# CMSC 132: Object-Oriented Programming II

## Hashing

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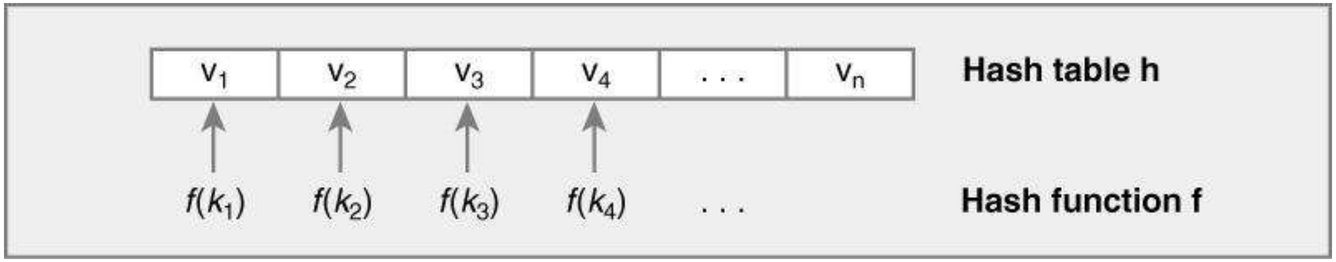
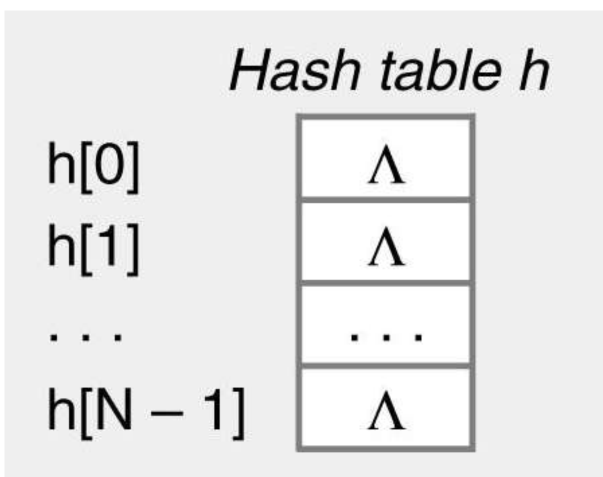
# Hashing

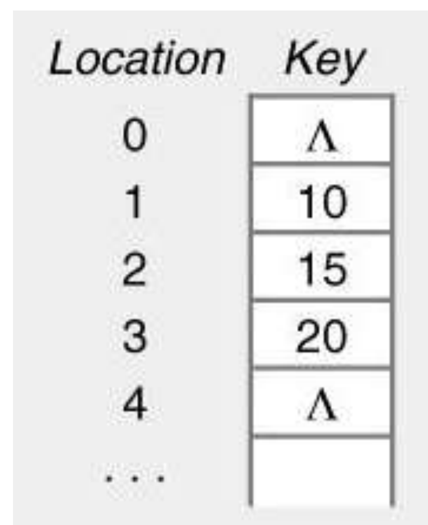
- **Hashing**
  - **Hashing function → function that maps data to a value (e.g., integer)**
  - **Hash Code/Hash Value → value returned by a hash function**
  - **Hash functions can be used to speed up data access**
  - **We can achieve O(1) data access using hashing**
- **Approach**
  - **Use hash function 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

- Hash Function → Function for converting key into hash value
- For hash table of size N
  - Must reduce hash value to 0..N – 1
  - Can use modulo operator → hash value = Math.abs(keyValue % N)
- Example Problem
  - Assign 4 parking spaces to 4 people using
    - h(key) = keyValue % 4
  - What happens if we have 4 spaces and 8 people?
    - Collision → Same hash value for multiple keys
- Bucket
  - Each table entry can be referred to as a bucket
  - In some implementations the bucket is represented by a list (those elements hashing to the same bucket are placed in the same list)
- Properties of a Good Hash Function
  - Distributes (scatters) values uniformly across range of possible values
  - It is not expensive to compute

# 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(keyValue % 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 * keyValue) % N)**
  - **Where**
    - **N is table size**
    - **a is large prime number**

# Hash Function

- **Example**

  **hash("apple") = 5**
  **hash("watermelon") = 3**
  **hash("grapes") = 8**
  **hash("kiwi") = 0**
  **hash("strawberry") = 9**
  **hash("mango") = 6**
  **hash("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**

  **hash("apple") = 5**
  **hash("watermelon") = 3**
  **hash("grapes") = 8**
  **hash("kiwi") = 0**
  **hash("strawberry") = 9**
  **hash("mango") = 6**
  **hash("banana") = 2**
  **hash(“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 |

# 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 ) and not Math.abs( x ) % N
- About absolute value in Java
  - Math.abs(Integer.MIN_VALUE) == Integer.MIN_VALUE !
  - Will happen 1 in $2^{32}$ times (on average) for random int values

# Hashing in Java

- Object class has built-in support for hashing
  - Method int hashCode( ) provides
    - Numerical hash value for any object
    - 32-bit signed int
- Default hashCode( ) implementation
  - Usually just address of object in memory
- Can override with new user definition
  - Must work with equals( )
  - Must satisfy the "hash code contract"

# Java Hash Code Contract

- **Java Hash Code Contract**

  **if a.equals(b) == true, then we 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**

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

# When to Override hashCode

- **You must write classes that satisfy the Java Hash Code Contract**
- **You will run into problems if you don't satisfy the Java Hash Code Contract and use classes that rely on hashing (e.g., HashMap, HashSet)**
  - **Possible problem – You add an element to a set but cannot find it during a lookup operation**
  - **See code distribution example**
- **Does the default equals and hashCode satisfy the contract? Yes!**
- **If you implement the Comparable interface you should provide the appropriate equals method which leads to the appropriate hashCode method**

# Java hashCode( )

- **Implementing hashCode( )**
  - **Include only information used by equals( )**
    - **Else 2 "equal" objects $\rightarrow$ 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$^{st}$ letter of 1$^{st}$ str**
    - **1$^{st}$ letter of 1$^{st}$ str + 1$^{st}$ letter of 2$^{nd}$ str**
    - **Length of 1$^{st}$ str + length of 2$^{nd}$ str**
    - **$\sum$ letter(s) of 1$^{st}$ str + $\sum$ letter(s) of 2$^{nd}$ str**

# 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);
```

# Pre-filtering with hashCode

- 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( )