CS 101: Computer Programming and Utilization

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Lecture 17: Representing network of entities

About These Slides

- Based on Chapter 23 of the book

An Introduction to Programming Through C++

by Abhiram Ranade (Tata McGraw Hill, 2014)

- Original slides by Abhiram Ranade

– First update by Sunita Sarawagi

Outline

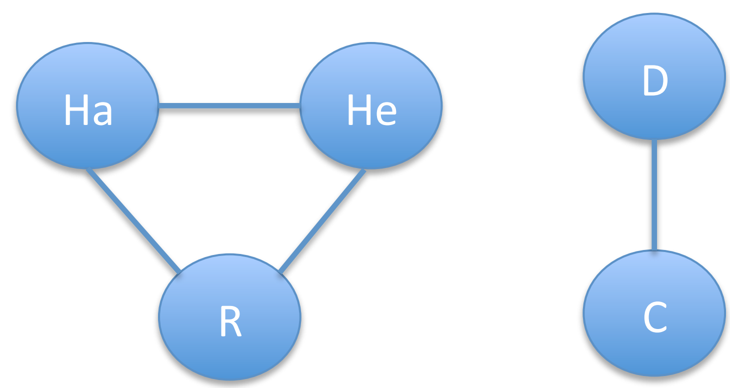
- We would like to represent any object of interest on a computer
  - Road map of India
  - Electrical circuit
  - Mathematical expressions
  - …
- All of these are examples of “graphs”
- How to represent graphs on a computer

Graph

- Graph G = (V,E), where
  - V = set of "vertices"
  - E = set of "edges" = sets of pairs of vertices
- Example: Road map of India
  - V = set of cities
  - E = pairs of cities connected directly by a road
- Edges may be ordered or unordered
  - Unordered: (u,v) and (v,u) both refer to the same edge
  - Ordered: (u,v) and (v,u) refer to distinct edges
- Roadmap: edges are usually unordered
  - However, we may choose ordered edges to indicate one-way roads.
- Vertices/Edges may be associated with attributes
  - Vertices in road map may have names, e.g. city names
  - Edges in road map may have names and lengths

A graph of friends

- Vertices = persons, Edge: connect friends
- Unordered: friendship is mutual
- Example:
  - V ={Harry, Hermione, Ron, Draco, Crabbe}
  - E ={(Harry,Hermione), (Ron, Hermione), (Harry, Ron), (Draco, Crabbe)}



Representing a person

- "For every entity you should have a class"
  - What information would you put in each object of the class?

```
struct Person{
  string name;
  string address;
  vector<Person*> friends;
};
```

- `Person*` or `Person`?

Representing the 5 persons

```
Person persons[5];
persons[0].name = “Harry”;
persons[1].name = “Hermione”;
persons[2].name = “Ron”;
persons[3].name = “Draco”;
persons[4].name = “Crabbe”;
```

- Now we have created the vertices

Adding the edges

- Harry, Hermione are friends, so we should do...

```
persons[0].friends.push_back(&persons[1]);
persons[1].friends.push_back(&persons[0]);
```

- We need to make entries for both.
- So we could instead have a function

```
void MF(Person &p, Person &q){
  p.friends.push_back(&q);
  q.friends.push_back(&p);
}
```

- So now we just call it for each friendship:

```
MF(persons[0],persons[1]);
MF(persons[1],persons[2]);
MF(persons[2],persons[0]);
MF(persons[3],persons[4]);
```

Exercise

- Read in the name of a person and print that persons friends.

```
cin >> name;
for(int i=0; i<5; i++)
 if(name == persons[i].name){
  for(size_t j=0;
        j<persons[i].friends.size();
        j++)
   cout << persons[i].friends[j]->
              name<<endl;
 }
```

A C++11 Enhancement

- Read in the name of a person and print that persons friends.

```
cin >> name;
for(int i=0; i<5; i++)
 if(name == persons[i].name){
  // fp is of type (Person * &) == auto
  for(auto fp : persons[i].friends)
   cout << fp->name << endl;
}
```

- "Range based loop": for(type id : container){..}
- Block executed for all elements id of the container
- vectors, maps, are containers

Another enhancement: can we avoid the search completely?

```
map<string,vector<string> > friends;
friends["Harry"].push_back("Hermione");
friends["Hermione"].push_back("Harry");
...

// Print friends of all persons
for(auto p : friends){
  cout << p.first <<": ";
  for(auto f : p.second) cout << f <<' ';
  cout << endl;
}
```

What if edges have attributes?

- Suppose friendships have ”intensity”
- Solution 1:

```
struct Person{
  string name;
  vector<Person*> friends;
  vector<double> intensity;
};
```

Solution 2

```
struct EdgeData{
  double intensity;
  double duration;
};
struct Person{
  string name;
  vector<Person*> friends;
  vector<EdgeData*> edgedata;
};
void makefriends{Person &p, Person &q, EdgeData *e){
  p.friends.push_back(&q); p.edgedata.push_back(e);
  q.friends.push_back(&p); q.edgedata.push_back(e);
}
```

Remarks

- Solution 1 stores two copies of intensity – in each of the two Person objects
- Solution 2 stores one copy; each Person object has a pointer to it.
  - Will require less memory if there is a lot of edge data
  - If there are multiple copies of the same information we are always worried about updating both copies consistently – source of bugs.
- Vertex data and edge data can both be on the heap if needed.

Adjacency Matrix Representation

```
struct VertexData{ string name;};
struct EdgeData{
  bool valid;
  double intensity, duration;
};
VertexData v[nVertices];
EdgeData e[nVertices][nVertices];
```

- If there is an edge from vertex i to vertex j, then set
  - `e[i][j].valid = true, e[i][j].intensity = ...`
- If no edge then set
  - `e[i][j].valid = false;`
- Many variations possible. See book.

Remarks

- For graph with V vertices and E edges
  - Adjacency list uses: $O(V+E)$ memory
  - Adjacency matrix uses: $O(V^2)$ memory
  - Adjacency list is better if graph has few edges.

Announcements

- Thursday graded lab.
- Cribs: empty, negative marks for needless cribs.
- Help session.

Example Graph Queries

- Check if x and y are direct friends.

```
map<string,vector<string> > friends;
cin >> x >> y;
bool xy_friends = false;
for (string f : friends[x]) {
   if (f == y) {
      xy_friends = true;
      break;
   }
}
```

Example Graph Queries

- Find friend of friends, or the set of nodes reachable by one hop on a graph.

```
map<string,vector<string> > friends;
cin >> query;
map<string,int> friendsOfFriends;
for (string f : friends[query]) {
   for (string g : friends[f]) {
         friendOfFriends[g]++;
   }
}
for (auto s : friendOfFriends)
     cout << s.first << " ";
```

Example: Is there a path between two nodes?

```
bool check_friends(string x, map<string,bool>&
visited, string y) {
    if (x == y) return true;
   visited[x]=true;
   for (string f : friends[x]) {
        if (visited.find(f) == visited.end()) {
         if (check_friends(f, visited, y)) return true;
        }
   }
   return false;
}
main() {cin >> x >> y; map<string,bool> visited;
cout << check_friends(x,visited, y);}
```

Graph between different types of nodes

- Web:
  - Given pages, each with a url and a sequence of words in it.
  - Given a query word, find all page-urls that contain it.
- View this as a graph with
  - two types of nodes
    - Page nodes
    - Word nodes.
  - Directed edges from pages to word that contain it.

Indexing the documents

```
void loadPages(Web &web) {
   map<string, vector<string> > pages;
   map<string, vector<string>> words;
   for (int i = 0; i < num_pages; i++) {
       string url; int num_words;
       cin >> url >> num_words;
       while (--num_words)  {
           string word;  cin >> word;
           pages[url].push_back(word);
           words[word].push_back(url);
       }
    }
    while (true) {
         cin >> query;
        for (auto u : words[query]) {
                  cout << u << " ";
        }
    }
}
```