Pointers, Pointers, Pointers

CSE 333

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Nicholas Batchelder
Leanna Mi Nguyen

Administrivia (1)

- Exercise 2 out today!
  - Due Wednesday @ **10 am**
- Homework 0 due tonight @ **11 pm**
  - You should be pretty far along by now
  - Went over gitlab setup in sections on thursday

Administrivia (2)

- HW1 was pushed to repos on Friday
  - Linked list and hash table implementations in C
  - Download starter code using `git pull` in your course repo
    - Fine to do this before submitting hw0, just will have to deal with some basic merging
    - Might have "merge conflict" if your local repo has unpushed changes
      - If your changes are all in commits, default git merge handling will almost certainly do the right thing
      - To avoid, always do a `git pull` before any git commit or push
      - If you have **uncommitted** changes, do some research on git "stashes"
  - If you haven't already, start reading the assignment and looking at the code now!
    - For large projects, you want to pace yourself so if something baffling happens, you can let it go for the day and come back to it tomorrow

Administrivia (3)

- Exercise grading
  - Score is an overall evaluation: 3/2/1/0 = superior / good / marginal / not sufficient for credit
    - We expect lots of 2's and 3's at first, more 3's on later exercises
  - Scores are **NOT** proportional to grade: a 2 isn't 70%, it's pretty good.
  - Then additional ±0 rubric items as needed
    - These are a quick way of communicating "why" – reasons for deductions or comments about your solution
    - 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"

Lecture Outline

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

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)
- Valid pointer arithmetic:
  - Add/subtract an integer and a pointer
  - Subtract two pointers (within same stack frame or malloc block)
  - Compare pointers (<, <=, ==, !=, >, >=), including `NULL`
- Pointer arithmetic is scaled by `sizeof(*p)`
  - Works nicely for arrays
  - Does not work on `void*`, since `void` doesn't have a size!
    - Acts like unscaled integer arithmetic

Practice Solution

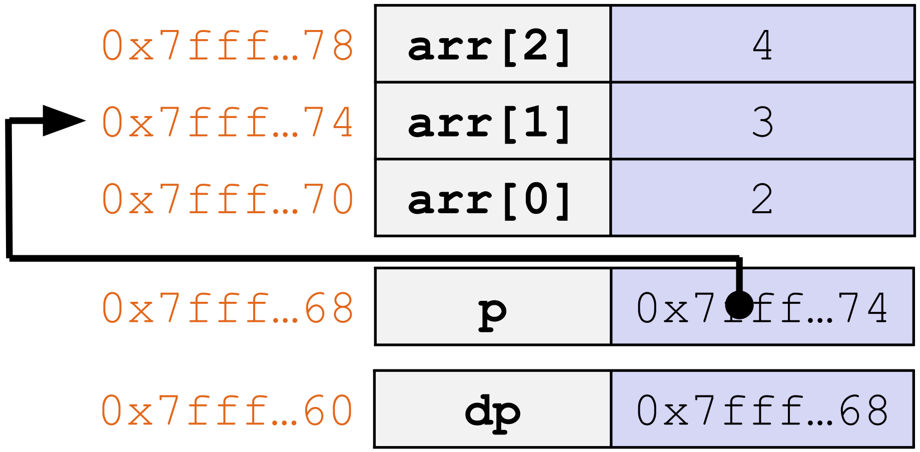
Note: arrow points to *next* instruction to be executed.

boxarrow2.c

```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;
}
```



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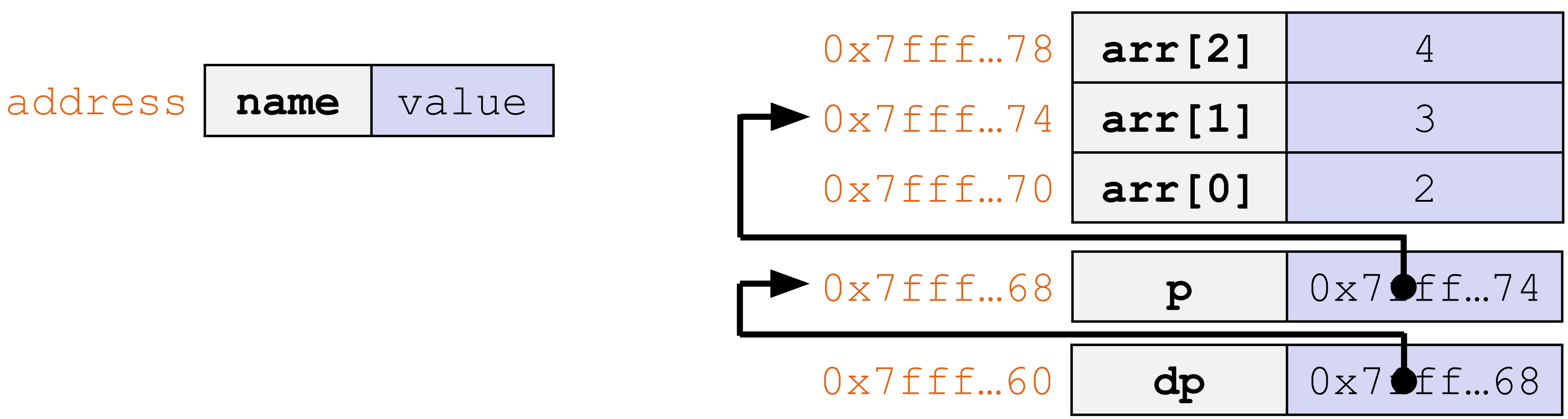

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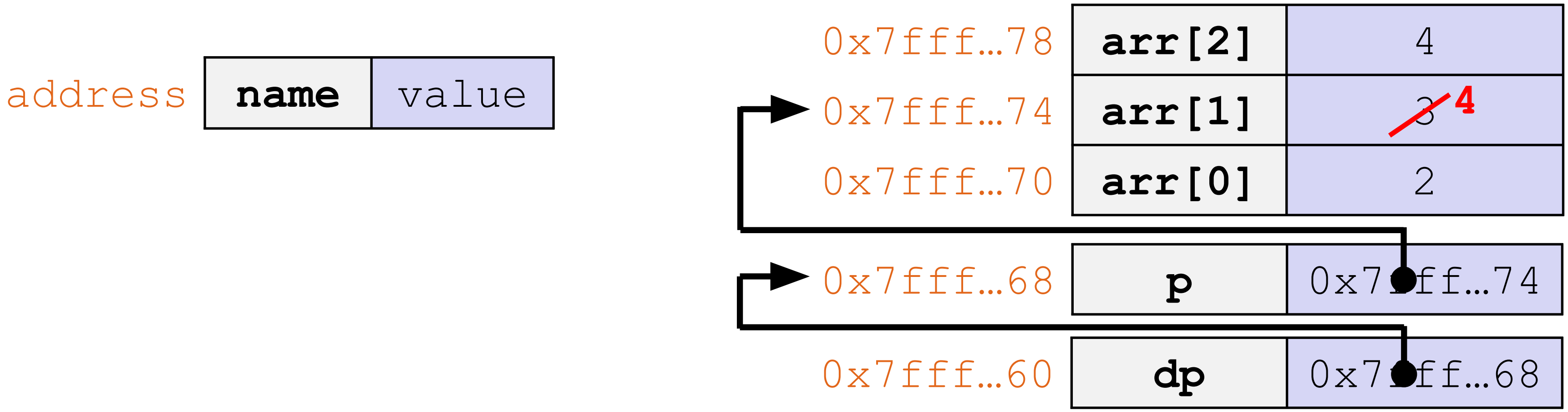

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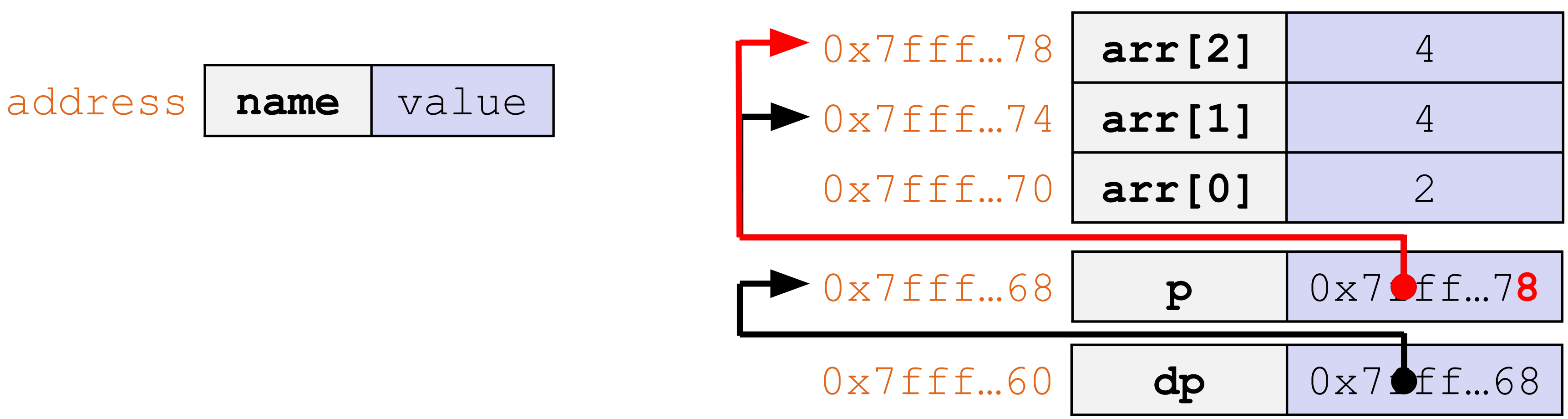

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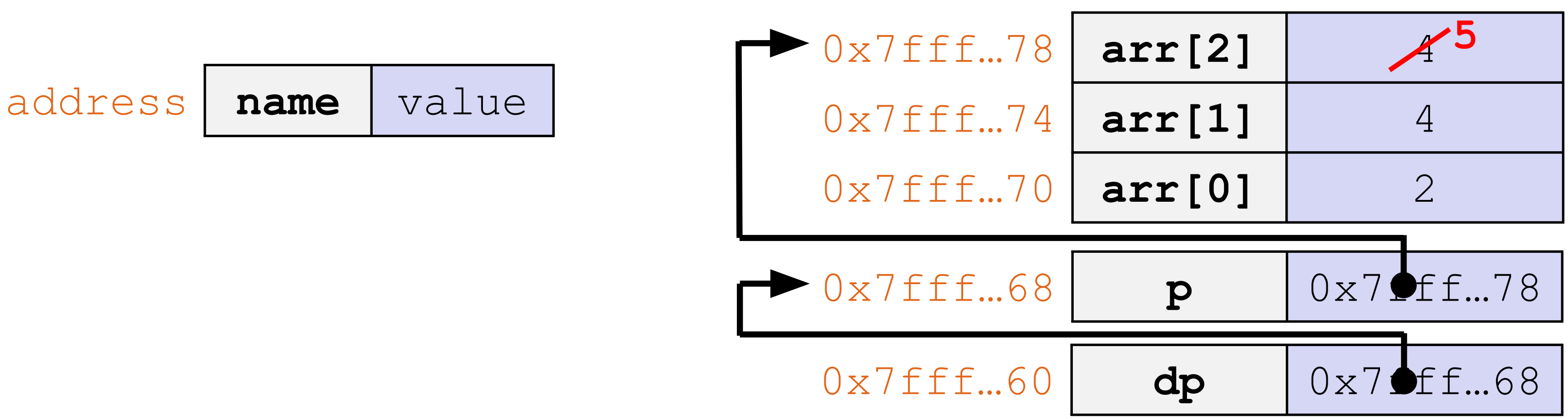

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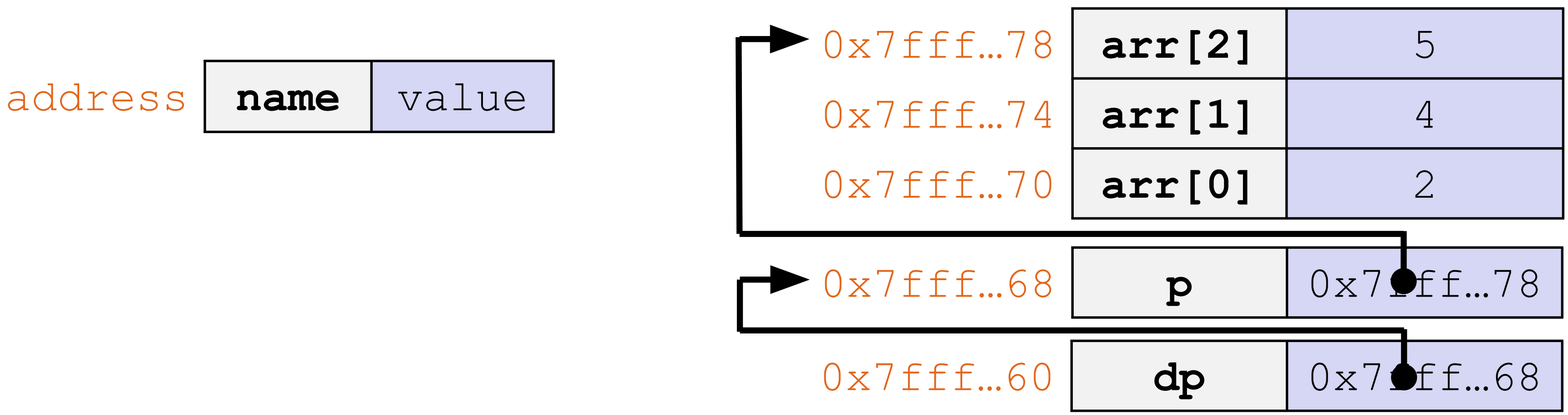
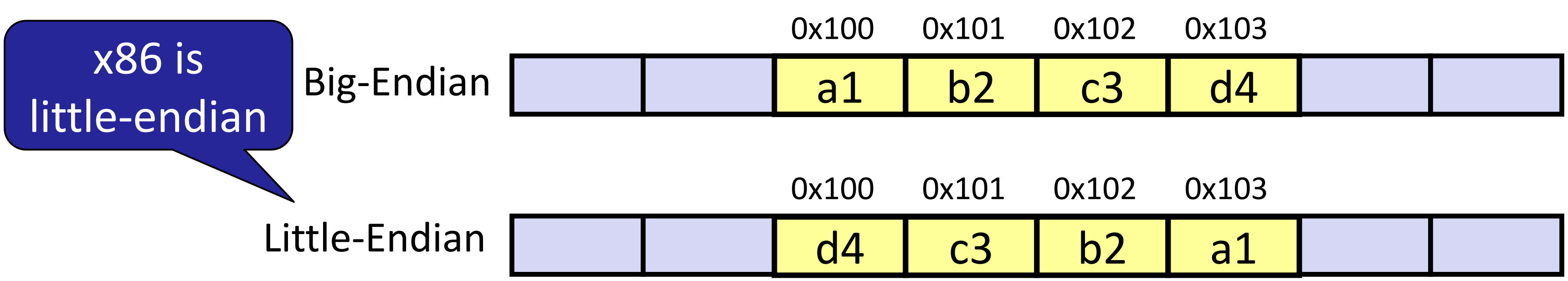


How are multi-byte values stored in memory?

- Memory is byte-addressed, so we need to determine how consecutive bytes combine into a single value
- Endianness determines what ordering that multi-byte data gets read and stored
  - Big-endian: Least significant byte has *highest* address
  - Little-endian: Least significant byte has *lowest* address
- **Example:** 4-byte data 0xa1b2c3d4 at address 0x100



Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

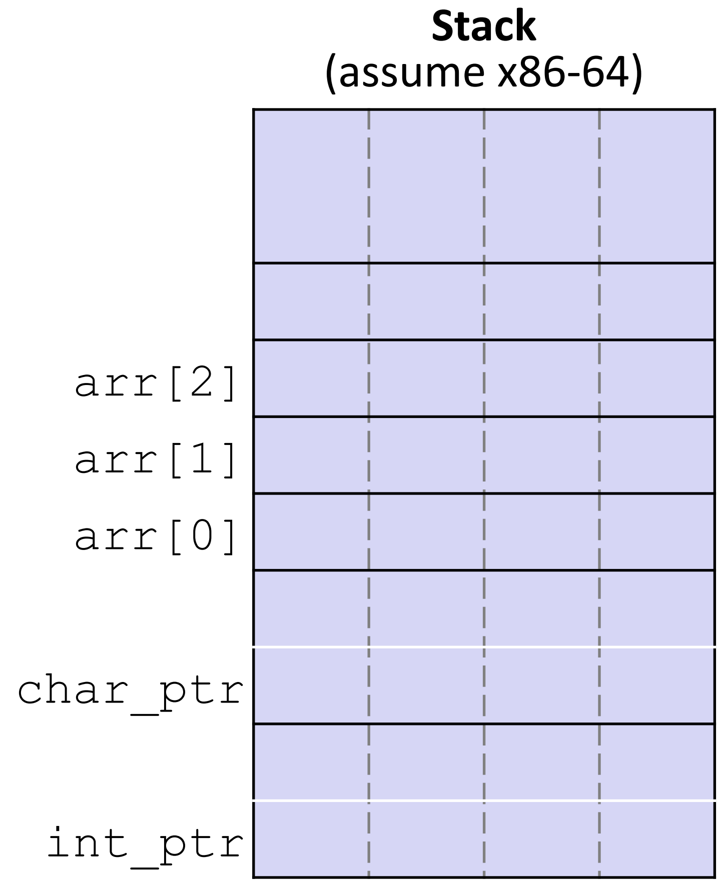
```
int main(int argc, char** argv) {
  int arr[3] = {1, 2, 3};
  int* int_ptr = &arr[0];
  char* char_ptr = (char*) int_ptr;

  int_ptr += 1;
  *int_ptr = 4;
  int_ptr += 2;

  char_ptr += 1;
  char_ptr += 3;

  return EXIT_SUCCESS;
}
```

pointerarithmetic.c



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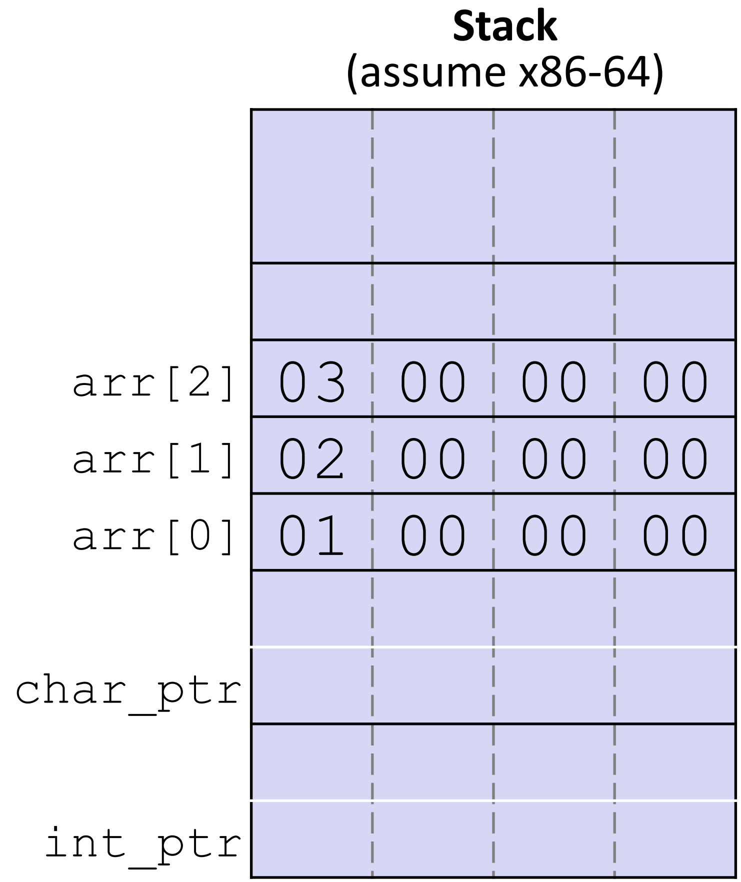

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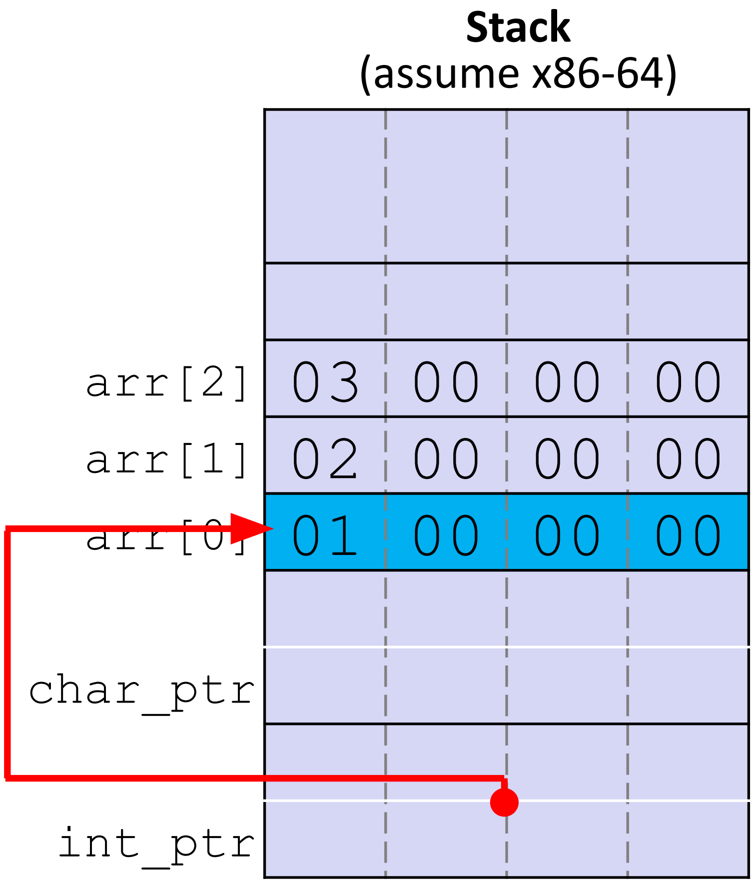
pointerarithmetic.c



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  int_ptr += 1;
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  int_ptr += 2;

  char_ptr += 1;
  char_ptr += 3;

  return EXIT_SUCCESS;
}
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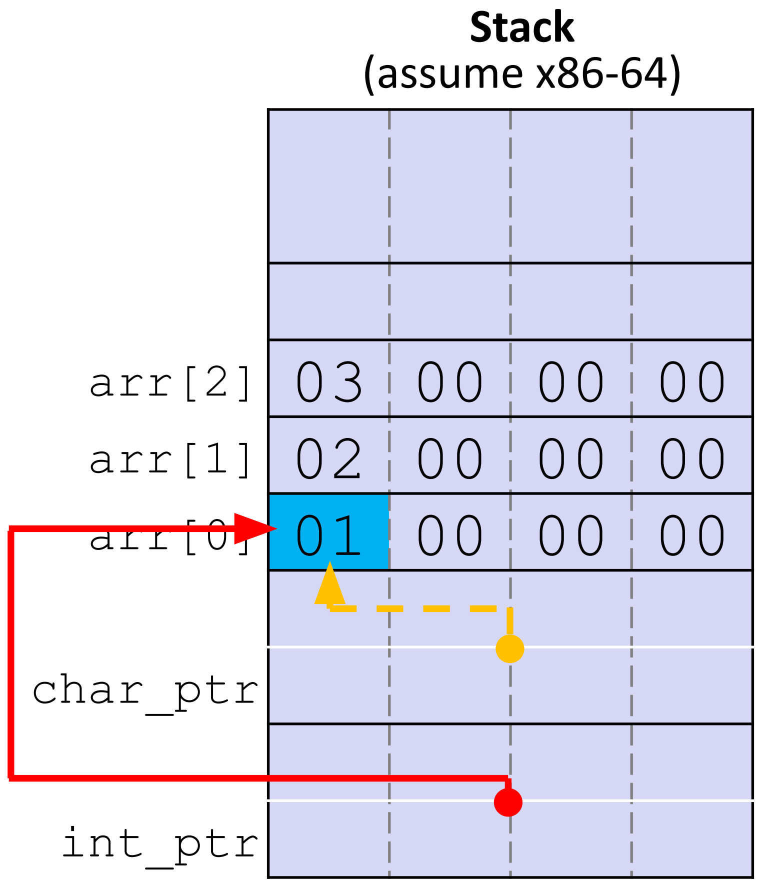
pointerarithmetic.c



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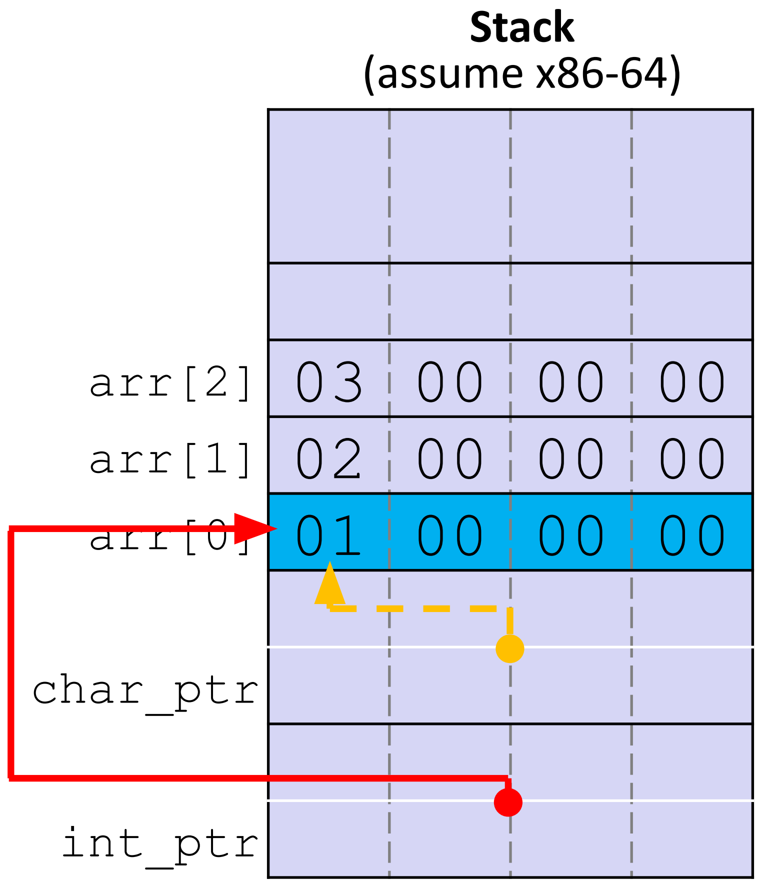
pointerarithmetic.c



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

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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  int arr[3] = {1, 2, 3};
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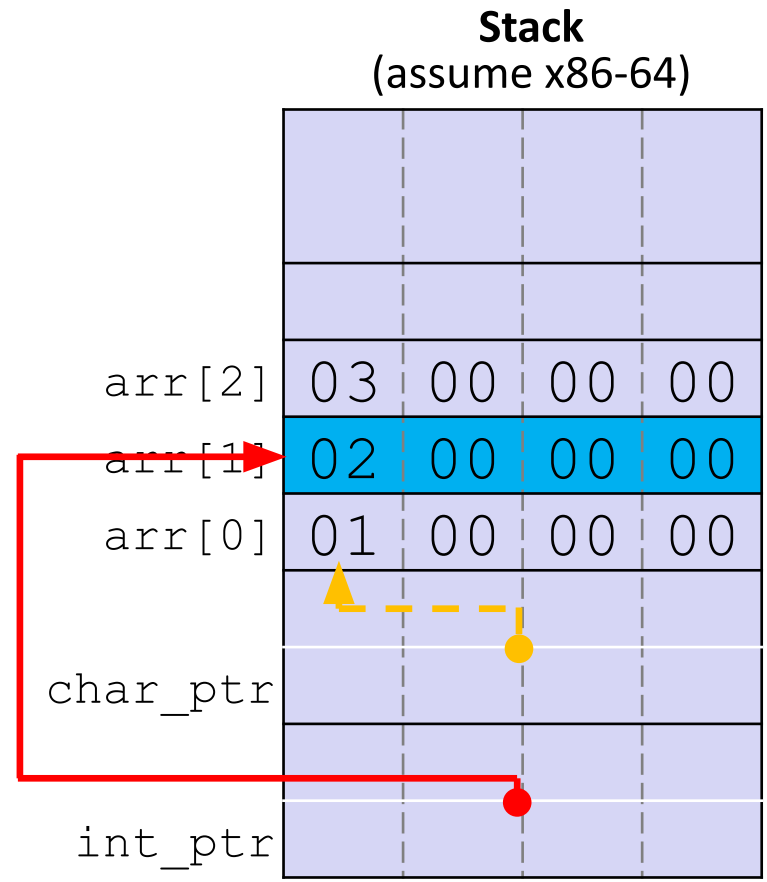
}
```

pointerarithmetic.c

int_ptr: 0x0x7ffffffde014

***int_ptr:** 2



Pointer Arithmetic Example

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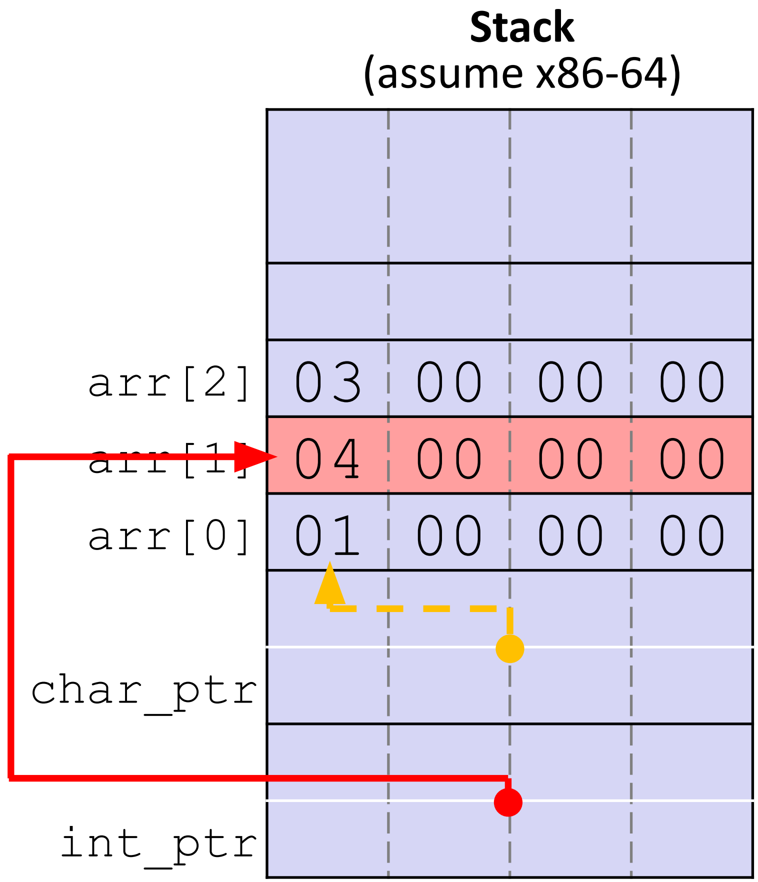
  *int_ptr = 4;
  int_ptr += 2;

  char_ptr += 1;
  char_ptr += 3;

  return EXIT_SUCCESS;
}
```

pointerarithmetic.c

int_ptr: 0x0x7ffffffde014
***int_ptr:** 4



Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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  int arr[3] = {1, 2, 3};
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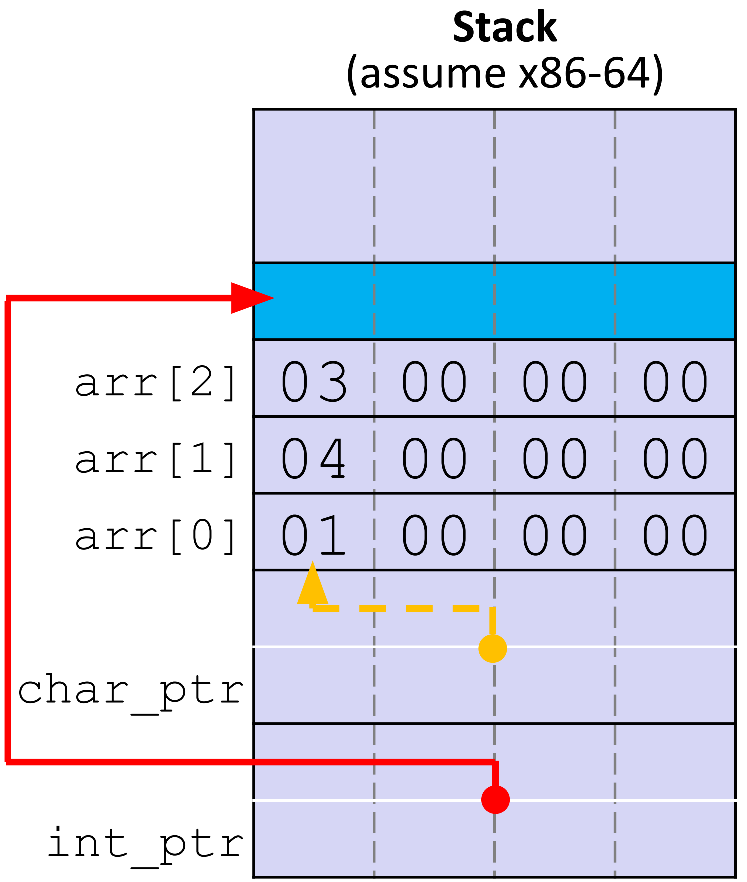
  int_ptr += 1;
  *int_ptr = 4;
  int_ptr += 2;   // uh oh

  char_ptr += 1;
  char_ptr += 3;

  return EXIT_SUCCESS;
}
```

pointerarithmetic.c

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



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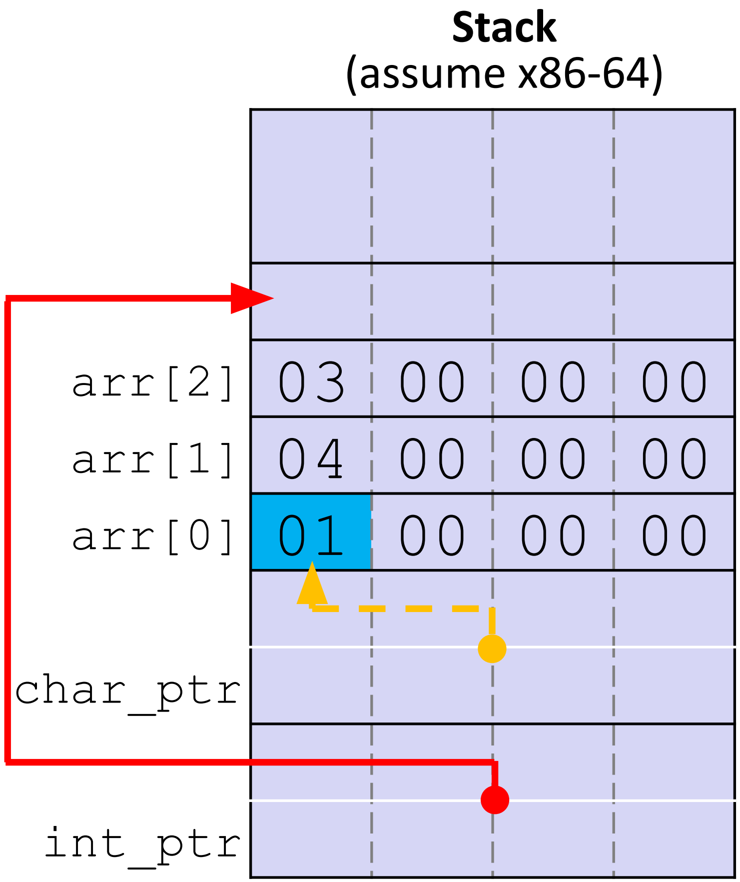
pointerarithmetic.c



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

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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

  int_ptr += 1;
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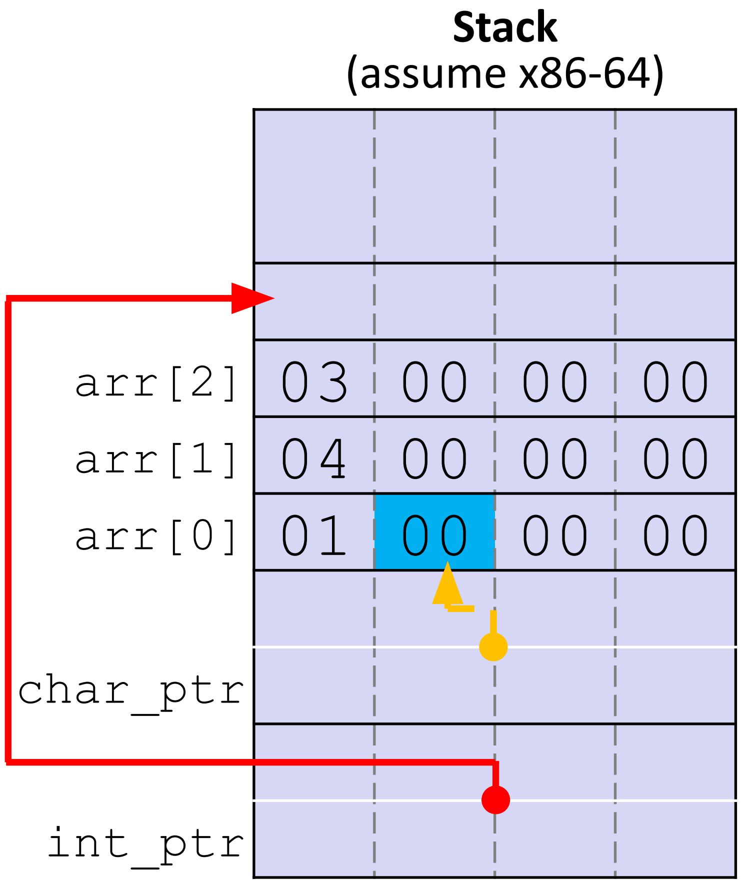
pointerarithmetic.c




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

Pointer Arithmetic Example

Note: Arrow points to *next* instruction.

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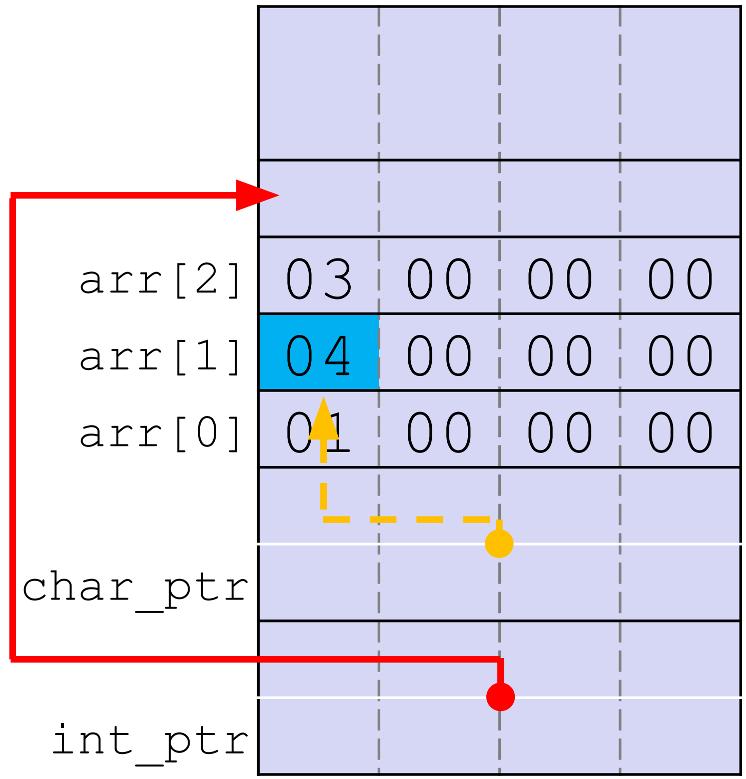
pointerarithmetic.c

char_ptr: 0x0x7fffffde014

***char_ptr:** 4

Stack
(assume x86-64)



- This code does not swap its parameter values – why?

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);
  ...
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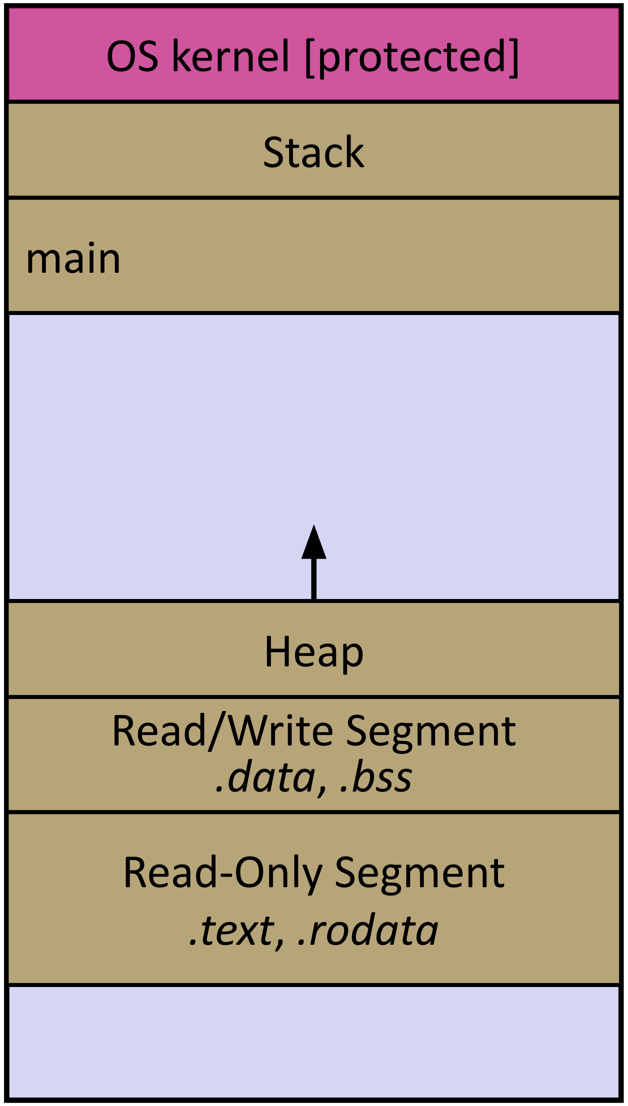

C parameters are Call-By-Value

- 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

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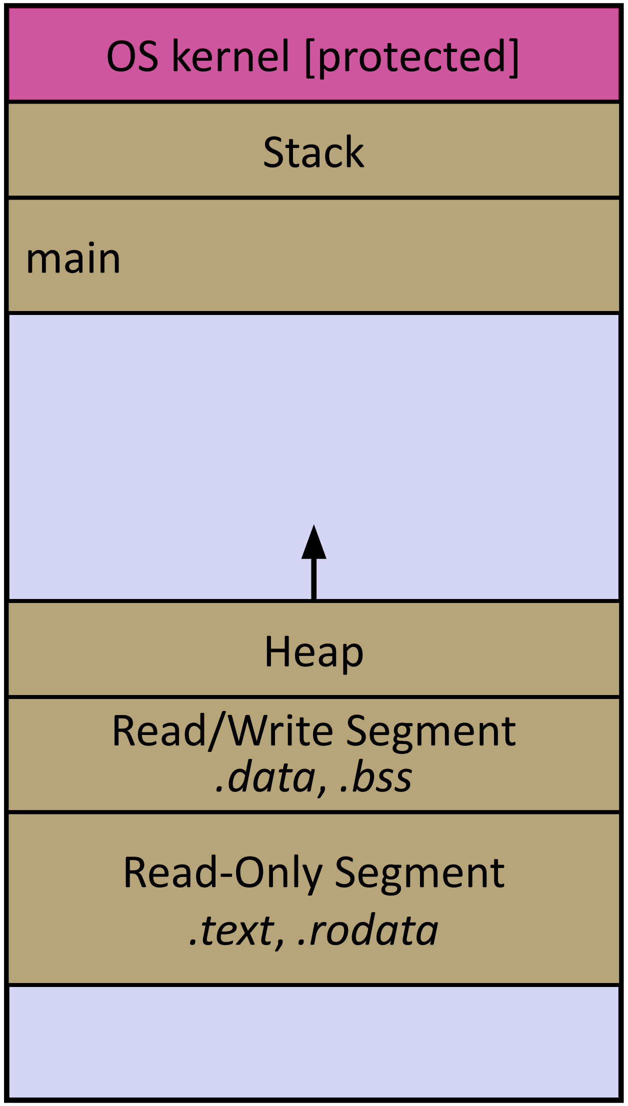

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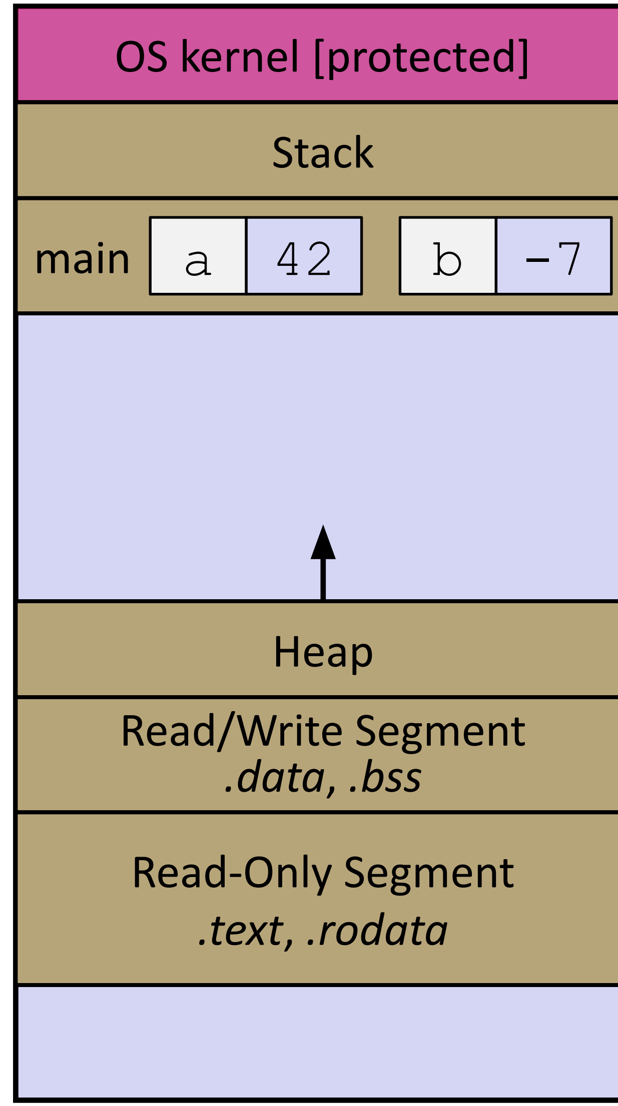

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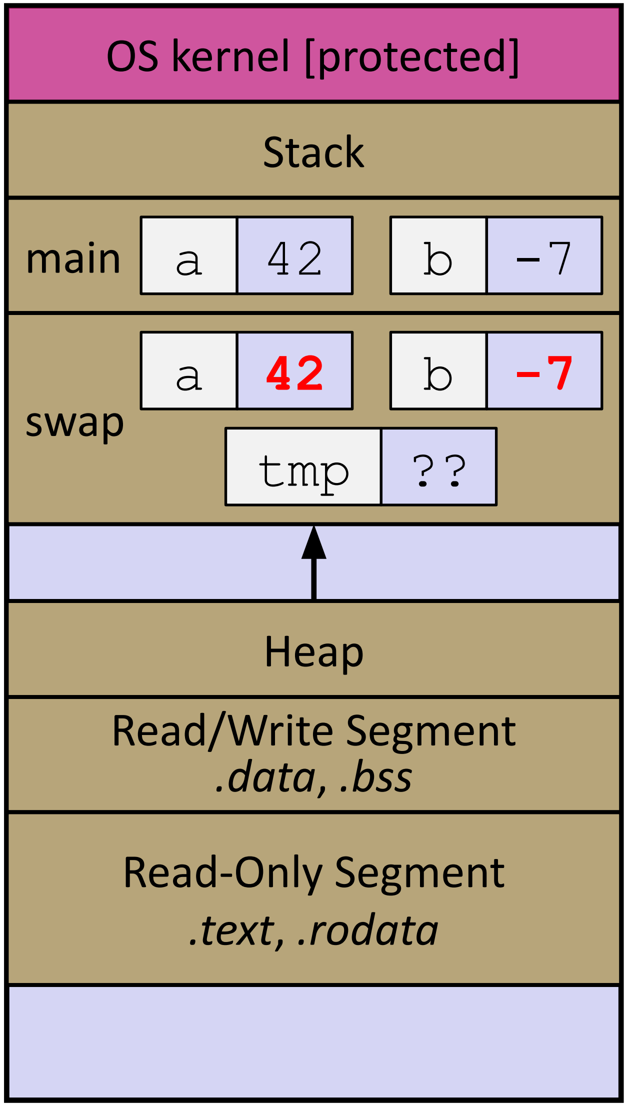

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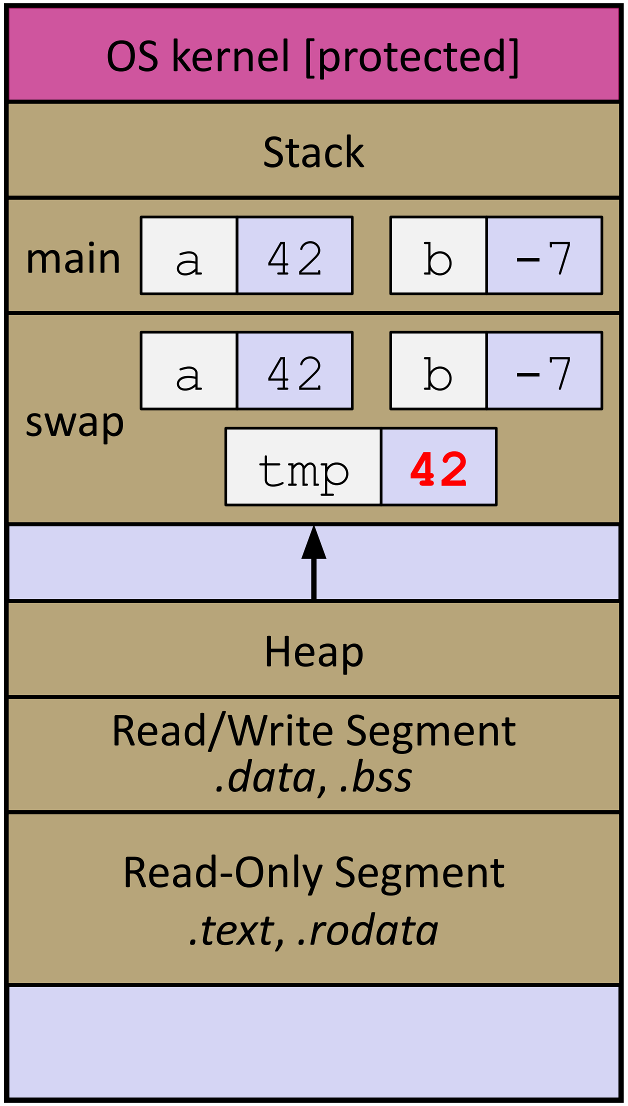

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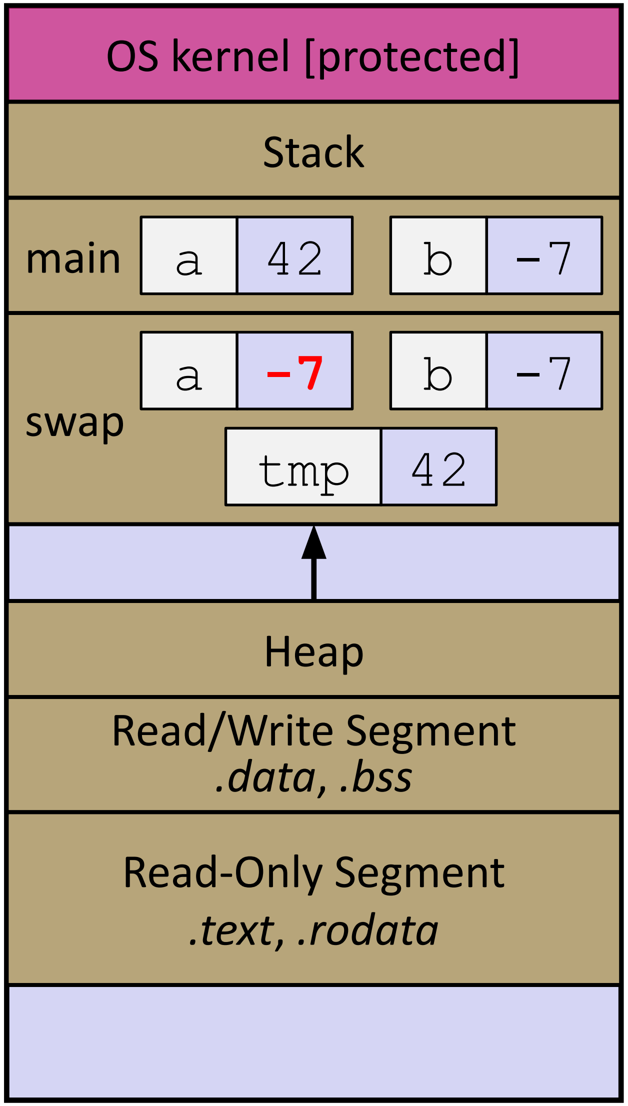

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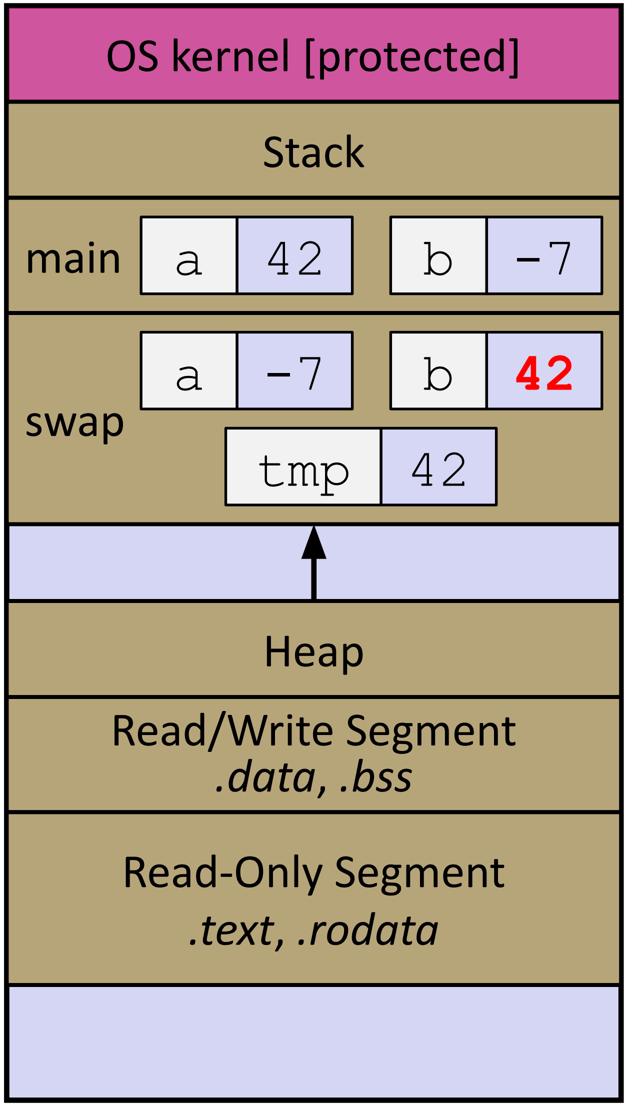

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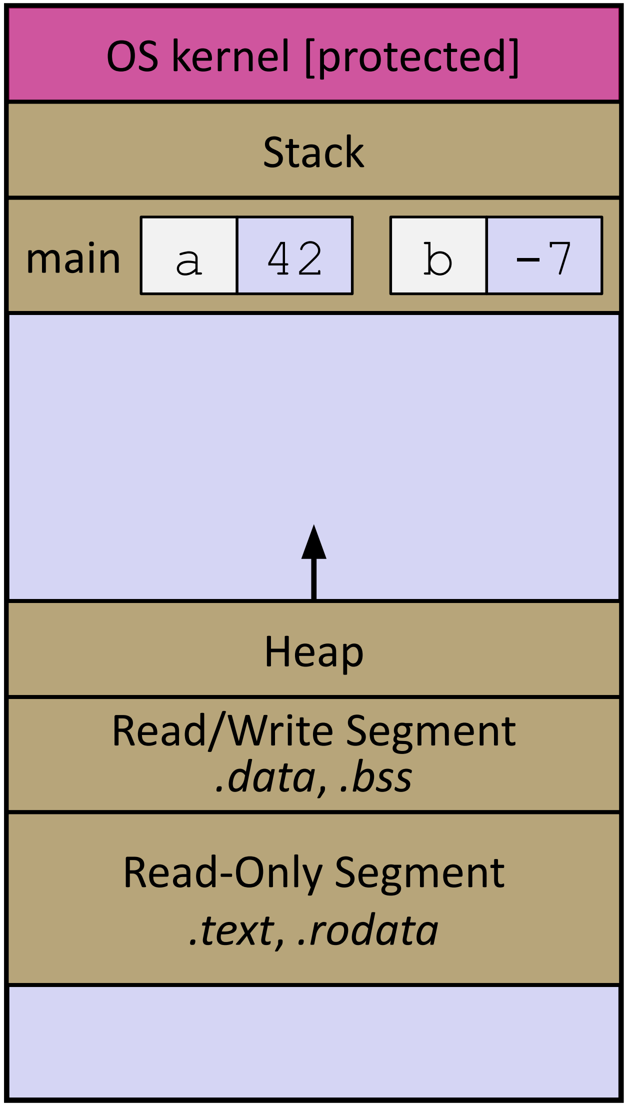

Faking Call-By-Reference in C

- 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

```
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;
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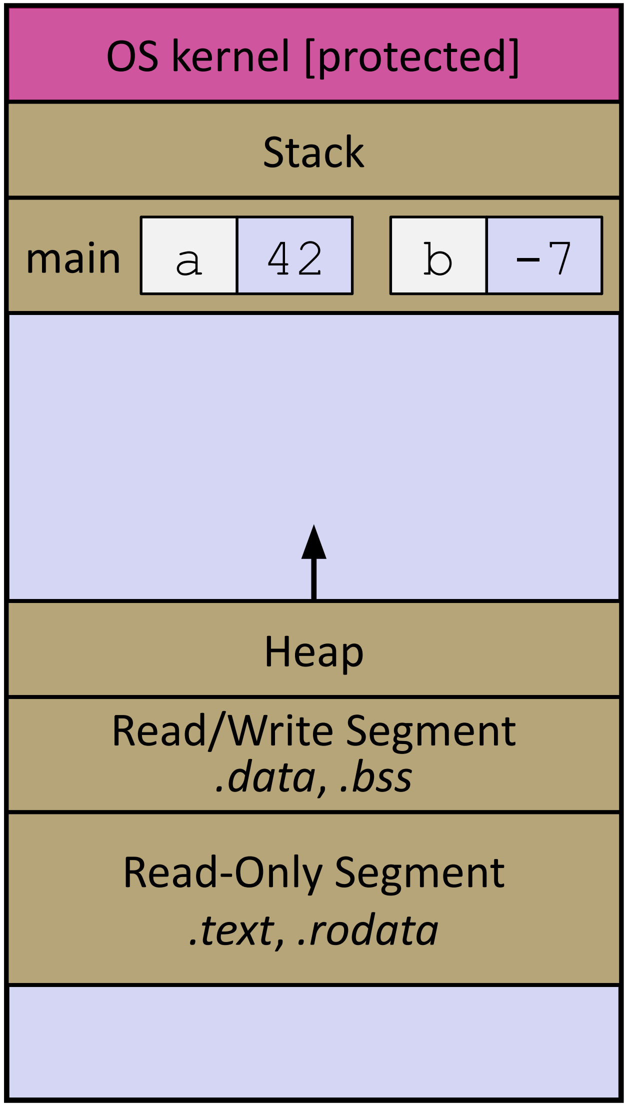

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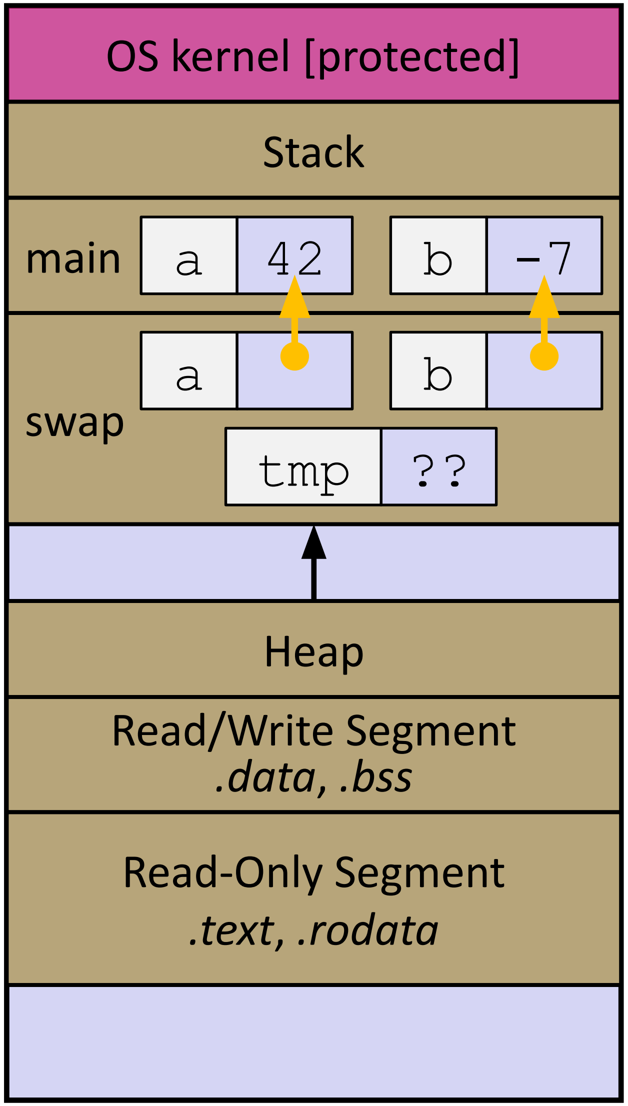

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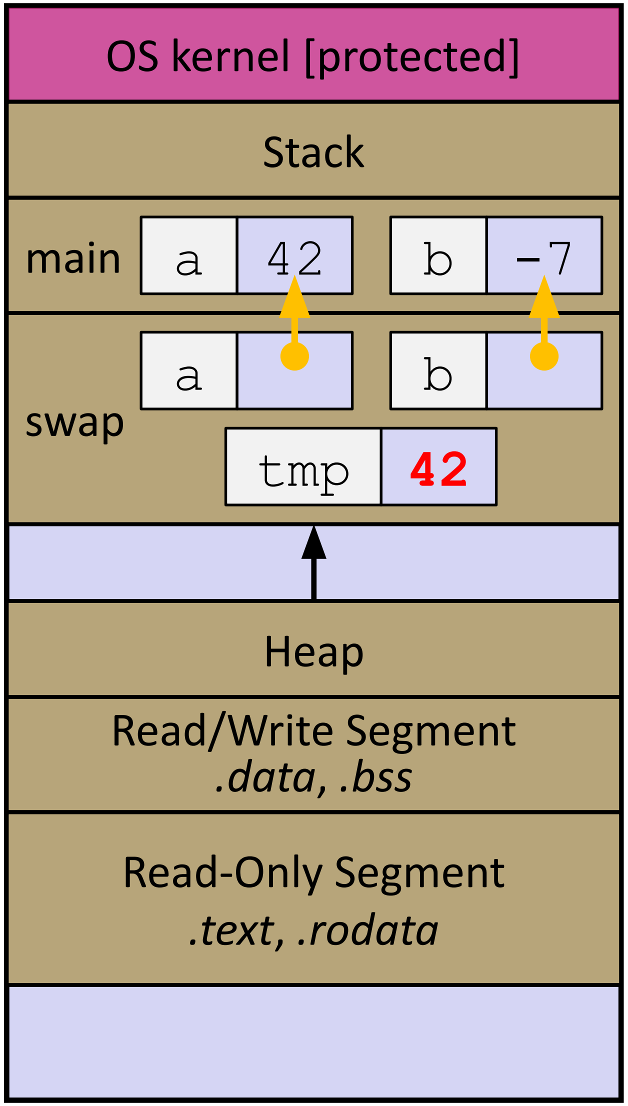
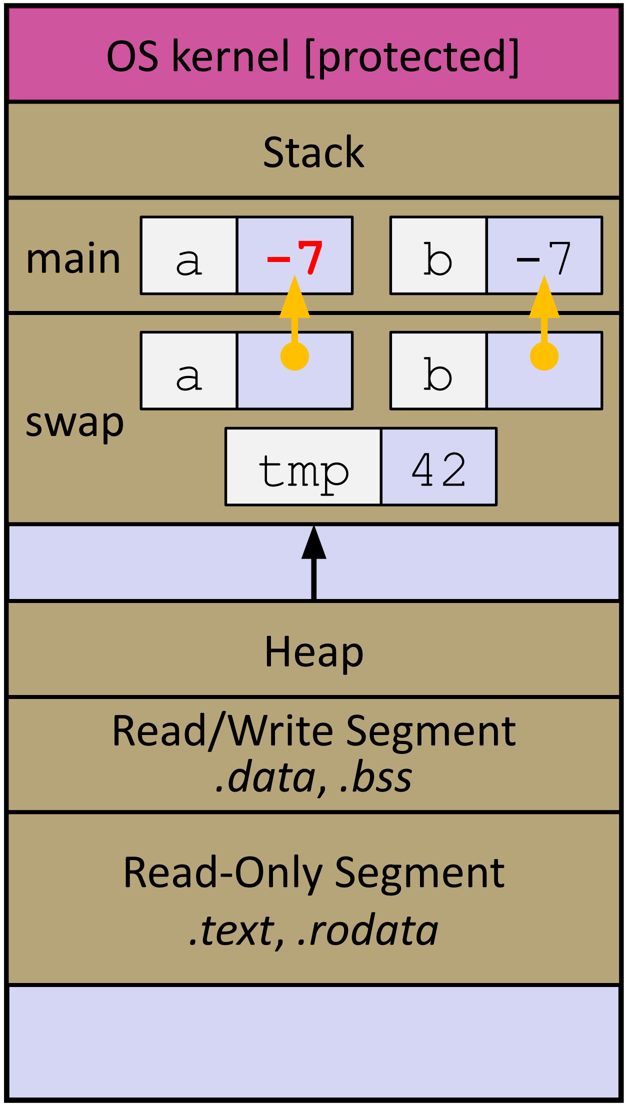


Fixed Swap



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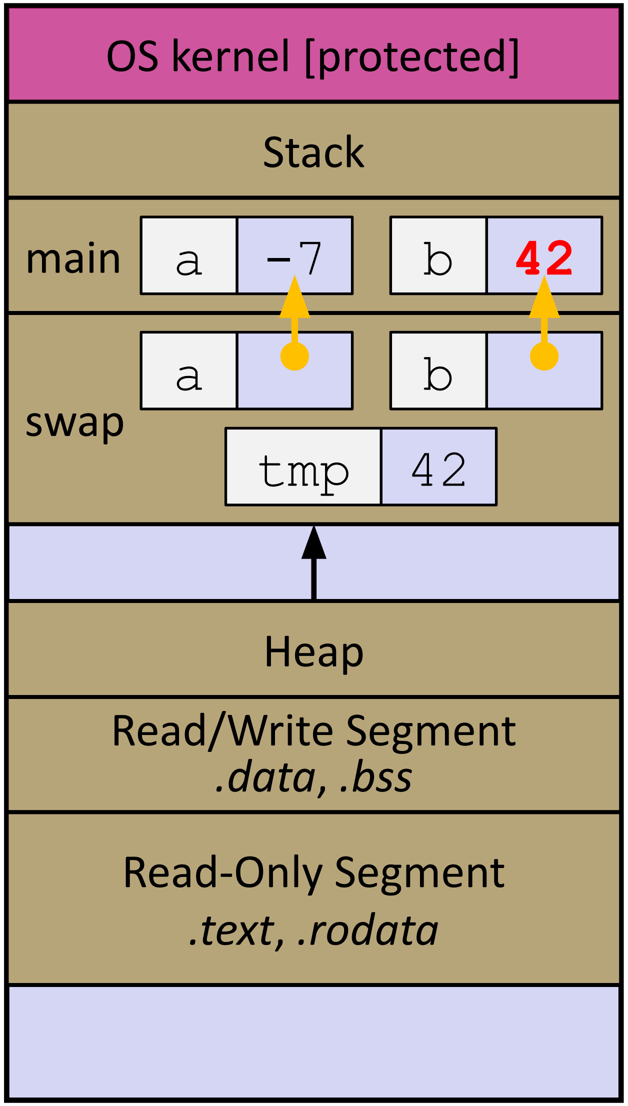
  ...
```

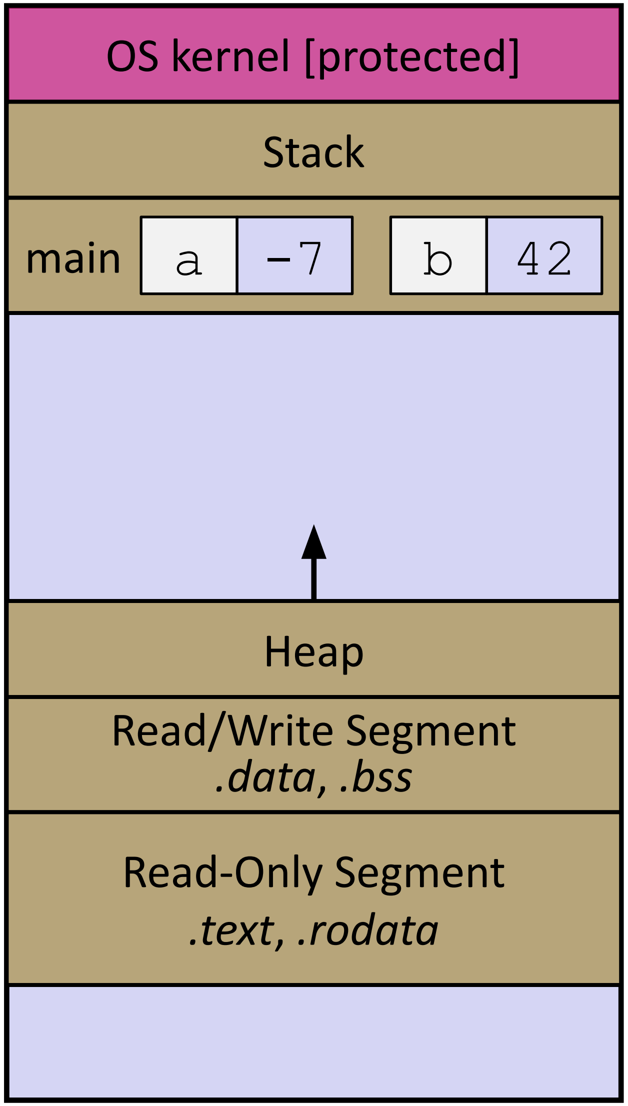


Fixed Swap

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);
  ...
```



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 return arrays, or 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
- Heap-allocated Memory
  - `malloc()` and `free()`
  - Memory leaks
- `struct`s and `typedef`

Pointers and Arrays

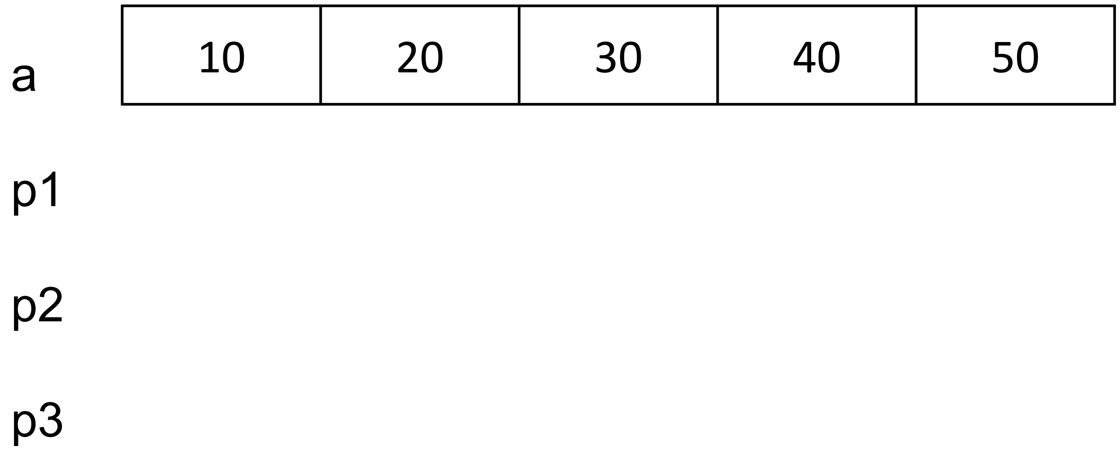
- A pointer can point to an array element
  - You can use array indexing notation on **all** pointers
    - `ptr[i]` is the same as `*(ptr+i)` - reference the data `i` elements forward from `ptr`
  - An array name's value is the beginning address of the array
    - Like a pointer to the first element of array

```
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;
```

Pointers and Arrays: Trace

Note: Arrow points to *next* instruction.

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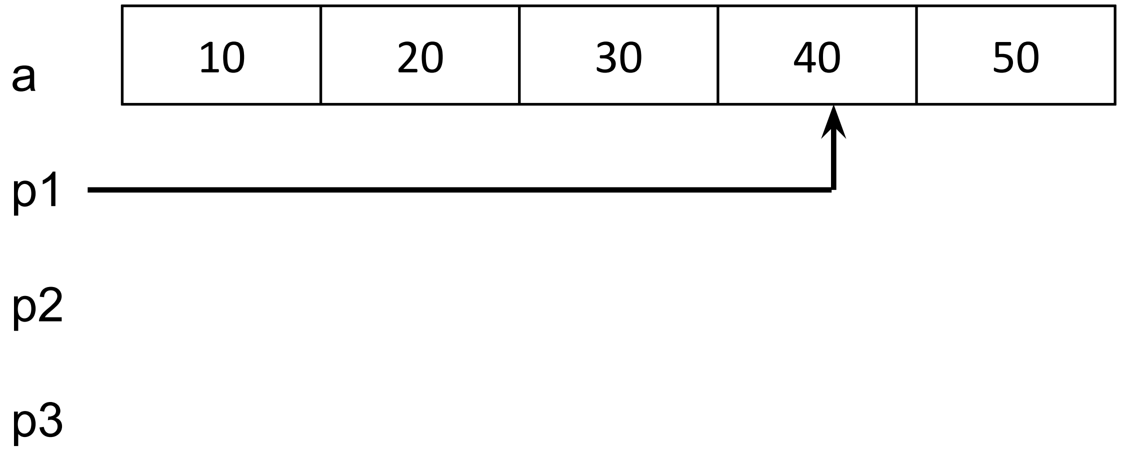


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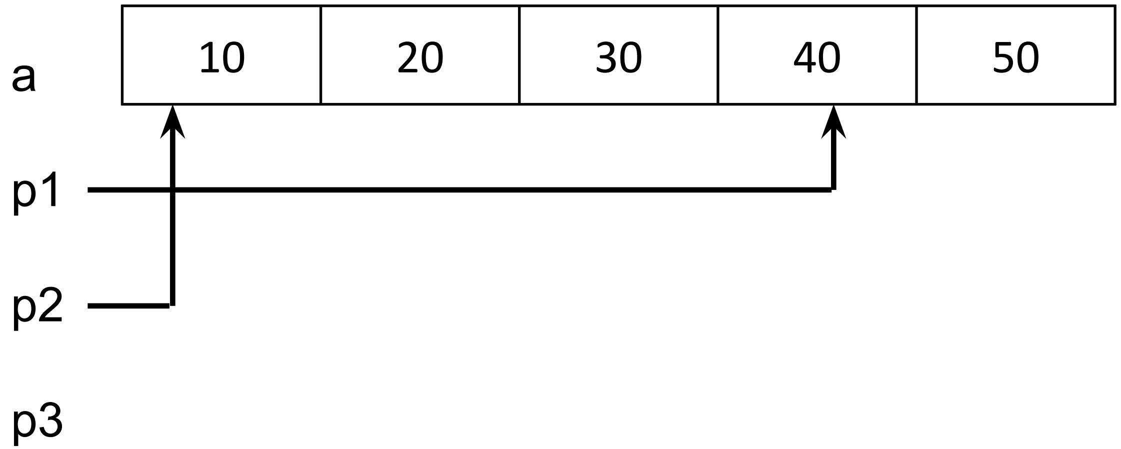


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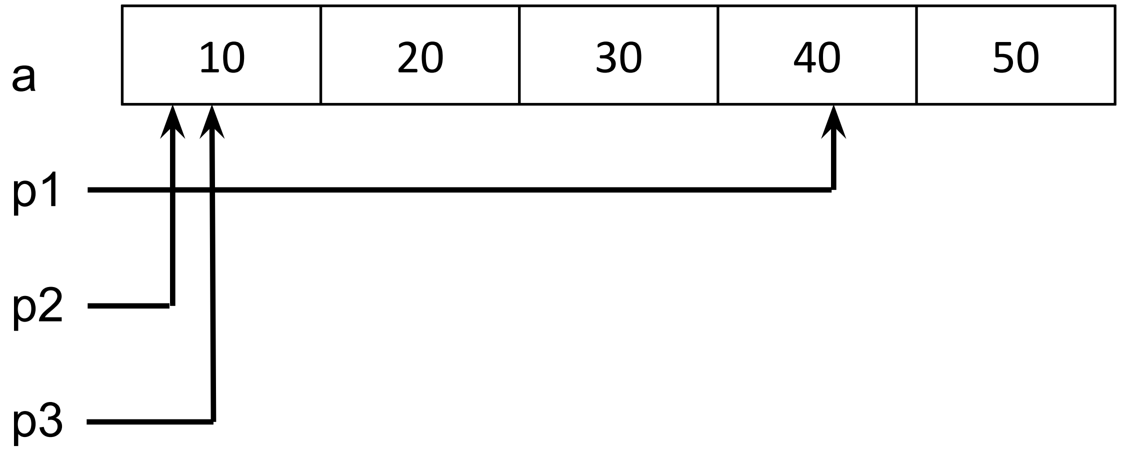


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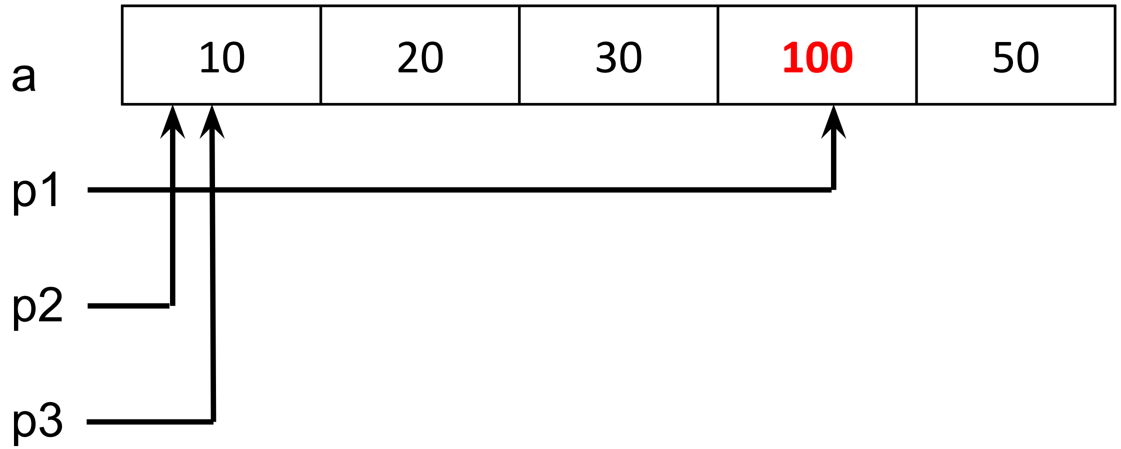


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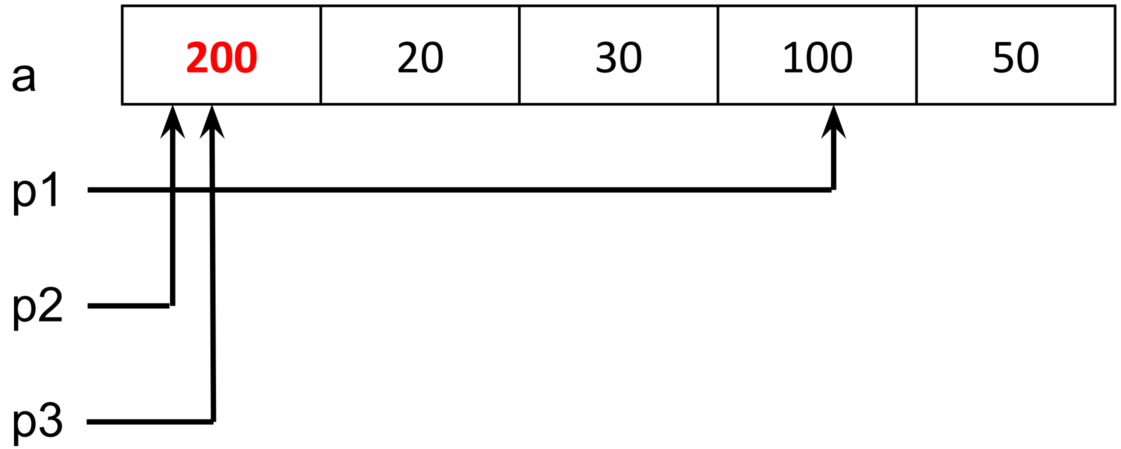


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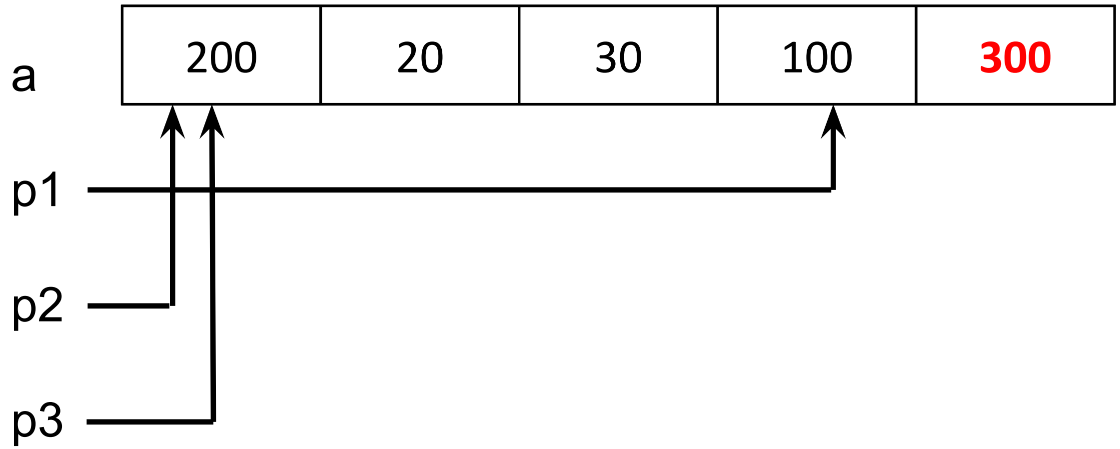


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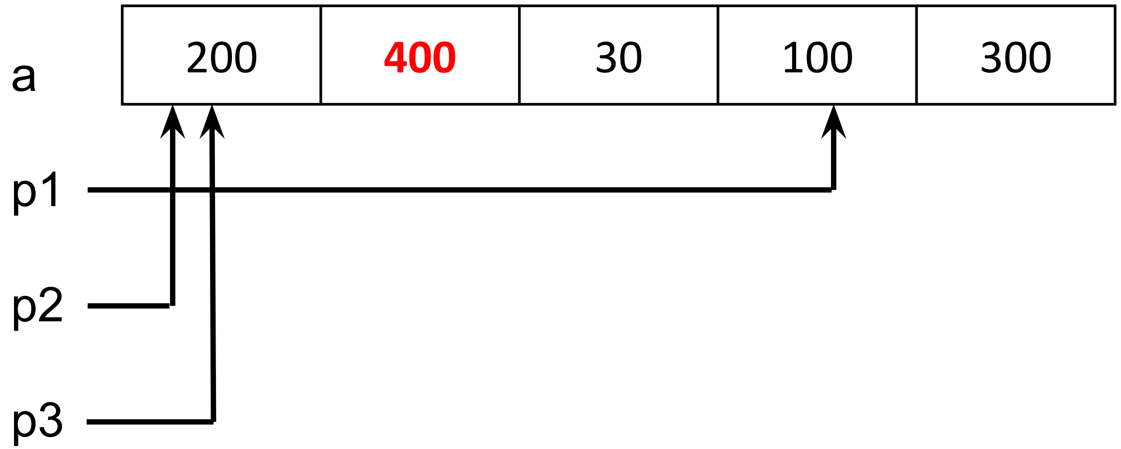


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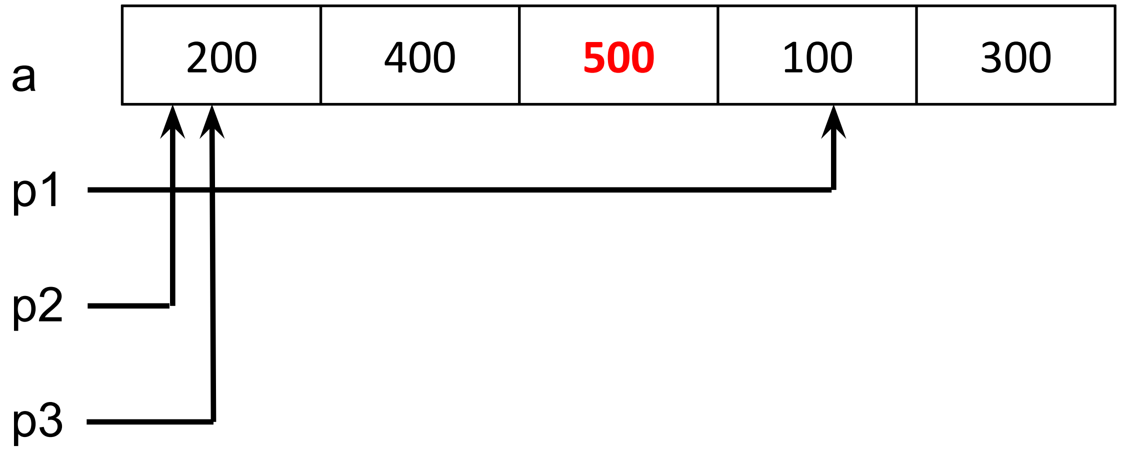


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int* p1 = &a[3];  // refers to a's 4th element
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int* p3 = a;      // refers to a's 1st element

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

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**
- Heap-allocated Memory
  - `malloc()` and `free()`
  - Memory leaks
- `struct`s and `typedef`

Function Pointers

- Based on what you know about assembly, what is a function name, really?
  - Just an address of code!
  - 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 (* map_op)(int n)) {
  for (int i = 0; i < len; i++) {
    a[i] = (*map_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 declaration

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

That's it! Don't forget:

- Exercise 2 out today, due Wednesday @ **10 am**
- Homework 0 due tonight @ **11 pm**
- Homework 1 out now, due next week.
  - Get started now, so there's lots of time to ask questions and get help!

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