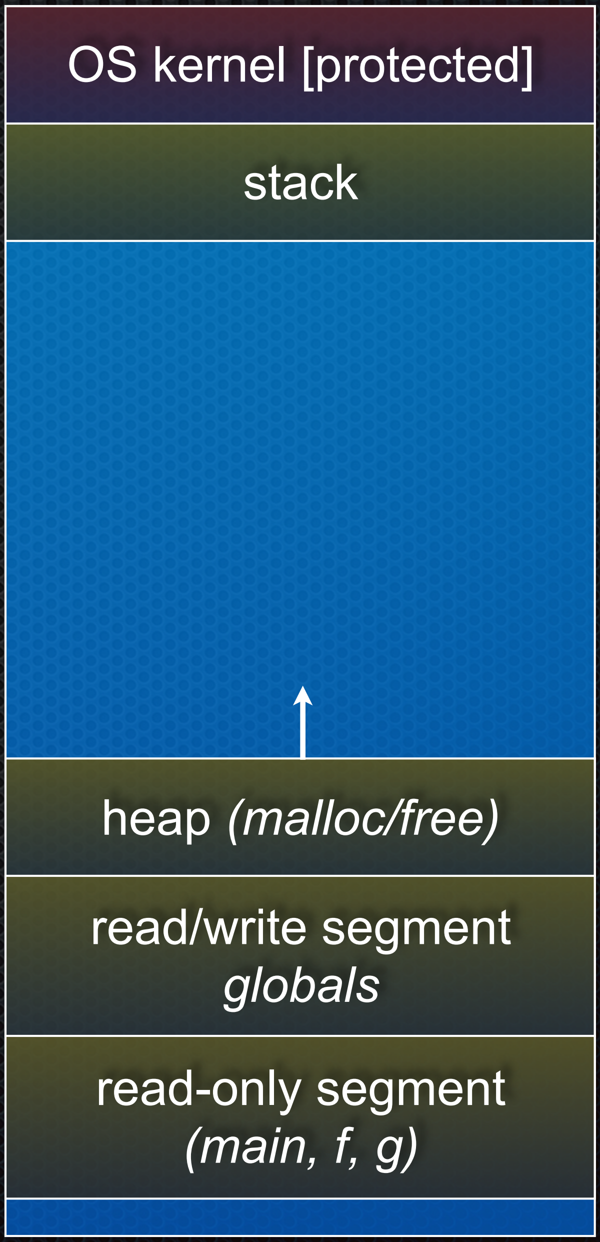
```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```

The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```

The stack in action

```
int main(int argc,
         char **argv) {
  int n1 = f(3, -5);
  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
  return param * 2;
}
```



Addresses and &

&foo produces the virtual address of *foo*

addresses.c

```
#include <stdio.h>

int foo(int x) {
  return x+1;
}

int main(int argc, char **argv) {
  int x, y;
  int a[2];

  printf("x      is at %p\n", &x);
  printf("y      is at %p\n", &y);
  printf("a[0]   is at %p\n", &a[0]);
  printf("a[1]   is at %p\n", &a[1]);
  printf("foo    is at %p\n", &foo);
  printf("main   is at %p\n", &main);

  return 0;
}
```

Pointers

*type *name;   // declare a pointer*
*type *name = address;   // declare + initialize a pointer*

a pointer is a variable that contains a memory address

- it points to somewhere in the process' virtual address space

pointy.c

```
int main(int argc, char **argv) {
  int x = 42;
  int *p;         // p is a pointer to an integer

  p = &x;         // p now contains the address of x

  printf("x  is %d\n", x);
  printf("&x is %p\n", &x);
  printf("p  is %p\n", p);

  return 0;
}
```

A stylistic choice

C gives you flexibility in how you declare pointers

- one way can lead to visual trouble when declaring multiple pointers on a single line
- the other way is what I prefer

```
int* p1;
int *p2; // i prefer
```

```
int* p1, p2;    // bug?; equivalent to int *p1; int p2;
int* p1, * p2; // correct

or

int *p1;   // correct - better
int *p2;   // (int *p1, *p2; is also ok, but less robust)
```

Dereferencing pointers

**pointer   // dereference a pointer*
**pointer = value; // dereference / assign*

dereference: access the memory referred to by a pointer

deref.c

```
#include <stdio.h>

int main(int argc, char **argv) {
  int x = 42;
  int *p;        // p is a pointer to an integer
  p = &x;        // p now contains the address of x

  printf("x  is %d\n", x);
  *p = 99;
  printf("x  is %d\n", x);

  return 0;
}
```

Self exercise #1

Write a function that:

- accepts an array of 32-bit unsigned integers, and a length
- reverses the elements of the array in place
- returns void (nothing)

Self exercise #2

Write a function that:

- accepts a function pointer and an integer as an argument
- invokes the pointed-to function
  - with the integer as its argument

Self exercise #3

Write a function that:

- accepts a string as a parameter
- returns
  - the first whitespace-separated word in the string (as a newly allocated string)
  - and, the size of that word

See you on Friday!