

Data Structures

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Realdolmen

June 23, 2017



Who am I?

- ▶ Master of Engineering: Computer Science (KUL)
 - ▶ Computational informatics
- ▶ Realdolmen: acADDemICT in 09/2015
- ▶ Current project: Planning infrastructure @ Infrabel



Outline

- ① Introductory Data Structures
 - Array
 - Linked List
 - Hash Table
 - Tree
- ② Java Collection API & Map API
 - Java Collection API
 - Java Map API
- ③ Advanced Data Structures
 - Stuff. . .



Outline

1 Introductory Data Structures

- Array
- Linked List
- Hash Table
- Tree

2 Java Collection API & Map API

- Java Collection API
- Java Map API

3 Advanced Data Structures

- Stuff...



What are Data Structures?

Data Structure¹

A way in which data are stored for efficient search and retrieval.
Different data structures are suited for different problems.

- ▶ Data type \neq data structure
- ▶ `java.util.HashSet` vs. hash table
- ▶ array vs. array

¹Encyclopædia Britannica

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Stuff...



Array

Definition

- ▶ An indexed set of related elements.²
 - ▶ An assemblage of items that are randomly accessible by integers, the index.³
-
- ▶ Example: linear array



² Oxford Dictionary

³ National Institute of Standards & Technology

Array

Operations

- ▶ `get`
- ▶ `set`
- ▶ `indexOf`



Array

Operations

- ▶ `get`
- ▶ `set`
- ▶ `indexOf`



`get(1)`

Array

Operations

- ▶ `get`
- ▶ `set`
- ▶ `indexOf`



`get(1)`

Array

Operations

- ▶ `get` $O(1)$
- ▶ `set`
- ▶ `indexOf`



`get(1)`

Array

Operations

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`set(2)`

Array

Operations

- ▶ `get` $O(1)$
- ▶ `set`
- ▶ `indexOf`



`set(2)`

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`indexOf(object)`

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`indexOf(object)`

Array

Operations

- ▶ `get` $O(1)$
- ▶ `set` $O(1)$
- ▶ `indexOf` $O(n)$



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Linked List

Definition

A linked list is a data structure in which the objects are arranged in a linear order. Unlike arrays in which the linear order is determined by indices, the order is determined by a pointer in each object.⁴

- Different types: singly, doubly, multiply, circular, ...
- Example: doubly linked list



⁴ Introduction to Algorithms By Cormen, Leieron, Rivest & Stein

Linked List

Operations

- ▶ add/remove first/last
- ▶ get/insertAt
- ▶ indexOf



Linked List

Operations

- ▶ add/remove first/last
- ▶ get/insertAt
- ▶ indexOf

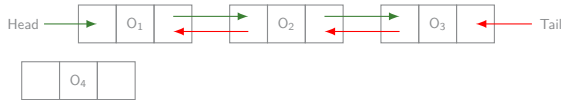


`addFirst(O_4)`

Linked List

Operations

- ▶ add/remove first/last
- ▶ get/insertAt
- ▶ indexOf

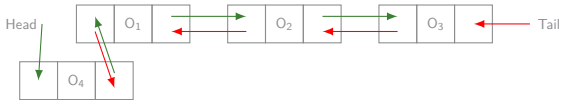


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Linked List

Operations

- ▶ add/remove first/last
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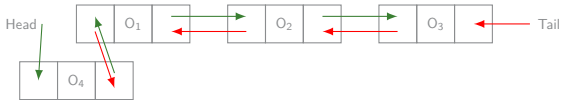


`addFirst(O4)`

Linked List

Operations

- ▶ add/remove first/last $O(1)$
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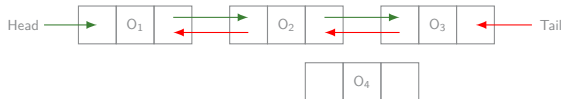


insertAt(2)

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt
- ▶ indexOf

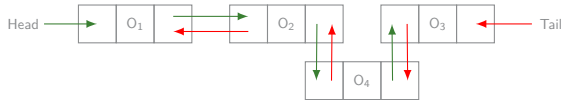


insertAt(2)

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt
- ▶ indexOf

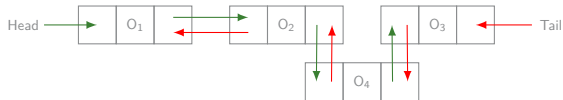


insertAt(2)

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf



insertAt(2)

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf



`indexOf(O2)`

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf

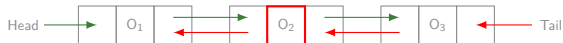


`indexOf(O2)`

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf



`indexOf(O2)`

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf $O(n)$



`indexOf(O_2)`

Linked List

Operations

- ▶ add/remove first/last $O(1)$
- ▶ get/insertAt $O(n)$
- ▶ indexOf $O(n)$



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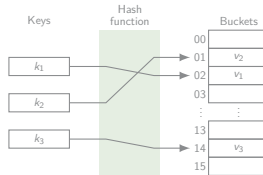


Hash Table

Definition

A dictionary in which keys are mapped to array positions by hash functions.⁵

- ▶ Hash functions: determinism, uniformity, defined range, data normalisation, non-invertible, perfect, . . .
- ▶ Collisions resolution: chaining, open addressing, . . .
- ▶ Example:

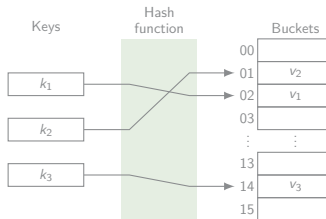


⁵ National Institute of Standards & Technology

Hash Table

Operations

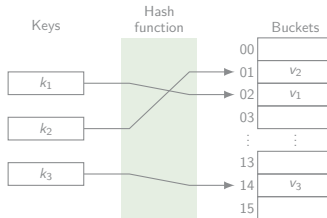
- put
- remove
- get



Hash Table

Operations

- put
- remove
- get

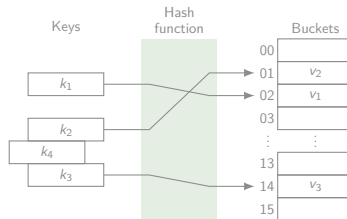


put(0₄)

Hash Table

Operations

- put
- remove
- get

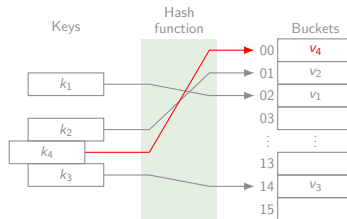


put(04)

Hash Table

Operations

- put
- remove
- get

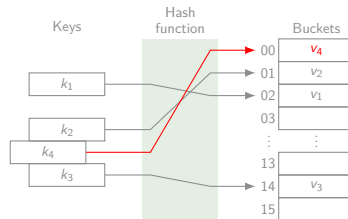


put (04)

Hash Table

Operations

- put $O(1) / O(n)$
- remove
- get

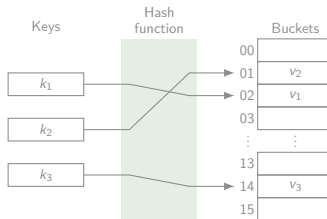


put(0_4)

Hash Table

Operations

- put $O(1) / O(n)$
- remove
- get

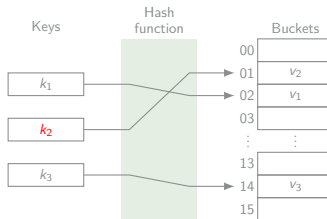


`remove(02)`

Hash Table

Operations

- put $O(1) / O(n)$
- remove
- get

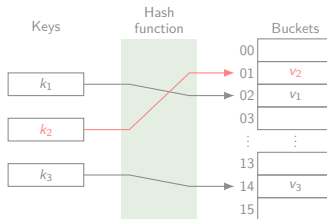


`remove(02)`

Hash Table

Operations

- put $O(1) / O(n)$
- remove
- get

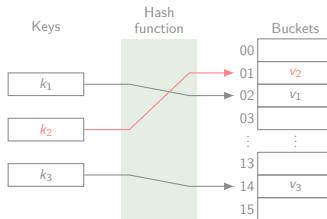


`remove(02)`

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get

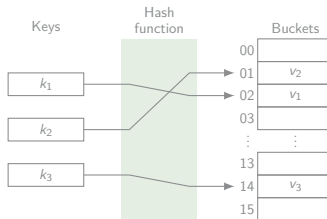


`remove(02)`

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get

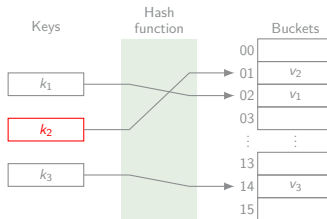


get(0₂)

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get

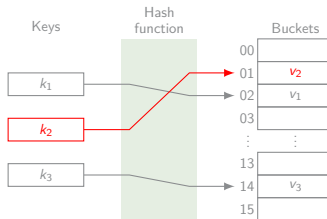


get(0₂)

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get

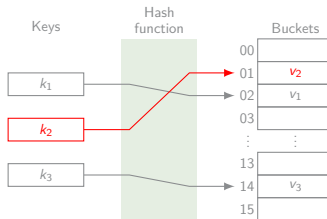


get(0_2)

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get $O(1) / O(n)$

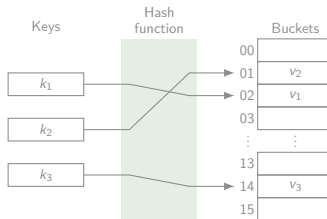


get(0_2)

Hash Table

Operations

- put $O(1) / O(n)$
- remove $O(1) / O(n)$
- get $O(1) / O(n)$



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 - Red-Black Tree

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Tree

Definition

A data structure made up of nodes or vertices and edges without having any cycle. A tree that is not empty consists of a root node and potentially many levels of additional nodes that form a hierarchy.

- ▶ Depth, binary, (nearly) complete, ...
- ▶ Example:

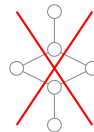
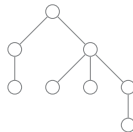


Tree

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A data structure made up of nodes or vertices and edges without having any cycle. A tree that is not empty consists of a root node and potentially many levels of additional nodes that form a hierarchy.

- ▶ Depth, binary, (nearly) complete, ...
- ▶ Example:



Binary Heap

Definition (Heap)

A complete tree where every node has a key more extreme (greater or less) than or equal to the key of its parent.⁶

Definition (Binary Heap)

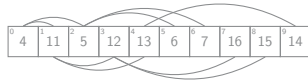
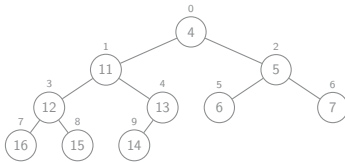
A binary heap data structure is an array object that we can view as a nearly complete binary tree that satisfies the min-heap or max-heap property.⁷

⁶ National Institute of Standards & Technology

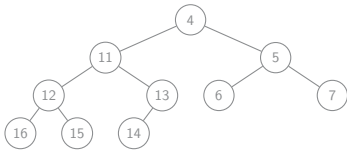
⁷ Introduction to Algorithms By Cormen, Leieron, Rivest & Stein

Binary Min-Heap

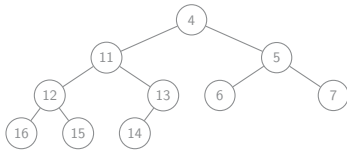
- ▶ $\text{Parent}(n) \quad \lfloor \frac{n-1}{2} \rfloor$
- ▶ $\text{Left}(n) \quad 2n + 1$
- ▶ $\text{Right}(n) \quad 2(n + 1)$



Binary Min-Heap



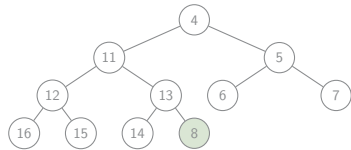
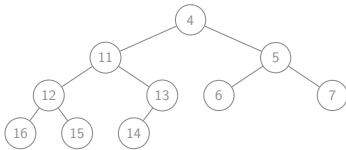
Binary Min-Heap



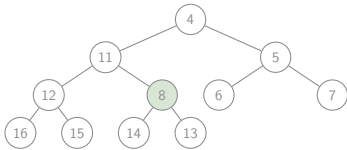
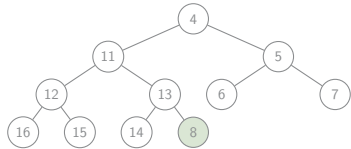
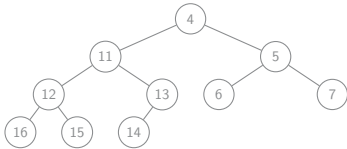
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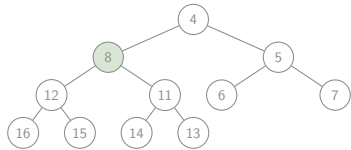
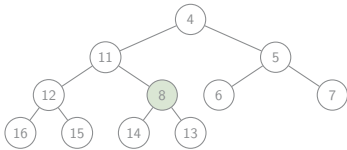
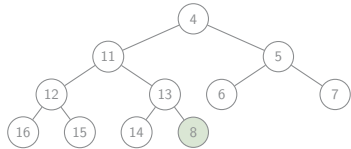
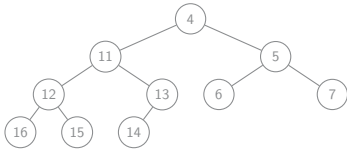
Binary Min-Heap



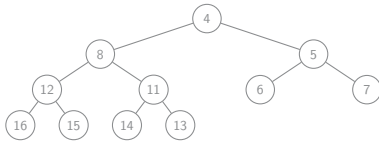
Binary Min-Heap



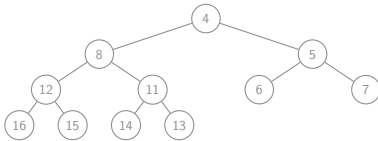
Binary Min-Heap



Binary Min-Heap



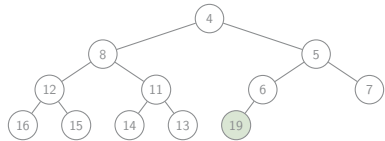
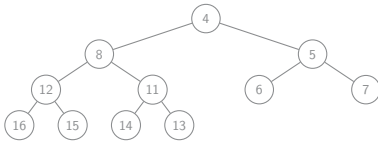
Binary Min-Heap



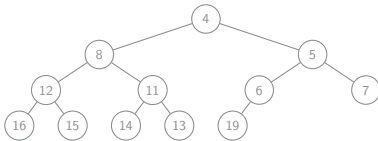
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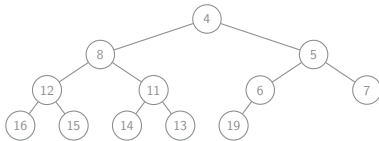
Binary Min-Heap



Binary Min-Heap



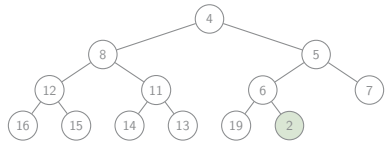
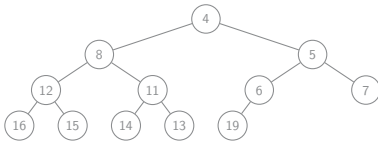
Binary Min-Heap



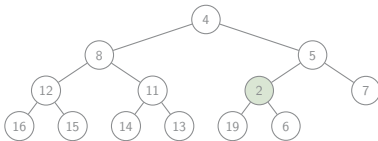
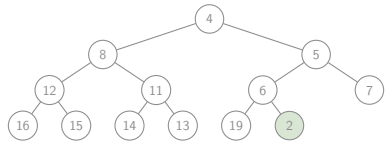
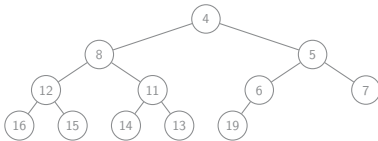
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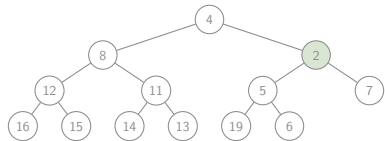
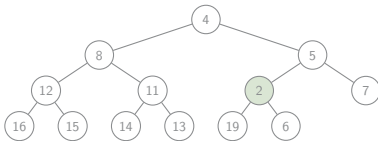
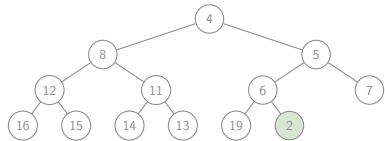
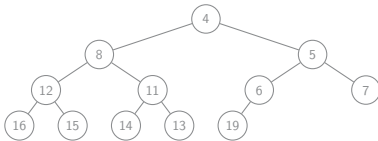
Binary Min-Heap



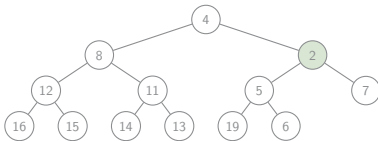
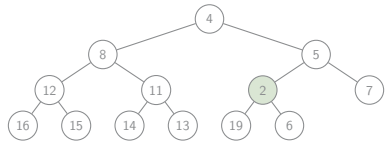
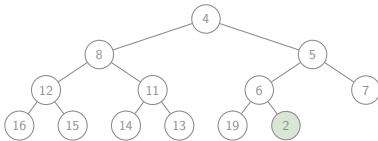
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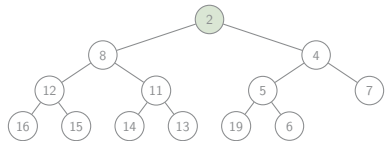
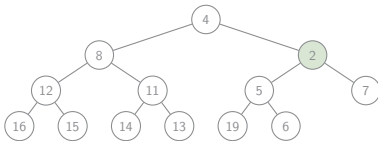
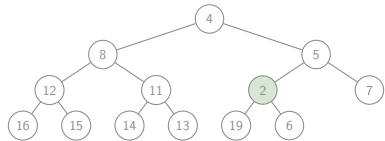
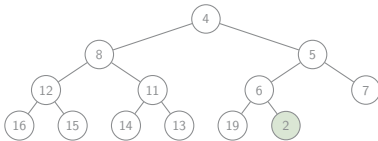
Binary Min-Heap



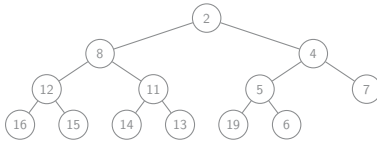
Binary Min-Heap



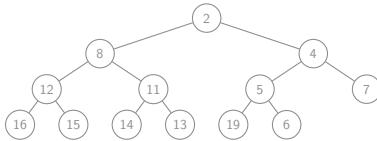
Binary Min-Heap



Binary Min-Heap



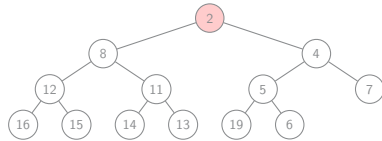
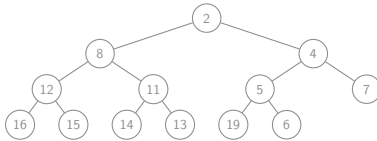
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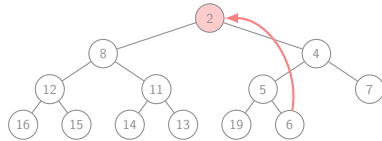
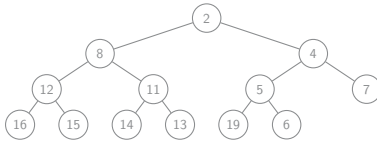
poll



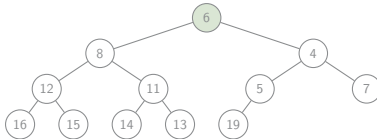
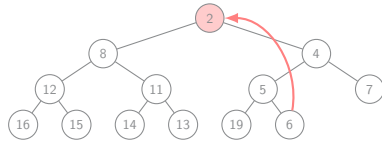
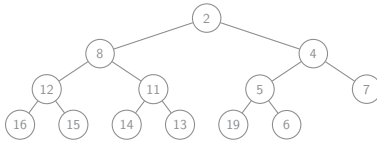
Binary Min-Heap



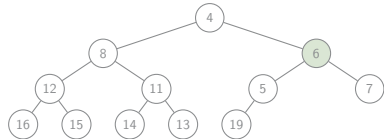
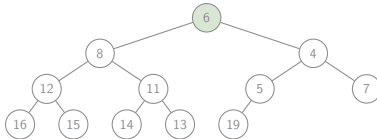
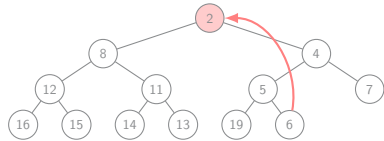
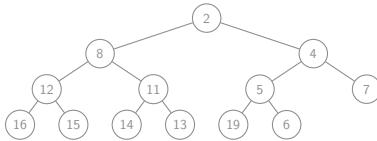
Binary Min-Heap



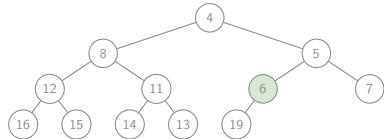
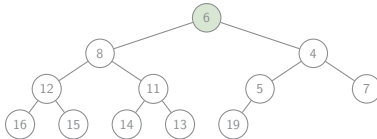
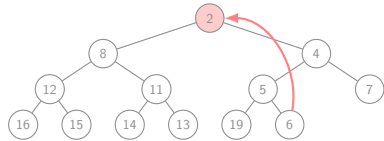
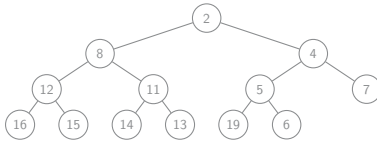
Binary Min-Heap



Binary Min-Heap



Binary Min-Heap



Binary Min-Heap

Operations

- ▶ `insert`
- ▶ `removeAt`
- ▶ `peek`
- ▶ `poll`



Binary Min-Heap

Operations

- ▶ insert $O(\log n)$
- ▶ removeAt $O(\log n)$
- ▶ peek $O(1)$
- ▶ poll $O(\log n)$



Binary Min-Heap

Operations

- ▶ insert $O(\log n)$
 - ▶ removeAt $O(\log n)$
 - ▶ peek $O(1)$
 - ▶ poll $O(\log n)$
-
- ▶ Heapsort
 - ▶ Frequently used in Priority Queues



Red-Black Tree

...



Red-Black Tree

...



Outline

- 1 Introductory Data Structures
 - Array
 - Linked List
 - Hash Table
 - Tree
- 2 Java Collection API & Map API
 - Java Collection API
 - Java Map API
- 3 Advanced Data Structures
 - Stuff...



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Java Collection API

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Java Collection API

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Java Map API

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Java Map API

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Stuff...

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