Pointers, Pointers, Pointers

CSE 333 Winter 2025

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Administrivia

- Exercise 2 out this morning; due Monday 10 am
- Homework 0 due Monday night, 11:59 pm
  - Logistics and infrastructure for projects
    - Use `cpplint` and `valgrind` for exercises, too
  - Git: add/commit/push, then tag with `hw0-final`, then push tag
    - Then clone your repo somewhere totally different and do `git checkout hw0-final` and verify that all is well
      - Leave yourself enough time before 11:59 pm to fix any problems
      - Do ***not*** just check the gitlab web page – clone the repo and test!
      - If trouble, *throw away* this extra copy and fix things in the original repo, add/commit/push, retag, and repeat
  - Reminder: all exercises/hw **must** work properly on current Allen School Linux machines (attu/lab/VM)

Yet More Administrivia

- HW1 assignment posted now. Starter code will be pushed to repos late today or tomorrow morning.
  - Linked list and hash table implementations in C
  - Get starter code using `git pull` in your course repo
    - Might have “merge conflict” if your local repo has unpushed changes
      - Default git merge handling will almost certainly do the right thing
      - If git drops you into vi(m), :q to quit or :wq if you want to save changes
      - To avoid, **always** do a `git pull` before any git commit or push
  - Read the assignment and start reading the code this weekend
    - For large projects, you must pace yourself so if something baffling happens, you can let it go for the day and come back to it tomorrow

Yet More Administrivia

- Exercise grading – Gradescope abuse
  - Score is an overall evaluation: 3/2/1/0 = superior / good / marginal / not sufficient for credit
    - We expect lots of 2's and fewer 3's at first, more 3's on later exercises
  - There are additional ±0 rubric items to give us a way to communicate "why" – feedback / comments / reasons for score
    - Allows us to be more consistent in feedback
    - The ±0 "score" is just because that's how we have to use Gradescope to handle feedback notes – it does not contribute to "the points"

- Hoping to have ex0 scores out shortly, but infrastructure…

Lecture Outline

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

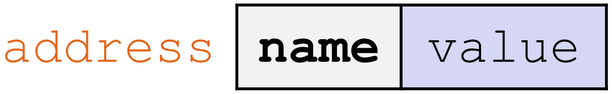
Box-and-Arrow Diagrams

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 EXIT_SUCCESS;
}
```


address

name

value

Box-and-Arrow Diagrams

boxarrow.c

```
int main(int argc, char** argv) {
  int x = 1;
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  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 EXIT_SUCCESS;
}
```
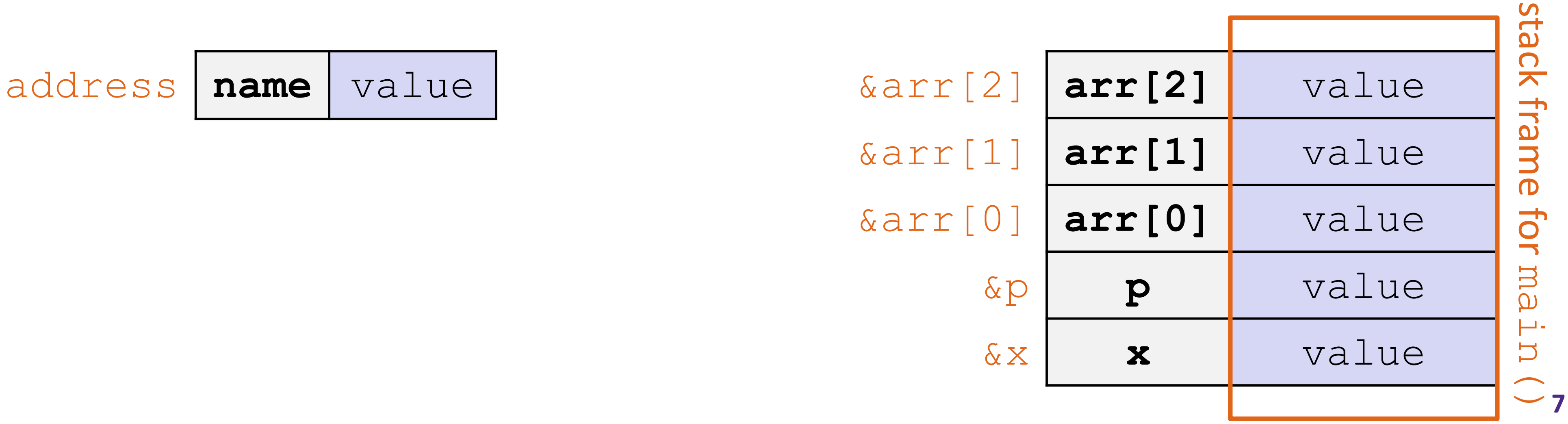



address	name	value

&arr[2]	**arr[2]**	value
&arr[1]	**arr[1]**	value
&arr[0]	**arr[0]**	value
&p	**p**	value
&x	**x**	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 EXIT_SUCCESS;
}
```

address	**name**	value

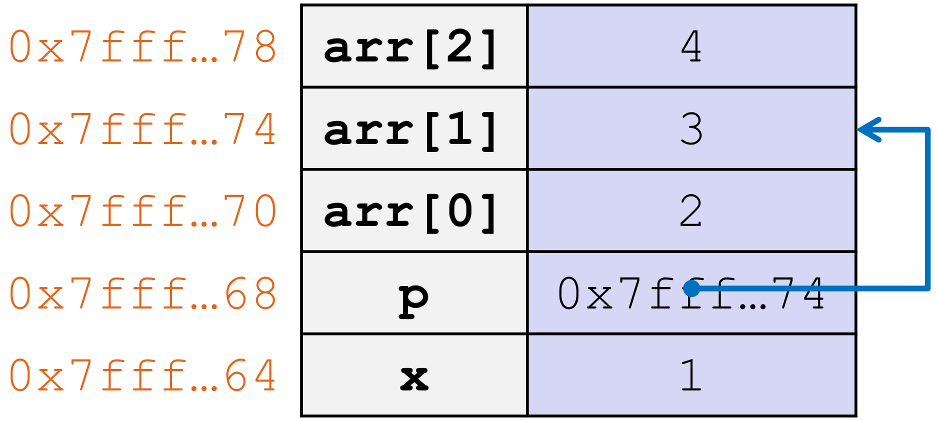
&arr[2]	**arr[2]**	4
&arr[1]	**arr[1]**	3
&arr[0]	**arr[0]**	2
&p	**p**	&arr[1]
&x	**x**	1

Box-and-Arrow Diagrams

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 EXIT_SUCCESS;
}
```

address	name	value



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 and a pointer
  - Subtract two pointers (within same 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 EXIT_SUCCESS;
}
```

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

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

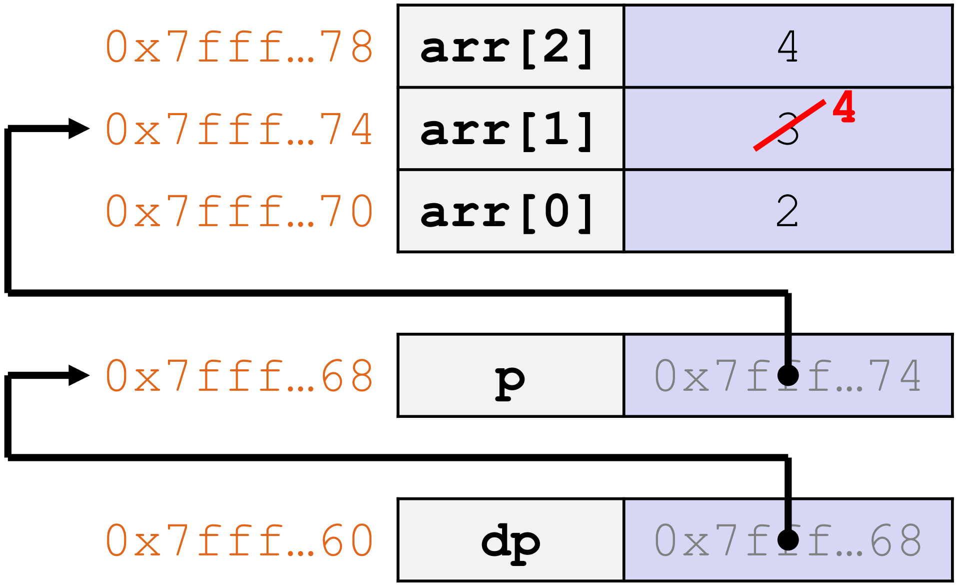
Practice Solution

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 EXIT_SUCCESS;
}
```

address	name	value



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

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boxarrow2.c

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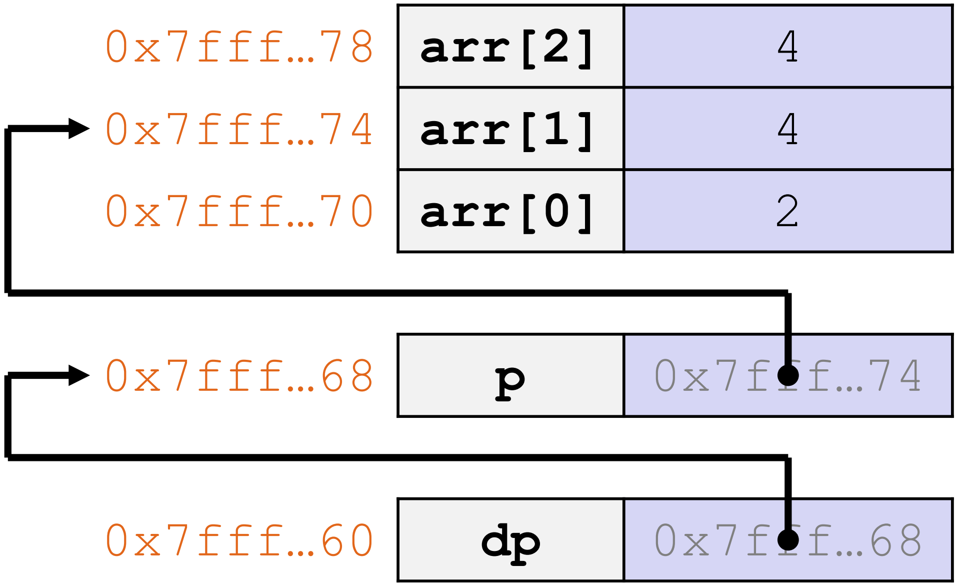
  *(*dp) += 1;
  p += 1;
  *(*dp) += 1;

  return EXIT_SUCCESS;
}
```



address	name	value
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0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
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  int arr[3] = {2, 3, 4};
  int* p = &arr[1];
  int** dp = &p;  // pointer to a pointer

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

  return EXIT_SUCCESS;
}
```

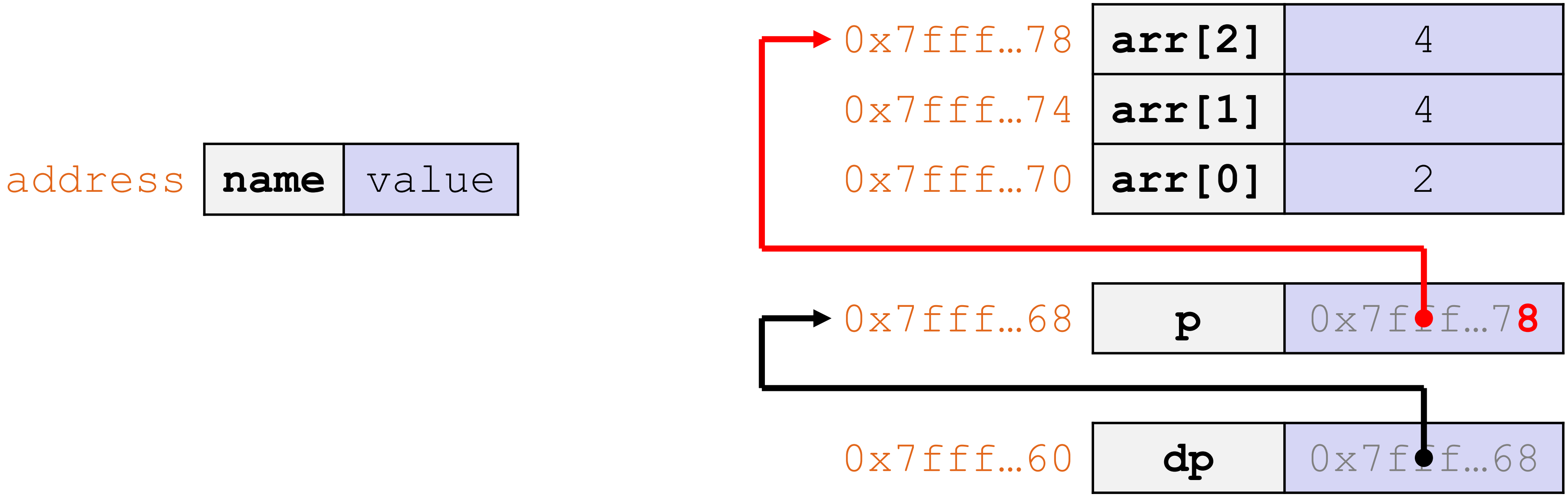

address	name	value
0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…7**8**
0x7fff…60	dp	0x7fff…68

Practice Solution

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

  return EXIT_SUCCESS;
}
```
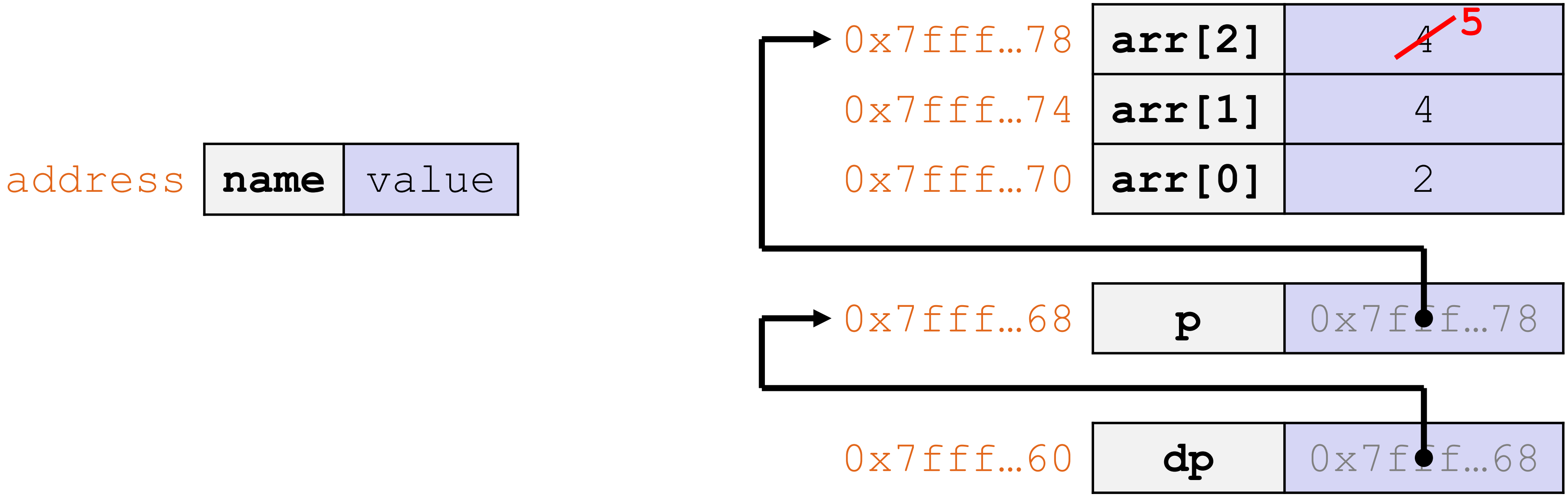



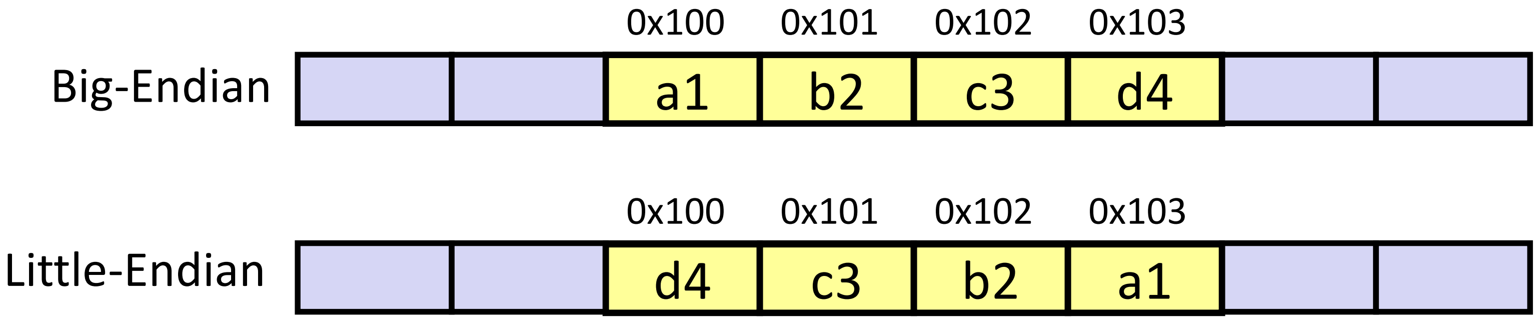
address	name	value

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

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



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

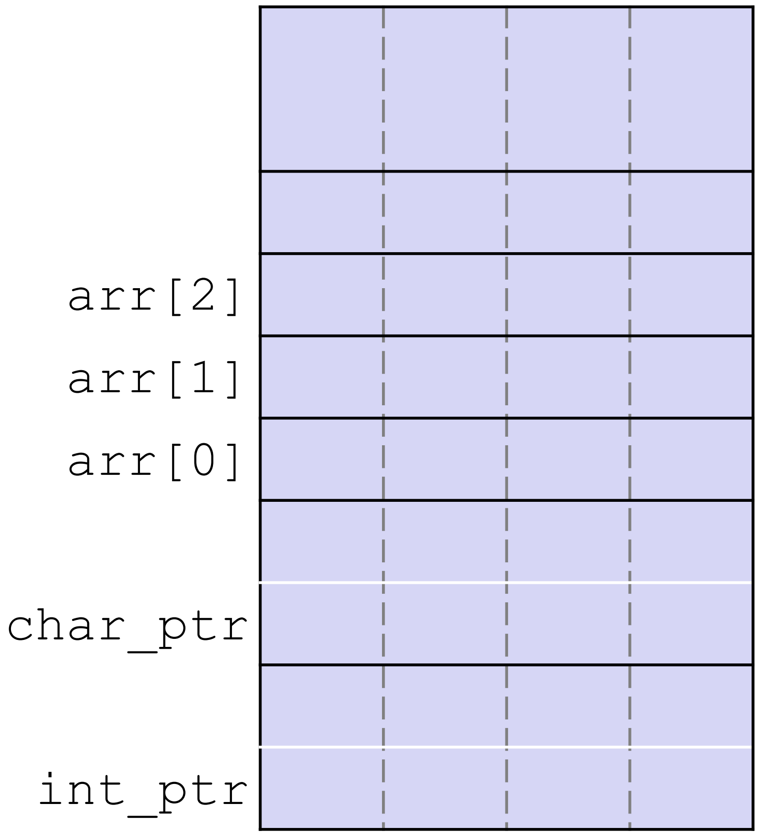
Pointer Arithmetic Example

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 EXIT_SUCCESS;
}
```

pointerarithmetic.c

Stack
(assume x86-64)



Pointer Arithmetic Example

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```
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;
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  char_ptr += 1;
  char_ptr += 2;

  return EXIT_SUCCESS;
}
```
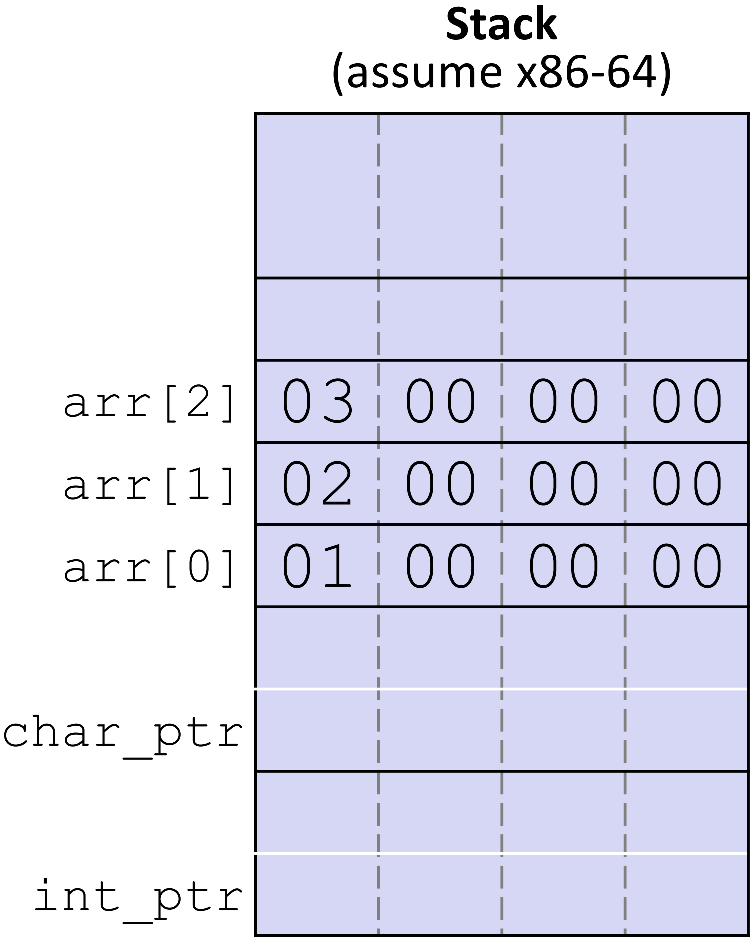

pointerarithmetic.c



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

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 EXIT_SUCCESS;
}
```

pointerarithmetic.c

Stack
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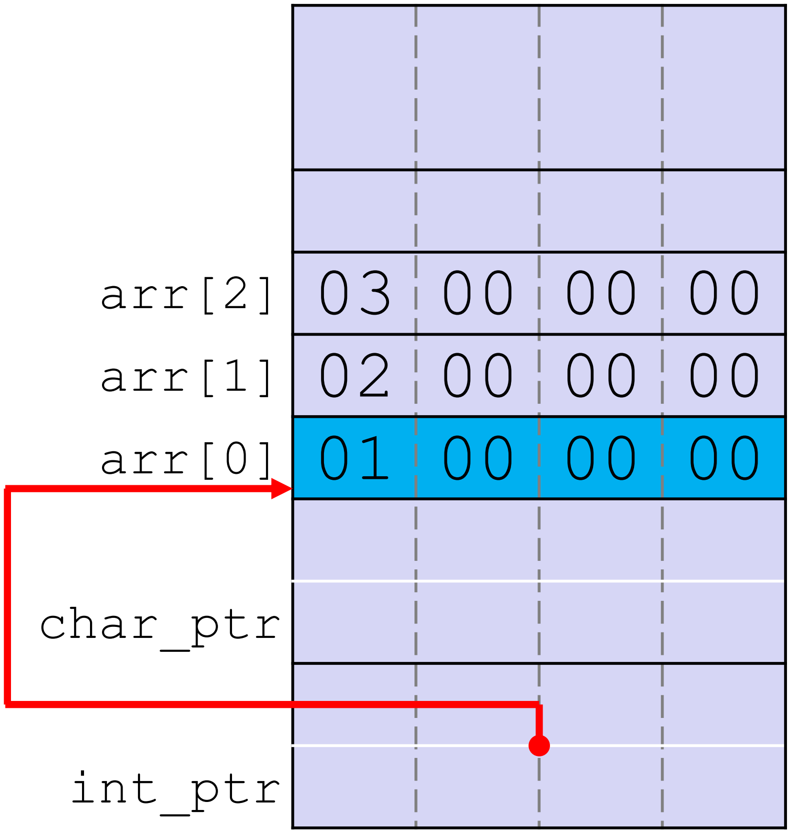

arr[2]	03	00	00	00
arr[1]	02	00	00	00
arr[0]	01	00	00	00
char_ptr				
int_ptr				

Pointer Arithmetic Example

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;
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  char_ptr += 1;
  char_ptr += 2;

  return EXIT_SUCCESS;
}
```
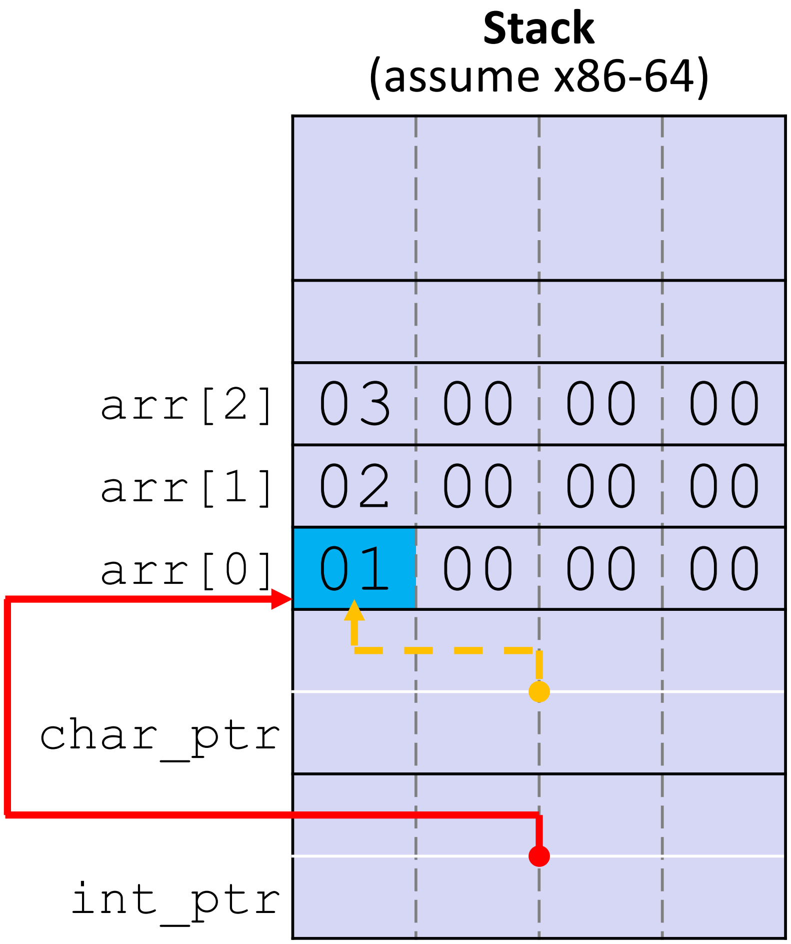

pointerarithmetic.c



Pointer Arithmetic Example

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;
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  char_ptr += 1;
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  return EXIT_SUCCESS;
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pointerarithmetic.c

Stack
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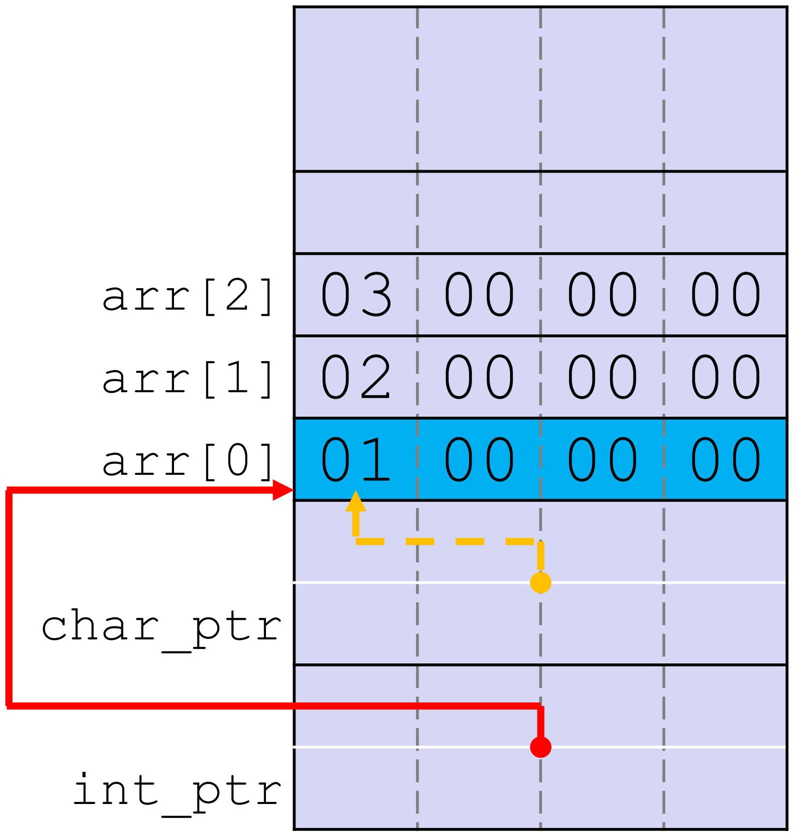

```
 int_ptr:   0x0x7ffffffde010
*int_ptr:   1
```

Pointer Arithmetic Example

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;
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  char_ptr += 1;
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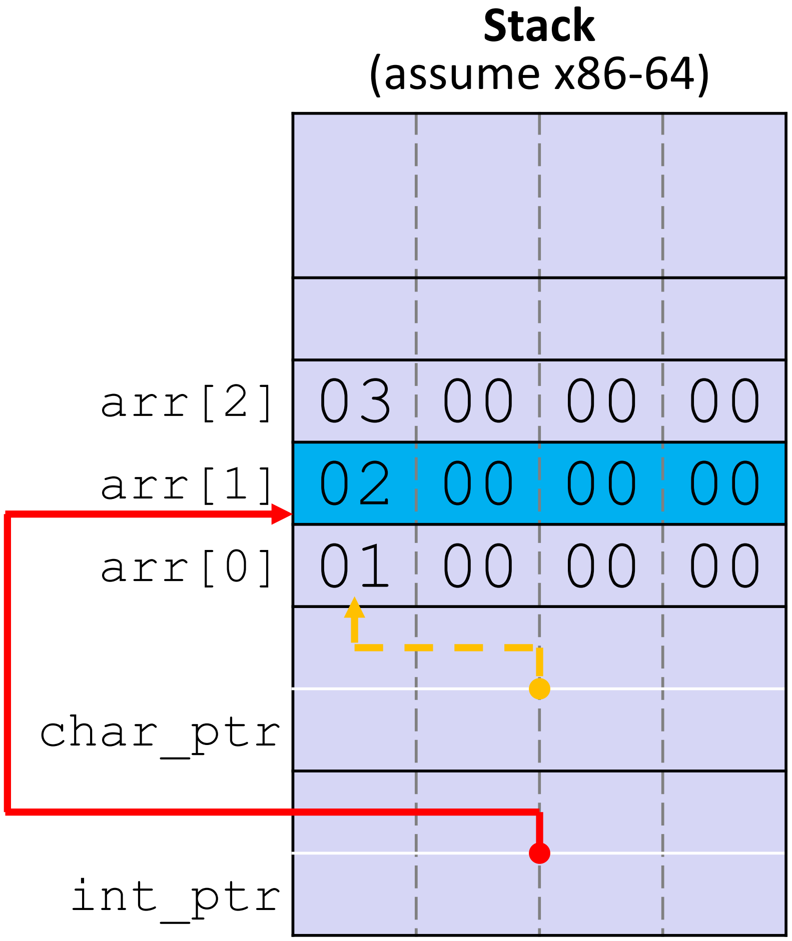
  return EXIT_SUCCESS;
}
```

pointerarithmetic.c



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

Pointer Arithmetic Example

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

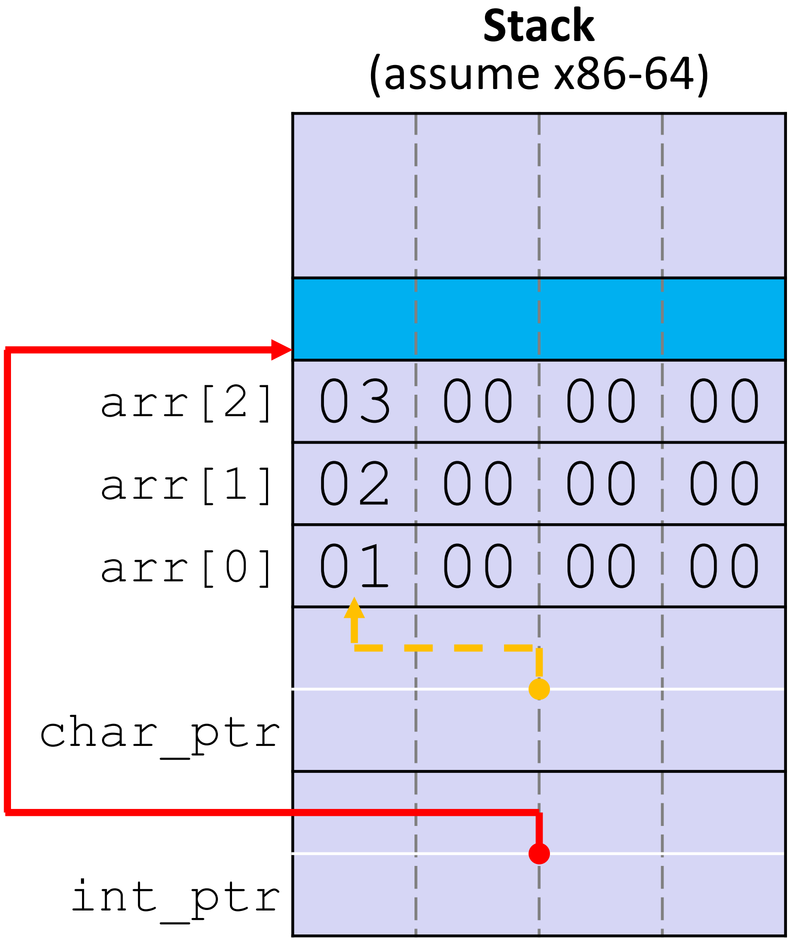
→ char_ptr += 1;
  char_ptr += 2;

  return EXIT_SUCCESS;
}
```

pointerarithmetic.c

int_ptr: 0x0x7fffffde01**C**

***int_ptr:** **???**



Stack
(assume x86-64)

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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  int_ptr += 1;
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  return EXIT_SUCCESS;
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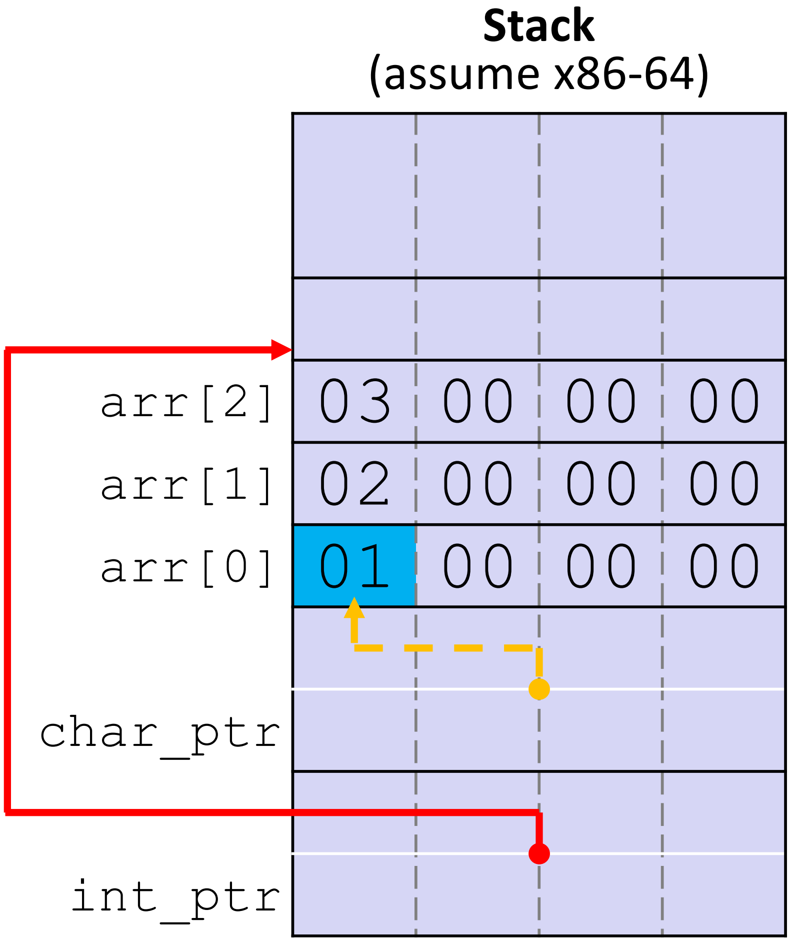
pointerarithmetic.c



```
 char_ptr:   0x0x7ffffffde010
*char_ptr:   1
```

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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

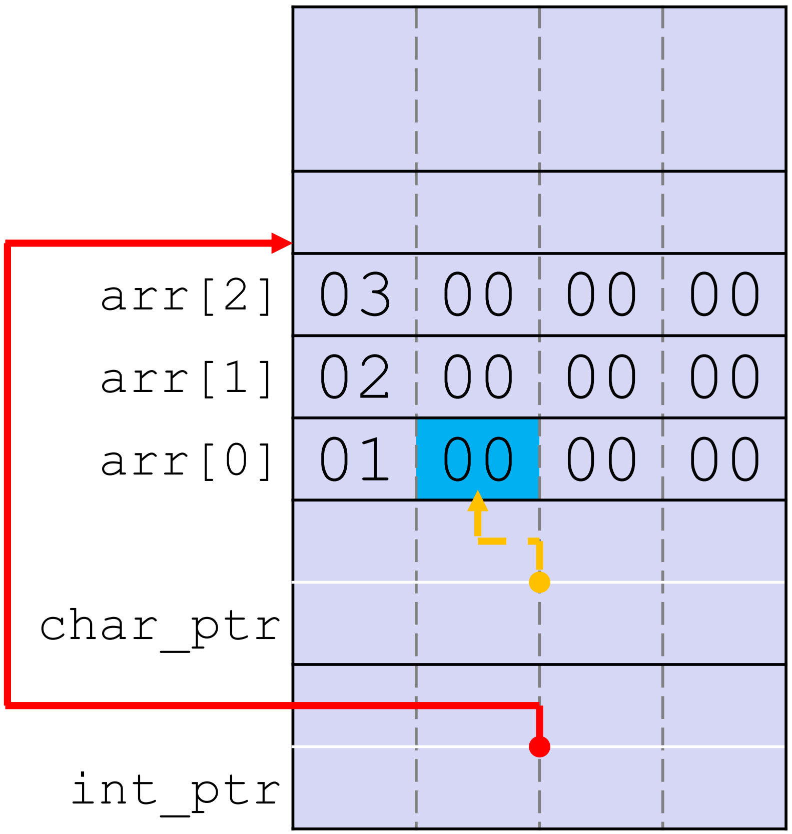
  int_ptr += 1;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
→ char_ptr += 2;

  return EXIT_SUCCESS;
}
```

pointerarithmetic.c

Stack
(assume x86-64)



```
 char_ptr:   0x0x7fffffde011
*char_ptr:   0
```

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

```
int main(int argc, char** argv) {
  int arr[3] = {1, 2, 3};
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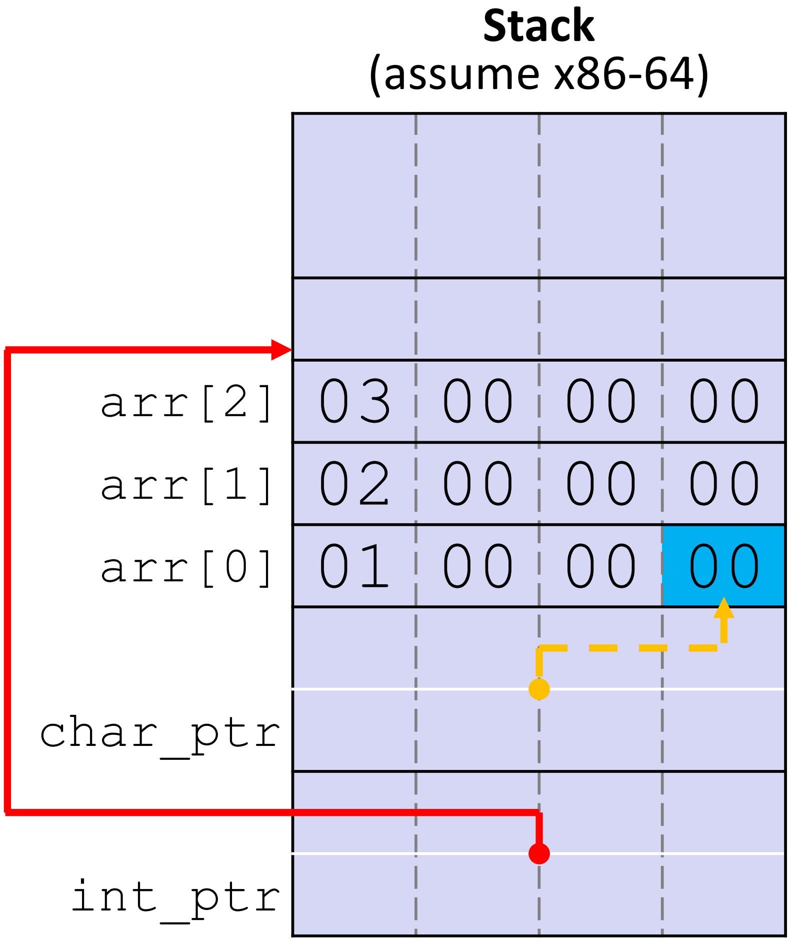
pointerarithmetic.c



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:   0x0x7fffffde013
*char_ptr:   0
```

Lecture Outline

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

C parameters are Call-By-Value

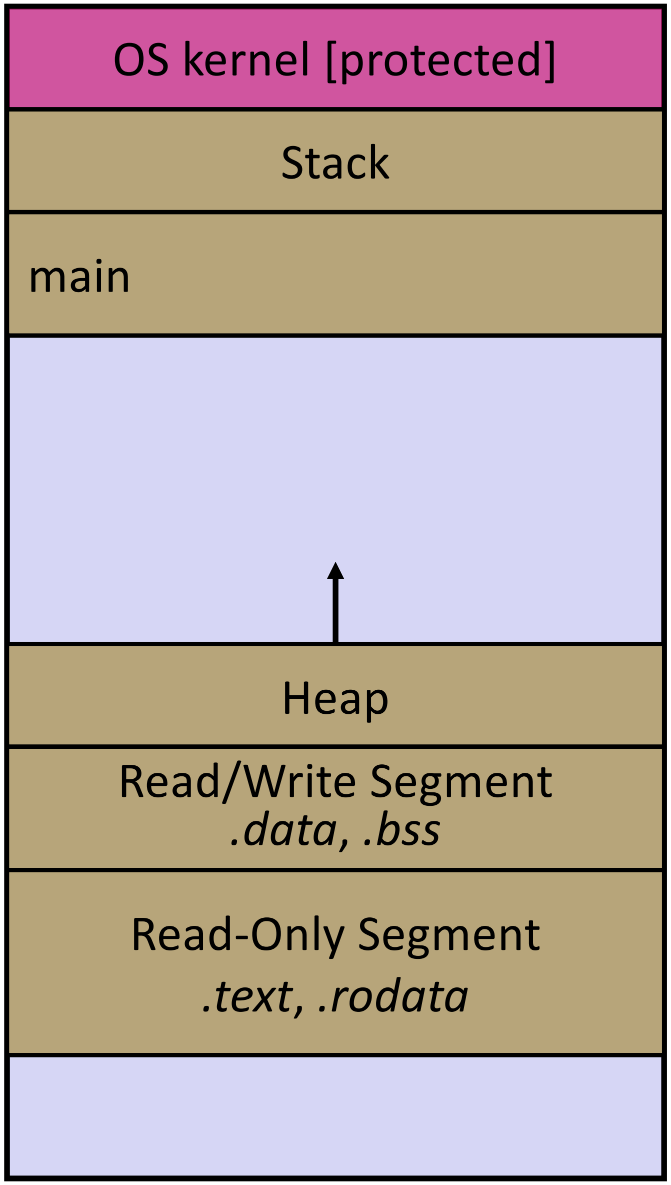
- C (and Java) pass arguments by *value*
  - Callee receives a **local copy** of the argument
    - Register or Stack
  - If the callee modifies a parameter, the caller's copy *isn't* modified

```
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

Note: Arrow points to *next* instruction.



brokenswap.c

```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

brokenswap.c

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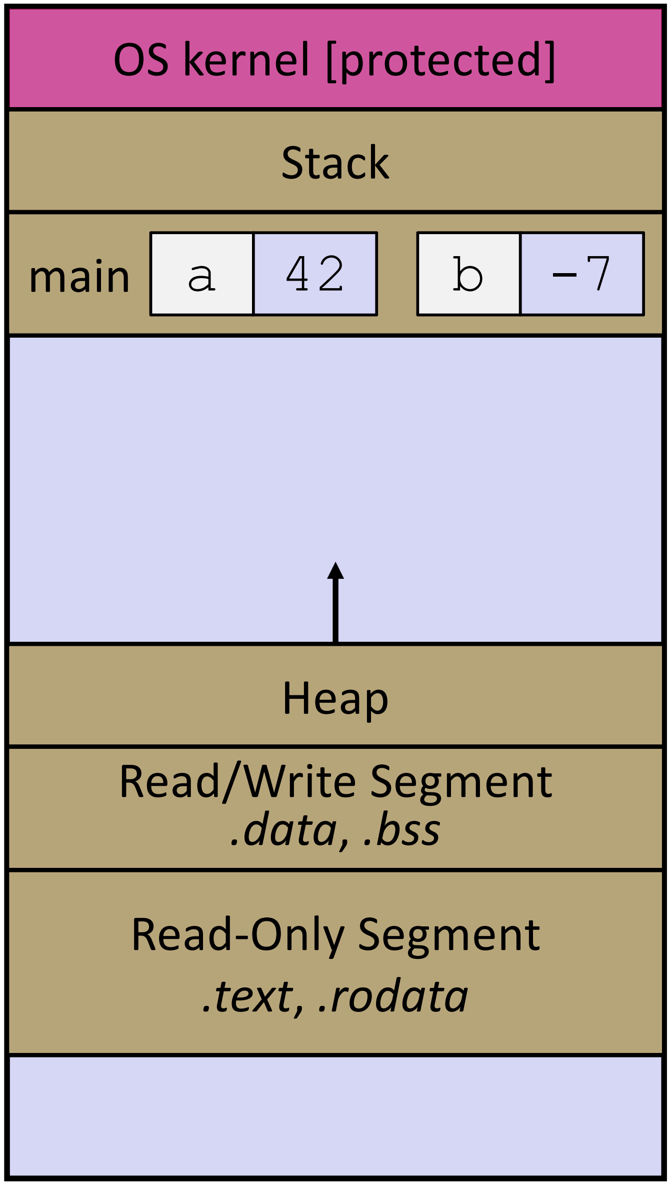
```



OS kernel [protected]

Stack

main a 42 b -7

Heap

Read/Write Segment
.data, .bss

Read-Only Segment
.text, .rodata

Broken Swap

brokenswap.c

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

int main(int argc, char** argv) {
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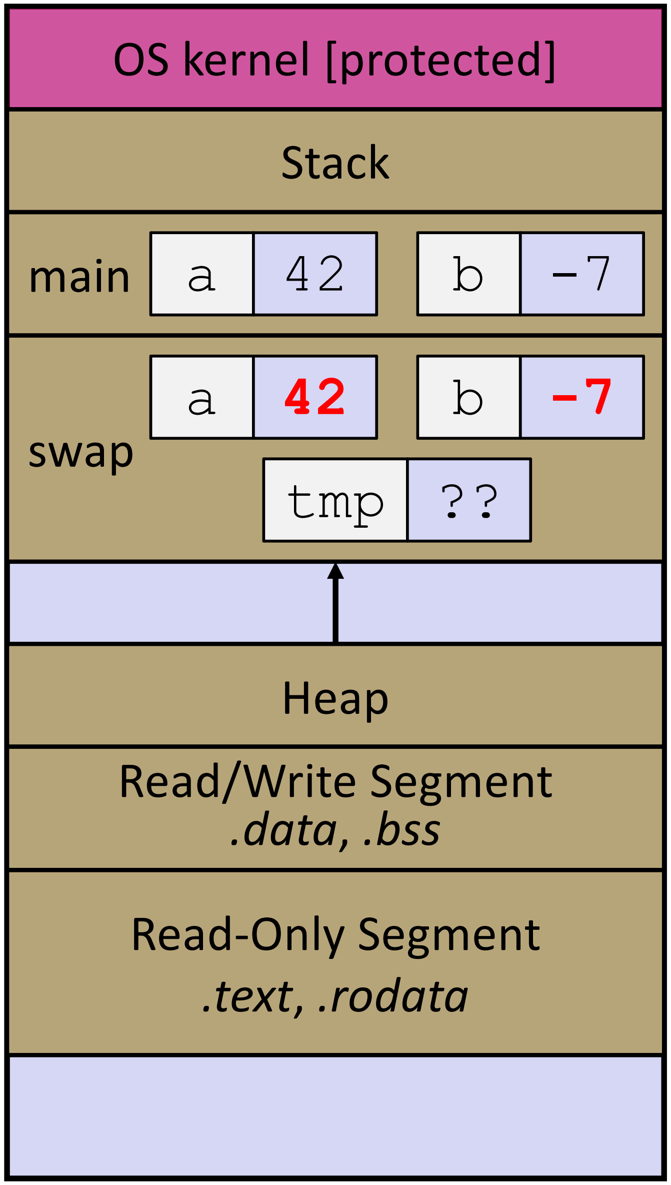
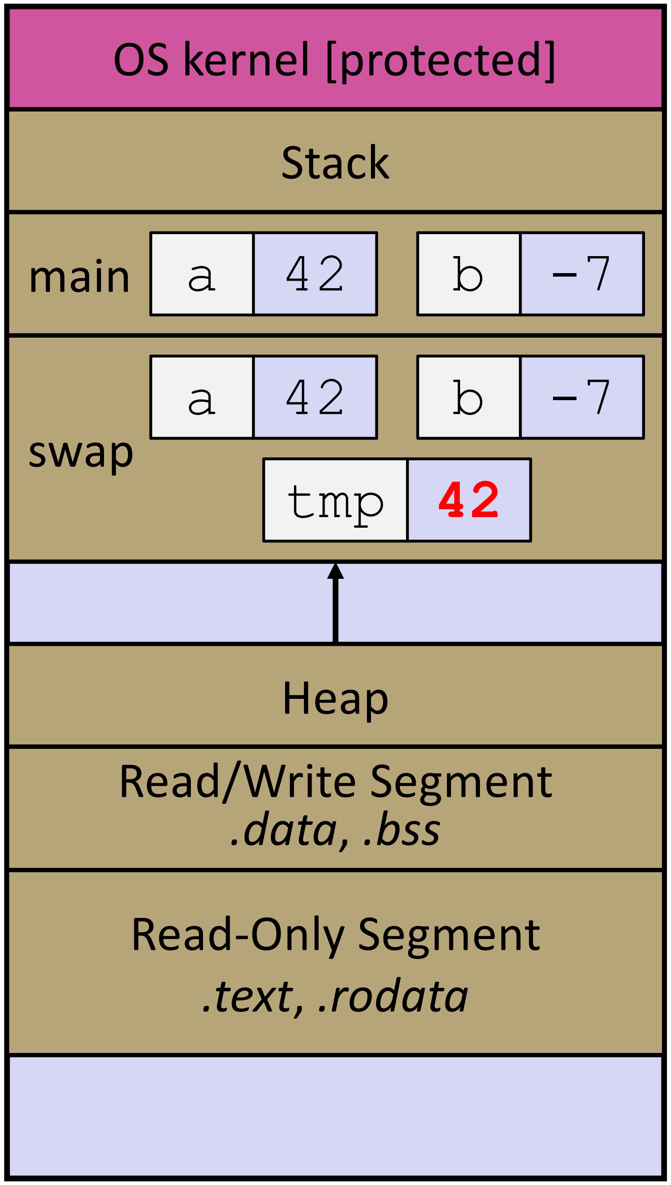


Broken Swap



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Broken Swap

brokenswap.c

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  ...
```
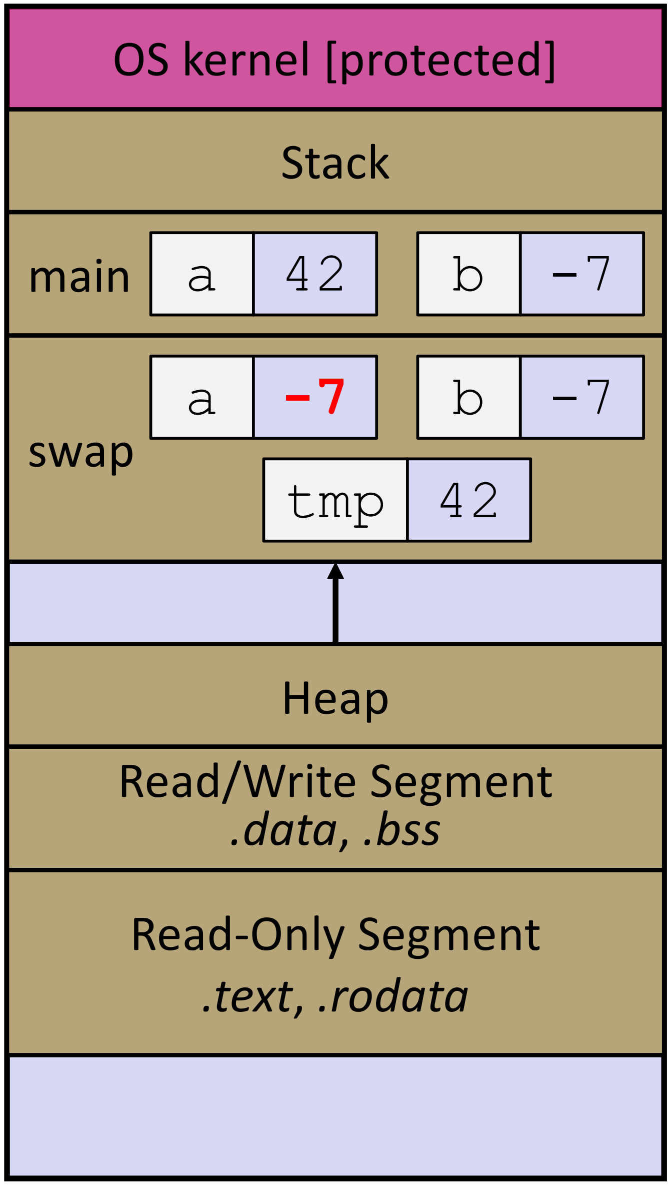
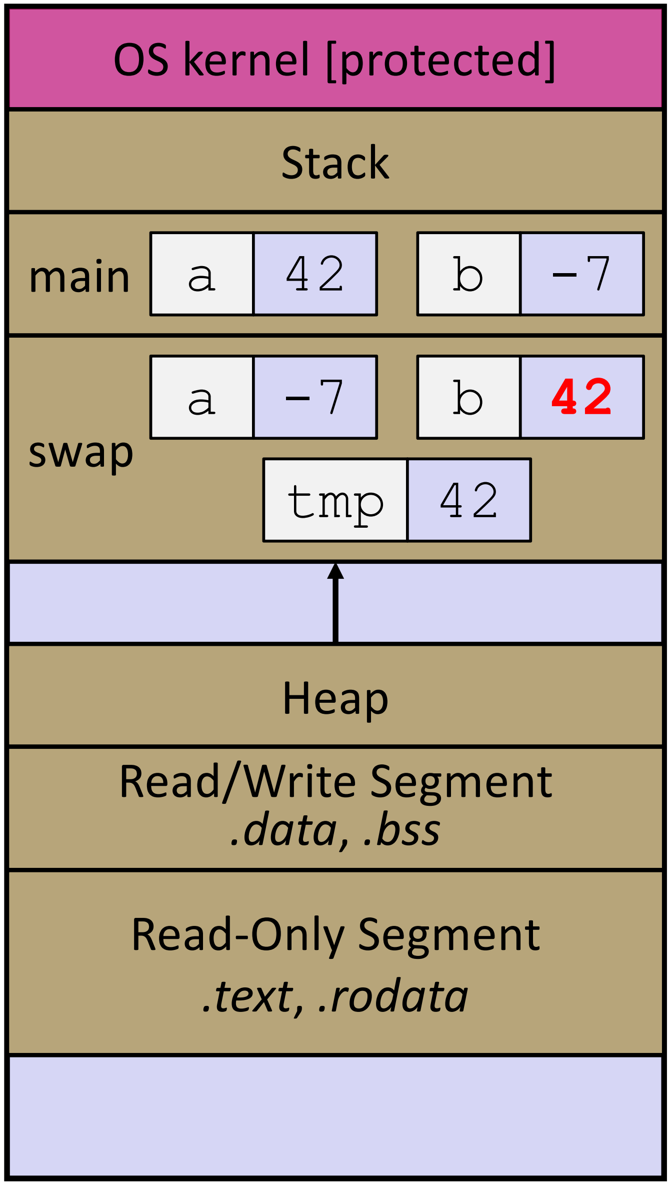



Broken Swap



OS kernel [protected]

Stack

main a 42 b -7

swap a -7 b 42 tmp 42

Heap

Read/Write Segment
.data, .bss

Read-Only Segment
.text, .rodata

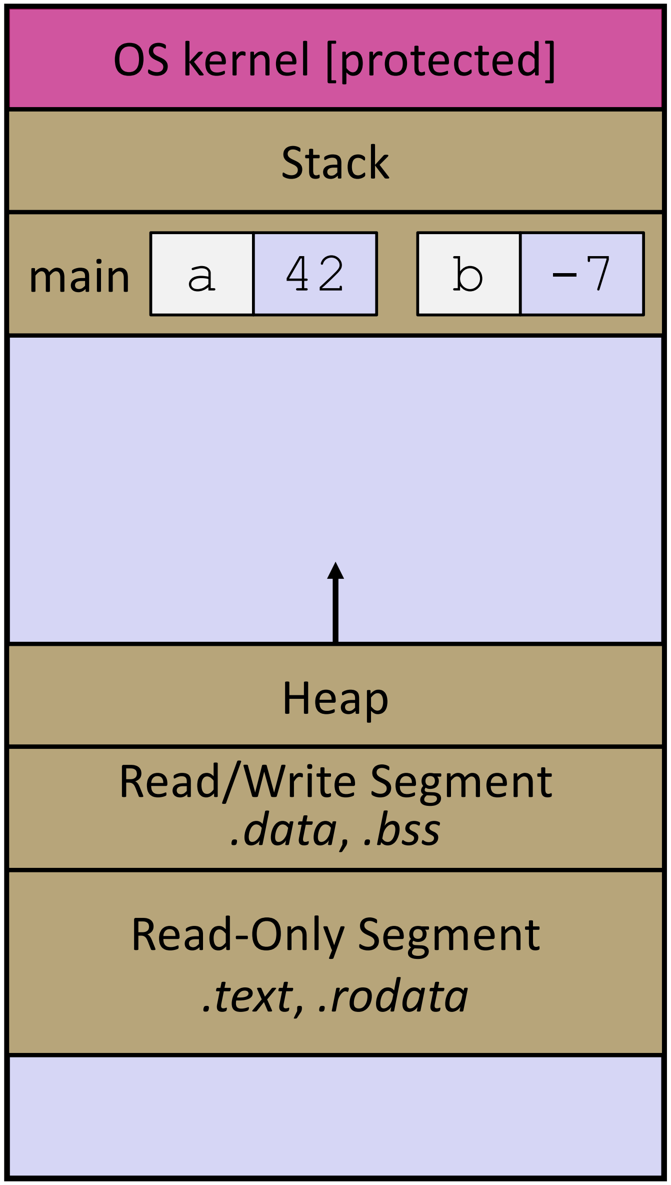
brokenswap.c

```
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

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);
  ...
```



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

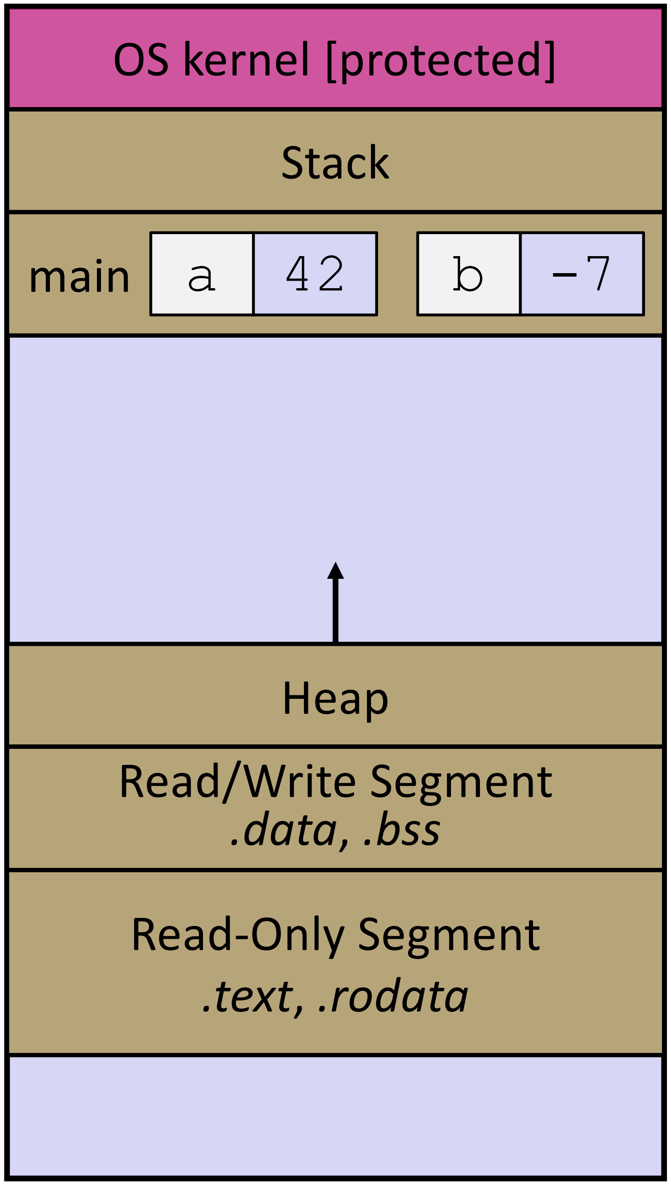
```c
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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

Fixed Swap

Note: Arrow points to *next* instruction.

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);
  ...
```



OS kernel [protected]

Stack

main a 42 b -7

Heap

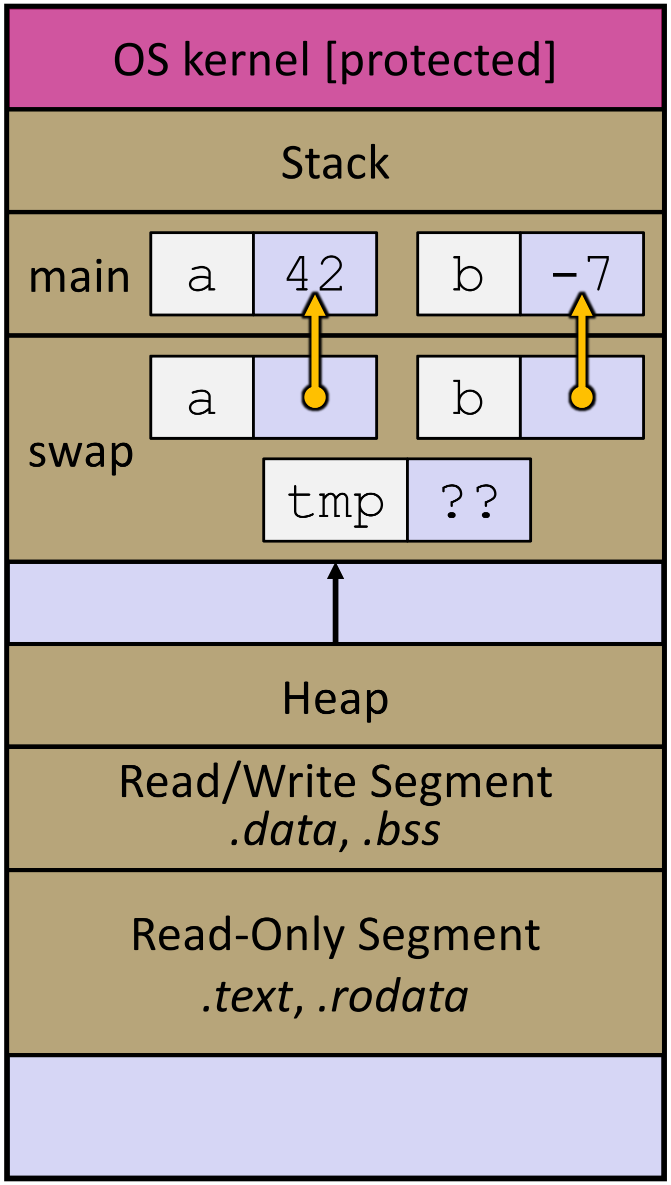
Read/Write Segment
.data, .bss

Read-Only Segment
.text, .rodata

Fixed Swap

swap.c

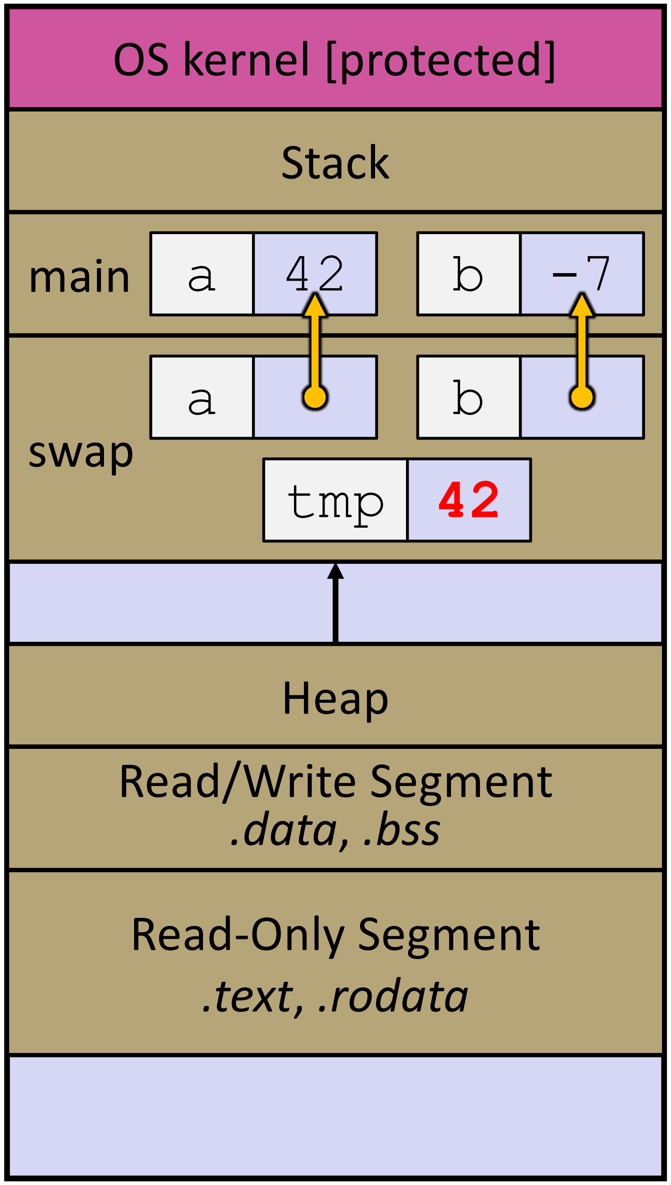
```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

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



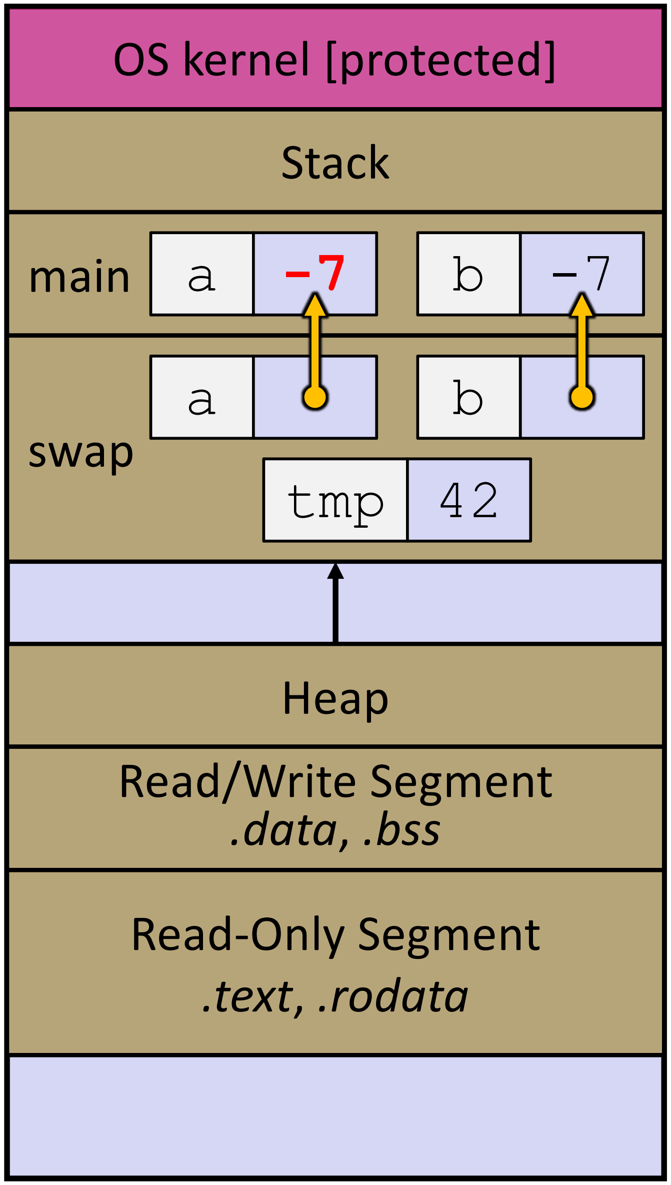
Fixed Swap

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);
  ...
```



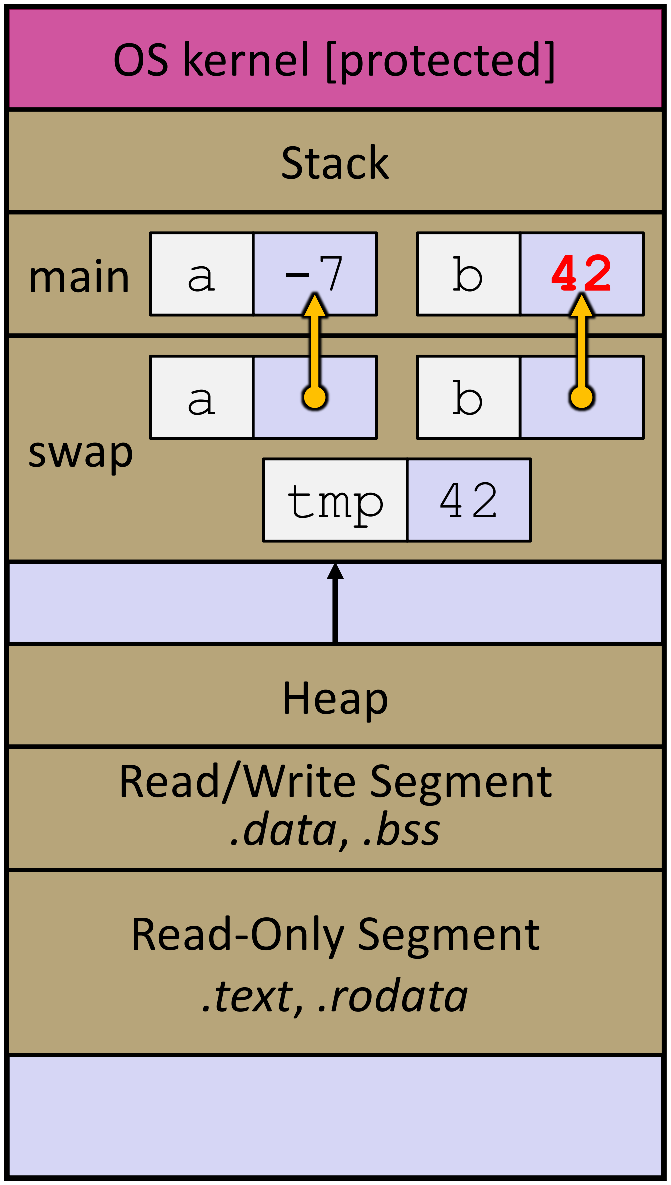
Fixed Swap



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



OS kernel [protected]

Stack

main a -7 b 42

swap a b tmp 42

Heap

Read/Write Segment
.data, .bss

Read-Only Segment
.text, .rodata

swap.c

```
void swap(int* a, int* b) {
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  swap(&a, &b);
  ...
```

Fixed Swap

swap.c

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

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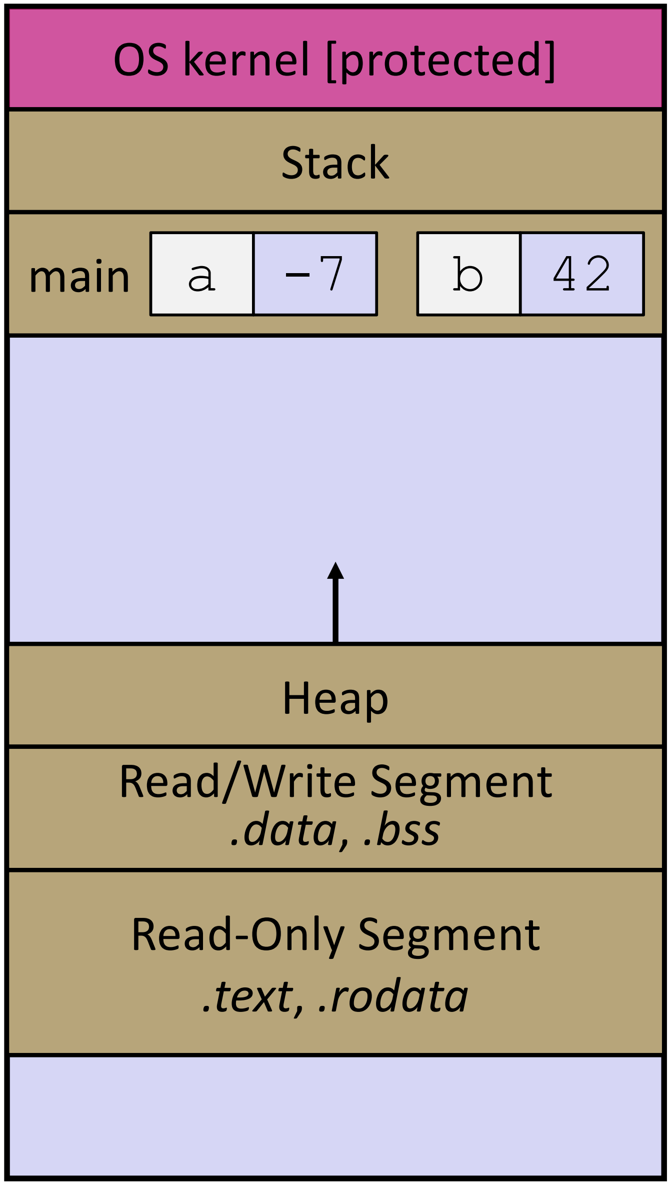



OS kernel [protected]

Stack

main

a	-7

b	42

Heap

Read/Write Segment
.data, .bss

Read-Only Segment
.text, .rodata

Output Parameters

Warning: Misuse of output parameters is *the* largest cause of errors in this course!

- Output parameter
  - A pointer parameter used to store (via dereference) a function output value *outside* of the function's stack frame
  - Typically points to/modifies something in the Caller's scope
  - Useful if you want to have multiple return values

- Setup and usage:
  1) Caller creates space for the data (*e.g.*, `type var;`)
  2) Caller passes a pointer to that space to Callee (*e.g.*, `&var`)
  3) Callee has an output parameter (*e.g.*, `type* outparam`)
  4) Callee uses parameter to store data in space provided by caller (*e.g.*, `*outparam = value;`)
  5) Caller accesses output via modified data (*e.g.*, `var`)

Lecture Outline

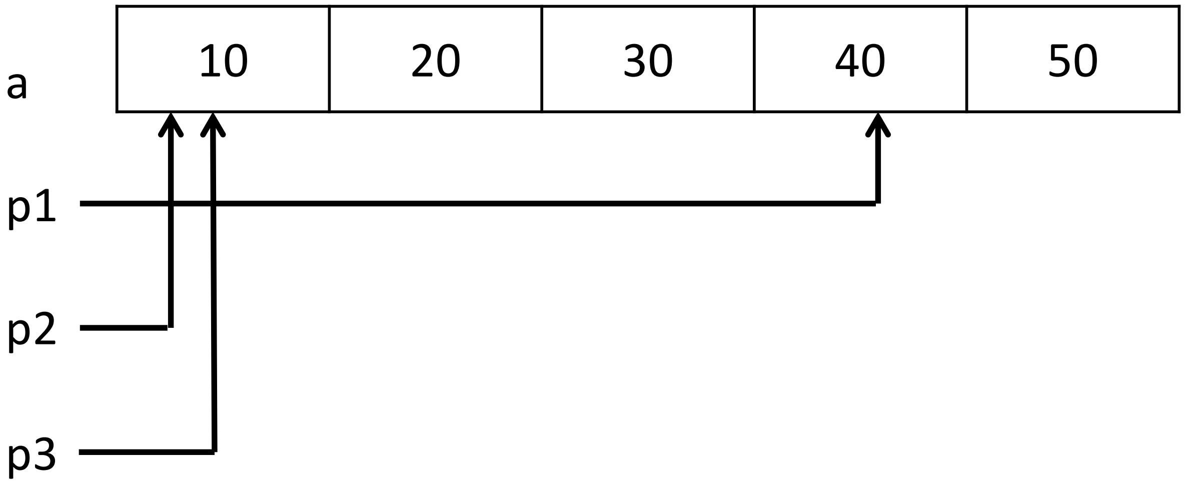
- Pointers & Pointer Arithmetic
- Pointers as Parameters
- **Pointers and Arrays**
- Function Pointers

Pointers and Arrays

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

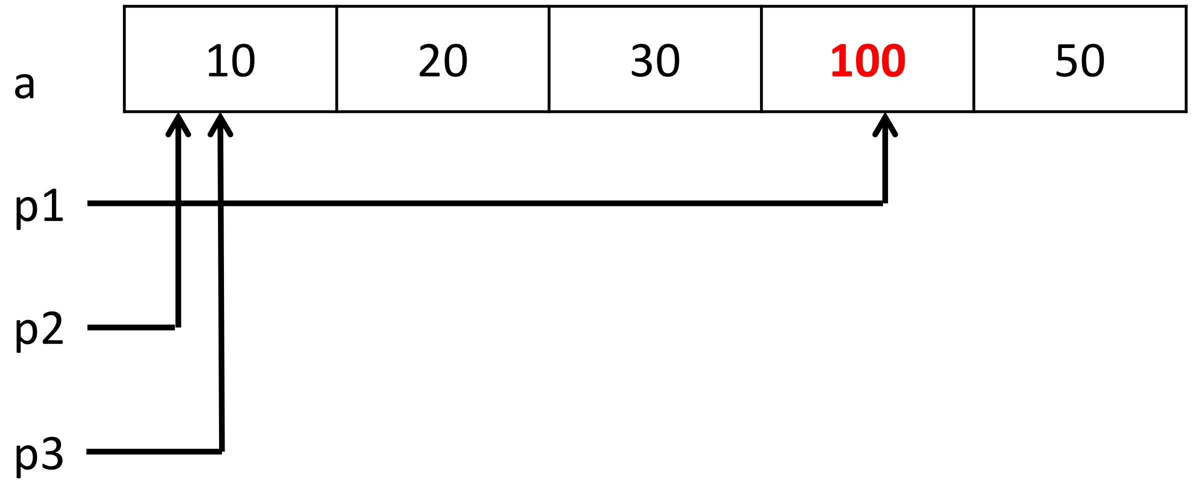
```
int a[] = {10, 20, 30, 40, 50};
int* p1 = &a[3];  // refers to a's 4th element
int* p2 = &a[0];  // refers to a's 1st element
int* p3 = a;      // refers to a's 1st element

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

Pointers and Arrays - Trace



```
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
```

Pointers and Arrays - Trace



```
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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;
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p1[1] = 300;
p2[1] = 400;
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```
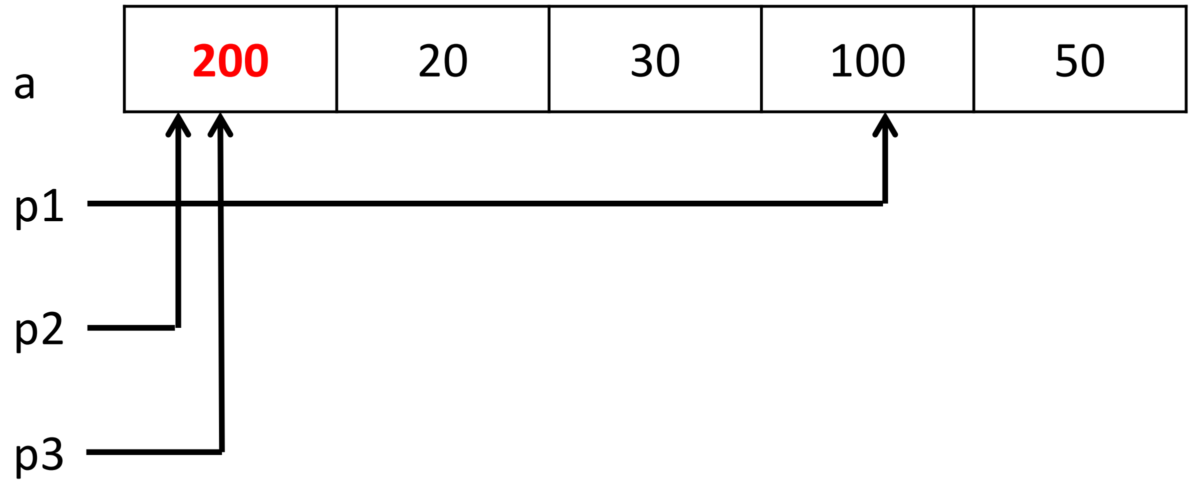

Pointers and Arrays - Trace



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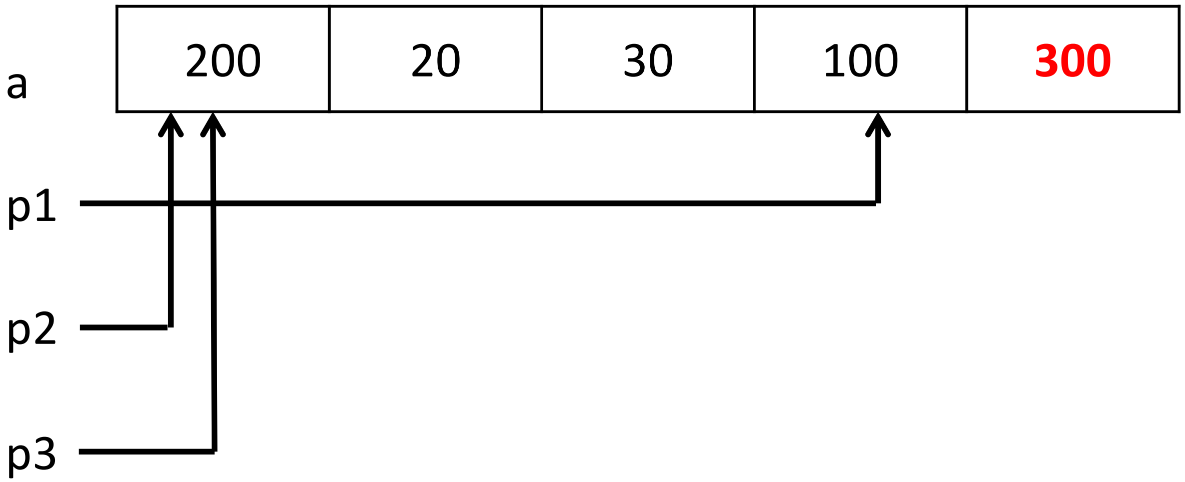
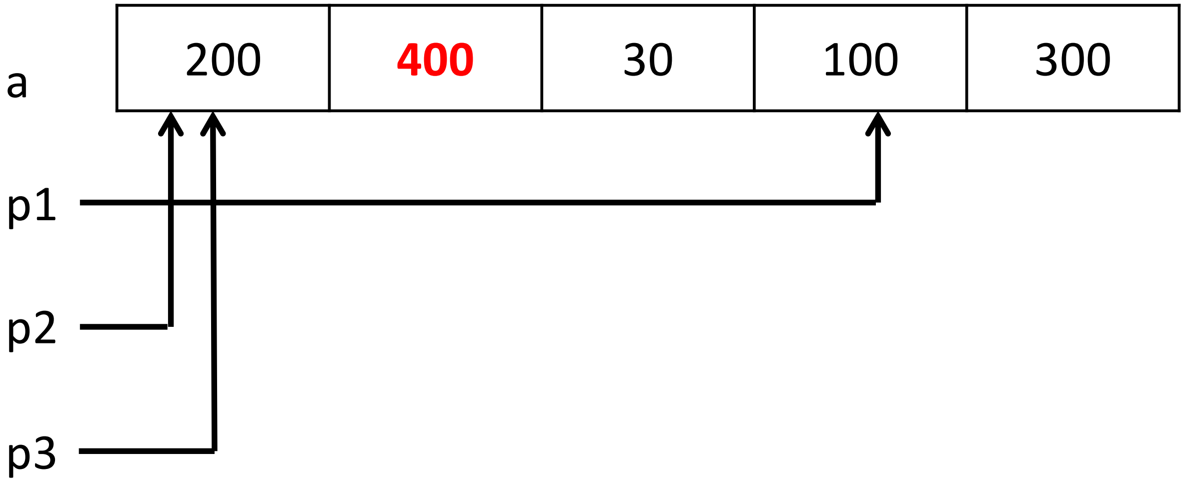

Pointers and Arrays - Trace



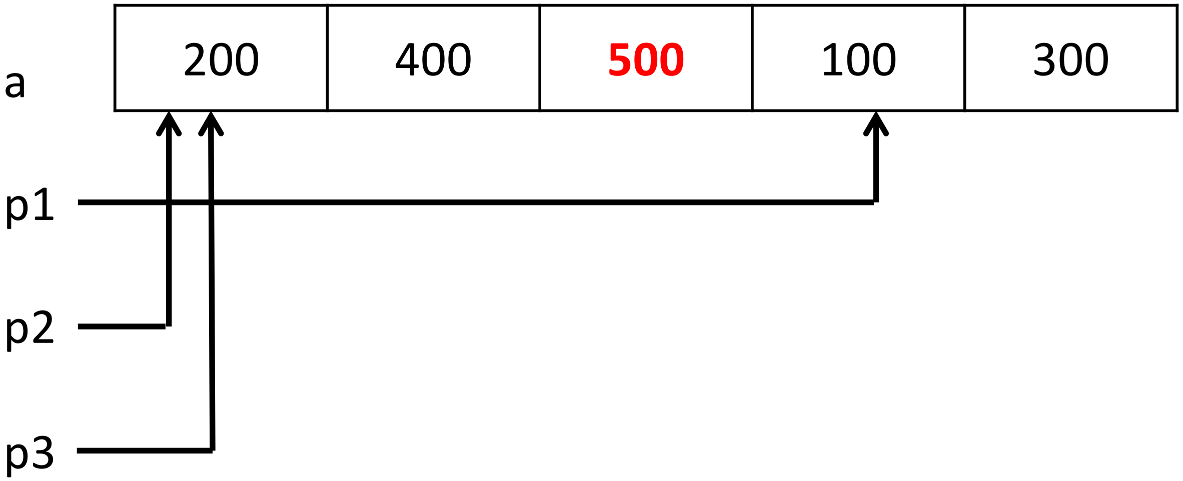
```
int a[] = {10, 20, 30, 40, 50};
int* p1 = &a[3];  // refers to a's 4th element
int* p2 = &a[0];  // refers to a's 1st element
int* p3 = a;      // refers to a's 1st element

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

Pointers and Arrays - Trace



```
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
```

Pointers and Arrays - Trace



```
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 (by value) as pointers to the first array element
  - The `[]` syntax for parameter types is just for convenience
    - OK to use whichever best helps the reader

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

- Based on what you know about assembly, what is a function name, really?
  - Can use pointers that store addresses of functions!

- Generic format:

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

  - Looks like a function prototype with extra `*` in front of name
  - Why are parentheses around `(* name)` needed?

- Using the function:

```
(*name)(arg1, …, argN)
```

  - Calls the pointed-to function with the given arguments and return the return value (but * is optional since all you can do is call it!)

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

Function Pointer Example

- C allows you to omit & on a function parameter and omit * when calling pointed-to function; both assumed implicitly.

```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};
  map(arr, LEN, square);
  ...
```

implicit funcptr dereference (no * needed)

no & needed for func ptr argument

Extra Exercise #1

- Use a box-and-arrow diagram for the following program and 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 EXIT_SUCCESS;
}
```

Extra Exercise #2

- Write a program that determines and prints out whether the computer it is running on is little-endian or big-endian.
  - Hint: `pointerarithmetic.c` from today's lecture or `show_bytes.c` from 351

Extra Exercise #3

- Write a function that:
  - Arguments: [1] an array of ints and [2] an array length
  - Malloc's an `int*` array of the same element length
  - Initializes each element of the newly-allocated array to point to the corresponding element of the passed-in array
  - Returns a pointer to the newly-allocated array

Extra Exercise #4

- Write a function that:
  - Accepts a function pointer and an integer as arguments
  - Invokes the pointed-to function with the integer as its argument