Java lists, maps and not only...

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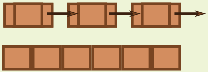
Outline

Introduction

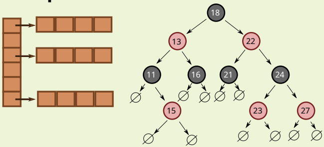
- Java collections are sophisticated implementations of algorithms for storing data (see also Cormen's "Introduction to algorithms")
- All collections implement iteration
- Lists are implemented as sequential collections backed by arrays and linked lists
- Sets, besides iteration, are also allowing checking if the item is present.
- Maps are associative containers which allow quick access by object-key (any object, also other than integer).
- Trees are underlying some implementations of Maps and Sets
- Lists maintain item order while it is not guaranteed in Sets and Maps.

The plan

Lists



Maps



$$\sum_{\infty}^{n=1} \qquad 0 < \left| \lim_{x \to \infty} \frac{f(x)}{g(x)} \right| < \infty$$

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

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.

$$f(x) = O(g(x)) \wedge f(x) = o(g(x)) \implies f(x) = \Theta(g(x))$$

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:

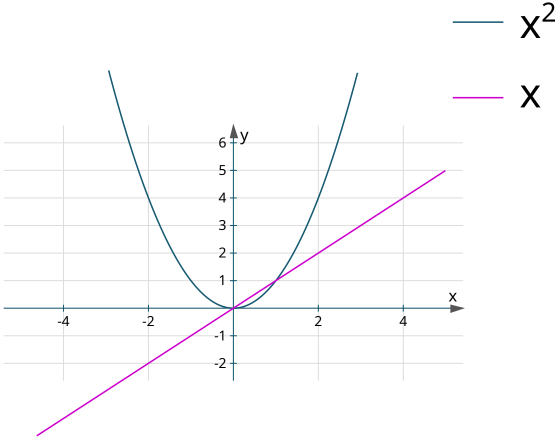
$$0 < \lim_{x \to \infty} \left| \frac{f(x)}{g(x)} \right| < \infty$$

Some things that programmers usually know

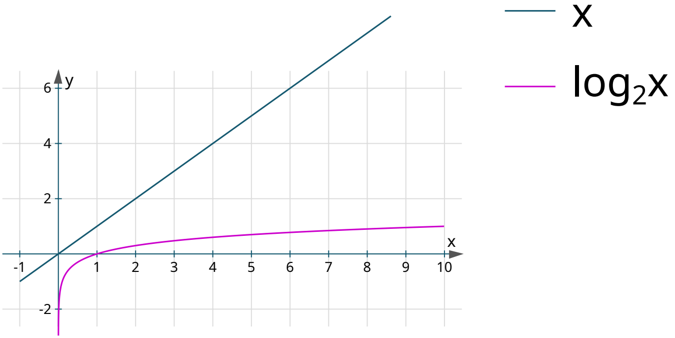
We use given notation extensively to describe algorithm time of execution (and memory consumption). Hence for us (generally):

- 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

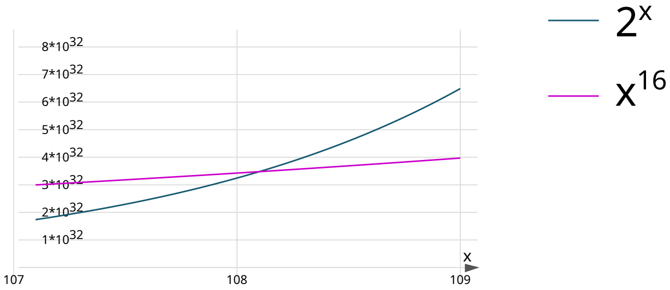
Examples



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
107
108
109
x
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

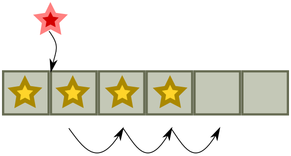
- Allocated as a one block in memory (more “array-ish” than “list-ish”)
- Quick “please get me an element at position *n*” (further referred to as **get**): $\Theta(1)$
- Slow “please insert element at position *n*, moving all following elements to the right” (further referred to as **insert**): $O(n)$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

Generics and wildcards

```java
public void addToList(List<? extends Number> lst) {
  Number item1 = lst.get(0);
  lst.add(3);
}

List<Float> floatList = ...;
addToList(floatList);
```

Generics and wildcards

```java
public void addToList(List<? extends Number> lst) {
  Number item1 = lst.get(0); // ok
  lst.add(3); // error
}

List<Float> floatList = ...;
addToList(floatList);
```

Generics and wildcards

```java
public void addToList(List<? super Integer>) {
  Integer i = lst.get(0);
  lst.add(4);
}

List<Number> numberList = ...;
addToList(numberList);
```

Generics and wildcards

```java
public void addToList(List<? super Integer>) {
  Integer i = lst.get(0); // error
  lst.add(4); // ok
}

List<Number> numberList = ...;
addToList(numberList);
```

Generics and wildcards

```
// https://stackoverflow.com/questions/4343202

public class Collections {
    public static <T> void copy(List<? super T> dest,
   List<? extends T> src) {
        for (int i = 0; i < src.size(); i++)
            dest.set(i, src.get(i));
    }
}
```

Type erasure

```java
public class Node<T> {
    private T data;
    private Node<T> next;

    public Node(T data, Node<T> next) {
        this.data = data;
        this.next = next;
    }

    public void setData(T data) {
        this.data = data;
    }

    public T getData() {
        return data;
    }
}

public class Main {
    public static void main(String[] args) {
        Node<Integer> node = new Node<>(10, null);
        Integer i = node.getData();
        node.setData(20);
    }
}
```

```java
public class Node {
    private Object data;
    private Node next;

    public Node(Object data, Node next) {
        this.data = data;
        this.next = next;
    }

    public void setData(Object data) {
        this.data = data;
    }

    public Object getData() {
        return this.data;
    }
}

public class Main {
    public Main() {
    }

    public static void main(String[] args) {
        Node node = new Node(10, (Node)null);
        Integer i = (Integer)node.getData();
        node.setData(20);
    }
}
```

Figure 5: Type erasure

Type erasure

- Replace unbound type E with Object
- Add typecasting to all method calls
- Object has no information of type it was created with[1]
- `ClassCastException` will be called if contraints are violated

[1] except for class that inherits type-specified generic

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

Remove all strings containing letter a

```java
List<String> lst = new ArrayList<>();
lst.addAll(Arrays.asList("marek","basia","kotek","paw"
    ));
// remove all words containing letter a
```

Remove all strings containing letter a

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for (String l : lst) {
    if (l.contains("a")) {
        lst.remove(l);
    }
}
```

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List<String> lst = new ArrayList<>();
lst.addAll(Arrays.asList("marek","basia","kotek","paw"
    ));
// remove all words containing letter a
for (String l : lst) { //
    ConcurrentModificationException
     if (l.contains("a")) {
         lst.remove(l);
     }
}
```

ListIterator

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
```

How much do the object weight in Java

```
public class C1 {
  boolean a;
  int b;
} // size 24

public class C2 {
  boolean a;
  int b;
  int c;
} // size 24

public class C3 {
  boolean a;
  int b;
  int c;
} // size 32
```

HashMap

- Fast finding element by the key (further referred to as: **lookup**): $O(1)$.[2]
- 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.

[2]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

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

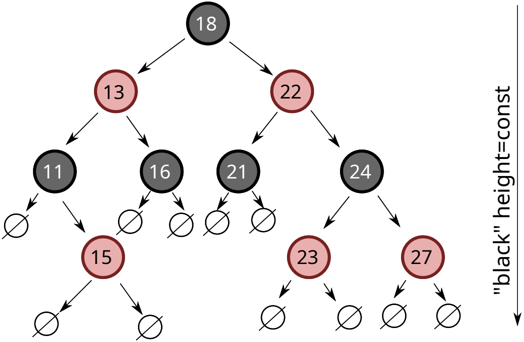
$$x.\mathrm{hashCode}() == y.\mathrm{hashCode}() \not\Longrightarrow x.\mathrm{equals}(y)$$

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

How to write tests

- Create test that checks constraint on empty or broken code
- Run the test to confirm that it fails (if it passes, the checks are incorrect)
- During the test compilation it might be needed to create more empty methods - this is the Development part in TDD
- Fix the code and fill the empty methods
- Tests should pass

Excercise 1

- Open the project, and enter the `t1` package
- in `src/`*`main`*`/java/t1` we have code that we need to fix
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- FIFO queue is First-In-First-Out. Whatever is put first, should come out first.

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- Run the efficiency test `PerformanceTestsForT1` - all should

Excercise 2

- see `src/`*`main`*`/java/t2` and `src/`*`test`*`/java/t2`
- First focus on `first_exercise_testGBPtoPLN` - right click on the test name and *run testname*.

Excercise 2

- see `src/`*main*`/java/t2` and `src/`*test*`/java/t2`
- First focus on `first_exercise_testGBPtoPLN` - right click on the test name and *run testname*.
- why there is no such currency conversion, providing that we have added it in the map in `initStatic` method?

Excercise 2

- see `src/main/java/t2` and `src/test/java/t2`
- First focus on `first_exercise_testGBPtoPLN` - right click on the test name and *run testname*.
- 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`

Excercise 2

- see `src/main/java/t2` and `src/test/java/t2`
- First focus on `first_exercise_testGBPtoPLN` - right click on the test name and *run testname*.
- 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

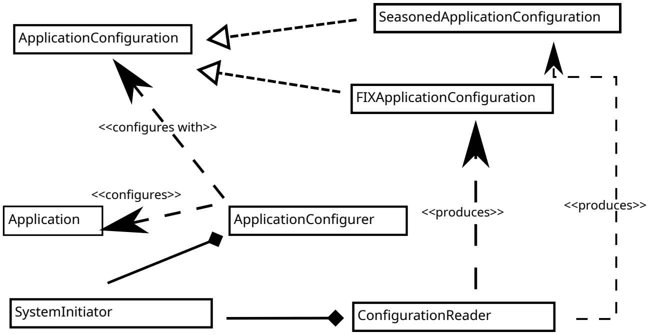
- see `src/`*main*`/java/t3` and `src/`*test*`/java/t3`
- List must not grow, must throw proper exceptions.
- List must contain the java's Array as as storage for the items
- How to initialize the storing array for any T? Why `new T[]` is not working?

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

Excercise 6

- see `src/`*main*`/java/t6` and `src/`*test*`/java/t6`
- `testRunningTimeEasy` — focus on time of execution, why it is so slow
- `testMemEfficiencyEasy` — try to experiment with memory and drop the required by test below 42. You will see the test fails.

Excercise 6

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- `testMemEfficiencyEasy` — try to experiment with memory and drop the required by test below 42. You will see the test fails.
- `testMemEfficiencyIntermediate` — try to achieve the 32 MB memory by using list other than LinkedList

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- `testMemEfficiencyEasy` — try to experiment with memory and drop the required by test below 42. You will see the test fails.
- `testMemEfficiencyIntermediate` — try to achieve the 32 MB memory by using list other than LinkedList
- `testMemEfficiencyExpert` – try to achieve 26 MB by initializing the list with the number of items known a priori.

Excercise 6

- see `src/main/java/t6` and `src/test/java/t6`
- `testRunningTimeEasy` — focus on time of execution, why it is so slow
- `testMemEfficiencyEasy` — try to experiment with memory and drop the required by test below 42. You will see the test fails.
- `testMemEfficiencyIntermediate` — try to achieve the 32 MB memory by using list other than LinkedList
- `testMemEfficiencyExpert` – try to achieve 26 MB by initializing the list with the number of items known a priori.
- `testMemEfficiencyMaster` – try to achieve 12 MB by writing your own suited `int`-based collection.

Summary

Test Driven Development

- Always start with test

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- Test must fail

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- Make the test passing by fixing the code

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- Big O notation, small o notation, theta θ notation
- Java's *sophisticated* collections give us access to best algorithm implementation
- Even though, using incorrect implementation, we can break things up
- Even though, sometimes we may need to have our own implementation (read: **use libraries**)

Generics

- One code for many usages
- `? extends` and `? super`
- Type erasure will clear typed info

Thank you