CSE 333

Lecture 2 - arrays, memory, pointers

Administrivia

ex0, hw0 were due 15 minutes ago!

- let me know if you had any logistical issues with either

ex1 is out today, due on Monday

hw1 is out today, due in two weeks

Today’s agenda

More C details

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

Defining a function

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

sum_fragment.c

```
// sum 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

Why?

sum_badorder.c

```
#include <stdio.h>

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

// sum 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: find an ordering that respects the restriction

sum_betterorder.c

```
#include <stdio.h>

// sum 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;
}
```

Of course, this isn't always possible…

Problem: ordering

Solution 2:

- Separate notions of <u>declaration</u> and <u>definition</u>
- Place <u>declaration</u> before use
- (Place <u>definition</u> most anywhere…)

```
#include <stdio.h>

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

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

// This is the definition of sumTo
int sumTo(int max) {
  int i, sum = 0;
  for (i=1; i<=max; i++) {
    sum += i;
  }
  return sum;
}
```

sum_declared.c

Arrays

type name[size];

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

Example:

- allocates 100 ints’ worth of memory
  - initially, each array element contains garbage data
- associates the name `scores` with that memory

An array does not know its own size

- sizeof(scores) is not reliable; only works in some situations
- recent versions of C allow the declared array size to be an expression

```
int[] vecAdd(int[] A, int[] B, int n ) {
    int result[n];  // OK in C99
    …
}
```

Array initialization

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

- allocates and array and fills it with supplied values
- if fewer values are given than the array size, fills rest with 0

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

Arrays as parameters

It's tricky to use arrays as parameters

- *Array names* are passed by value
  - which means that *array contents* are always passed by reference
- The language doesn't provide any way to determine the length of an array (you have to write code if you want that)

```
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;
  // there isn't anything you can write that means "a's length"
  for (i = 0; i < ...???
}
```

Arrays as parameters

Solution 1: declare the array size in the function

- problem: this isn't really a solution at all!

  but, what does it do?

```
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++) {
    sum += a[i];
  }
  return sum;
}
```

arraysum.c

Pop quiz 1:
Can you spot the bug in this code?

Pop quiz 2:
What do you think happens when you run it?

Religious battle 1:
Which is better, C arrays or Java arrays?

Returning an array

Local variables, including arrays, are stack allocated

- The memory they occupy is release when a function returns (and may be reused for some other purpose)
- Therefore, local arrays can't be safely returned from functions

```
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`

But I thought C always passes & returns by value?

Stopgap Solution: an output parameter

Create the “returned” array in the caller

- pass it as an *output parameter* to copyarray
- we’ll see a better way later in the course

```
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!

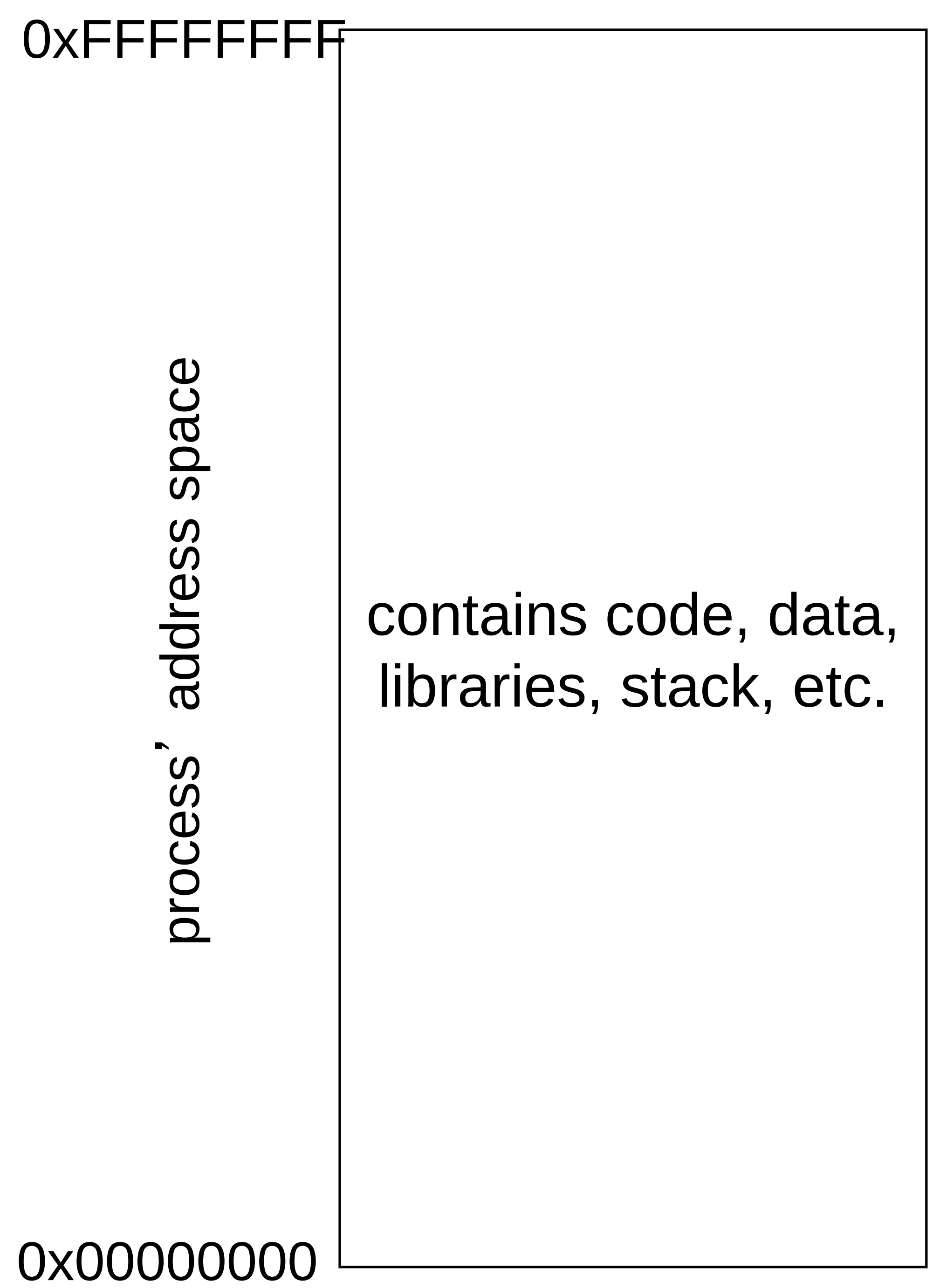
process 1 process 2 • • • process N

operating system

Program memory:
Processes and virtual memory

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

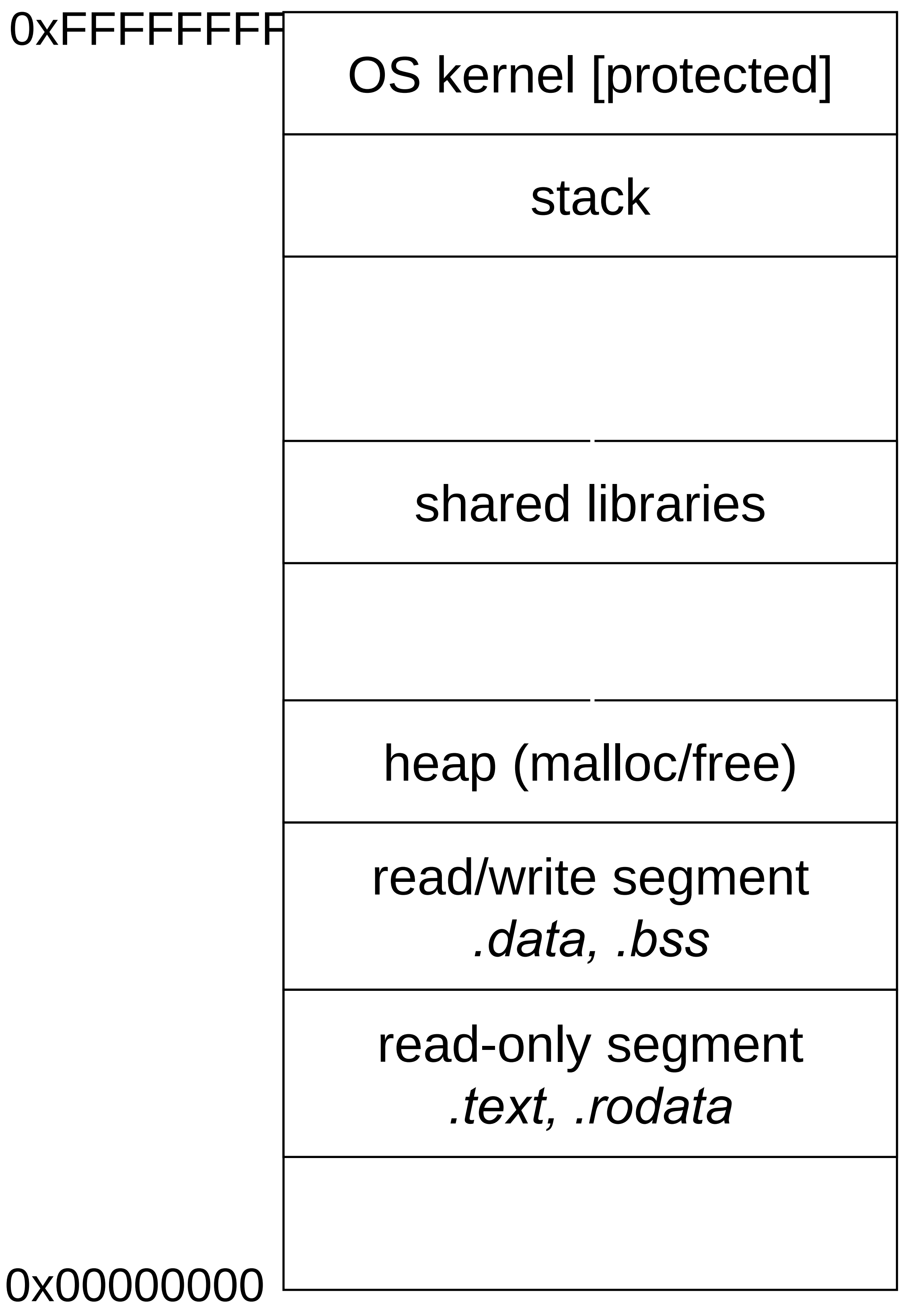
- this is called the process' *address space*
- contains the process' virtual memory, visible only to it
  - 2^{32} bytes on 32 bit host
  - 2^{64} bytes on 64 bit host



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 allocate data associated with function calls

- when you call a function, compiler-inserted code will allocate a stack frame to store:
  - the function call arguments
  - 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

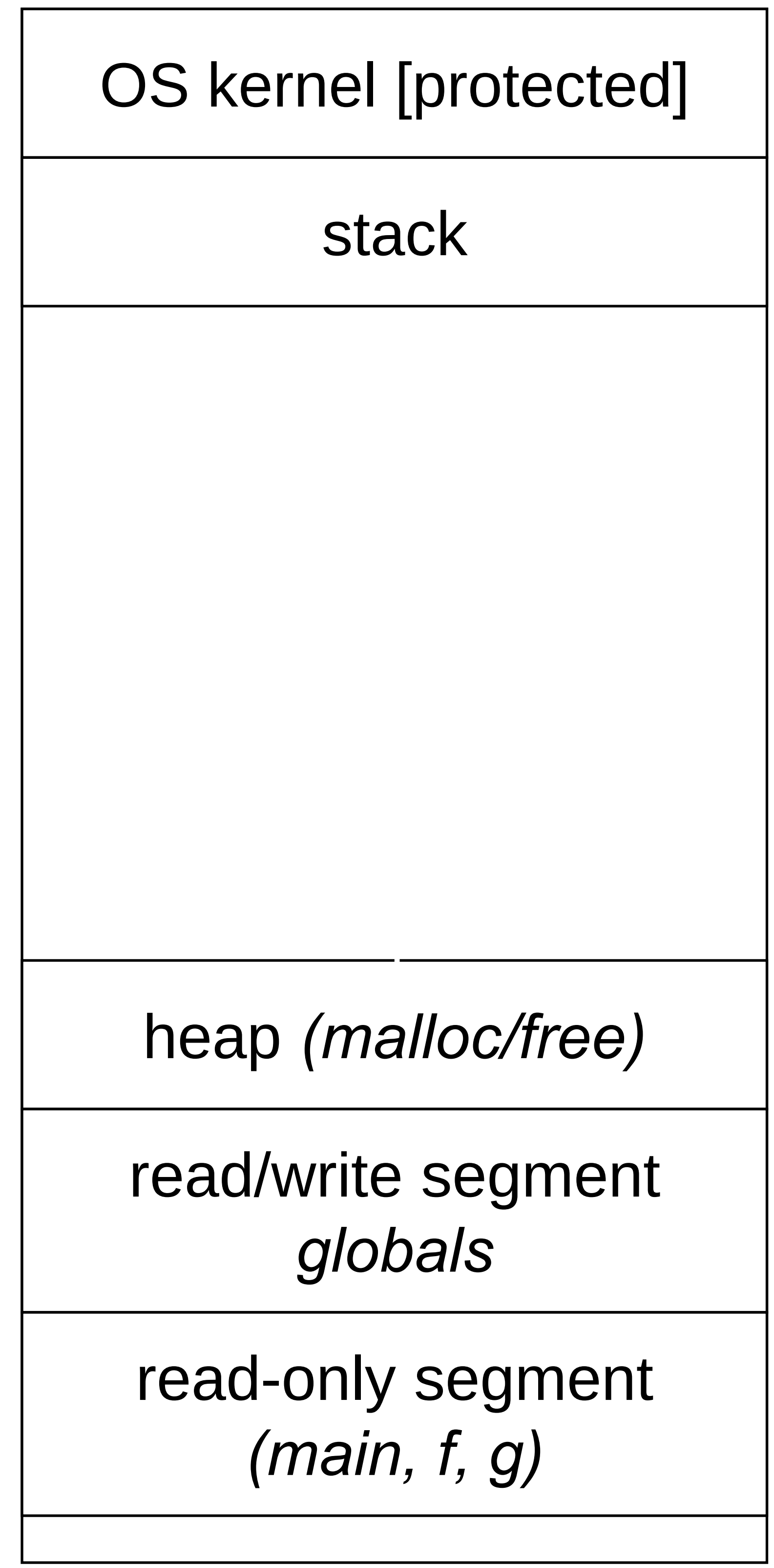
a stack frame

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

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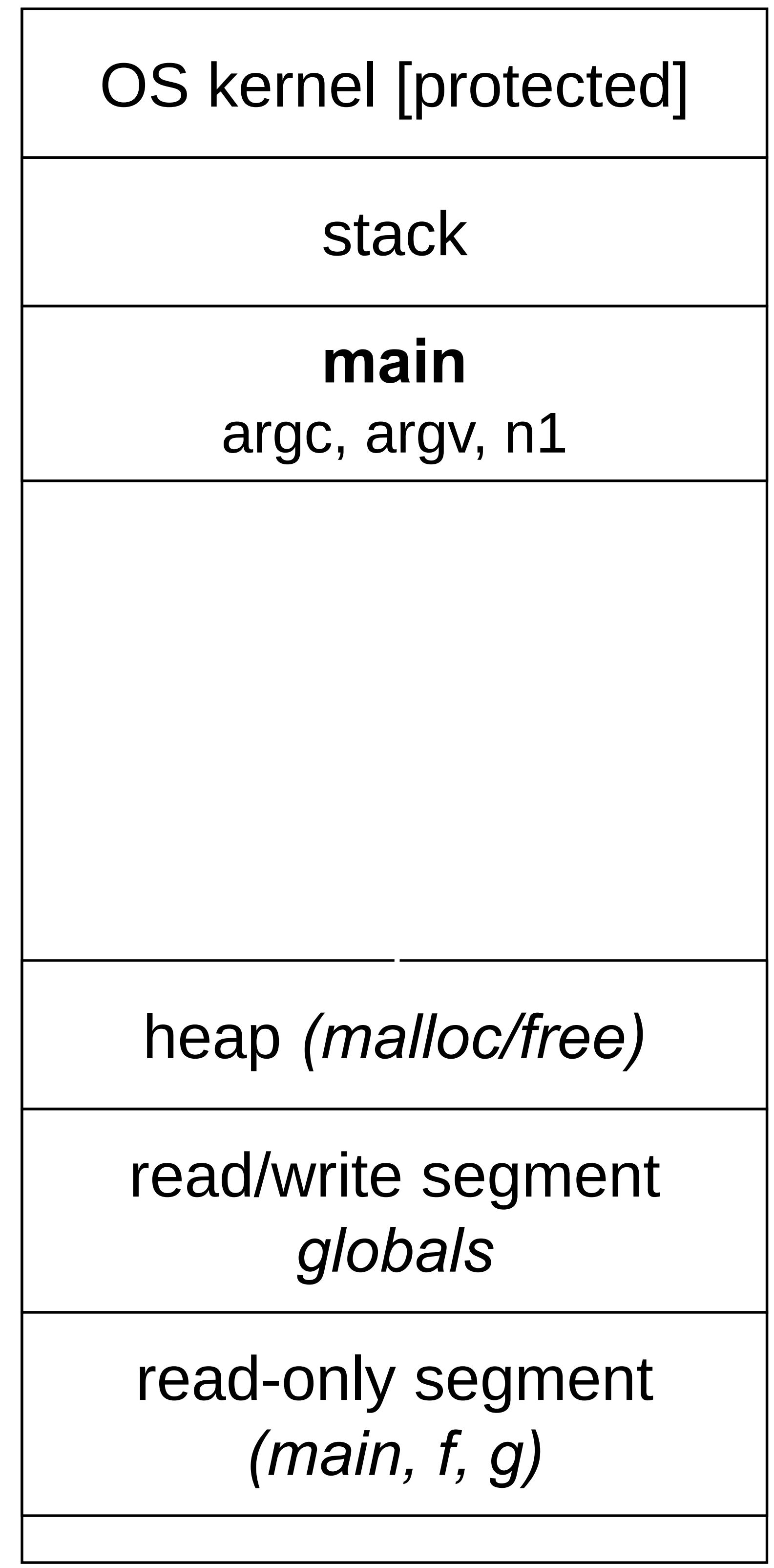

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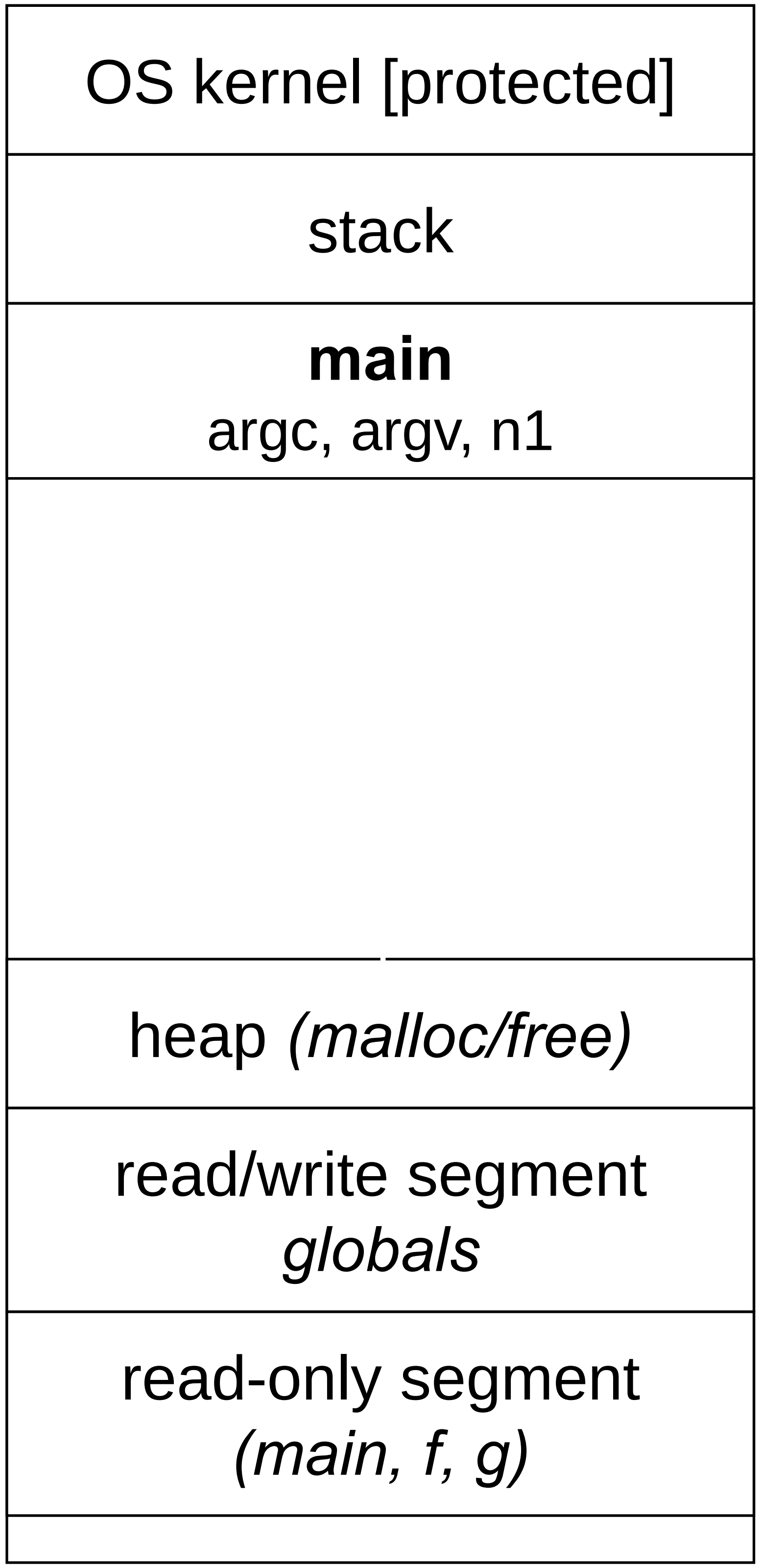

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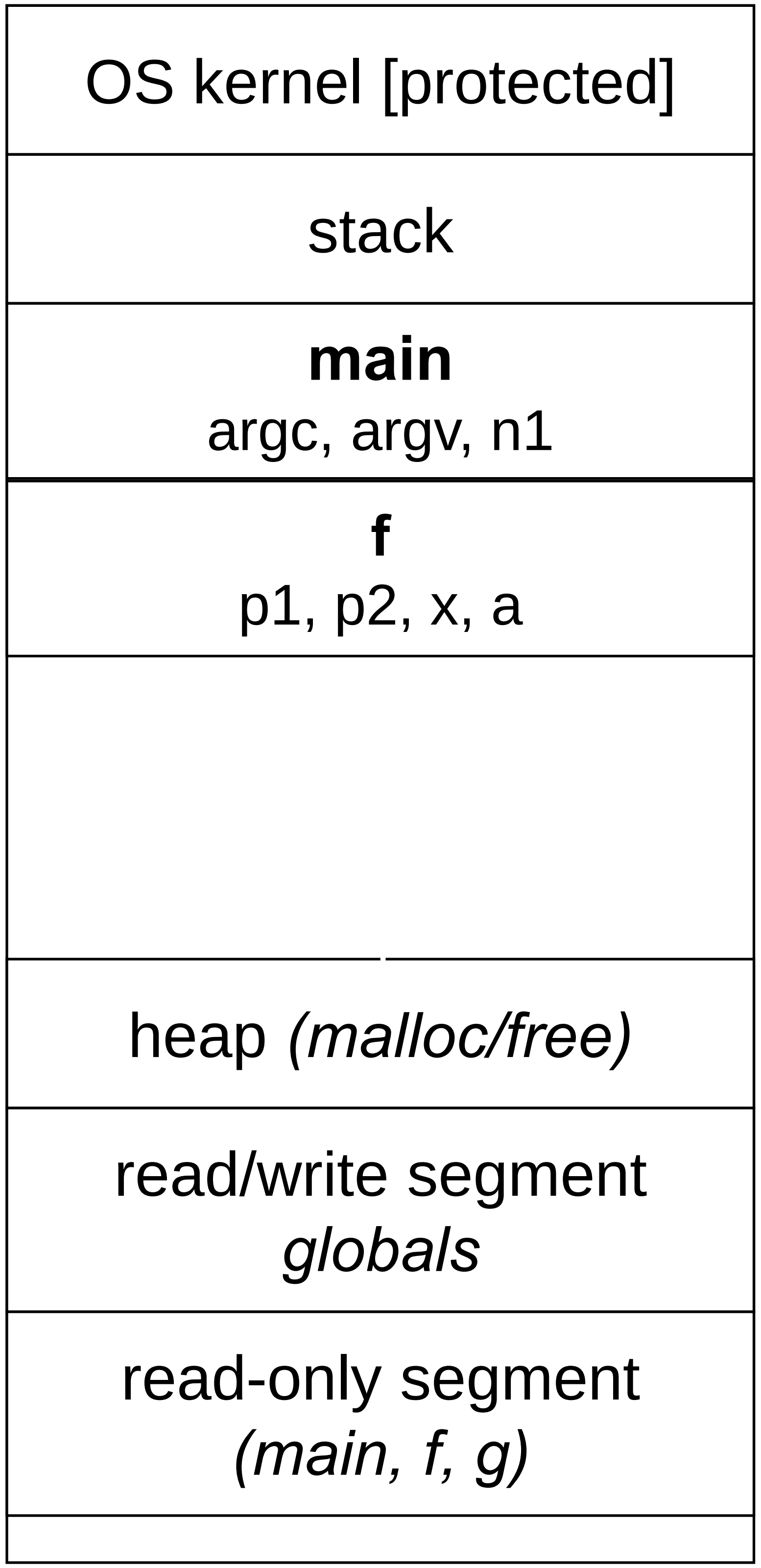

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  int n1 = f(3, -5);
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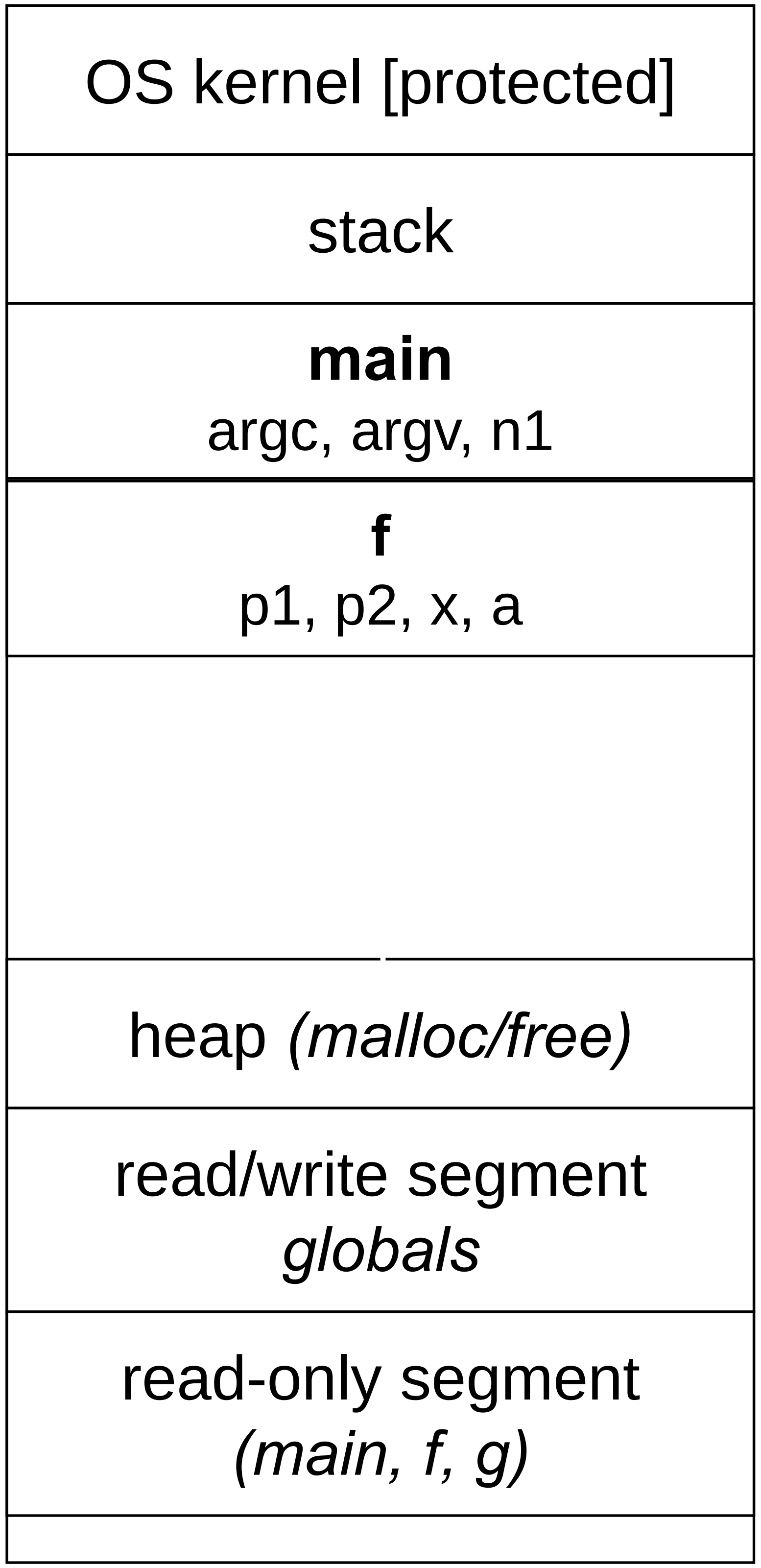

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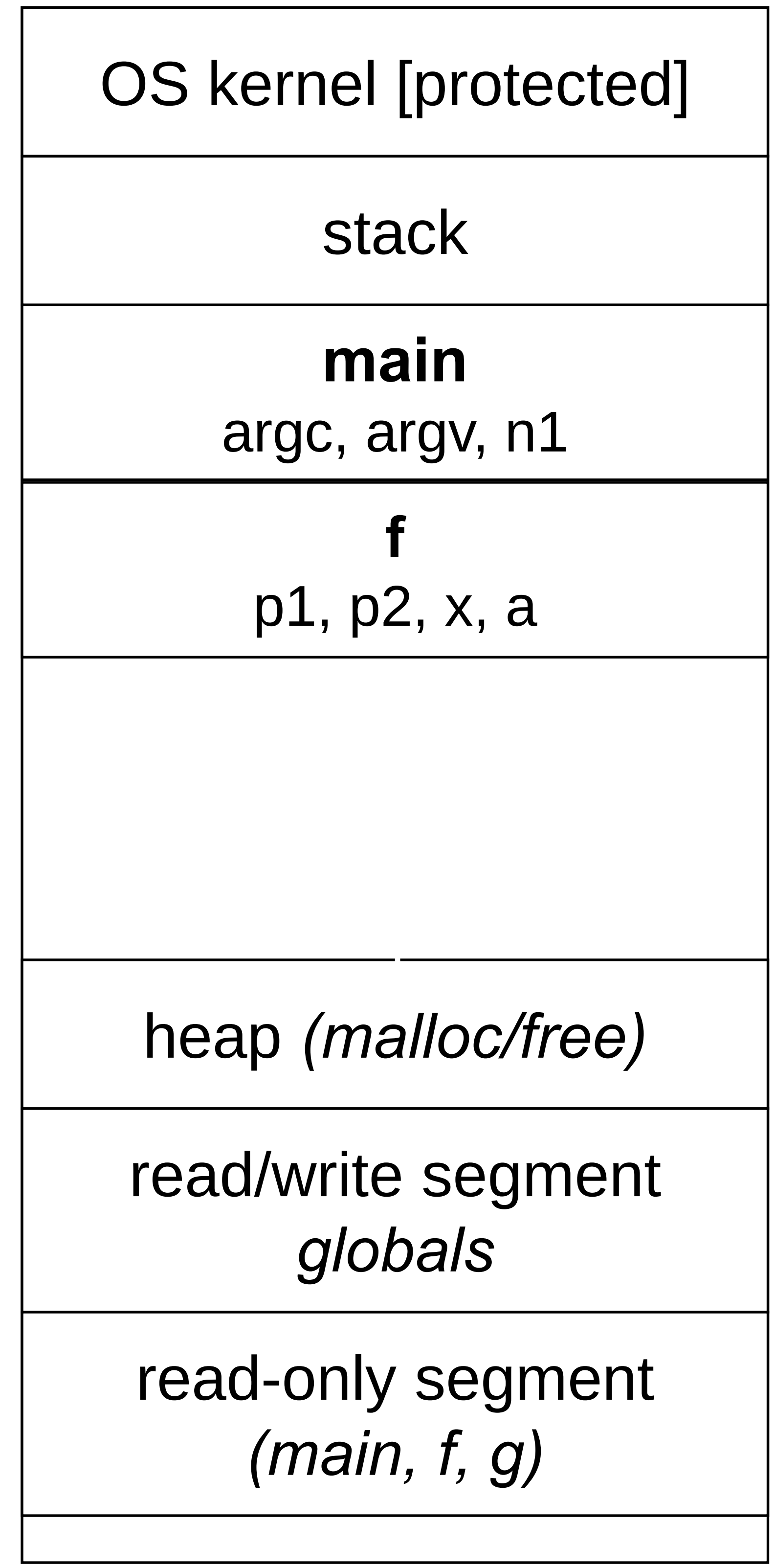

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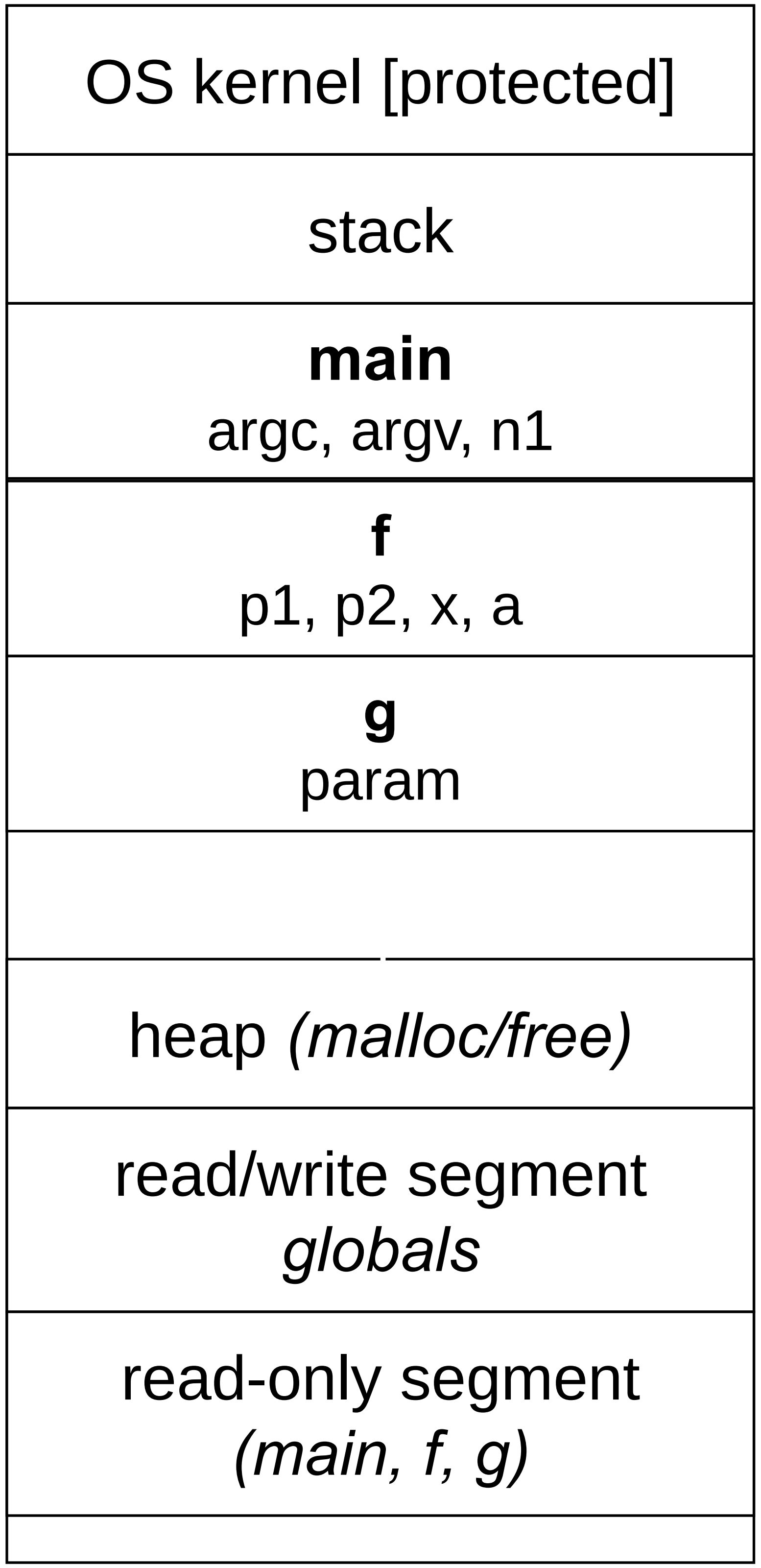

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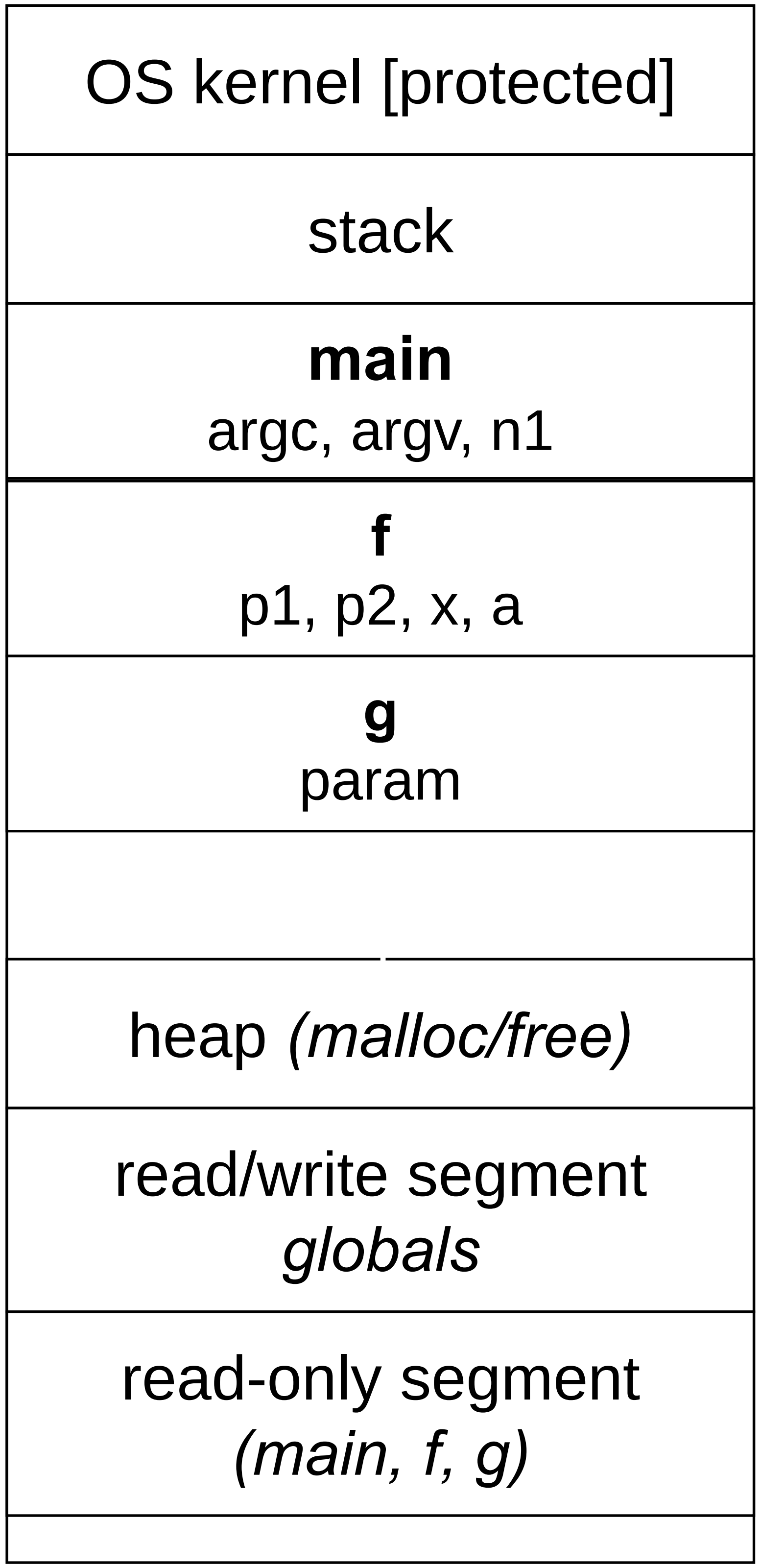

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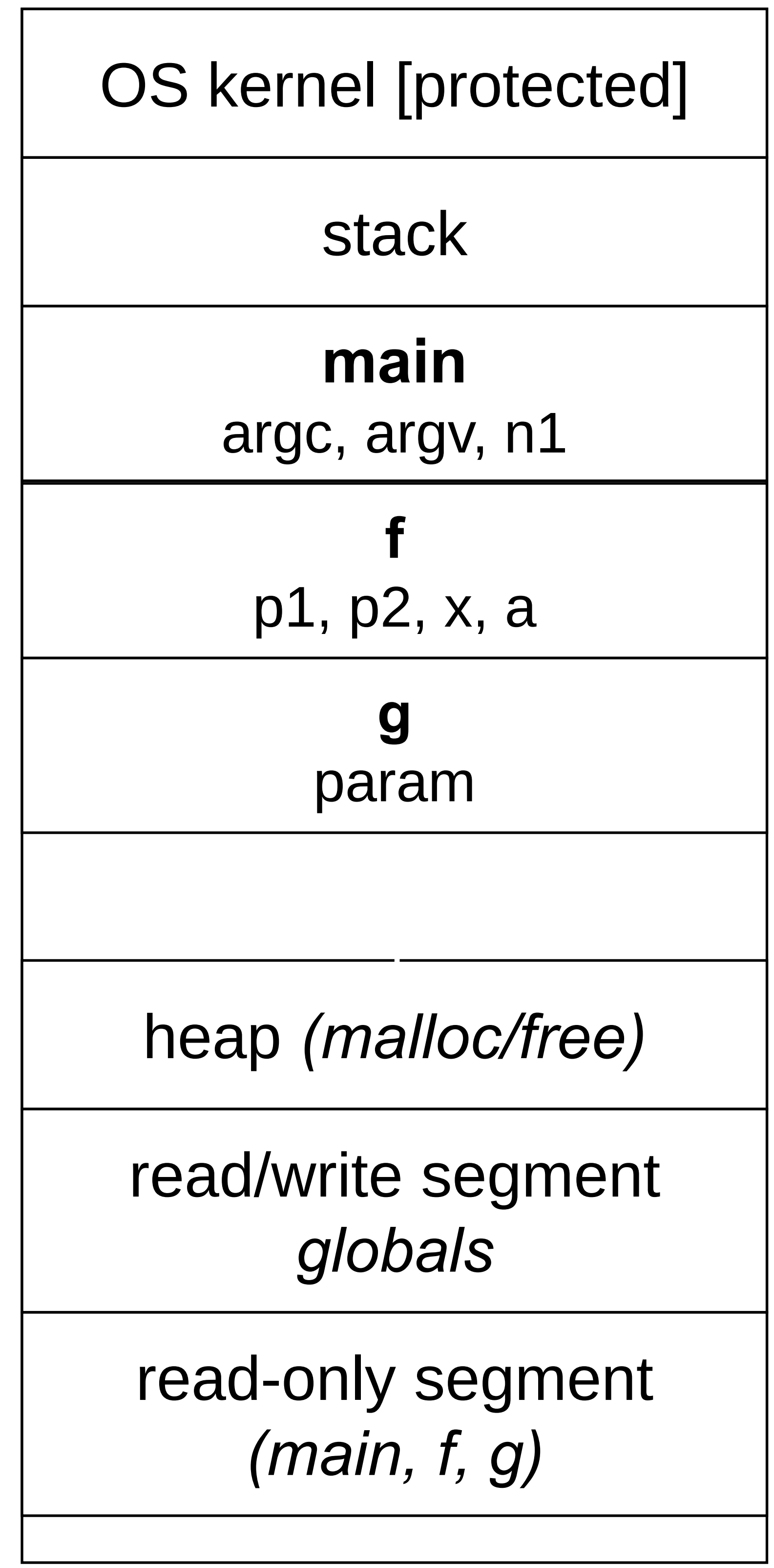

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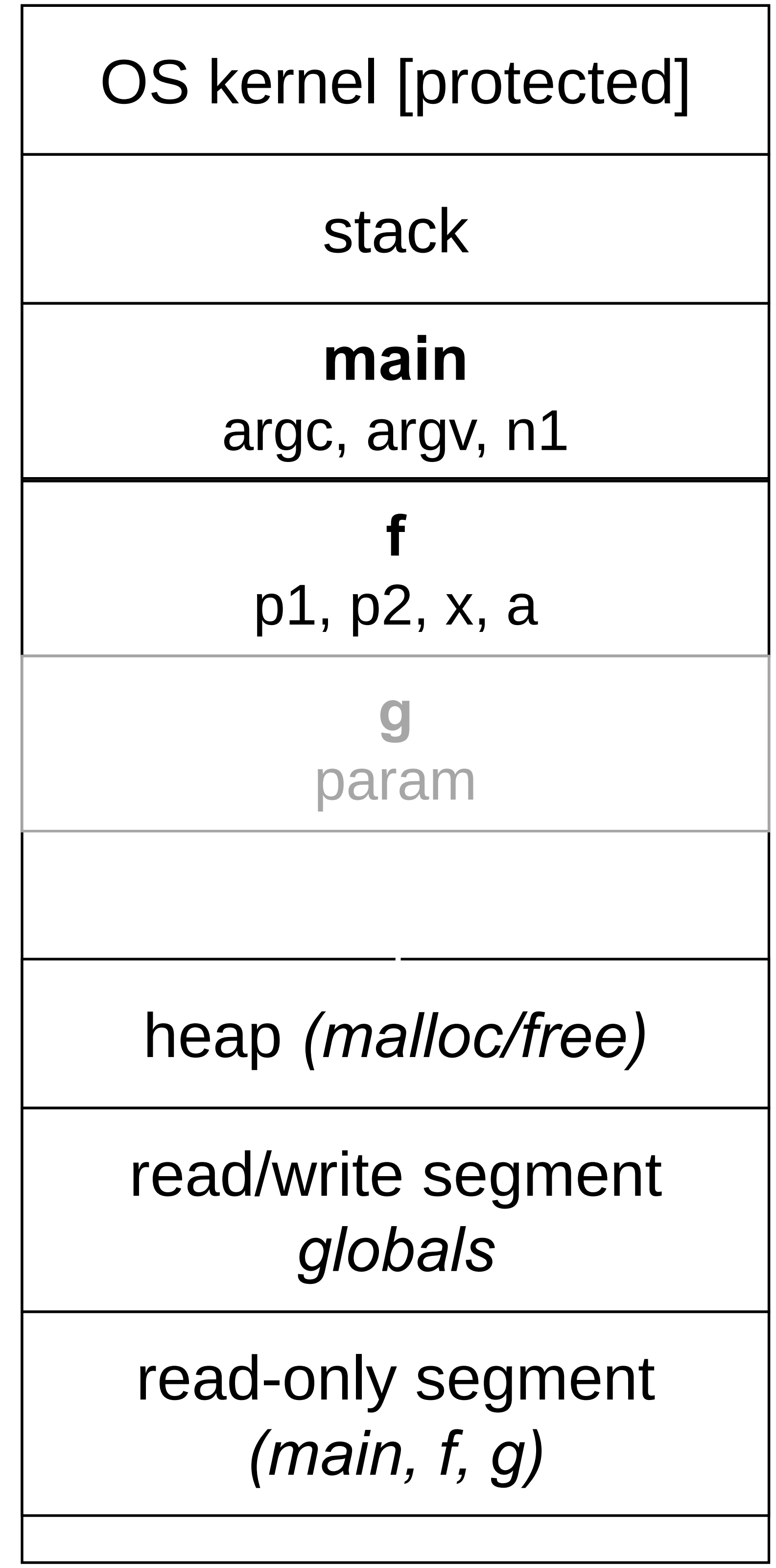

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  int a[3];
  ...
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  return x;
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  return param * 2;
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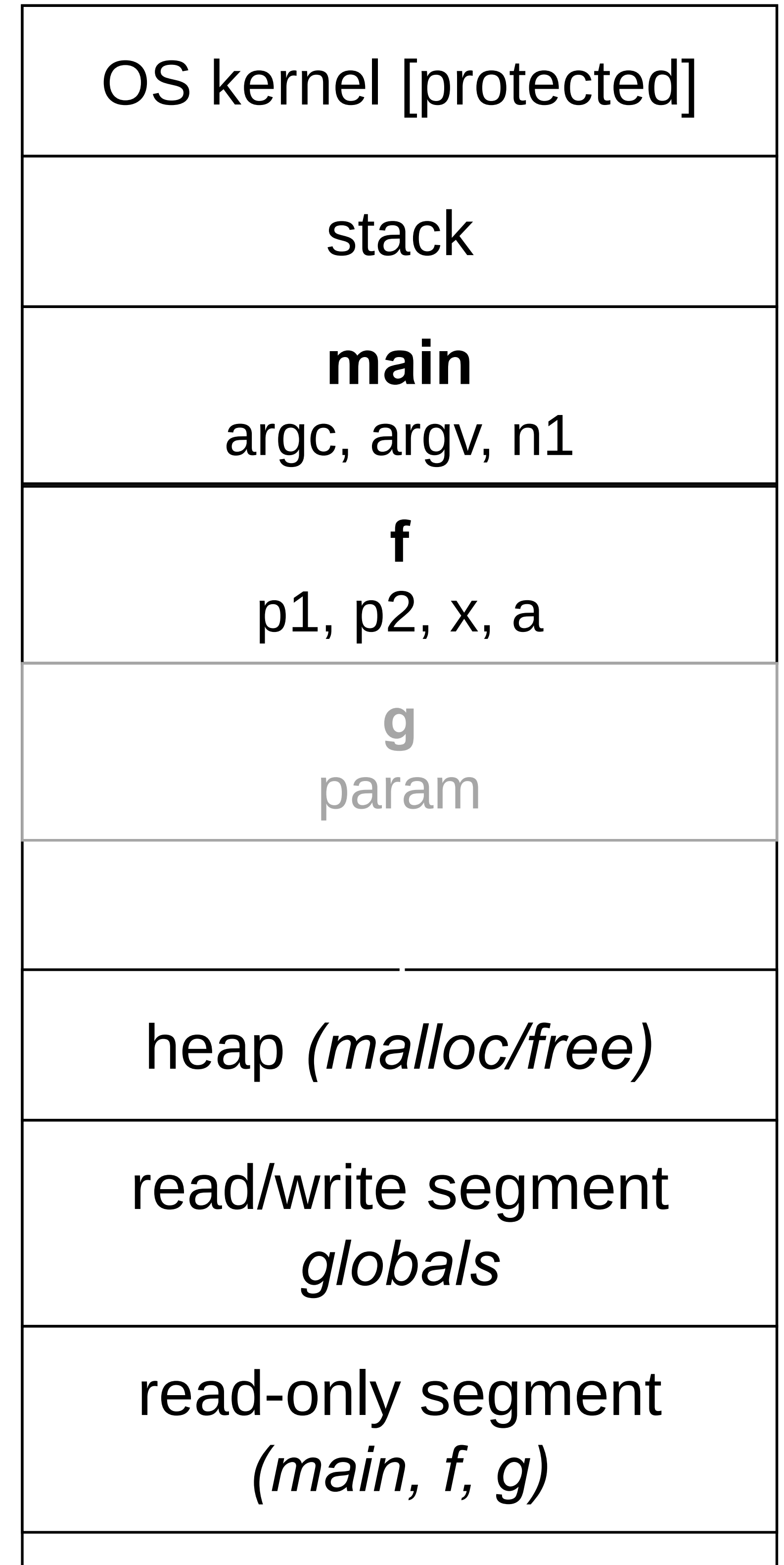

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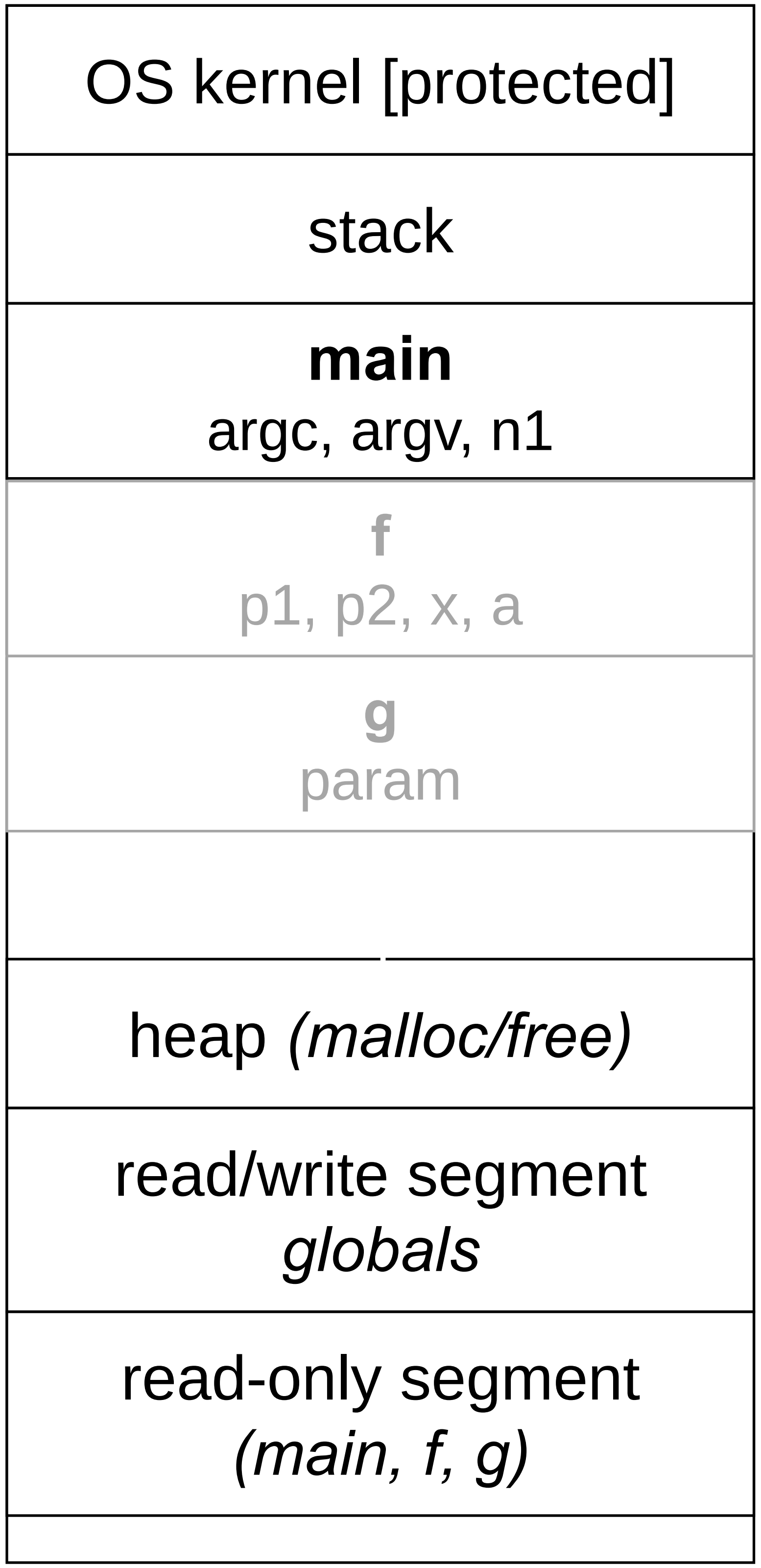

These are slightly modified versions of slides prepared by Steve Gribble

The stack in action

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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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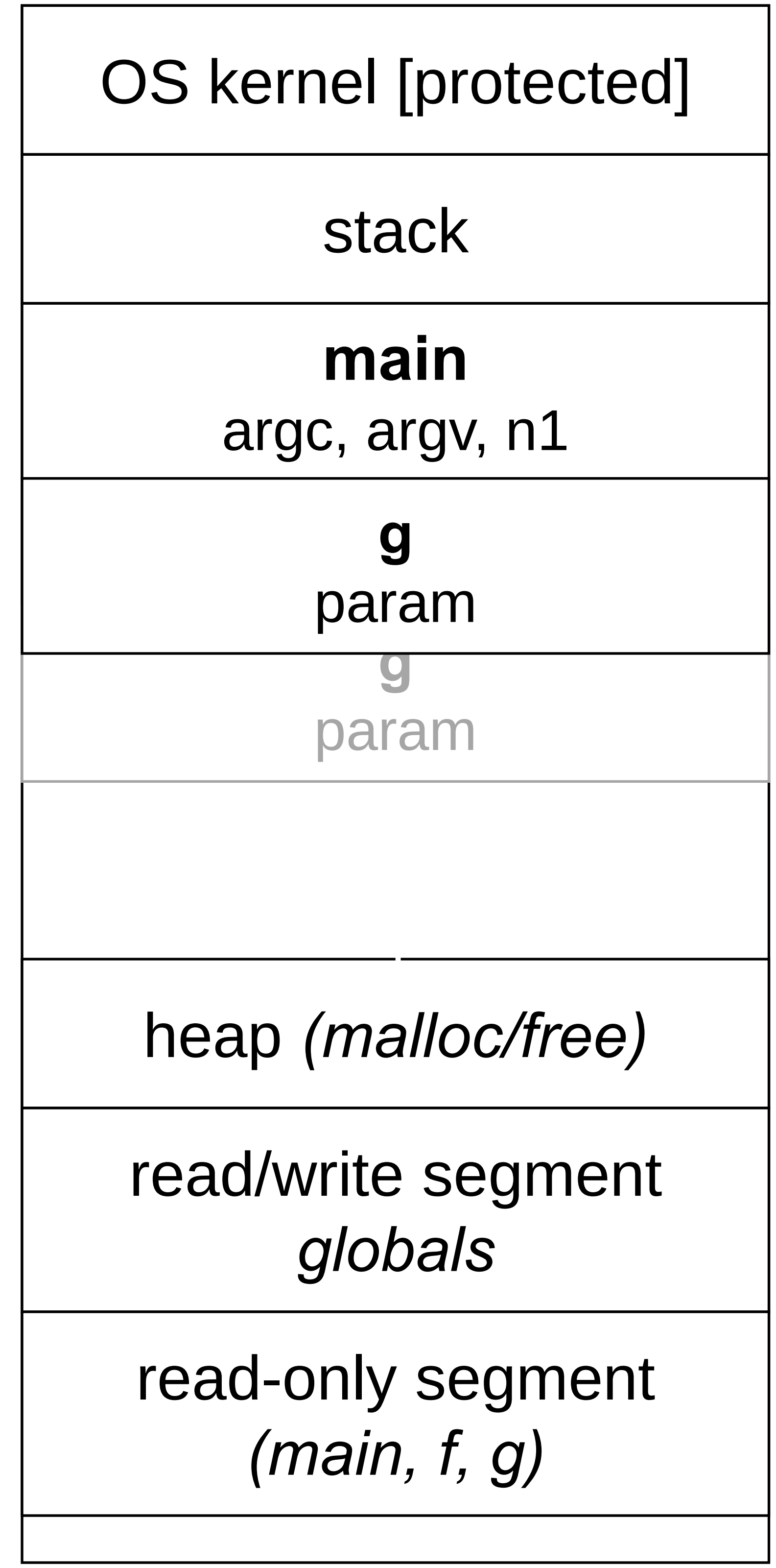

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  int x;
  int a[3];
  ...
  x = g(a[2]);
  return x;
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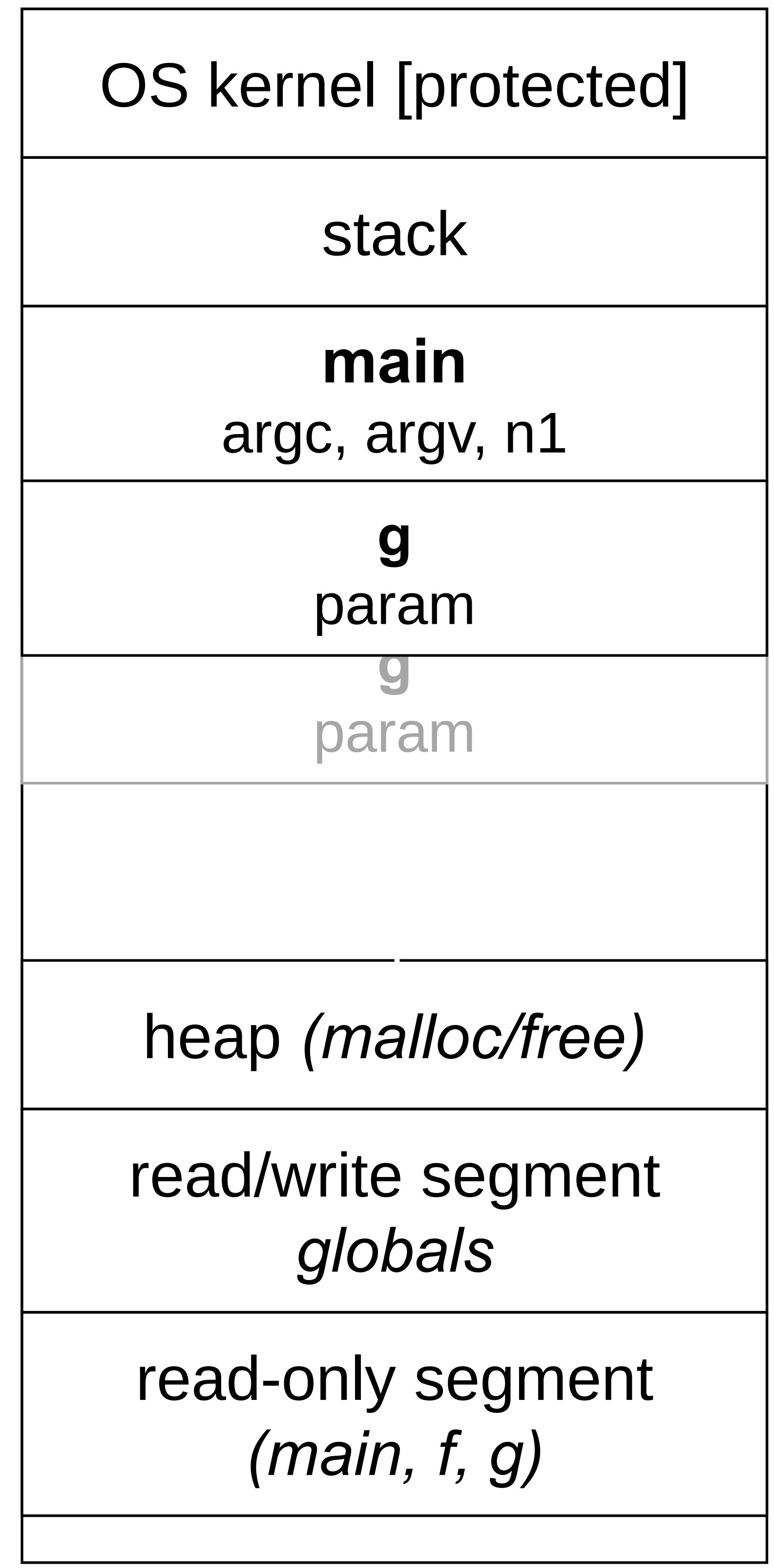

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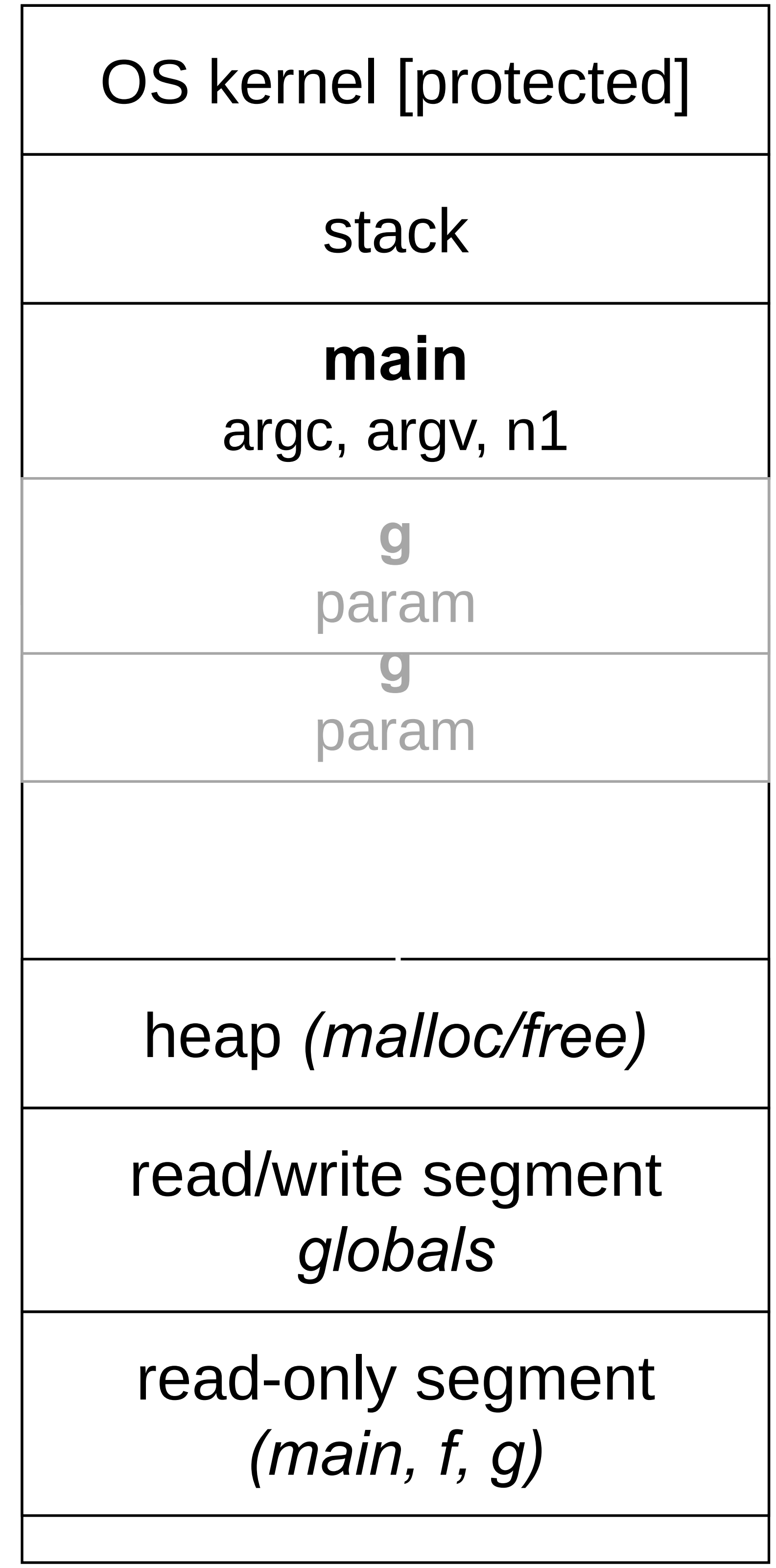

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The stack in action

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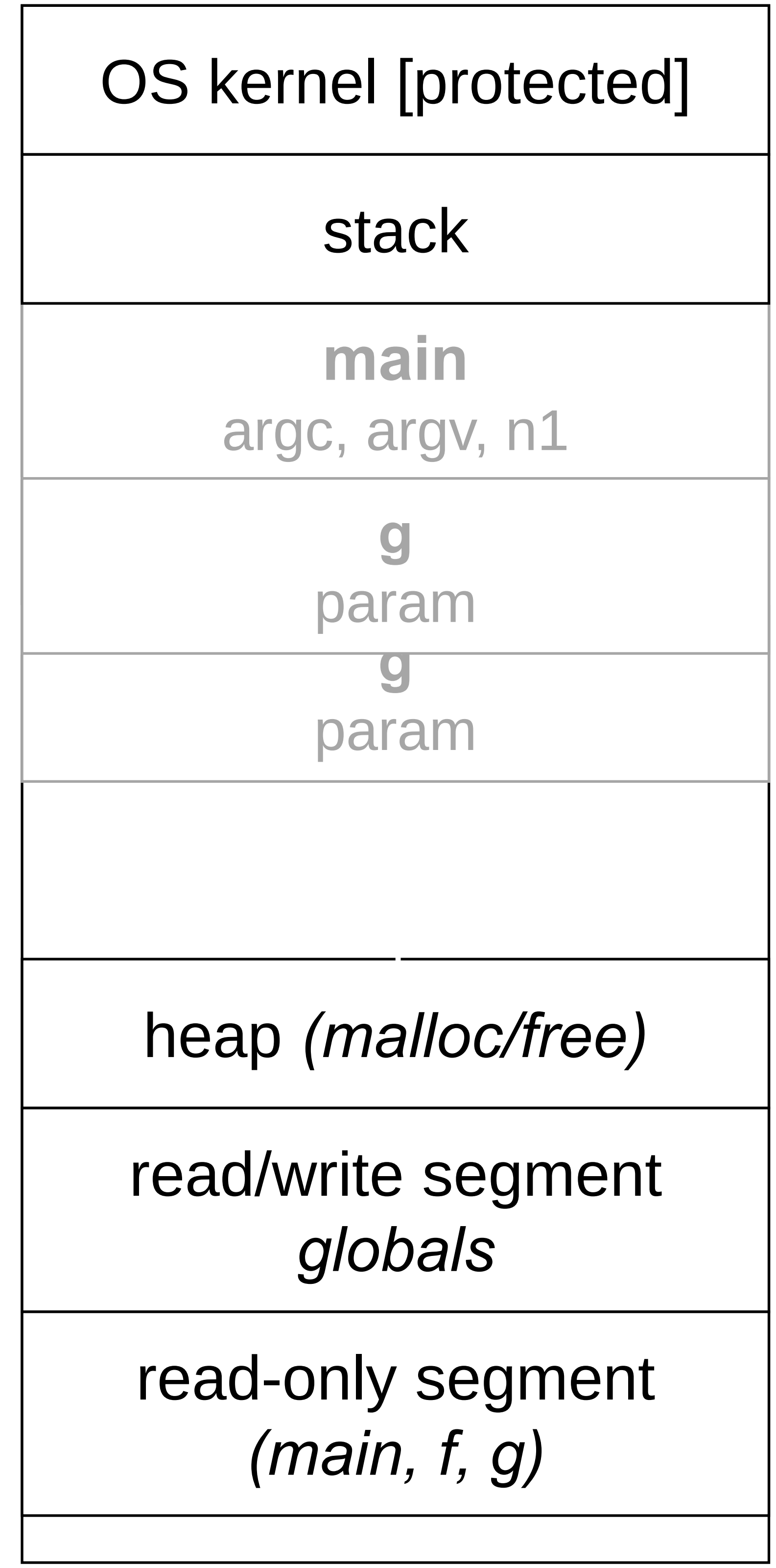

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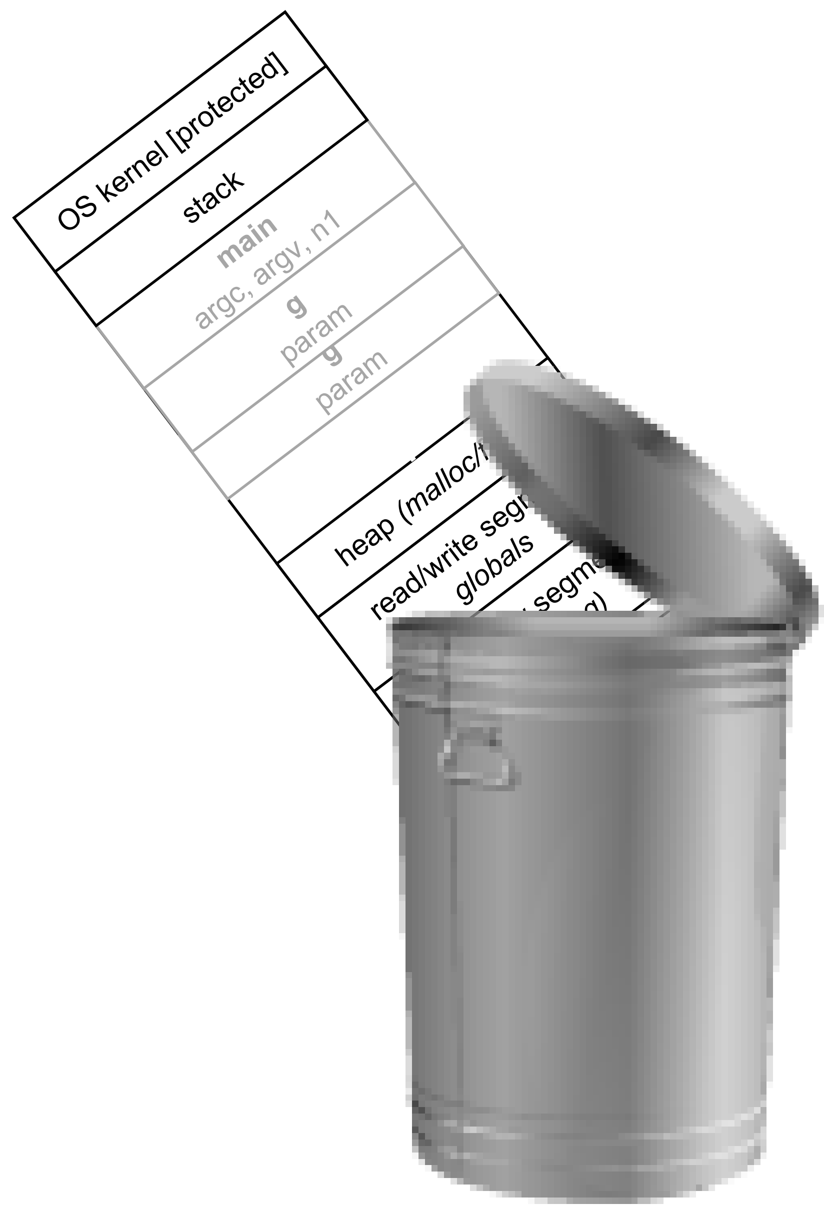
The stack in action



Addresses and the & operator

&foo produces “the address of” *foo*

```
#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;
}
```

addresses.c

```
$ ./addresses
x     is at 0x7ffff4259338
y     is at 0x7ffff425933c
a[0]  is at 0x7ffff4259330
a[1]  is at 0x7ffff4259334
foo   is at 0x4004f4
main  is at 0x400503
```

These are slightly modified versions of slides prepared by Steve Gribble

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 stores 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

```
int* p1;     // these three are all basically the same
int * p2;
int  *p3;

int *p4, *p5;  // these two are basically the same
int* p6, *p7;

int* p8, p9;   // bug?; equivalent to int *p8; int p9;
```

Dereferencing pointers

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

dereference: access the memory referred to by a pointer

deref.c

```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 stores 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!