C Data, Parameters

CSE 333 Spring 2023

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Relevant Course Information

- Exercise 1 due Friday morning, 11:00 am
  - Submission via Gradescope (contact us if you don't have access)
  - Make sure that you are testing on the CSE Linux environment
  - Sample solution will be posted Friday afternoon

- Homework 0 due Monday night, 11:59 pm *(complete individually)*
  - Logistics and infrastructure for projects
    - `cpplint` and `valgrind` are useful for exercises, too
  - You need to set up an SSH key and clone GitLab repo
    - Do this *before* section on Thursday
  - We will submit to Gradescope from your repo for you

Poll Everywhere

pollev.com/cse333sp

Which of the following statements is FALSE?

A. With the standard `main` syntax, it is always safe to use `argv[0]` ← will be the name of the executable

[✓ B. Your program's returned status code is unimportant]

C. Using function declarations is beneficial to both single- and multi-file C programs

single : flexible ordering of functions
multi : use definitions in other files

D. Defined error constants need to be looked up in function documentation, man pages, or header files like errno.h

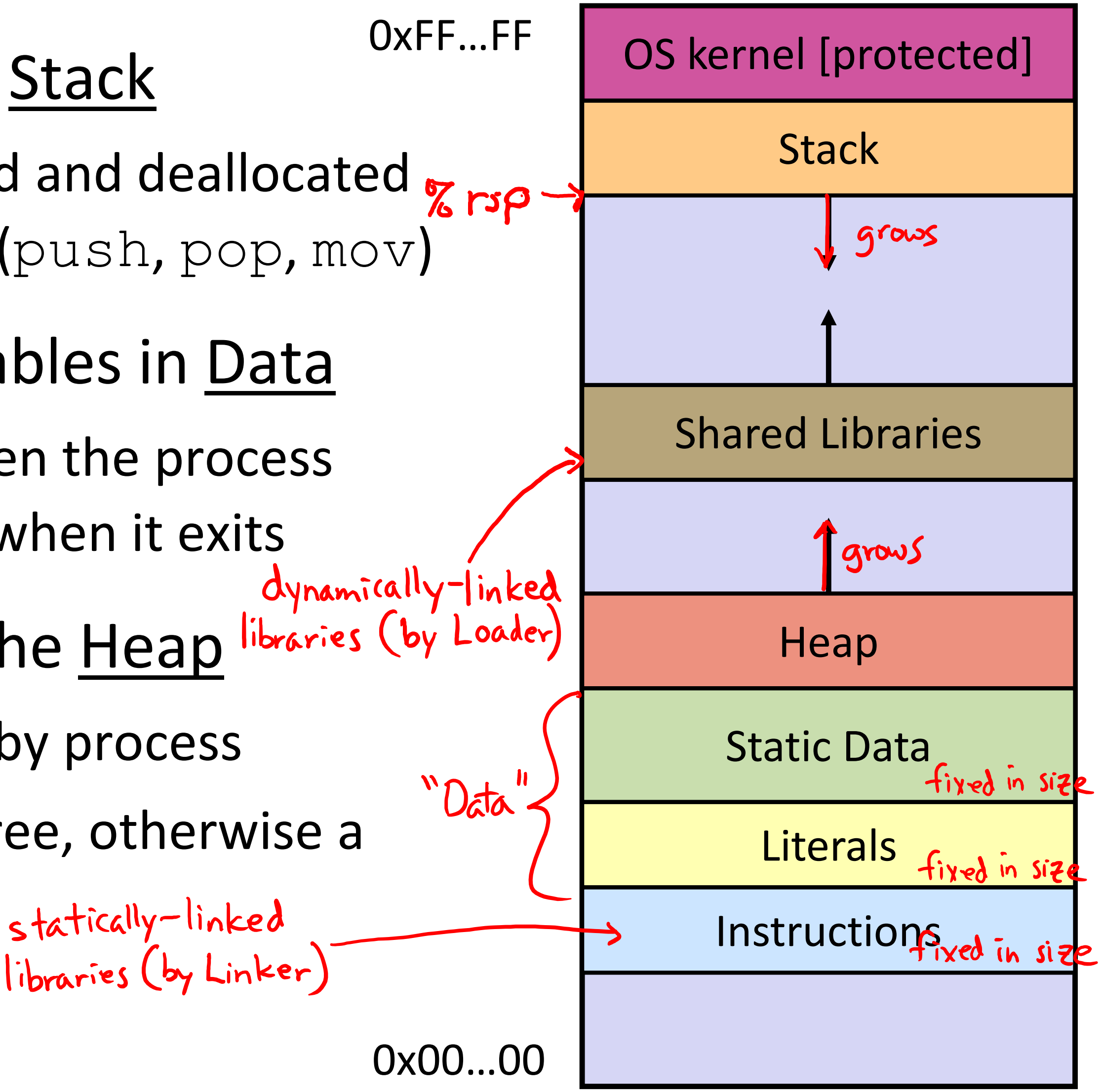
E. We're lost…

Lecture Outline

- **C Data Considerations**
  - **Memory**
  - **Arrays and Pointers Review**
- C Parameters
  - Arrays and Pointers as Parameters

Memory Management

- *Local* variables on the Stack
  - **Automatically-**allocated and deallocated via calling conventions (`push`, `pop`, `mov`)
- *Global* and *static* variables in Data
  - **Statically-**allocated when the process starts and deallocated when it exits
- `malloc`-ed data on the Heap
  - **Dynamically-**allocated by process
  - Must call `free()` to free, otherwise a memory leak

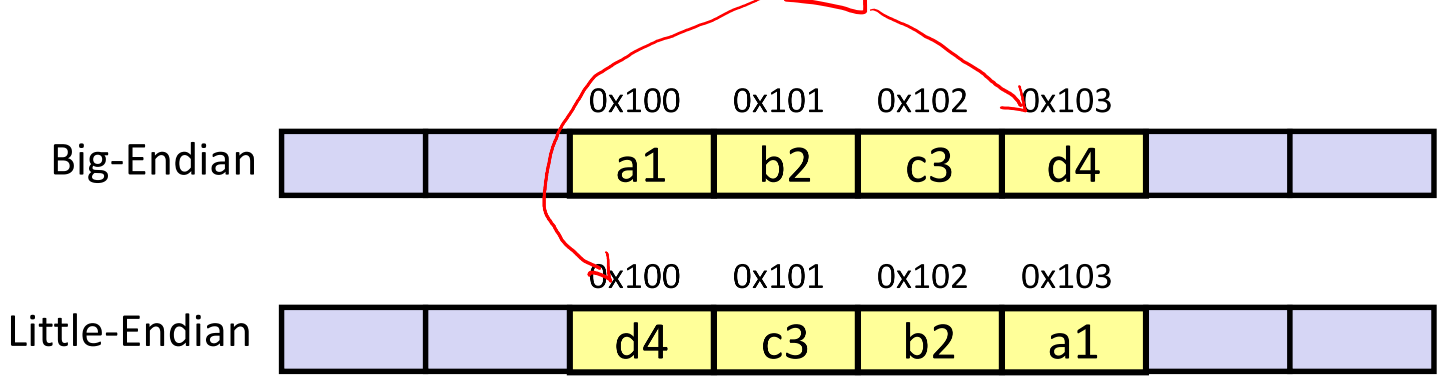


Endianness

- 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

Pointers

- Variables that store addresses
  - It points to somewhere in the process' virtual address space
  - `&foo` produces the virtual address of `foo`

equivalent, just be consistent

- Generic definition: `type* name;` or `type *name;`
  - Recommended: do not define multiple pointers on same line:
    `int *p1, p2;` not the same as `int *p1, *p2;`

    ptr int ptr ptr
  - Instead, use:

```
int *p1;
int *p2;
```

- *Dereference* a pointer using the unary `*` operator
  - Access the memory referred to by a pointer

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)`

  size of the thing being pointed at

  - Works nicely for arrays
  - Does not work on `void*`, since `void` doesn't have a size!
    - Not allowed, though confusingly GCC allows it as an extension ☹
- Valid pointer arithmetic:
  - Add/subtract an integer to/from a pointer
  - Subtract two pointers (within stack frame or malloc block)
  - Compare pointers (<, <=, ==, !=, >, >=), including `NULL`
  - … but plenty of valid-but-inadvisable operations, too

Poll Everywhere

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

ptr_poll.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;
}
```

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

A. {2, 3, 4}
B. {3, 4, 5}
C. {2, 6, 4}
[✓ D. {2, 4, 5}]
E. We're lost…

Practice Solution

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

ptr_poll.c

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

  return EXIT_SUCCESS;
}
```

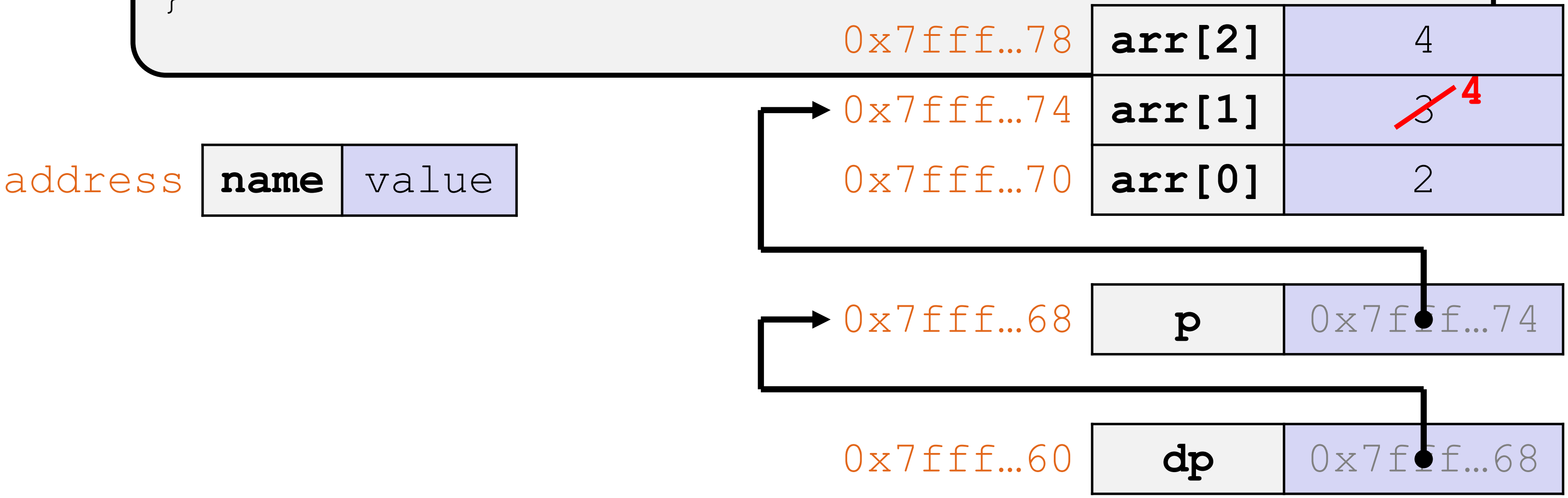

address	name	value
0x7fff…78	arr[2]	4
0x7fff…74	arr[1]	~~3~~ 4
0x7fff…70	arr[0]	2
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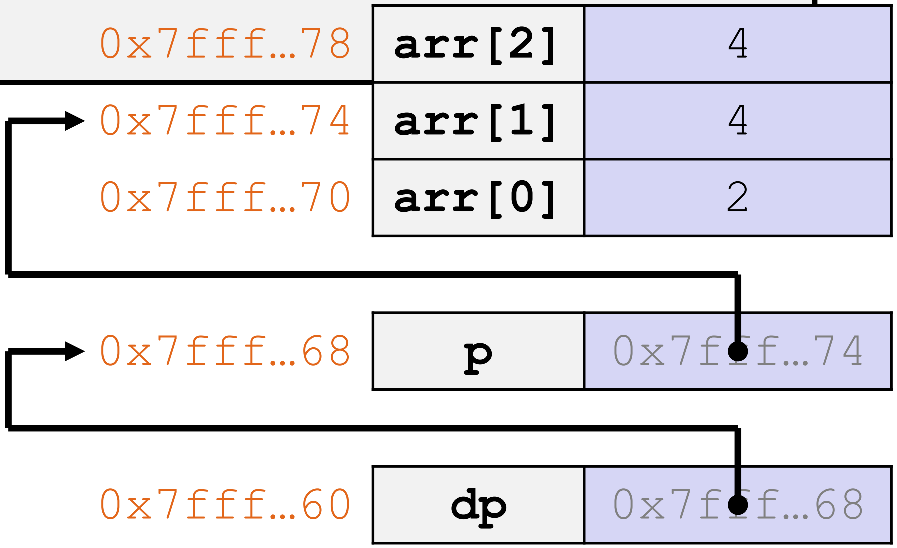

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ptr_poll.c

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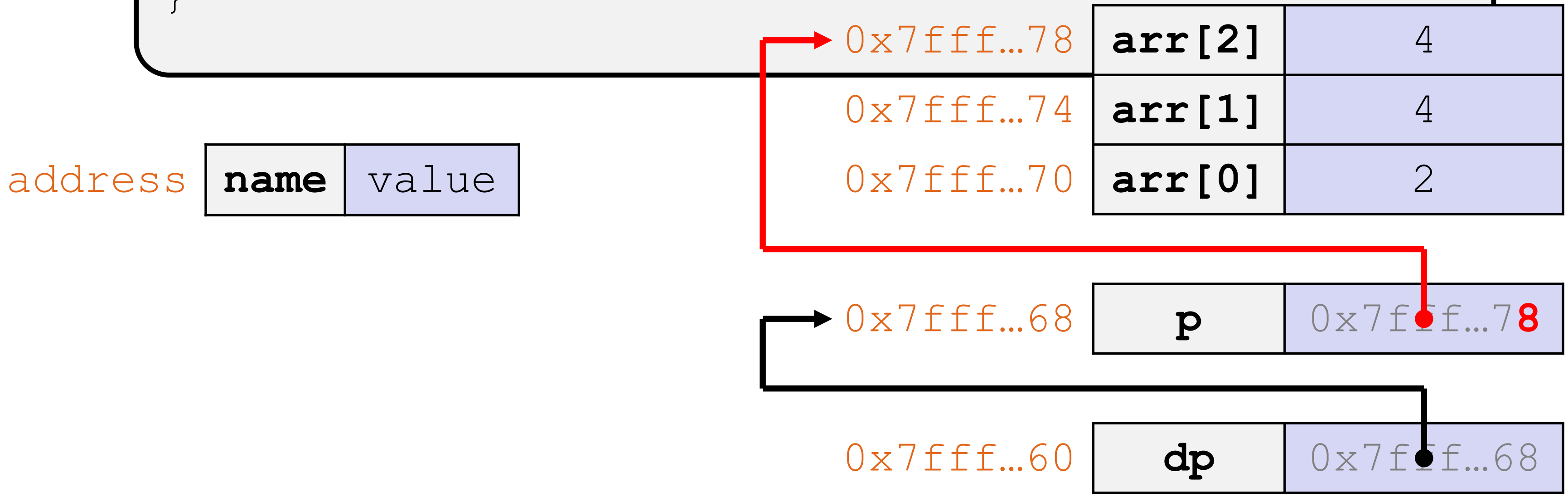
  int arr[3] = {2, 3, 4};
  int* p = &arr[1];
  int** dp = &p;  // pointer to a pointer

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

  return EXIT_SUCCESS;
}
```



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

  return EXIT_SUCCESS;
}
```
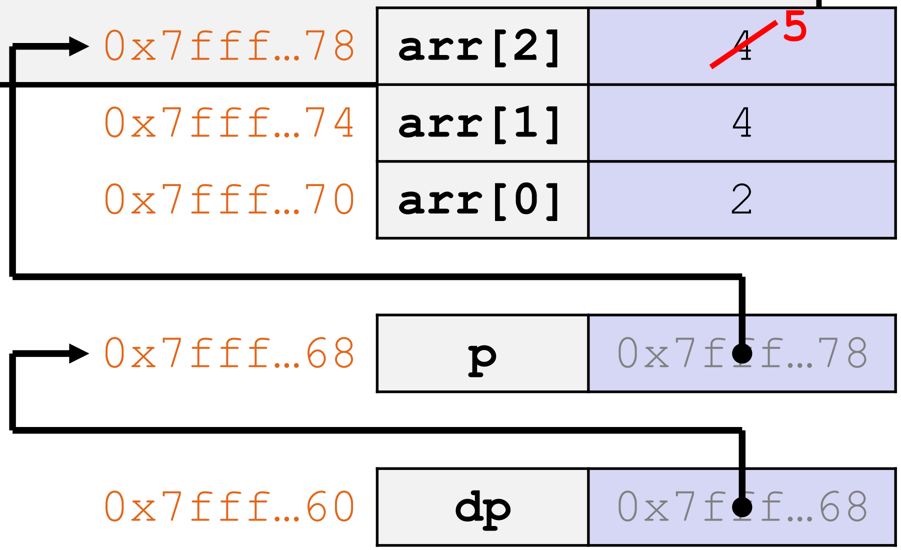



address	name	value
0x7fff…78	arr[2]	~~4~~ 5
0x7fff…74	arr[1]	4
0x7fff…70	arr[0]	2
0x7fff…68	p	0x7fff…78
0x7fff…60	dp	0x7fff…68

address name value

Arrays

- Definition: `type name[size]` allocates `size*sizeof(type)` bytes of *contiguous* memory
  - By default, array values are "mystery" data (*i.e.*, uninitialized)
  - Normal usage is a compile-time constant for `size` (*e.g.*, `int scores[175];`)

- Size of an array
  - Not stored anywhere – array does not know its own size!
    - `sizeof(array)` only works in the variable scope of array definition
  - Recent versions of C (but *not* C++) allow for variable-length arrays
    - Uncommon and can be considered bad practice [*we won't use*]

```
int n = 175;
int scores[n];   // OK in C99
```

Using Arrays

optional when initializing

- Initialization: `type name[size] = {val0,…,valN};`
  - { } initialization can *only* be used at time of definition
  - If no size supplied, infers from length of array initializer

- Array name used as identifier for "collection of data"
  - ☆ Array name produces the address of the start of the array
    - Cannot be assigned to / changed
  - `name[index]` specifies an element of the array and can be used as an assignment target or as a value in an expression

not necessary

```
int primes[6] = {2, 3, 5, 6, 11, 13};
primes[3] = 7;
primes[100] = 0;  // memory smash!
```

(hope for segfault)

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 – reference the data i elements forward from ptr

ptr[i] ⟷ *(ptr+i) ⟷ *(i+ptr) ⟷ i[ptr]

DON'T USE, but illustrates that it's all pointers under the hood

  - 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
```

Lecture Outline

- C Data Considerations
  - Memory
  - Arrays and Pointers Review
- **C Parameters**
  - **Arrays and Pointers as Parameters**

Parameters: reference vs. value

- There are two fundamental parameter-passing schemes in programming languages
- Call-by-value / "Pass-by-value"
  - Parameter is a local variable initialized with a copy of the calling argument when the function is called; manipulating the parameter only changes the copy, *not* the calling argument
  - **C**, **Java**, C++ (most things)
- Call-by-reference / "Pass-by-reference"
  - Parameter is an alias for the supplied argument; manipulating the parameter manipulates the calling argument
  - C++ references (we'll see these later)

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

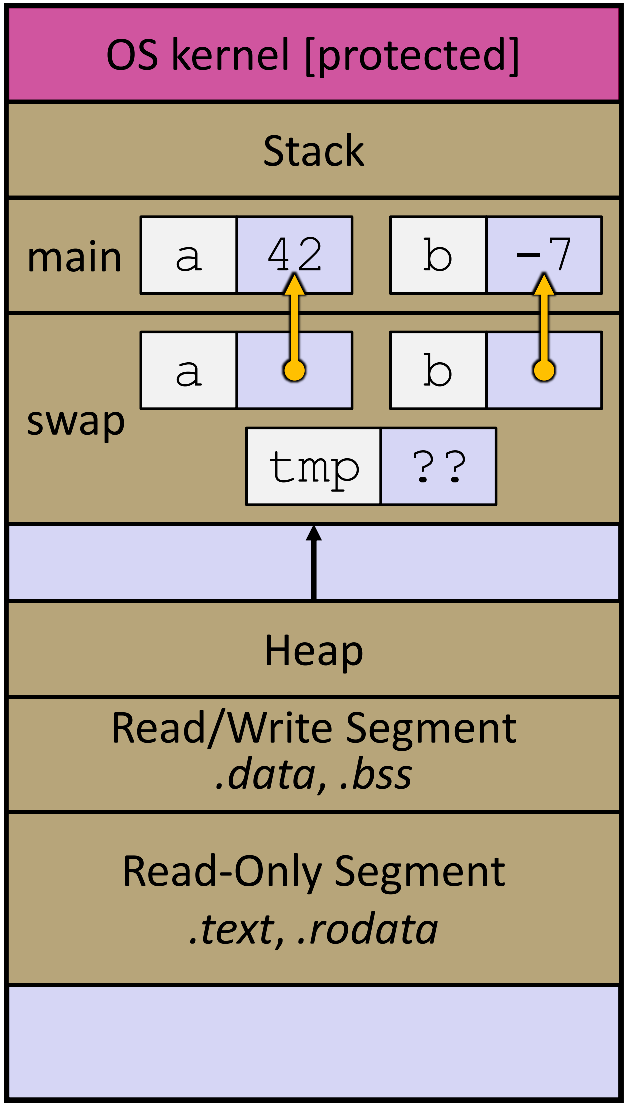
a-ptr b-ptr

```
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);
  ...
```



Arrays as Parameters

- It’s tricky to use arrays as parameters
  - What happens when you use an array name as an argument?
    get address of start of array
  - Arrays do not know their own size

```
// sums all elements of the array a
int SumAll(int a[]);

int main(int argc, char** argv) {
  int numbers[] = {9, 8, 1, 9, 5};
  int sum = SumAll(numbers);
  return EXIT_SUCCESS;
}

int SumAll(int a[]) {
  int i, sum = 0;
  for (i = 0; i < ...???
}
```

Solution 1: Declare Array Size

```
// sums all elements of the array a
int SumAll(int a[5]);  // prototype

int main(int argc, char** argv) {
  int numbers[] = {9, 8, 1, 9, 5};
  int sum = SumAll(numbers);
  printf("sum is: %d\n", sum);
  return EXIT_SUCCESS;
}

int SumAll(int a[5]) {
  int i, sum = 0;
  for (i = 0; i < 5; i++) {
    sum += a[i];
  }
  return sum;
}
```

- Problem: loss of generality/flexibility

Solution 2: Pass Size as Parameter

```c
// sums all elements of the array a
int SumAll(int a[], int size);

int main(int argc, char** argv) {
  int numbers[] = {9, 8, 1, 9, 5};
  int sum = SumAll(numbers, 5);
  printf("sum is: %d\n", sum);
  return EXIT_SUCCESS;
}

int SumAll(int a[], int size) {
  int i, sum = 0;
  for (i = 0; i < size; i++) {
    sum += a[i];
  }
  return sum;
}
```

arraysum.c

- Standard idiom in C programs!

Arrays: Call-by-what?

- Technical answer: a `T[]` array parameter is "promoted" to a pointer of type `T*`, and the *pointer* is passed by value
  - So it acts like a *call-by-reference array* – caller's array can be changed if callee modifies the array parameter elements
  - But it's really a *call-by-value pointer* – the callee's pointer parameter can be changed without affecting the caller's array
    - This is because `T[i]` is really `*(T+i)`. We aren't changing `T`!

```c
void CopyArray(int src[], int dst[], int size) {
  int i;
  dst = src;  // doesn't copy the array, copies the address
  for (i = 0; i < size; i++) {
    dst[i] = src[i];  // copies source array to itself
  }
}
```

Array Parameters

STYLE TIP

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

This code:

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

int main( ... ) {
  int a[5];
  ...
  F(a);
  return EXIT_SUCCESS;
}

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

pointer

array

Equivalent to:

```
void F(int* a);

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

void F(int* a) {
```

Returning an Array

- Local variables, including arrays, are allocated on the Stack
  - They “disappear” when a function returns!
  - Can’t safely return local arrays from functions
    - Can’t return an array as a return value – why not?

returns address
has to fit in %rax?

```c
int* CopyArray(int src[], int size) {
  int i, dst[size];    // OK in C99

  for (i = 0; i < size; i++) {
    dst[i] = src[i];
  }

  return dst;    // no compiler error, but wrong!
}
```

returns address of start of local array on Stack

buggy_copyarray.c

Solution: Output Parameter

- Create the "returned" array in the caller
  - Pass it as an output parameter to `CopyArray()`
    - A pointer parameter that allows the called function to store values that the caller can use
  - Works because arrays are "passed" as pointers

no return value!

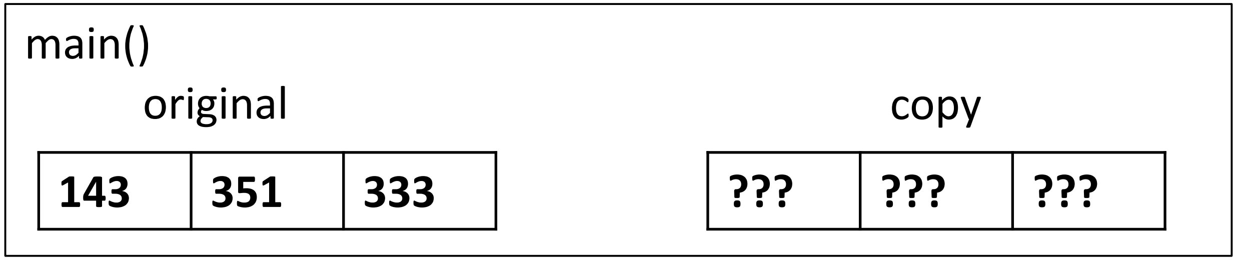
```
void CopyArray(int src[], int dst[], int size) {
  int i;

  for (i = 0; i < size; i++) {
    dst[i] = src[i];
  }
}
```

output parameter used to "pass" data to caller

data stored by dereferencing pointer

copyarray.c

Array Memory Diagram



main()

original

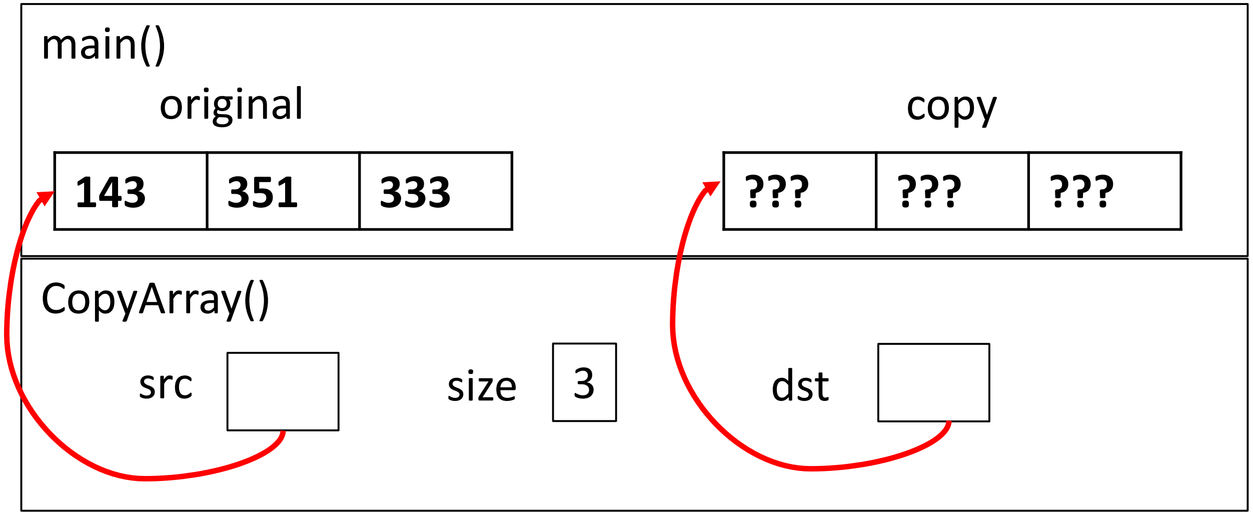
143	351	333

copy

???	???	???

```
int main(){
  int original[] = {143, 351, 333};
  int copy[3];
  CopyArray(original, copy, 3);
}

void CopyArray(int src[], int dst[], int size) {
  for (int i = 0; i < size; i++) {
    dst[i] = src[i];
  }
}
```

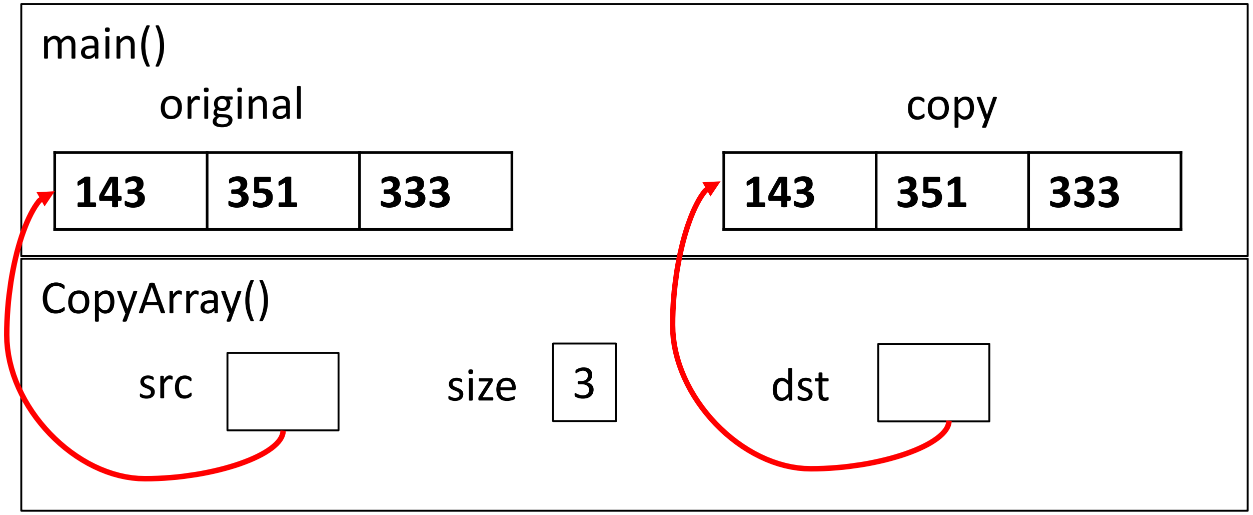
Array Memory Diagram



```
int main(){
  int original[] = {143, 351, 333};
  int copy[3];
  CopyArray(original, copy, 3);
}

void CopyArray(int src[], int dst[], int size) {
  for (int i = 0; i < size; i++) {
    dst[i] = src[i];
  }
}
```

`dst[i]` is really `*(dst+i)`. We aren't changing `dst`!

Array Memory Diagram



```
int main(){
  int original[] = {143, 351, 333};
  int copy[3];
  copyArray(original, copy, 3);
}

void CopyArray(int src[], int dst[], int size) {
  for (int i = 0; i < size; i++) {
    dst[i] = src[i];
  }
}
```

`dst[i]` is really `*(dst+i)`. We aren't changing `dst`!

Output Parameters

- Output parameters are common in library functions
  - `long int strtol(char* str, char** endptr,`
    `int base);`
  - `int sscanf(char* str, char* format, ...);`

output parameters

```
int   num, i;
char* p_end, str1 = "333 rocks";
char  str2[10];

// converts "333 rocks" into long - p_end is conversion end
num = (int) strtol(str1, &p_end, 10);

// reads string into arguments based on format string
num = sscanf("3 blind mice", "%d %s", &i, str2);
```

333

"returns" data in 2 ways!

stores data in corresponding output params

outparam.c

Extra Exercises

- Some lectures contain “Extra Exercise” slides
  - Extra practice for you to do on your own without the pressure of being graded
  - You may use libraries and helper functions as needed
    - Early ones may require reviewing 351 material or looking at documentation for things we haven’t discussed in 333 yet
  - Always good to provide test cases in `main()`

- Solutions for these exercises will be posted on the course website
  - You will get the most benefit from implementing your own solution before looking at the provided one

Extra Exercise #1

- Write a function that:
  - Accepts an array of 32-bit unsigned integers and a length
  - Reverses the elements of the array in place
  - Returns nothing (`void`)

Extra Exercise #2

- 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 0;
}
```

Extra Exercise #3

- Write a program that determines and prints out whether the computer it is running on is little-endian or big-endian.
  - Hint: `show_bytes.c` from 351 Lecture 3