# TIMING PROGRAMS, COUNTING OPERATIONS

#### (download slides and .py files to follow along)

6.100L Lecture 21

Ana Bell

#### WRITING EFFICIENT PROGRAMS

- So far, we have emphasized correctness. It is the first thing to worry about! But sometimes that is not enough.
- Problems can be very complex
- But data sets can be very large: in 2014
   Google served
   30,000,000,000,000
   pages covering
   100,000,000 GB
  - of data

### EFFICIENCY IS IMPORTANT

- Separate time and space efficiency of a program
- Tradeoff between them: can use up a bit more memory to store values for quicker lookup later
  - Think Fibonacci recursive vs. Fibonacci with memoization
- Challenges in understanding efficiency
  - A program can be **implemented in many different ways**
  - You can solve a problem using only a handful of different algorithms
- Want to separate choice of implementation from choice of more abstract algorithm

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#### EVALUATING PROGRAMS

- Measure with a timer
- Count the operations
- Abstract notion of order of growth

#### ASIDE on MODULES

- A module is a set of python definitions in a file
  - Python provides many useful modules: math, plotting/graphing, random sampling for probability, statistical tools, many others
- You first need to "import" the module into your environment

```
import time
import random
import dateutil
import math
```

 Call functions from inside the module using the module's name and dot notation

```
math.sin(math.pi/2)
```

## TIMING

#### **TIMING A PROGRAM**

- Use time module import time
- Recall that importing means to bring in that class into your own file

def c to f(c): Seconds since the epoch: Jan 1, 1970 return c\*9.0/5 + 32

- Start clock
- Call function
- Stop clock

- tstart = time.time()
- c to f(37)
  - dt = time.time() tstart

print(dt, "s,")

#### TIMNG c\_to\_f

Very fast, can't even time it accurately

c\_to\_f(1) took 0.0 seconds c\_to\_f(10) took 0.0 seconds c\_to\_f(100) took 0.0 seconds c\_to\_f(1000) took 0.0 seconds c\_to\_f(10000) took 0.0 seconds c\_to\_f(100000) took 0.0 seconds c\_to\_f(1000000) took 0.0 seconds c\_to\_f(1000000) took 0.0 seconds

#### TIMING mysum

- As the input increases, the time it takes also increases
- Pattern?
  - 0.009 to 0.05 to 0.5 to 5 to ??

```
mysum(1) took 0.0 sec
mysum(10) took 0.0 sec
mysum(100) took 0.0 sec
mysum(1000) took 0.0 sec
mysum(10000) took 0.0019927024841308594 sec
mysum(100000) took 0.009970903396606445 sec
mysum(1000000) took 0.05089521408081055 sec
mysum(1000000) took 0.4966745376586914 sec
mysum(10000000) took 5.688449382781982 sec
```

#### TIMING square

- As the input increases the time it takes also increases
- square called with 100000 did not finish within a reasonable amount of time
- Maybe we can guess a pattern if we are patient for one more round?

square(1) took 0.0 sec square(10) took 0.0 sec square(100) took 0.0 sec square(1000) took 0.06244492530822754 sec square(10000) took 5.553335428237915 sec

#### TIMING PROGRAMS IS INCONSISTENT

- GOAL: to evaluate different algorithms
- Running time should vary between algorithms
- **X** Running time **should not vary between implementations**
- Running time should not vary between computers
- **X** Running time **should not vary between languages**
- **Running time is should be predictable** for small inputs
  - Time varies for different inputs but cannot really express a relationship between inputs and time needed
  - Can only be measured a posteriori

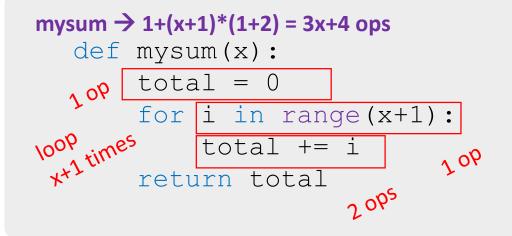


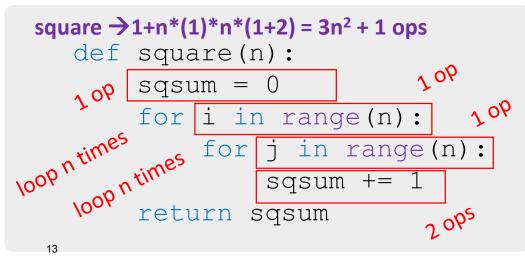
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## COUNTING

#### COUNTING OPERATIONS

- Assume these steps take constant time:
  - Mathematical operations
  - Comparisons
  - Assignments
  - Accessing objects in memory
- Count number of operations executed as function of size of input





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#### COUNTING c\_to\_f

No matter what the input is, the number of operations is the same

c\_to\_f(100): 3 ops, 1.0 x more c\_to\_f(1000): 3 ops, 1.0 x more c\_to\_f(10000): 3 ops, 1.0 x more c\_to\_f(100000): 3 ops, 1.0 x more c\_to\_f(1000000): 3 ops, 1.0 x more c\_to\_f(1000000): 3 ops, 1.0 x more

#### COUNTING mysum

As the input increases by 10, the number if operations ran is approx. 10 times more.

mysum(100): 304 ops, 1.0 x more mysum(1000): 3004 ops, 9.88158 x more mysum(10000): 30004 ops, 9.98802 x more mysum(100000): 300004 ops, 9.9988 x more mysum(1000000): 3000004 ops, 9.99988 x more mysum(1000000): 3000004 ops, 9.99999 x more

#### COUNTING square

 As the input increases by 10, the number of operations is approx.
 100 times more.

square(1): 5 ops, 1.0 x more square(10): 311 ops, 62.2 x more square(100): 30101 ops, 96.78778 x more square(1000): 3001001 ops, 99.69772 x more square(10000): 300010001 ops, 99.96998 x more

As the input increases
 by 2, the number of
 operations is approx.
 4 times more.

square(128): 49281 ops, 1.0 x more
square(256): 196865 ops, 3.99474 x more
square(512): 786945 ops, 3.99738 x more
square(1024): 3146753 ops, 3.99869 x more
square(2048): 12584961 ops, 3.99935 x more
square(4096): 50335745 ops, 3.99967 x more
square(8192): 201334785 ops, 3.99984 x more

### COUNTING OPERATIONS IS INDEPENDENT OF COMPUTER VARIATIONS, BUT ...

- GOAL: to evaluate different algorithms
- Running "time" should vary between algorithms
- Running "time" should not vary between implementations
  - Running "time" should not vary between computers
- Running "time" should not vary between languages
- Running "time" is should be predictable for small inputs
- No real definition of which operations to count
  - Count varies for different inputs and can derive a relationship between inputs and the count



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#### ... STILL NEED A BETTER WAY

- Timing and counting evaluate implementations
- Timing and counting **evaluate machines**
- Want to evaluate algorithm
- Want to evaluate scalability
- Want to evaluate in terms of input size



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