

# Algorithms and Data Structures

## B7. ADTs Map and Set

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## B7.1 Introduction

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## B7.1 Introduction

## Reminder: Abstract Data Type

### Abstract Data Type

Description of a data type, summarizing the possible data and the possible operations on this data.

- ▶ **User perspective:** How can I use the data type?
- ▶ In contrast to data structures, not specifying the concrete representation of the data.

## Dynamic Sets

- ▶ **Mathematical set**: unordered collection of distinct objects.
  - ▶ Can be finite or infinite.
  - ▶ Does not change.
- ▶ A **dynamic set** in computer science is slightly different.
  - ▶ Can grow, shrink or otherwise change.
  - ▶ Finite.
  - ▶ Entries (keys) can sometimes be associated with satellite data.
- ▶ Now: Two ADTs for dynamic sets:
  - ▶ Map
  - ▶ Set

## B7.2 Map

## Map

A **map** stores (key, value) pairs such that each possible key occurs at most once in the collection. It supports the following operations:

- ▶ **Insert** a given key and value. If the key is already present, update the associated value.
- ▶ **Remove** the entry for a given key.
- ▶ **Lookup** the entry for a given key (or return that there is none).

Also known as **associative array**, **dictionary** or **symbol table**.

Exact names of operations can differ.

Similar to arrays, but using keys instead of indices.

## Map: Data Structures and Running Times

The following data structures can easily be adapted to implement maps:

data structure	insertion	removal or lookup
	avg./worst	avg./worst
linked list	$O(1)/O(1)$	$O(n)/O(n)$
hash table	$O(1)/O(n)$	$O(1)/O(n)$
binary search tree	$O(\log n)/O(n)$	$O(\log n)/O(n)$
red-black tree	$O(\log n)/O(\log n)$	$O(\log n)/O(\log n)$

## Maps in Java and Python

### Java:

- ▶ Interface Map
- ▶ For example implemented by HashMap (hash table) and TreeMap (red-black tree).

```
Map<String, Integer> map = new TreeMap<>();
map.put("a key", 42);
map.put("another key", 17)
Integer value = map.get("aKey");
```

### Python:

- ▶ Built-in dict (hash table)

```
map = dict()
map["a key"] = 42
map["another key"] = 17
# or alternatively:
# map = {"a key" : 42, "another key" : 17}
value = map["a key"]
```

## B7.3 Set

## Set

A **set** stores keys such that each possible key occurs at most once in the collection. It supports the following operations:

- ▶ **Insert** a given key into a set (if it is not already included).
- ▶ **Remove** the given key from a set.
- ▶ **Lookup** whether a given key is in a set.
- ▶ **Iteration** over all elements of a set in an arbitrary order.

In addition, there is often support for the following operators:

- ▶ **Union** of two sets.
- ▶ **Intersection** of two sets.
- ▶ **Difference** of two sets.

Exact names of operations can differ.

## Data Structures

We can use the same data structures for sets as for maps.

- ▶ Do not store a value with the key.
- ▶ Implementation of operators union, intersection can be done based on the core operations or with highly specialized algorithms:
  - ▶ E.g., union, intersection and difference possible in  $O(m \log(\frac{n}{m} + 1))$  for two red-black trees of sizes  $m$  and  $n$  (where  $m \leq n$ ).

## Sets in Java

Java:

- ▶ Interface Set
- ▶ For example implemented by HashSet (based on hash table) and TreeSet (based on red-black tree).

```
Set<Integer> nums1 = new HashSet<>();
Set<Integer> nums2 = new HashSet<>();
nums1.add(42);
nums1.add(17);
nums2.add(42);
nums2.add(13);
nums2.add(19);
nums2.remove(13);
nums1.retainAll(nums2); // intersection
if (nums1.contains(42)) {
    System.out.println("Found 42");
}
```

## Sets in Python

Python:

- ▶ Built-ins set and frozenset (both based on hash tables; frozen sets are immutable and hashable)

```
s1 = set()
s1.add(42)
s1.add(17)
s2 = {42, 13, 19}
s2.remove(13)
s1 &= s2 # intersection
if 42 in s1:
    print("Found 42")
```

## B7.4 Summary

## Summary

- ▶ **Maps** and **sets** are abstract data types for dynamic sets.
  - ▶ Maps map keys to their associated values.
  - ▶ Sets only store elements.
  - ▶ Both are typically implemented based on hash tables or balanced trees (such as red-black trees).