Computer Science I

Arrays

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Outline

Part I: Introduction

Arrays

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- Usually more than one number, string, object, etc. must be stored and processed
- *Collections* of data can be stored in *arrays*
- An "array" is an *ordered series or arrangement*

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- Indexing is usually done with the square brackets `[]`

Example

index	0	1	2	3	4	5	6	7	8
contents	48	9	17	5	29	72	42	101	32

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- i-the element is

$$i \times 4$$

bytes away from the beginning of the array

Memory Offsets

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$2 \times 4 = 8$ bytes

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index	0	1	2	3	4	5	6	7	8
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$3 \times 4 = 12$ bytes

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index	0	1	2	3	4	5	6	7	8
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$4 \times 4 = 16$ bytes

Memory Offsets

index	0	1	2	3	4	5	6	7	8
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$5 \times 4 = 20$ bytes

Part II: Using Arrays

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- Once declared, indexing can be used to access values

```
arr[0] = 42;
arr[1] = 12;
arr[2] = arr[0] + 20;
arr[9] = 3.75; //truncation

printf("a[0] = %d\n", a[0]);
```

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int primes[] = { 2, 3, 5, 7, 11, 13, 17 };
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- Example of *code elision*
- Problem: You still need to keep track of the *size* of the array

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int n = 10;
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- Just because you *can* (or more accurately *might*) be able to do this, doesn't mean you should
- Avoid in general

Pitfalls

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- `arr[3]` was not set, its value could be anything
- Never make assumptions about uninitialized variables
- Always initialize yourself

- Accessing invalid indices is *undefined behavior*

Pitfalls
Out-of-bounds indexing

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arr[10] = 42;
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- May lead to:
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  - Incorrect results
- *Your* responsibility to do *bookkeeping*

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- Idiomatic loops over arrays
- Demonstration

```
int n = 10;
int primes[] = { 2, 3, 5, 7, 11, 13, 17, 19, 23, 29 };
int sum = 0;

for(int i=0; i<n; i++) {
  sum += primes[i];
}
```

Part III: Dynamic Arrays

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- Better solution: use *dynamic arrays*

- Dynamic memory is allocated in a program's *heap*

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- Dynamically allocate memory on the heap using `malloc()` (**M**emory **Alloc**ation)

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Part IV: Memory Management

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Introduction
Using Arrays
Dynamic Arrays
Memory Management
Arrays & Functions
Multi-dimensional Arrays
Shallow vs Deep

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  - Illegal memory access/segmentation faults

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Demonstration


```
#include<stdlib.h>
#include<stdio.h>
int main(int argc, char **argv) {

  int n = 100;
  int *arr = (int *) malloc(n * sizeof(int));

  //process the array
  for(int i=0; i<n; i++) {
    arr[i] = (i+1);
  }

  free(arr);

  return 0;
}
```

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Dangling Pointers


```
int *arr = (int *) malloc(n * sizeof(int));
//...
free(arr);

//arr still points to a memory location, but is no longer valid
printf("arr points to %p\n", arr);
//accessing is undefined behavior:
arr[0] = 42;

//best to reset to NULL;
free(arr);
arr = NULL;
```

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- Don't `free` freed memory

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Part V: Arrays & Functions

- Goal: use arrays with functions

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- Recall: you always need to do your own *bookkeeping* with arrays
- Anytime you pass an array, you also need to pass its *size*
- Anytime you return an array, you need a way to implicitly determine its size

Write a function that takes an array of integers and returns the sum of its values.

Demonstration


```c
/**
 * This function takes an integer array (of size n) and
 * returns the sum of its elements.  It returns 0 if the
 * array is NULL.
 */
int sum(int *arr, int n) {

  if(arr == NULL) {
    return 0;
  }
  int total = 0;
  for(int i=0; i<n; i++) {
    total += arr[i];
  }
  return total;
}
```

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Returning Arrays


```c
#include <stdlib.h>
#include <stdio.h>

int * foo() {
  int b[3];
  b[0] = 10;
  b[1] = 20;
  b[2] = 30;
  return b;
}

int main(int argc, char **argv) {
  int *a = foo();
  for(int i=0; i<3; i++) {
    printf("a[%d] = %d\n", i, a[i]);
  }
  return 0;
```

Exercises

- Write a function that takes an integer n and returns an array of n integers, all initialized to 1
- Write a function that takes an integer array and returns a new *copy* of the array with all instances of zero removed

Part VI: Multidimensional Arrays

- Up to now: 1-dimensional arrays

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- 4+ dimensional arrays:

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- 2-D arrays:
  - Rows & columns
  - Tabular data
  - Matrices
- 3-D arrays:
  - Rows, columns, & "lanes"
  - 3-dimensional data
- 4+ dimensional arrays:
  - Rethink what you're doing

Multidimensional Arrays

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- Demonstration

Multidimensional Arrays


```c
int n = 10;
int **matrix = NULL;
matrix = (int **) malloc(n * sizeof(int*));
for(int i=0; i<n; i++) {
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↓

*matrix[0]

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*matrix[2]

⋮

*matrix[n−1]

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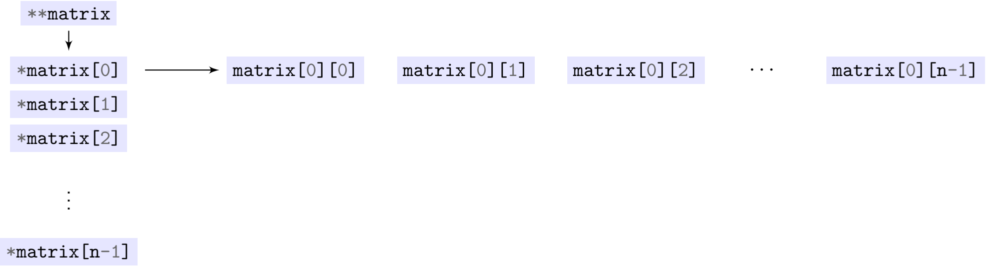

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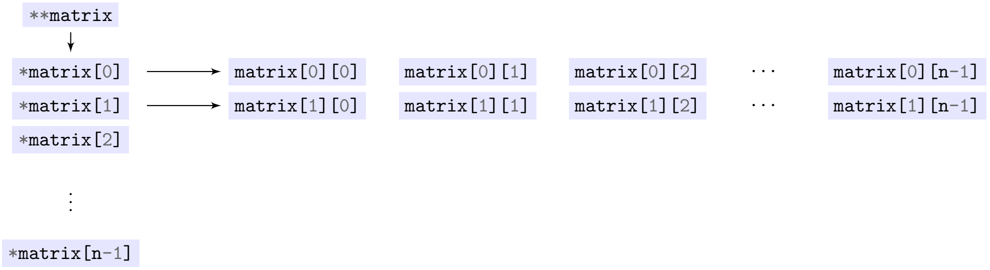

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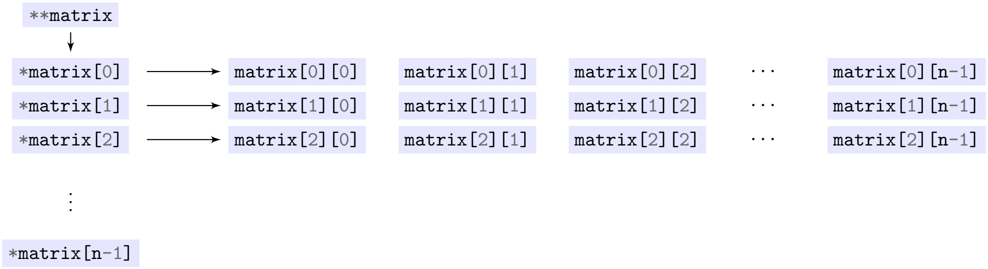

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matrix = (int **) malloc(n * sizeof(int*));
for(int i=0; i<n; i++) {
  matrix[i] = (int *) malloc(n * sizeof(int));
}
```

```
**matrix
   ↓
*matrix[0]   →  matrix[0][0]    matrix[0][1]    matrix[0][2]    ···  matrix[0][n-1]
*matrix[1]   →  matrix[1][0]    matrix[1][1]    matrix[1][2]    ···  matrix[1][n-1]
*matrix[2]   →  matrix[2][0]    matrix[2][1]    matrix[2][2]    ···  matrix[2][n-1]
    ⋮
*matrix[n-1] →  matrix[n-1][0]  matrix[n-1][1]  matrix[n-1][2]  ···  matrix[n-1][n-1]
```

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- Use two nested for-loops to iterate over each row/column

```
for(int i=0; i<n; i++) {
  for(int j=0; j<n; j++) {
    matrix[i][j] = (2*i+3*j);
  }
}
printf("last row/column value = %d\n", matrix[n-1][n-1]);
```

Demo


```c
#include<stdlib.h>
#include<stdio.h>

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

  int n = 3;
  int **matrix = NULL;
  matrix = (int **) malloc(n * sizeof(int*));
  for(int i=0; i<n; i++) {
    matrix[i] = (int *) malloc(n * sizeof(int));
  }

  int value = 1;
  for(int i=0; i<n; i++) {
    for(int j=0; j<n; j++) {
      matrix[i][j] = value;
      value++;
```

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- Cannot simply free the matrix: `free(matrix)`
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- You must free each row before you free the array of pointers

```
for(int i=0; i<n; i++) {
  free(matrix[i]);
}
free(matrix);
```

Alternative: Contiguous Allocation


```c
#include <stdlib.h>

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

  int n = 5, m = 3;
  int **arr = (int **)malloc(sizeof(int *) * n);
  arr[0] = (int *)malloc(sizeof(int) * (n * m));

  for(int i=1; i<n; i++) {
    arr[i] = (*arr + (m * i));
  }

  int value = 1;
  for(int i=0; i<n; i++) {
    for(int j=0; j<m; j++) {
      arr[i][j] = value;
      value++;
```

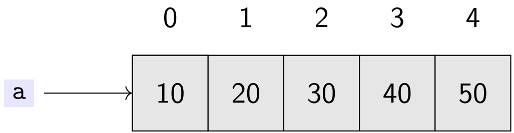
Part VII: Shallow vs. Deep Copies

Shallow Copy

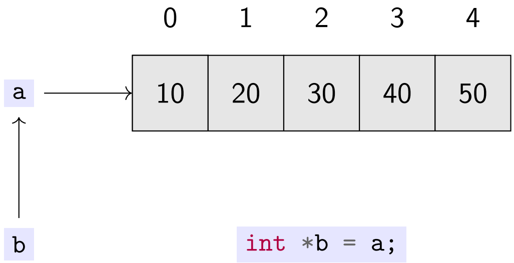
Consider the following piece of code, what does it print?

```
//create an array containing {10, 20, 30, 40, 50}
int n = 5;
int *a = (int *) malloc(n * sizeof(int));
for(int i=0; i<n; i++) {
  a[i] = (i+1)*10;
}

//let's make a "copy"
int *b = a;
b[0] = 42;

//what is in a[0]?
printf("a[0] = %d\n", a[0]);
```

Shallow Copy

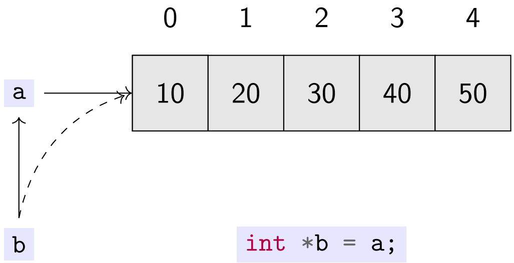


Shallow Copy



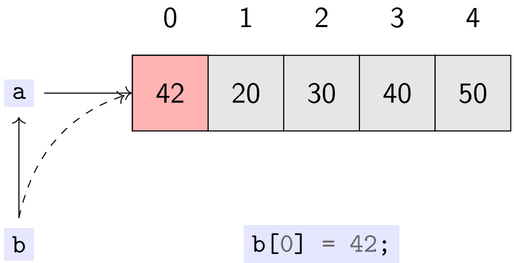

```
int *b = a;
```

Shallow Copy




```
int *b = a;
```

Shallow Copy




```
b[0] = 42;
```

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- A shared reference is a *shallow copy*

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- A shared reference is a *shallow copy*
- Multiple pointers refer to the same memory location/array
- Changes to one reference affect the other
- Not typically what we want with a "copy"

Deep Copy

- In contrast: a *deep copy* is when we have two *separate* arrays with the same *contents*

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- Two *different* memory locations
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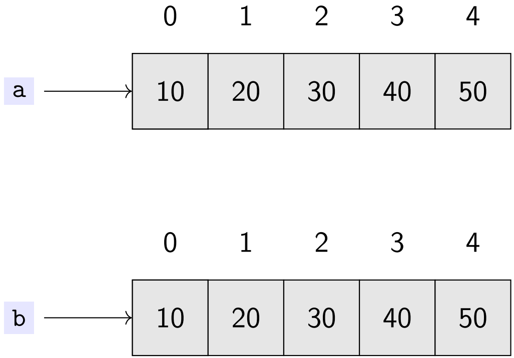
- Example
- Demo: write a deep copy function

Deep Copy



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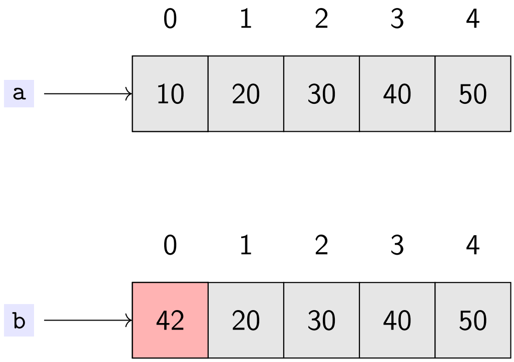


```
b[0] = 42;
```

Deep Copy


```c
/**
 * This function creates a deep copy of the
 * given array.
 */
int * deepCopy(const int *a, int n) {
  if(a == NULL || n < 0) {
    return NULL;
  }
  int *copy = (int *) malloc(n * sizeof(int));
  for(int i=0; i<n; i++) {
    copy[i] = a[i];
  }
  return copy;
}
```