Function Pointers and Abstract Data Types

CS 217

Reminder: Midterm Exam

- Exam logistics on Thu Oct 27
  - Date/time: Thursday October 27 at 10:00-10:50am (in lecture)
  - Open books, open notes, open mind, but not open laptop/PDA
  - Covering material from lecture, precept, and reading, but not tools
- Review in Thu Oct 13 lecture
  - Chris DeCoro will go over these practice questions
    - Fall 2002: #3, #5
    - Spring 2002: #3, #7
    - Spring 2004: #1, #4
    - Fall 2004: #1, #3, #4, #5
  - I recommend you try the problems in advance
  - See Chris' e-mail for other good practice problems to try
  - Answers to old exams made available online later this week

http://www.cs.princeton.edu/courses/archive/fall05/cos217/exams.html

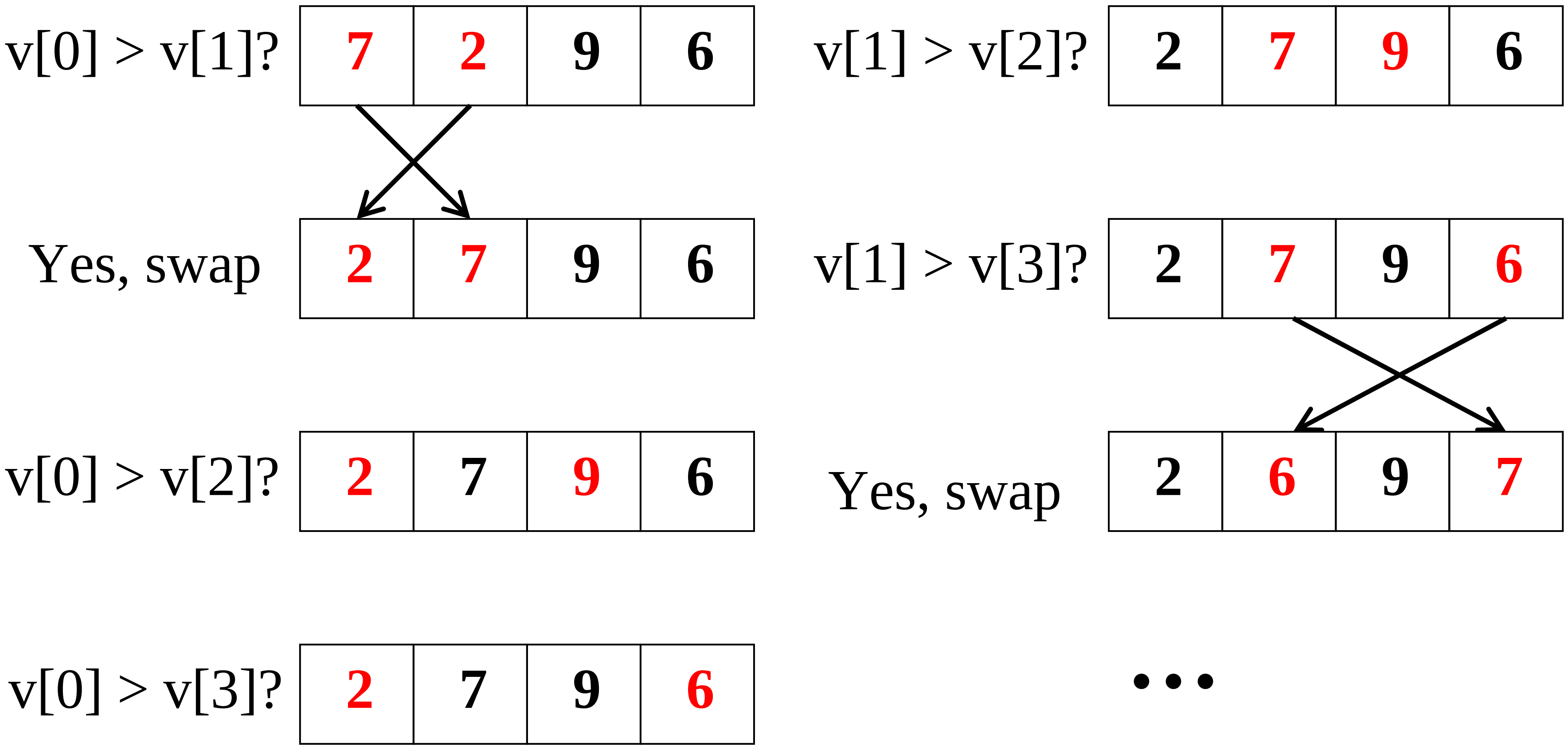
Goals of Today’s Lecture

- Function pointers
  - Sorting an array of integers
  - Sorting an array of strings
  - Sorting an array of *any* type
    - Void pointers and casting
    - Pointers to functions
- Abstract Data Types
  - Making “array” an ADT

Sorting an Array of Integers

- Example problem
    - Input: array **v** of **n** integers
    - Output: array in sorted order, from smallest to largest
- Many ways to sort, but three common aspects
    - Comparison between any two elements
    - Exchange to reverse the order of two elements
    - Algorithm that makes comparisons and exchanges till done
- Simple approach
    - Go one by one through the **n** array elements
    - By the end of step **`i`**, get **`i`**th smallest value in element **`i`**
        - Compare element **`i`** with all elements after it
        - Swap values if the **`i`**th element is larger

Integer Sorting Example



v[0] > v[1]?	7	2	9	6
Yes, swap	2	7	9	6
v[0] > v[2]?	2	7	9	6
v[0] > v[3]?	2	7	9	6

v[1] > v[2]?	2	7	9	6
v[1] > v[3]?	2	7	9	6
Yes, swap	2	6	9	7

…

Integer Sorting Function

```
void sort(int *v, int n)
{
    int i, j;

    for (i = 0; i < n; i++) {
        for (j = i+1; j < n; j++) {
            if (v[i] > v[j]) {
                int swap = v[i];
                v[i] = v[j];
                v[j] = swap;
            }
        }
    }
}
```

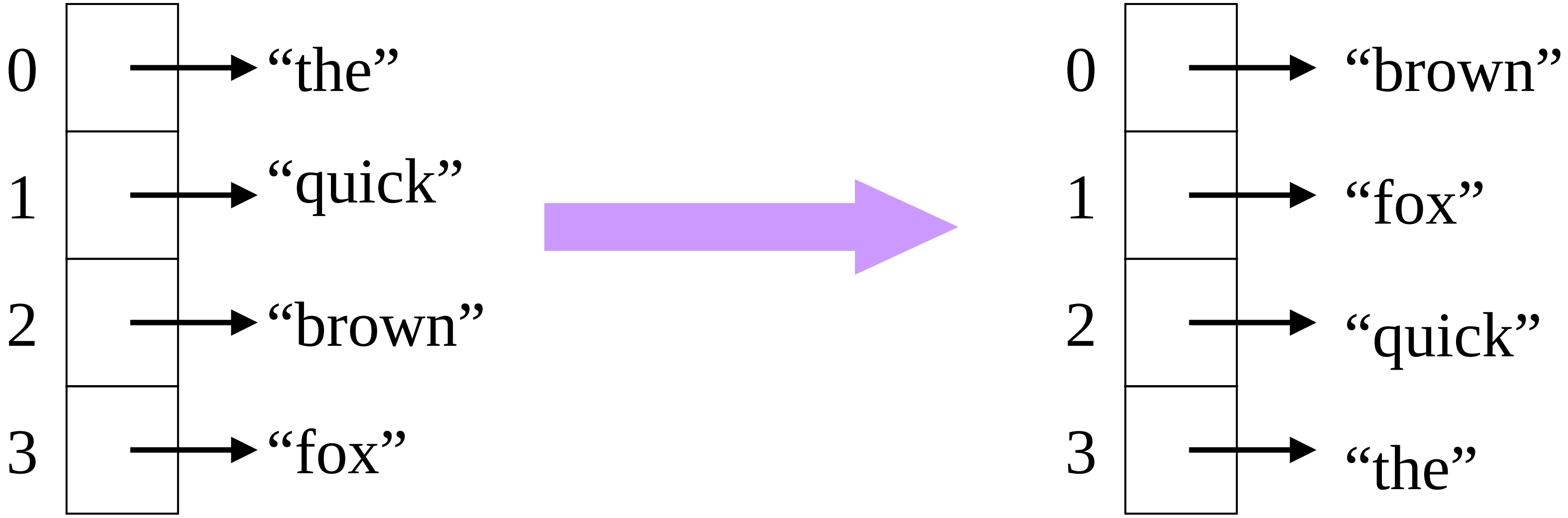
comparison

swap

Sorting an Array of Strings

- Data types are different
  - Array elements are **`char*`**
  - Swap variable is **`char*`**

- Comparison operator is different
  - The greater-than ("**>**") sign does not work
  - Need to use **strcmp()** function instead



String Sorting Function

```
void sort(char *v[], int n)
{
  int i, j;

  for (i = 0; i < n; i++) {
    for (j = i+1; j < n; j++) {
      if (strcmp(v[i], v[j]) > 0) {
        char* swap = v[i];
        v[i] = v[j];
        v[j] = swap;
      }
    }
  }
}
```

comparison

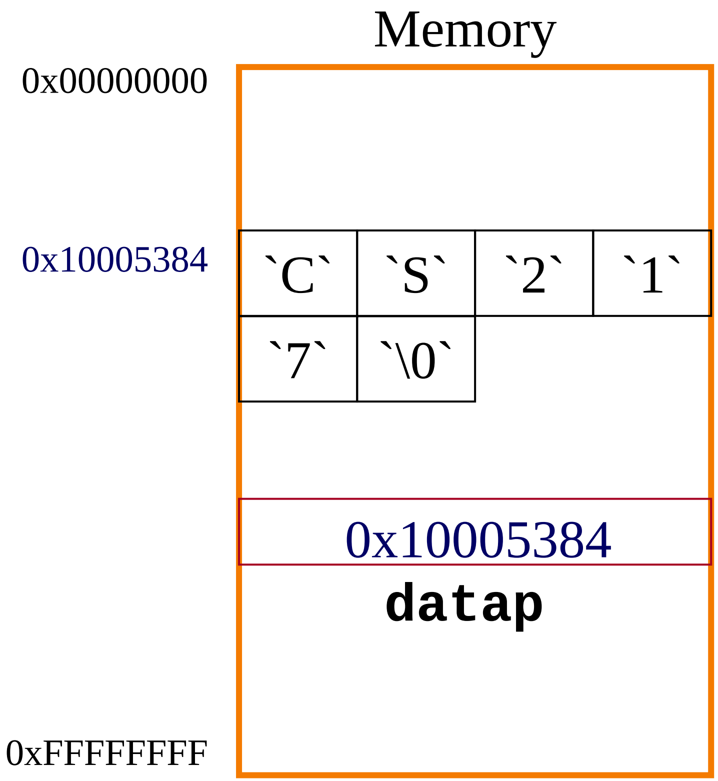
swap

Creating a Generic Function

- Generic function
  - A single **`sort()`** function that works for all data types
- C's notion of data types is getting in our way
  - We need to accept parameters in any type
    - **`sort(int *v, int n)`** is only good for integer arrays
    - **`sort(char *v[], int n)`** is only good for string arrays
  - We need to have local variables of any type
    - **`int swap`** is only good for swapping integers
    - **`char* swap`** is only good for swapping strings
- Different types need different comparison operators
  - Greater-than sign ("**`>`**") is only good for numerical types
  - **`strcmp()`** is only good for strings
  - We need to be able to tell **`sort()`** what comparison function to use

Generalizing: Void Pointers

- Generic pointers are the same as any other pointer
  - Except they point to a variable with no specific type
  - Example: **`void *datap = “CS217”;`**
- Difference:
  - Regular pointers: compilers “know” what they point to
  - void pointers: compilers “don’t know” what they point to
- Common Uses:
  - Abstract data types supporting *polymorphism**
  - Pass pointer to function that could be any of several types



Memory

0x00000000

0x10005384

`C` `S` `2` `1`

`7` `\0`

0x10005384

datap

0xFFFFFFFF

* Allowing the same definitions to be used with different types of data

Void Pointers in Sort

- Function parameters
  - Input: array of pointers to some unknown type

```
void sort(void *v[], int n)
```

- Local swap variable
  - Pointer to some unknown type

```
void *swap = v[i];
v[i] = v[j];
v[j] = swap;
```

- But, what about the comparison step?
  - Need to be able to pass a *function* to sort

Casting: Explicit Type Conversions

- Casting
  - As if the expression were assigned to a variable of the specified type
  - E.g., **`int *intp1`** cast into void pointer by **`(void *) intp1`**
- C does many implicit conversions
  - E.g., function **`double sqrt(double)`**
    - – Can be called as **`sqrt(2);`**
    - – Which is treated as **`sqrt((double) 2);`**
- Sometimes useful to make conversion explicit
  - Documentation: making implicit type conversions explicit
    - – E.g., getting the integer part of a floating-point number
    - – Done by **`int_part = (int) float_number;`**
  - Control: overrule the compile by forcing conversions we want
    - – E.g., getting the fractional part of a floating-point number
    - – Done by frac_part = f – (int) f;

Generic Sort Function

```
void sort(void *v[], int n,
            int (*compare)(void *datap1, void *datap2))
{
    int i, j;

    for (i = 0; i < n; i++) {
        for (j = i+1; j < n; j++) {
            if ((*compare)(v[i], v[j]) > 0) {
                void *swap = v[i];
                v[i] = v[i];
                v[j] = swap;
            }
        }
    }
}
```

`compare` is a pointer to a function that has two **`void*`** arguments and returns an **`int`**, and **`(*compare)`** is the function.

Using Generic Sort With String

```
#include <stdio.h>
#include <string.h>
#include “sort.h”

int main() {
    char* w[4] = {“the”, “quick”, “brown”, “fox”};

    sort((void **) w, 4, (int (*)(void*,void*)) strcmp);
    …
}
```

pointer to a function

Using Generic Sort With Integers

```
#include <stdio.h>
#include “sort.h”

int CompareInts(void *datap1, void *datap2) {
    int *intp1 = (int *) datap1;
    int *intp2 = (int *) datap2;
    return (*intp1 - *intp2);
}

int main() {
    int* w[4];

    w[0] = malloc(sizeof(int));
    w[0] = 7;
    …
    sort((void **) w, 4, (int (*)(void*,void*))CompareInts);
    …
}
```

pointer to a function

Making “Array” an ADT

- Arrays in C are error prone
  - Access elements before the array starts (e.g., **`v[-1]`**)
  - Access elements past the end of array (e.g., **`v[n]`**)
  - Modify the variable that keeps track of size (e.g., **n**)
- Protect programmers with an array ADT
  - Create and delete an array
  - Get the current length
  - Read an array element
  - Append, replace, remove
  - Sort

Array ADT: Interface

array.h

client does not know implementation

```
typedef struct Array *Array_T;

extern Array_T Array_new(void);
extern void Array_free(Array_T array);

extern int Array_getLength(Array_T array);
extern void *Array_getData(Array_T array, int index);

extern void Array_append(Array_T array, void *datap);
extern void Array_replace(Array_T array, int index, void *datap);
extern void Array_remove(Array_T array, int index);

extern void Array_sort(Array_T array,
                     int (*compare)(void *datap1, void *datap2));
```

Client Using Array ADT: Strings

```
#include “array.h”
#include <stdio.h>

int main() {
    Array_T array;
    int i;

    array = Array_new();

    Array_append(array, (void *) “COS217”);
    Array_append(array, (void *) “IS”);
    Array_append(array, (void *) “FUN”);

    for (i = 0; i < Array_getLength(array); i++) {
        char *str = (char *) Array_getData(array, i);
        printf(str);
    }

    Array_free(array);

    return 0;
}
```

Client Using Array ADT: Integers

```
#include “array.h”
#include <stdio.h>

int main() {
    Array_T array;
    int one=1, two=2, three=3;
    int i;

    array = Array_new();

    Array_append(array, (void *) &one);
    Array_append(array, (void *) &two);
    Array_append(array, (void *) &three);

    for (i = 0; i < Array_getLength(array); i++) {
        int *datap = (int *) Array_getData(array, i);
        printf(“%d “, *datap);
    }

    Array_free(array);

    return 0;
}
```

Array ADT Implementation

```
#include “array.h”

#define MAX_ELEMENTS 128

struct Array {
    void *elements[MAX_ELEMENTS];
    int num_elements;
};


Array_T Array_new(void) {
    Array_T array = malloc(sizeof(struct Array));
    array->num_elements = 0;
    return array;
}


void Array_free(Array_T array) {
    free(array);
}
```

Array ADT Implementation (Cont)

```
int Array_getLength(Array_T array) {
    return array->num_elements;
}

void *Array_getData(Array_T array, int index) {
    return array->elements[index];
}

void Array_append(Array_T array, void *datap) {
    int index = array->num_elements;
    array->elements[index] = datap;
    array->num_elements++;
}

void Array_replace(Array_T array, int index, void *datap) {
    array->elements[index] = datap;
}
```

Array ADT Implementation (Cont.)

```
void Array_insert(Array_T array, int index, void *datap) {
    int i;

    /* Shift elements to the right to make room for new entry */
    for (i = array->num_elements; i > index; i--)
        array->elements[i] = array->elements[i-1];

    /* Add the new element in the now-free location */
    array->elements[index] = str;
    array->num_elements++;
}


void Array_remove(Array_T array, int index) {
    int i;

    /* Shift elements to the left to overwrite freed spot */
    for (i = index+1; i < array->num_elements; i++)
        array->elements[i-1] = array->elements[i];

    array->num_elements--;
}
```

Array ADT Implementation (Cont.)

```
void Array_sort(Array_T array,
                int (*compare)(void *datap1, void *datap2))
{
    int i, j;

    for (i = 0; i < array->num_elements; i++) {
        for (j = i+1; j < array->num_elements; j++) {
            if ((*compare)(array->elements[i], array->elements[j]) > 0) {
                void *swap = array->elements[i];
                array->elements[i] = array->elements[j];
                array->elements[j] = swap;
            }
        }
    }
}
```

Summary

- Module supporting operations on single data structure
  - Interface declares operations, not data structure
  - Interface provides access to simple, complete set of operations
  - Interface provides flexibility and extensibility
- Trick is providing functionality AND generality
  - Take advantage of features of programming language
    - void pointers
    - function pointers
- Advantages
  - Provide complete set of commonly used functions (re-use)
  - Implementation is hidden from client (encapsulation)
  - Can use for multiple types (polymorphism)