CMSC 132:
Object-Oriented Programming II

Hashing

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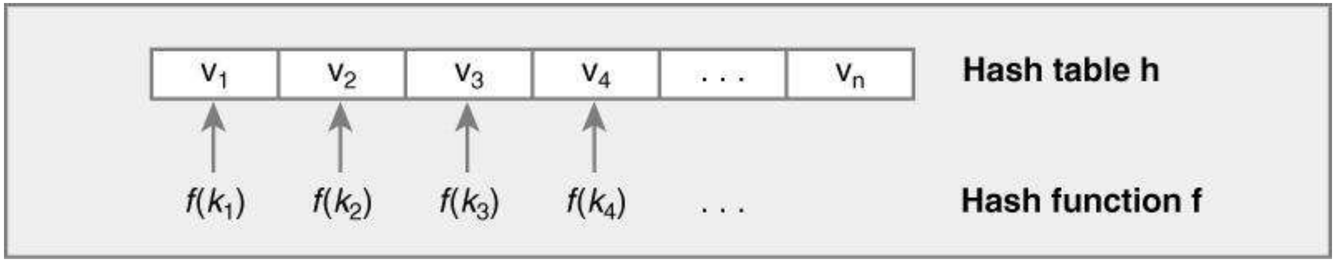
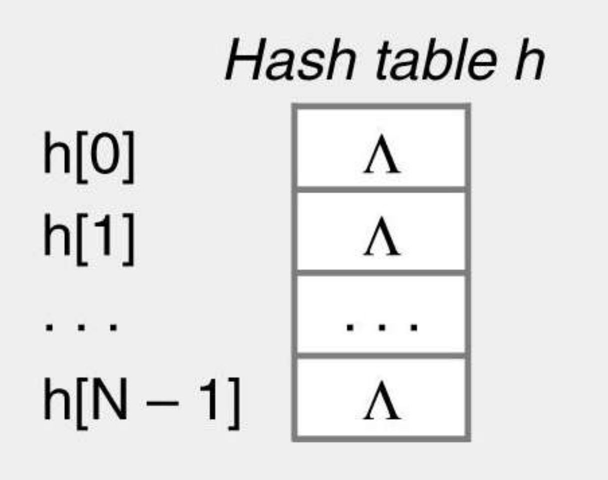
Hashing

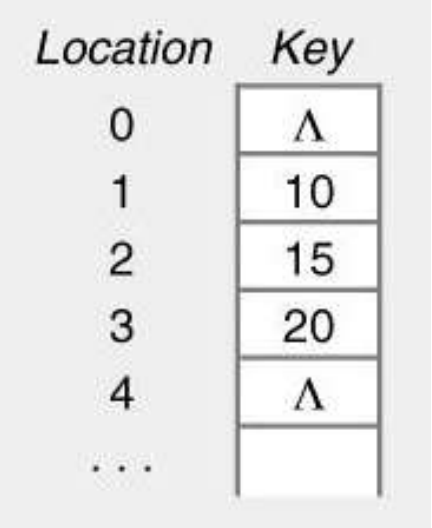
- **Hashing**
  - **Hashing function → function that maps data to a value (e.g., integer)**
  - **Hash Code/Hash Value → value returned by a hash function**
  - **Hash functions can be used to speed up data access**
  - **We can achieve O(1) data access using hashing**
- **Approach**
  - **Use hash function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

- **Suspose 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

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

- **Collision**
  - **Same hash value for multiple keys**

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
    - 1st letter of 1st str
    - 1st letter of 1st str + 1st letter of 2nd str
    - Length of 1st str + length of 2nd str
    - $\sum$ letter(s) of 1st str + $\sum$ letter(s) of 2nd 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( ))**

```
if ( a.hashCode( ) == b.hashCode( ) )
        result = a.equals( b );
    else result = false;
```

  - **Efficient if hashCode( ) is faster than equals( )**