# What is efficiency in programming?

### Why efficiency is important?

## Types of efficiency

# Space and Time Efficiency

# Our focus - Time

# Techniques to measure time efficiency

### Techniques

- 1. Measuring time to execute
- 2. Counting operations involved
- 3. Abstract notion of order of growth

# 1. Measuring Time

### **Problems with this approach**

Different time for different algorithm	V
Time varies if implementation changes	*
Different machines different time	*
Does not work for extremely small input	*
Time varies for different inputs, but can't establish a relationship	*

## 2. Counting Operations

### COUNTING OPERATIONS

- assume these steps take constant time:
  - mathematical operations
  - comparisons
  - assignments
  - accessing objects in memory loop\*
- then count the number of operations executed as function of size of input

```
def c_to_f(c):
    return c*9.0/5 + 32
def mysum(x):
     total
            in range(x+1):
         total += i
     return total
      mysum \rightarrow 1+3x ops
```

### **Problems with this approach**

Different time for different algorithm	V
Time varies if implementation changes	×
Different machines different time	V
No clear definition of which operation to count	*
Time varies for different inputs, but can't establish a relationship	V

### What do we want

- 1. We want to evaluate the algorithm
- 2. We want to evaluate scalability
- 3. We want to evaluate in terms of input size

# DIFFERENT INPUTS CHANGE HOW THE PROGRAM RUNS

```
a function that searches for an element in a list
def search_for_elmt(L, e):
    for i in L:
        if i == e:
            return True
    return False
```

- when e is first element in the list → BEST CASE
- when e is not in list → WORST CASE
- when look through about half of the elements in list -> AVERAGE CASE

### 3. Orders of Growth

### ORDERS OF GROWTH

#### Goals:

- want to evaluate program's efficiency when input is very big
- want to express the growth of program's run time as input size grows
- want to put an upper bound on growth as tight as possible
- do not need to be precise: "order of" not "exact" growth
- we will look at largest factors in run time (which section of the program will take the longest to run?)
- thus, generally we want tight upper bound on growth, as function of size of input, in worst case

### EXACT STEPS vs O()

```
def fact_iter(n):
    """assumes n an int >= 0"""
    answer = 1
    while n > 1:
        answer *= n
        n -= 1
    return answer
        return answer
```

- computes factorial
- number of steps: 1\*5\*\*1
- worst case asymptotic complexity:
  - ignore additive constants
  - ignore multiplicative constants

### So the idea is simple

```
n^{2} + 2n + 2

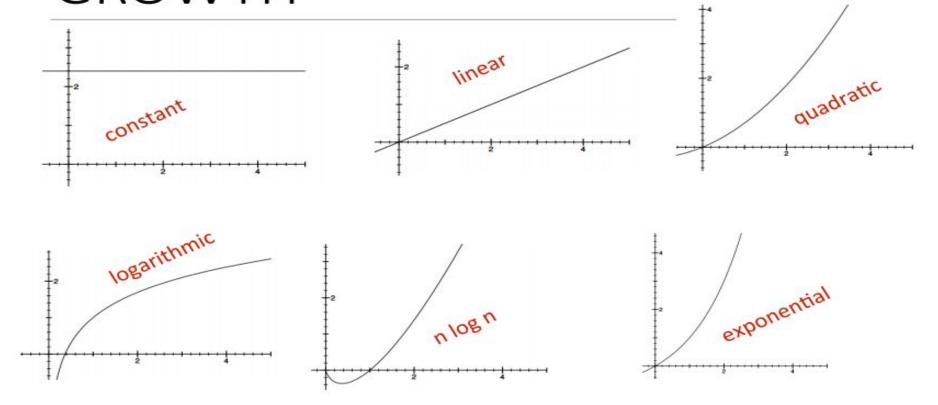
n^{2} + 100000n + 3^{1000}

log(n) + n + 4

0.0001*n*log(n) + 300n

2n^{30} + 3^{n}
```

# TYPES OF ORDERS OF GROWTH



#### Law of addition

### Law of Addition for O():

- used with sequential statements
- O(f(n)) + O(g(n)) is O(f(n) + g(n))
- for example,

```
for i in range(n):
    print('a')
for j in range(n*n):
    print('b')
```

is  $O(n) + O(n*n) = O(n+n^2) = O(n^2)$  because of dominant term

### Law of multiplication

### **Law of Multiplication** for O():

- used with nested statements/loops
- O(f(n)) \* O(g(n)) is O(f(n) \* g(n))
- for example,

```
for j in range(n):

print('a')
O(n) = O(n*n) = O(n-2)
for i in range(n):
```

is  $O(n)*O(n) = O(n*n) = O(n^2)$  because the outer loop goes n times and the inner loop goes n times for every outer loop iter.

### **Complexity Growth**

	CLASS	n=10	= 100	= 1000	= 1000000
	O(1)	1	1	1	1
	O(log n)	1	2	3	6
ì	O(n)	10	100	1000	1000000
	O(n log n)	10	200	3000	6000000
	O(n^2)	100	10000	1000000	100000000000
	O(2^n)	1024	12676506 00228229 40149670 3205376	1071508607186267320948425049060 0018105614048117055336074437503 8837035105112493612249319837881 5695858127594672917553146825187 1452856923140435984577574698574 8039345677748242309854210746050 6237114187795418215304647498358 1941267398767559165543946077062 9145711964776865421676604298316 52624386837205668069376	Good luck!!