

CMSC 132: Object-Oriented Programming II

Sets, Maps, Hashing



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Overview

- **Sets**
- **Maps**
- **Hashing**
- **Java equals and hashCode()**

Set Data Structures

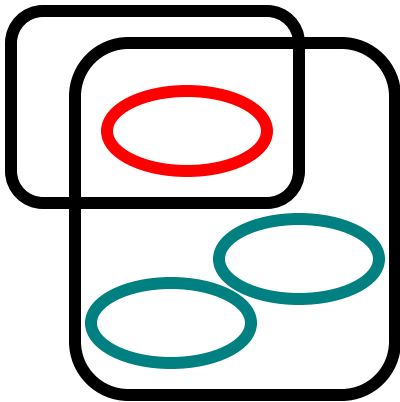
- No relationship between elements

- Types of sets

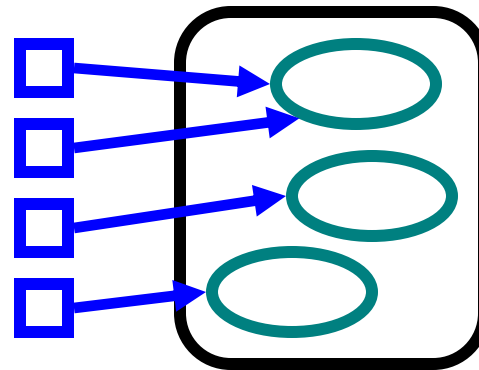
- Set

- Map

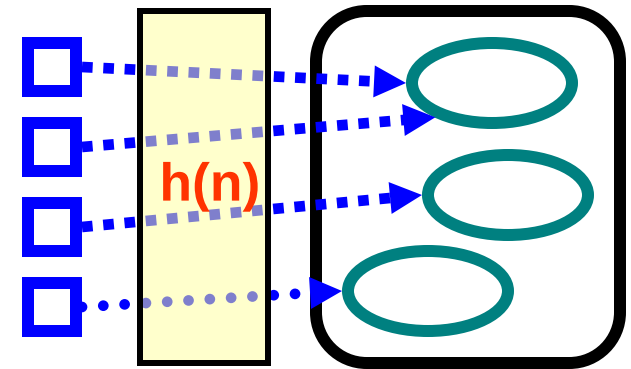
- Hash Table



Set



Map



Hash Table

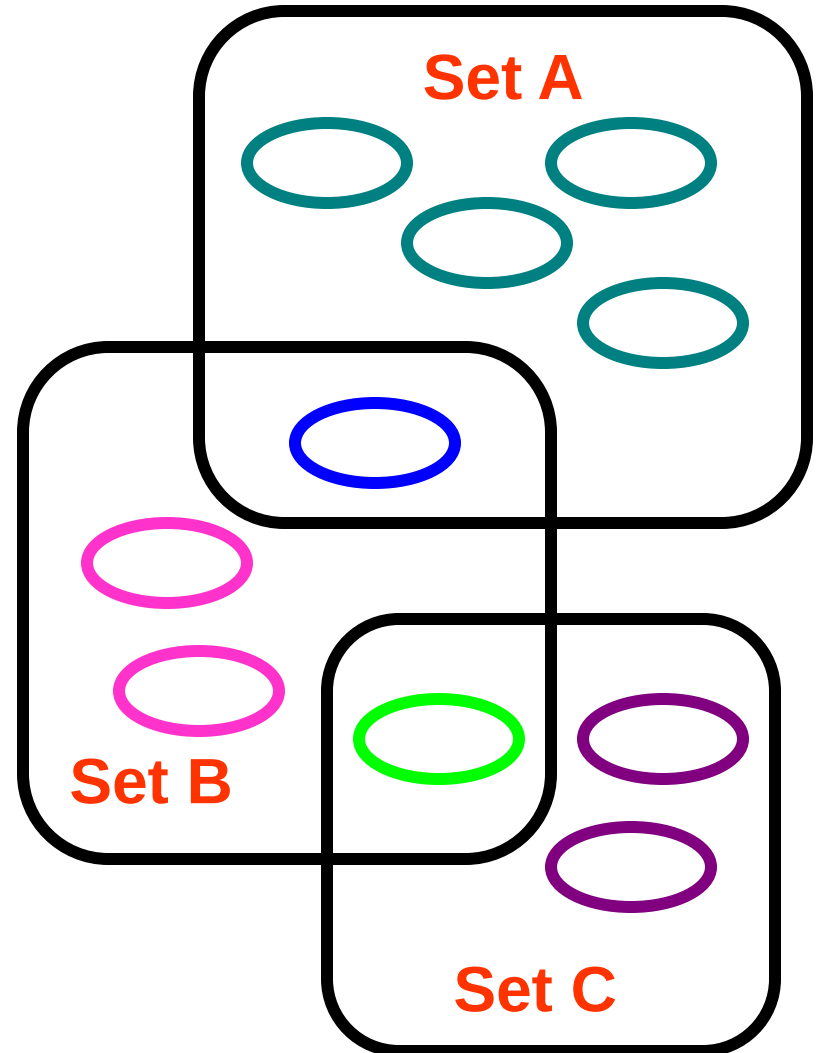
Sets

■ Properties

- Collection of elements without duplicates
- No ordering (i.e., no front or back)
- Order in which elements added doesn't matter

■ Implementation goal

- Offer the ability to find / remove element quickly
- Without searching through all elements



How Do Sets Work in Java?

- Finding matching element is based on equals()
- To build a collection for a class
 - Need to define your own equals(Object) method
 - Default equals() uses reference comparison
 - I.e., a.equals(b) → a == b
 - a, b equal only if reference to same object
 - Many classes have predefined equals() methods
 - Integer.equals() → compares value of integer
 - String.equals() → compares text of string

Set Concrete Classes

■ HashSet

- Elements must implement hashCode() method

■ LinkedHashSet

- HashSet supporting ordering of elements
- Elements can be retrieved in order of insertion

■ TreeSet

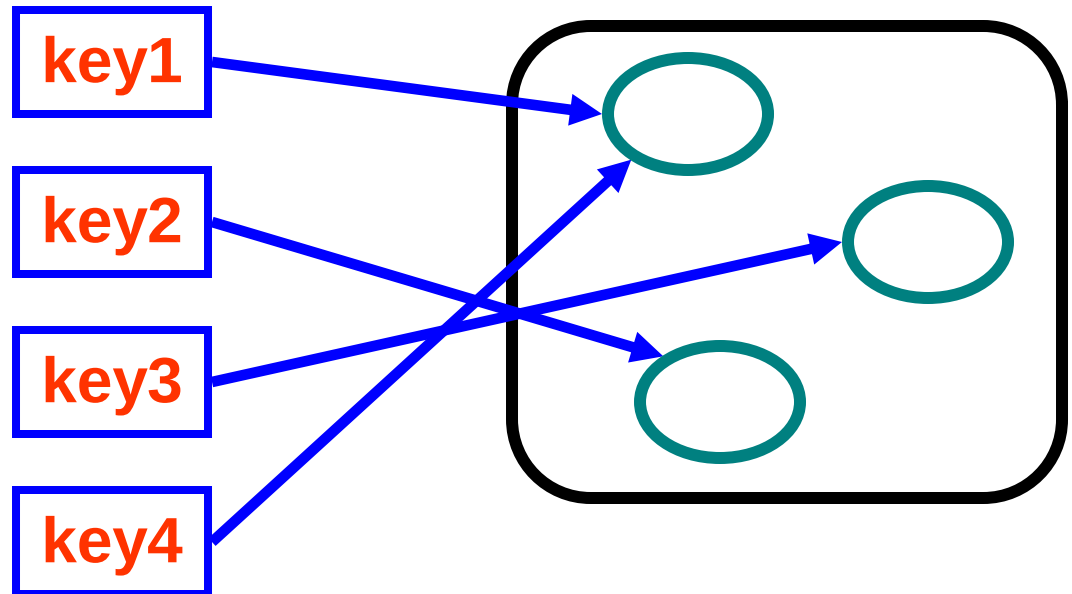
- Elements must be comparable
 - Implement Comparable or provide Comparator
- Guarantees elements in set are sorted

Map Definition

- Map (associative array)
 - Unordered collection of **keys**
 - For each key, an associated object
 - Can use key to retrieve object
- Can view as array indexed by **any** (key) value

- Example

A[“**key1**”] = ...



Map Interface Methods

■ Methods

- `void put(K key, V value)` // inserts element
- `V get(Object key)` // returns element
- `V remove(Object key)` // removes element
- `int size()` // key-value mappings
- `void clear()` // clears the map
- `boolean containsKey(Object key)` // looks for key
- `boolean containsValue(Object value)` // looks for value
- `boolean isEmpty()` // empty map?
- `Set<K> keySet( )` // entire set of keys
- `Collection<V> values()` // values in the map

Map Properties

■ Map keys & map objects

■ Can also treat keys & values as collections

- Access using `keySet( )`, `values( )`

■ Aliasing

- Each key refers only a single object
- But object may be referred to by multiple keys

■ Keys & values may be of complex type

- `Map<Object Type1, Any Object Type2>`
- Including other collections, maps, etc...

Map Implementation

■ Implementation approaches

■ Two parallel arrays

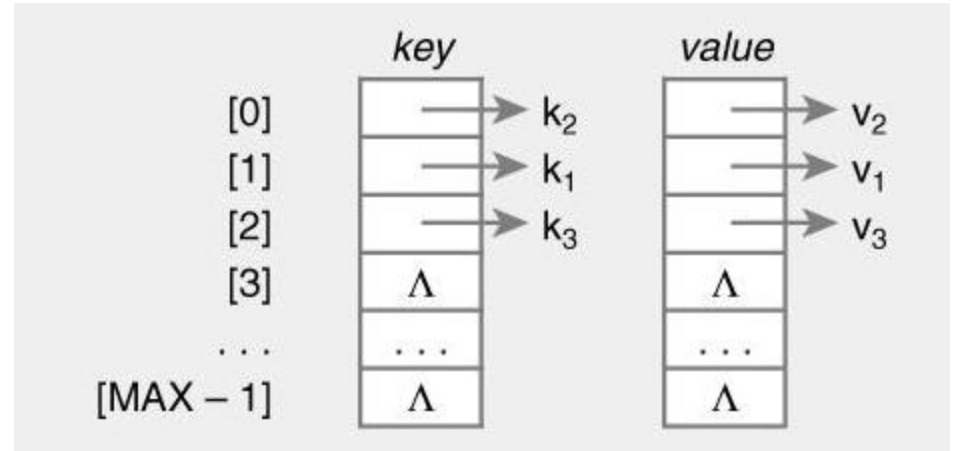
■ Unsorted

■ Sorted

■ Linked list

■ Binary search tree

■ Hash table

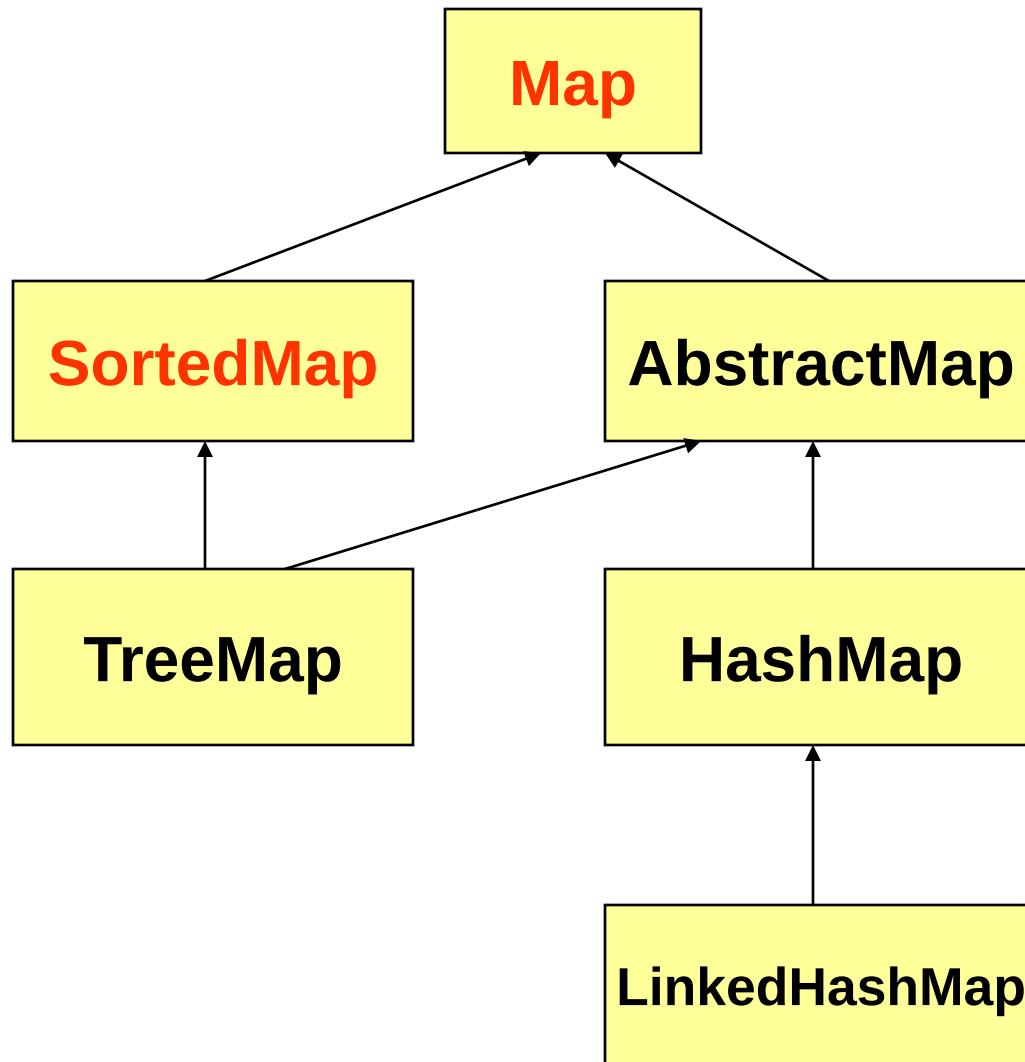


■ Java Collections Framework

■ TreeMap → uses red-black (balanced) tree

■ HashMap → uses hash table

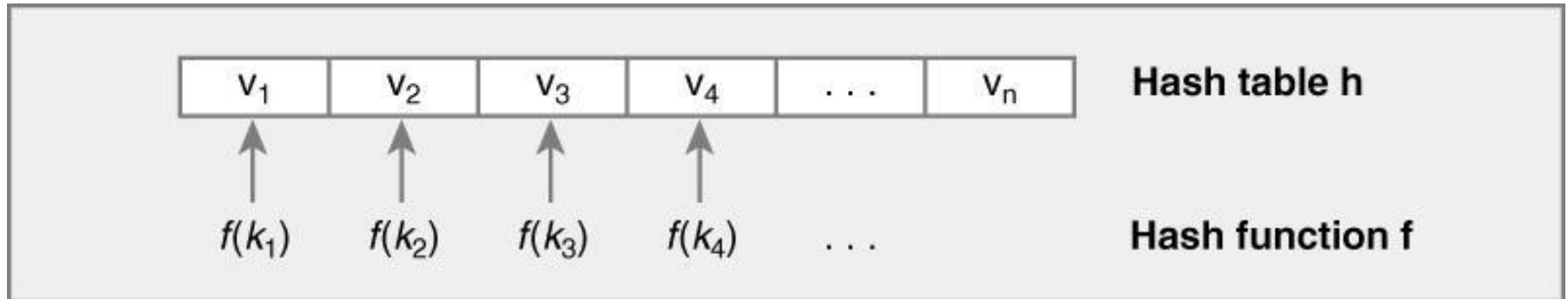
Java Collections Map Hierarchy



Hashing

■ Approach

- Use **hash function** to convert key into number (**hash value**) used as index in **hash table**



Hashing

■ Hash Table

- Array indexed using hash values
- Hash table A with size N
- Indices of A range from 0 to $N-1$
- Store in $A[\text{hashValue} \% N]$

Hash table h

$h[0]$	Λ
$h[1]$	Λ
$\dots$	$\dots$
$h[N - 1]$	Λ

<i>Location</i>	<i>Key</i>
0	Λ
1	10
2	15
3	20
4	Λ
$\dots$	

Hash Function

- Function for converting key into hash value

- For Java

 - Hash value $\Rightarrow$ 32-bit signed int

 - Default hash function $\Rightarrow$ `int hashCode( )`

- For hash table of size N

 - Must reduce hash value to $0..N - 1$

 - Can use modulo operator

 - `Math.abs(hash value % N)`

Scattering Hash Values

- Hash function should **scatter** hash values uniformly across range of possible values
 - Reduces likelihood of conflicts between keys
- $\text{Hash}(\text{<everything>}) = 0$
 - Satisfies definition of hash function
 - But not very useful (all keys at same location)
- Could use $\text{Math.abs}(\text{key.hashCode}() \% N)$
 - Might not distribute values well
 - Particularly if N is a power of 2

Scattering Hash Values

- **Multiplicative congruency method**
 - Produces good hash values
 - Hash value = $\text{Math.abs}((a * \text{key.hashCode}()) \% N)$
 - Where
 - N is table size
 - a is large prime number

Beware of % (Modulo Operator)

- The % operator is integer remainder

$$x \% y == x - y * (x / y)$$

- Result may be negative

$$-|y| < x \% y < +|y|$$

- $x \% y$ has same sign as x

- $-3 \% 2 = -1$

- $-3 \% -2 = -1$

- Use `Math.abs( x % N )`, not `Math.abs(x) % N`

- Since `Math.abs(Integer.MIN_VALUE) == Integer.MIN_VALUE !`

- Will happen 1 in 2^{32} times (on average) for random int values

Art and Magic of hashCode()

- There is no “right” hashCode function
 - Art involved in finding good hashCode function
 - Also for finding hashCode to hashBucket function
- From java.util.HashMap

```
static int hashBucket(Object x, int N) {  
    int h = x.hashCode();  
    h += ~(h << 9);  
    h ^= (h >>> 14);  
    h += (h << 4);  
    h ^= (h >>> 10);  
    return Math.abs(h % N);  
}
```

Hash Function

■ Example

`hashCode("apple") = 5`

`hashCode("watermelon") = 3`

`hashCode("grapes") = 8`

`hashCode("kiwi") = 0`

`hashCode("strawberry") = 9`

`hashCode("mango") = 6`

`hashCode("banana") = 2`

■ Perfect hash function

- Unique values for each key

0	kiwi
1	
2	banana
3	watermelon
4	
5	apple
6	mango
7	
8	grapes
9	strawberry

Hash Function

■ Suppose now

`hashCode("apple") = 5`

`hashCode("watermelon") = 3`

`hashCode("grapes") = 8`

`hashCode("kiwi") = 0`

`hashCode("strawberry") = 9`

`hashCode("mango") = 6`

`hashCode("banana") = 2`

`hashCode("orange") = 3`

■ Collision

- Same hash value for multiple keys

0

kiwi

1

2

banana

3

watermelon

4

5

apple

6

mango

7

8

grapes

9

strawberry

Hashing in Java

- Object class has built-in support for hashing
 - Method `int hashCode( )` provides
 - Numerical hash value for any object
- `hashCode( )` provides **pre-filter** for `equals( )`
 - Check `equals( )` only if `hashCode( )` is identical
 - Example
 - ```
if (a.hashCode() == b.hashCode())
 result = a.equals(b);
else result = false;
```
  - Efficient if `hashCode( )` is faster than `equals( )`

# Hashing in Java

- **Default hashCode( ) implementation**
  - Usually just address of object in memory
- **Can override with new user definition**
  - Must work with equals( )
  - Following Java “**hashCode contract**”

# Java Hash Code Contract

## ■ hashCode()

- Must return same value for object in each execution, provided information used in equals( ) comparisons on the object is not modified

## ■ equals()

- if `a.equals(b) == true`, then must **guarantee**  
`a.hashCode( ) == b.hashCode( )`
- Inverse is not true → `!a.equals(b)` does not imply  
`a.hashCode( ) != b.hashCode( )`
  - Though Java libraries may be more efficient
- Converse is also not true → `a.hashCode( ) == b.hashCode( )` does not imply `a.equals(b) == true`

# Java hashCode()

## ■ Implementing hashCode( )

### ■ Include only information used by equals( )

- Else 2 “equal” objects → different hash values

### ■ Using all / more of information used by equals( )

- Help avoid same hash value for unequal objects

## ■ Example hashCode( ) functions

### ■ For pair of Strings

- 1<sup>st</sup> letter of 1<sup>st</sup> str
- 1<sup>st</sup> letter of 1<sup>st</sup> str + 1<sup>st</sup> letter of 2<sup>nd</sup> str
- Length of 1<sup>st</sup> str + length of 2<sup>nd</sup> str
- $\sum \text{letter(s) of 1}^{\text{st}} \text{ str} + \sum \text{letter(s) of 2}^{\text{nd}} \text{ str}$