Hash Tables and Graphs

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I know you are going to ask anyways!

- Why is the site so slow?
- Are/When we charging?
- Were does the money come from?
- Are we shutting down for 3 months?
- Why do to kill Fakesters?
- It would be really cool if...

Notions of Equality

- Java has two notions of equality for objects and arrays, (e.g. int[]) reference equality and data equality.
- For “primitive types” (ints, longs, bytes), only data equality. 3 == 3 always.

Reference Equality

- Reference equality is when two objects or arrays refer to the same data in memory. They are aliases for each other.
  - *MyData a = new MyData(...);*
  - *MyData b = a;*
- This type of equality is tested by "=="
  - (*a == b)* is true in the example above.
- if *(a == b)* is true, then *a* and *b* are actually the same object. A change in one will result in a change in the other.

Data Equality

- Data equality for when two different objects have the same data but different locations in memory.
- This eqality is tested with method
  - *boolean equals(Object o)*
- If *(a.equals(b))* is *true* then they contain the same data, but may be different objects.

Sample Class, 1

```
public class MyData {

    private String name;
    private int age

    public MyData(String value, int age) {
        this.name = name;
        this.age = age
    }
}
```

Test Output, 1

```
public static void main(String[] args) {

    MyData a = new MyData("Fred", 23);
    MyData b = new MyData("Fred", 23);
    MyData c = a;

    System.out.println("a == b  " + (a ==b));  // ref equality
    System.out.println("a == c  " + (a ==c)); // ref equality
    System.out.println("a.equals(b) ” + (a.equals(b)));  // data
    equality
    System.out.println("a.equals(c) “ + (a.equals(c)));  // data
    equality
}
```

```
a == b  false
a == c  true
a.equals(b) false    Huh???
a.equals(c) true
```

Equals Default Behavor

- By default, the class *Object* defines equals to be the same as reference equality.
- This means *equals* will return *false*, on objects with the same data but with different references!
- You must define your equals method, individually testing fields.
- You might not need to test every field.

Sample Class 2

```
public class MyData {

    private String name;
    private int age

    public MyData(String value, int age) {
        this.name = name;
        this.age = age
    }

    public boolean equals(Object o) {
        MyData rhs = (MyData)o;
        return name.equals(rhs.name) && age == rhs.age;
    }
}
```

Test Harness and Output

```
public static void main(String[] args) {

    MyData a = new MyData("Fred", 23);
    MyData b = new MyData("Fred", 23);
    MyData c = a;

    System.out.println("a == b  " + (a ==b));
    System.out.println("a == c  " + (a ==c));
    System.out.println("a.equals(b) " + (a.equals(b)));
    System.out.println("a.equals(c) " + (a.equals(c)));
}
```

```
a == b  false
a == c  true
a.equals(b) true   // good!
a.equals(c) true
```

When to Reference Equality

Use Reference Equality (==) when

- All the objects to be tested are already created and no more are being added.
- Preventing “self-assignment” (e.g. a = a)
- When the program is short-lived
- Preventing “double-counting” when iterating through a list.

```
MyData a = from a collection.
MyData other = null
for (Iterator i = collection.iterator(); i.hasNext();
  other = (MyData) i.next()) {
  if (a != other) { do something; }
}
```

When to use Data Equality

- Use Data Equality (equals) everywhere else!
  - Objects are being created from an external source and being compared with internal data
    - From the database
    - From user input
    - From a web query string or form
    - Any remote source

  When the program is long-lived

  Server environments

  In most cases you won't be wrong to use data equality. You just might be a bit slower.

Hash Tables Revisited

Hash Tables are the Most Important Data Structure!

You use them all the time!

Java has some tricks you need to know about!

Hash Tables and Hash Sets

- A Set in general, is a collection of unique objects, no duplicates!
- A Hash Tables is a colllections of mappings between a key and a value. Keys are unique and form a set.
- A Hash Set is a special implementation of a set that uses hashing to quickly find elements. One way to think of a hash set is that it's a hash table but the keys and values are the same.

java.util.HashMap

- Standard “chained” implementation. Java does not have a native open addressing version.
- Has a number of “buckets” each of which has a (singularly linked) list holding data.
- “An Array of Linked Lists” (Question: why single instead of doublely linked list?)
- When accessing or adding data, *HashMap* converts the key into a number by use of *int hashCode();*
- The integer is then turned into a bucket number (i.e. an array index).

Hash Codes

- *hashCode* is defined in *java.lang.Object* which all objects are derivied from
- It converts the object into a number (int) such that
  - Does it quickly
  - Is consistant and deterministic. Two objects with indentical data (or are “equal”) should produce the same has code
  - Given a collection of objects, the hash code they produce should be essentially random – no clumping or repeats.

More Hash Codes

- Java defines a pretty good hash function for the *String* class based on the data the string contains.
- For custom classes you write, Java uses an internal memory reference for the hash. Just like the default *equals()*. Not so good.
- Write your own!
- Easiest way to use the hashCode() of a internal value (e.g. Name, Key, etc)

```
public class Foo {
    protected String name;
    int hashCode() { return name.hashCode(); }
}
```

More Hash Codes

- If you have a unique integer identifier (user id, social security number, account number), you can use that as is.
- Java's *HashMap* will also scramble further the result to make it “more random like”

HashMap and Equality

- After a bucket is selected, the corresponding linked list is searched to see if the object already exists.
- It's important to make sure your custom classes define the *boolean equals(Object o)*
- If you don't, Java uses “reference equality”, which is ok in some situations, NOT ok in most server situation.

Example Class, 3

```
public class MyData {

    private String name;
    private int age

    public MyData(String name, int age) {
          this.name = name;
          this.age = age
    }

    public int hashCode() {
          return name.hashCode(); // could be fancier but ok
    }

    public boolean equals(Object o) {
          MyData rhs = (MyData)o;
          return name.equals(rhs.val) && age == rhs.age;
    }
}
```

Test Harness

```
public static void main(String[] args) {

    HashSet map = new HashSet();
    MyData a = new MyData("Fred", 23);
    MyData b = new MyData("Fred", 23);
    MyData c = new MyData("Fred", 23);
    map.add(a);
    map.add(b);
    System.out.println("Hash Code for a = " + a.hashCode());
    System.out.println("Hash Code for b = " + b.hashCode());
    System.out.println("Hash Code for c = " + c.hashCode());
    System.out.println("Set size = " + map.size());
    System.out.println("C Exists? " + map.contains(c));
}
```

Test Output

Output:

```
Hash Code for a = 110182
Hash Code for b = 110182
Hash Code for c = 110182
Set size = 1
C Exists? true
```

- What happens if we remove the *equals()* method? And why?
- What happens if we remove the *hashCode()* method? Any why?
- What happens if both *equals()* and *hashCode()* are missing?

HashMap Constructors

- *java.util.HashMap* has three constructors:
  - *HashMap();// default 16 buckets, 75% load*
  - *HashMap(int capacity); // default 75% load*
  - *HashMap(int capacity, float load); // you pick*
- *capacity* is the number of buckets
- *load* is average the number of elements each bucket can hold
- After that, a *resize* event happens.
- This happens size() > capacity * load

HashMap Resize Events

- Once the size exceeds the threshold, a resize event happens:
  - The number of buckets is doubled.
  - Every element is rehashed
- No big deal for small maps, but every expensive with large maps (k or M).
- The *HashMap* default is only 16, with load of 75%. After 12 elements are added a resize event happens.
- Multiple resizes event can happen when adding a large data. Can be Slow.

HashMap Summary

- When creating new objects, always
  - write *hashCode()*
  - write *equals()*
  - write *toString()*
- This is a good idea anyways!
- Understand the *HashMap/HashSet* constructors and set appropriately, especially when you know the data set is going to be large. It's ok to be generous.

Graphs

- An extension or generalization of trees.
- With trees, each node has exactly one parent.
- With graphs, each node can have many parents.

What do you use them for?

- Airline routes – for travel sites, and for the airlines themselves
- Logisitcs – shipping and delivery routes
- Manufacturing – robotic control and circuit boards – Try to minimize motion, increase speed.
- Information management and visualization (words, books, data, websites)
- and... social networks!

Nodes and Vertices

- With trees, a data point is a “node”
- With graphs, a data point is sometimes called a “vertex”, plural “vertices”
- It's perfectly fine to use “nodes” when talking about graphs.
- I like nodes better since it's easier to name methods, and it's faster to type!

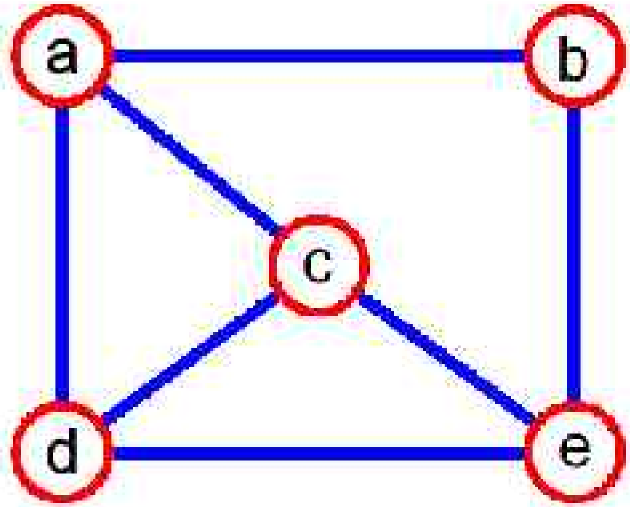
What is a Graph?

- A **graph G** = (**V**,**E**) is composed of:

  V: set of *vertices*

  E: set of *edges* connecting the *vertices* in **V**

- An **edge e** = (u,v) is a pair of vertices
- Example:



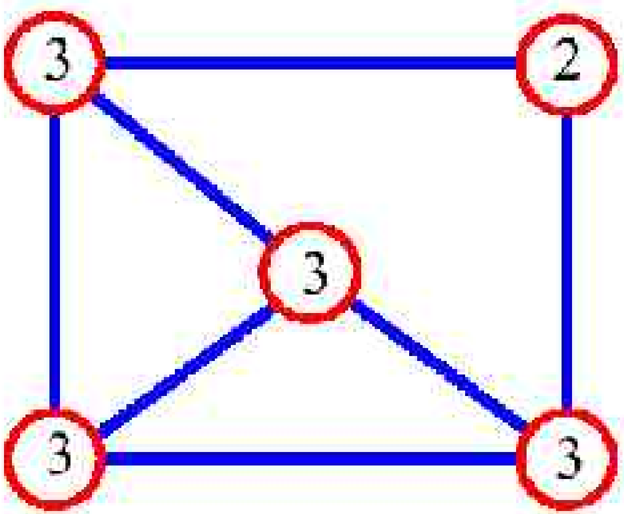
V= {a,b,c,d,e}

E= {(a,b),(a,c),(a,d), (b,e),(c,d),(c,e), (d,e)}

Slide adapted from Goodrich & Tamassia

Graph Terminology

- adjacent vertices: connected by an edge
- degree (of a vertex): # of adjacent vertices



$$\sum_{v \in V} \deg(v) = 2(\#\text{ edges})$$

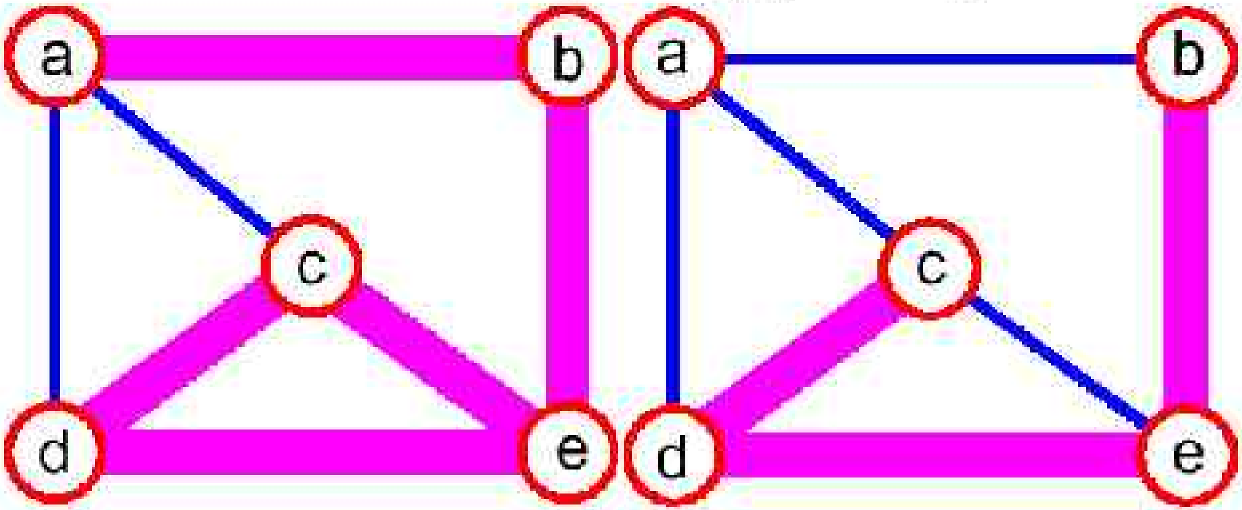
- Since adjacent vertices each count the adjoining edge, it will be counted twice

Slide adapted from Goodrich & Tamassia

Degree 1

- Nodes degree 1 away can be called
- Adjacent
- Neighbors
- Friends

path: sequence of vertices $v_1, v_2, \ldots v_k$ such that consecutive vertices v_i and v_{i+1} are adjacent.

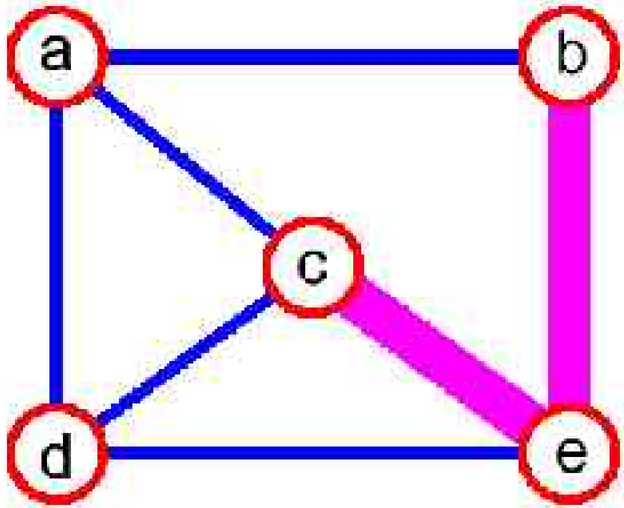


a b e d c

b e d c

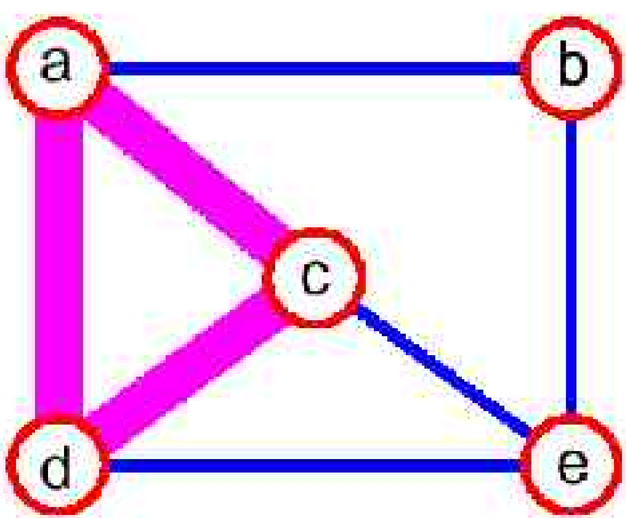
Slide adapted from Goodrich & Tamassia

- simple path: no repeated vertices



b e c

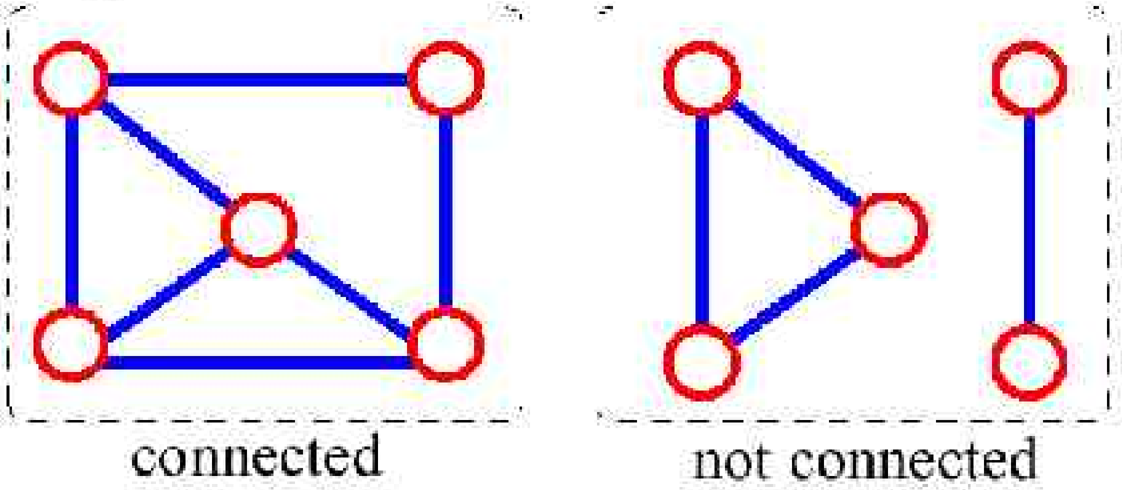
- cycle: simple path, except that the last vertex is the same as the first vertex



a c d a

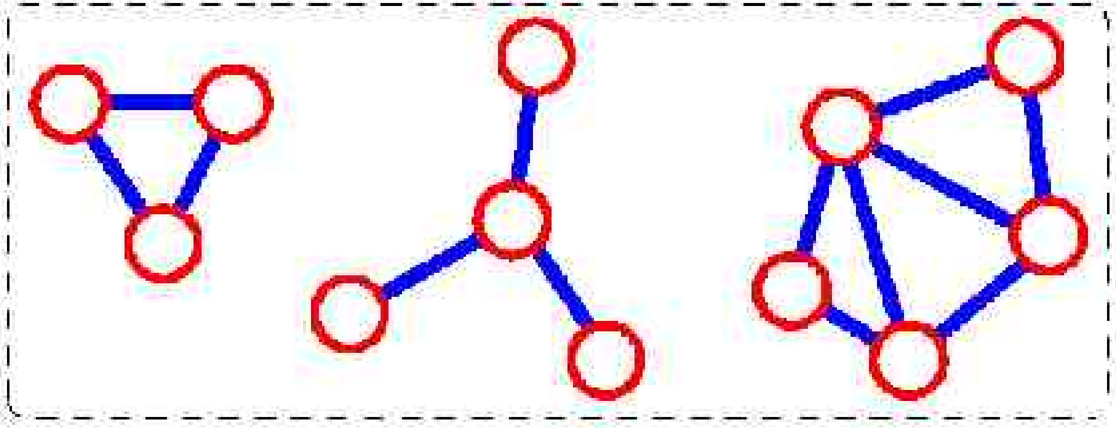
Even More Terminology

- connected graph: any two vertices are connected by some path



Slide adapted from Goodrich & Tamassia

- subgraph: subset of vertices and edges forming a graph
- connected component: maximal connected subgraph. E.g., the graph below has 3 connected components.



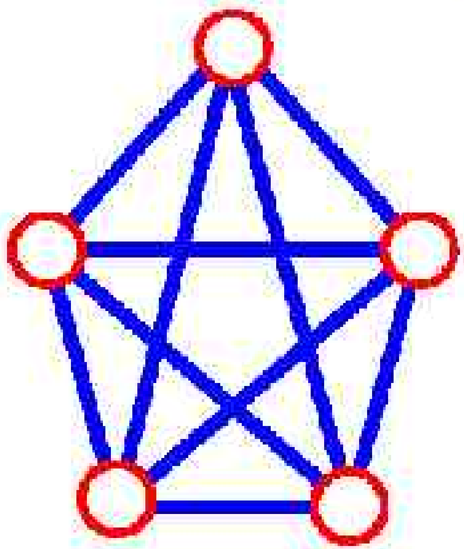
Connectivity

Let **n** = #vertices
m = #edges

- complete graph - all pairs of vertices are adjacent

$$m = (1/2)\sum_{v \in V} \deg(v) = (1/2)\sum_{v \in V} (n - 1) = n(n-1)/2$$

- Each of the **n** vertices is incident to **n** - 1 edges, however, we would have counted each edge twice!!! Therefore, intuitively, **m** = **n**(**n**-1)/2.



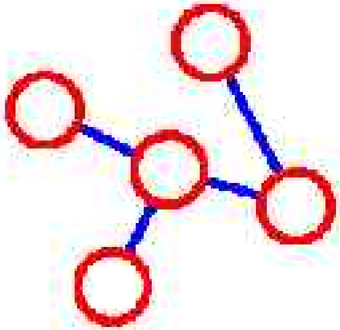
n = 5
m = (5 * 4)/2 = 10

Slide adapted from Goodrich & Tamassia

More Connectivity

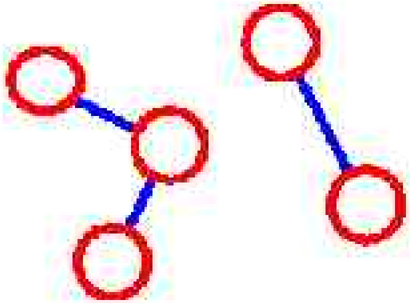
n = #vertices
m = #edges

- For a tree m = n - 1



n = 5
m = 4

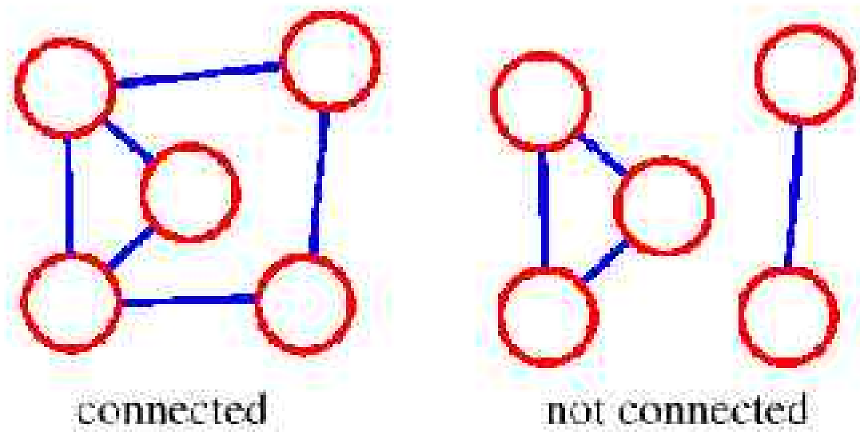
- If m < n - 1, G is not connected



n = 5
m = 3

Connected Components

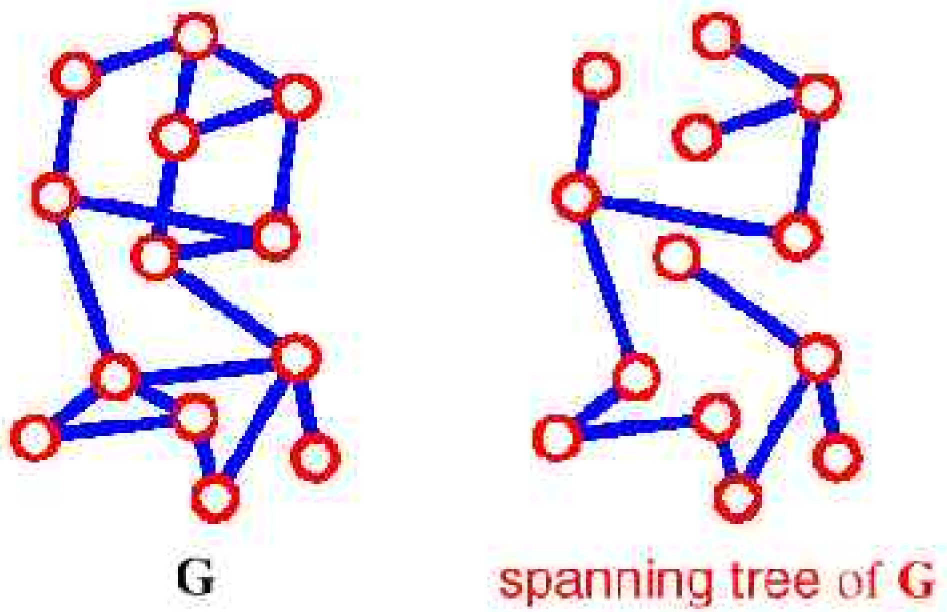
Connected Graph: any two vertices connected by a path



Connected Component: maximal connected subgraph of a graph

Spanning Tree

- A **spanning tree** of **G** is a subgraph which
  - is a tree
  - contains all vertices of **G**



- Failure on any edge disconnects system (least fault tolerant)

Slide adapted from Goodrich & Tamassia

Textbook Representation of Nodes

- At least from the second edition, page 620:

```
class Vertex {

   public char label;                    //  label, e.g. 'A'
   public boolean wasVisited;  // huh???

   public Vertex(char lab) {
       label = lab;
       wasVisited = false;
   }
}
```

Bad Bad Bad

- What does “lastVisited” have anything to do with a node? Is anything in the definition of a node involve if the node was 'visited' or not?
- It is a temporary variable for use by another (as of yet unspecified) algorithm.
- Mixing *algorithms* into the *data structure* is in general a bad idea.   This is ok, when doing user iterface, but for servers!
- We will revisit the books choice in a bit, since it provides a good negative example.

Node Representation

- Let's start over. All a node really needs is a "key" or sometype of unique identifier. For simplicity, let's just use a String.

```
Class Node {
  public String key;
  ... other data here...

  public Node(String key, ...other data...) {
     this.key = key;   //etc.
  }
}
```

- Why is *key* public? Should we use a method instead?
- Do we need to use a *String*? Can we use plain *Object*?

Adjacentcy Lists

- An adjacentcy list is simply a list that contains what other nodes are neighbors (friends).
- The map could be as simple as an array.

  Nodes[] adjList = {node1, node2, node3}

Adjacentcy Lists with Dynamic Storage

- More complicated version can have dynamic-sized storage.
- ArrayList
- LinkedList

```
ArrayList adjList = new ArrayList();
foreach neighbor
    adjList.add(the neighbor);
```

- Remember to cast when retrieving an element in the list!

```
Node n = (Node) adjList.get(2); // get second neighbor
```

Graph Data Structure

- The most common data structure for a graph is a *map* from a node or node's key to it's adjacentcy list.
- Typically a HashMap is used.

Node Abstraction

- Previous we assumed the Node object contained the key and the data, and the graph was mapping between a node and it's adjacentcy list, which was a list of Node objects.
- Frequenly you don't wan't or can't store all the information in the actual graph.
- In this case, the graph is a mapping between the keys to adjacencty list of just keys.
- The map is String to a List of Strings.

Comparison

- Full Node Objects

  Node(“Mary”, age=30) mapsTo
      {Node(“Fred”, age=10),
        Node(“Alice”, age 22),
        Node(“Bob”, age 43)}
- Pure Keys. Just uses Strings.
  “Mary” mapsTo “Fred”, “Alice”, “Bob”

- Sorry this is a terrible slide

Key to Node map

If represent a graph just using keys you need some way of turning the keys into more useful data.

- Another map (keys to DataObjects)
- Or in the database
  “select * from table where key=Mary”

Embedded Adjacentcy Lists

- One can also add the adjacentcy list into the node itself.

```
Class Node {
    public String key;
    public Node[] neighbors;
    ...other data...
}
```

- Maybe ok in some cases, but I don't like mixing the data structure of the graph in with the data structure of the node.

Adjacency Matrix

Who's adjacent to who is represented as a big matrix, with a “1” indicated a connection.

```
  a b c d e
a 0 0 1 0 1
b 0 0 0 0 0
c 1 0 0 0 0
d 0 0 0 0 0
e 1 0 0 0 0
 ex: a is connected to c and e
```

Center diagonal is normally all zeros. Normally nodes aren't self-connected.

“Lower triangle” is redundant in undirected graphs.

More on Matrix

- Typically not as efficient as using plain adjacency lists.
- Is used or preferred in some algorithms.
- Maybe useful, since the matrix form is always the same size in memory reguardless of how connected the graph is.
- If you need to use this form, take a look at *java.util.BitSet*.

Graph Abstraction

- Reguardless of what internal representation you decide on, the user of the graph shouldn't care.
- What should a graph class do?
  - Add or delete an edge
  - Add a node
  - Get adjacent nodes
  - Delete a node (and remove it's edges)
  - Report the number of nodes and edges
  - Provide a textual representation (toString)
  - (bonus: be able to dump and read itself to disk)

A Simple Graph Interface

```
import java.util.ArrayList;
public interface Graph {
    public getAdjacent(String key, ArrayList list)
    public ArrayList setAdjacent(String key)
    public int nodes();
    public int edges();
    public void addNode(String key);
    public void deleteNode(String key);
    public void addEdge(String key1, String key2);
    public String toString(); // dump it to text
    public int hashCode();// ??
    public boolean equals(); // ??
    }
```