Java lists, maps and not only...

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2019-10-22

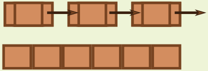
Outline

Introduction

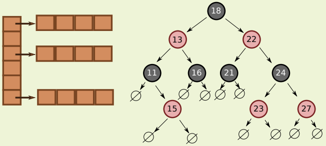
- We're going to have some fun with lists and maps
- Lists and maps are **basic** data structures, and in this context "Basic" means *being a base of everything else*

The plan

Lists



Maps



$$\sum_{\infty}^{n=1}$$

$$0 < \left| \lim_{x \to \infty} \frac{f(x)}{g(x)} \right| < \infty$$

Algorithm analysis

The Big O, Ω, Θ notation

When there exists $n_0 > 0$ and $c > 0$ for which we can say that:

$$\forall n > n_0 \; f(n) \leq c \cdot g(n)$$

we say that f is big-O g and write $f(x) = O(g(x))$

When there exists $n_0 > 0$ and $c > 0$ for which we can say that:

$$\forall n > n_0 \; f(n) \geq c \cdot g(n)$$

we say that f is big-Ω g and write $f(x) = \Omega(g(x))$

The Big Θ notation

When we can say that $f(x) = O(g(x)) \wedge f(x) = \Omega(g(x))$ we say that f is Big Θ g and write:

$$f(x) = \Theta(g(x))$$

Examples

- Given $g(x) = x^2$ and $f(x) = 3x^2 + 4$ we can say that $f(x) = O(g(x))\dots$
- Given $g(x) = x^3$ and $f(x) = 100x^2 + 4x^3$ we can say that $f(x) = O(g(x))\dots$
- Given $g(x) = 2^x$ and $f(x) = 2^x + x^{64}$ we can say that $f(x) = O(g(x))\dots$

We can also easily say that $x^2 = O(2^x)$, and $x^2 = \Omega(1)$ but it is not very interesting. This observation is very weak. We are rather interested in finding the closest matches.

Θ sufficient condition

The most interesting is finding the simple in form, but exact, match of the function. This match is symbolised by Θ.

$$f(x) = O(g(x)) \land f(x) = o(g(x)) \Longrightarrow f(x) = \Theta(g(x))$$

If $f(x) = \Theta(g(x))$, it means that f is grows asymptotically as fast as g.
Sufficient condition for $f(x) = \Theta(g(x))$ is:

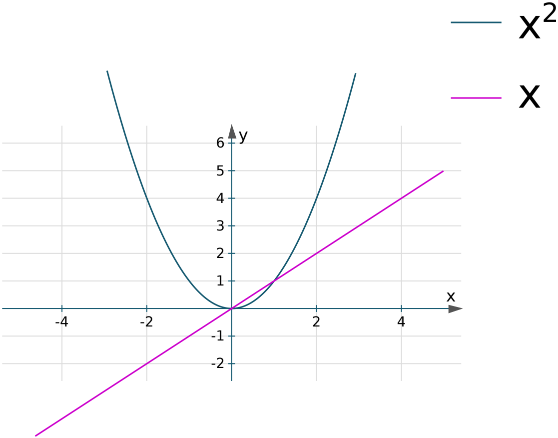
$$0 < \lim_{x \to \infty} \left| \frac{f(x)}{g(x)} \right| < \infty$$

Some things that programmers usually know

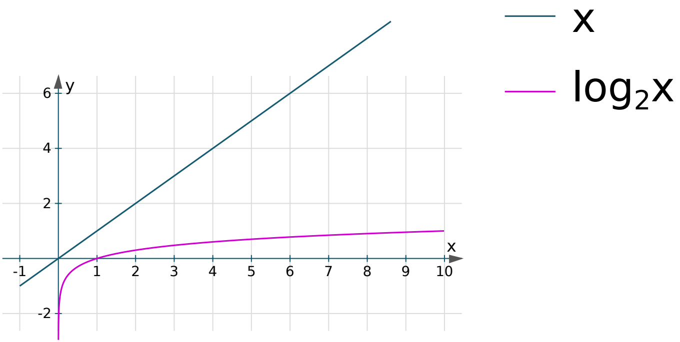
We use given notation extensively to describe algorithm time of execution (and memory consumption). Hence for us (generally):

- x^2 is worse than x
- x is worse than $\log x$
- 2^x is worse than x^{16} and it's bad
- $x!$ – it's so much, we don't distinguish between $x!$ and 2^x. Those are equally BAD.
- We often don't distinguish between logarithm and exponential bases

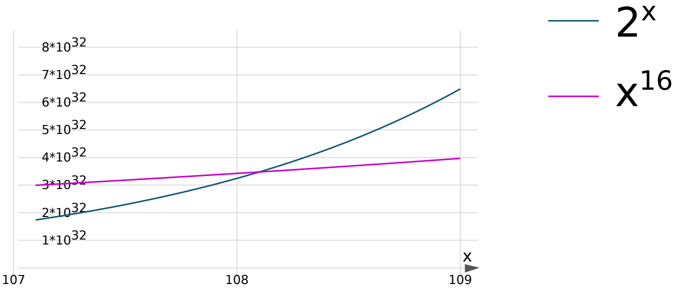
Examples



Examples



Examples


8*10^32
7*10^32
6*10^32
5*10^32
4*10^32
3*10^32
2*10^32
1*10^32
x
107
108
109
2^x
x^16

Worst case scenario

Programmers also consider worst case (pessimistic) scenarios of algorithms and their complexity. Some algorithms work very slow on some special cases of input data. E.g. **quicksort**, despite of being $O(n \cdot \log n)$ runs at n^2 time, when in every partitioning selected pivot divides data to lengths: 1 and rest.
Having that in mind, we can select, for example, **heapsort**, which has worst case running time still $n \cdot \log n$

Need to know by heart

- *All arrays and lists in Java are indexed from 0!!!*

ArrayList

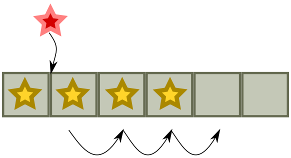
- Allocated as a one block in memory (more "array-ish" than "list-ish")
- Quick "please get me an element at position n" (further referred to as **get**): $\Theta(1)$
- Slow "please insert element at position n, moving all following elements to the right" (further referred to as **insert**): $O(n)$
- Slow "please delete element at position n, moving all following elements to the left" (further referred to as **delete**): $O(n)$

ArrayList

- Quick **append** - a special-case of the insert at the last place, i.e. when for n equal number of elements: $\Theta(1)$, but only when the underlying array size is $N > n + 1$
- When ArrayList is full, to perform insert we need to expand underlying array. We do it by increasing size by twice the current size.
- Is really the **append** operation $\Theta(1)$???

ArrayList pros and cons

- Insert at an arbitrary place costs n operations for $n = s - i$ where s is number of items and i is the position we insert at.



Amortised cost. Amortised analysis

- We analyse amortised cost of operations amortised by their number.
- Amortised cost for given $f(n)$ is $F(n)$ that:

$$F(n) = \frac{T(n)}{n}$$

where

$$T(n) = \sum_{x=0}^{n} f(x)$$

Amortised cost. Amortised analysis

- For array initialised to 2, in the **append** operation we have cost:

$$1, 1, n_1 = 2, 1, 1, n_2 = 4, 1, 1, 1, 1, n_3 = 8$$

  where n_x is n-th resize cost equals array's size at the moment of resize.

- If we use an accounting method to tell that every operation, we put additional 2 operations' time on a special account, for a later use, we can reuse that time at critical sections of resizing. Our account state is then:

Amortised cost. Amortised analysis

Operation	Account state
+2	2
+2	4
-2	2
+2	4
+2	6
-4	2
+2	4
+2	6
+2	8
+2	10
-8	2

Table 1: Amortised analysis using accounting method

Amortised cost. Amortised analysis

SVG Animation for the amortised cost accounting method

Amortised cost. Amortised analysis

- In this case we say that operation **append** on ArrayList is $O(1)$ and keep in mind that sometimes it can stop our system for a very long time. So if we want to get overall computation time fit, we can allow us to expand a very large ArrayList, but when we are low-latency needers, we might need to search for a better solution.

LinkedList

- Allocated as linked list of many objects
- Every inserted object needs a wrapper object, so the number of objects in memory are at least **twice** the number of elements in list.
- Fast **append**: $\Theta(1)$
- Fast **insert** but only when given a **preceeding node** in the list.
- Fast **delete** but under the same conditions as **insert**
- Slow **get**: $O(n)$
- Does not need to grow - **append** is not lagging from time to time.

LinkedList - pros

- LinkedList implements `Deque` which gives us nice stack and fifo methods: `pollFirst`, `pollLast`, `peekFirst`, `peekLast`

LinkedList - cons

- Every item in LinkedList is of a class LinkedList.Item which has much overhead.

mark hash gcAge tLock tId	klassPtr ref to class	length length ptr	padding
4-8 bytes	4-8 bytes	4 bytes	up to mod arch

How much do the object weight in Java

```
class A { }

class B extends A { }

class C {
    boolean a;
}
```

How much do the object weight in Java - compressed pointers

java -XX:+UseCompressedOops

```
sizeof A = 16
sizeof B = 16
sizeof C = 16
sizeof Boolean = 16
sizeof Char = 16
sizeof Integer = 16
sizeof Long = 24
sizeof class java.util.LinkedList$Node = 24
```

How much do the object weight in Java - *not* compressed pointers

java -XX:-UseCompressedOops

```
sizeof A = 16
sizeof B = 16
sizeof C = 24
sizeof Boolean = 24
sizeof Char = 24
sizeof Integer = 24
sizeof Long = 24
sizeof class java.util.LinkedList$Node = 40
```

HashMap

- Fast finding element by the key (further referred to as: **lookup**): $O(1)$.[1]
- Fast putting a key-value pair (further referred to as: **insert**): ($O(1)$, pessimitically $n = \mathrm{size}$, when map needs to grow.
- Fast remove: $O(1)$ (HashMap does not shrink).
- Values with the same hash stored in *LinkedList*, collisions may occur.

[1] When time is longer, in properly setup map (i.e. number of buckets $>$ size), it means that collisions occur. This can be the sign of incorrect hash function.

HashMap

$$x.\mathrm{equals}(y) \implies x.\mathrm{hashCode}() == y.\mathrm{hashCode}()$$

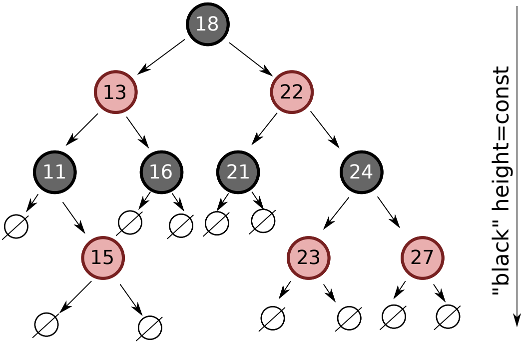
$$x.\mathrm{hashCode}() == y.\mathrm{hashCode}() \not\Longrightarrow x.\mathrm{equals}(y)$$

TreeMap

- Implemented by Red-Black tree.
- Keys are sorted.
- Quite good lookup: $O(\log n)$
- Quite good insert: $O(\log n)$
- Quite good delete: $O(\log n)$
- Memory consumption: $O(n)$.

Red-black tree

For each path count of black nodes ("black length") is constant



Algorithms visualised

https://www.cs.usfca.edu/~galles/visualization/java/visualization.html

Excercise 1

- Open the project, and enter the t1 package
- in `src/`*main*`/java/t1` we have code that we need to fix
- in `src/`*test*`/java/t1` we have tests that need to pass
- Please implement FIFOQueue using appropriate Java's list implementation
- Please implement LIFOQueue using appropriate Java's list implementation
- What happens when we change the selected implementation of list to another? Does the test still pass? What is the difference

Excercise 2

- see `src/`*main*`/java/t2` and `src/`*test*`/java/t2`
- First ocus on `first_exercise_testGBPtoPLN`
- why there is no such currency conversion, providing that we have added it in the map in `initStatic()` method?
- Next focus on `second_excercise_testPLNtoGBP`
- Why the test is failing? What is the printed result?

Excercise 3

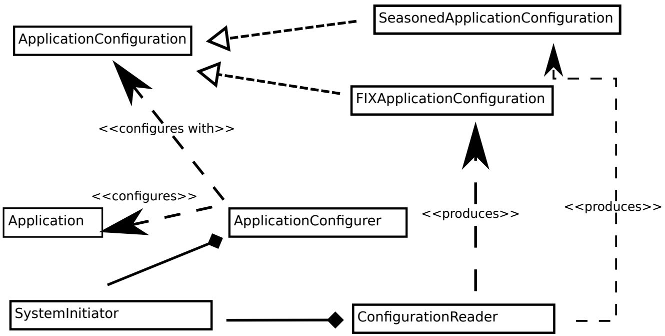
- see `src/`*main*`/java/t3` and `src/`*test*`/java/t3`
- List must not grow, must throw proper exceptions.
- List must contain the java's Array as as storage for the items
- How to initialize the storing array for any T? Why `new T[]` is not working?

Excercise 4

- see `src/`*`main`*`/java/t4` and `src/`*`test`*`/java/t4`
- Why the assertNull does not work?

Excercise 5

- see `src/`*`main`*`/java/t5` and `src/`*`test`*`/java/t5`
- Uncomment code in the test
- Why the code does not compile? How can we fix it?



Excercise 6

- see `src/`*main*`/java/t6` and `src/`*test*`/java/t6`
- `testRunningTimeEasy` - focus on time of execution, why it is so slow
- `testMemEfficiencyEasy` - focus on time of execution, why it is so slow