ECE 220

Lecture x000B - 10/02

Recap

- Last time:
  - Pointer/array duality & pitfalls
  - Strings a.k.a. char arrays and functions (`sscanf`, `fgets`)
  - Multi-dimensional arrays

Multi-dimensional arrays

- C allows for defining *multi-dimensional* arrays (we already saw them with string arrays).
- The *dimension* of an array is determined by the minimum number of indices required to access its individual elements.

One dimensional array

0	1	2	3

Two dimensional array

0,0	0,1	0,2	0,3
1,0	1,1	1,2	1,3
2,0	2,1	2,2	2,3

Multi-dimensional arrays

- The syntax for two dimensional arrays is:

```
type varname[nr][nc];
```

where `nr` and `nc` are the number of rows & columns.

- Example: `int a[3][4];`

One dimensional array

a[0]	a[1]	a[2]	a[3]

Two dimensional array

a[0][0]	a[0][1]	a[0][2]	a[0][3]
a[1][0]	a[1][1]	a[1][2]	a[1][3]
a[2][0]	a[2][1]	a[2][2]	a[2][3]

Allocating memory

One dimensional array

a[0]	a[1]	a[2]	a[3]

	Offsets
a[0]	0
a[1]	1
a[2]	2
a[3]	3

How to calculate offset?

Column index

`offset = ri * nc + ci`

Row index

...	*Offsets*
a[1][2]	6
a[1][3]	7
a[2][0]	8
a[2][1]	9
a[2][2]	10
a[2][3]	11

Two dimensional array

a[0][0]	a[0][1]	a[0][2]	a[0][3]
a[1][0]	a[1][1]	a[1][2]	a[1][3]
a[2][0]	a[2][1]	a[2][2]	a[2][3]

C follows what is called *row-major order*, i.e rows first.

More than 2D?

- C allows creating arrays with multiple dimensions.
- Example: Here is a three dimensional array where the first dimension has size `x`, the second dimension has size `y` and last dimension has size `z`.

```
int arr3d[x][y][z];
```

- **Question**: How will `arr3d[4][3][2]` be stored in memory?
  - Hint 1: *Last index varies fastest.*
  - Hint 2: Element `arr3d[x-1][y-1][z-1]` will be bottom most.

Initializing 2D arrays

- There are multiple ways to initialize a 2D array.
- Here are *four* equivalent ways to initialize a 2×3 array:
  - `int a[2][3] = {{1,2,3},{4,5,6}};`
  - `int a[2][3] = {1,2,3,4,5,6};`
  - `int a[][3] = {{1,2,3},{4,5,6}};`
  - `int a[][3] = {1,2,3,4,5,6};`
- Why not: `int a[2][] = {{1,2,3},{4,5,6}};` ?

Exercise

Write a C function that given a matrix `mat` of size `nr` × `nc` and another matrix `tr_mat` of size `nc` × `nr` copies the *transpose* of `mat` into `tr_mat`.

```
# include<stdio.h>

void transpose(int *mat, int *tr_mat, ______, ______){
  for (int i=0; ______; i++)
    for (int j=0; ______; j++)
      ________________ = ____________;
}

void print_mat(int *mat, int nr, int nc){
  for (int i=0; i<nr; i++){
    for (int j=0; j<nc; j++)
      printf("%d", mat[i*nc +j]);
    printf("\n");
  }
  printf("\n");
}
```

2D shape information is lost!

Matrix is passed in as a pointer.

Dimensions are NOT global variables

Exercise

Write a C function that given a matrix `mat` of size `nr` $\times$ `nc` and another matrix `tr_mat` of size `nc` $\times$ `nm` copies the *transpose* of `mat` into `tr_mat`.

```
# include<stdio.h>

void transpose(int *mat, int *tr_mat, ______, ______){
  for (int i=0; ______; i++)
    for (int j=0; ______; j++)
      ________________ = ____________;
}

void print_mat(int *mat, int nr, int nc){
  for (int i=0; i<nr; i++){
    for (int j=0; j<nc; j++)
      printf("%d", mat[i*nc +j]);
    printf("\n");
  }
  printf("\n");
}
```

Lets fill in the blanks!

Today: Lesson objectives

- Understand and be able to implement some common array operations
  - **Search**: Linear and binary searches
  - **Sorts**: Insertion, selection, bubble and time permitting quick sorts.

Problem solving: searching

- Searching whether an element is in a list very common operation
- We explore two approaches for 1-D arrays:
  - Linear search
  - Binary search

Linear search

- This is as vanilla as a search gets.
- Go through the list from beginning to end until a match is found:
    - Search item is often called *key.*
    - Animation

Linear search - implementation

```
int linear_search(int list[], int n, int key){
    for (int i = 0; i < n; i++){

    if (________________)
        return i;
    }
    ________________;
}
```

Binary search

- In linear search if *key* happens to be last item in list (of size n) then we make n comparisons - denoted $O(n)$ for time complexity.
    - *However*, if the list is sorted then we can use this to our advantage.
    - Compare given `key` to middle element `mid`.
        - If `key > mid` focus search on right half
        - If `key < mid` focus search on left half
        - If `key == mid` then done
- Animation

Binary search

```
int binary(int arr[], int n, int key){
  int low = 0;       // Left pointer
  int high = _____; // Right pointer

  while (high >= low){
    int mid = (__________) / 2; // Pick middle element

    // Logic to focus search on left or right of mid
    if (key == arr[mid])
      return mid;
    else if (key < arr[mid])
      high = _______;
    else
      low = ________;
  }
  return -1; // Loop exited, element not present.
}
```

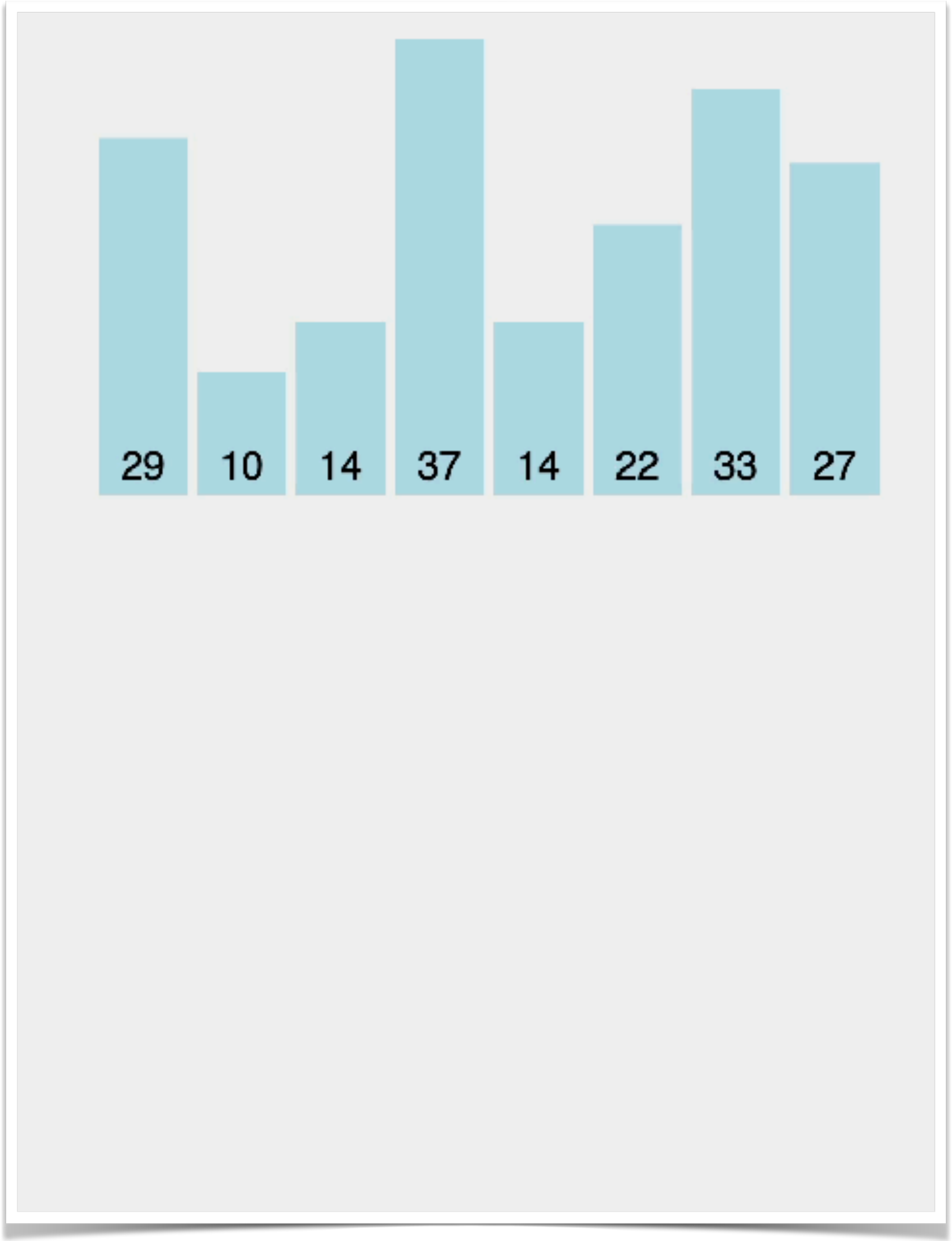
Sorting

- Why sort lists or arrays?
  - We saw one reason
    - Searching
  - Other reasons?
    - Assigning students by UIN to exam rooms.
    - Etc.

- Finding efficient algorithms for sorting is highly researched problem.
- Many flavors exist: bubble sort, selection sort, insertion sort, quick sort, etc.
- Knowing some of them off the top of your head … probably required for technical interview.

Selection sort

- Conceptually one of the simplest algorithms.
- Starting from one end of array, make N passes.
    - In Nth pass, find Nth smallest item and bring it to the Nth spot with a swap.
    - After N passes, array is sorted.

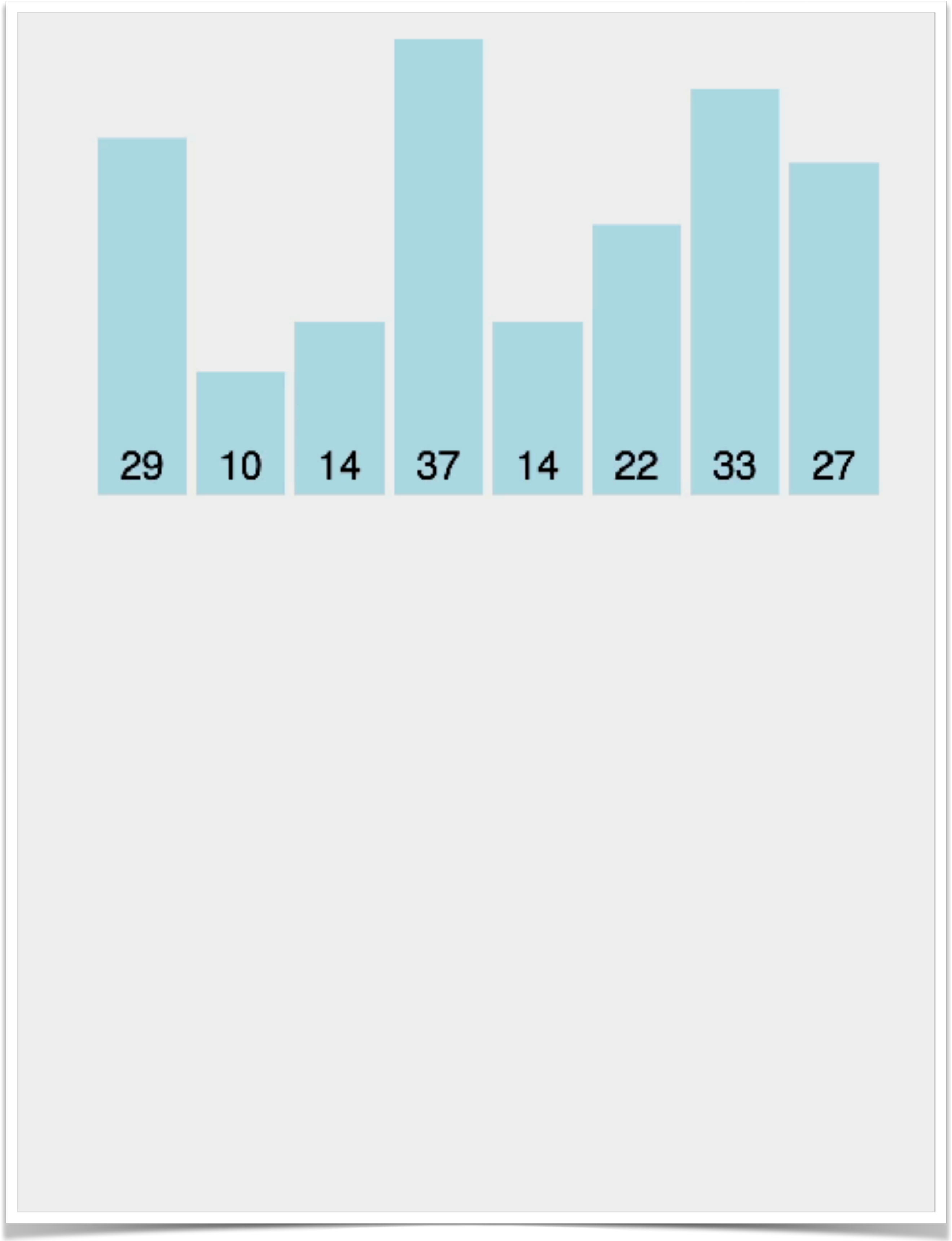


Selection sort

```
void selection_sort(int arr[], int n){
  for (int i = 0; _________; i++){

    int min_idx = i; // Initialize min to first item

    // Find the minimum in the  sublist: list[i..arraySize-1]
    for (int j = i + 1; j < n; j++)
      if (_____________________)
        min_idx = j;

    // swap list[i] with list[currentMinIndex] if necessary;
    if (min_idx != i){
      _______ = ____________;
      arr[min_idx] = arr[i];
      arr[i] = min;
    }
  }
}
```

Insertion sort

- Conceptually think of sorting a handful of cards.
- Start from one end of array, assume leftmost element sorted.
    - Pick the next card and insert it into the right place in the sorted array; moving elements if needed.
    - After a single pass, array is sorted.

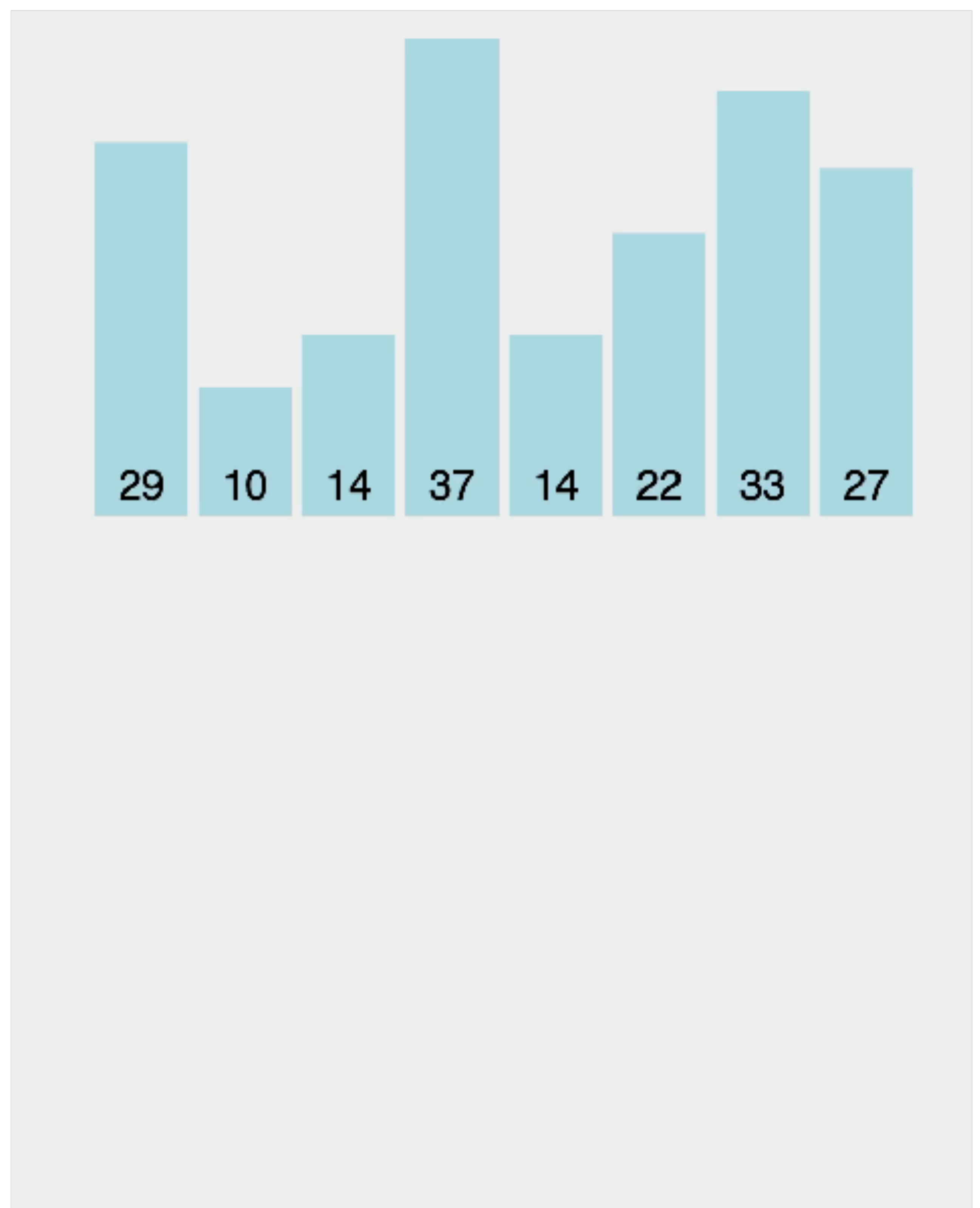


Insertion sort

```
void insertion_sort(int arr[], int n){
   for (int i = 1; i < n; i++){

      /* Insert list[i] into a sorted sublist list[0..i-1] so that
         list[0..i] is sorted. */

      int current = arr[i];
      int k;

      for (k = i - 1; __________________________; k--)
       // Move elements one spot over
        _________________ = _________________;

      // Insert the current element into list[k+1]
      arr[k + 1] = current;
   }
 }
```

Bubble sort

- One of the more naive sort algorithms with poor performance.
- Iteratively make passes over the array
  - Comparing adjacent pairs & swapping if not in order until …
  - No more swaps are made.



Implementation left as an exercise.

Quick sort

- One of the more faster sorting algorithms.
- Key idea: choose a pivot element; then …
  - Move all elements greater than pivot to right of it and smaller than pivot to left of it.
  - Subdivide & repeat
- Many varieties exist; this course cannot cover them all.
  - How to pick pivot?
    - First, last, mid, random, etc.
  - *Recursive* vs. iterative.
- Main point: understand one variety and understand it well.

ECE 220

A special on Quicksort: Lecture x000B+

PDF-Link: https://courses.grainger.illinois.edu/ece220/fa2025/lectures/itabrah2/Quicksort_itabrah2.pdf

Git: https://github.com/iabraham/ece220-fa25/blob/main/lec11_1002/advanced/quicksort.c