ALGORITHMS AND DATA STRUCTURES LECTURE 5 – HASH TABLE AND BST

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2. Hash Table
3. Binary Search Tree
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HASHING

Hashing means using some function or algorithm to map object data to some representative integer value

This so-called hash code (or simply hash) can then be used as a way to narrow down our search when looking for the item in the set

Object class contains hashCode() method with its default implementation

Recommended: Each class provides its own implementation of hashCode()

HASHING: STRING EXAMPLE

```
public final class String
{
   private final char[] s;
   ...

   public int hashCode()
   {
      int hash = 0;
      for (int i = 0; i < length(); i++)
         hash = s[i] + (31 * hash);
      return hash;
   }
}
```

ith character of s

```
String s = "call";
int code = s.hashCode();
```

$3045982 = 99 \cdot 31^3 + 97 \cdot 31^2 + 108 \cdot 31^1 + 108 \cdot 31^0$

$= 108 + 31 \cdot (108 + 31 \cdot (97 + 31 \cdot (99)))$

(Horner's method)

Horner's method to hash string of length L: L multiplies/adds.

Equivalent to $h = s[0] \cdot 31^{L-1} + \ldots + s[L-3] \cdot 31^2 + s[L-2] \cdot 31^1 + s[L-1] \cdot 31^0$

HASHING:‘STANDARD’ RECIPE

Combine each **significant** field using the <u>31x + y</u> rule.

If field is a primitive type, use wrapper type hashCode()

If field is null, return 0

If field is a reference type, use hashCode()

If field is an array, apply to each entry

```
public final class Transaction implements Comparable<Transaction>
{
   private final String  who;
   private final Date    when;
   private final double  amount;

   ...

   public int hashCode()
   {
      int hash = 17;
      hash = 31*hash + who.hashCode();
      hash = 31*hash + when.hashCode();
      hash = 31*hash + ((Double) amount).hashCode();
      return hash;
   }
}
```

nonzero constant

typically a small prime

HASH TABLE

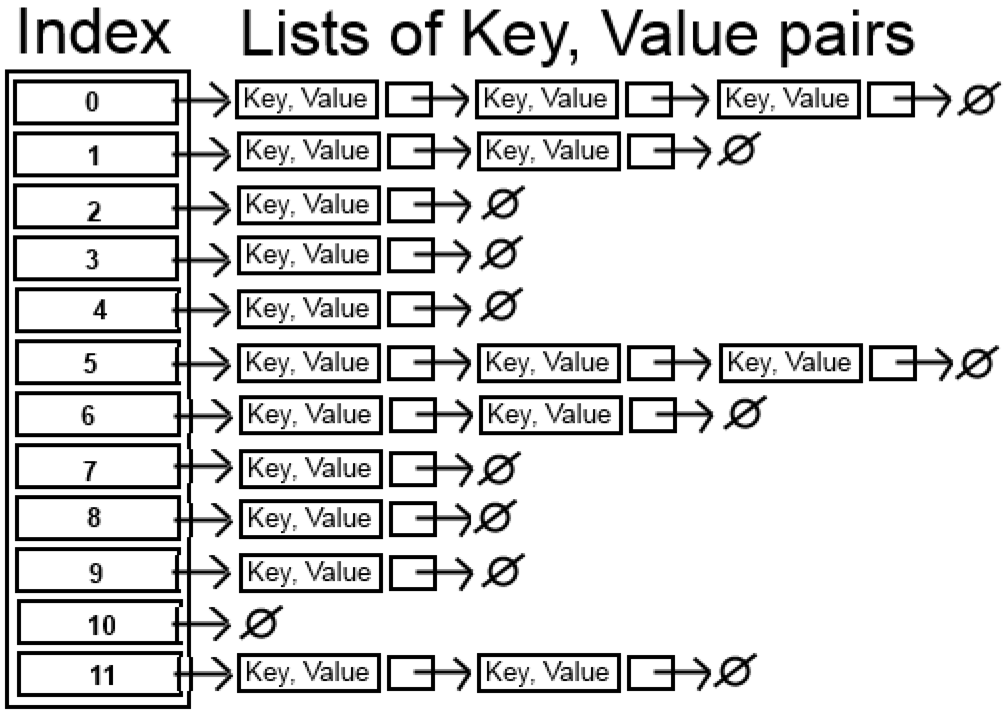
Hash table maps keys to values. Any non-null object can be used as a key or as a value

To successfully store and retrieve objects from a hashtable, the objects used as keys must implement the hashCode method and the equals method.

It looks like “an array of singly-linked lists (**chains**)”

Each linked list is accepted as **bucket**

Array size indicates number of buckets



Average case:

- Insertion = deletion = retrieving = searching = **O(1)**

HASH TABLE

The **capacity** (number of buckets - **M**) and **load factor** are parameters that affect to its performance

The **load factor** is a measure of how full the hash table is allowed to get before its capacity is automatically increased (LF should be around 0.75)

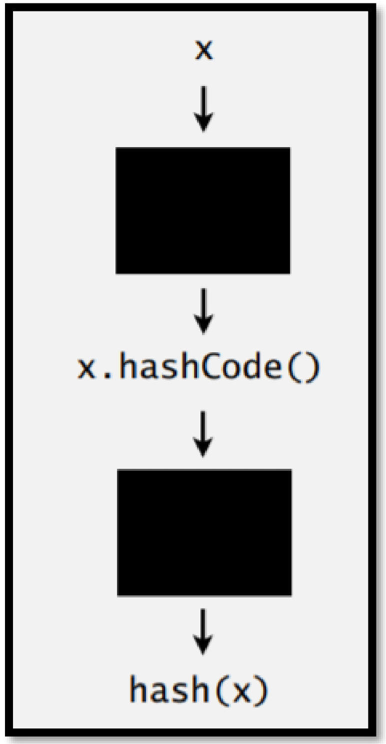
The hashCode is used to get an index of *chain* by **hash()** method (**Modular hashing**)

```
private int hash(Key key)
{   return Math.abs(key.hashCode()) % M;   }
```

1-in-a-billion bug

```
private int hash(Key key)
{   return (key.hashCode() & 0x7fffffff) % M;   }
```

correct



HASH TABLE

Collision – having same index for several nodes (cannot be avoided)

- A new node should be added to the same chain (bucket)

Challenge: Deal with collisions efficiently

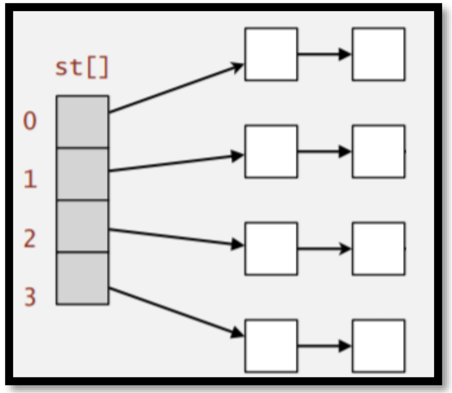
Target: Uniform distribution

Analysis: Number of probes for search/insert is proportional to N/M

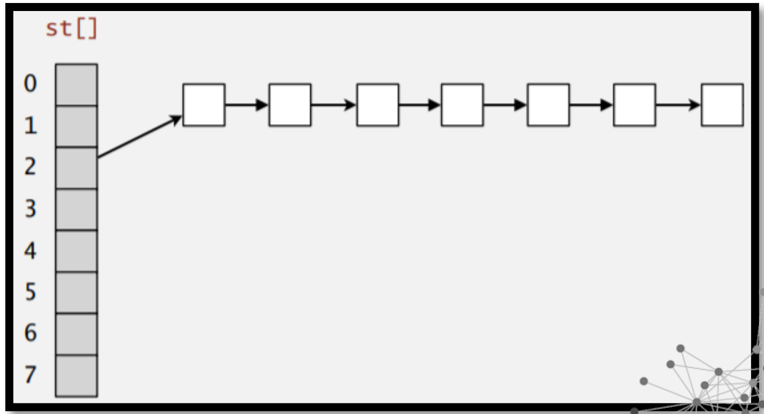
- M too large ⇒ too many empty chains
- M too small ⇒ chains too long
- Typical choice: M ~ N / 4 ⇒ constant-time ops

Once a hash table has passed its load factor - it has to rehash [create a new bigger table, and re-insert each element to the table]

Best case



Worst case



HASH TABLE: EXAMPLE

```java
public class MyHashTable<K, V> {

    private class HashNode<K, V> {...}

    private HashNode<K, V>[] chainArray; // or Object[]
    private int M = 11; // default number of chains
    private int size;

    public MyHashTable() {...}

    public MyHashTable(int M) {...}

    private int hash(K key) {...}

    public void put(K key, V value) {...}

    public V get(K key) {...}

    public V remove(K key) {...}

    public boolean contains(V value) {...}

    public K getKey(V value) {...}
}
```

```java
private class HashNode<K, V> {
    private K key;
    private V value;
    private HashNode<K, V> next;

    public HashNode(K key, V value) {
        this.key = key;
        this.value = value;
    }

    @Override
    public String toString() {
        return "{" + key + " " + value + "}";
    }
}
```

BINARY SEARCH TREE

A BST is a binary tree in symmetric order.

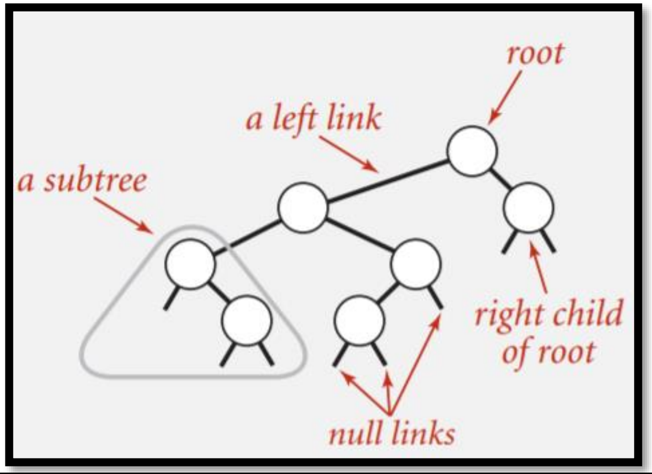
Each node has two references to left and right nodes

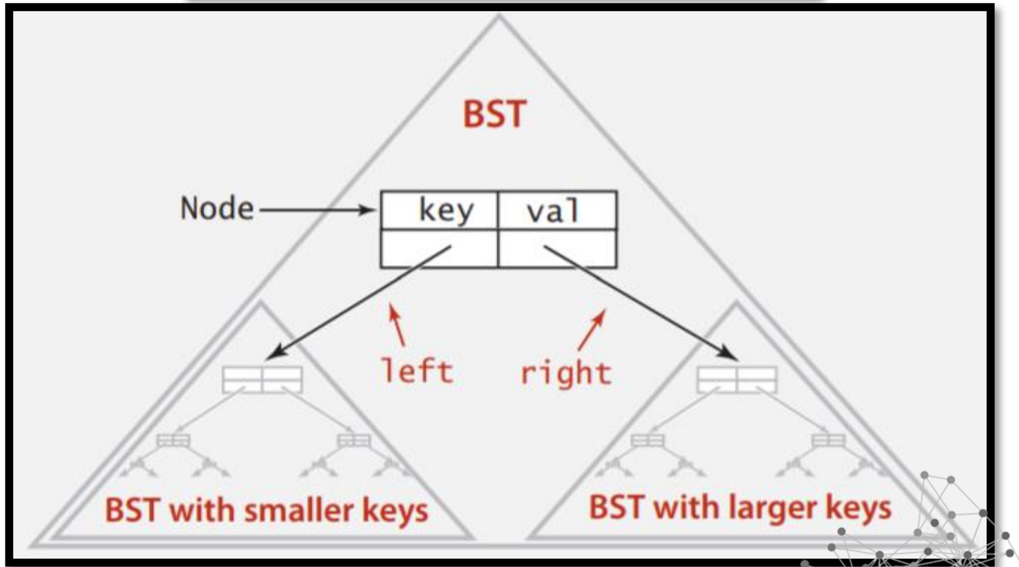
Symmetric order. Each node has a key, and every node's key is:

- Larger than all keys in its left subtree
- Smaller than all keys in its right subtree

A Node is composed of four fields

- Key and Value
- Left and right subtree references





BINARY SEARCH TREE

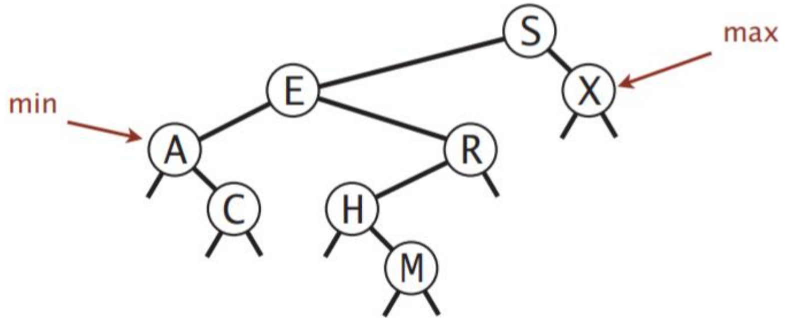
A BST uses O(log(N)) for most manipulations

Search: If less, go left; if greater, go right; if equal, search hit

Insert: If less, go left; if greater, go right; if null, insert

GetMin(): Most left node

GetMax(): Most right node




```java
public class BST<K extends Comparable<K>, V> {
    private Node root;
    private class Node
    {
        private K key;
        private V val;
        private Node left, right;
        public Node(K key, V val)
        {
            this.key = key;
            this.val = val;
        }
    }
    public void put(K key, V val) {...}

    public V get(K key) {...}

    public void delete(K key) {...}

    public Iterable<K> iterator() {...}
}
```

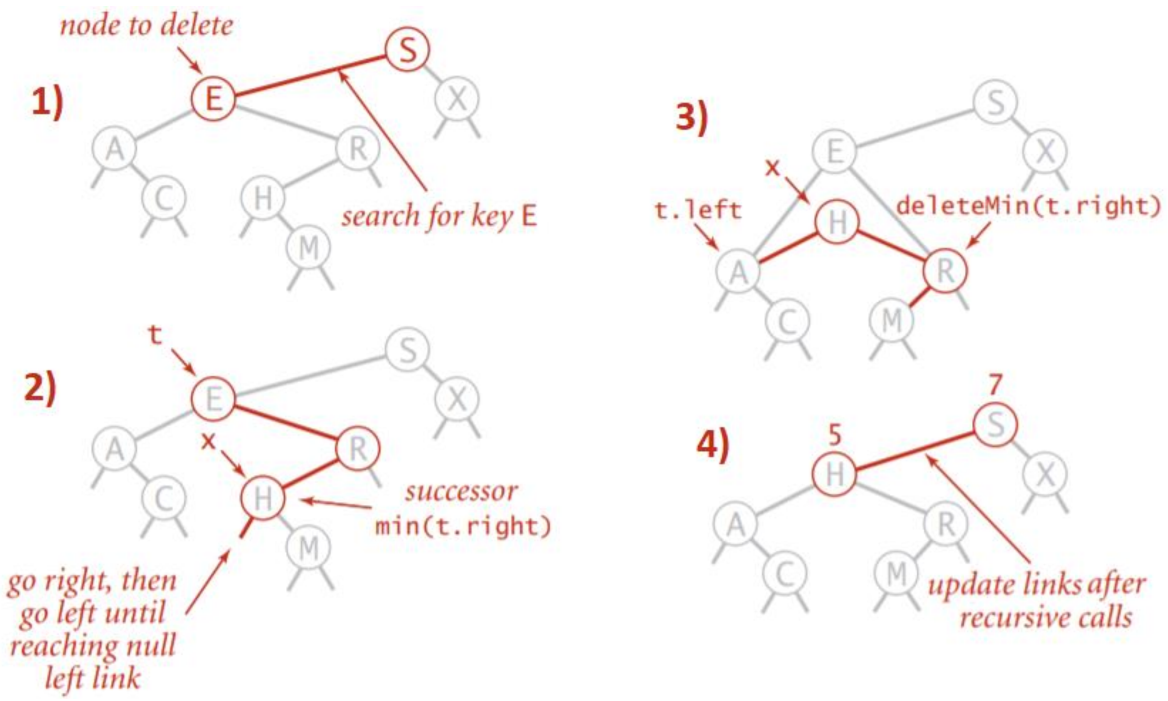
BINARY SEARCH TREE: DELETE

To delete a node with key k: search for node t containing key k

Case 1 (1 child): Delete t by replacing parent link

Case 2 (2 children):

- Find successor x of t
- Delete the minimum in t's right subtree
- Put x in t's spot



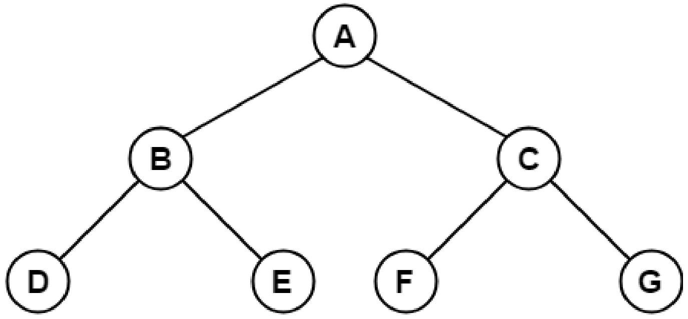
guarantee			average case			ordered ops?	operations on keys
search	insert	delete	search hit	insert	delete		
N	N	N	$1.39 \lg N$	$1.39 \lg N$	$\sqrt{N}$	✔	compareTo()

BST: INORDER TRAVERSAL

In BST, **inorder traversal** is used to get nodes in increasing order (Left-Root-Right)

Ordered iteration

- Traverse left subtree
- Enqueue key
- Traverse right subtree



Inorder Traversal : D , B , E , A , F , C , G

```
public Iterable<Key> keys()
{
    Queue<Key> q = new Queue<Key>();
    inorder(root, q);
    return q;
}

private void inorder(Node x, Queue<Key> q)
{
    if (x == null) return;
    inorder(x.left, q);
    q.enqueue(x.key);
    inorder(x.right, q);
}
```

LITERATURE

Algorithms, 4th Edition, by Robert Sedgewick and Kevin Wayne, Addison-Wesley

- Chapters 3.2, 3.4

Grokking Algorithms, by Aditya Y. Bhargava, Manning

- Chapter 5

GOOD LUCK!