CSC 212: Data Structures and Abstractions

Computational Cost

Marco Alvarez

Department of Computer Science and Statistics
University of Rhode Island

Fall 2020

Quick notes

- Attending lectures and labs
  - **take notes** (by hand or typing) — avoid just taking screenshots
  - be **ready to answer** questions
- Assignment 1
  - **autograder** active by Thursday afternoon to accept submissions
  - use **double** variables in all calculations
  - the **median** of a list of even length is the average of the two elements in the middle
  - include **pixel i, j** as part of the local neighborhood
  - when calculating standard deviation, divide by **n**

Analyzing running time

Empirical Analysis

- **Run** algorithm
- Measure actual time

Mathematical Model

- **Analyze** algorithm
- Develop Model

Theoretical Models

Mathematical model

- High-level analysis — **no need to implement**
- Independent of HW/SW
- Based on **counts** of basic **instructions**
  - additions, multiplications, comparisons, etc
  - exact definition <u>not important</u> but **must be relevant** to the problem

Basic assumptions

- In order to use a **formal framework**, we will make certain assumptions
  - count basic instructions: additions, multiplications, comparisons, assignments
  - each instruction takes one time unit
  - instructions are executed sequentially
  - infinite memory
- Focus on analyzing **running time**

Example

- What to count?
  - only relevant instructions? all instructions?

```
double sum = 1;
for (int i = 0 ; i < n ; i ++) {
        sum = sum * i;
}
```

lets also plot both cases …

Example

```
for (int i = 0 ; i < n ; i ++) {
    for (int j = 0 ; j < n ; j ++) {
        sum = sum * j;
    }
}
```

Example

```
for (int i = 0 ; i < n ; i ++) {
    for (int j = 0 ; j < n*n ; j ++) {
        sum = sum * j;
    }
}
```

Example

```
for (int i = 0 ; i < n ; i ++) {
    for (int j = 0 ; j < i ; j ++) {
        sum = sum * j;
    }
}
```

Example

```
for (int i = 0 ; i < n ; i ++) {
    for (int j = 0 ; j < n ; j ++) {
        for (int k = 0 ; k < n ; k ++) {
            // count 1 instruction
        }
    }
}
```

Example

```
for (int i = 0 ; i < n ; i ++) {
    for (int j = 0 ; j < i*i ; j ++) {
        for (int k = 0 ; k < j ; k ++) {
            // count 1 instruction
        }
    }
}
```

Some rules …

- Single loops
  - essentially the number of iterations times the number of instructions performed at each iteration
- Nested loops
  - count instructions inside out
  - careful with the range of the loop
  - when possible, multiplications can be used for counts from each loop
- Consecutive statements
  - just add the counts
- Conditionals
  - consider the branch with the highest count

Computational cost

- Number of **basic instructions** required by the algorithm to process an input of a certain **size n**

$$T(n)$$

- basic instructions are always **relevant** to the problem
  - ex: find max in an array
    - # of comparisons
  - ex: sum elements in an array
    - # of additions

Comparing computational cost

find (x,y,z) s.t. x+y+z=k

find (x,y) s.t. x+y=k

find x=k

Size of Input	n^3	n^2	n
n = 1	1	1	1
n = 10	1,000	100	10
n = 100	1,000,000	10,000	100
n = 1000	1,000,000,000	1,000,000	1,000
n = 10000	1,000,000,000,000	100,000,000	10,000
n = 100000	1,000,000,000,000,000	10,000,000,000	100,000
n = 1000000	1,000,000,000,000,000,000	1,000,000,000,000	1,000,000
n = 10000000	1,000,000,000,000,000,000,000	100,000,000,000,000	10,000,000

Growth Rate

n	log log n	log n	n	n log n	n^2	n^3	2^n
16	2	4	2^4	$4 \cdot 2^4 = 2^6$	2^8	2^{12}	2^{16}
256	3	8	2^8	$8 \cdot 2^8 = 2^{11}$	2^{16}	2^{24}	2^{256}
1024	≈ 3.3	10	2^{10}	$10 \cdot 2^{10} \approx 2^{13}$	2^{20}	2^{30}	2^{1024}
64K	4	16	2^{16}	$16 \cdot 2^{16} = 2^{20}$	2^{32}	2^{48}	2^{64K}
1M	≈ 4.3	20	2^{20}	$20 \cdot 2^{20} \approx 2^{24}$	2^{40}	2^{60}	2^{1M}
1G	≈ 4.9	30	2^{30}	$30 \cdot 2^{30} \approx 2^{35}$	2^{60}	2^{90}	2^{1G}

growth of $T(n)$ as $n \to \infty$

```cpp

int main(int argc, char*argv[]){
    std::string input_file_name = std::string(argv[1]);
    std::string output_file_name = std::string(argv[2]);

    std::vector<std::vector<double>> data;

    ReadFile(input_file_name, &data);

    WriteFile(output_file_name, &data);
}

// Read 2D array from a file
void ReadFile(std::string file_name, std::vector<std::vector<double>> * image_data){
    // Create the input filestream - opens the file & prepares it for reading
    std::ifstream file(file_name);

    // Creates a temporary vector to represent one row
    std::vector<double> new_row;

    // Temporary string to hold a single line of the file
    std::string str;

    // Reads all lines in the file, 1 at at time
    while (std::getline(file, str)) {
       // Converts our string into a stringstream
       std::istringstream ss(str);
       // Temp double to store a converted value from a line
       double token;

        // Reads all values from the stringstream (current row), converts to double
        while(ss >> token){
            // Adds the converted value to the row
            new_row.push_back(token);
        }
        // Pushes our constructed vector of doubles to the 2D vector
        image_data->push_back(new_row);
        new_row.clear();
    }
}

void WriteFile(std::string file_name, std::vector<std::vector<double>> * image_data){
    // Opens the outfile file, prepares it for writing
    std::ofstream output_file(file_name);

    // Loop rows
    for(unsigned int i = 0; i < image_data->size(); i++){
        // Loop columns
        for(unsigned int j = 0; j < (*image_data)[i].size(); j++){
            // Output each value and a space
            output_file << (*image_data)[i][j] << " ";
        }
        // Output a newline character after every row
        output_file << std::endl;
    }
}

```