CMSC 132: Object-Oriented Programming II

Hashing

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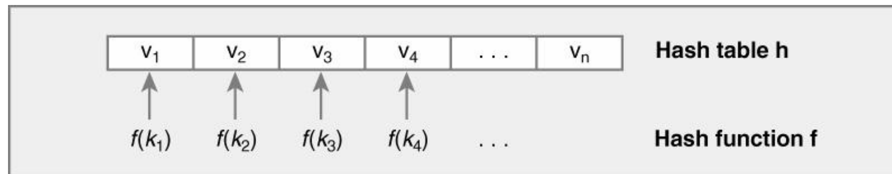
Overview

- Hashing
  - Scattering Hash Values
  - Hash Function
- Hash Tables
  - Open Addressing
  - Chaining

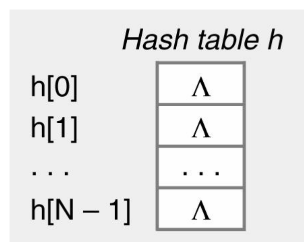
Hashing

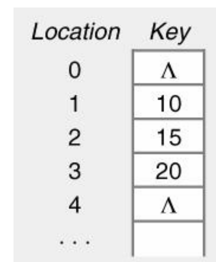
- Approach
  - Use hash function to convert key into number (hash value) used as index in hash table



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

Scattering Hash Values

- Should scatter hash values uniformly across range of possible values
  - 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, N are large primes

Beware of % (Modulo Operator)

- The % operator is integer remainder

  x % y == x – y * (x / y)

- Not what mathematicians expect

3/2 == 1	3%2 == 1
2/2 == 1	2%2 == 0
1/2 == 0	1%2 == 1
0/2 == 0	0% 2 == 0
(– 1)/2 == 0	(– 1)%2 == – 1
(– 2)/2 == – 1	(– 2)%2 == 0
(– 3)/2 == – 1	(– 3)%2 == – 1

- Use Math.abs(x % N)
  - Rather than Math.abs(x) % N

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

- **Suspect 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

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

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

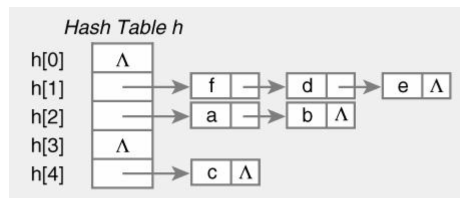
Types of Hash Tables

- **Open addressing**
  - **Store objects in each table entry**

Hash table h

h[0]	(k_4, v_4)
h[1]	Λ
h[2]	Λ
h[3]	(k_1, v_1)
h[4]	(k_3, v_3)
h[5]	(k_2, v_2)

- **Chaining (bucket hashing)**
  - **Store lists of objects in each table entry**



Open Addressing Hashing

- Approach
  - Hash table contains objects
  - Probe ⇒ examine table entry
  - Collision
    - Move K entries past current location
    - Wrap around table if necessary
  - Find location for X
    1. Examine entry at A[key(X)]
    2. If entry = X, found
    3. If entry = empty, X not in hash table
    4. Else increment location by K, repeat

Open Addressing Hashing

- Approach
  - Linear probing
    - K = 1
    - May form clusters of contiguous entries
  - Deletions
    - Find location for X
    - If X inside cluster, leave non-empty marker
  - Insertion
    - Find location for X
    - Insert if X not in hash table
    - Can insert X at first non-empty marker

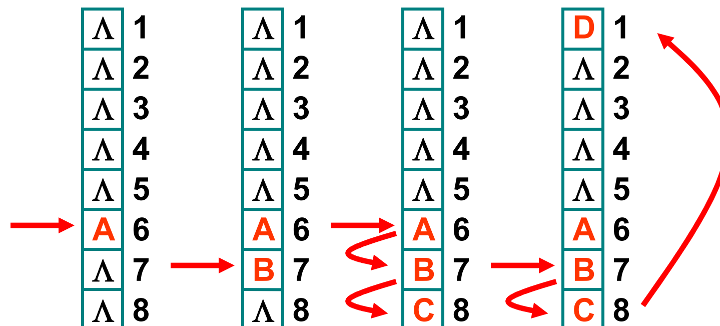
Open Addressing Example

- Hash codes
  - H(A) = 6 H(C) = 6
  - H(B) = 7 H(D) = 7
- Hash table
  - Size = 8 elements
  - Λ = empty entry
  - * = non-empty marker
- Linear probing
  - Collision ⇒ move 1 entry past current location

Λ	1
Λ	2
Λ	3
Λ	4
Λ	5
Λ	6
Λ	7
Λ	8

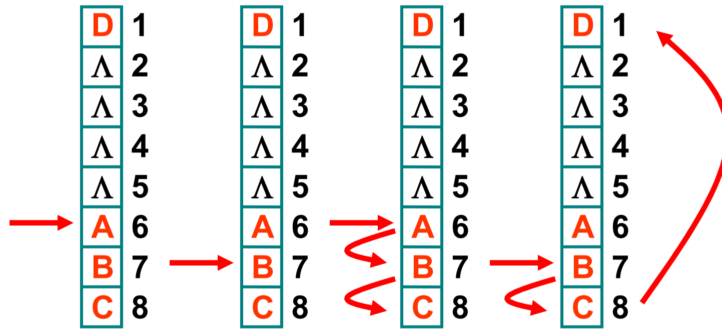
Open Addressing Example

- Operations
  - Insert A, Insert B, Insert C, Insert D



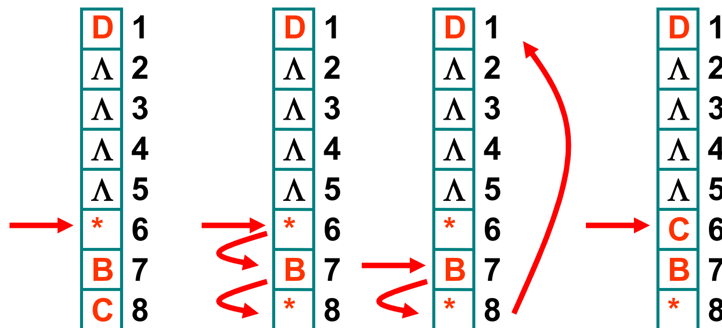
Open Addressing Example

- Operations
  - Find A, Find B, Find C, Find D



Open Addressing Example

- Operations
  - Delete A, Delete C, Find D, Insert C



Efficiency of Open Hashing

- Load factor = entries / table size
- Hashing is efficient for load factor < 90%

α	Number of Comparisons	Approximate Behavior	(Table Size N = 100)
0.1	1.06	O(1)	
0.2	1.13		
0.3	1.21		
0.4	1.33		
0.5	1.50		
0.6	1.75		
0.7	2.17		
0.8	3.00	O(log N)	
0.9	5.50		
0.95	10.5		
0.98	26.5	O(N)	
0.99	50.5		

Chaining (Bucket Hashing)

- Approach
  - Hash table contains lists of objects
  - Find location for X
    - Find hash code key for X
    - Examine list at table entry A[key]
  - Collision
    - Multiple entries in list for entry

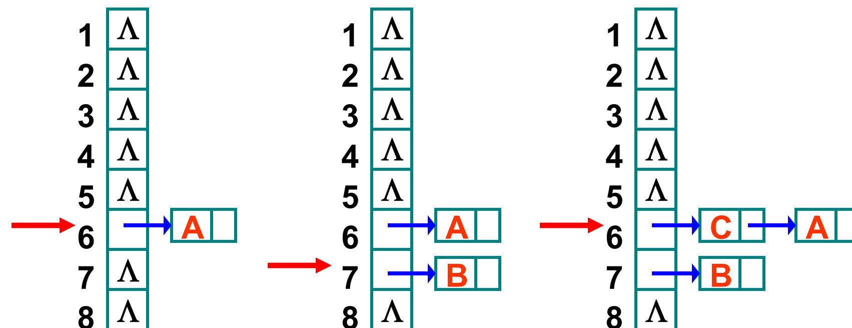
Chaining Example

- **Hash codes**
  - H(A) = 6   H(C) = 6
  - H(B) = 7   H(D) = 7
- **Hash table**
  - Size = 8 elements
  - Λ = empty entry

1	Λ
2	Λ
3	Λ
4	Λ
5	Λ
6	Λ
7	Λ
8	Λ

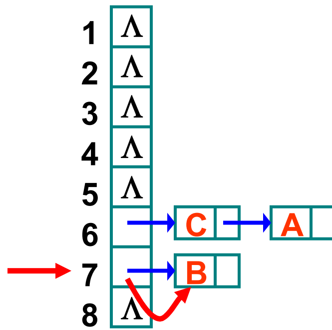
Chaining Example

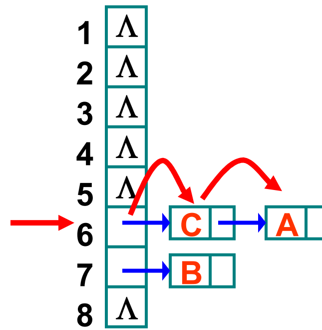
- **Operations**
  - Insert A,   Insert B,   Insert C



Chaining Example

- Operations
  - Find B, Find A





Efficiency of Chaining

- Load factor = entries / table size
- Average case
  - Evenly scattered entries
  - Operations = O(load factor)
- Worse case
  - Entries mostly have same hash value
  - Operations = O(entries)

Hashing in Java

- Collections
  - hashMap & hashSet implement hashing
- Objects
  - Built-in support for hashing
    - boolean equals(object o)
    - int hashCode( )
  - Can override with own definitions
  - Must be careful to support Java contract
    - if a.equals(b) == true
      - then a.hashCode( ) == b.hashCode( ) must be true