



Function Pointers and Abstract Data Types

Prof. David August
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

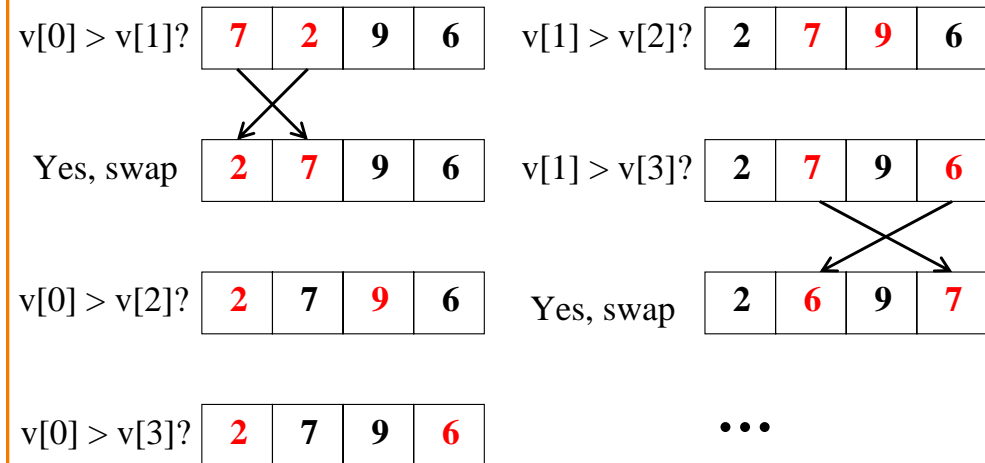


Sorting an Array of Integers

- **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



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

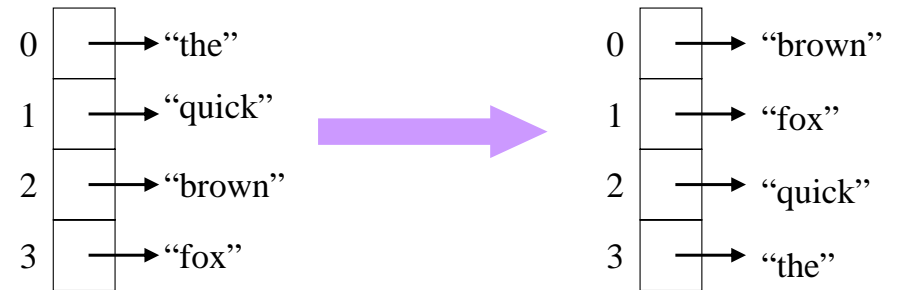
swap

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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



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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

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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

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Generalizing: Void Pointers



- **Generic pointers are the same as any other pointer**

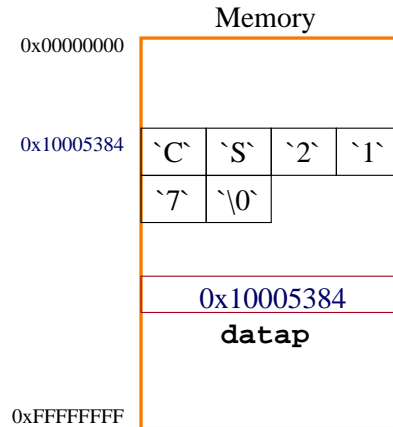
- Except they point to a variable **with no specific type**
- Example: `void *datap = "CS217";`

- **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

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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

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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;`

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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[j];  
                v[j] = swap;  
            }  
        }  
    }  
}
```

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

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Using Generic Sort With String



```
#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

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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(void) {
    int* w[4];

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

pointer to a function

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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

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Array ADT: Interface



array.h client does not know implementation

```
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));
```

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Client Using Array ADT: Strings



```
#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;
}
```

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Client Using Array ADT: Integers



```
#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;
}
```

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Array ADT Implementation



```
#include "array.h"

enum {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);
}
```

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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;
}
```

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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--;
}
```

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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;
            }
        }
    }
}
```

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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)

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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)

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