This 4-hour course is updated at
https://github.com/JeremyCoxBMI/PythonDataStructures

Data Structures for "Non-programmers"

We all write programs, but few of us have experience as a Software Developer and some of us don't have a CS Bachelor's. We're students learning this stuff.

A key piece of feedback from BMI research professors is that many students do not have knowledge of data structures, which is critical to their work. Data Structures is the third class of three in the Undergraduate Computer Science curriculum, which makes it inaccessible to any graduate student who has not already completed it.

Learn everything YOU NEED to know as a "non-programmer" about data structures in two 2-hour sessions!
Come and learn

a. Understand the fundamental principles of data structures
b. Apply fundamental principles to your work
c. Know when to ask for help (and what to say)!

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## Lecture Outline

A. For next week
   a. https://www.python.org/
   b. Put it on laptop: Downloads → Get Python 2.7 NOT Python 3.5
B. Goals for class
   a. Understand fundamental principles of data structures
   b. Apply fundamental principles to your work
   c. Know when to ask for help (and what to say)!
   d. NOT a goal for you to be algorithms or data structures expert
C. Vocabulary
   a. Data Structure is how we store information + associated functions
      i. Data structures have advantages and disadvantages.
   b. Implementation is a specific approach to represent the data structure.
      i. Implementations introduce new advantages and disadvantages.
   c. Programming Language specific details can impact implementation
      i. Languages also have advantages and disadvantages. You may pick a language because it is better to implement something.

d. Container – simplest data structure
e. Model of computing: I am the computer, and the white board is my memory
    i. ACTIVITY: demonstrate Linked List

D. Fundamentals of Data Structures
a. Understand the basics, so you know when you are in trouble before you are in big trouble.
    i. How to know the program works correctly and how long it will take to run.

b. Four resources
    i. CPU $
    ii. Memory $$
    iii. Disk space $$$
    iv. Programmer Time. $$$$$$$$$$$$$$$$$$$$
        1. (Most valuable: enter the naïve algorithm). $$$

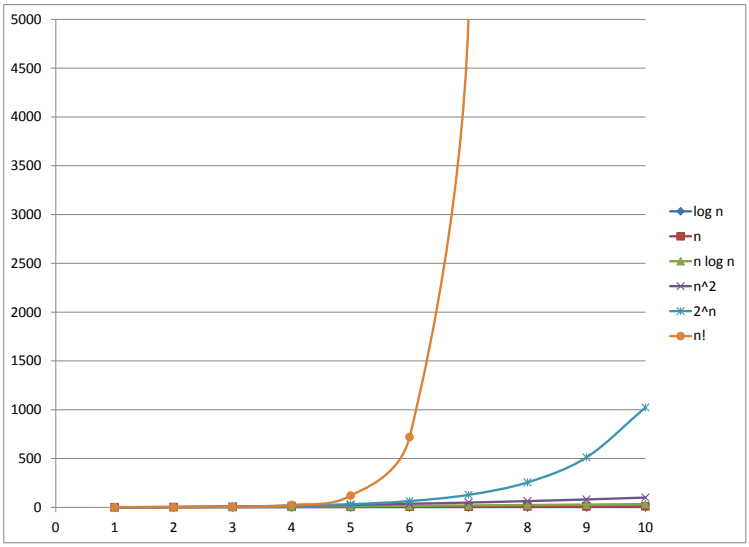
c. Algorithm
    i. Strategy to solve a problem and get a correct answer.
    ii. We know how to solve most problems, but almost all are "incalculable."
        1. Example: chess and Big Blue 1989 (start), 1995 (prototype), 1996 (loss), 1997 (win vs Kasparov)
    iii. Some solutions are better than others. However, usually different solutions are better suited in different situations. Now we have choices.

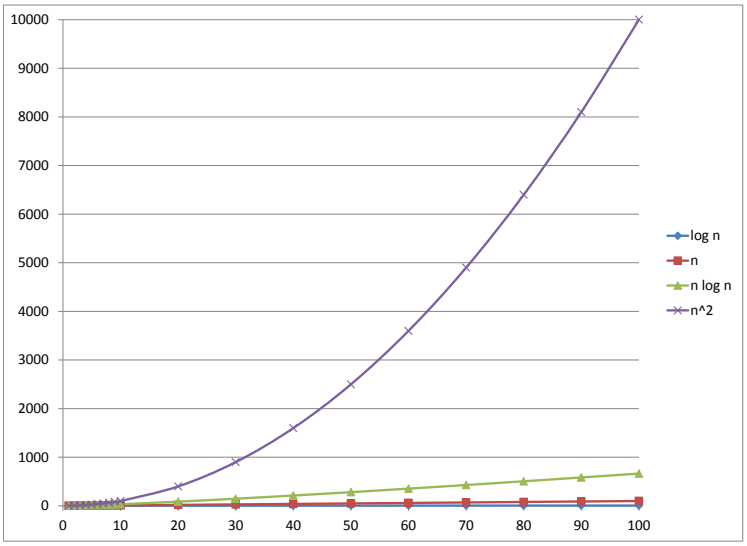
d. How do you choose? PRIMARY REASON to study data structures is to know strengths and weaknesses and to pick the right tool for the job.
    i. Your goal for this class is (1) to be able to know what data structure is being used (2) ability to look it up in a "book" and know what it's weaknesses are (3) when to ask for help from a CS professional.
    ii. Demonstration of sorted list, guess sorted list, list, heap

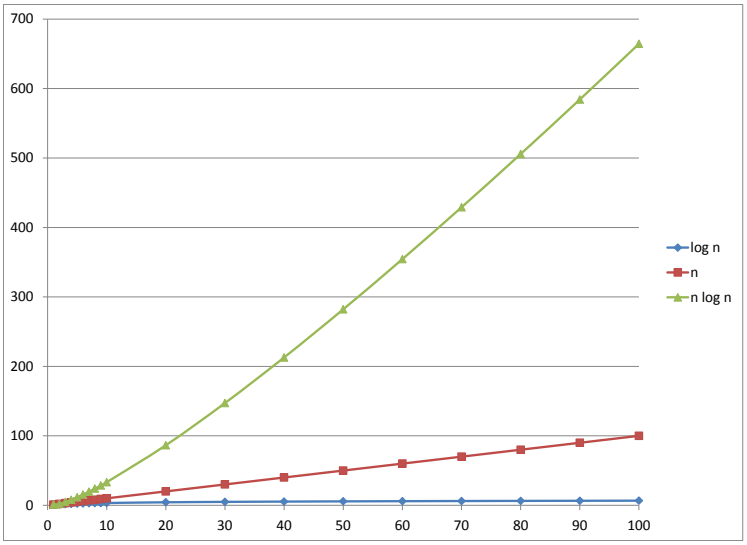
e. Introduce O(n) notation
    i. Relative number of computations. (This is a rough, not precise measure)
        1. Simplify: HOW MUCH TIME, keep time spent to a minimum
    ii. WORST-CASE: what does worst-case mean?
        1. example: bubble sort → O(n^2) or is it (n^2)/2?
        2. do you always want to design for the worst case scenario?
        3. for bubble sort: worst case is a reverse list -- but why?
            a. (this insight lead to quick sort)
    iii. $1 < \log(n) < n < \log(n^2) < \ldots < \log(n^C) < n^C < n! < C^n < P(n,r)$
        1. C is a constant
        2. Going over n^2 is undesirable

3. Geometric or combinatorial – unsustainable

iv. Best case and average case exist, although I am not certain there is a universal notation. Sometimes Θ (best) and Ω (average) are used (Wikipedia).






E. Compare three containers

| | Write insert() | Read contains()? | Space required | Comments |
|---|---|---|---|---|
| List | O(1) | O(n) | n | |
| Heap | O(log n) | O(log n) | n | fixed maximum size |
| Sorted List | O(n) | O(log n) | n | |

a. Which applications belong to which?[1]
   i. Grocery List
   ii. Priority Queue (Wife's Honey-do list, Tasks at Work)
   iii. Patients in a data table
b. Do board exercises, where we add things to list, heap, and sorted list. (Do we want a max-heap or a min-heap?)
c. Heap is "partially sorted" so you can ONLY READ first value, you don't know where the 15th value is.

F. When to ask for help
   a. How long will my program run?
   b. I need a faster algorithm
   c. I am using too much memory
   d. I can't figure out the algorithm
   e. I can't get it to work right
   f. I got a weird compiler/interpreter error
      i. Computers sometimes make mistakes (Shh! It's a secret.)

G. How to get help: <u>bring the details</u>

[1] Heap has limited sort property, always know what maximum is.

a. Don't ask me "will my program finish before Christmas?" without details.
    i. Get help long before this point
b. If I had a nickel for someone asking me this simple question, "Why doesn't my program work?"
c. Can you clearly define what are you trying to compute?
    i. As simple as "converting A -> B"
    ii. It is very common that this is not clear. Getting this clear is essential.
    iii. This question drives me crazy. "Can you go try this program on our data?"
d. What data structure and algorithm are you using? Why?
e. What is your theoretical and observed O() function?
f. What is going wrong?
    i. Bad computation
    ii. Speed (too slow)
    iii. Memory (too much)
    iv. Does it happen only in some circumstances? (does it ever work?)

H. Fun With Arrays and Pointers
a. Fixed (or Static) vs Dynamic memory
    i. Array vs Linked List
    ii. Static Memory -- very stable, fixed size
    iii. Dynamic memory – slightly unstable, prone to misbehavior
    iv. Compare Array and Linked List
        1. Both implement the idea of a list of numbers.
        2. Besides size difference, how do they compare on
            a. insert()
            b. get()
    v. Talk about implementing a Heap as an Array or Tree
    vi. Garbage Collection
        1. C and C++ language allow direct dynamic memory control.
            a. Good to micromanage if you need to. But if you don't it's a big hassle. Programmer time: $$$$$
        2. Other commonly used languages do this automatically.
b. Arrays are pointers
    i. 0-index math and memory
    ii. Let's resize an array to
c. Implement my list from before as
    i. Array is fixed length
    ii. Linked list takes more memory, O(n) time to access nth member.

I. Data structure: Map
a. Maps can be built in many ways
b. Math: Map stores (x, f(x)), and lets you lookup f(x) given an x.

c. Programming: a Data Structure

J. Case Study in building the KLUE map
   a. How do you store the map in memory?
      i. My map is huge, so I don't want to waste memory
      ii. Problem: one to many relationship
      iii. Can we save by not writing down keys?
      iv. Could make a list of pairs
         1. key is static
         2. value is dynamic, unknown length
   b. Building a Map in Java
      i. Map Long to List<Long> (DYNAMIC)
         1. HashMap stores separately
            a. a list of keys
            b. a hash table to pointers to values
         2. Problem is that values change size.
            a. costs time
         3. Problem: memory fragmentation. 50% I lose all benefit.
            a. It's actually worse, the garbage collector goes apeshit
      ii. Solution:
         1. Store heap as an array of all (key, value) pairs (STATIC)
         2. When heap is full,
            a. Output in order as dump to disk
            b. Destructive In-place Heapsort
         3. Later, combine the databases