CMSC 132:
Object-Oriented Programming II

Sets, Maps, Hashing

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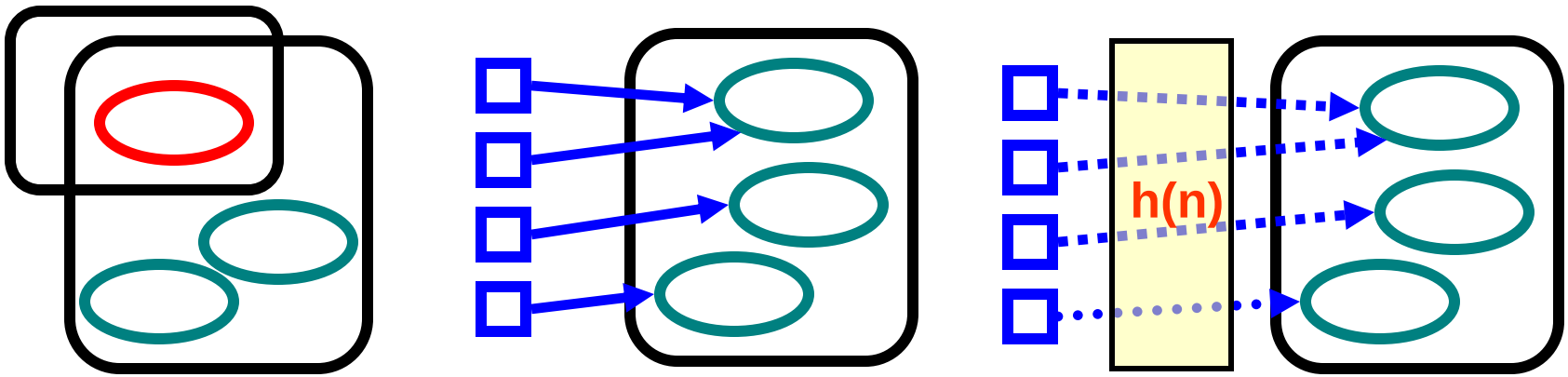
Overview

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

Set Data Structures

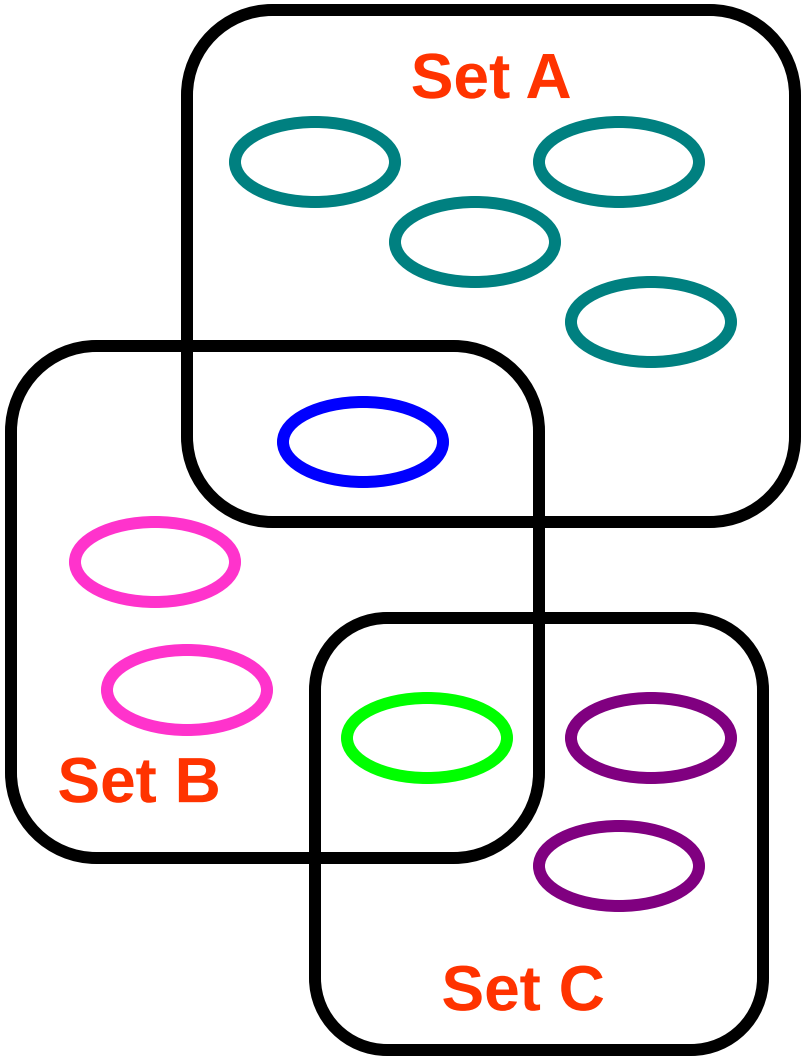
- No relationship between elements
- Types of sets
  - Set
  - Map
  - Hash Table



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

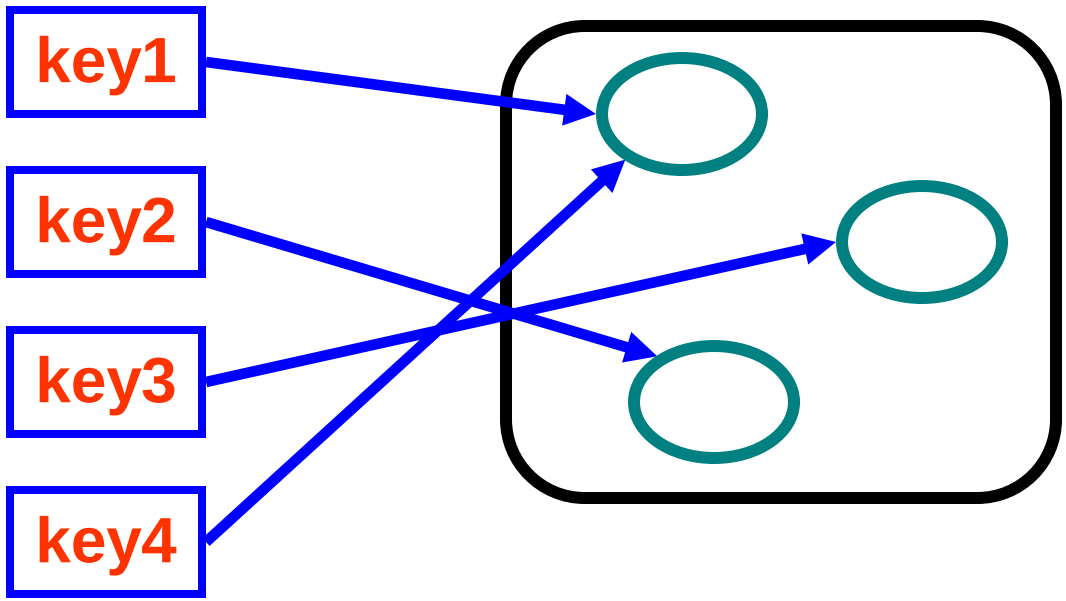
Set Concrete Classes

- **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

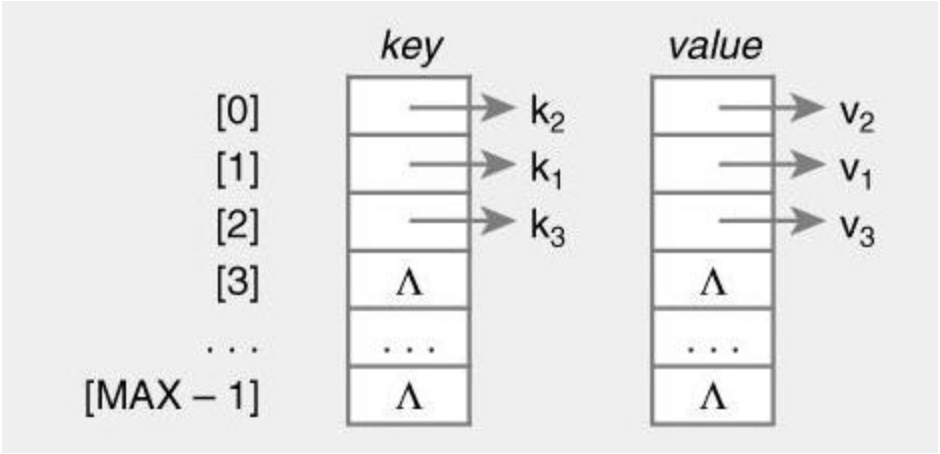
- **Methods**
  - `void put(K key, V value)` // inserts element
  - `V get(Object key)` // returns element
  - `V remove(Object key)` // removes element
  - `int size()` // key-value mappings
  - `void clear()` // clears the map
  - `boolean containsKey(Object key)` // looks for key
  - `boolean containsValue(Object 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…**

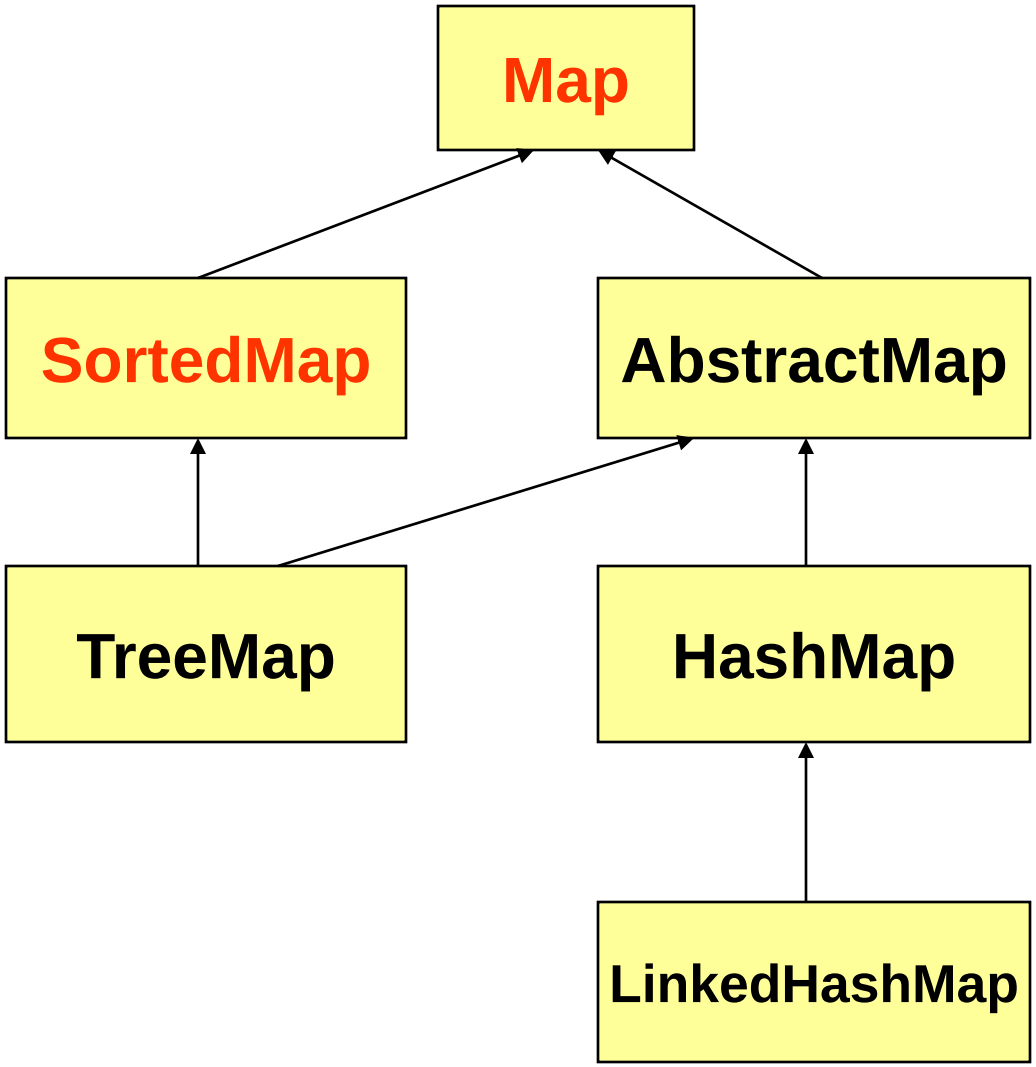
Map Implementation

- **Implementation approaches**
  - **Two parallel arrays**
    - **Unsorted**
    - **Sorted**
  - **Linked list**
  - **Binary search tree**
  - **Hash table**



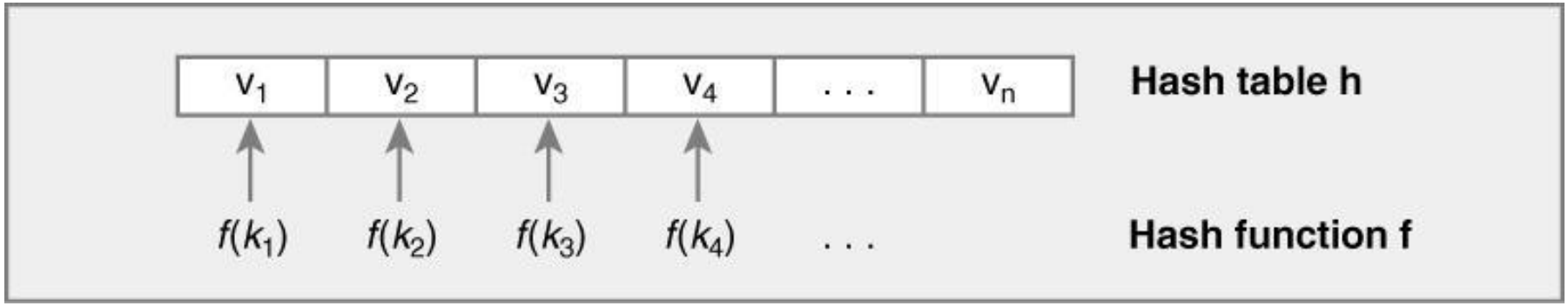
- **Java Collections Framework**
  - **TreeMap → uses red-black (balanced) tree**
  - **HashMap → uses hash table**

Java Collections Map Hierarchy



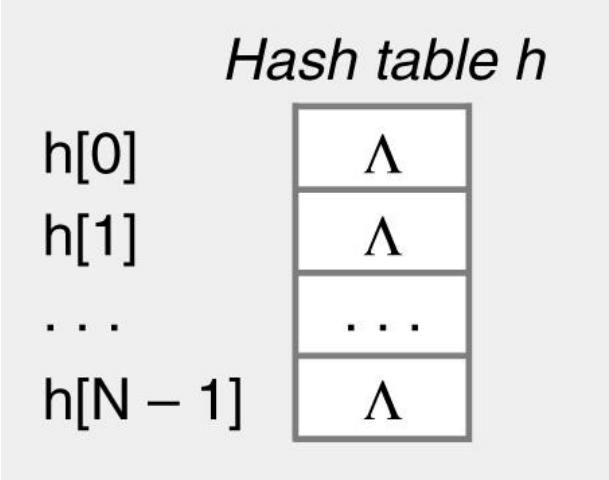
Hashing

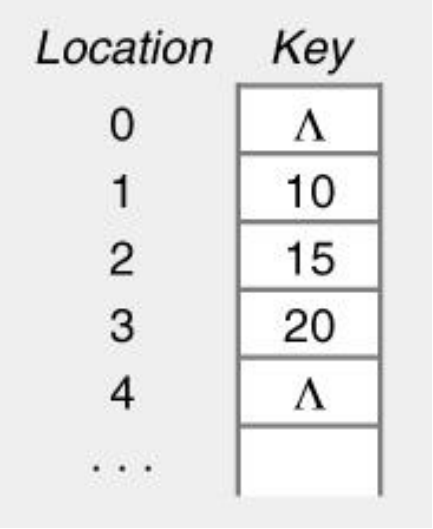
- **Approach**
  - **Use hash function to convert key into number (hash value) used as index in hash table**



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[hashValue % N]**





Hash Function

- Function for converting key into hash value

- For Java
  - Hash value ⇒ 32-bit signed int
  - Default hash function ⇒ 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
- Hash(<everything>) = 0
  - Satisfies definition of hash function
  - But not very useful (all keys at same location)
- Could use Math.abs(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 = Math.abs((a * 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

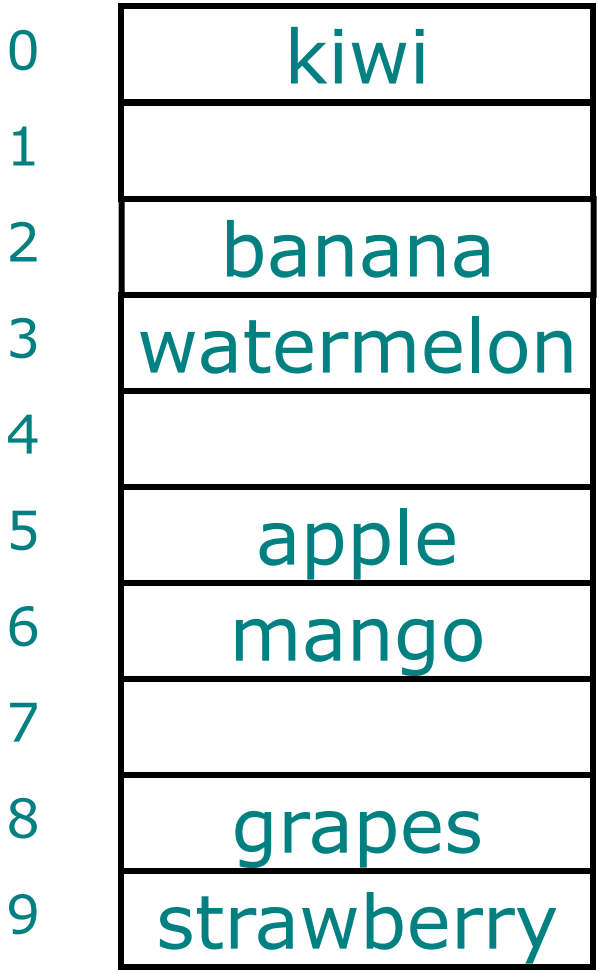
```
static int hashBucket(Object x, int N) {
    int h = x.hashCode();
    h += ~(h << 9);
    h ^=  (h >>> 14);
    h +=  (h << 4);
    h ^=  (h >>> 10);
    return Math.abs(h % N);
```

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**

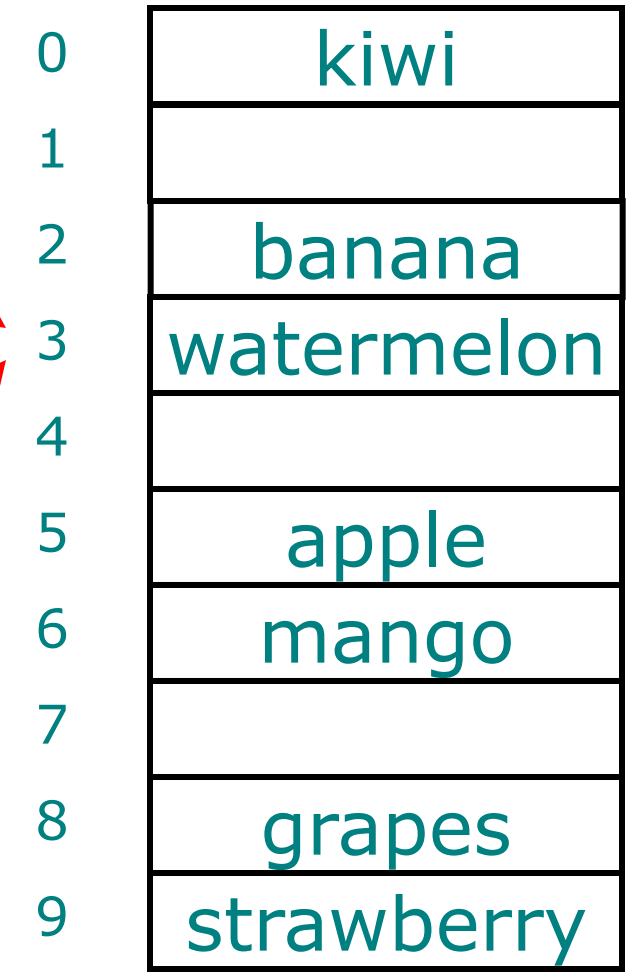


Hash Function

- **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**



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**
    - **1st letter of 1st str**
    - **1st letter of 1st str + 1st letter of 2nd str**
    - **Length of 1st str + length of 2nd str**
    - **∑ letter(s) of 1st str + ∑ letter(s) of 2nd str**