CSE 333

Lecture 2 - arrays, memory, pointers

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Administrivia 1

ex0 was due this morning! Solution posted after class

Any problems (logistics, content, other)?

ex1 out now, due Monday morning, 10 am

Now that clint has arrived (with hw0), use it on exercises, too

Administrivia 2

- hw1 out this afternoon, due in 2 weeks (Thur 10/12)
  - Linked list and hash table implementations in C
  - Get the starter code by doing a “git pull” in your course repo
    - Might be some issues if your local repo has unpushed changes
      - See the CSE 333 Git Tutorial for tips
      - If Git decides you need to do a merge it might drop you into vi(m)
      - To escape: :q, or :wq if you make any changes, but default is fine
      - Set your EDITOR environment variable if you want something other than vim

Administrivia 3

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 unless absolutely necessary)

Today's agenda

More C details

- functions
- refresher on C's memory model
  - address spaces
  - the stack
- arrays
- 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

```c
#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; 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 appear before first use

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!

process 1 process 2 • • • process N

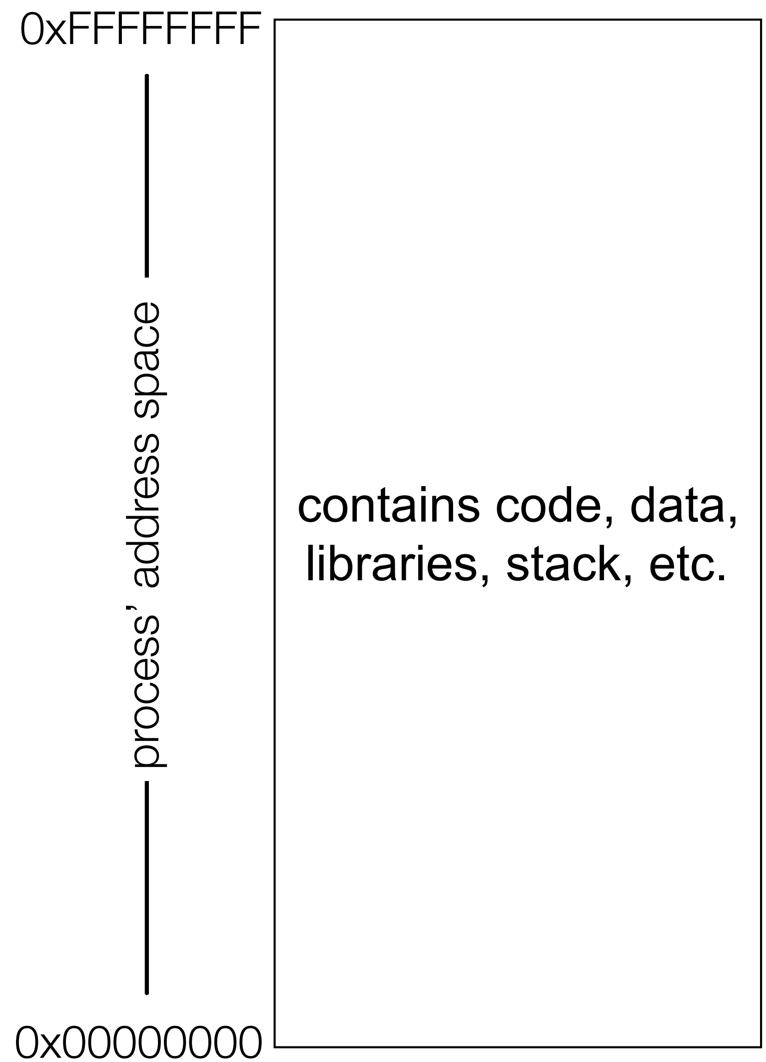
----

operating system

Processes and virtual memory

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

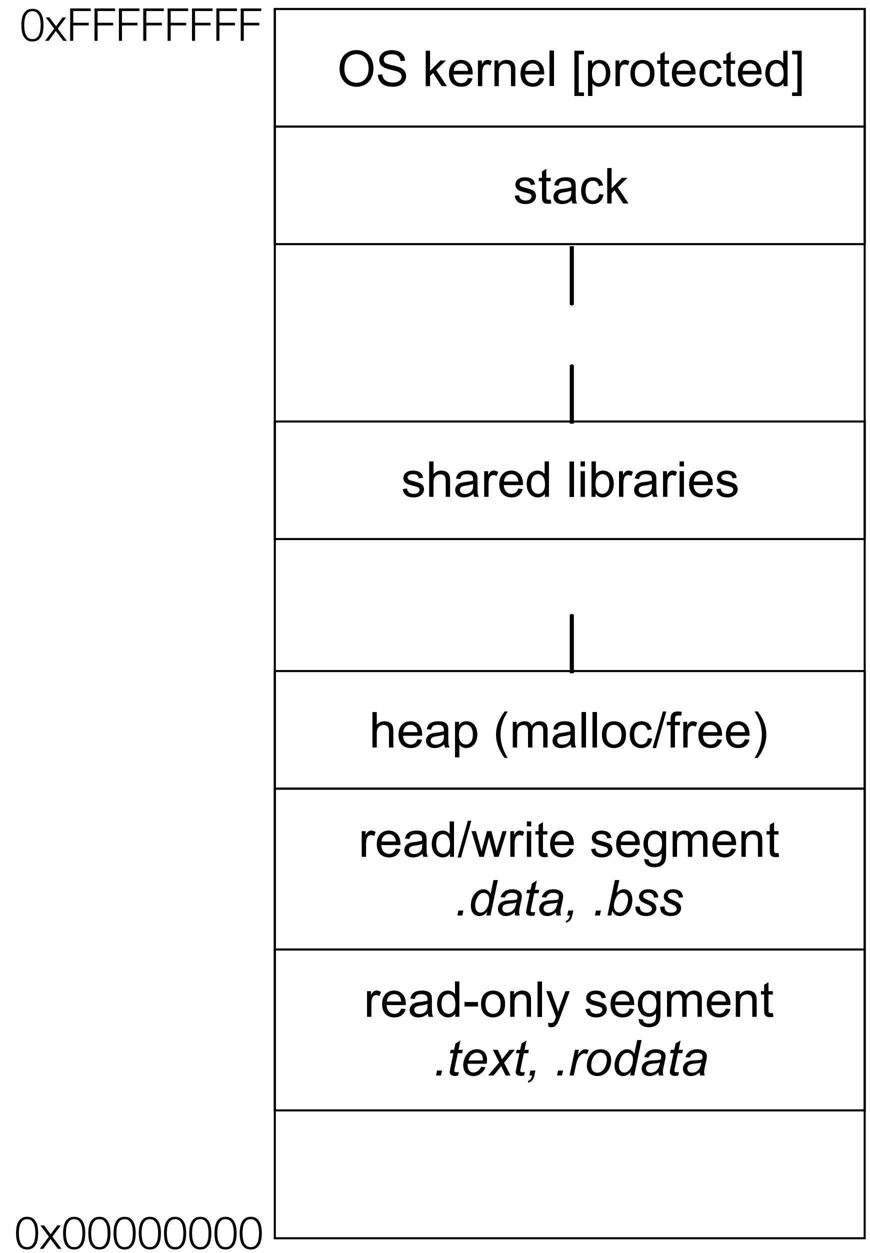
- this is called the process' ***address space***
- contains the process' virtual memory, visible only to it
- 2^{32} bytes on 32 bit host
- 2^{64} bytes on 64 bit host



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

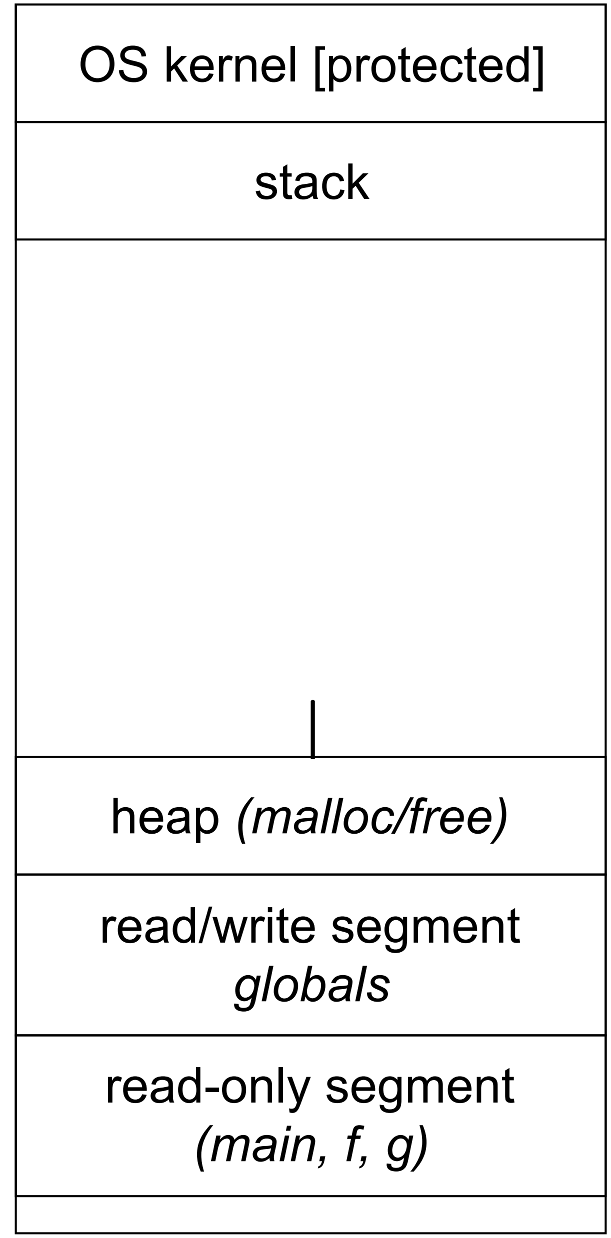
a stack frame

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;
}

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  return param * 2;
}
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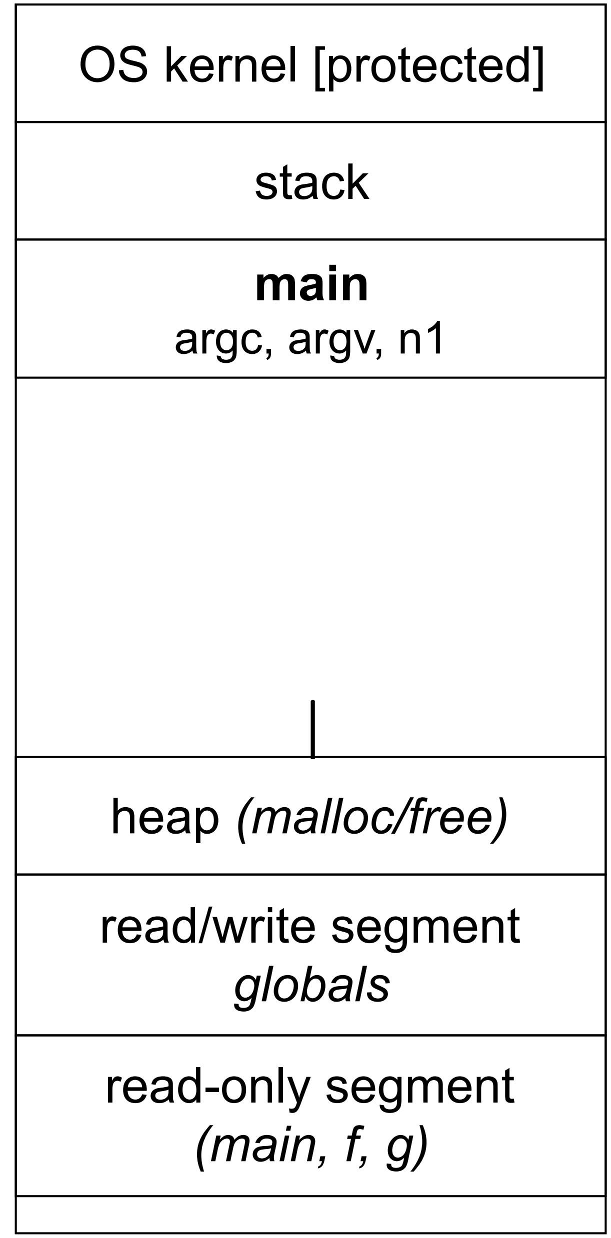

The stack in action

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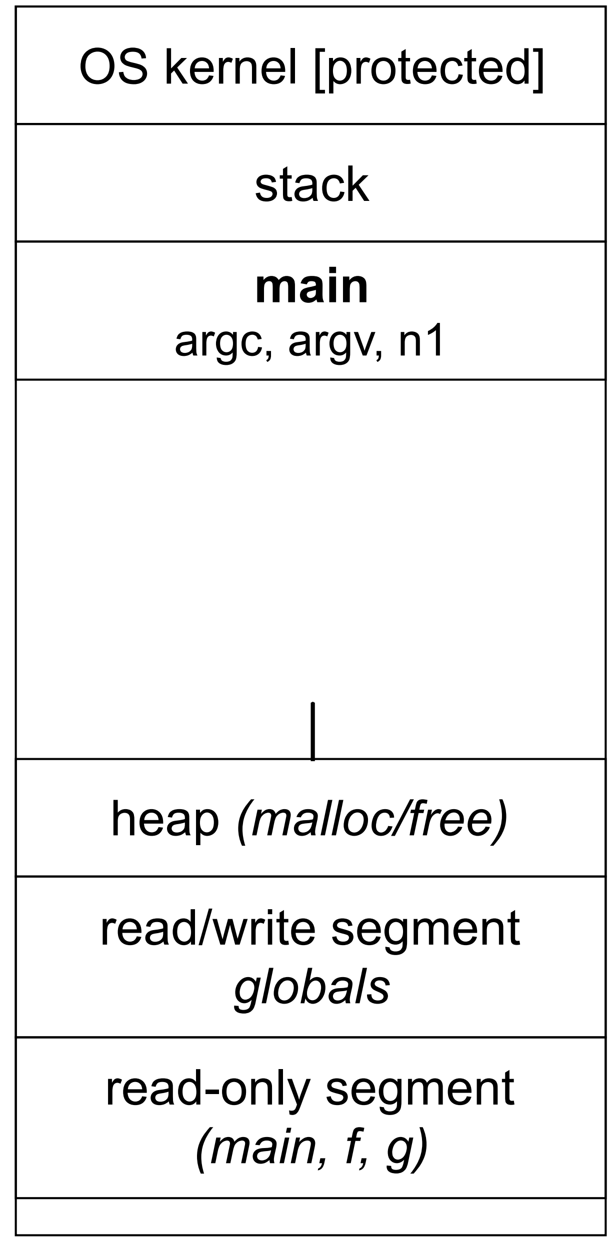
int g(int param) {
  return param * 2;
}
```



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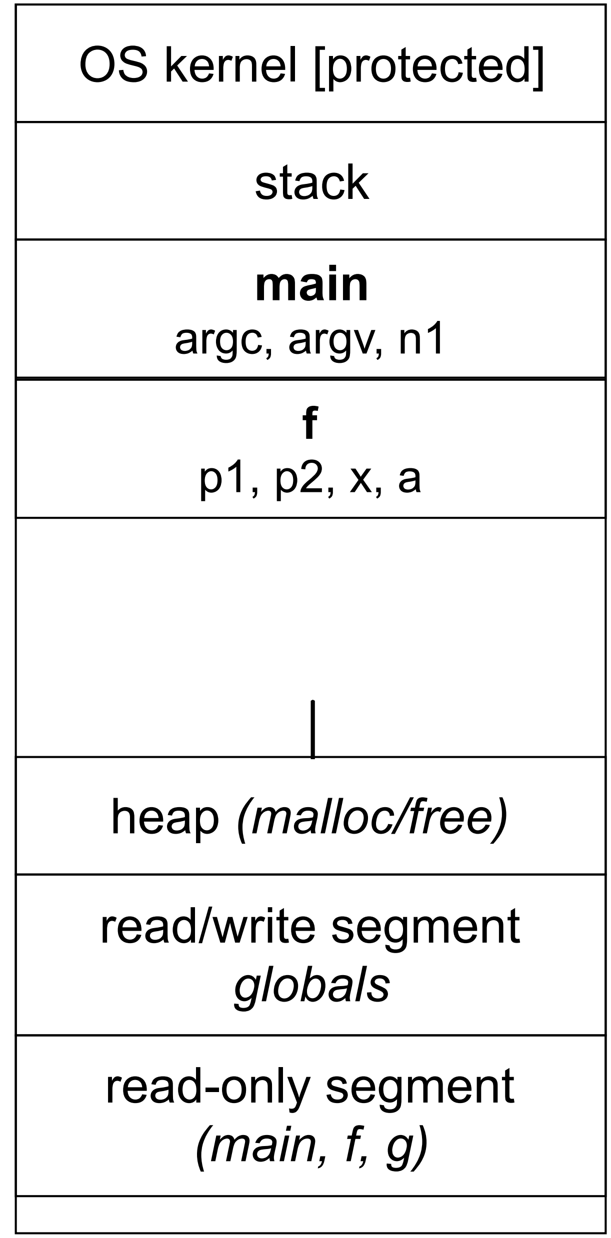

The stack in action

```
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  int n1 = f(3, -5);
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}

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  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
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  return param * 2;
}
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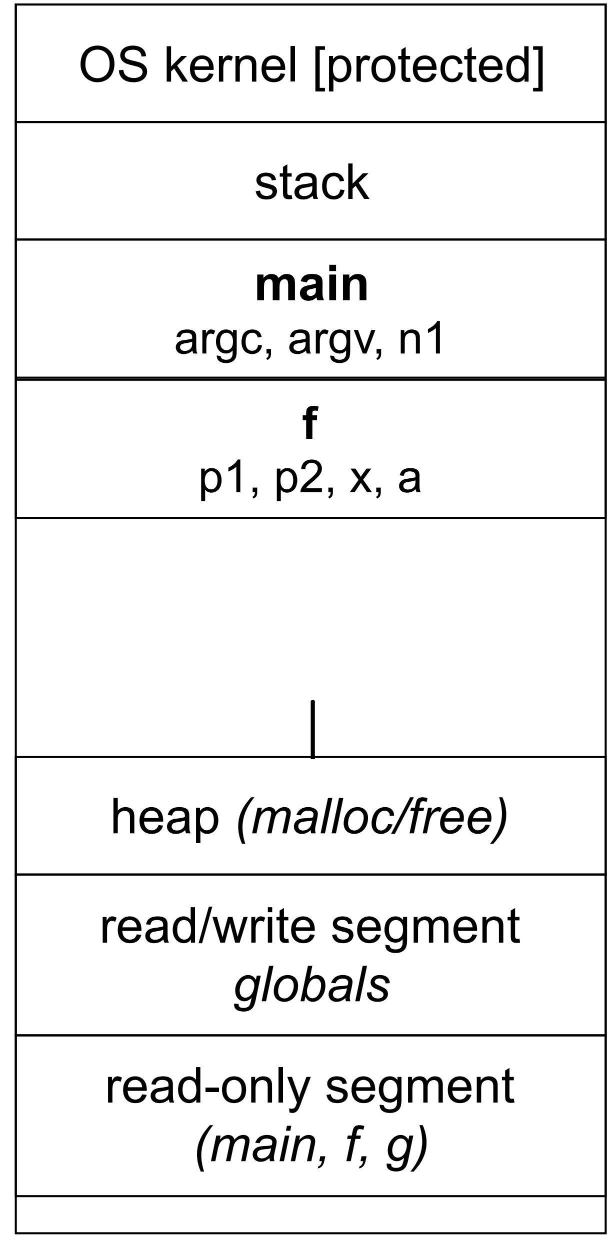

The stack in action

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

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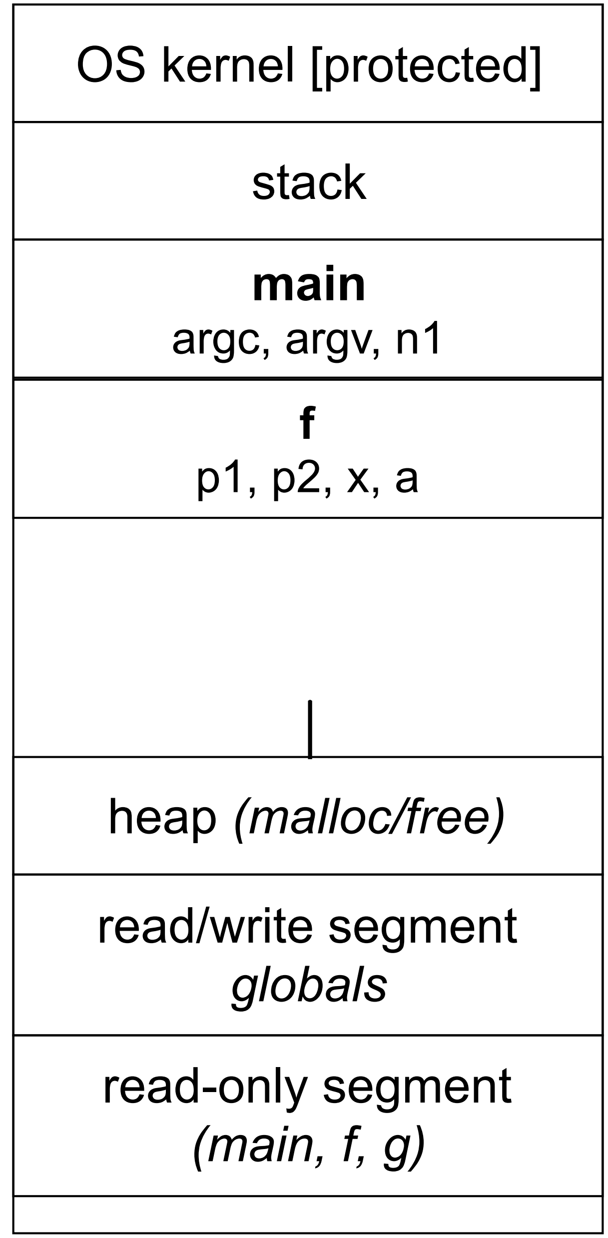

The stack in action

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  int a[3];
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  return param * 2;
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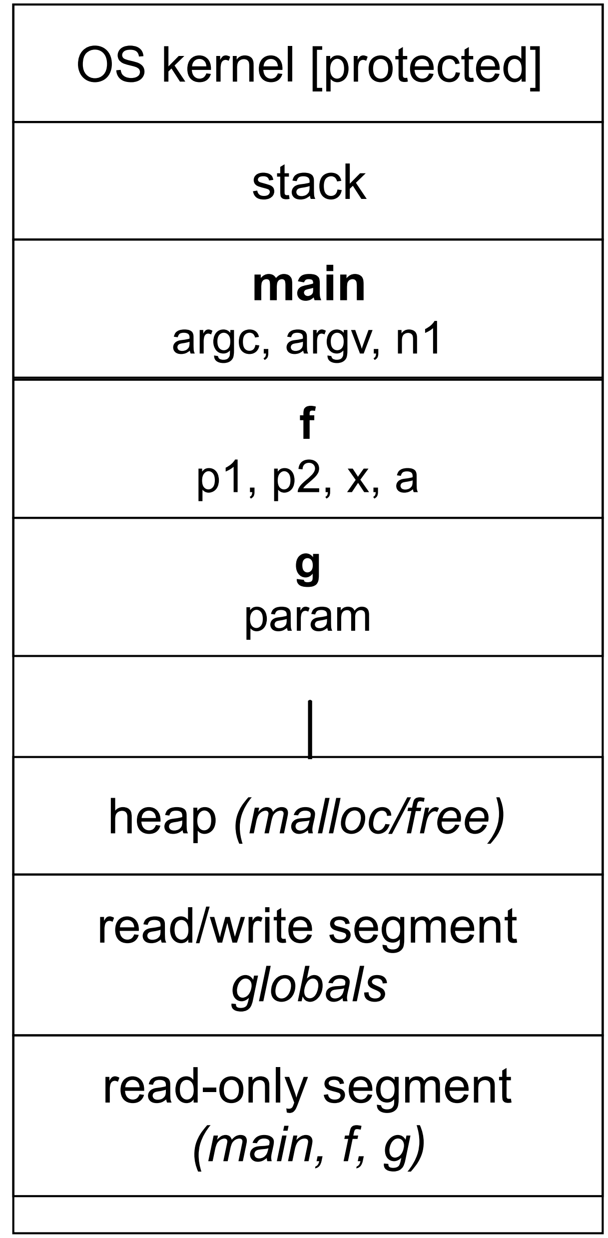

The stack in action

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  return param * 2;
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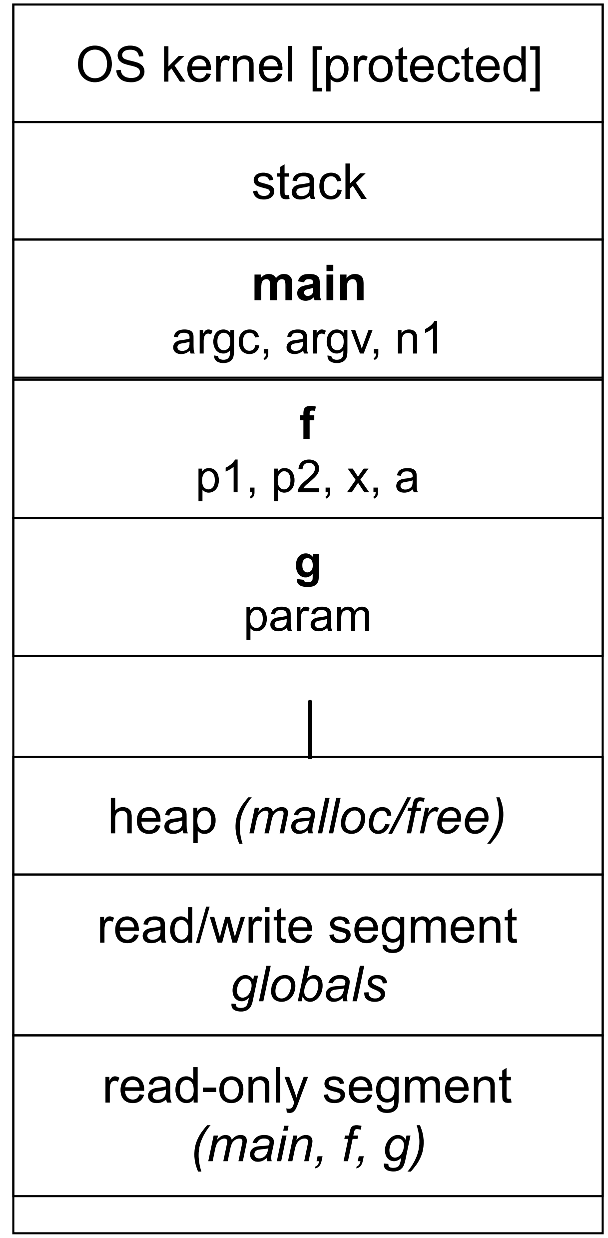

The stack in action

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int main(int argc,
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  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;
}
```

OS kernel [protected]
stack
main argc, argv, n1
f p1, p2, x, a
g param
heap *(malloc/free)*
read/write segment *globals*
read-only segment *(main, f, g)*

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;
}
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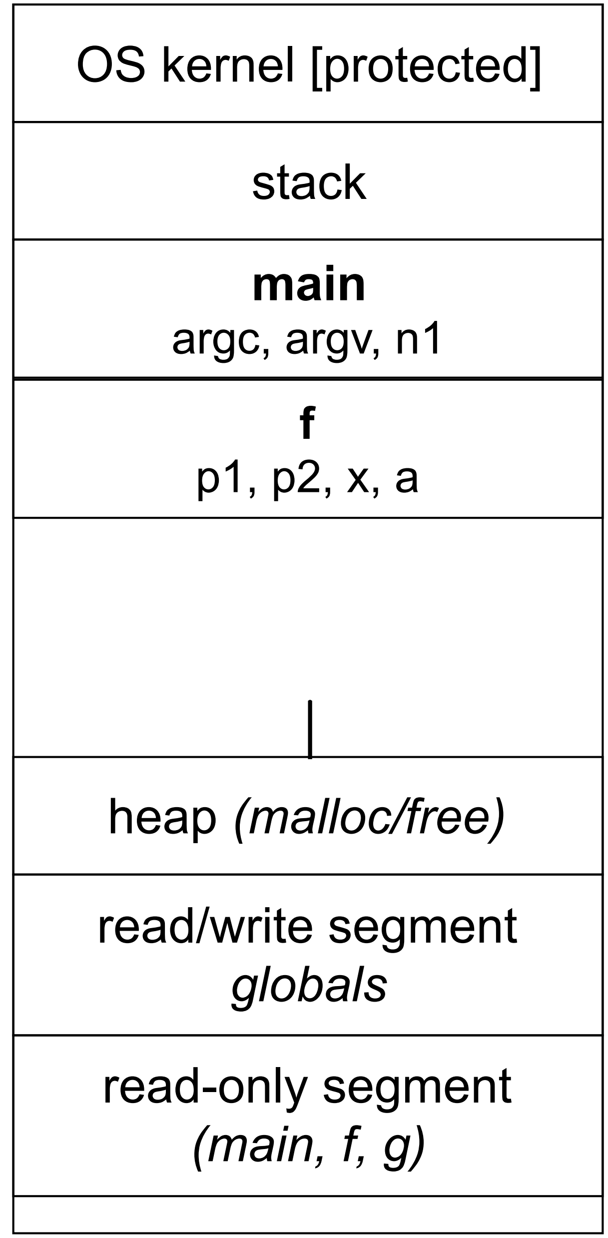

The stack in action

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         char **argv) {
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  n1 = g(n1);
}

int f(int p1, int p2) {
  int x;
  int a[3];
  ...
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  return x;
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  return param * 2;
}
```

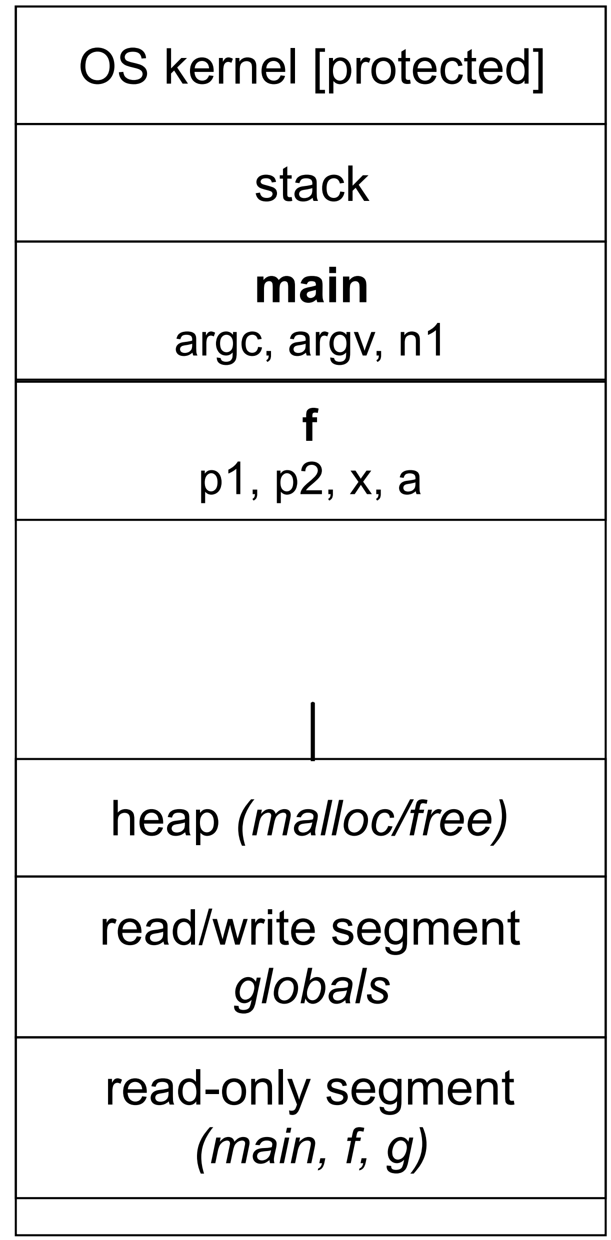

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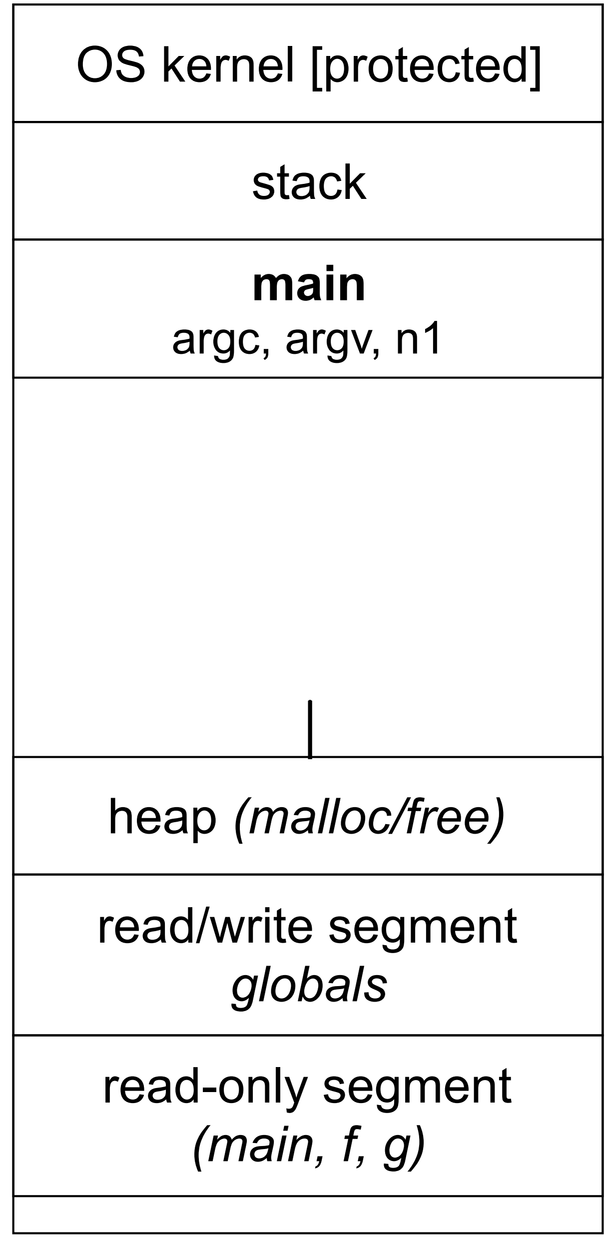

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  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

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

OS kernel [protected]
stack
main argc, argv, n1
g param
heap *(malloc/free)*
read/write segment *globals*
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The stack in action

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

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  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
}

int g(int param) {
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}
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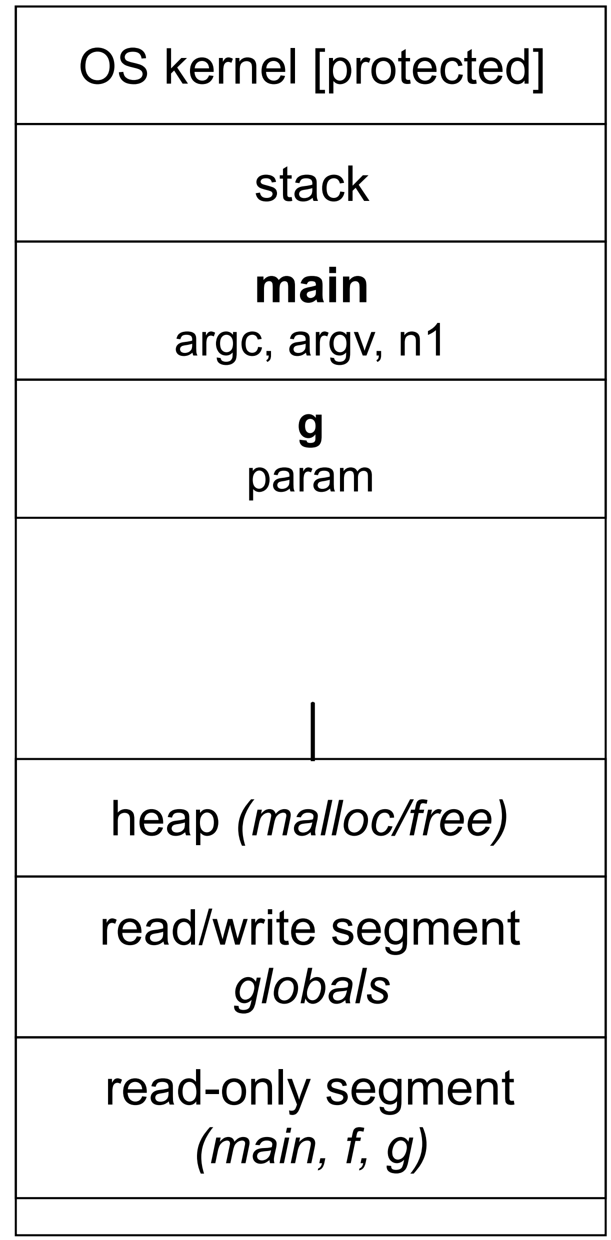

The stack in action

```
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];
  ...
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  return x;
}

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

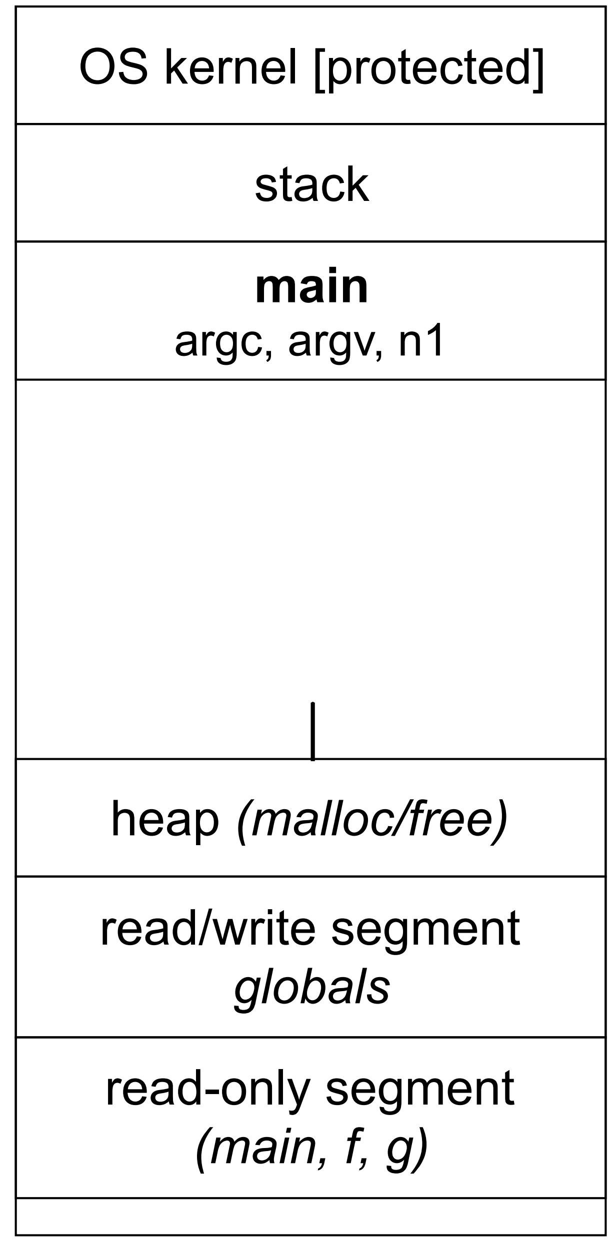

The stack in action

```
int main(int argc,
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  return param * 2;
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```

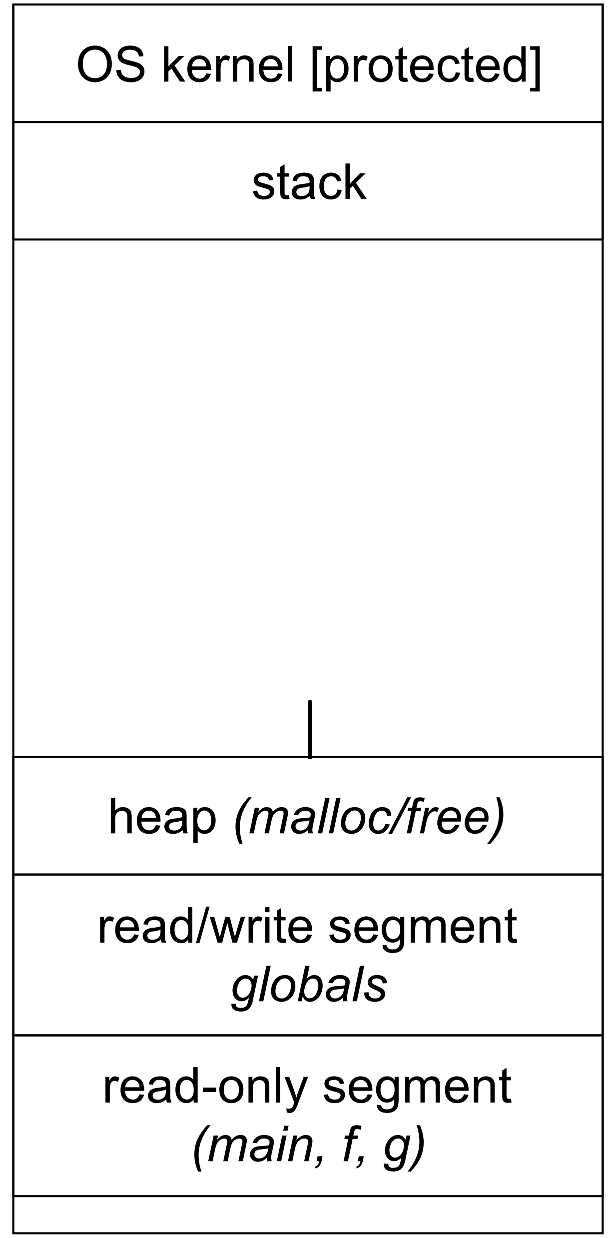

Arrays

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 uncommon; also 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 in prog. languages

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]

OK, technicality: In C, "call-by-reference" is really a call-by-value pointer. Let's consider it to be call-by-reference when intended/works that way.

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 -- no compiler
               // error, but wrong
}
```

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

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 more robust, preferred

```
int* p1;
int *p2; // better
```

```
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 Monday!