Algorithmic complexity: Speed of algorithms

UW CSE 160

Spring 2018

How fast does your program run?

- Usually, this *does not matter*
- Correctness is more important than speed

- Computer time is much cheaper than human time
- The cost of your program depends on:
  - Time to write and verify it
    - High cost: salaries
  - Time to run it
    - Low cost: electricity
- An inefficient program may give you results faster

Sometimes, speed does matter

- Programs that need to run in real time
  - e.g. will my car crash into the car in front of me?
- Very large datasets
  - Even inefficient algorithms usually run quickly enough on a small dataset
  - Example large data set:

    Google:

    67 billion pages indexed (2014)

    5.7 billion searches per day (2014)

    Number of pages searched per day??

Program Performance

We'll discuss two things a programmer can do to improve program performance:

- Good Coding Practices
- Good Algorithm Choice

Good Coding Practices (1)

- Minimize amount of work inside of loops

```
y = 500
for i in range(n):
    z = expensive_function()
    x = 5.0 * y / 2.0 + z
    lst.append(x + i)
```

Move computations that WILL NOT CHANGE outside/above the loop whenever possible.

Good Coding Practices (2)

- Minimize amount of work inside of loops

```
for i in friends_of_friends(n):
    for j in friends_of_friends(n):
        # do stuff with i and j
```

Move computations that WILL NOT CHANGE outside/above the loop whenever possible.

Good Coding Practices (3)

- Avoid iterating over data multiple times when possible

```
for base in nucleotides:
    if base == 'A':
        # code here


for base in nucleotides:
    if base == 'C':
        # code here


for base in nucleotides:
    if base == 'T':
        # code here


for base in nucleotides:
    if base == 'G':
        # code here
```

```
for base in nucleotides:
    if base == 'A':
        # code here


    elif base == 'C':
        # code here


    elif base == 'T':
        # code here


    elif base == 'G':
        # code here
```

Even without the loop, it is more efficient to use the if elif elif than multiple if statements
(Potentially fewer cases will be checked with the elif option vs. the if option where all
four options will always be checked.)

Good Coding Practices (4)

- Expensive operations:
  - Reading files
  - Writing files
  - Printing to the screen
- Try to open the file once and read in all the data you need into a data structure.
- Accessing the data structure will be MUCH faster than reading the file a second time.

Testing and Developing your Program

- Test your program on a SMALL input file.
  - This will allow you to calculate expected results by hand to check for correctness
  - But it can also make your development process easier if you have to wait a shorter time for your program to run

Good Algorithm Choice

- Good choice of algorithm can have a much bigger impact on performance than the good coding practices mentioned.

- However good coding practices can be applied fairly easily

- Trying to come up with a better algorithm can be a (fun!) challenge

- Remember:
  Correctness is more important than **speed!!**

How to compare two algorithms?

- Implement them both in Python
- Run them and time them

A Better Way to Compare Two Algorithms

- Hardware?
  - Count number of "operations" something independent of speed of processor
- Properties of data set? (e.g. almost sorted, all one value, reverse sorted order)
  - Pick the worst possible data set: gives you an upper bound on how long the algorithm will take
  - Also it can be hard to decide on what is and "average" data set
- Size of data set?
  - Describe running time of algorithm as a function of data set size

Asymptotic Analysis

- Comparing "Orders of Growth"
- This approach works <u>when problem size is large</u>
  - When problem size is small, "constant factors" matter
- A few common Orders of Growth:

<u>Example:</u>

- Constant   O(1)   integer + integer
- Linear   O(n)   iterating through a list
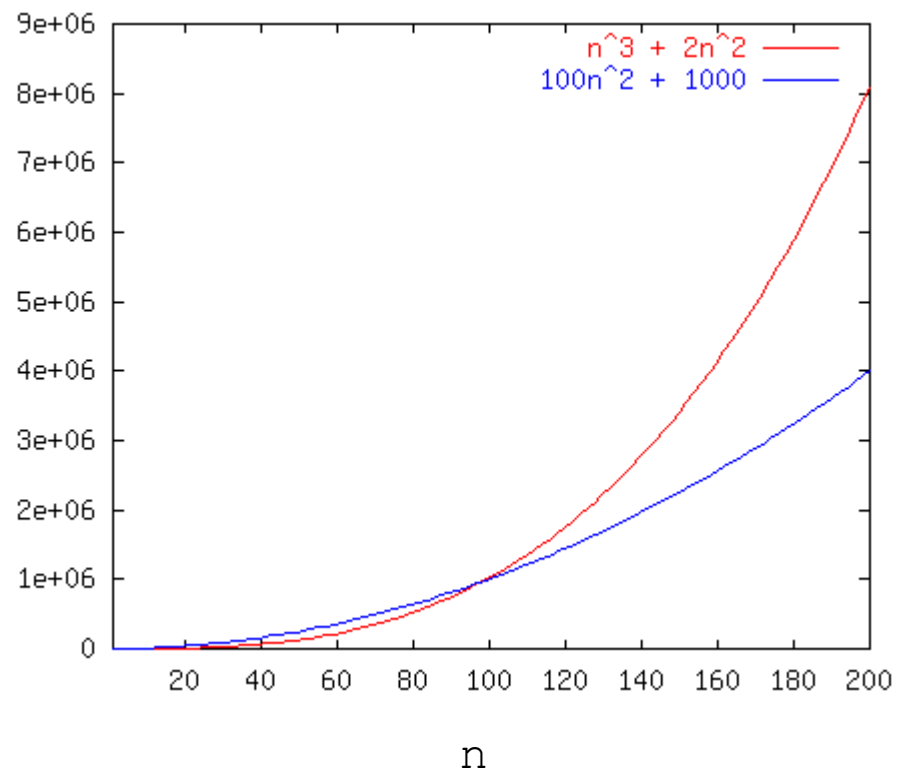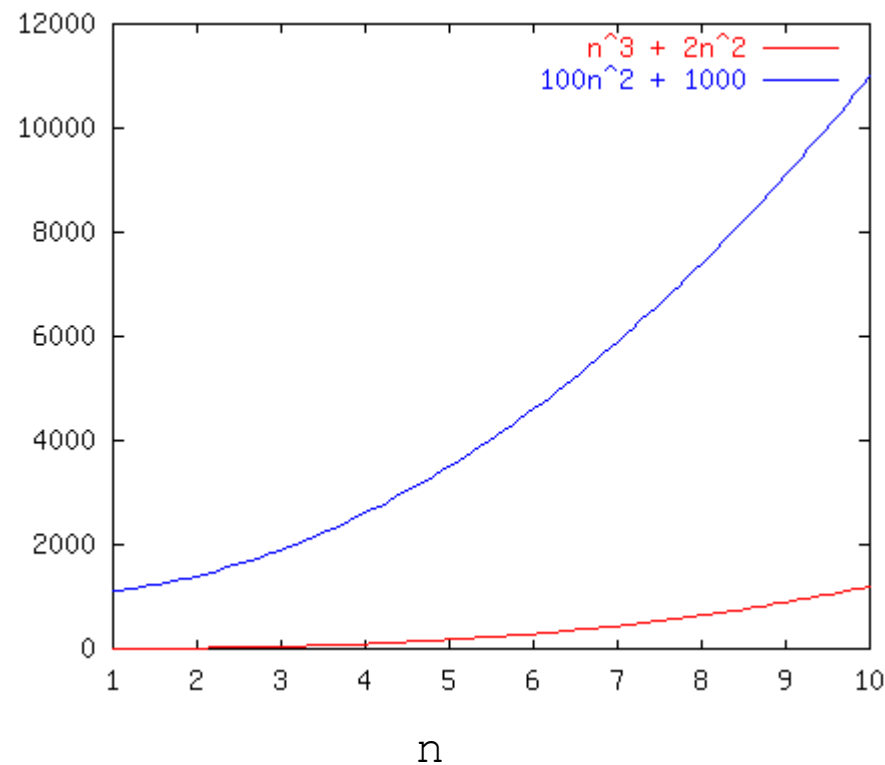- Quadratic   O(n^2)   iterating through a grid

Which Function Grows Faster?

$$O(n^3)$$ $$O(n^2)$$

$$n^3 + 2n^2$$ vs. $$100n^2 + 1000$$

Running Times of Python Operations

<u>Constant Time operations</u>: O(1)
- – Basic Math on numbers (+ - * /)
- – Indexing into a sequence (eg. list, string, tuple) or dictionary
  - • E.g. `myList[3] = 25`
- – List operations: `append, pop`(at <u>end</u> of list)
- – Sequence operation: `len`
- – Dictionary operation: `in`
- – Set operations: `in, add, remove, len`

<u>Linear Time operations</u>: O(n)
- – `for` loop traversing an entire sequence or dictionary
- – Built in functions: `sum, min, max`, slicing a sequence
- – Sequence operations: `in, index, count`
- – Dictionary operations: `keys(), values(), items()`
- – Set operations: `&, |, -`
- – String concatenation (linear in length of strings)

Note: These are general guidelines, may vary, or may have a more costly worst case. Built in functions (e.g. sum, max, min, sort) are often faster than implementing them yourself.

Example: Processing pairs

```
def make_pairs(list1, list2):
    """Return a list of pairs.
    Each pair is made of corresponding elements of list1 and list2.
    list1 and list2 must be of the same length."""
    …


assert make_pairs([100, 200, 300], [101, 201, 301]) == [[100, 101],
[200, 201], [300, 301]]
```

- 2 nested loops vs. 1 loop
- Quadratic (n^2) vs. linear (n) time

Example: Searching

```
def search(value, lst):
    """Return index of value in list lst.
    The value must be in the list."""
    …
```

- Any list vs. a sorted list
- Linear (n) vs. logarithmic (log n) time

Example: Sorting

```
def sort(lst):
    """"Return a sorted version of the list lst.
    The input list is not modified."""
    …

assert sort([3, 1, 4, 1, 5, 9, 2, 6, 5]) == [1, 1,
2, 3, 4, 5, 5, 6, 9]
```

- selection sort vs. quicksort
- 2 nested loops vs. recursive decomposition
- time: quadratic (n^2) vs. log-linear (n log n) time

Note: Calling built in sorting methods sort or sorted in Python has O(n log n) time