CSC 212: Data Structures and Abstractions

Computational Cost

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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** activate 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 not important 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 $n \to \infty$

credit: openDSA