Introduction to Programming (CS 101)

Spring 2024

Lecture 14:

More about {arrays, structs, strings}

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Based on material developed by Prof. Abhiram Ranade and Prof. Manoj Prabhakaran

Recap: Lexicographically compare two strings

```
int compare(char A[], char B[]) {
    int i = 0;
    while(true) {
        if(A[i] == '\0' && B[i] == '\0') return 0;
        if(A[i] == '\0') return -1;
        if(B[i] == '\0') return 1;
        if(A[i] < B[i]) return -1;
        if(A[i] > B[i]) return 1;
        i++;
    }
}
int main() {
    char A[30], B[30];
    cin.getline(A,30); cin.getline(B,30);
    cout << A << " " << B << " " << compare(A,B) << endl;
}
```

Takes two strings A, B and returns 0 if they are equal, 1 if A is lexicographically greater than B and -1 otherwise.

Recap

What is the output of the following program?

```
main_program {
  char c1[20] = "hello";
  char c2[] = {'h','e','l','l','o'};

  if(!compare(c1,c2))
    cout << "c1=c2";
  else if(compare(c1,c2) == 1)
    cout << "c1>c2";
  else
    cout << "c1<c2";
}
```

```
int compare(char A[], char B[]) {
   int i = 0;
   while(true) {
      if(A[i] == '\0' && B[i] == '\0') return 0;
      if(A[i] == '\0') return -1;
      if(B[i] == '\0') return 1;
      if(A[i] < B[i]) return -1;
      if(A[i] > B[i]) return 1;
      i++;
   }
}
```

A c1=c2

B c1>c2

C c1<c2

`c1` is automatically terminated with a `'\0'`, while `c2` isn't. Note that the assignment operator cannot be used again once a string is initialized. `c1 = "world";` after `char c1[20] = "hello";` will result in a compiler error.

Merge sort

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Divide-and-Conquer

- Some *algorithms* use a Divide-and-Conquer strategy (a.k.a. Divide-Conquer-and-Combine)
  - A problem instance is divided into two or more smaller problems
  - The smaller instances are solved recursively
  - The results are then combined to get the result for the original instance
- An example: Merge Sort

```
resultType f(inputType x) {

  if (baseCase(x))
    return handleBaseCase(x);

  inputType x1, x2;
  Divide(x,x1,x2);

  resultType y1, y2;
  y1 = f(x1); y2 = f(x2);

  return Combine(y1,y2);
}
```

Merge Sort

- Split into two (almost) equal halves, and recursively sort each half
- Merge the two sorted arrays into a single sorted array

53	46	94	43	17	12	60	98	86	50	36	26	57	80	77	18

Recursively sort

Recursively sort

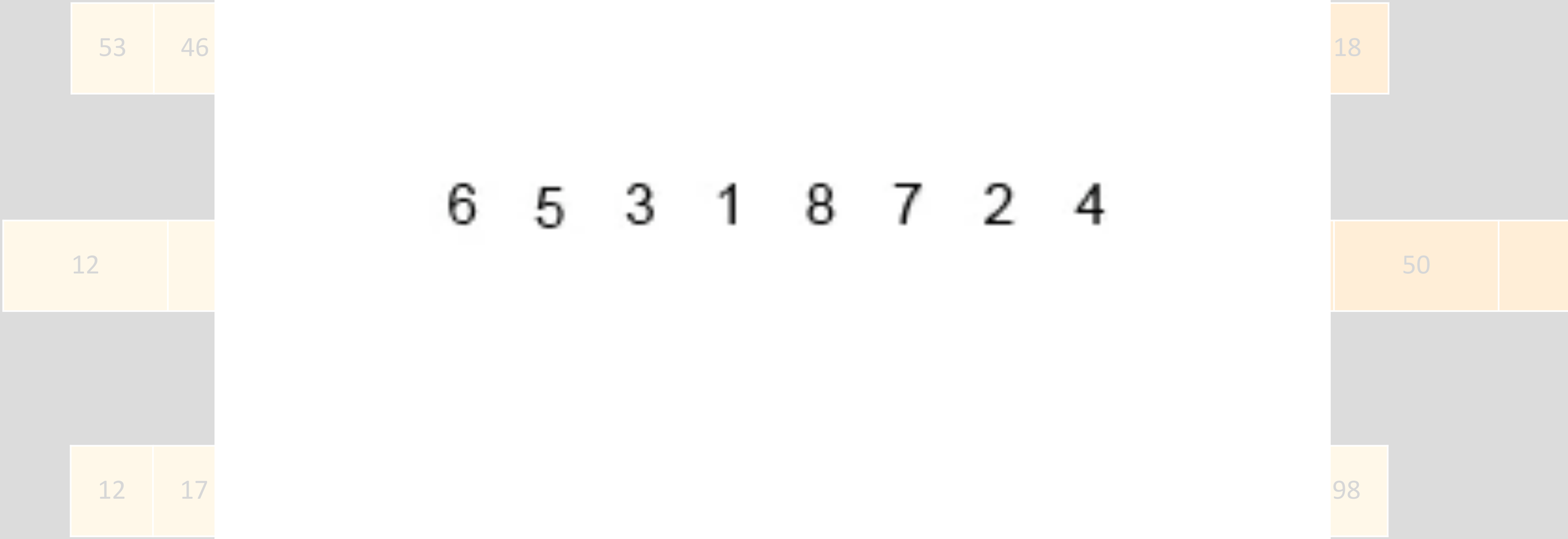
12	17	43	46	53	18	26	36	50

Merge

12	17	18	26	36	43	46	50	53	57	60	77	80	86	94	98

Merge Sort

- Split into two (almost) equal halves, and recursively sort each half
- Merge t



6 5 3 1 8 7 2 4

Video derived from: https://en.wikipedia.org/wiki/Merge_sort#/media/File:Merge-sort-example-300px.gif

Merge Sort

```
// merge X[left..mid] and X[mid+1..right] into Y[left..right], where mid = (left+right)/2
void merge(const int X[], int Y[], int left, int right) {
     int mid = (left+right)/2, L = left, R = mid+1;   // L,R: next indices of left/right halves
     for(int i=left; i <= right; ++i) {
          if(L <= mid && (R > right || X[L] <= X[R])) Y[i] = X[L++];    // copy from left
          else Y[i] = X[R++];                                            // copy from right
     }
}
```

12	17	43	46	53	18	26	36	50	

Merge

12	17	18	26	36	43	46	50	53	57	60	77	80	86	94	98

Merge Sort

Output will be in the array out[ ] in indices left,...,right. A temporary array scratch[ ] passed as input (since its size is not known at compile-time).

```
void sort (const int in[], int out[],
           int left, int right,
                     int scratch[]) {

  if (left==right) {
    out[left] = in[left];
    return;
  }
  int mid = (left+right)/2;
  sort(in,scratch,left,mid,out);
  sort(in,scratch,mid+1,right,out);

  merge(scratch,out,left,right);
}
```

```
resultType f(inputType x) {

  if (baseCase(x))
    return handleBaseCase(x);

  inputType x1, x2;
  Divide(x,x1,x2);

  resultType y1, y2;
  y1 = f(x1); y2 = f(x2);

  return Combine(y1,y2);
}
```

More about multidimensional arrays

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2D arrays

- Recall matrices can be implemented using 2D arrays. Example:

```
float vals[2][3];
```

vals[0][0]	vals[0][1]	vals[0][2]
vals[1][0]	vals[1][1]	vals[1][2]

- We can define two-dimensional character arrays:

```
char countries[3][20] = {"India", "China", "Sri Lanka"};
```

- `countries[i]` will return the address of the zeroth character of the `i`th string in `countries`

2D arrays

```
int main() {
  char countries[3][20] = {"India", "China", "Sri Lanka"};
  char capitals[3][20] = {"New Delhi", "Beijing", "Colombo"};
  char country[20];
  cout << "Enter country: ";
  cin.getline(country, 20);
  int i;
  for(int i = 0; i < 3; i++) {
    if(compare(country,countries[i]) == 0) { //compare defined earlier
       cout << "Capital -> " << capitals[i] << endl; break;
    }
  }
  if(i == 3) cout << "Do not know the capital\n";
}
```

Passing two-dimensional arrays to functions

- One can pass a 2D array to a function. However, the second dimension must be given as a compile-time constant. Example:

```
void print(char countries[][20], int num) {
  for(int i = 0; i<num; i++) cout << countries[i] << endl;
}
```

- Such a `print` function can only be used with `char` arrays where the second dimension is 20
- Can be overcome with more flexible array types like `vector` (coming in later slides)

More about structs

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More about structs

- If a `struct` definition appears before many functions, it will be visible to all the functions

- To avoid making copies, structs can be passed by reference

```
struct CS101Group {
  char name[4]; //G1, G13, etc.
  string TAs[10];
  unsigned short int size;
  ⋮
};
void printGroup(const CS101Group& grp) {
  cout << "name = " << grp.name << endl;
  ⋮
}
```

Passing structs by value

- Consider the following struct representing 2D points with x, y coordinates:

```
struct Point {
  double x;
  double y;
};
```

- The following function returns a `Point` that is the midpoint of the line joining two points:

```
Point midpoint(Point a, Point b) {
  Point mp;
  mp.x = (a.x+b.x)/2;
  mp.y = (a.y+b.y)/2;
  return mp;
}
```

```
int main() {
  Point p1 = {0,0};
  Point p2 = {100,200};
  Point p3 = midpoint(p1, p2);
  cout << midpoint(midpoint(p1,p2),p2).y;
}
```

150

output

Passing structs by reference

- Can pass struct parameters by reference (to avoid copies)

```
Point midpoint(const Point& a, const Point& b) {
  Point mp;
  mp.x = (a.x+b.x)/2;
  mp.y = (a.y+b.y)/2;
  return mp;
}
```

`const` means these reference parameters will not be altered during execution

- Say the parameters of `midpoint` were ordinary references and not `const` references. Now you try to run `cout << midpoint(midpoint(p1,p2),p2).y;` from `main()`, as before. What happens?
  - Compiler error!
  - Cannot pass a temporary object like `midpoint(p1,p2)` to a non-const reference parameter

structs and member functions

- Functions can be a part of the structure itself. Example:

```
struct Point {
  double x, y;
  double length() {
    return sqrt(x*x + y*y);
  }
  double shift(double dx, double dy) {
    x+=dx; y+=dy;
  }
};
```

- A member function is called on an object of the struct type using "." notation. Example:

```
Point p1; cout << p1.length();
```

structs and member functions

- Inside the body of the function, we can read or modify members of the struct object. Example: `x, y` are directly accessible within the functions `length` and `shift` below

```
struct Point {
  double x, y;
  double length() {
    return sqrt(x*x + y*y);
  }
  double shift(double dx, double dy) {
    x+=dx; y+=dy;
  }
  void alter(double a) {
    x = a; cout << length() << endl;
  }
};
```

Note that `x` of a struct object will be altered here. And the call to `length()` will refer to the object used with `alter`. That is, `p1.alter(10)` will calculate the length of `p1.`

More about strings

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More about `string`

- To use `string`, we need to add `#include <string>` to the program

```
string a = "hello", b = "world", c;
c = a;
```

Note that you do not need to worry about the size of the strings, unlike C-style strings

- Can read whitespace-delimited strings into a string using `getline`:

```
getline(cin, a); //to read a line into string a
```

Will read from console into `a`, until a newline is encountered

- Addition operator can be used with strings to concatenate them

```
c = a + " " + b; //will set c to "hello world"
```

- `a[i]` denotes the `i`th character of the string `a`

More about `string`

- Many useful member functions are available for `string`

```
string a = "hello";
int i = a.find("he"); //returns the starting index of the
                      //first occurrence of "he" within string a
int j = a.find("l", 3); //find starting from index 3
```

- If a given string is not found, find returns a constant `string::npos`

- Comparison expressions `<, >, =` can be used for strings `a, b` assuming a lexicographic order
  - Lexicographic order: Similar to how words are organized in a dictionary
  - Comparison is done character by character, and based on underlying ASCII values
  - Example: "`hello`" < "`world`", "`hello`" > "`Hello`" (ASCII value of h > ASCII value of H)

Dynamic arrays (`vector`)

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Dynamic allocation

- C++ contains three primary array styles:

  1. C-style arrays (inherited from C, you have already learned about these)

  2. `std::array` array type

  3. `std::vector` array type

  Part of C++'s Standard Template Library (STL)

- `std::vector` is arguably the most flexible of the three types and has many useful supporting features

- We will focus on `std::vector` since it offers many benefits

`vector` (I)

- To use vectors, add the header line "`#include <vector>`" to the beginning of the program

- A vector can be initialized like an array. Example:

```
vector<int> A = {1, 2, 3};
```

Template argument: Defines the type of the elements in the vector

```
vector<float> B; //creating an empty vector of floats
```

- Elements can be accessed like an array. Example:

```
for(int i=0; i < A.size(); i++)
  cout << A[i] << " ";
```

Handy! You can use `A.size()` to determine the size of the vector

- Another method to access vector elements: `at()`.
  - `A.at(2)` will access the third element of `A` like `A[2]`.
  - Unlike `[]`, the `at()` method also performs bound checking of whether the index lies within the vector; so it allows for safely accessing vector elements

`vector` (II)

- `std::vector` is a very flexible alternative to C-style arrays

- A vector can dynamically grow or shrink

```
vector<char> C;
C.push_back('a'); //adds an element to the end of the vector
C.resize(3,'b'); //the vector becomes {'a', 'b', 'b'}
```

Value by which the extra elements of the vector are initialized

```
C.resize(2,'b'); //the vector becomes {'a', 'b'}
```

Extra elements exceeding the new size are deleted

- Vectors can be copied, passed/returned by value or reference

```
void printVector(vector<int>& v) { // ... print the vector elements
// call inside main()
vector<int> A = {1,3,5}; printVector(A);
```

`vector`: Many other useful operations

- Remove the last element of the vector using `pop_back()`

```
vector<int> A = {11, 22, 33};
A.pop_back(); //the vector becomes {11, 22}
```

- Use `empty()` to check if the vector is empty

```
vector<int> A = {11, 22, 33};
cout << (A.empty() ? "empty\n" : "not empty\n");
```

- `front()` and `back()` allows for access to the first and last element of a vector

- A range-based for loop can be used to access the elements of a vector as follows:

```
for(int x : A)
  cout << x << endl;
```

- Quick way to initialize a vector of size n with all elements having the same value:

```
vector<int> A(n, 0); // will initialize A with n elements, all = 0
```

Represent a matrix using `vector`

```
vector<vector<int>> A = {{11, 22, 33},
                         {44, 55, 66},
                         {77, 88, 99}};
```

11	22	33
44	55	66
77	88	99

```
void print(vector<vector<int>>& matrix) {
  for(int i = 0; i<matrix.size(); i++) {
    for(int x : matrix[i])
      cout << x << endl;
  }
}

int main() {
  print(A); //if A is defined as above
}
```

[Optional]: Finding maximum subarray

Given an array of ints, find a contiguous subarray with the largest sum and return its sum.

```
int maxSubArraySum(const vector<int>& nums) {
    int maxSum = nums[0];
    int maxUntil_i = nums[0];
    for (int i = 1; i < nums.size(); i++) {
        int x = nums[i];
        maxUntil_i = max(x, maxUntil_i + x);
        maxSum = max(maxSum, maxUntil_i);
    }
    return maxSum;
}

int main() {
    vector<int> nums = {-2, 1, -3, 4, -1, 2, 1, -5, 4};
    cout << "Maximum subarray sum: " << maxSubArraySum(nums) << endl;
    return 0;
}
```

Reference: https://en.wikipedia.org/wiki/Maximum_subarray_problem