Data Structures

Searching

Searching Efficiencies

- Best case: *O*(1)
- Worst Case: *O*(n)
- We can easily achieve: *O*(log n)

Linear Search

```
int   linearsearch(int x[], int n, int key)
{
  int       i;

  for (i = 0;  i < n;  i++)
      if (x[i] == key)
            return(i);

  return(-1);
}
```

Improved Linear Search

```
int   linearsearch(int x[], int n, int key)
{
  int       i;
  //This assumes an ordered array
  for (i = 0;  i < n && x[i] <= key;  i++)
      if (x[i] == key)
            return(i);

  return(-1);
}
```

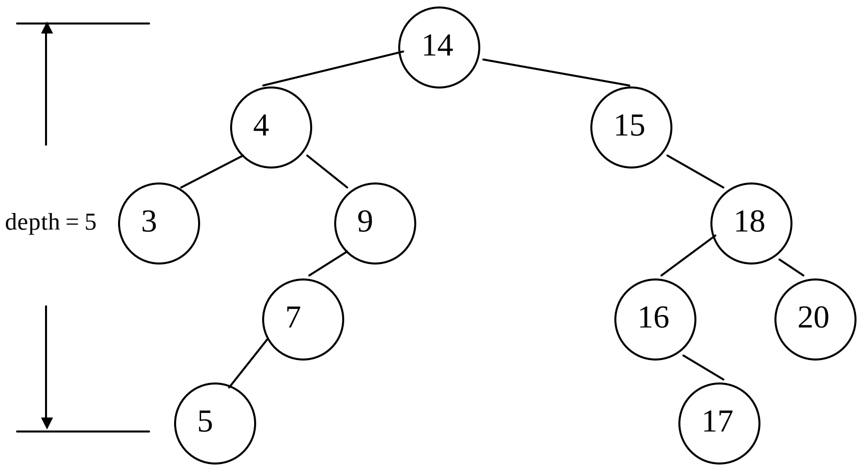
Binary Search

```
int   binarysearch(int x[], int n, int key)
{
  int low, high, mid;

  low = 0;
  high = n -1;
  while (low <= high)   {
      mid = (low + high) / 2;
      if (x[mid] == key)
            return(mid);
```

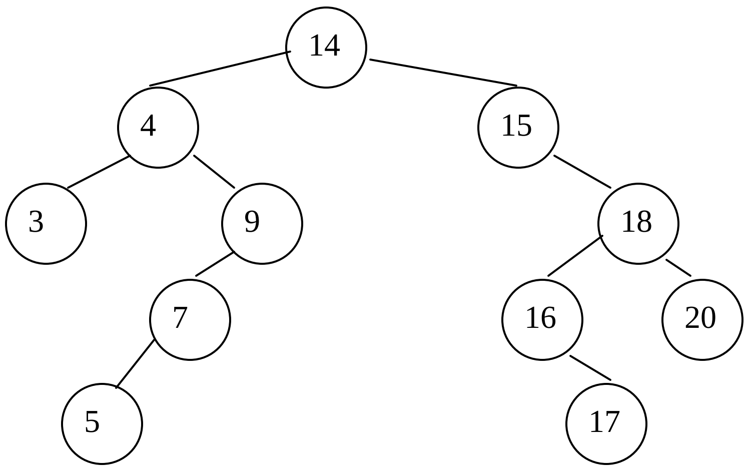
Binary Search (continued)

```
      if (x[mid] > key)
            high = mid - 1;
      else
            low = mid + 1;
  }

  return(-1);
}
```

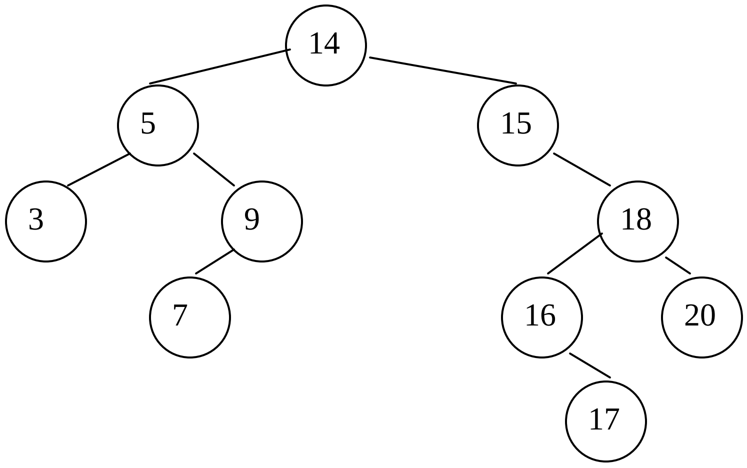
A Binary Search Tree



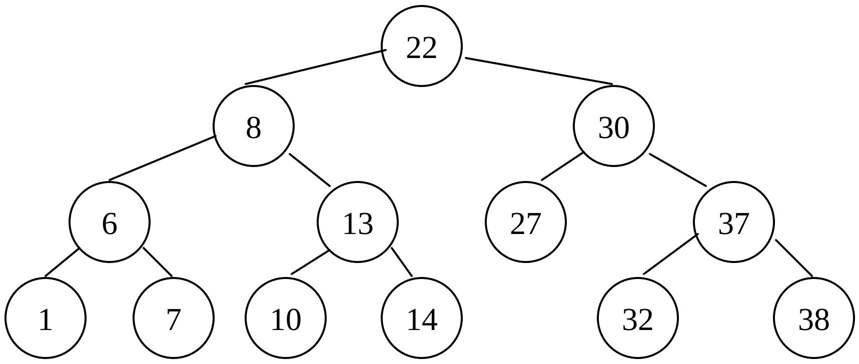
Deleting A Node On A Search Tree - Before



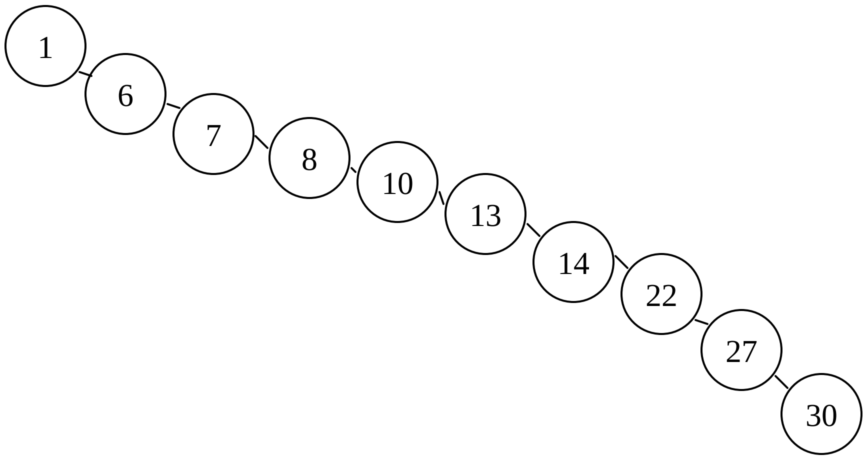
Deleting A Node On A Search Tree - After



Is Balancing a Tree Important?



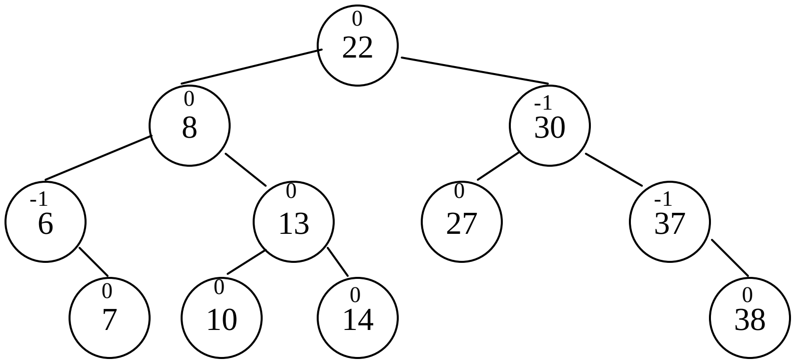
Is Balancing a Tree Important?



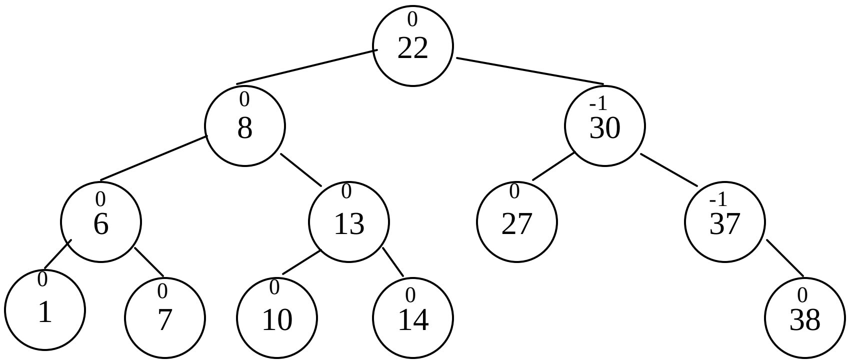
An AVL Tree

- An AVL Tree is a search tree where the depth of the left and right subtree can differ by no more than one level.

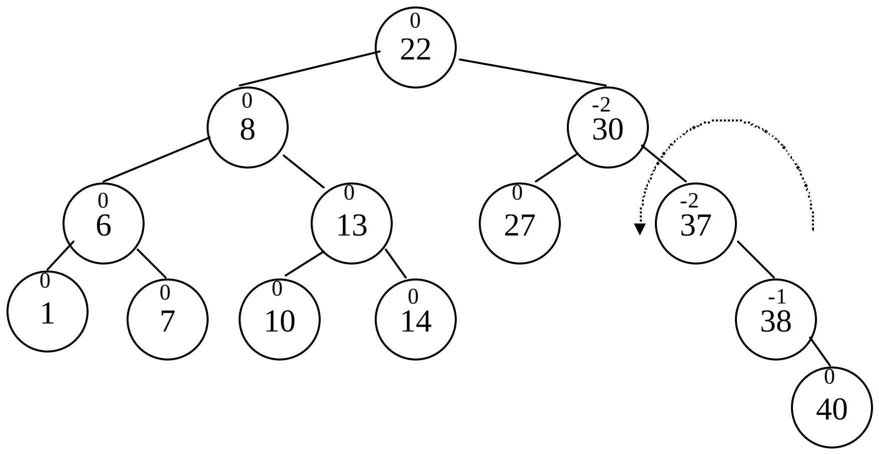
An AVL Tree



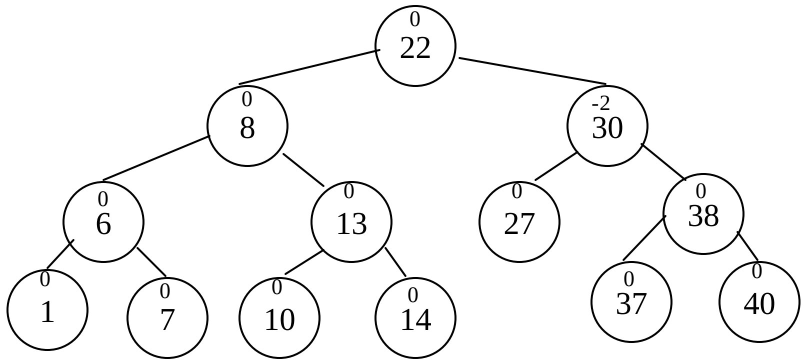
Inserting A Node On An AVL Tree



Inserting A Node On An AVL Tree



After Rotating



AVL.h

```
#include    <iostream>

using namespace std;

typedef     int   infotype;

struct nodetype   {
  infotype        info;
  int                   balance;
  struct nodetype *left, *right;
};

typedef     struct nodetype   *nodeptr;
```

```
class AVLTree     {
public:
  AVLTree(void);
  AVLTree(infotype key);
  nodeptr   maketree(infotype key);
  void      traverse(void);
  nodeptr   insert(infotype key);
private:
  nodeptr   tree;
  void      rightRotation(nodeptr p);
  void      leftRotation(nodeptr p);
  void      intrav(nodeptr tree);
};
```

AVL.cpp

```
#include    "AVL.h"

// AVLTree() -    Default constructor creating a
//                null tree
AVLTree::AVLTree(void)  {
  tree = NULL;
}


// AVLTree() -    Initializing constructor
//                creating a one-node tree
AVLTree::AVLTree(infotype key)      {
  tree = maketree(key);
}
```

```
// traverse() -   Does an in-order traversal
//                using the recursive method
void  AVLTree::traverse(void) {
  intrav(tree);
}

// maketree() - Creates a node for the AVL tree
nodeptr     AVLTree::maketree(infotype key)     {
  nodeptr   p;

  p = new struct nodetype;
  p -> info = key;
  p ->balance = 0;
  p ->left = p ->right = NULL;
  return p;
}
```

```
// rightRotation() -    Rotates an AVL subtree to
//                      the right
void  AVLTree::rightRotation(nodeptr p)   {
  nodeptr q, hold;
  q = p -> left;
  hold = q -> right;
  q -> right = p;
  p -> left = hold;
}

// leftRotation() -     Rotates an AVL subtree to
//                      the left
void  AVLTree::leftRotation(nodeptr p)    {
  nodeptr q, hold;
  q = p -> right;
  hold = q -> left;
  q -> left = p;
  p -> right = hold;
}
```

```
// intrav() -     A recursive method to traverse
//                the tree in order
void  AVLTree::intrav(nodeptr tree) {
  static level = 0;
  level++;
  if (tree != NULL)     {
     intrav(tree -> left);
     cout << level << '\t' << tree -> info <<
  endl;
     intrav(tree-> right);
  }
  --level;
}
```

```
// insert() -     Inserts a record into its
//                proper place on an AVL tree
nodeptr     AVLTree::insert(infotype key) {
  nodeptr         fp, p, q, ya, fya, s;
  int             imbalance;
  // Part I - Search and insert into the binary
` //          tree
  fp = NULL;
  p = tree;
  fya = NULL;
  ya = p;

  // ya points to the youngest ancestor which may
  // become unbalanced.  fya points to ya's
  // father and fp points to the father of p
  while (p != NULL)     {
      if (key == p ->info)
            return p;
```

```
      q = (key < p -> info)?
                  p -> left: p -> right;
      if (q != NULL)
            if (q -> balance != 0)  {
                  fya = p;
                  ya = q;
            }
      fp = p;
      p = q;
  } // while p!= NULL

  // Insert new record
  q = maketree(key);
  q -> balance = 0;
  (key < fp -> info)?
            fp -> left = q: fp -> right = q;
```

```
// The balance on all nodes between
// ya and q must be changed from 0
p = (key < ya -> info)?
               ya -> left: ya -> right;
s = p;
while (p != q)  {
    if (key < p -> info)    {
          p -> balance = 1;
          p = p -> left;
    }
    else  {
          p -> balance = -1;
          p = p -> right;
    } // if key < p -> info
} // while p != q
```

```
// Part II - Ascertain whether or not the tree
// is unbalanced.
// If it is, q is the newly inserted node, ya
// is its youngest unbalanced ancestor, fya is
// ya's father and s is ya's son in the
// direction of the imbalance.
imbalance = (key < ya -> info)? 1 : -1;
if (ya -> balance == 0)     {
    // Another level has been added to the tree
    //    The tree remains balanced
    ya -> balance = imbalance;
    return q;
} // if (ya -> balance == 0)
if (ya -> balance != imbalance)   {
    // The added node has been placed in
    // the opposite direction of the imbalance
    // The tree remains balanced
    ya -> balance = 0;
    return q;
}
```

```
// Part III - the additional node has
// unbalanced the tree
// Rebalance it by performing the required
// rotations and then adjust the balances of
// the nodes involved.
if (s -> balance == imbalance)    {
    // ya nd s have been unbalanced in the same
    // direction
    p = s;
    if (imbalance == 1)
          rightRotation(ya);
    else
          leftRotation(ya);
    ya -> balance = 0;
    s -> balance = 0;
}
```

```
else      {
    // ya and s are unbalanced in opposite
    // directions
    if (imbalance == 1)     {
          p = s -> right;
          leftRotation(s);
          ya -> left = p;
          rightRotation(ya);
    }
    else  {
          p = s -> left;
          ya -> right = p;
          rightRotation(s);
          leftRotation(p);
    }
```

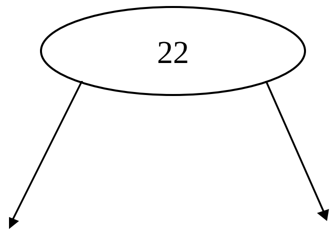
```
        // Adjust balance field for involved nodes
        if (p ->balance == 0)   {
              // p was inserted node
              ya -> balance = 0;
              s -> balance = 0;
        }
        else
              if (p -> balance == imbalance)      {
                    ya -> balance = -imbalance;
                    s -> balance = 0;
              }
              else  {
                    ya -> balance = 0;
                    s -> balance = imbalance;
              }
              p -> balance = 0;
    }
```

```
    // Adjust pointer to the rotated subtree
    if (fya == NULL)
        tree = p;
    else (ya == fya -> right)? fya -> right = p:
    fya -> left = p;
    return q;
  }
```

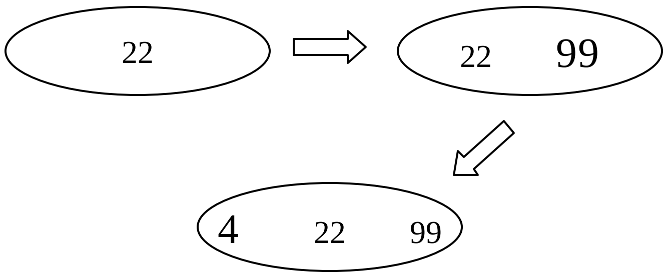
Inserting an AVL Tree: An Example

```
int   main(void)  {
  AVLTree   myTree(5);
  nodeptr   z;
  int i;


  for ( i = 6; i < 250; i++)  {
      z = myTree.insert(2*i);
  }
  myTree.traverse();
  return(0);
}
```

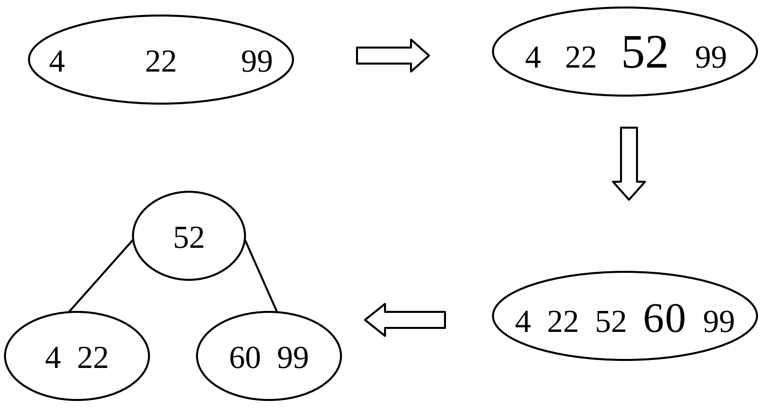
General Search Trees



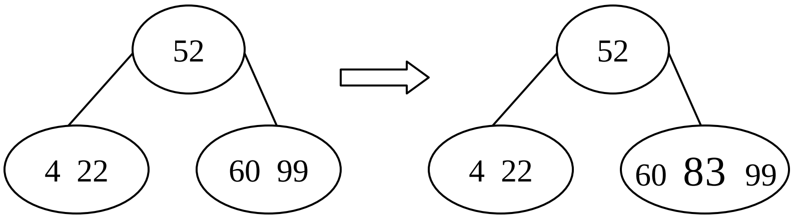
B Trees



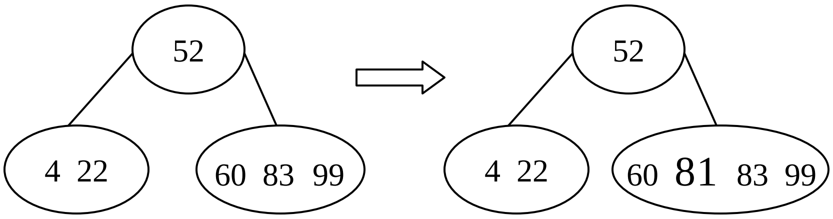
B Trees (continued)



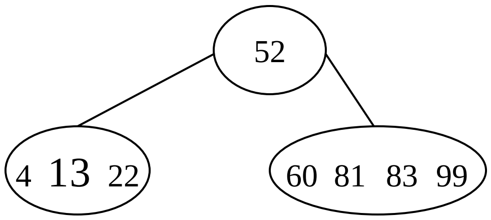
B Trees (continued)



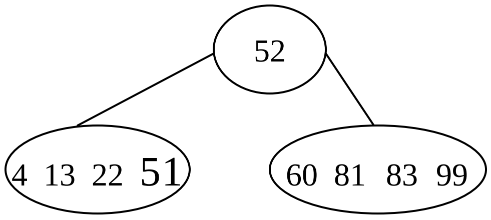
B Trees (continued)



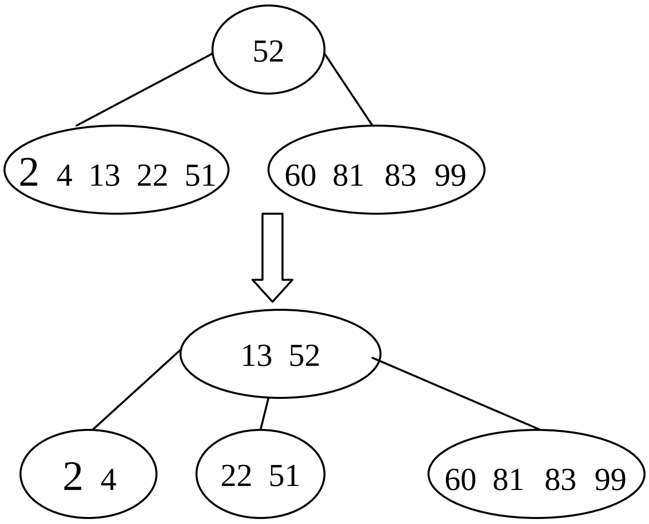
B Trees (continued)



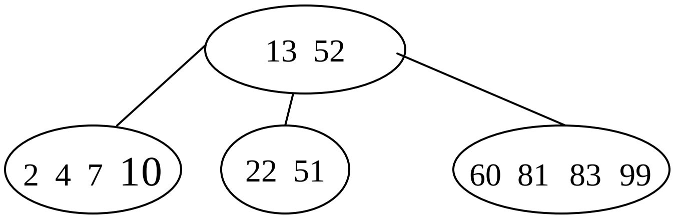
B Trees (continued)



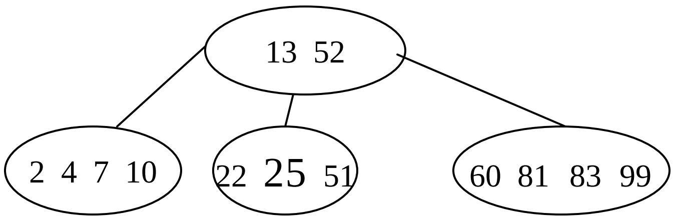
B Trees (continued)



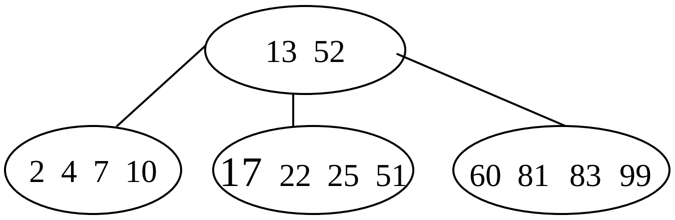
B Trees (continued)



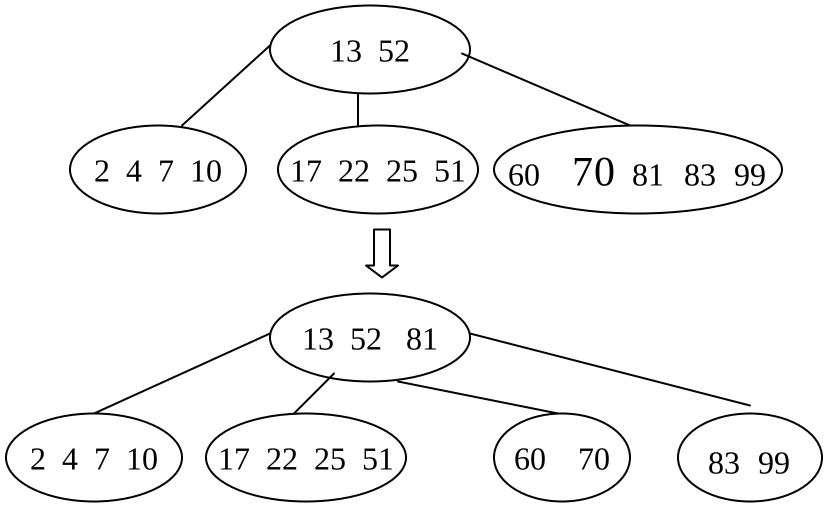
B Trees (continued)



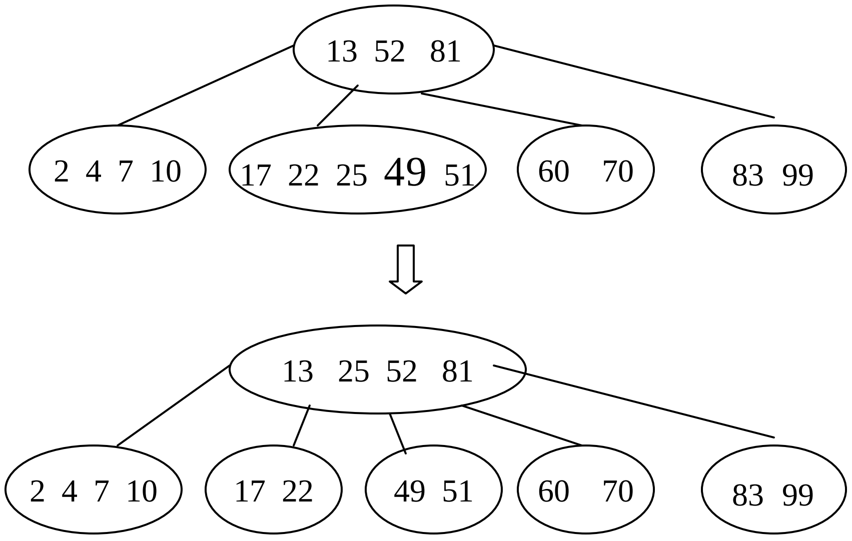
B Trees (continued)



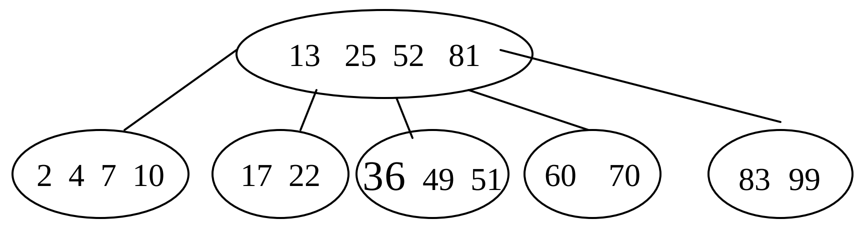
B Trees (continued)



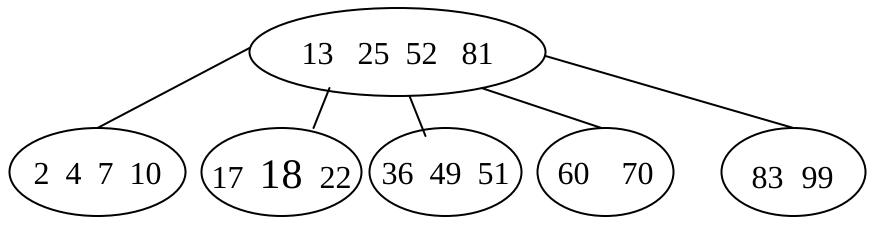
B Trees (continued)



B Trees (continued)



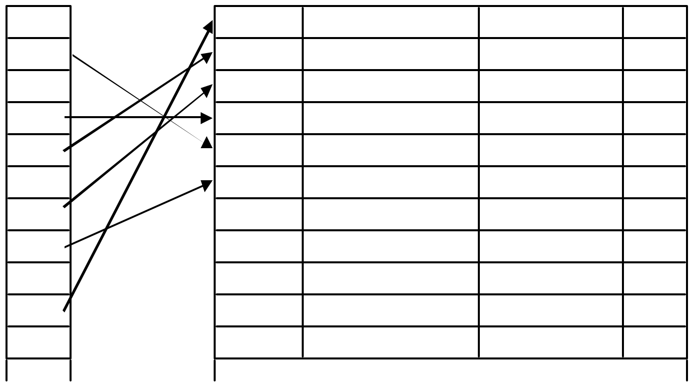
B Trees (continued)



Hashing

- Hashing is at best an O(1) searching process, searching a large array by compressing the key into a smaller value called a hash value.
- Hash values will not be unique which leads to ***hash collision*** or ***hash clash***. This is resolved by one of two means, one of which is called ***rehashing***.

Hash Table



Resolving Hash Collision

- Resolving hash collision is done by a process called ***rehashing***.
- The simplest strategy for rehashing is to simply add one to the hash value and store the record in the next available slot. If this is occupied keeping incrementing until an available slot is found. This is called ***linear probing***.

Hash.h

```
#include    <iostream>  // Necessary for input
                        // and output
#include    <string.h>  // Necessary for
                        // manipulating C-style
                        // strings
using namespace std;

// The necessary constants
const int   hashTableSize = 10000;
const int   keySize = 20;
const int   recordTableSize = 500;

// A prototypical record type to be stored
typedef     struct      {
  char      key[keySize];
} recordStuff;
```

```
// A class for a table to be searched via hashing
class HashTable   {
public:
  HashTable(void);      // The initialization
                        // constructor
                  // Finds the hash value
  int             hashValue(char *skey);
  //  Inserts a new record in the table
  bool      insertRecord(recordStuff myRecord);
  // Searches for a record by key
  bool      findRecord(recordStuff &foundRecord,
                        char *skey);

private:
  // The predecessor value of the index
  inline int      pred(int index)
            {return (index == 0)?
            hashTableSize - 1: index - 1;}
```

```
  // The successor value of the index
  inline int      succ(int index)
            {return (index == hashTableSize - 1)?
             0: index + 1;}
  int             recordTableLength;      //
  Number of entries in the table so far
  int             hashTable[hashTableSize];
  recordStuff     recordTable[recordTableSize];

};
```

Hash.cpp

```
#include    "Hash.h"

// HashTable() -   An initialization constructor
HashTable::HashTable(void)    {
  int i;

  // The whole table should be -1 because
  // there are no entries yet
  for (i = 0;  i < hashTableSize;  i++)
      hashTable[i] = -1;

  // The table is initially empty
  recordTableLength = 0;
}
```

```
// hashValue() -  Returns the hash value
int   HashTable::hashValue(char *skey)    {
  int i;
  long     sum = 0;

  // Add the ASCII code of the character
  //  and left shift one place
  for (i = 0;  i < strlen(skey)
                  && i < 8*sizeof(int)-8; i++)
      sum = (sum << 1) + (int)(skey[i]);
  return sum % hashTableSize;
}
```

```
// insertRecord() -     Inserts a new record in
//                      the table
bool  HashTable::insertRecord
                  (recordStuff myRecord)  {
  int index, firstIndex;

  // Make sure there's room for the new record
  if (recordTableLength == recordTableSize - 1)
      return(false);

  // Place the record in the next available slot
  recordTable[recordTableLength] = myRecord;

  // This is the expected hash value
  index = firstIndex = hashValue(myRecord.key);
```

```
  // If there is a hash collision, use linear
  // probing to find a spot for it in the hash
  // table
  while (hashTable[index] != -1
                  && index != pred(firstIndex))
      index = succ(index);

  // We searched the whole hash table
  //  and could not find room for it
  if (hashTable[index] != -1)
      return(false);

  // Don't forget to increment the length;
  // the table is one record larger
  hashTable[index] = recordTableLength++;
  return(true);
}
```

```
// findRecord() - Look for the record, return it
//                as a reference parameter and
//                return whether or not the
//                record was there
bool  HashTable::findRecord
      (recordStuff &foundRecord, char *skey)    {
  int index, firstIndex, recordIndex;

  // Find the proper hash value
  index = firstIndex = hashValue(skey);

  // Get the corresponding index in the record's
  table
  recordIndex = hashTable[index];
```

```
  //  This may not be it; we may have had hash
  //  collision that was resolved by linear
  //  probing
  while
      (strcmp(recordTable[recordIndex].key,
                                  skey) != 0
      && index != pred(firstIndex)) {
      index = succ(index);
      recordIndex = hashTable[index];
  }

  //  If the record was here, return an empty
  //  record and a result of false (ie, the
  //  record wasn't found
  if (strcmp(recordTable[recordIndex].key,
                                  skey) != 0) {
      strcpy(foundRecord.key, "");
      return false;
  }
```

```
    // Return the record and a result of true
    // (ie the record was found)
    foundRecord = recordTable[recordIndex];
    return true;
  }
```

A Driver To Test **`Hash.cpp`**

```
int   main(void)  {
  HashTable       h;
  recordStuff     rs;
  bool            found;

  strcpy(rs.key, "act");
  h.insertRecord(rs);
  found = h.findRecord(rs, "act");
  if (found)
      cout << strlen(rs.key) << "\""
            << rs.key << "\"" << endl;
  else
      cout << "\"" << "act"
            << "\" was not found." << endl;
  return(0);
}
```

Separate Chaining