Arrays and Pointer. Part 2

2019 Spring

Lecture Outline

- Pointers & Pointer Arithmetic
- Pointers as Parameters
- Pointers and Arrays
- Function Pointers

Box-and-Arrow Diagrams (1/4)

boxarrow.c

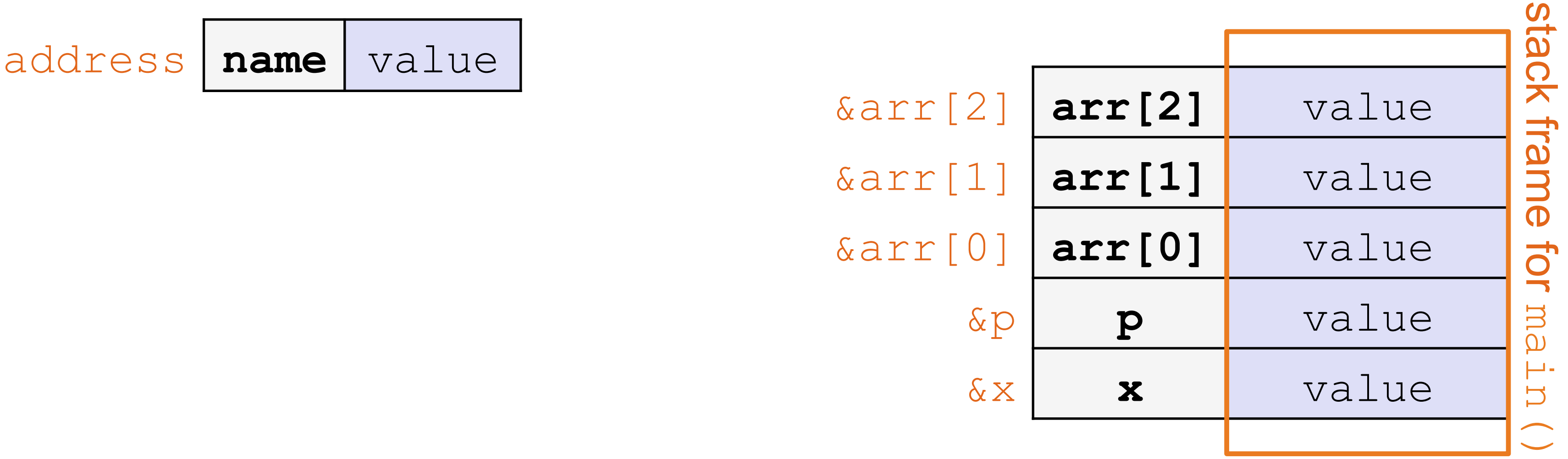
```c
int main(int argc, char** argv) {
  int x = 1;
  int arr[3] = {2, 3, 4};
  int* p = &arr[1];

  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 (2/4)

boxarrow.c

```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

&arr[2]	**arr[2]**	value
&arr[1]	**arr[1]**	value
&arr[0]	**arr[0]**	value
&p	**p**	value
&x	**x**	value

stack frame for main()

Box-and-Arrow Diagrams (3/4)

boxarrow.c

```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

&arr[2]	**arr[2]**	4
&arr[1]	**arr[1]**	3
&arr[0]	**arr[0]**	2
&p	**p**	&arr[1]
&x	**x**	1

Box-and-Arrow Diagrams (4/4)

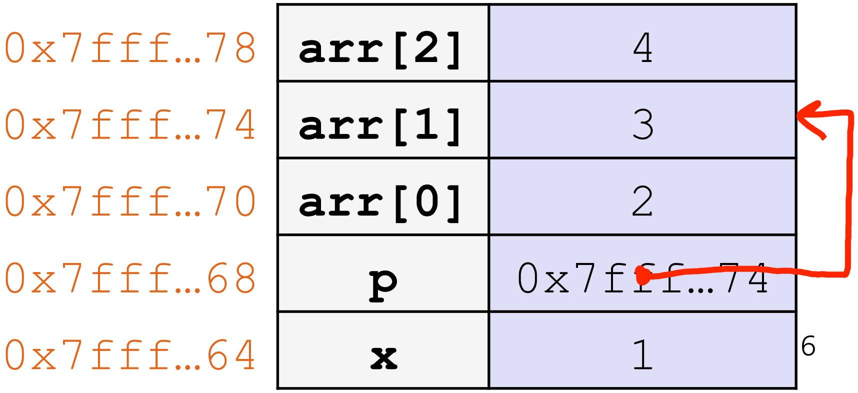
boxarrow.c

```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

p: get addr

*p: get data at addr
(follow arrow)



0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	3
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…74
0x7fff…64	x	1

Pointer Arithmetic

- Pointers are *typed*
  - Tells the compiler the size of the data you are pointing to
  - Exception: `void*` is a generic pointer (*i.e.* a placeholder)

- Pointer arithmetic is scaled by `sizeof(*p)`
  - Works nicely for arrays
  - Does not work on `void*`, since `void` doesn't have a size!

- Valid pointer arithmetic:
  - Add/subtract an integer to a pointer
  - Subtract two pointers (within stack frame or malloc block)
  - Compare pointers (<, <=, ==, !=, >, >=), including `NULL`

Practice Question

boxarrow2.c

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

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

  return 0;
}
```

At this point in the code, what values are stored in `arr[]`?

address	name	value

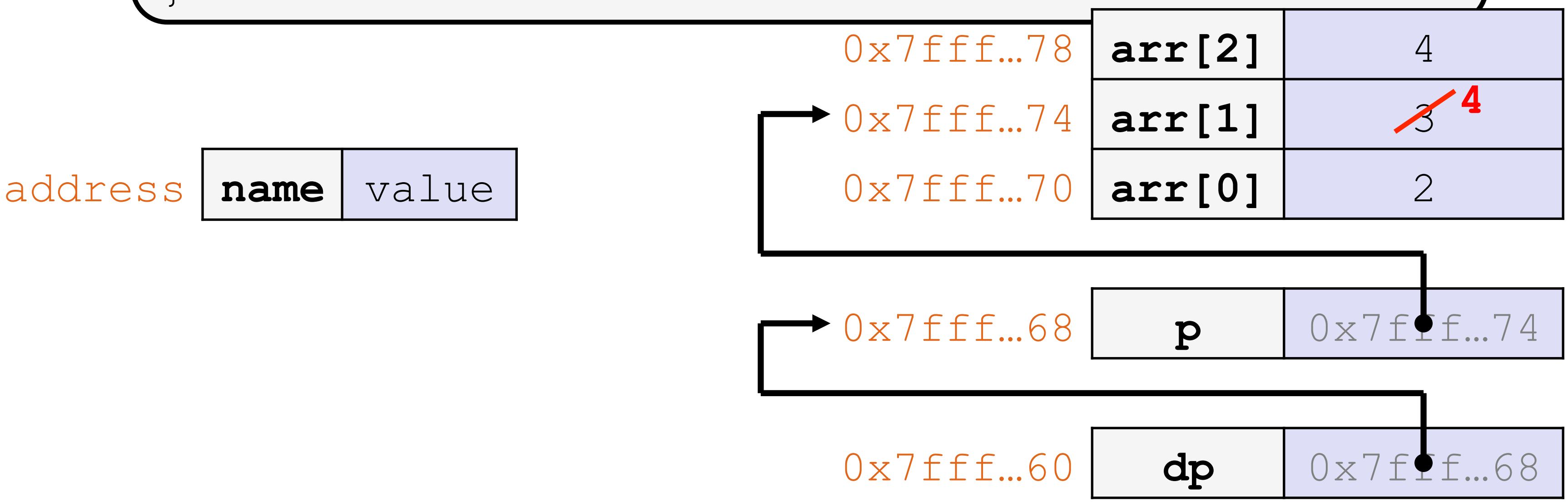
address	name	value
0x7fff…78	**arr[2]**	4
0x7fff…74	**arr[1]**	3
0x7fff…70	**arr[0]**	2
0x7fff…68	**p**	0x7fff…74
0x7fff…60	**dp**	0x7fff…68

Practice Solution (1/5)

Note: arrow points to *next* instruction to be executed.

boxarrow2.c

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

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

  return 0;
}
```



address	name	value
0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	~~3~~ 4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…74
0x7fff…60	dp	0x7fff…68

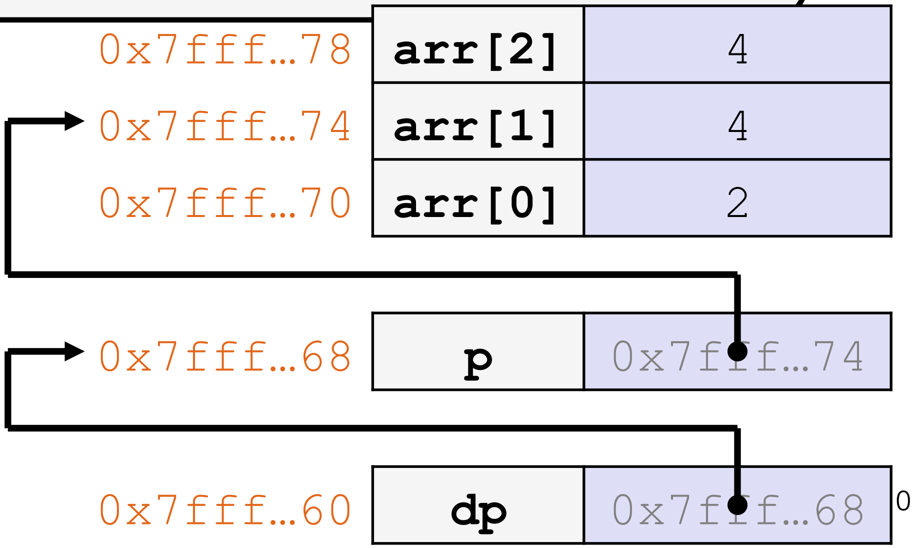
Practice Solution (2/5)

Note: arrow points to *next* instruction to be executed.

boxarrow2.c

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

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

  return 0;
}
```

address	name	value



address	name	value
0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…74
0x7fff…60	dp	0x7fff…68

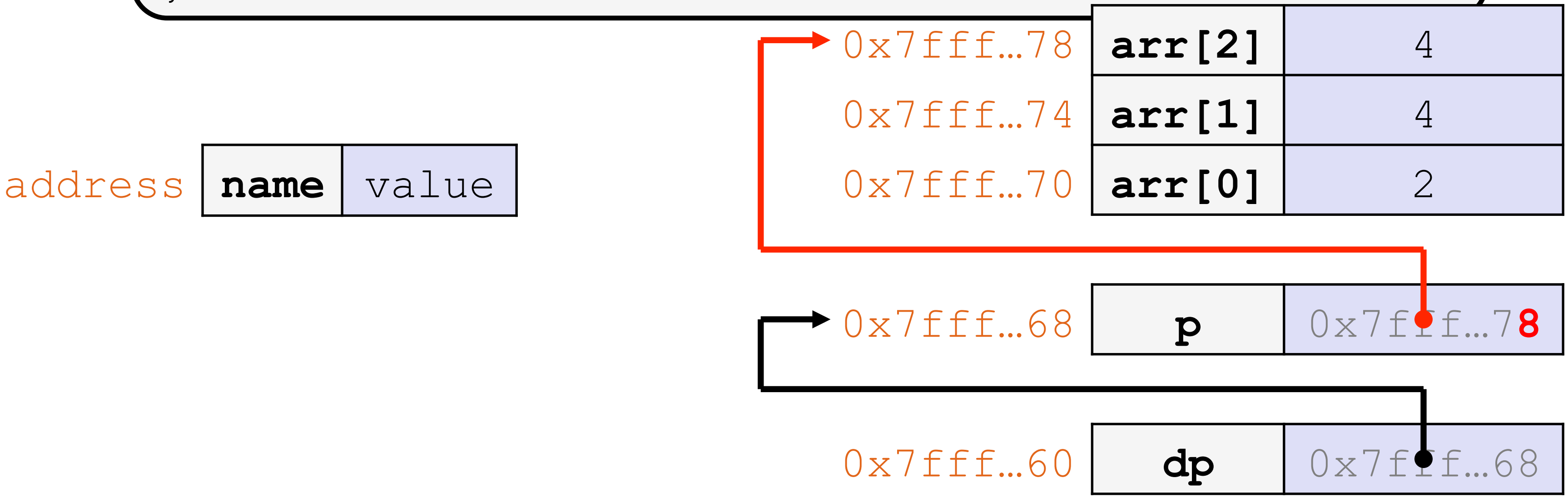
0

Practice Solution (3/5)

Note: arrow points to *next* instruction to be executed.

boxarrow2.c

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

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

  return 0;
}
```



address	name	value
0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…78
0x7fff…60	dp	0x7fff…68

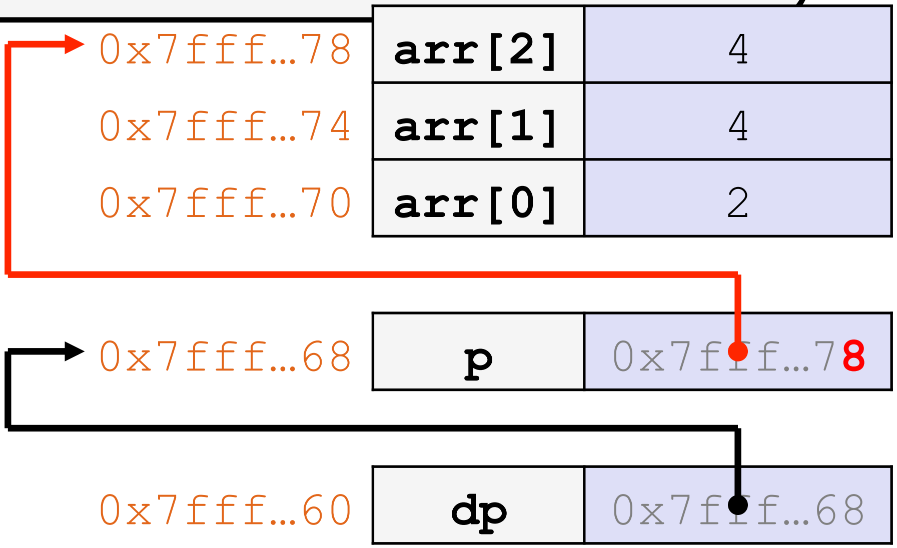
Practice Solution (4/5)

Note: arrow points to *next* instruction to be executed.

boxarrow2.c

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

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

  return 0;
}
```

address	name	value



0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…78
0x7fff…60	dp	0x7fff…68

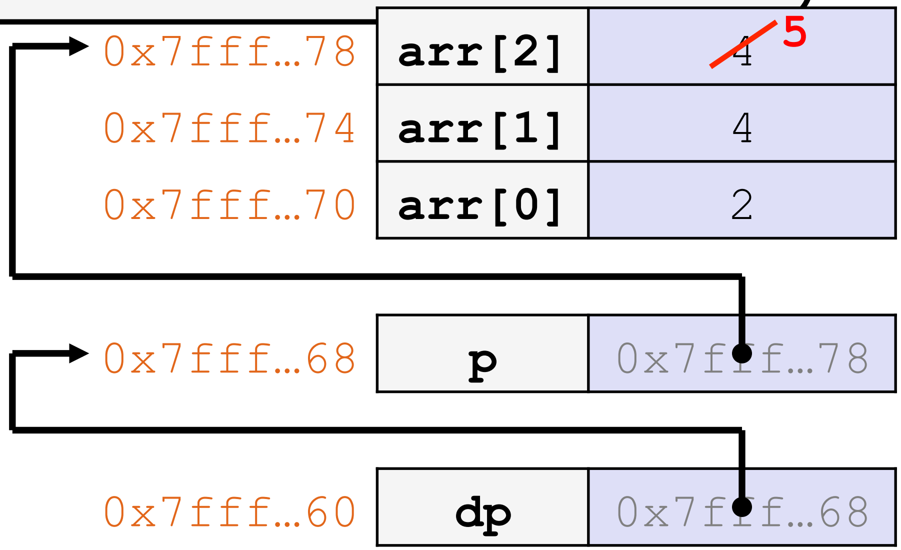
Practice Solution (5/5)

Note: arrow points to *next* instruction to be executed.

boxarrow2.c

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

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

  return 0;
}
```

address	name	value

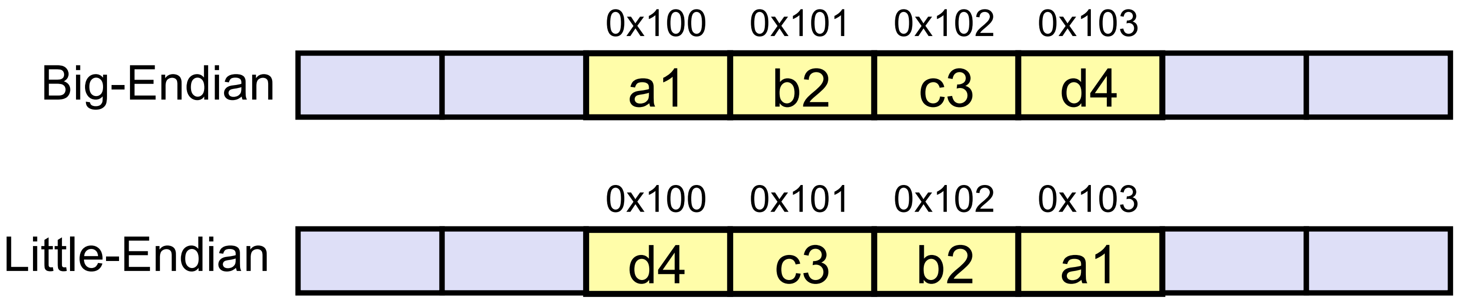


address	name	value
0x7fff…78	arr[2]	~~4~~ 5
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…78
0x7fff…60	dp	0x7fff…68

Endianness

- Memory is byte-addressed, so endianness determines what ordering that multi-byte data gets read and stored *in memory*
  - Big-endian：Least significant byte has *highest* address
  - Little-endian：Least significant byte has *lowest* address
    - X86-64

- **Example：** 4-byte data 0xa1b2c3d4 at address 0x100

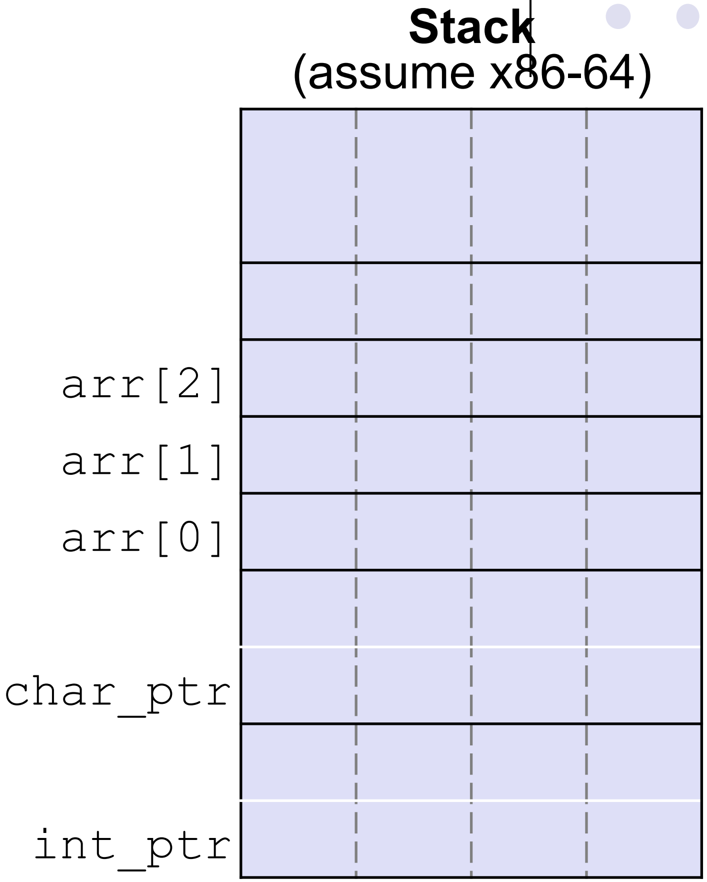


			0x100	0x101	0x102	0x103		
Big-Endian			a1	b2	c3	d4		
Little-Endian			d4	c3	b2	a1		

Pointer Arithmetic Example(1)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```



pointerarithmetic.c

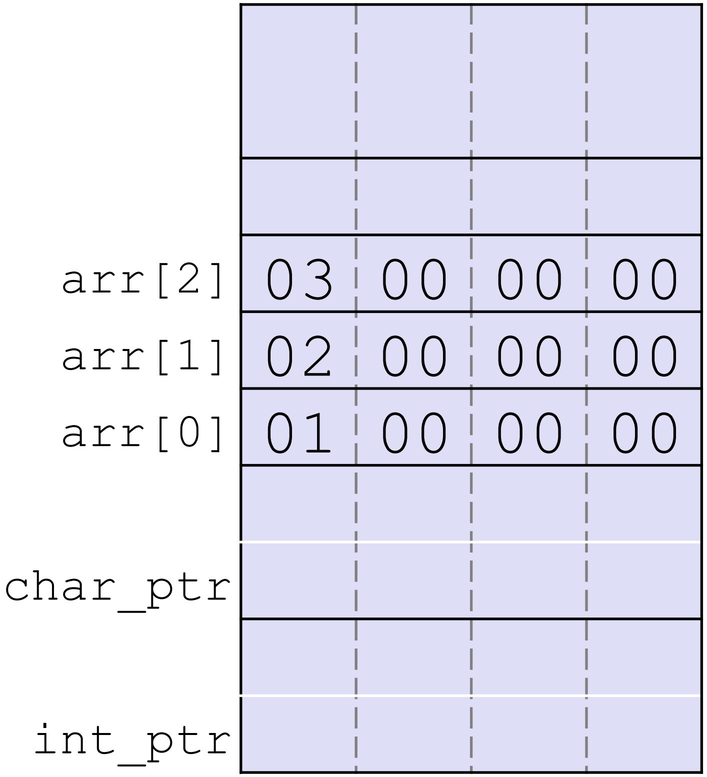
Pointer Arithmetic Example(2)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```

pointerarithmetic.c

Stack
(assume x86-64)

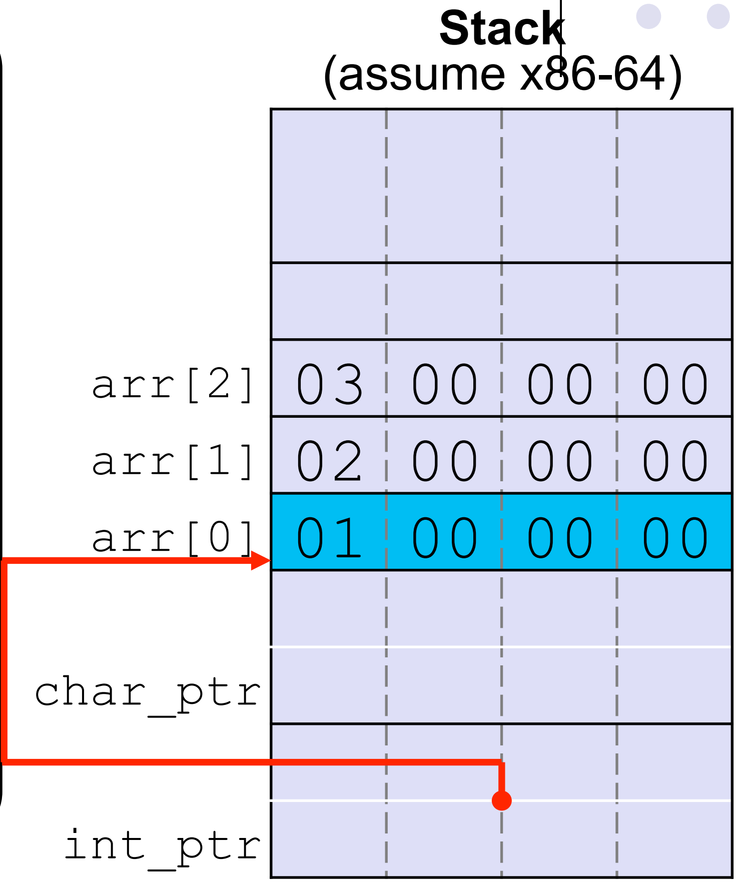


arr[2]	03	00	00	00
arr[1]	02	00	00	00
arr[0]	01	00	00	00
char_ptr				
int_ptr				

Pointer Arithmetic Example(3)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```



pointerarithmetic.c

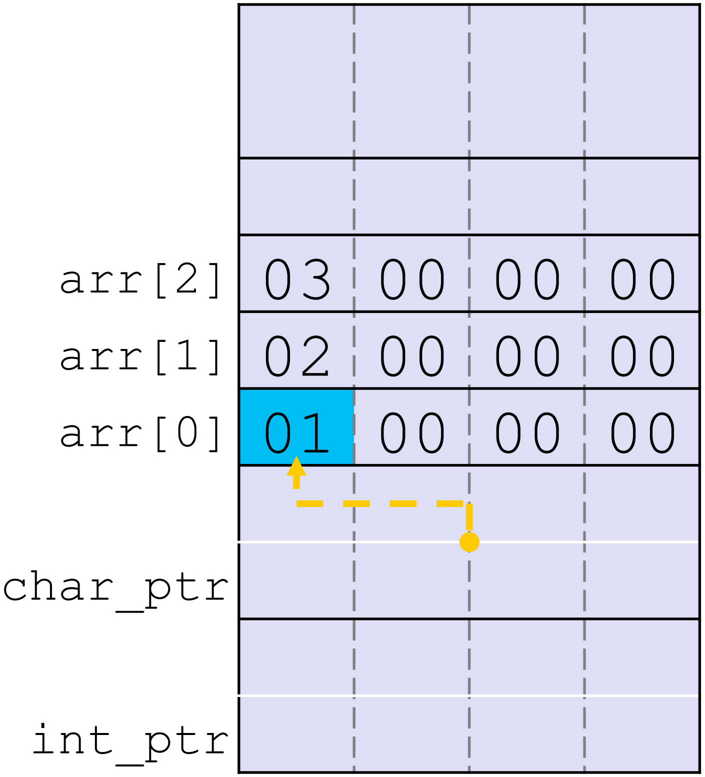
Pointer Arithmetic Example(4)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```

pointerarithmetic.c

Stack
(assume x86-64)

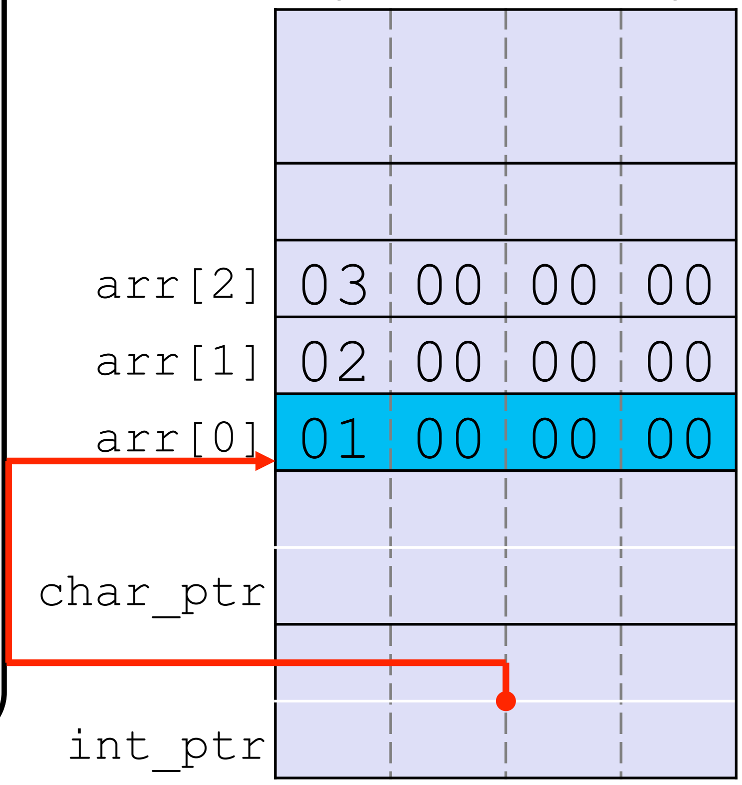


Pointer Arithmetic Example(5)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```

Stack
(assume x86-64)



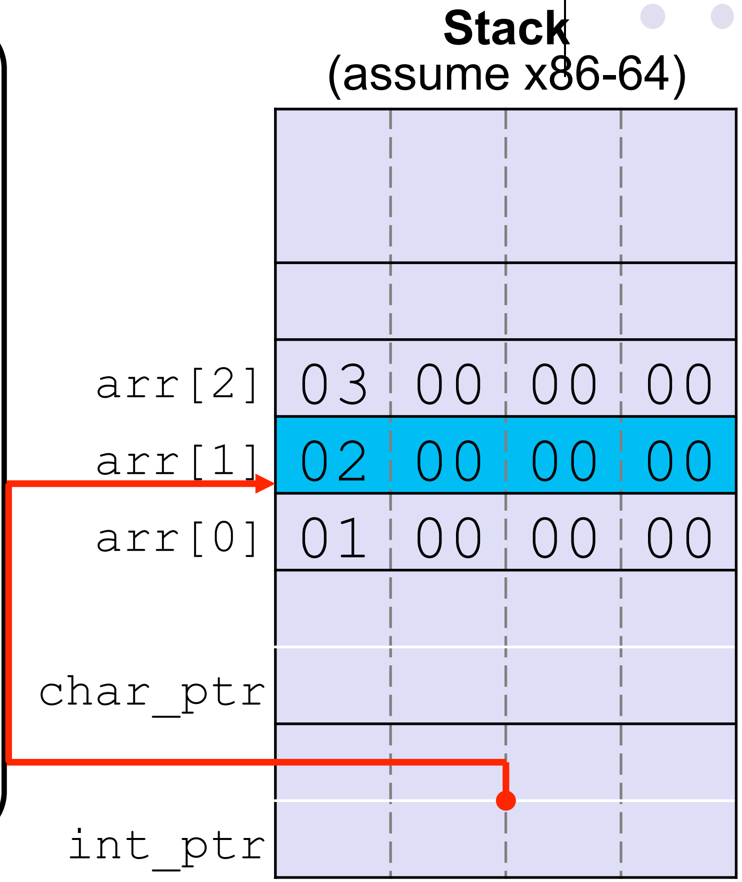
pointerarithmetic.c

```
 int_ptr:   0x0x7fffffde010
*int_ptr:   1
```

Pointer Arithmetic Example(6)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```



pointerarithmetic.c

```
 int_ptr:   0x0x7ffffffde014
*int_ptr:   2
```

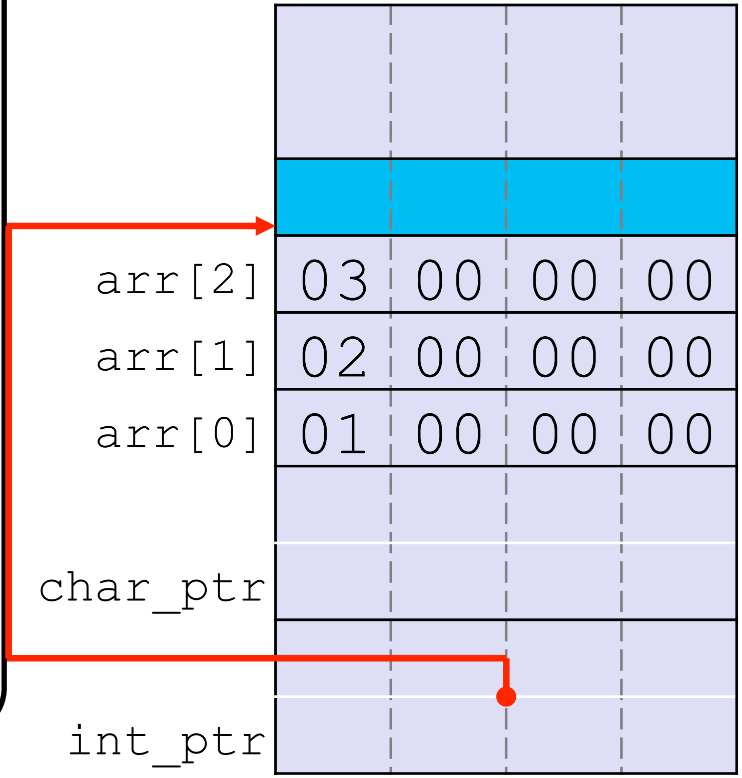
Pointer Arithmetic Example(7)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```

pointerarithmetic.c

Stack
(assume x86-64)



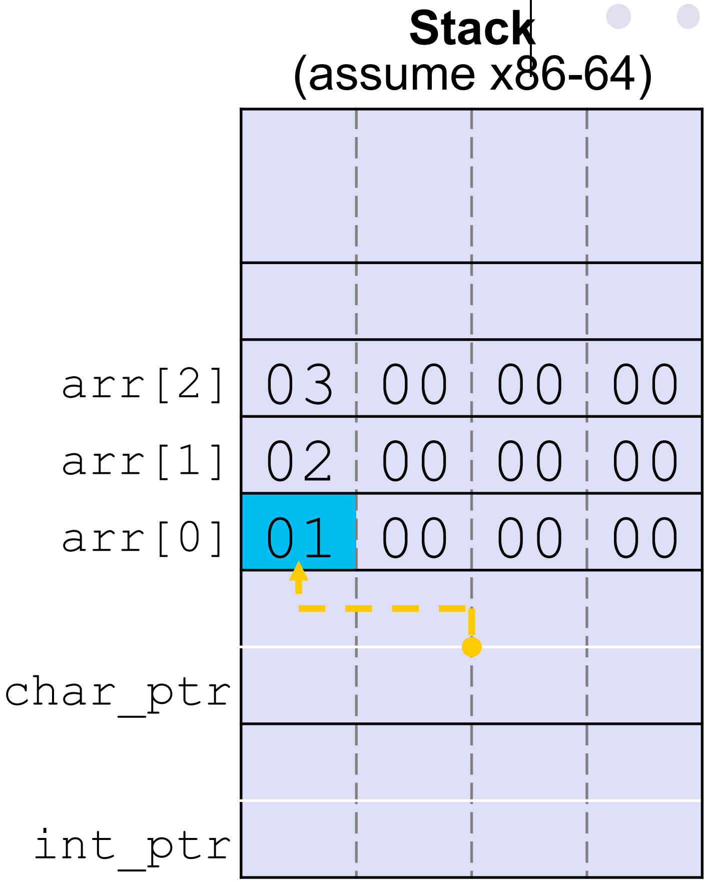
arr[2]	03	00	00	00
arr[1]	02	00	00	00
arr[0]	01	00	00	00
char_ptr				
int_ptr				

```
 int_ptr:   0x0x7ffffffde01C
*int_ptr:   ???
```

Pointer Arithmetic Example(8)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```



pointerarithmetic.c

```
 char_ptr:   0x0x7fffffde010
*char_ptr:   1
```

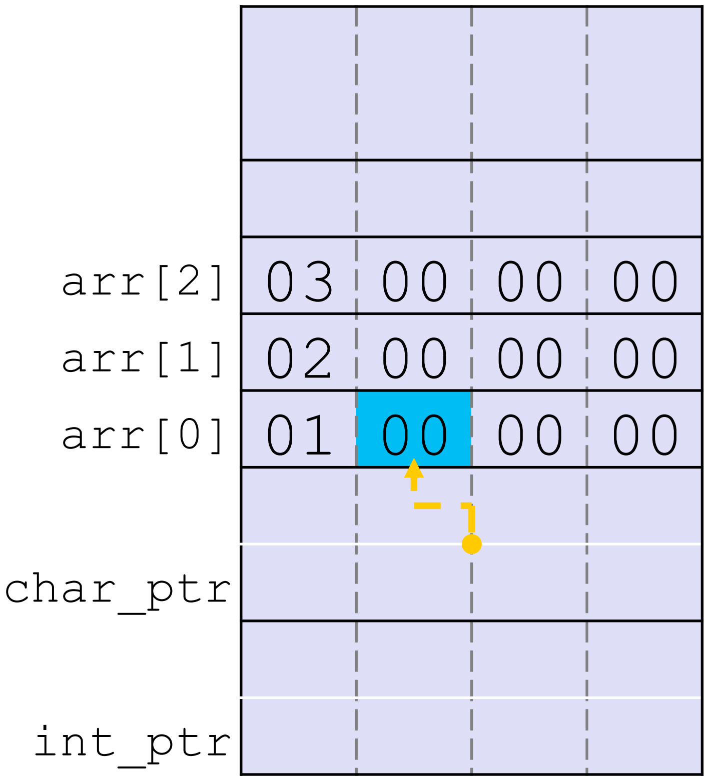
Pointer Arithmetic Example(9)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```

pointerarithmetic.c

Stack
(assume x86-64)



arr[2] 03 00 00 00

arr[1] 02 00 00 00

arr[0] 01 00 00 00

char_ptr

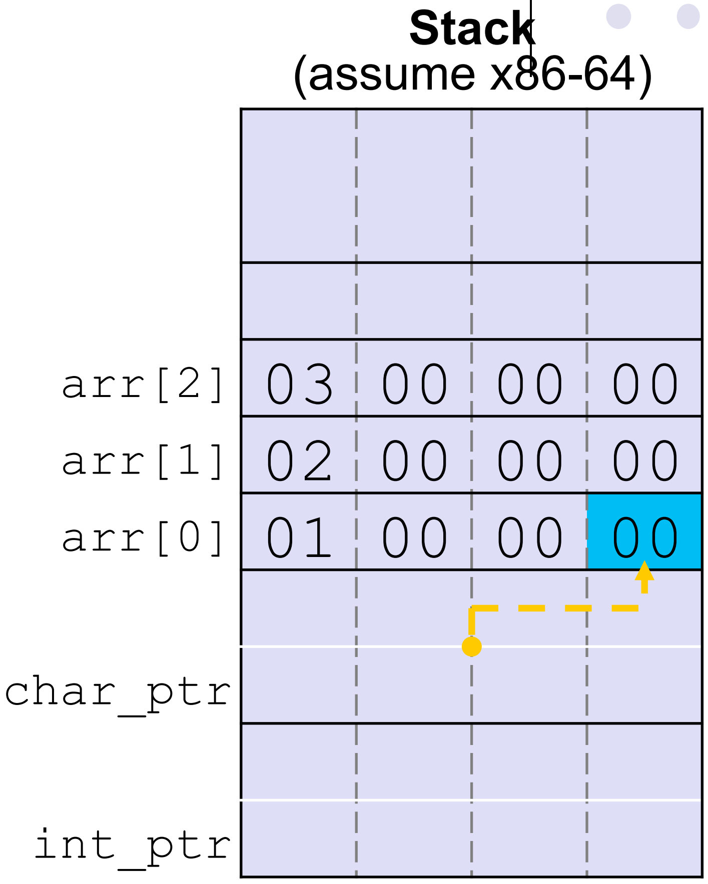
int_ptr

```
 char_ptr:   0x0x7ffffffde011
*char_ptr:   0
```

Pointer Arithmetic Example(10)

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 2;

  return 0;
}
```



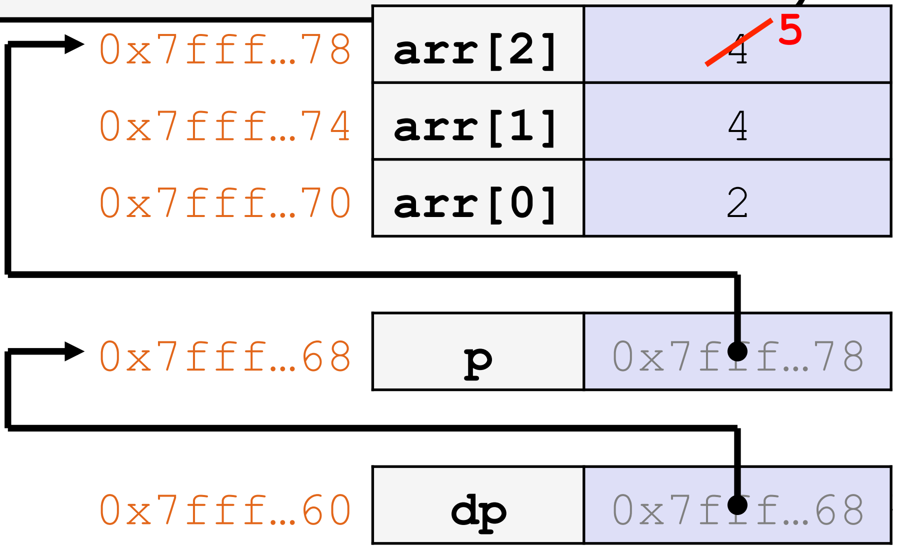
arr[2]	03	00	00	00
arr[1]	02	00	00	00
arr[0]	01	00	00	00

pointerarithmetic.c

```
 char_ptr:   0x0x7ffffffde013
*char_ptr:   0
```

Comparison (1/2)

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

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

  return 0;
}
```

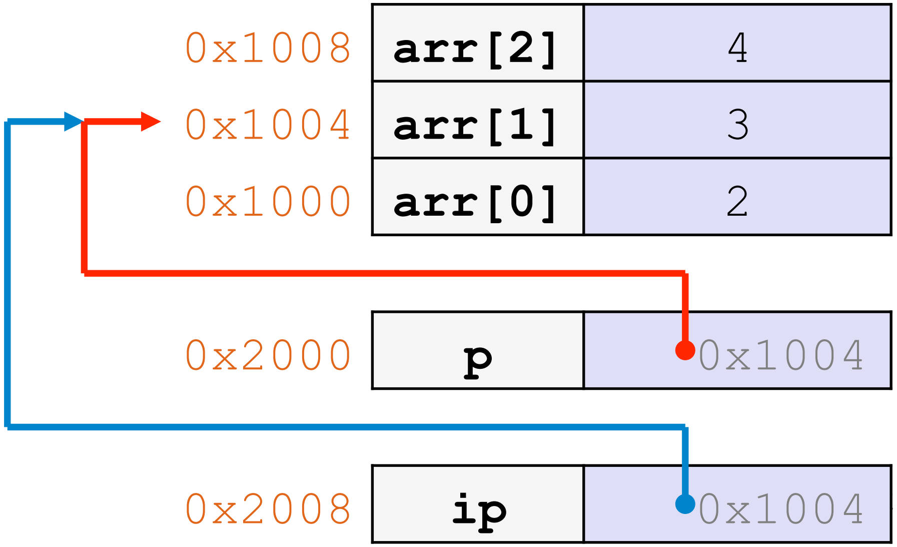


Address	Name	Value
0x7fff…78	arr[2]	~~4~~ 5
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…78
0x7fff…60	dp	0x7fff…68

Comparison (2/2)

pointercomp.c

```
int main(int argc, char** argv) {
  int arr[3] = {2, 3, 4};
  int* p = &arr[1];
  int* ip = p;  // pointer assignment
  (*p) += 10;
  p += 1;
  printf("&p: %p; p: %p; *p: %d\n", &p, p, *p);
  (*ip) += 20;
  printf("&ip: %p; ip: %p; *ip: %d\n", &ip, ip, *ip);
}
```



Lecture Outline

- Pointers & Pointer Arithmetic
- **Pointers as Parameters**
- Pointers and Arrays
- Function Pointers

C is Call-By-Value

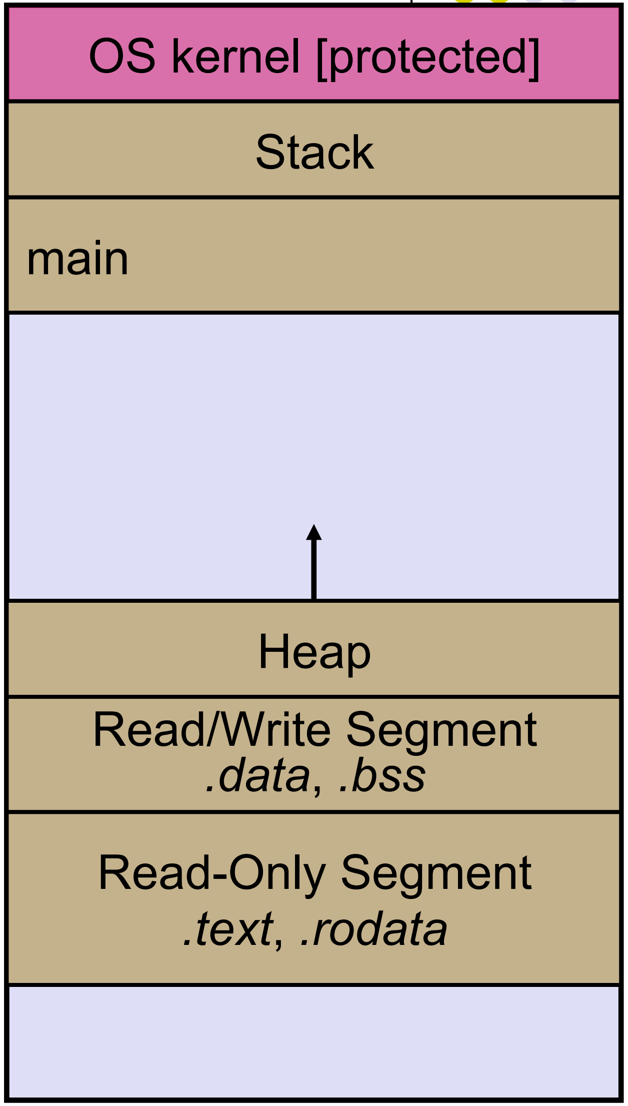
- C (and Java) pass arguments by *value*
  - Callee receives a **local copy** of the argument
    - Register or Stack
  - If the callee modifies a parameter, the caller's copy *isn't* modified

```
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);
  ...
```

Broken Swap (1/7)

brokenswap.c

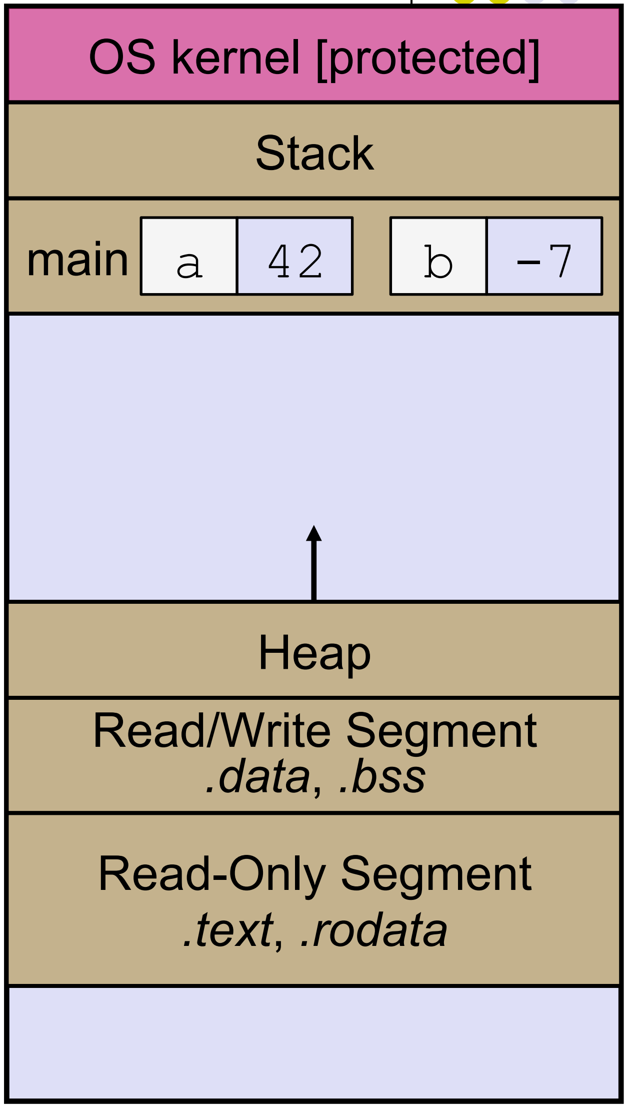
```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

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



Broken Swap (2/7)

brokenswap.c

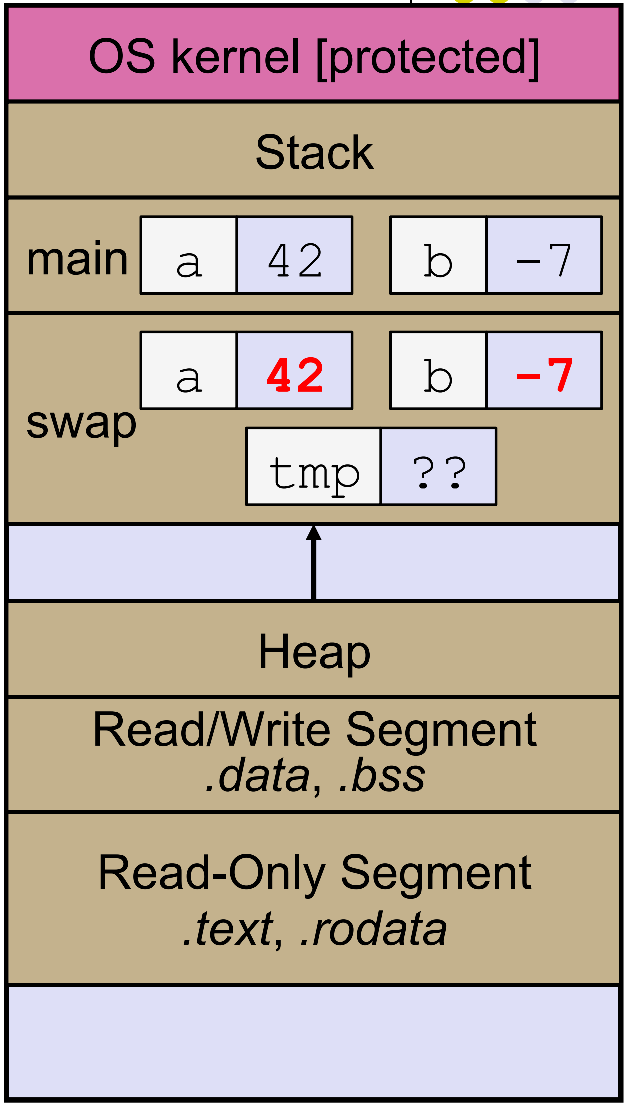
```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

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



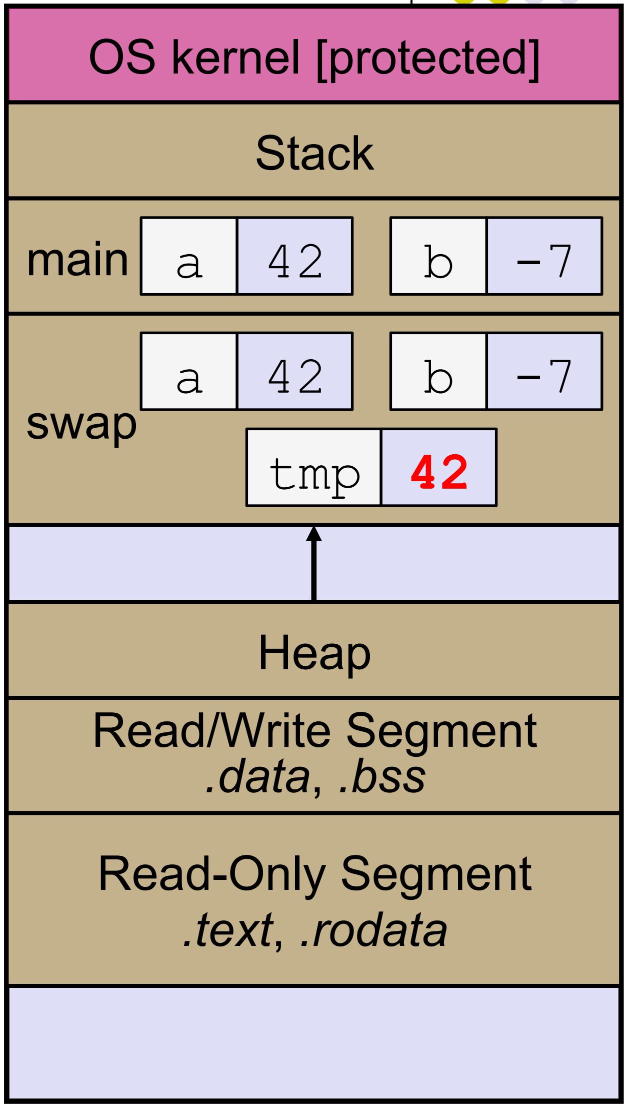
Broken Swap (3/7)

brokenswap.c

```
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);
  ...
```



Broken Swap (4/7)



OS kernel [protected]

Stack

main a 42 b -7

swap a 42 b -7

tmp **42**

Heap

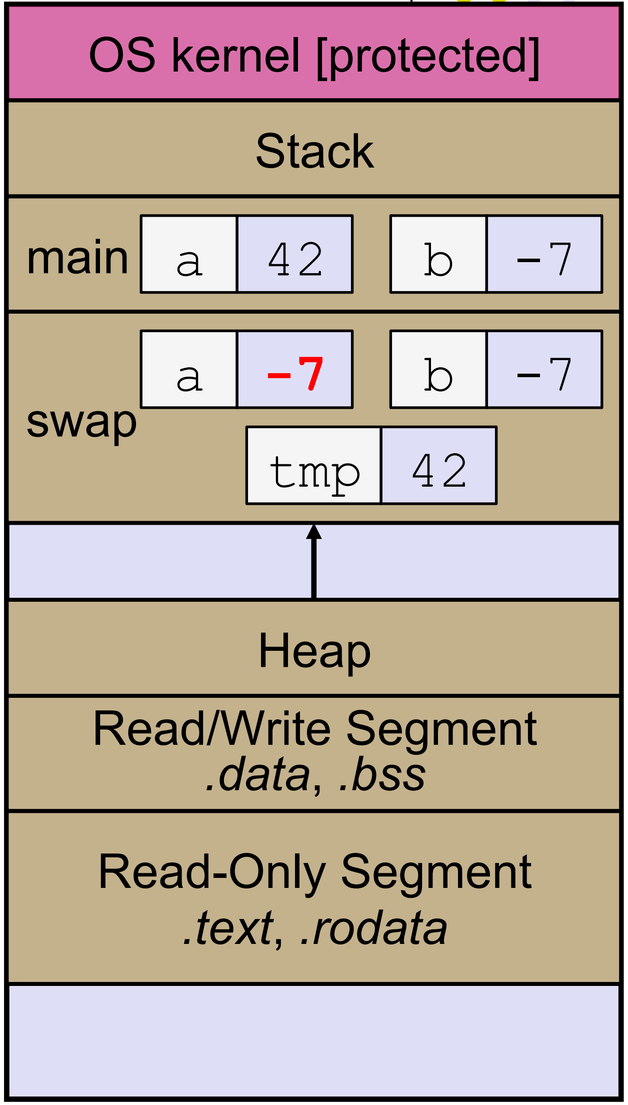
Read/Write Segment
.data, *.bss*

Read-Only Segment
.text, *.rodata*

brokenswap.c

```
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);
  ...
```

Broken Swap (5/7)



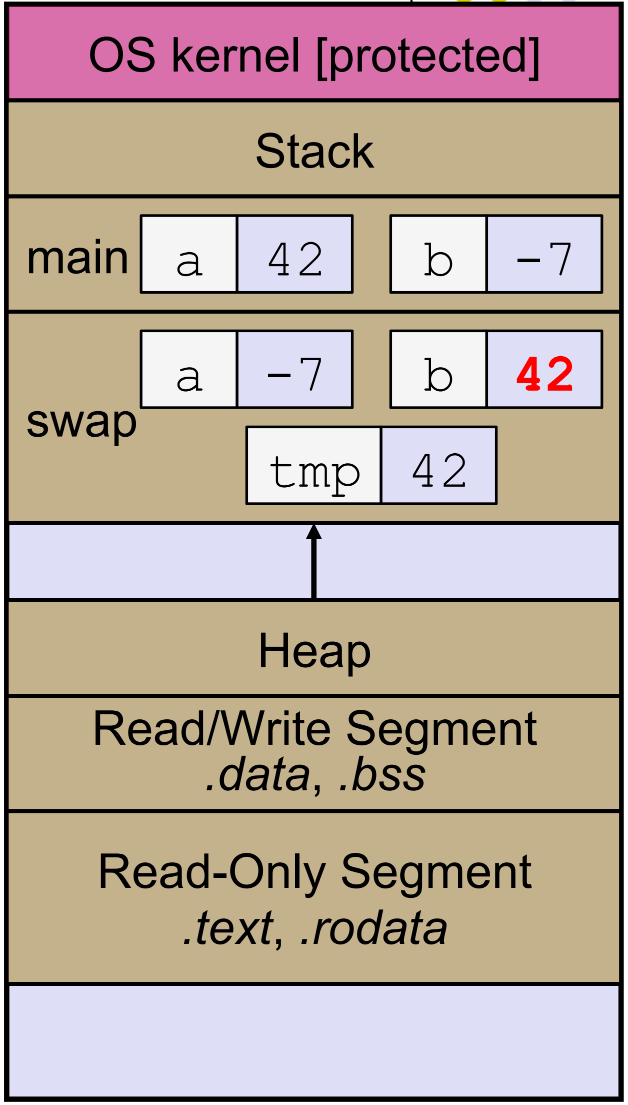
brokenswap.c

```
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);
  ...
```

Broken Swap (6/7)

brokenswap.c

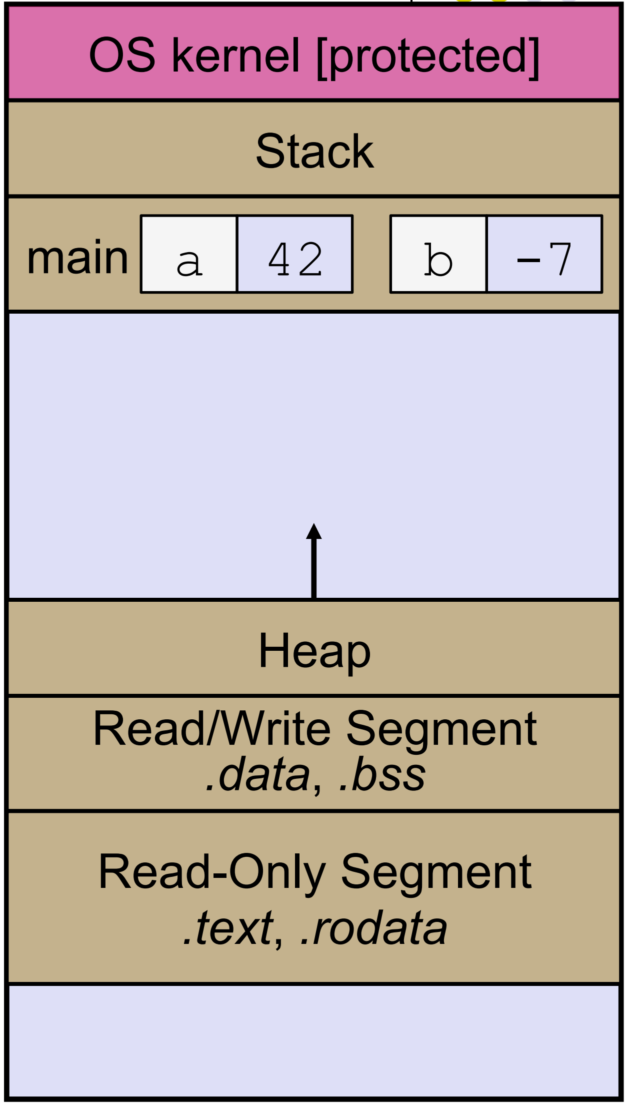
```
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

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



Broken Swap (7/7)

brokenswap.c

```
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);
  ...
```



OS kernel [protected]

Stack

main a 42 b -7

Heap

Read/Write Segment
.data, *.bss*

Read-Only Segment
.text, *.rodata*

Faking Call-By-Reference in C

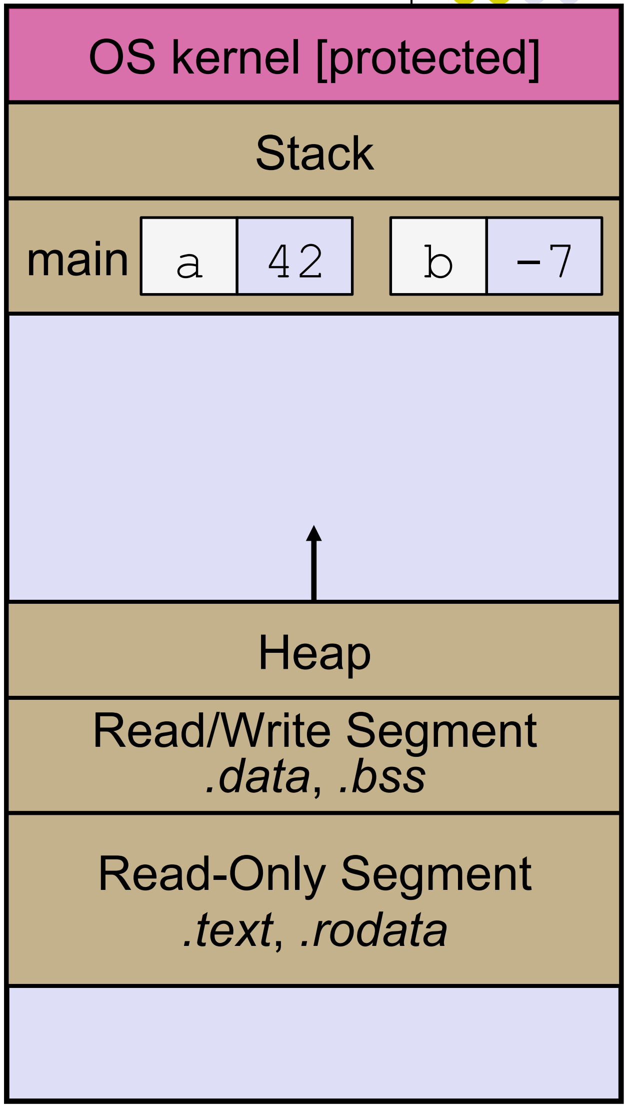
- Can use pointers to *approximate* call-by-reference
  - Callee still receives a **copy** of the pointer (*i.e.* call-by-value), but it can modify something in the caller's scope by dereferencing the pointer parameter

```c
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);
  ...
```

Fixed Swap (1/6)

swap.c

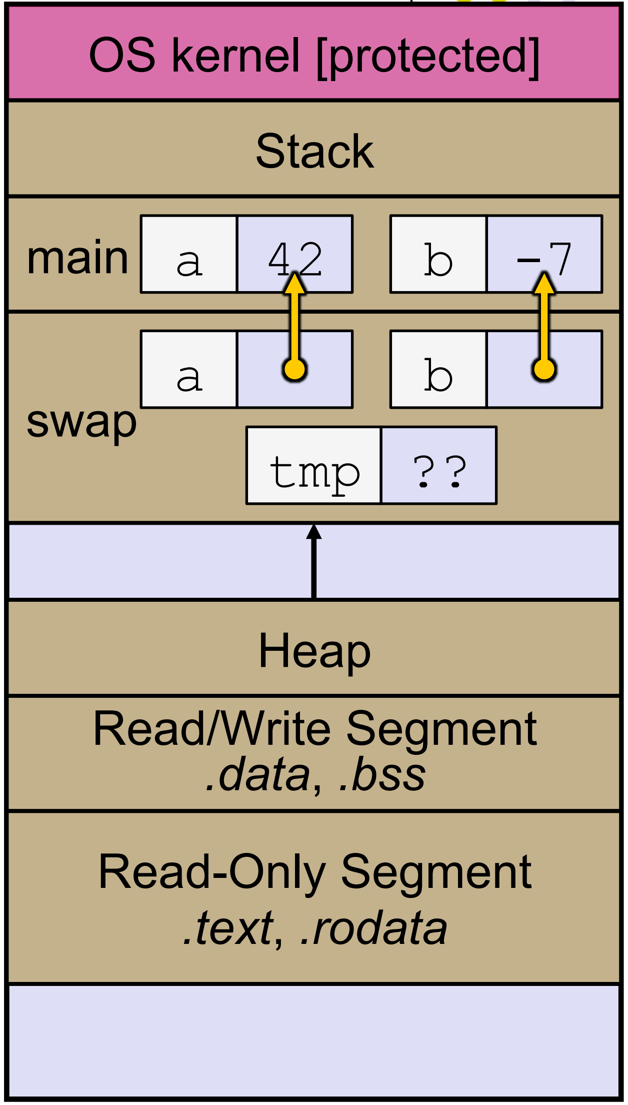
```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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



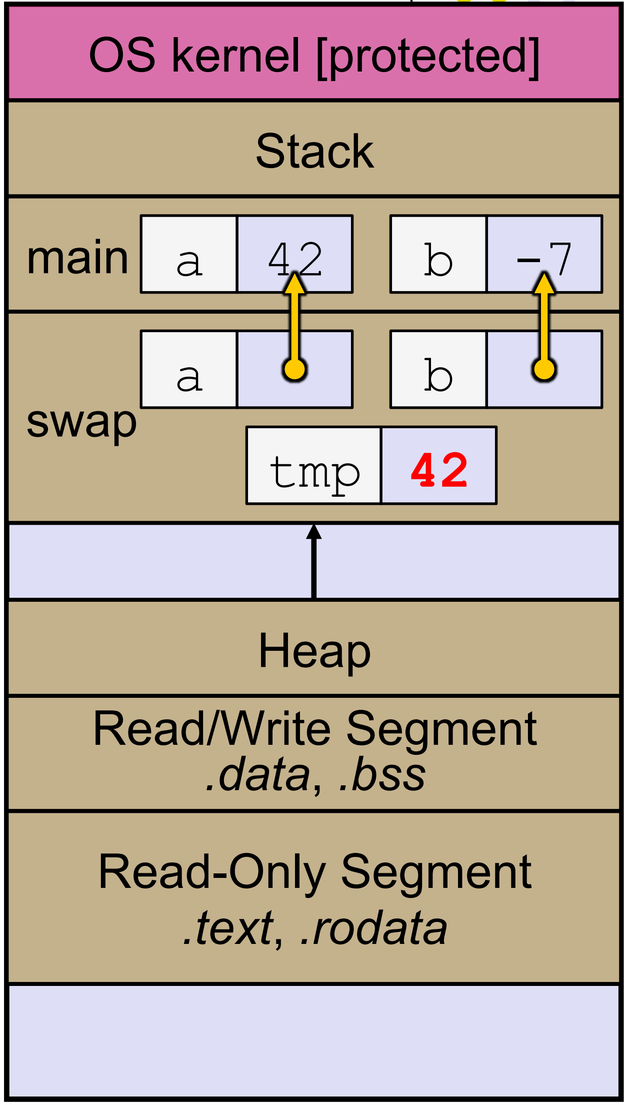
Fixed Swap (2/6)

swap.c

```
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);
  ...
```



Fixed Swap (3/6)

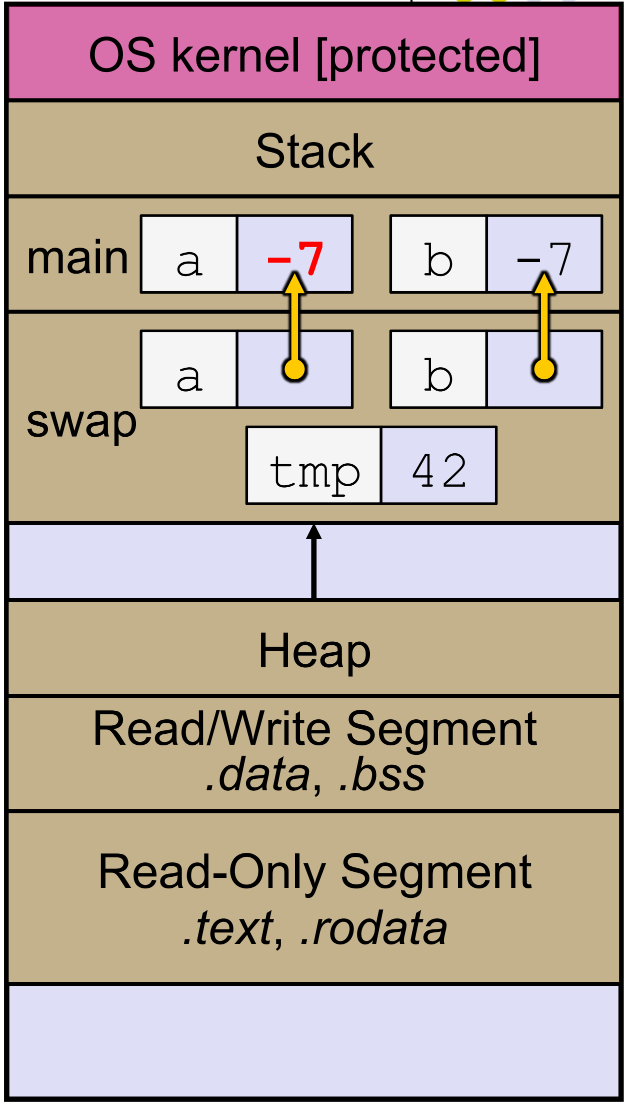


```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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

Fixed Swap (4/6)

swap.c

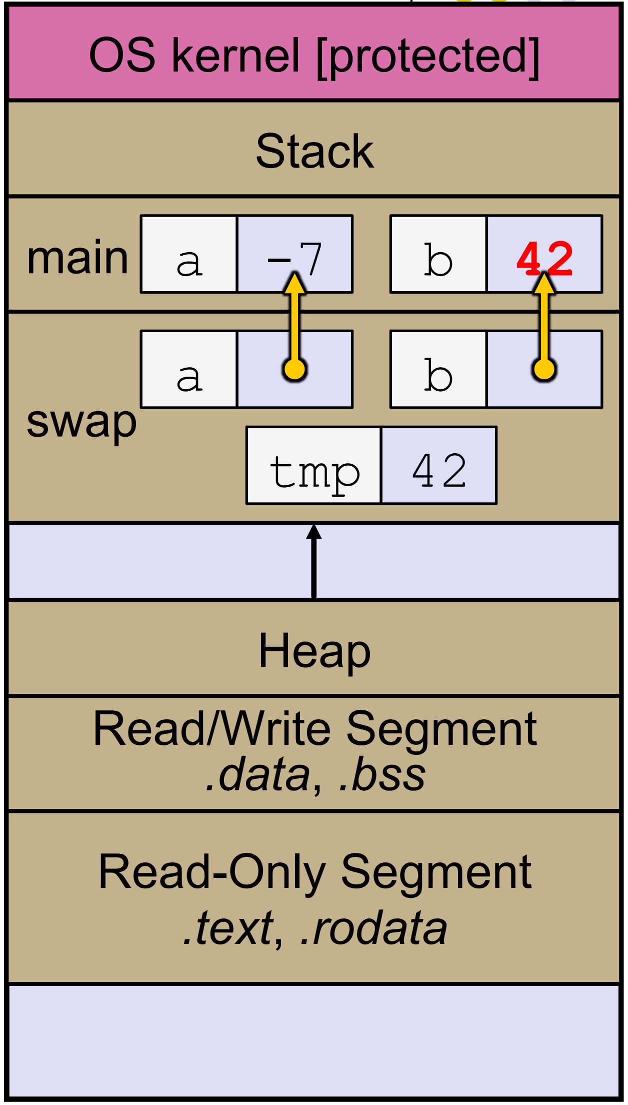
```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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



Fixed Swap (5/6)

swap.c

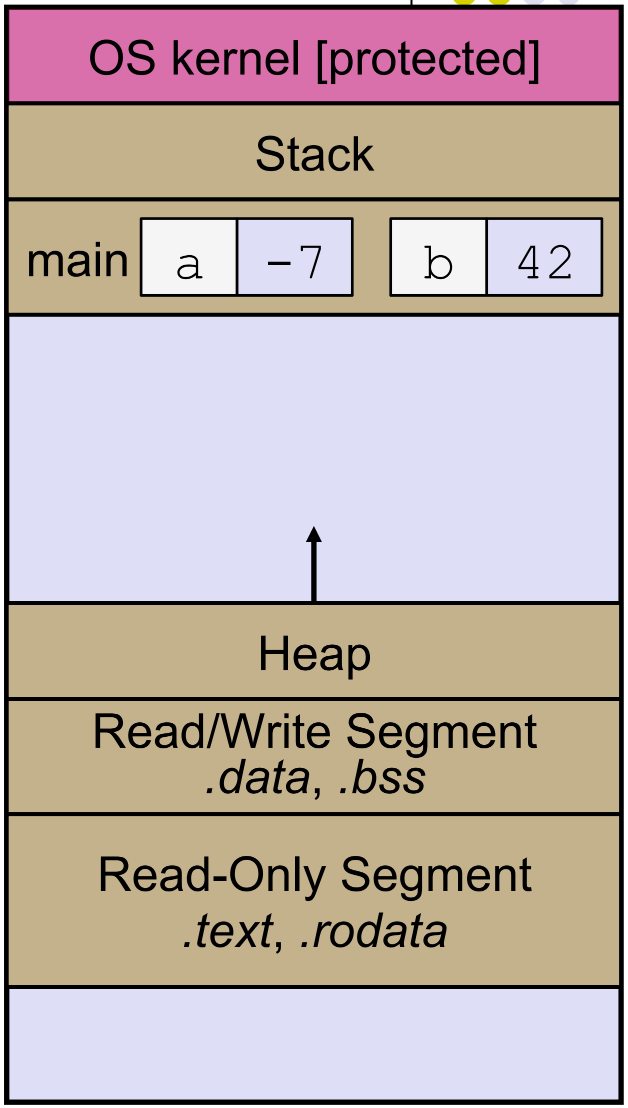
```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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



Fixed Swap (6/6)

swap.c

```
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);
  ...
```



Lecture Outline

- Pointers & Pointer Arithmetic
- Pointers as Parameters
- **Pointers and Arrays**
- Function Pointers

Pointers and Arrays

- A pointer can point to an array element
  - You can use array indexing notation on pointers
    - `ptr[i]` is `*(ptr+i)` with pointer arithmetic - get the data `i` elements forward from `ptr`
  - An array name will provide the beginning address of the array
    - *Like* a pointer to the first element of array, but can't change

```
int a[] = {10, 20, 30, 40, 50};
int* p1 = &a[3];  // refers to a's 4th element
int* p2 = &a[0];  // refers to a's 1st element
int* p3 = a;      // refers to a's 1st element

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

Array Parameters

- Array parameters are *actually* passed as pointers to the first array element
  - The `[]` syntax for parameter types is just for convenience

This code:

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

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

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

Equivalent to:

```
void f(int* a);

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

void f(int* a) {
```

Lecture Outline

- Pointers & Pointer Arithmetic
- Pointers as Parameters
- Pointers and Arrays
- Function Pointers

Function Pointers

jmp foo
address
PC

- Based on what you know about assembly, what is a function name, really?

  label → address

  - Can use pointers that store addresses of functions!
- Generic format:

  function pointer
  function prototype

  int foo(int);
  int (*fp)(int) = foo;
  int *fp(int)

  pointer!

  ```
  returnType (* name)(type1, …, typeN)
  ```

  - me
  - Why are parentheses around `(* name)` needed?

  to differentiate it from a function prototype

- Using the function:
  - Calls the pointed-to function with the given arguments and return the return value

  dereference

  ```
  (*name)(arg1, …, argN)
  ```

Function Pointer Example

- `map()` performs operation on each element of an array

```c
#define LEN 4

int negate(int num) {return -num;}
int square(int num) {return num*num;}

// perform operation pointed to on each array element
void map(int a[], int len, int (* op)(int n)) {
  for (int i = 0; i < len; i++) {
    a[i] = (*op)(a[i]);  // dereference function pointer
  }
}

int main(int argc, char** argv) {
  int arr[LEN] = {-1, 0, 1, 2};
  int (* op)(int n);    // function pointer called 'op'
  op = square;      // function name returns addr (like array)
  map(arr, LEN, op);
  ...
```

funcptr parameter

funcptr dereference

funcptr definition

funcptr assignment

map.c

Questions?