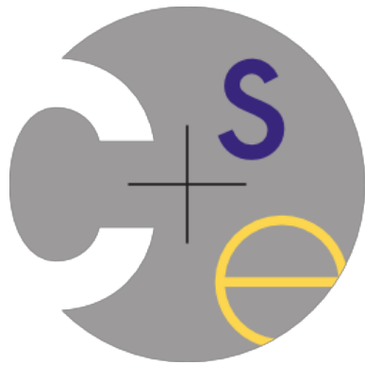
CSE 333

Lecture 3 - pointers, pointers, pointers



Agenda

Today's goals:

- pointers
- more pointers
- pointers and call-by-reference
- arrays and pointers

These are slightly modified versions of slides prepared by Steve Gribble

& and *

&foo *// address of foo - "address of"*
**pointer* *// dereference a pointer*
**pointer = value;* *// dereference / assign*

deref.c

```
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);
```

Something curious

Let's try running this program several times:

asr.c

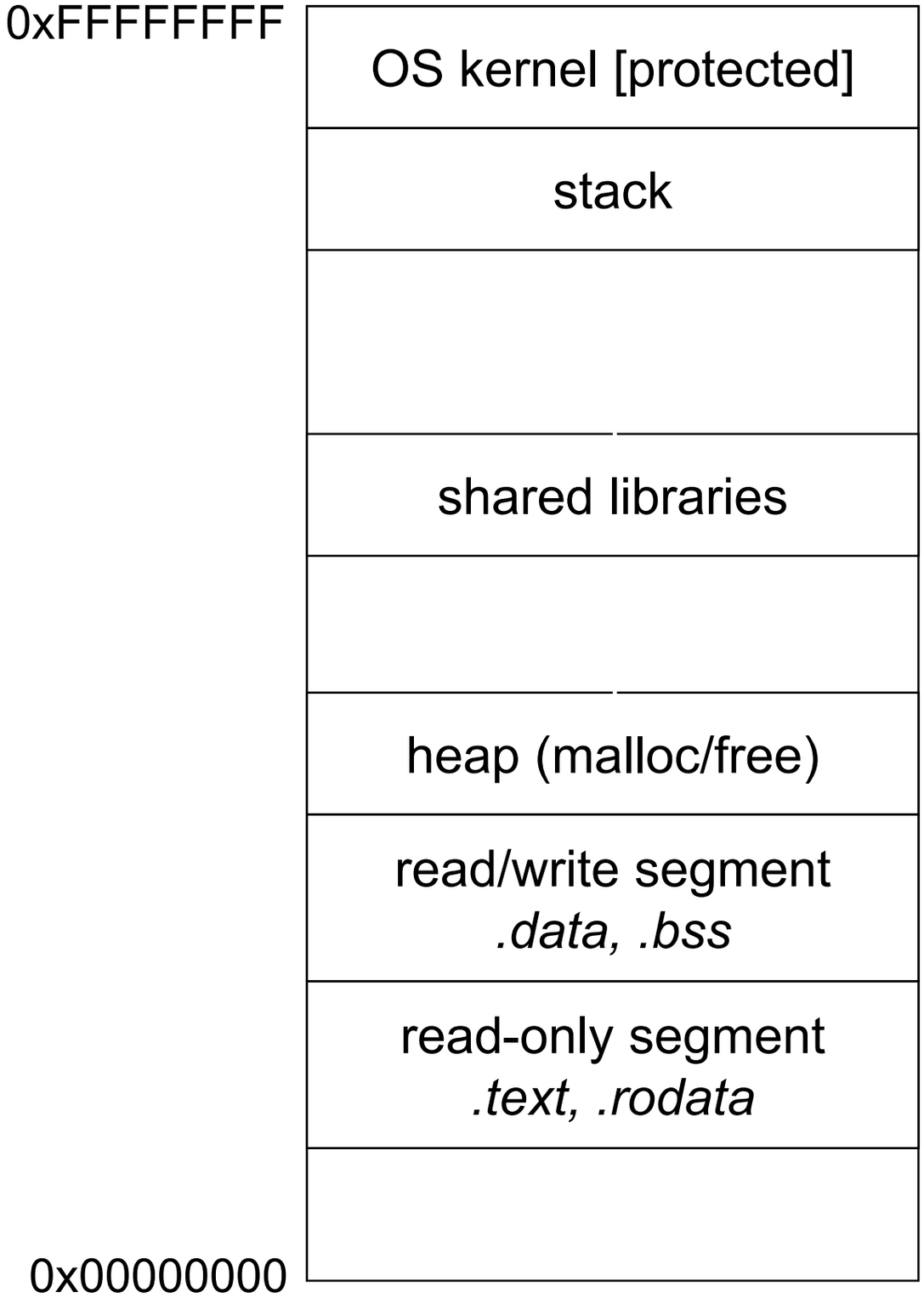
```
#include <stdio.h>

int main(int argc, char **argv) {
  int x = 1;
  int *p = &x;

  printf("&x: %p;  p: %p;  &p: %p\n",
                    &x, p, &p);
  return 0;
}
```

```
$ ./asr
&x: 0xbfa521dc;  p: 0xbfa521dc;  &p: 0xbfa521d8
$ ./asr
&x: 0xbf836f5c;  p: 0xbf836f5c;  &p: 0xbf836f58
$ ./asr
&x: 0xbfea39dc;  p: 0xbfea39dc;  &p: 0xbfea39d8
```

ASR

Linux uses address-space randomization for added security

- Linux randomizes:
  - base of stack
  - shared library (mmap) location
- makes stack-based buffer overflow attacks tougher
- makes debugging tougher
- google “disable linux address space randomization”



These are slightly modified versions of slides prepared by Steve Gribble

Box and arrow diagrams

boxarrow.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];

  printf("&x: %p;  x: %d\n", &x, x);
  printf("&arr[0]: %p;  arr[0]: %d\n", &arr[0], arr[0]);
  printf("&arr[2]: %p;  arr[2]: %d\n", &arr[2], arr[2]);
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);

  return 0;
}
```

address	name	value

&x	x	value

&arr[0]	arr[0]	value
&arr[1]	arr[1]	value
&arr[2]	arr[2]	value

&p	p	value

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Box and arrow diagrams

boxarrow.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];

  printf("&x: %p;  x: %d\n", &x, x);
  printf("&arr[0]: %p;  arr[0]: %d\n", &arr[0], arr[0]);
  printf("&arr[2]: %p;  arr[2]: %d\n", &arr[2], arr[2]);
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);

  return 0;
}
```

address	name	value
&x	x	1
&arr[0]	arr[0]	2
&arr[1]	arr[1]	3
&arr[2]	arr[2]	4
&p	p	&arr[1]

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Box and arrow diagrams

boxarrow.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];

  printf("&x: %p;  x: %d\n", &x, x);
  printf("&arr[0]: %p;  arr[0]: %d\n", &arr[0], arr[0]);
  printf("&arr[2]: %p;  arr[2]: %d\n", &arr[2], arr[2]);
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);

  return 0;
}
```

address	name	value
0xbfff2dc	x	1
0xbfff2d0	arr[0]	2
0xbfff2d4	arr[1]	3
0xbfff2d8	arr[2]	4
0xbfff2cc	p	0xbfff2d4

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Box and arrow diagrams

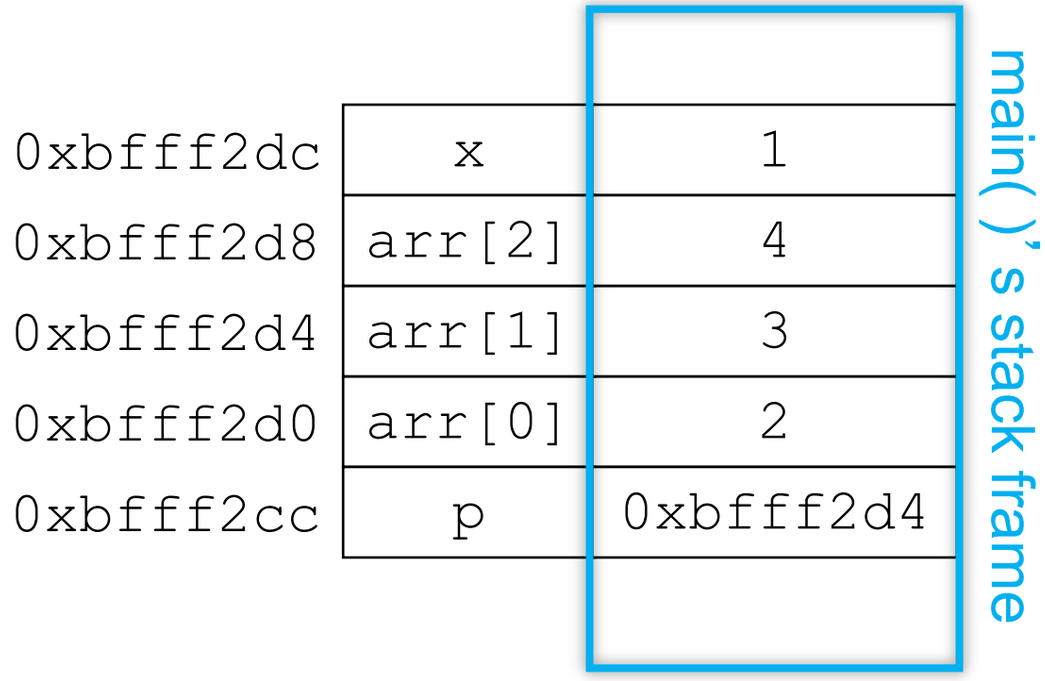
boxarrow.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];

  printf("&x: %p;  x: %d\n", &x, x);
  printf("&arr[0]: %p;  arr[0]: %d\n", &arr[0], arr[0]);
  printf("&arr[2]: %p;  arr[2]: %d\n", &arr[2], arr[2]);
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);

  return 0;
}
```

address	name	value



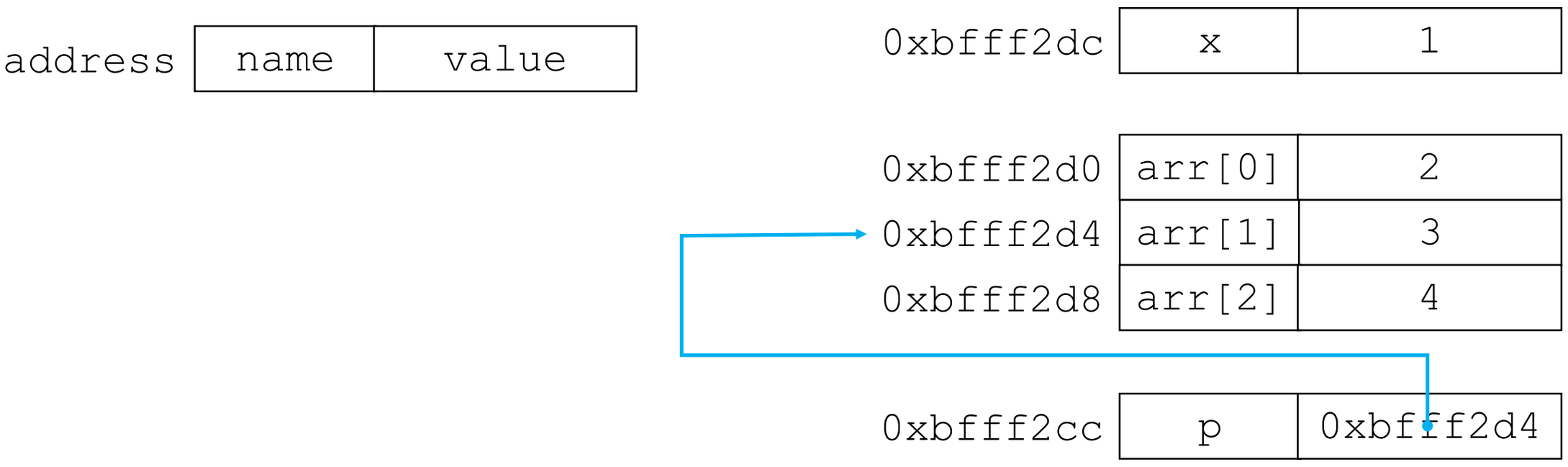
Box and arrow diagrams

boxarrow.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];

  printf("&x: %p;  x: %d\n", &x, x);
  printf("&arr[0]: %p;  arr[0]: %d\n", &arr[0], arr[0]);
  printf("&arr[2]: %p;  arr[2]: %d\n", &arr[2], arr[2]);
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);

  return 0;
}
```



These are slightly modified versions of slides prepared by Steve Gribble

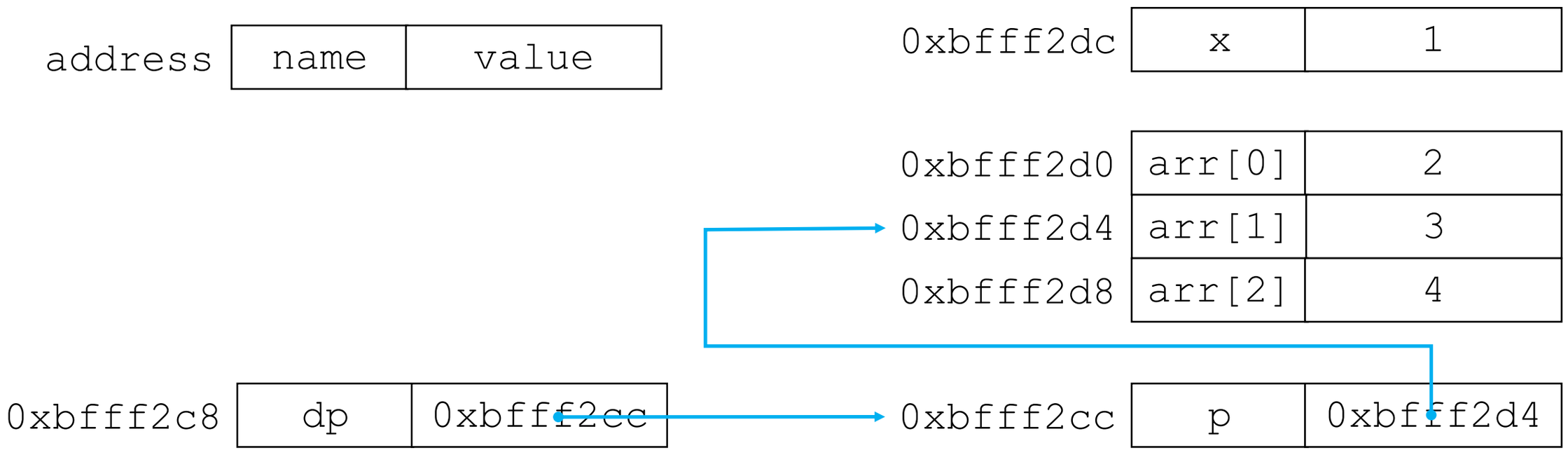
Box and arrow diagrams

boxarrow2.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];
  int **dp = &p;

  *(*dp) += 1;
  p += 1;
  *(*dp) += 1;

  return 0;
}
```



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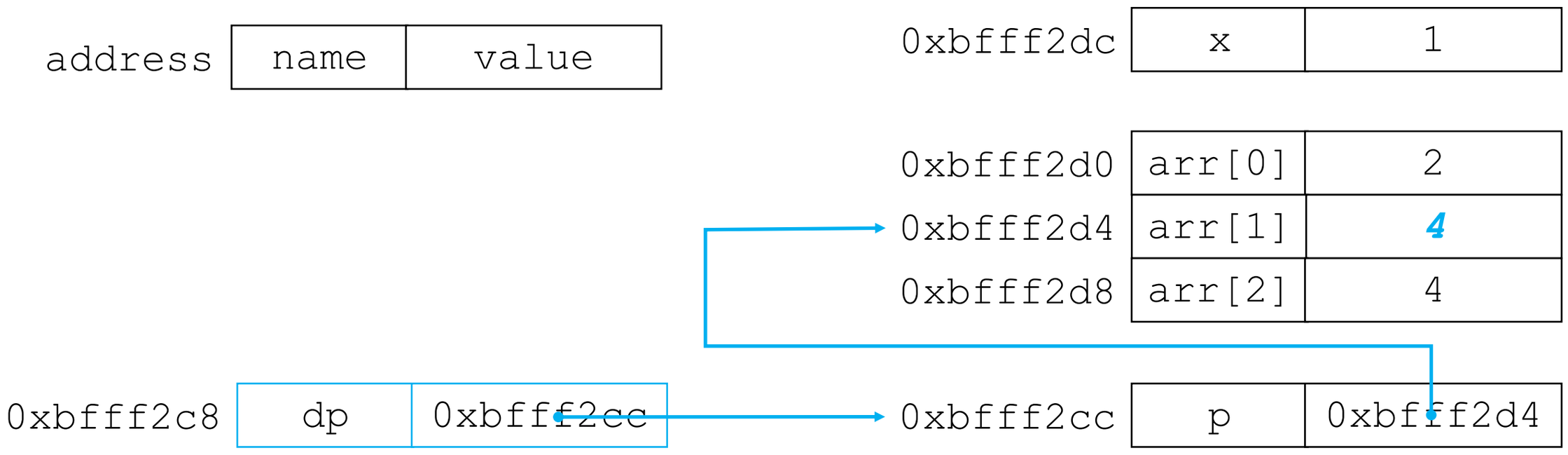
Box and arrow diagrams

boxarrow2.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];
  int **dp = &p;

  *(*dp) += 1;
  p += 1;
  *(*dp) += 1;

  return 0;
}
```



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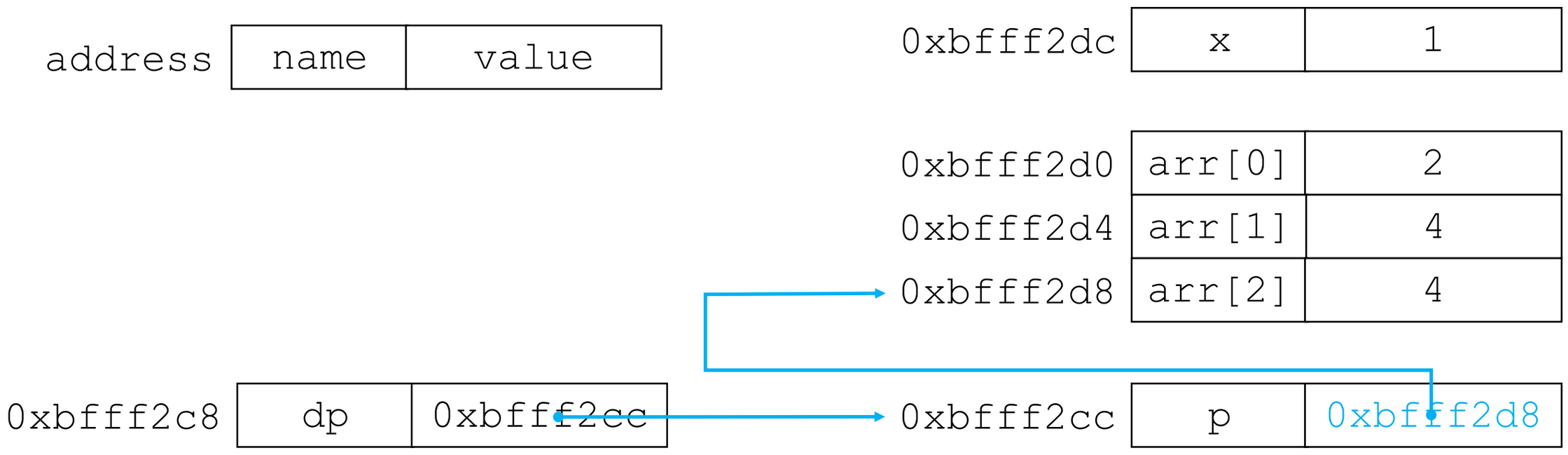
Box and arrow diagrams

boxarrow2.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];
  int **dp = &p;

  *(*dp) += 1;
  p += 1;
  *(*dp) += 1;

  return 0;
}
```



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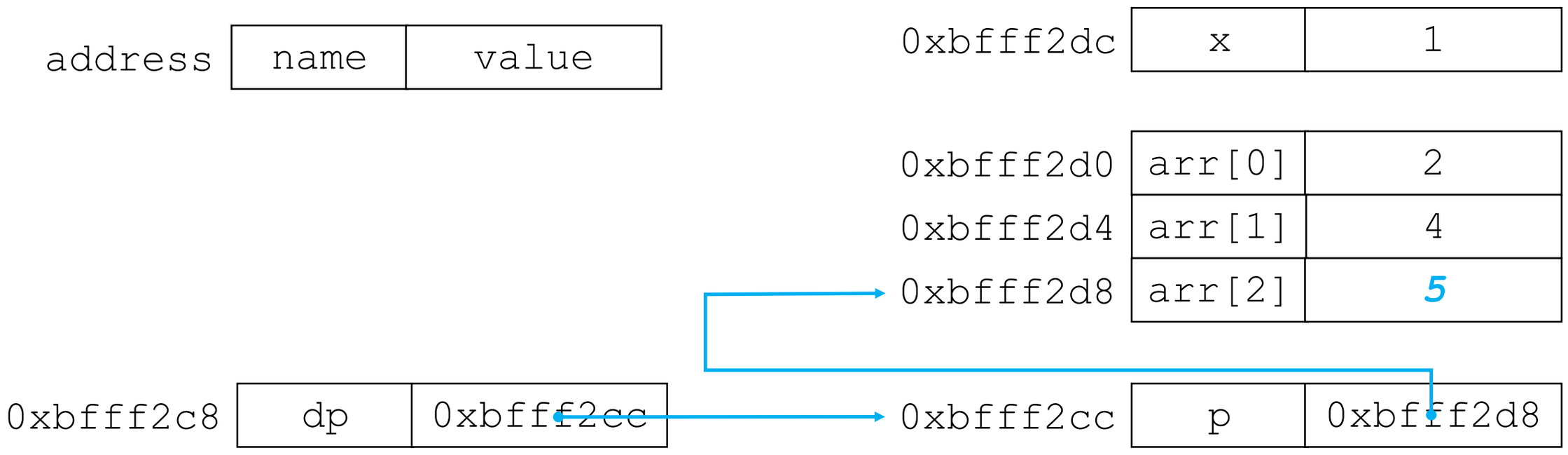
Box and arrow diagrams

boxarrow2.c

```
int main(int argc, char **argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int *p = &arr[1];
  int **dp = &p;

  *(*dp) += 1;
  p += 1;
  *(*dp) += 1;

  return 0;
}
```



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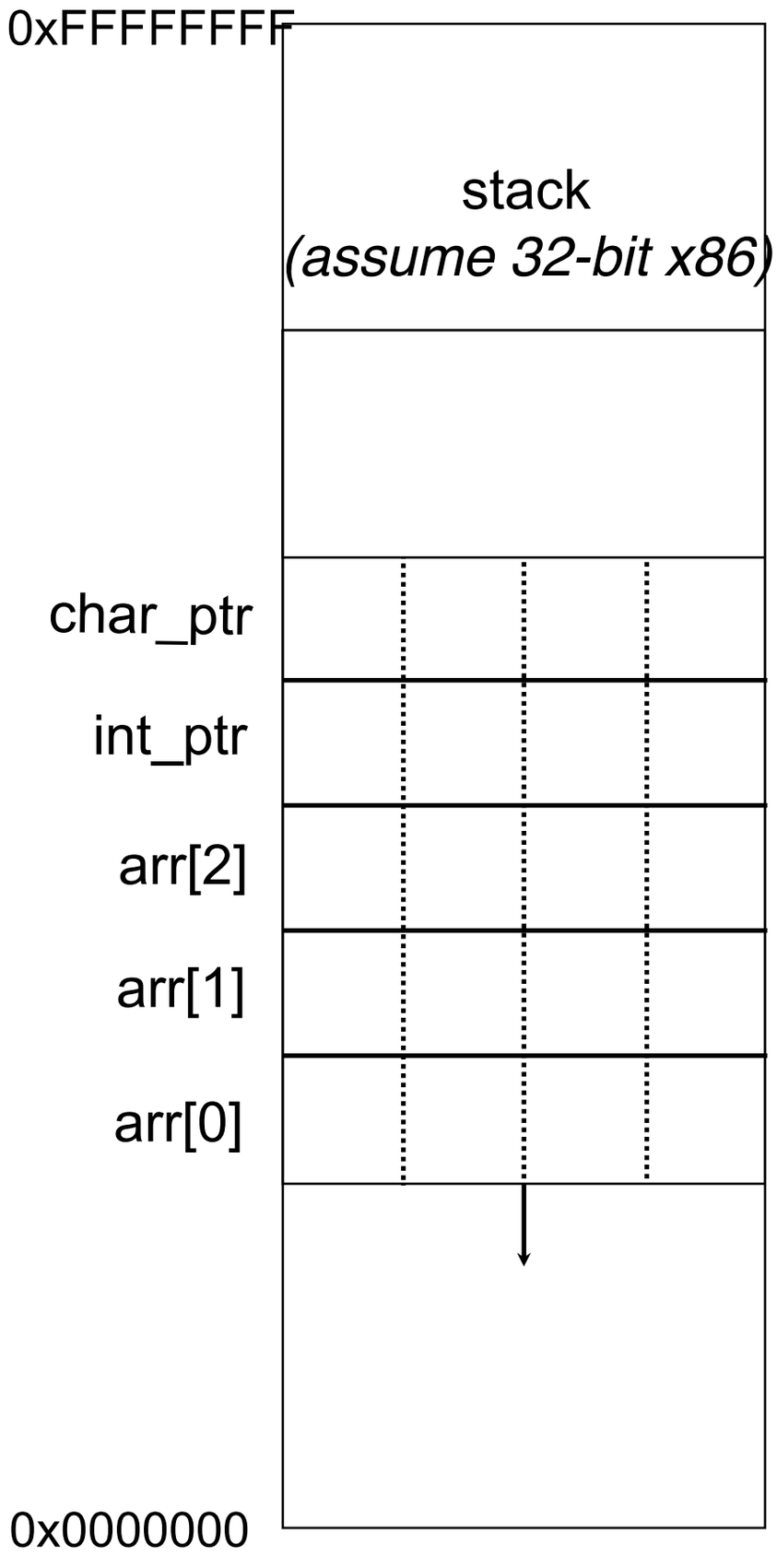
Pointer arithmetic

Pointers are typed

- `int *int_ptr;` **vs.** `char *char_ptr;`
- pointer arithmetic obeys those types
  - The address held in a pointer is always a byte address
  - int_ptr++ increments by 4; char_ptr++ increments by 1
- *see pointerarithmetic.c*

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

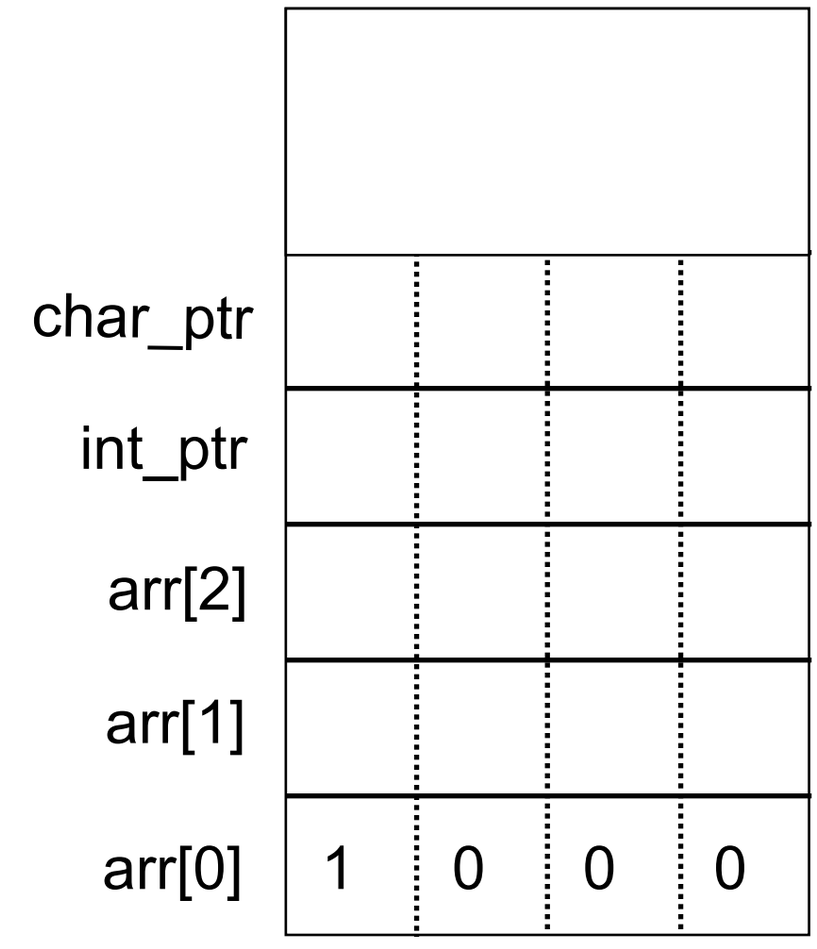
pointerarithmetic.c



```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

pointerarithmetic.c

stack
(assume 32-bit x86)

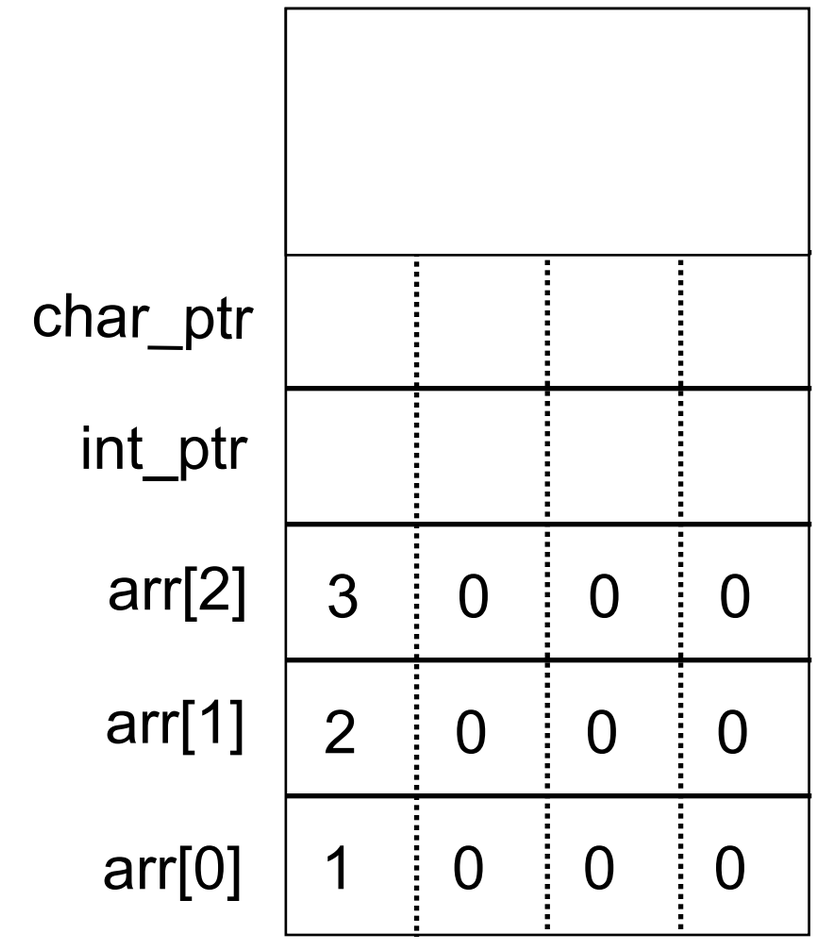


(x86 is little endian)

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

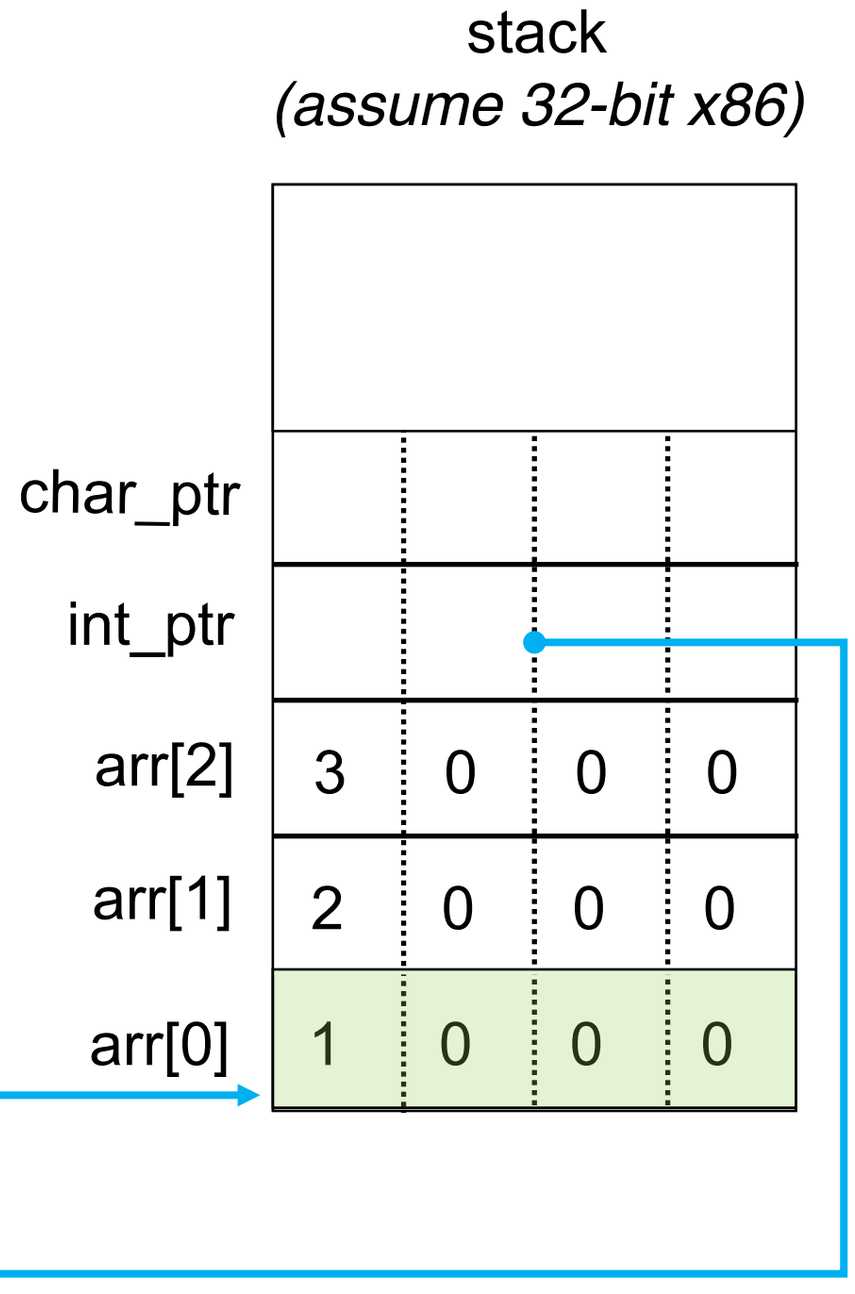
pointerarithmetic.c

stack
(assume 32-bit x86)



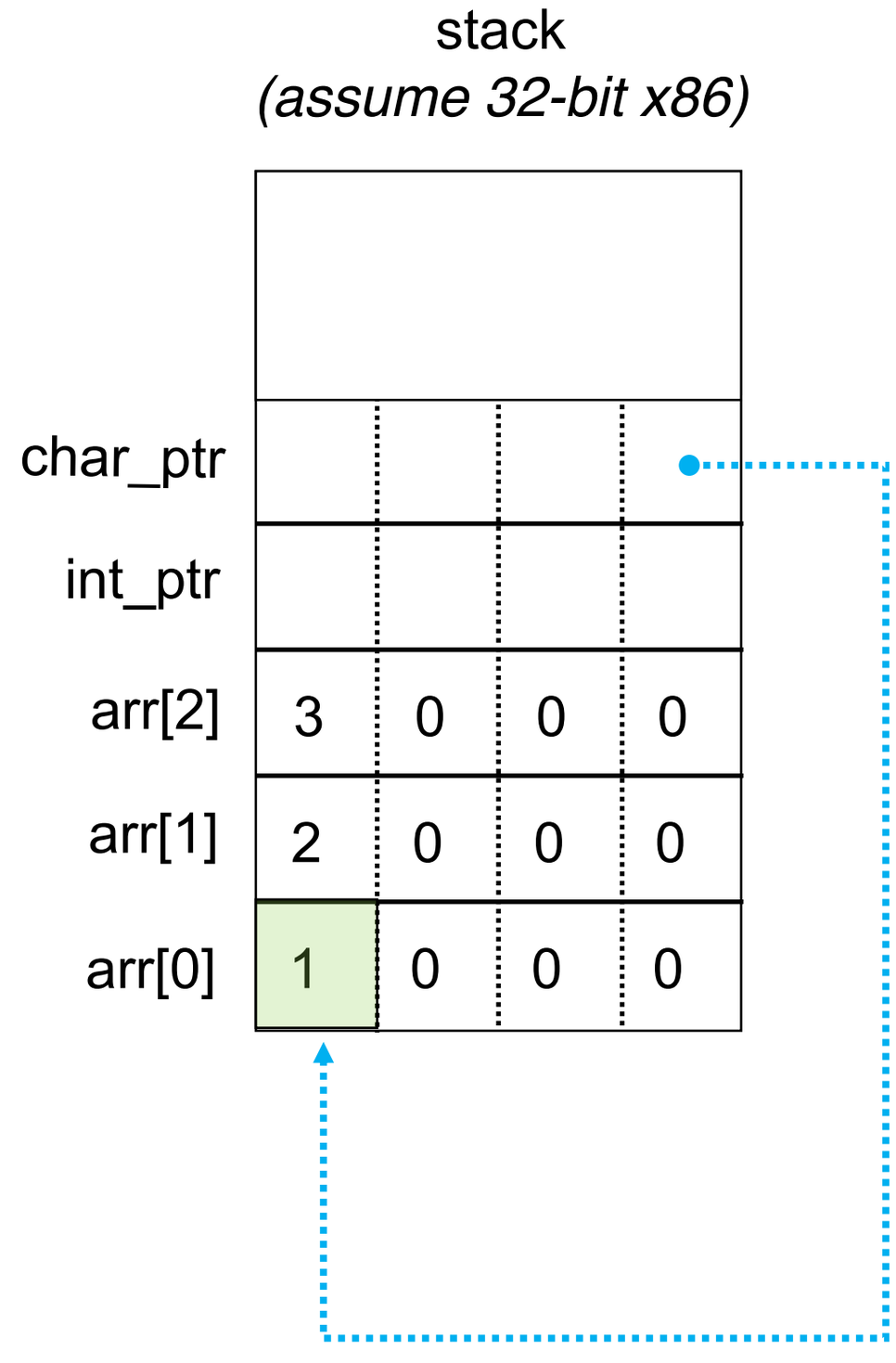
```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

pointerarithmetic.c



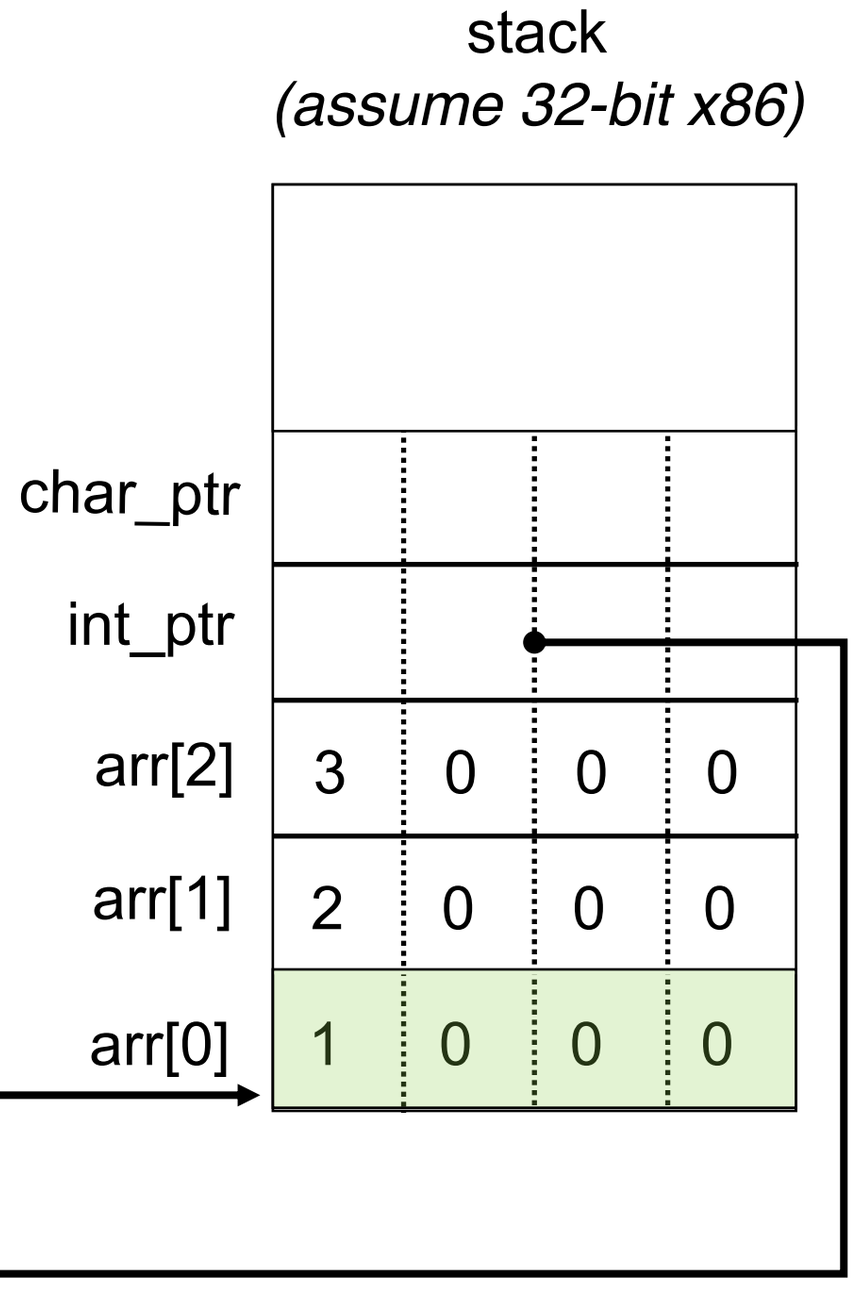
```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

pointerarithmetic.c



```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

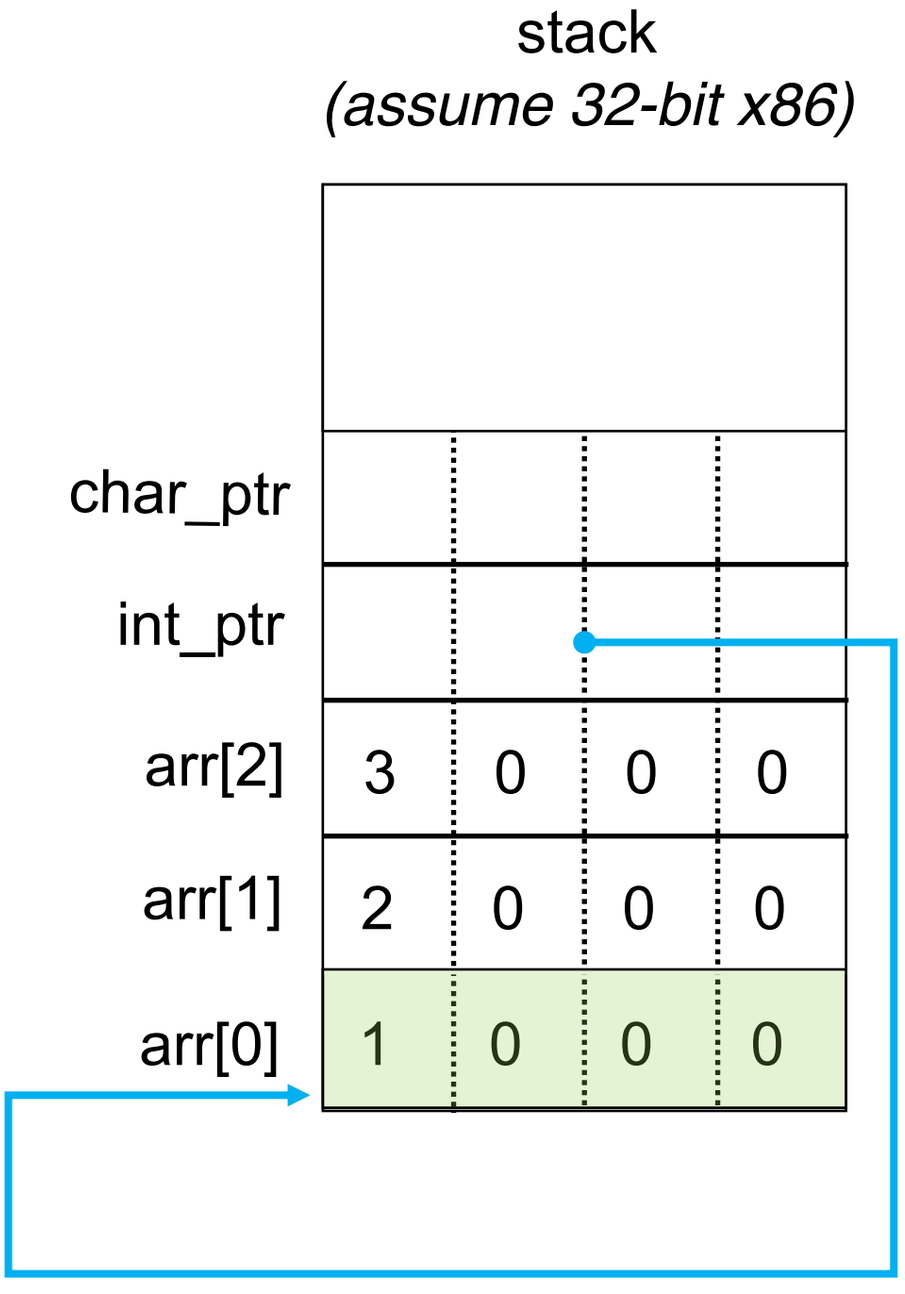
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

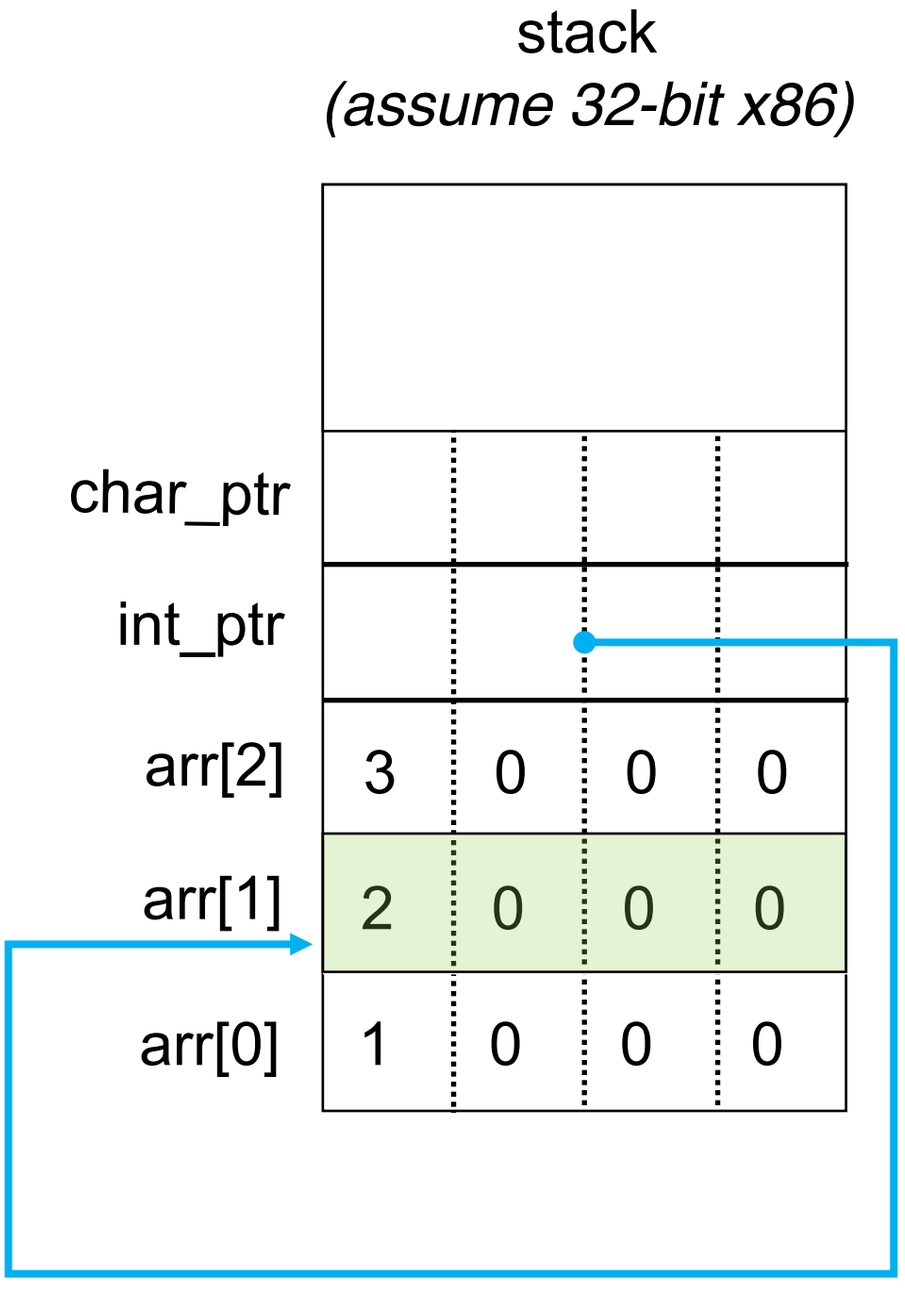
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

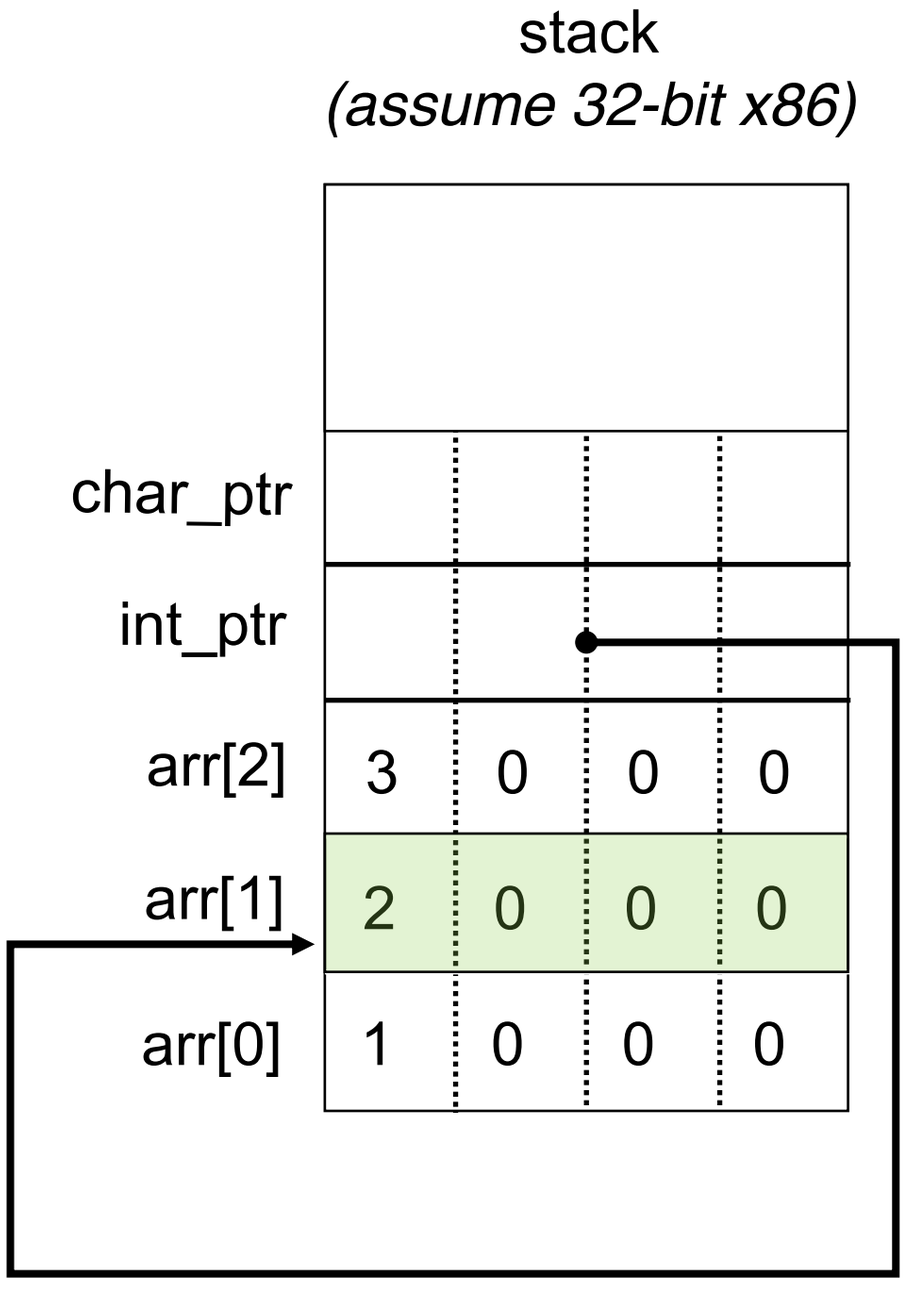
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

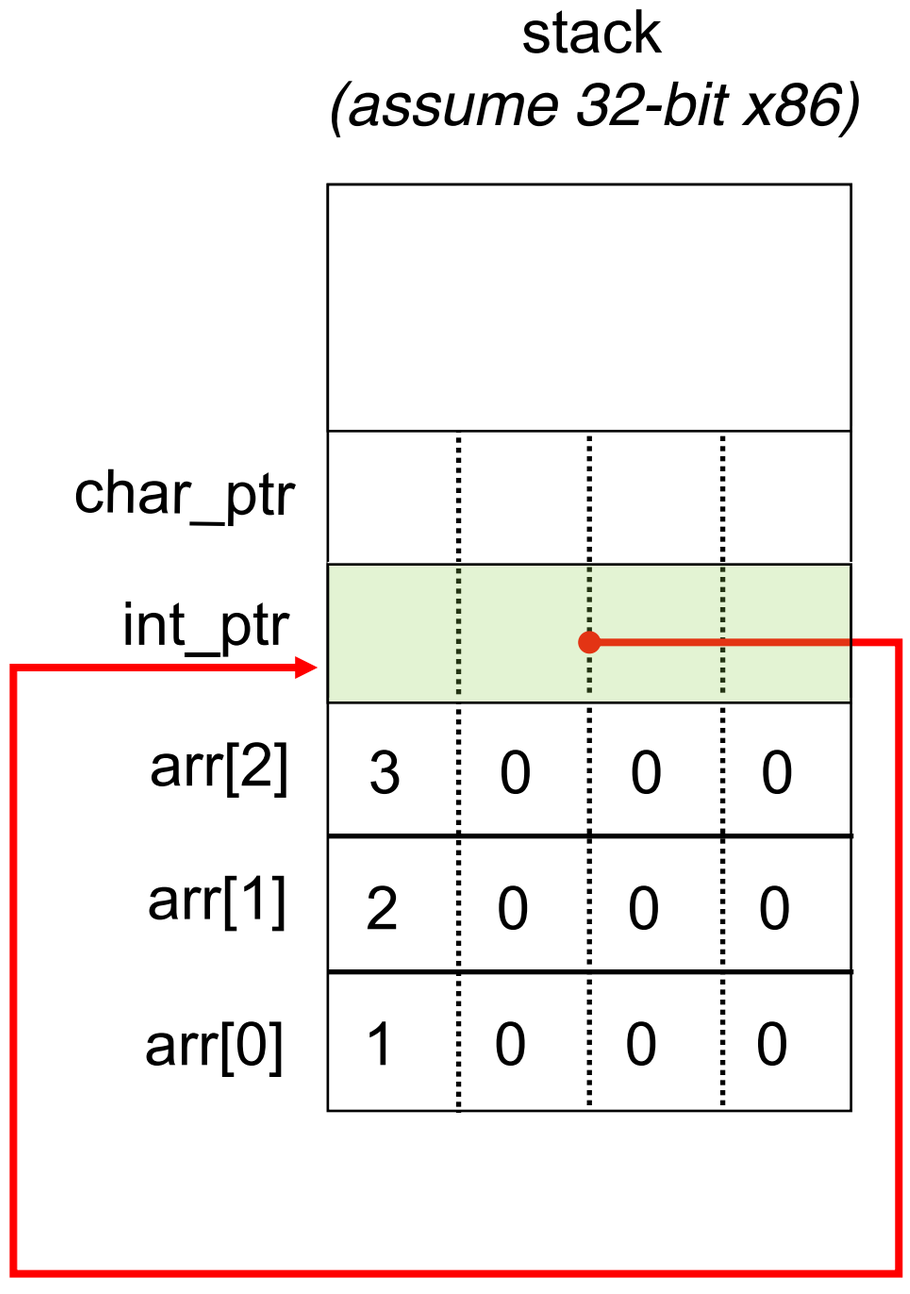
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
int_ptr: 0xbffff2b0;  *int_ptr: 2
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

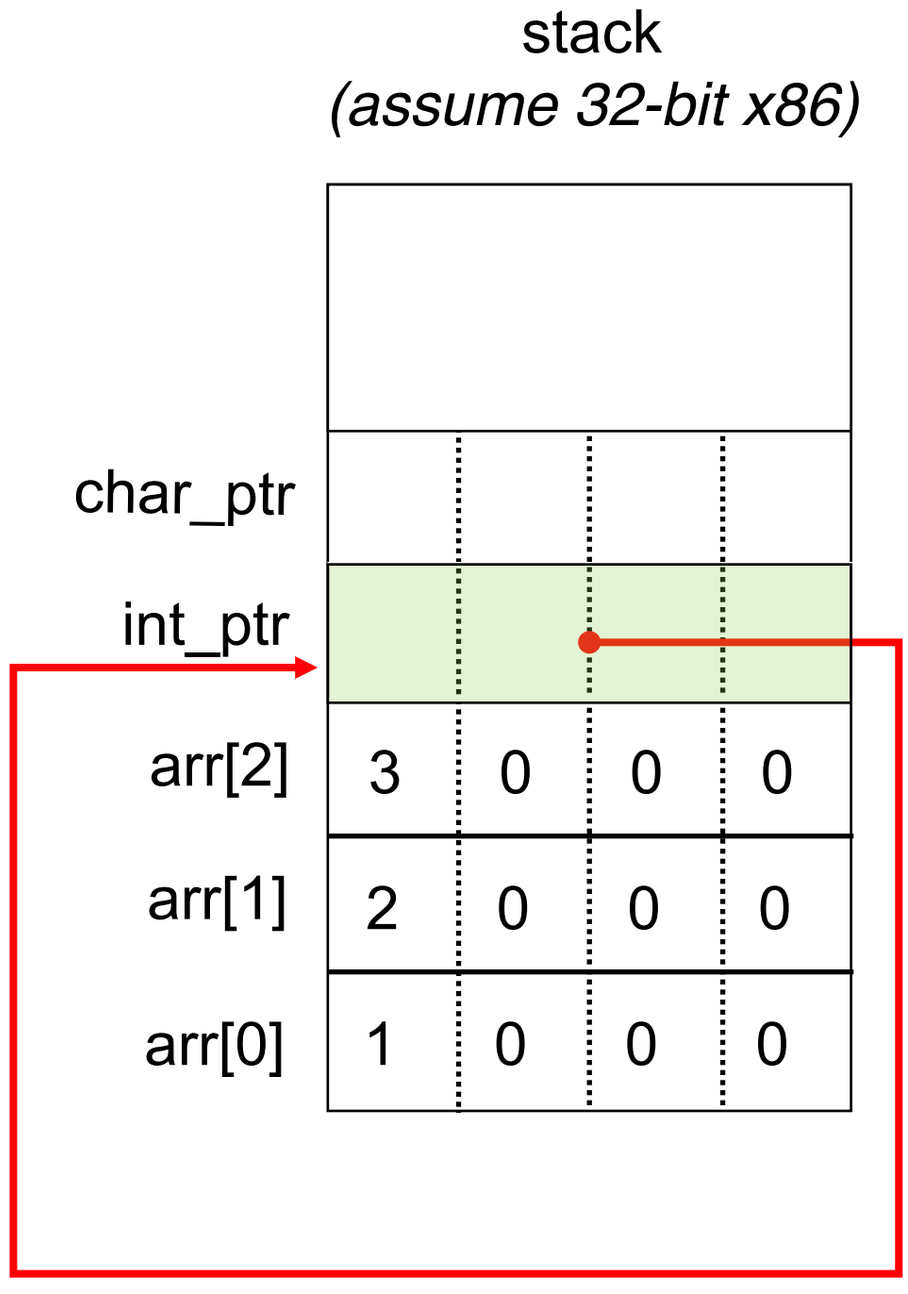
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
int_ptr: 0xbffff2b0;  *int_ptr: 2
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

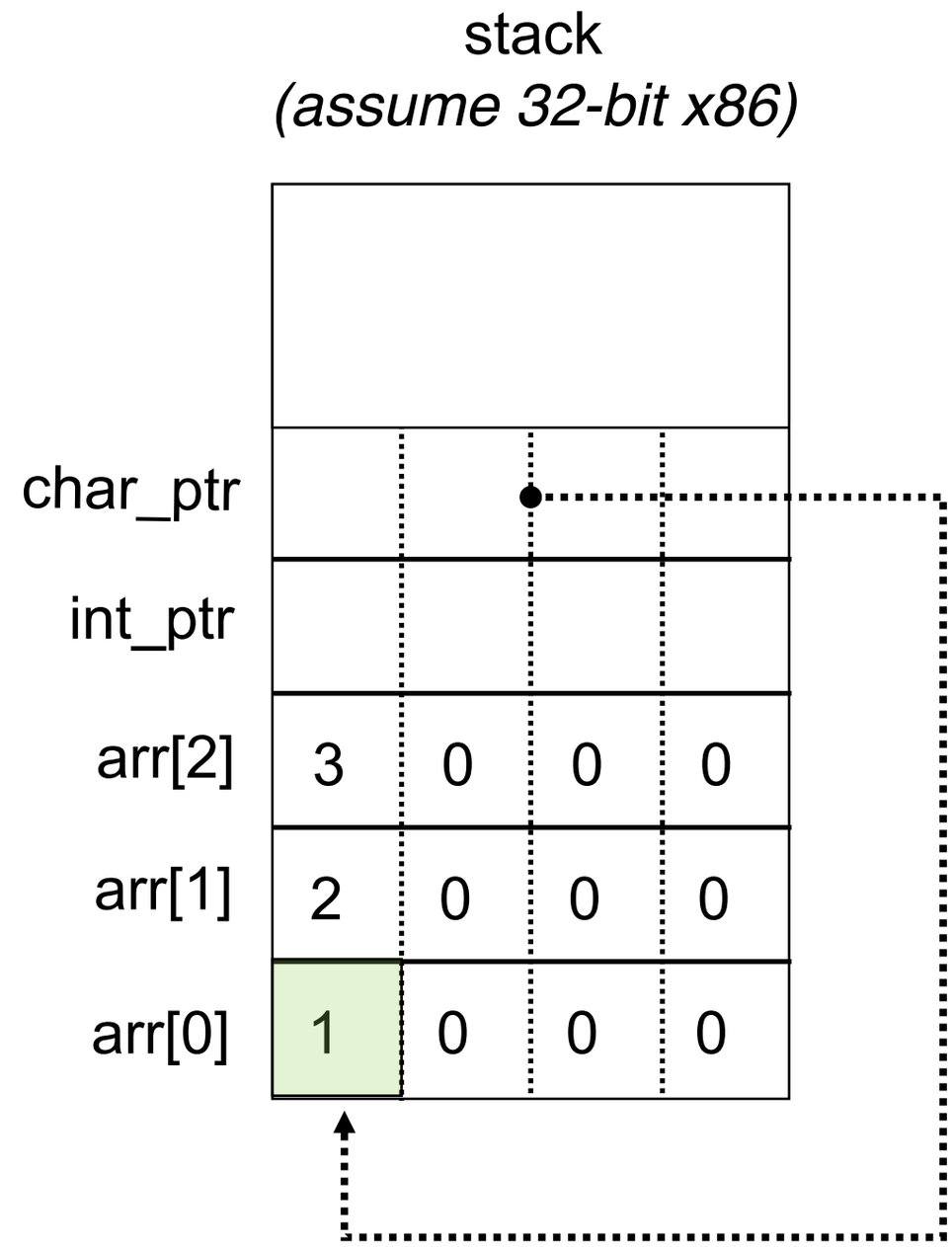
pointerarithmetic.c




```
int_ptr: 0xbffff2ac;  *int_ptr: 1
int_ptr: 0xbffff2b0;  *int_ptr: 2
int_ptr: 0xbffff2b8;   *int_ptr: -
                1073745224
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

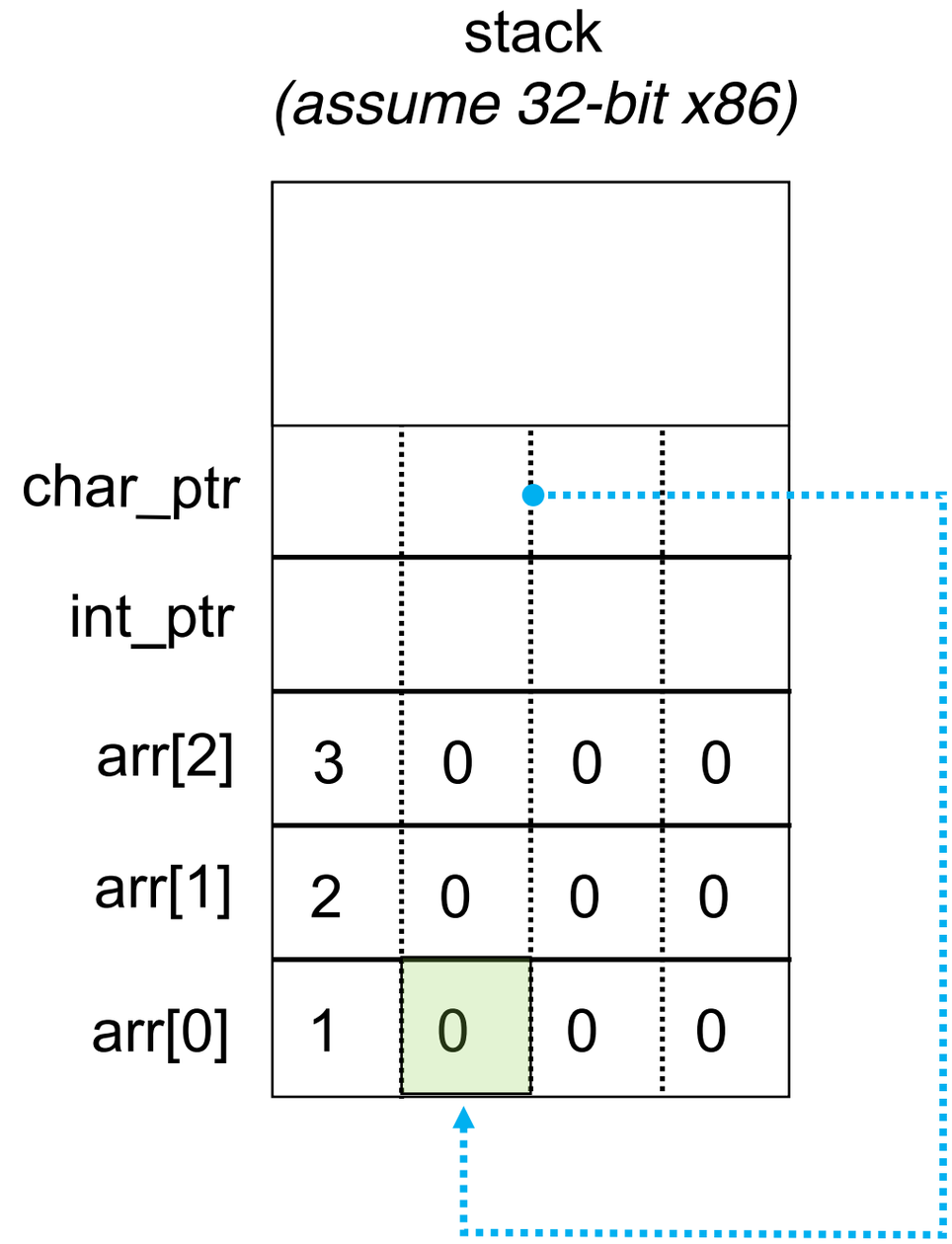
pointerarithmetic.c




```
char_ptr: 0xbffff2ac;  *char_ptr: 1
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

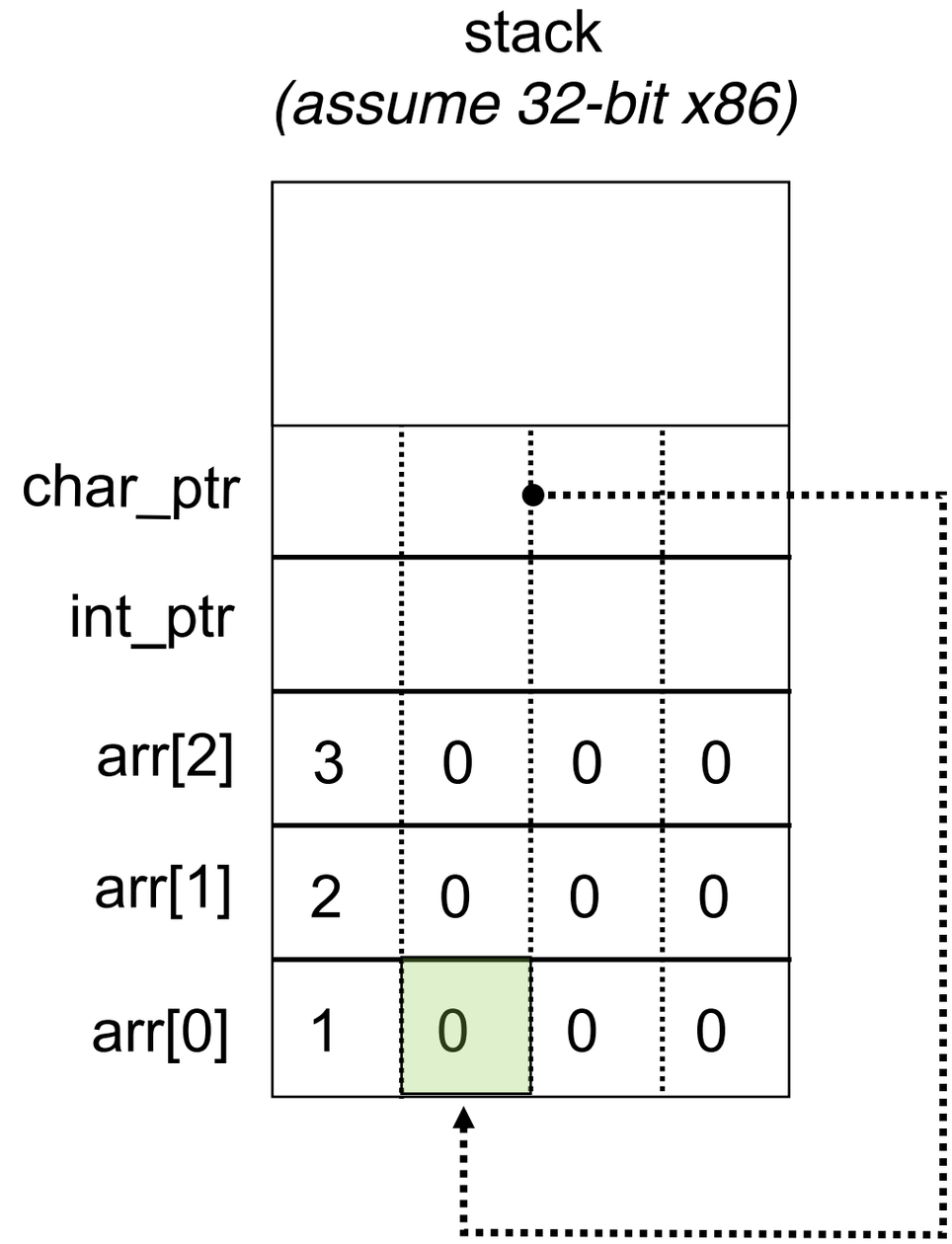
pointerarithmetic.c




```
char_ptr: 0xbffff2ac;  *char_ptr: 1
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

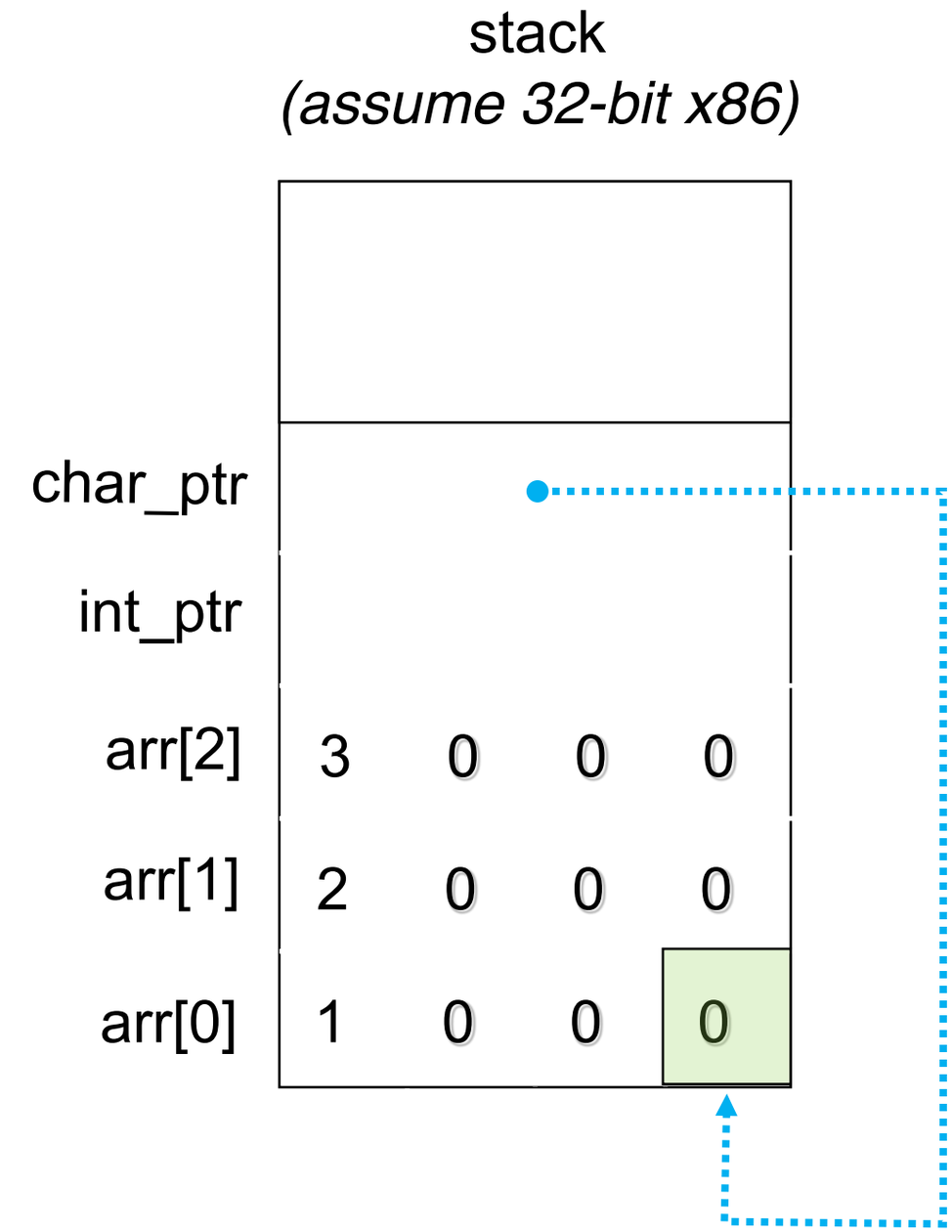
pointerarithmetic.c




```
char_ptr: 0xbffff2ac;  *char_ptr: 1
char_ptr: 0xbffff2ad;  *char_ptr: 0
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

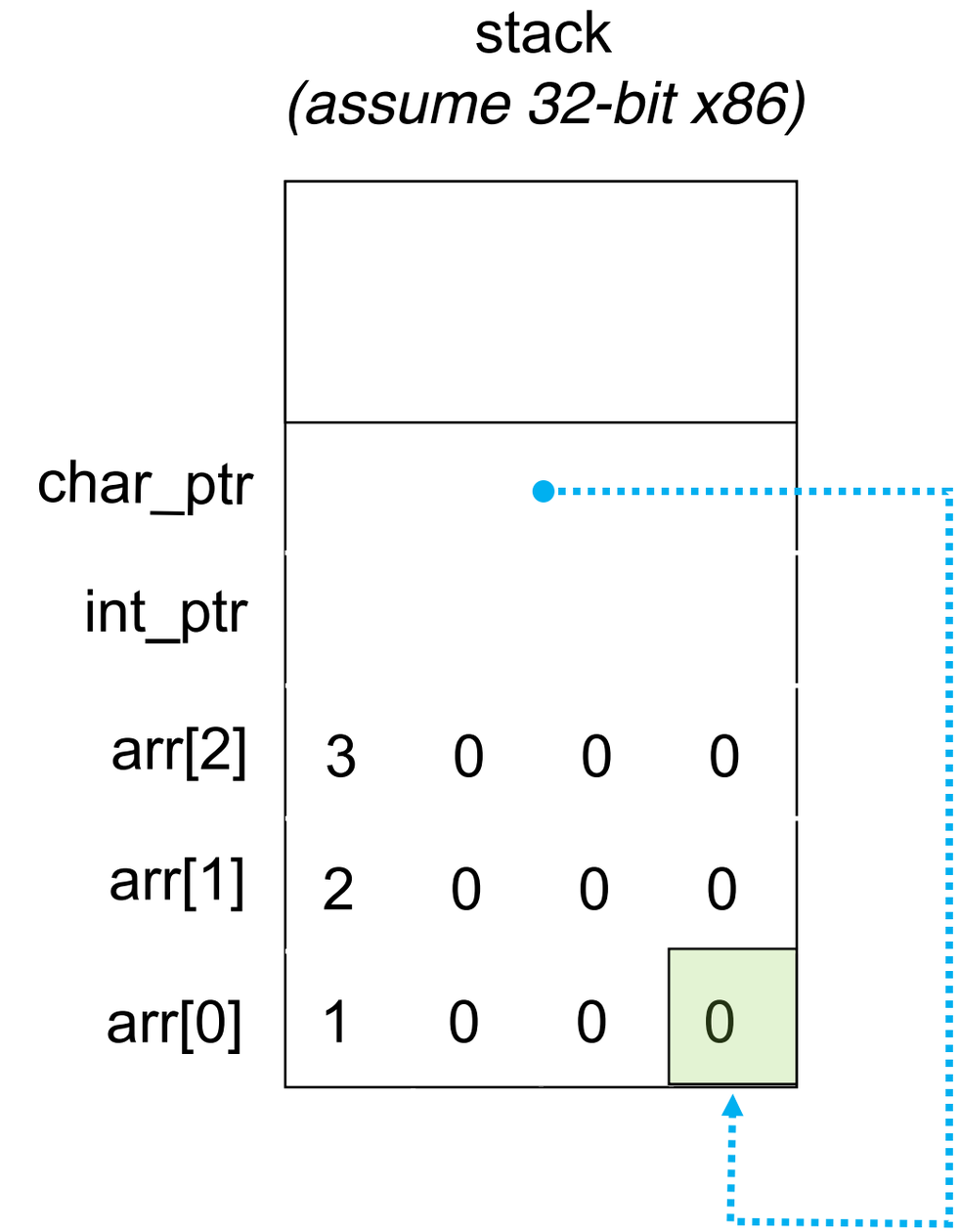
pointerarithmetic.c




```
char_ptr: 0xbffff2ac;  *char_ptr: 1
char_ptr: 0xbffff2ad;  *char_ptr: 0
```

```c
#include <stdio.h>

int main(int argc, char **argv) {
  int arr[3] = {1, 2, 3};
  int *int_ptr = &arr[0];
  char *char_ptr = (char *) int_ptr;

  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 1;
  printf("int_ptr: %p;  *int_ptr: %d\n",
         int_ptr, *int_ptr);
  int_ptr += 2;  // uh oh
  print("int_ptr: %p;   *int_ptr: %d\n",
        int_ptr, *int_ptr);

  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 1;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);
  char_ptr += 2;
  printf("char_ptr: %p;  *char_ptr: %d\n",
         char_ptr, *char_ptr);

  return 0;
}
```

pointerarithmetic.c




```
char_ptr: 0xbffff2ac;  *char_ptr: 1
char_ptr: 0xbffff2ad;  *char_ptr: 0
char_ptr: 0xbffff2af;  *char_ptr: 0
```

Pass-by-value

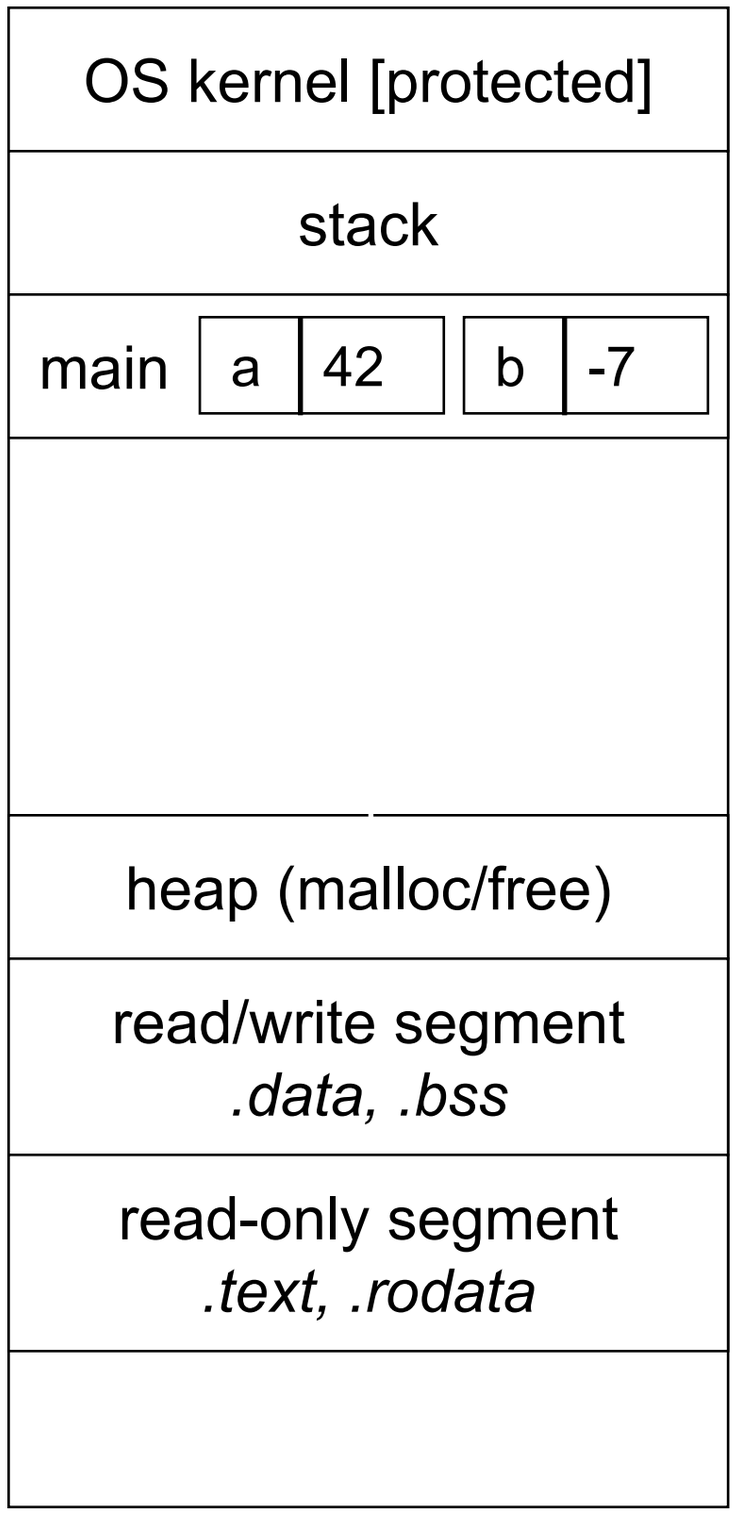
C passes arguments by value

- callee receives a copy of the argument
- if the callee modifies an argument, caller's copy isn't modified

```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv) {
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a, b);
  return 0;
}
```

brokenswap.c

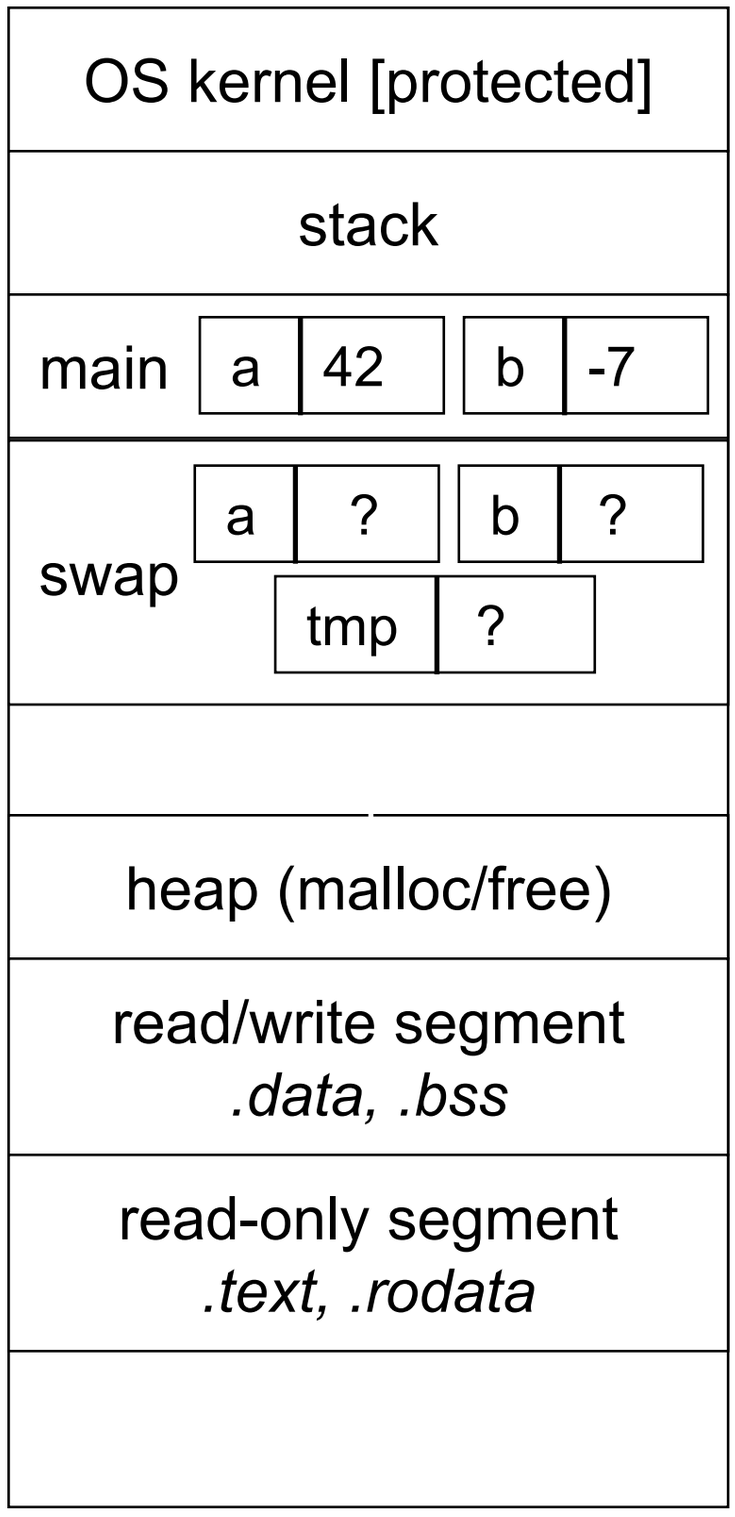
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}


int main(int argc, char **argv) {
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a, b);
  return 0;
}
```

brokenswap.c

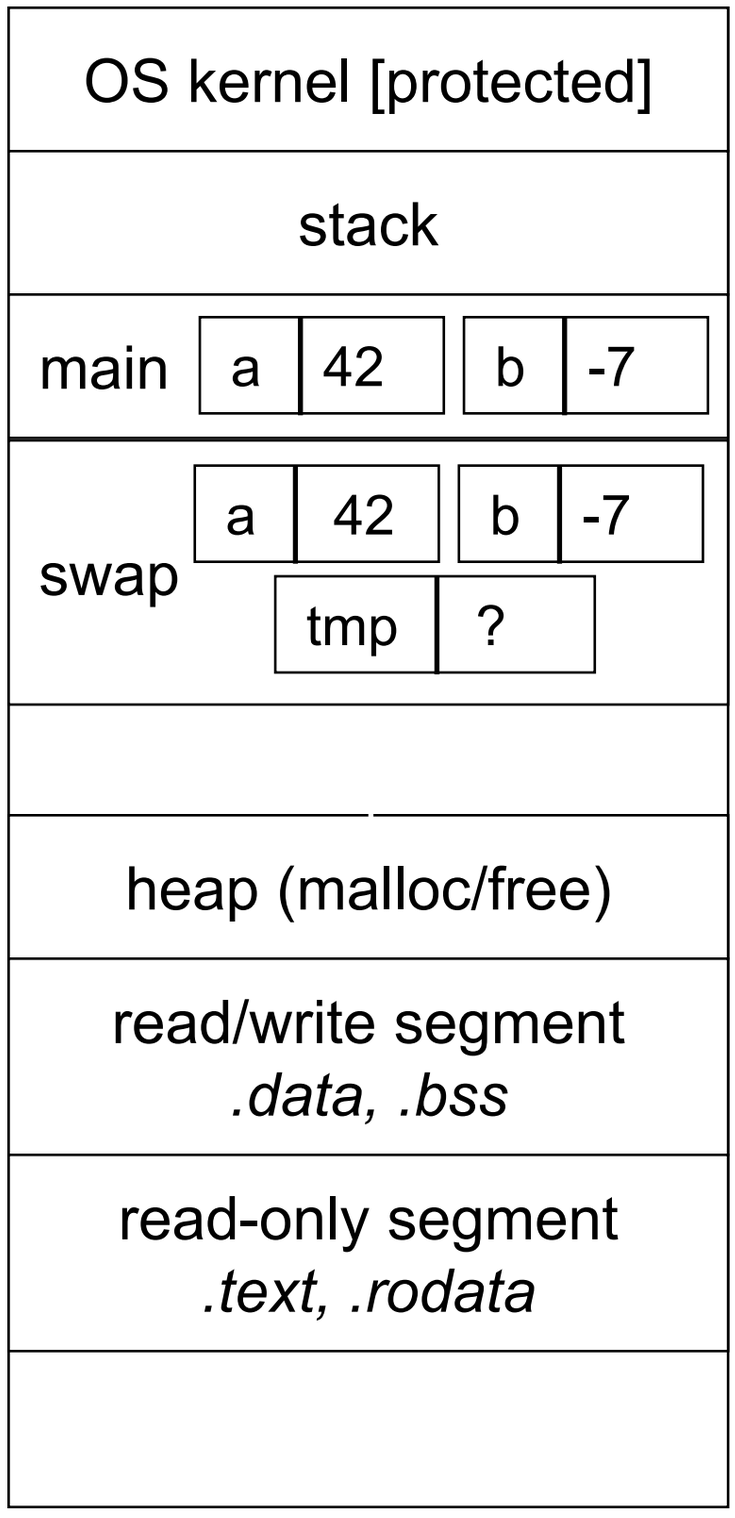
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

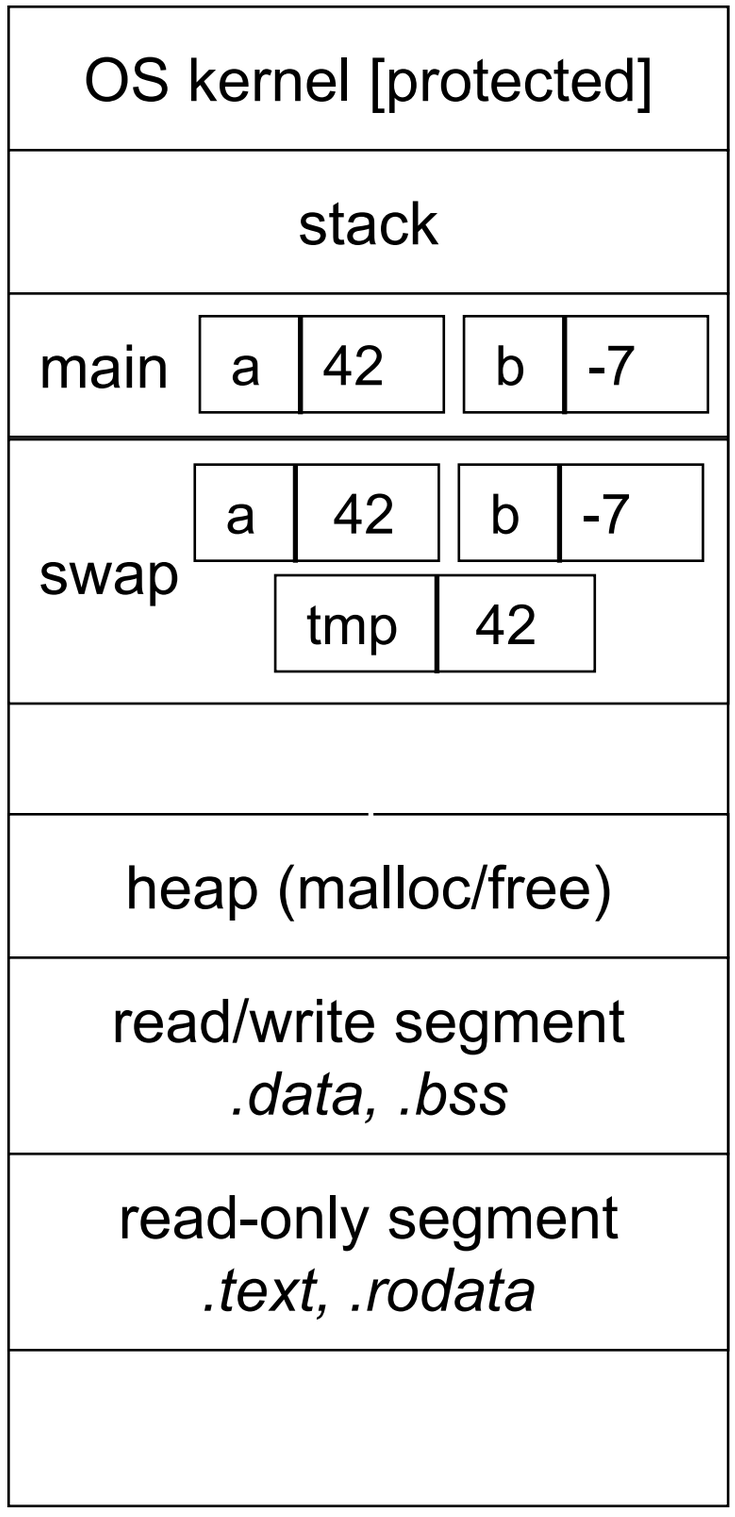
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

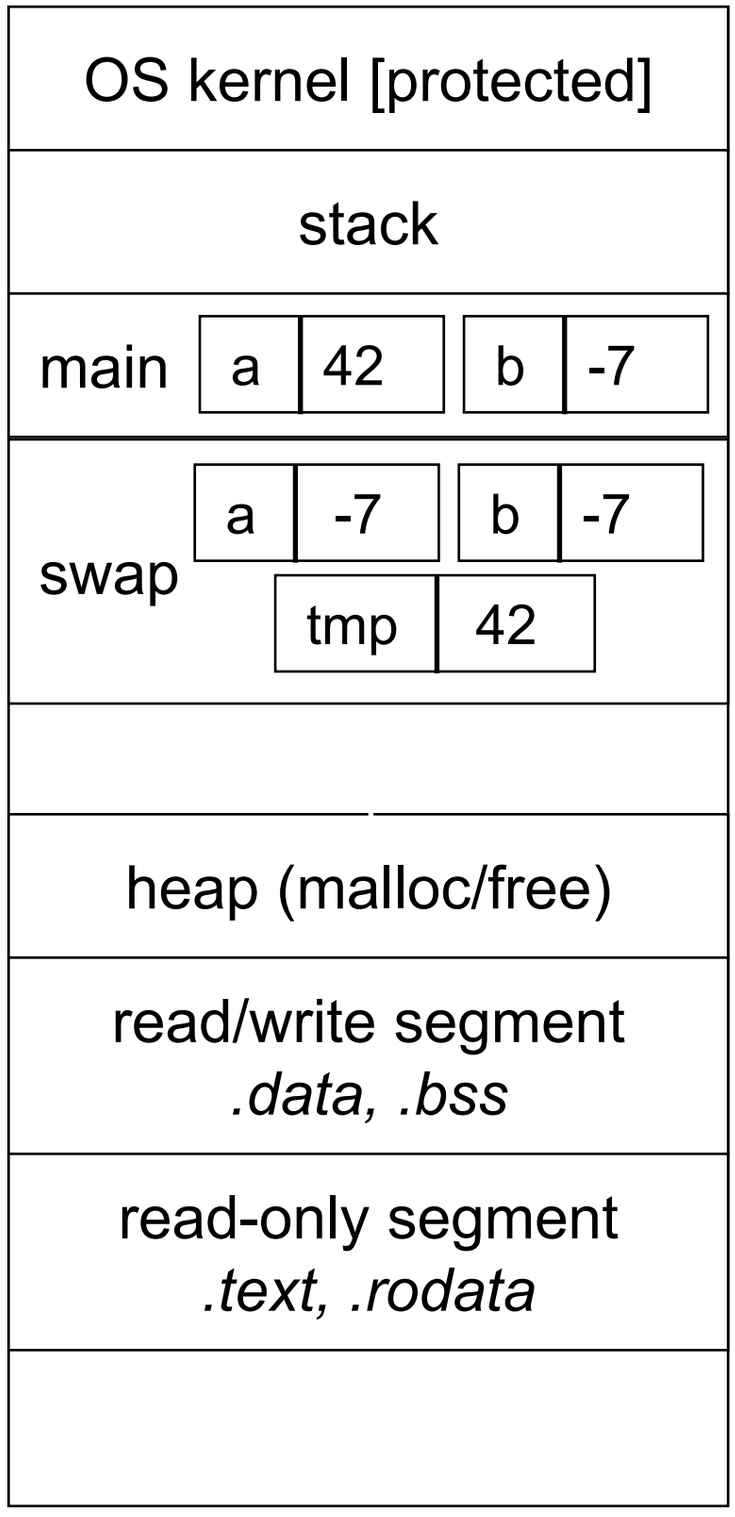
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

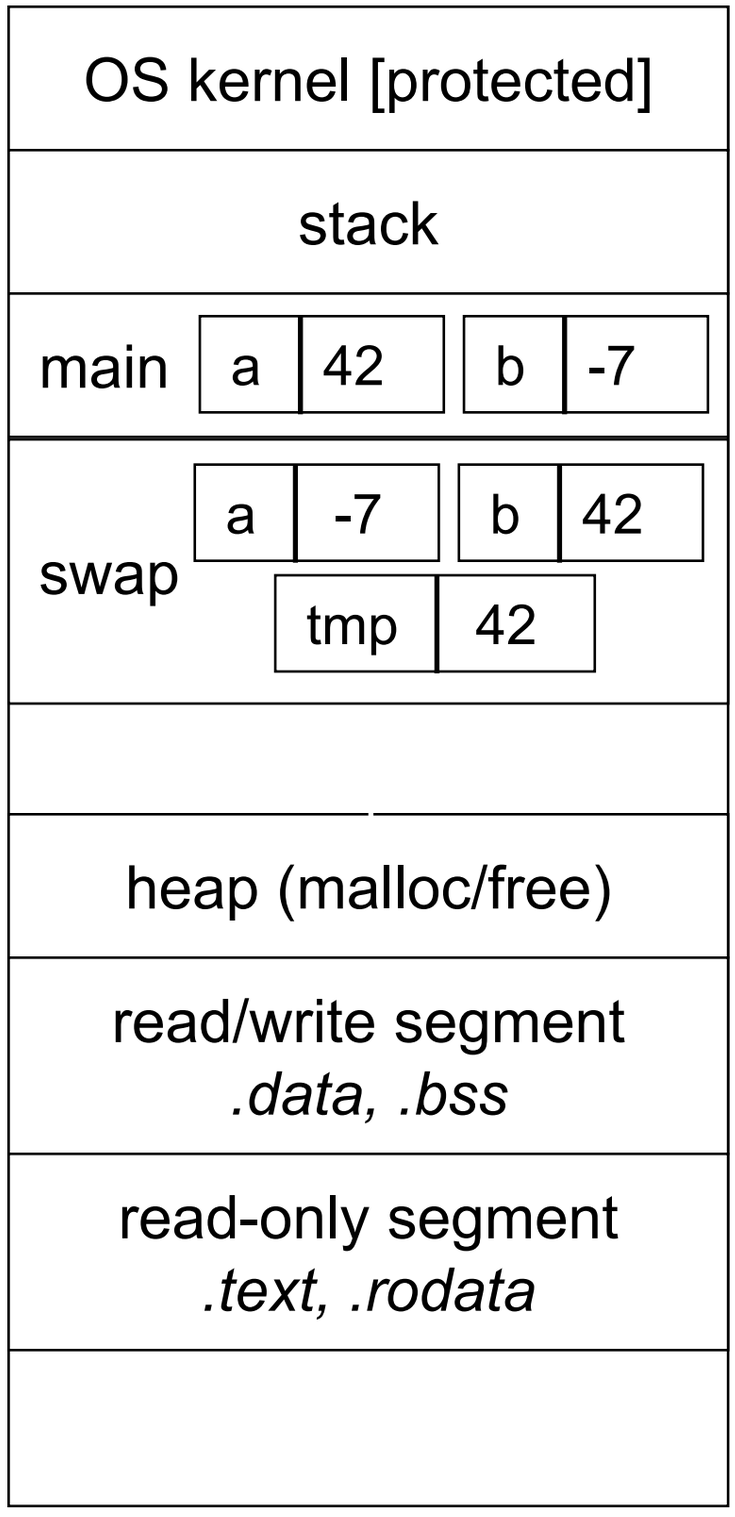
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

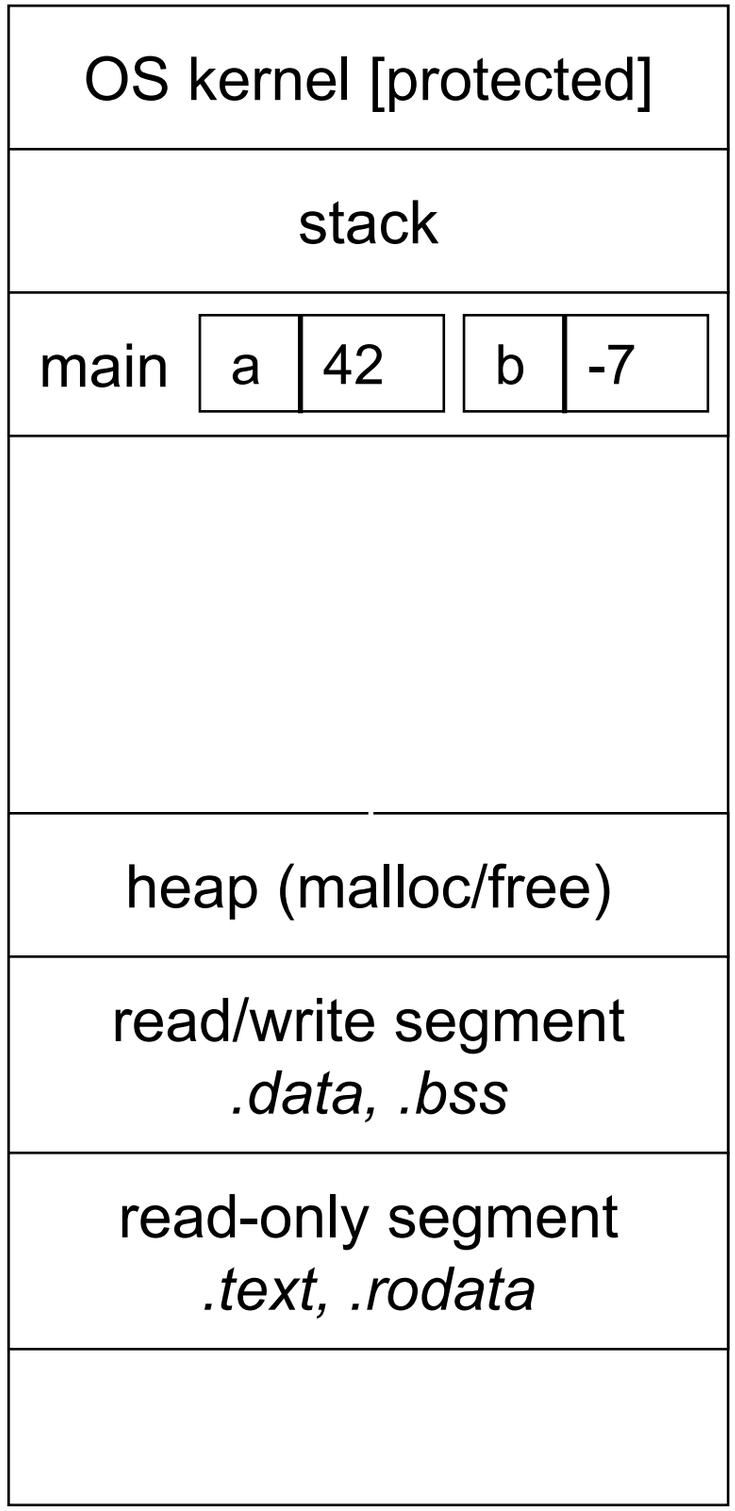
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

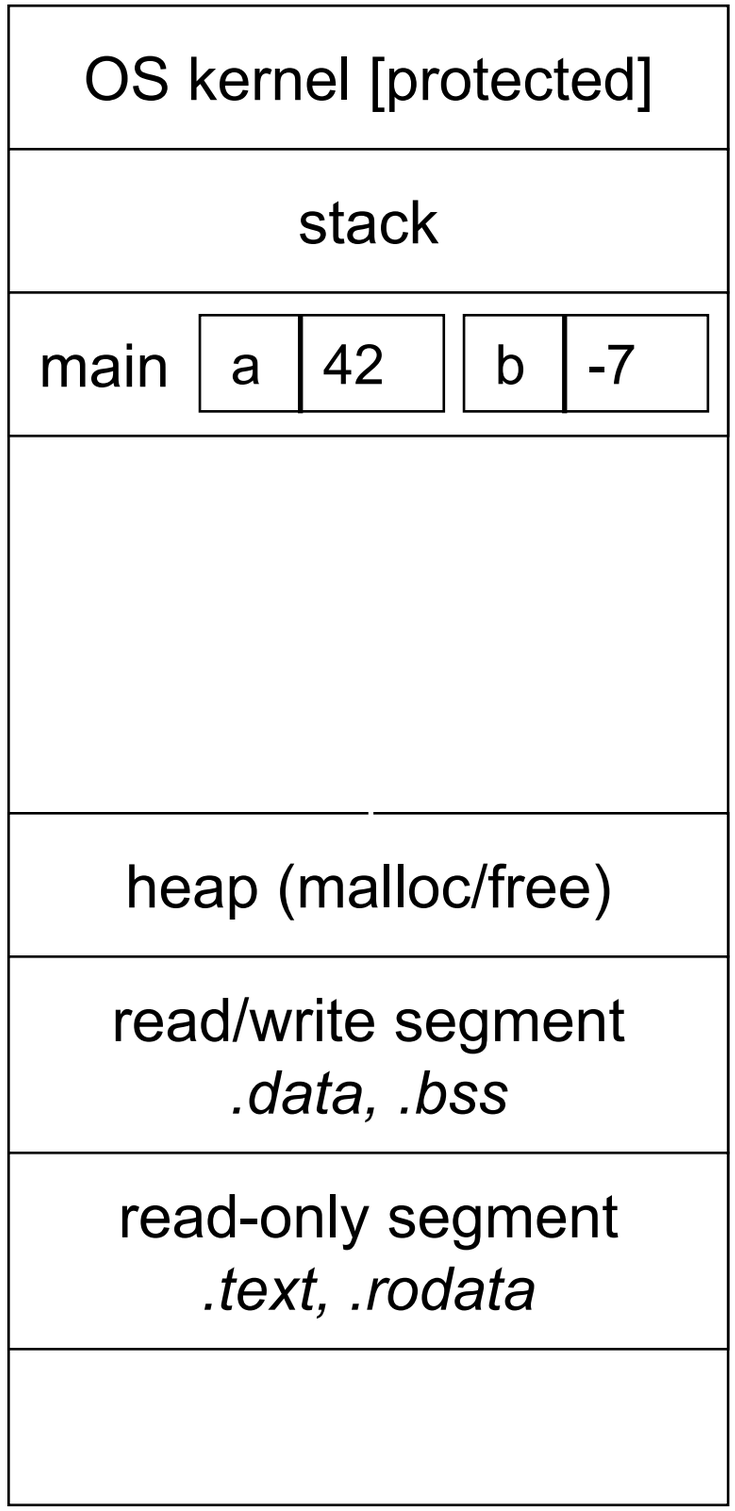
Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

Pass-by-value (stack)




```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

brokenswap.c

Pass-by-reference

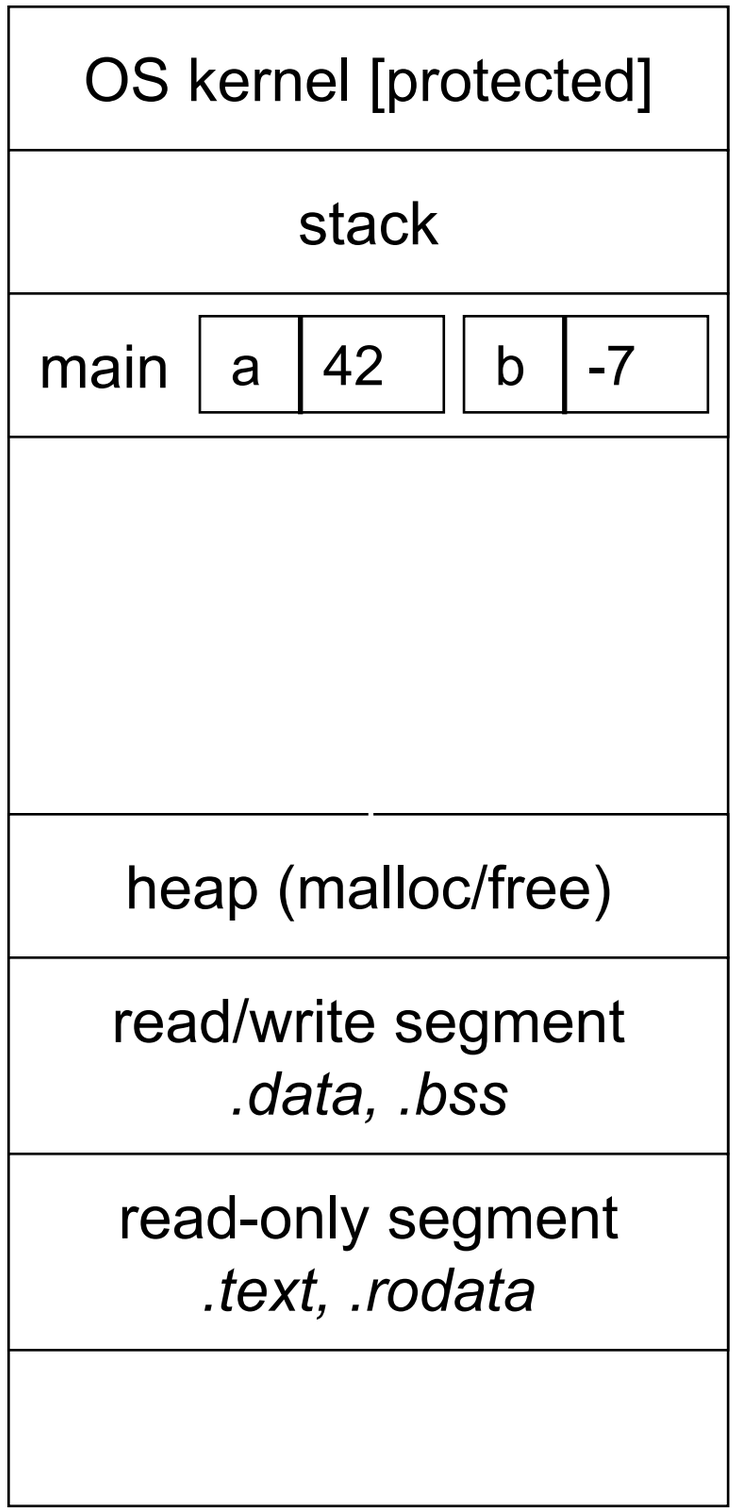
You can use pointers to pass by *reference*

- callee still receives a copy of the argument
  - but, the argument is a pointer
  - the pointer's value points-to the variable in the scope of the caller
- this gives the callee a way to modify a variable that's in the scope of the caller

```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

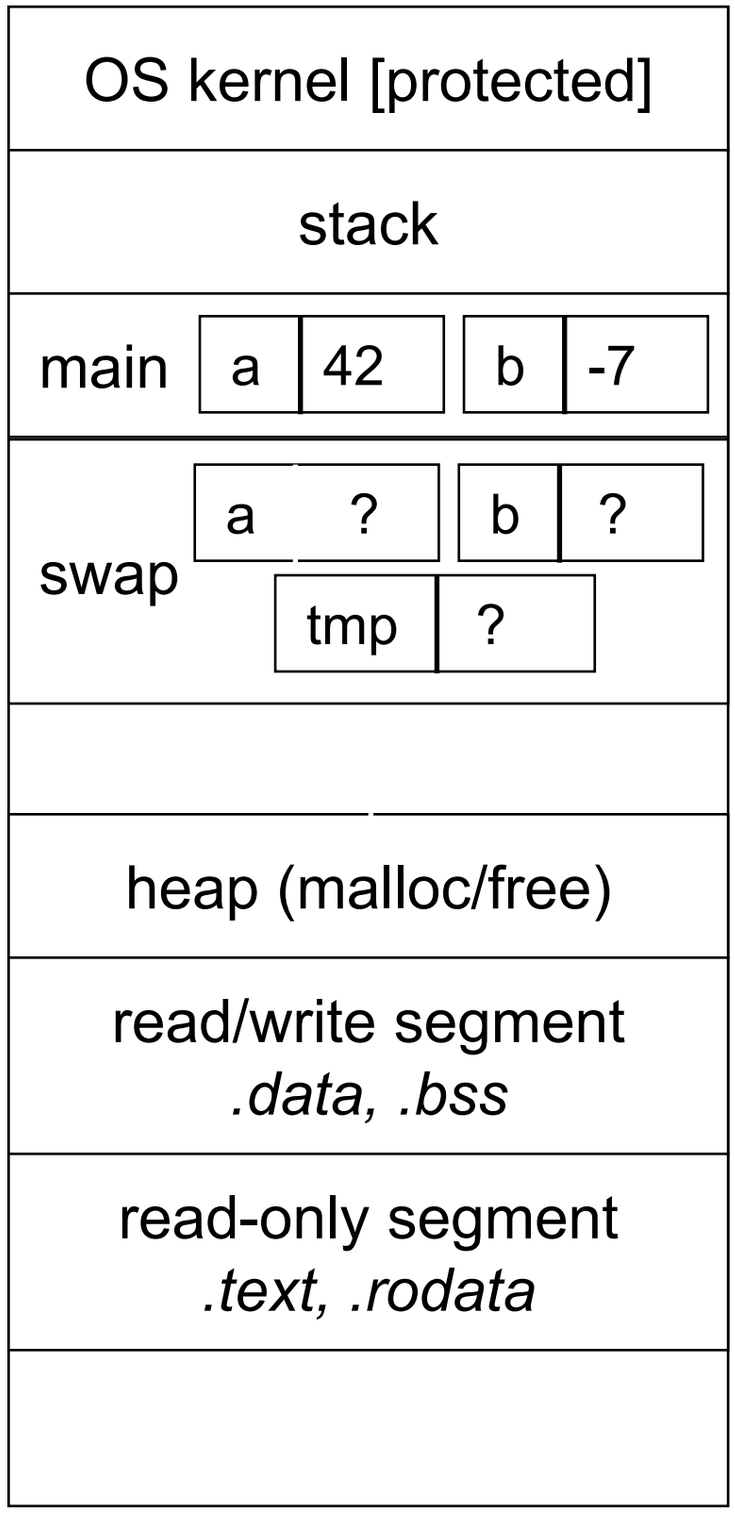
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

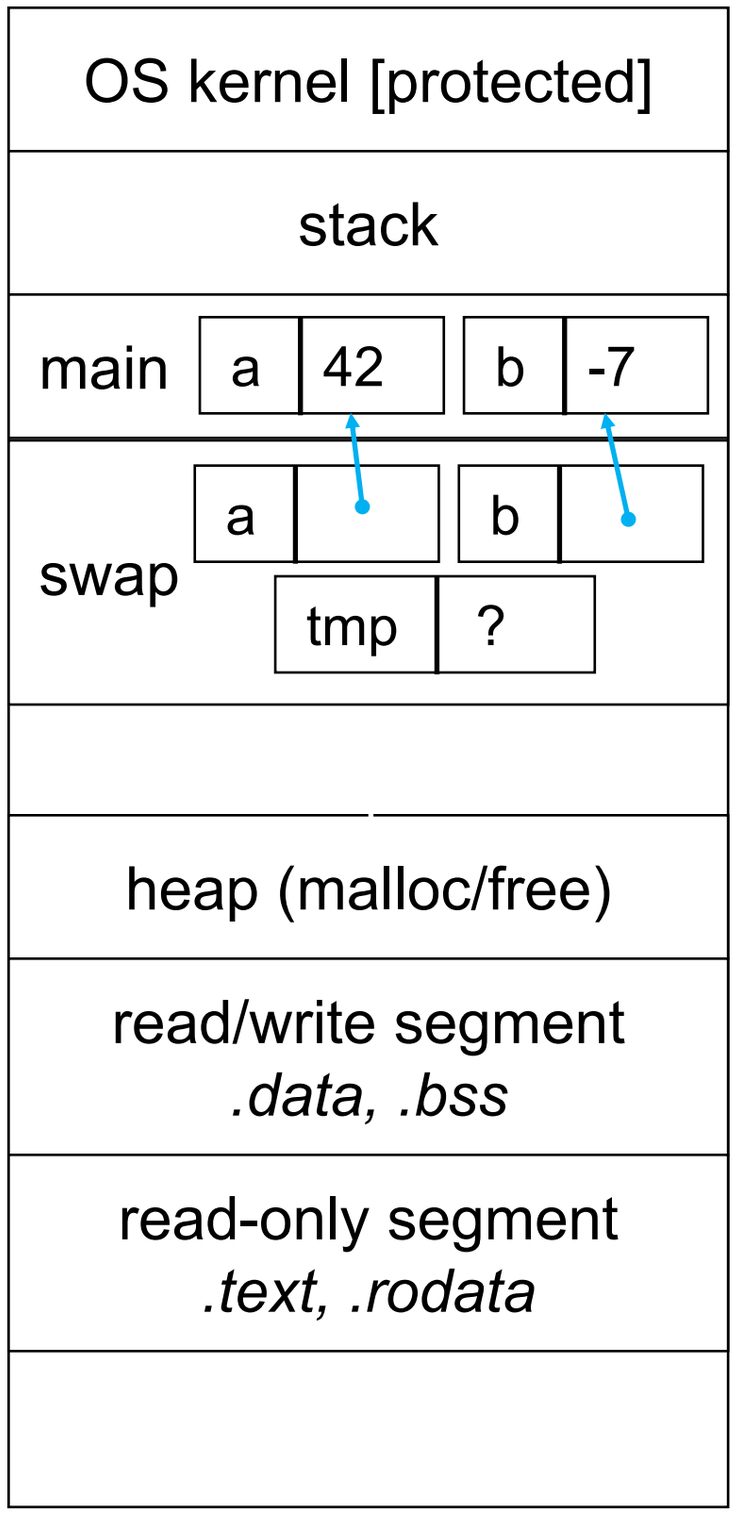
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

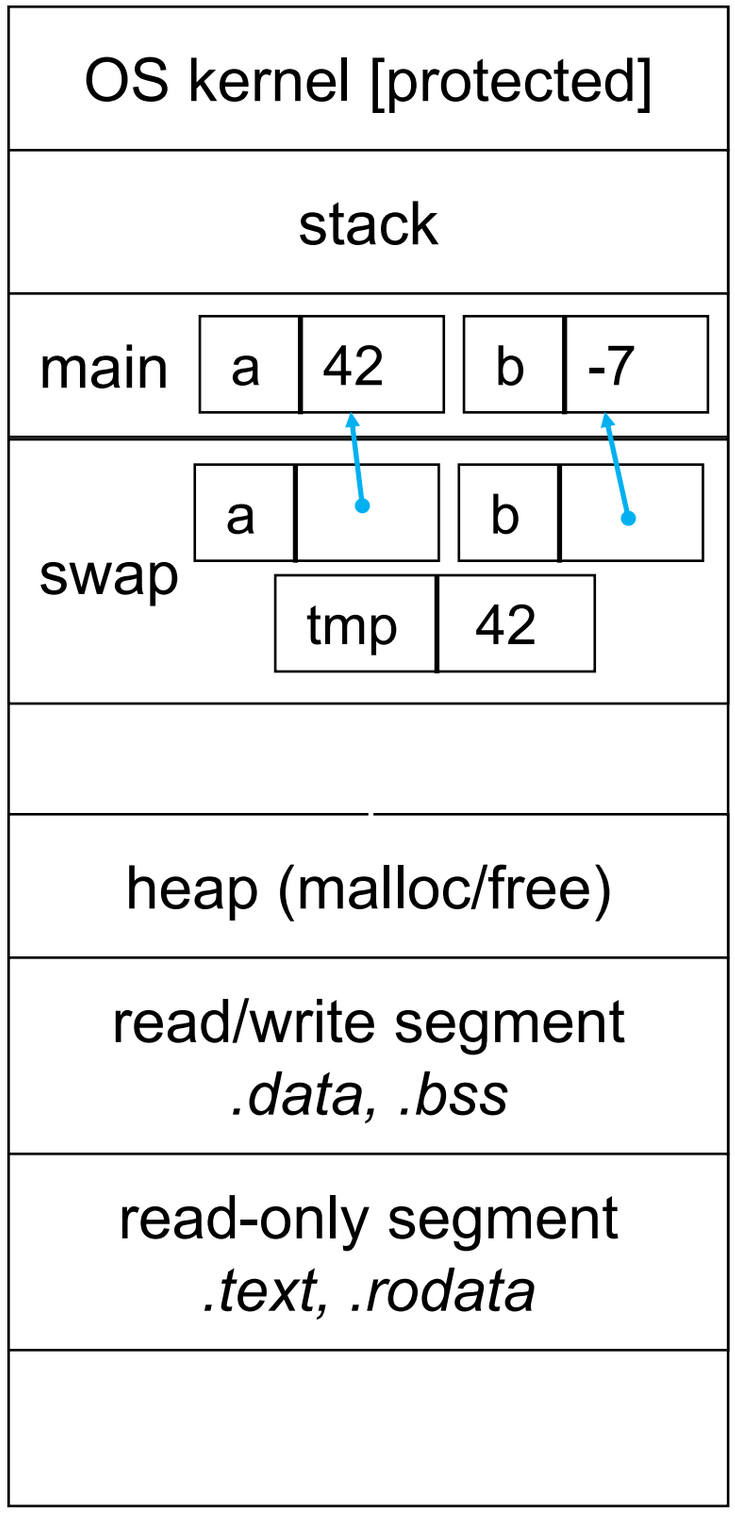
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

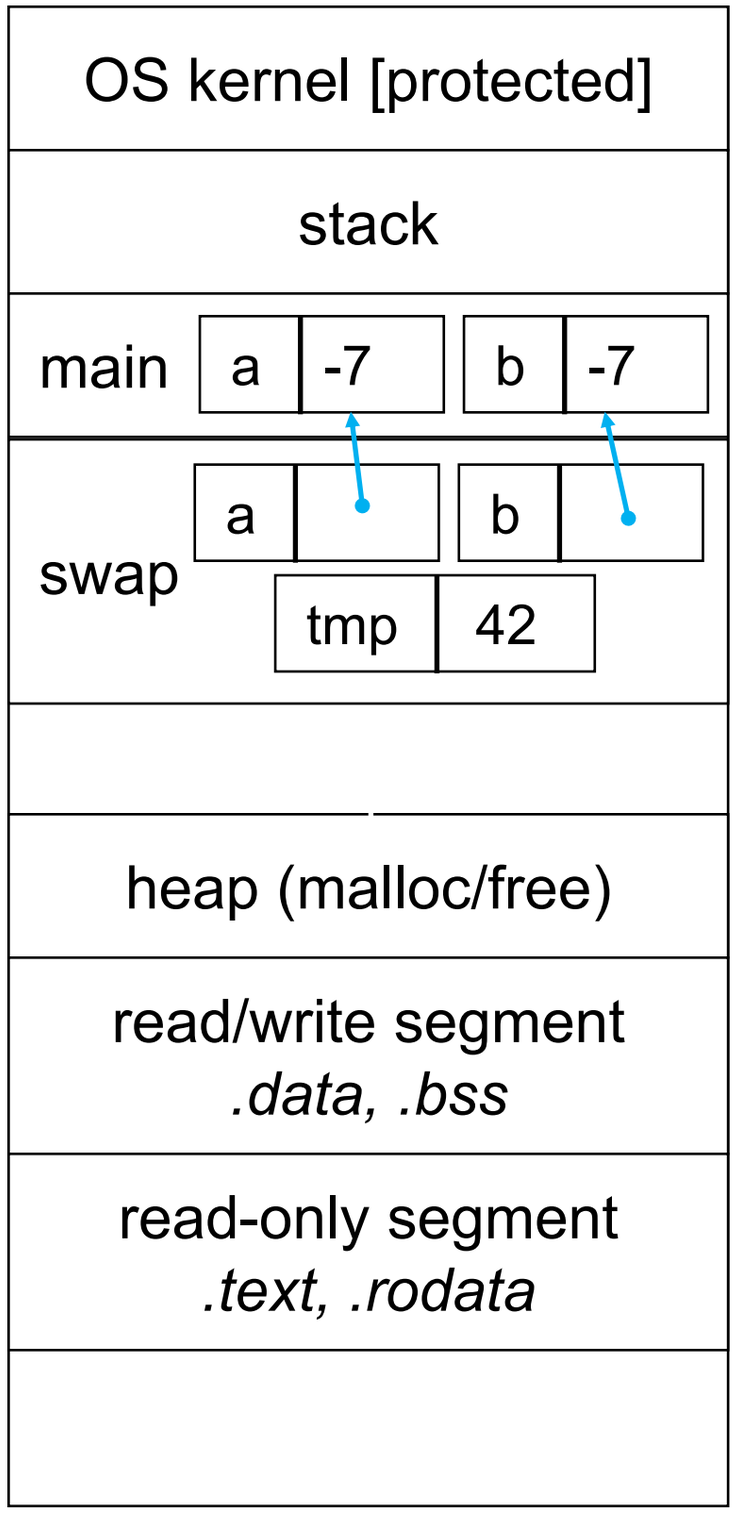
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

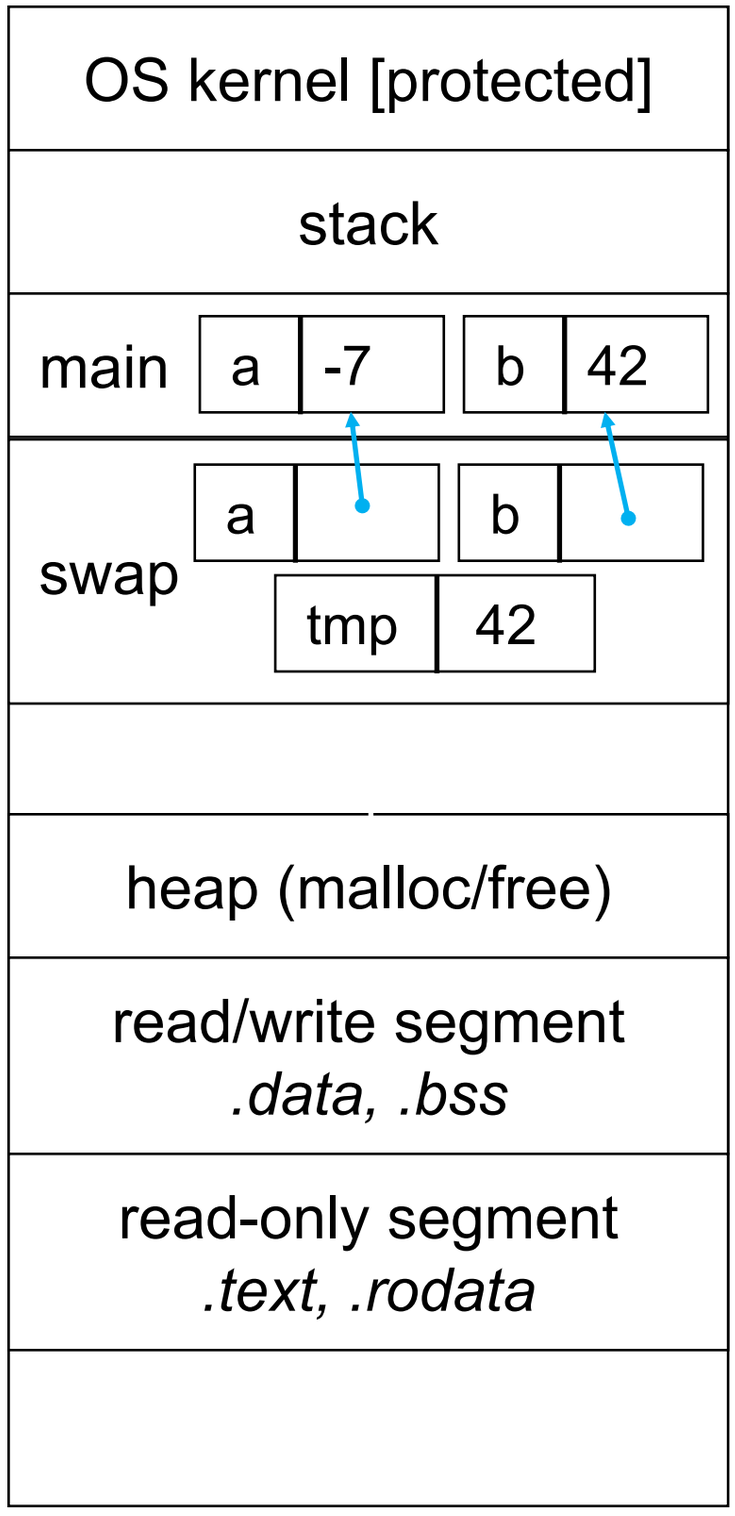
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

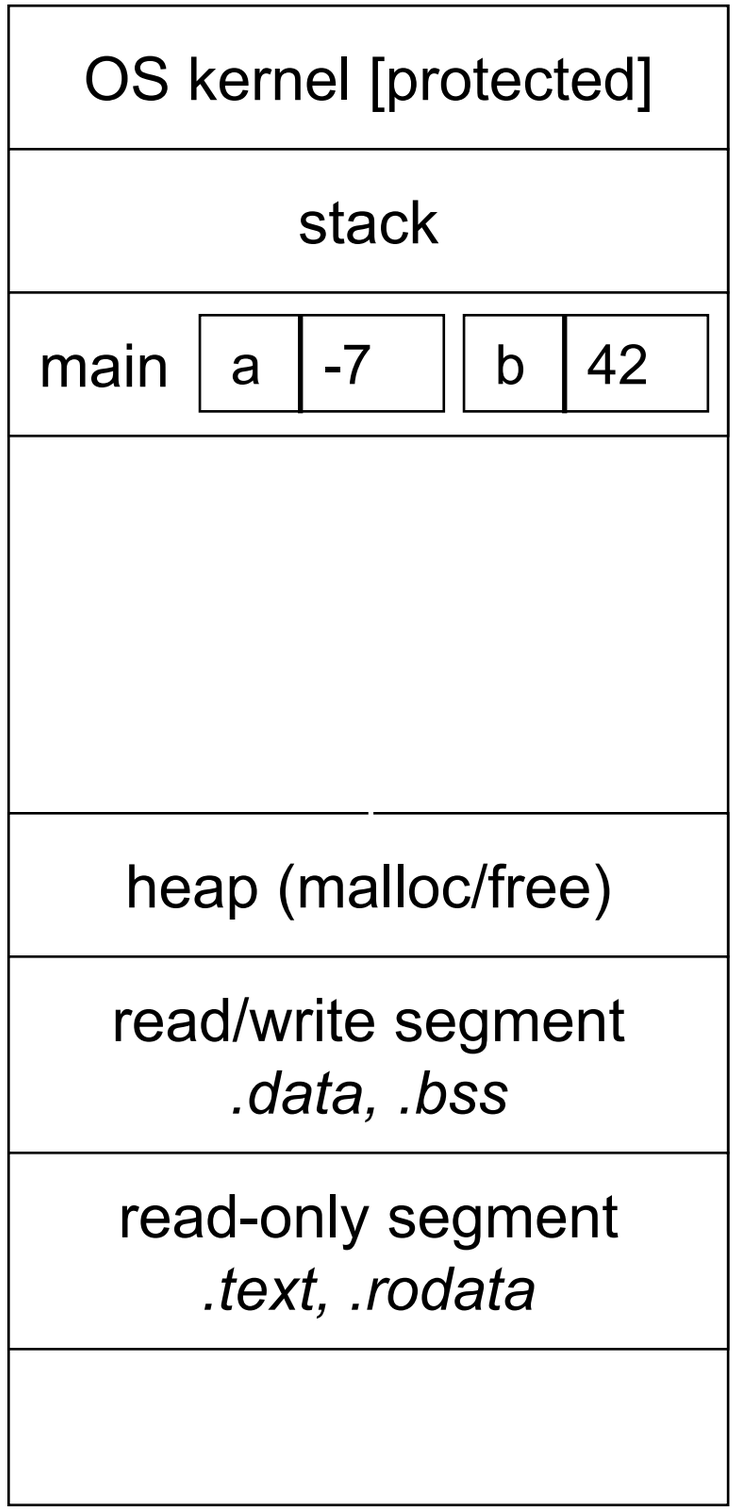
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

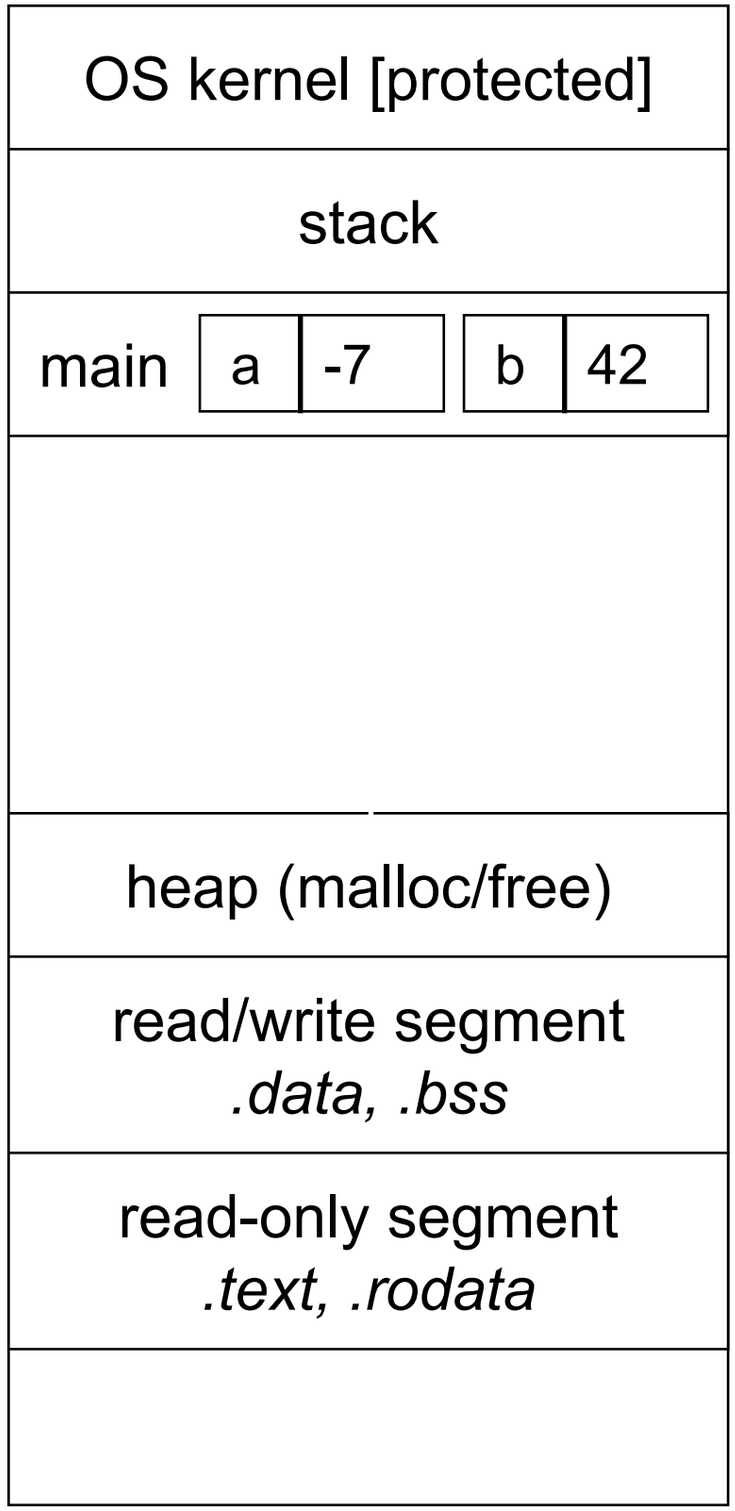
Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

Pass-by-reference (stack)




```
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char **argv)
{
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a,
b);
  return 0;
}
```

swap.c

Arrays and pointers

a pointer can point to an array element

- an array's name can be used as a pointer to its first element
- and, you can use `[]` notation to treat a pointer like an array
  - **`pointer[i]`** is **`i`** elements' worth of bytes forward from pointer

```
int a[5] = {10, 20, 30, 40, 50};
int* p1 = &a[3];   // refers to a's fourth element
int* p2 = &a[0];   // refers to a's first element
int* p3 = a;       // refers to a's first element

*p1 = 100;
*p2 = 200;
p1[1] = 300;
p2[1] = 400;
p3[2] = 500;    // final: 200, 400, 500, 100, 300
```

Passing arrays as parameters

Array parameters are really passed as pointers to the first array element

- the `[]` syntax on parameters is just for convenience

```
void f(int a[]);

int main(...) {
    int a[5];
    ...
    f(a);
    return 0;
}

void f(int a[] ){
```

your code

```
void f(int *a);

int main(...) {
    int a[5];
    ...
    f(&a[0]);
    return 0;
}

void f(int *a) {
```

equivalent code

These are slightly modified versions of slides prepared by Steve Gribble

Self-Exercise 1

Use a box-and-arrow diagram for the following program to explain what it prints out:

```
#include <stdio.h>

int foo(int *bar, int **baz) {
  *bar = 5;
  *(bar+1) = 6;
  *baz = bar+2;
  return *((*baz)+1);
}

int main(int argc, char **argv) {
  int arr[4] = {1, 2, 3, 4};
  int *ptr;

  arr[0] = foo(&(arr[0]), &ptr);
  printf("%d %d %d %d %d\n",
         arr[0], arr[1], arr[2], arr[3], *ptr);
  return 0;
}
```

Self-Exercise 2

Write a program that prints out whether the computer it is running on is little endian or big endian.

- (hint: see pointerarithmetic.c from today's lecture)

Self-Exercise 3

Write a function that:

- accepts an (array of ints) and an (array length) as arguments
- malloc's an (array of (int *)) of the same length
- initializes each element of the newly allocated array to point to the corresponding element in the passed-in array
- returns a pointer to the newly allocated array