Function Pointers and Abstract Data Types

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COS 217
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]?

Yes, swap

v[0] > v[2]?

v[0] > v[3]?

v[1] > v[2]?

v[1] > v[3]?

Yes, swap

...
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;
            }
        }
    }
}
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

```
0  ----> “the”                   0  ----> “brown”
1  ----> “quick”                1  ----> “fox”
2  ----> “brown”                2  ----> “quick”
3  ----> “fox”                  3  ----> “the”
```
String Sorting Function

```c
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;
            }
        }
    }
}
```
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

* 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

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

• Local swap variable
  ○ Pointer to some unknown type

```c
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;`
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[i] = 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

```c
#include <stdio.h>
#include <string.h>
#include "sort.h"

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

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

pointer to a function
#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(void) {
    int* w[4];
    w[0] = malloc(sizeof(int));
    *(w[0]) = 7;
    ...
    sort((void **) w, 4, (int (*)(void*,void*))CompareInts);
    ...
}
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

```c
typedef struct Array *Array_T;

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

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

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

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

client does not know implementation

array.h
#include "array.h"
#include <stdio.h>

int main(void) {
    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;
}
#include "array.h"
#include <stdio.h>

int main(void) {
    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;
}
#include "array.h"

defined {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);
}
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;
}
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.)

```c
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;
            }
        }
    }
}
```
Stupid Programmer Tricks

- `qsort` takes `int (*compare)(const void *, const void *)`
  - Comparison function returns integer greater than, equal, less than zero if first argument is greater than, equal, less than second

- **Common approach:**
  ```
  int ItemCompare(const void *pA, const void *pB) {
      Item *a = pA, *b = pB;
      return(a->field - b->field);
  }
  ```

- Bad idea when field is float or “long long” (64 bit)
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)