Section 2.2
Complexity of Algorithms

Time Complexity: Determine the approximate number of operations required to solve a problem of size n.

Space Complexity: Determine the approximate memory required to solve a problem of size n.

Time Complexity

- Use the Big-O notation

- Ignore house keeping

- Count the <u>expensive</u> operations only

Basic operations:

• searching algorithms - key comparisons

• sorting algorithms - list component comparisons

• numerical algorithms - floating point ops. (flops) - multiplications/divisions and/or additions/subtractions

Worst Case: maximum number of operations

Average Case: mean number of operations assuming an input probability distribution

Examples:

• Multiply an n x n matrix A by a scalar c to produce the matrix B:

```
procedure (n, c,  A, B)
    for i from 1 to n do
        for j from 1 to n do
            B(i, j) = cA(i, j)
        end do
    end do
```

Analysis (worst case):

Count the number of floating point multiplications.

n^2 elements requires n^2 multiplications.

time complexity is

$$O(n^2)$$

or

quadratic complexity.

• Multiply an n x n *upper triangular* matrix A

$$A(i, j) = 0 \text{ if } i > j$$

by a scalar c to produce the (upper triangular) matrix B.

```
procedure (n, c, A, B)
/* A (and B) are upper triangular */
    for i from 1 to n do
        for j from i to n do
            B(i, j) = cA(i, j)
        end do
    end do
```

Analysis (worst case):

Count the number of floating point multiplications.

The maximum number of non-zero elements in an n x n upper triangular matrix

$= 1 + 2 + 3 + 4 + . . . + n$

or

- remove the diagonal elements (n) from the total (n^2)
- divide by 2
- add back the diagonal elements to get

$$(n^2 - n)/2 + n = n^2/2 + n/2$$

which is

$$n^2/2 + O(n).$$

Quadratic complexity but the leading coefficient is 1/2

- Bubble sort: L is a list of elements to be sorted.

- We assume nothing about the initial order

- The list is in ascending order upon completion.

Analysis (worst case):

Count the number of list comparisons required.

Method: If the jth element of L is larger than the (j + 1)st, swap them.

Note: this is not an efficient implementation of the algorithm

```
procedure bubble (n, L)
/*
    - L is a list of n elements
    - swap  is an intermediate swap location
*/

    for i from n - 1 to 1 by -1 do
        for j from 1 to i do
            if L(j) > L(j + 1) do
                swap = L(j + 1)
                L(j + 1) = L (j)
                L(j) = swap
            end do
        end do
    end do
```

• Bubble the largest element to the 'top' by starting at the bottom - swap elements until the largest in the top position.

• Bubble the second largest to the position below the top.

• Continue until the list is sorted.

n-1 comparison on the first pass

n-2 comparisons on the second pass

.

.

.

1 comparison on the last pass

Total:

$$(n - 1) + (n - 2) + . \ . \ . \ . + 1 = O(n^2)$$

or

quadratic complexity

(what is the leading coefficient?)

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• An algorithm to determine if a function f from A to B is an injection:

Input: a table with two columns:

- Left column contains the elements of A.

- Right column contains the images of the elements in the left column.

Analysis (worst case):

Count comparisons of elements of B.

Recall that two elements of column 1 cannot have the same images in column 2.

One solution:

• Sort the right column

Worst case complexity (using Bubble sort)

$$O(n^2)$$

• Compare adjacent elements to see if they agree

Worst case complexity

$$O(n)$$

Total:

$$O(n^2) + O(n) = O(n^2)$$

Can it be done in linear time?