

CMSC 132:

OBJECT-ORIENTED PROGRAMMING II



Hashing

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Introduction

- If you need to find a value in a list what is the most efficient way to perform the search?
 - Linear search
 - Binary search
 - Can we have $O(1)$?

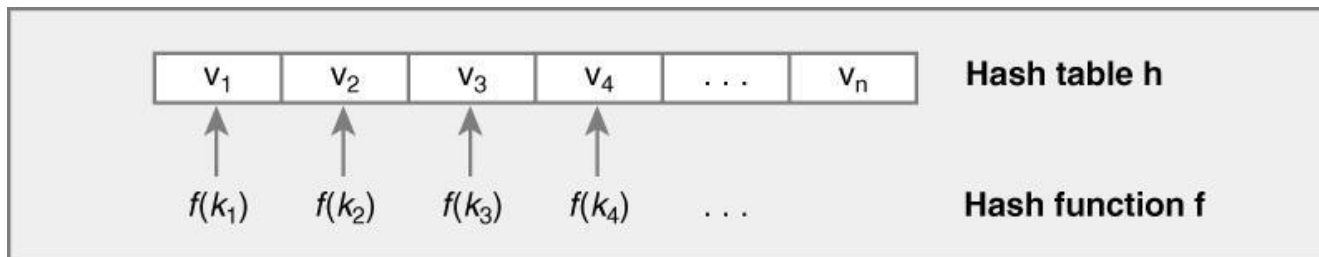
Hashing

- Hashing

- Hashing function $\rightarrow$ function that maps data to a value (e.g., integer)
- Hash Code/Hash Value $\rightarrow$ 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 $A[\text{hashValue} \% N]$

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

- 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 → $\text{hash value} = \text{Math.abs}(\text{keyValue} \% N)$
- Example Problem
 - Assign 4 parking spaces to 4 people using
 - $h(\text{key}) = \text{keyValue} \% 4$
 - 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
- $\text{Hash}(\text{<everything>}) = 0$
 - Satisfies definition of hash function
 - But not very useful (all keys at same location)
- Could use $\text{Math.abs}(\text{keyValue} \% N)$
 - Might not distribute values well
 - Particularly if N is a power of 2
- Multiplicative congruency method
 - Produces good hash values
 - Hash value = $\text{Math.abs}((a * \text{keyValue}) \% N)$
 - Where
 - N is table size
 - a is large prime number

Hash Function

- Example

$\text{hash}(\text{"apple"}) = 5$

$\text{hash}(\text{"watermelon"}) = 3$

$\text{hash}(\text{"grapes"}) = 8$

$\text{hash}(\text{"kiwi"}) = 0$

$\text{hash}(\text{"strawberry"}) = 9$

$\text{hash}(\text{"mango"}) = 6$

$\text{hash}(\text{"banana"}) = 2$

- 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 → 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
 - $\sum \text{letter(s) of 1}^{\text{st}} \text{ str} + \sum \text{letter(s) of 2}^{\text{nd}} \text{ str}$

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);  
}
```