Data Structures and Algorithms

Lecture 14.2: Graphs (cont.)

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C++ Reference Website

Outlines

Dynamic Array

โครงสร้างคล้ายแบบเดียวกับ list

STL → library

standard

Template

#include <list>

//main code

list<int> L;

L.push_back(1);

#include <vector> ของ Memory ติดกัน

Array ที่มีความยืดหยุ่น

vector<int> v;

v.push_back(1);

push เรื่อยๆ เต็มจะ Resize เอง

- Conclusions about graph representations
- Adjacency list implementation using C++ STL

Graph Representations: Complexity of Operations

Operation	Adjacency Matrix	Adjacency List
createGraph	$O(\|V\|^2)$	$O(\|V\|)$
addEdge	$O(1)$	$O(\|V\|)$
addVertex	$O(\|V\|^2)$	$O(\|V\|)$
removeVertex	$O(\|V\|^2)$	$O(\|V\|+\|E\|)$
removeEdge	$O(1)$	$O(\|V\|)$
isAdjacent	$O(1)$	$O(\|V\|)$
inDegree	$O(\|V\|)$	$O(\|V\|+\|E\|)$
outDegree	$O(\|V\|)$	$O(\|V\|)$
space to store graph	$O(\|V\|^2)$	$O(\|V\|+\|E\|)$
Remarks	Slow to add/remove vertices as matrix must be resized/copied	Slow to remove edges because it needs to iterate over the adjacent vertices

Graph Representations: Pros & Cons

- *Remarks*:
  - **Adjacency matrix:** Slow to add/remove vertices because the matrix must be resized/copied
  - **Adjacency list**: Slow to remove edges because it needs to iterate through all the adjacent vertices
- *Conclusions:* Adjacency list is generally preferred if the graph is *sparse,* i.e., when $|E| << |V|^2$. Adjacency matrix is preferred if the graph is *dense,* i.e., when $|E| \approx |V|^2$

Basic Graph Operations Using Adjacency-List Representation (1)

1 vector = 1 list

```
// A simple adjacency-list representation of graph using STL
#include <iostream>
#include <vector>
using namespace std;
// Function to create a graph with n vertices
vector<int>* createGraph(int n)
{
   // Return array of n lists (vectors)
   return new vector<int>[n];
}
// Function to add a directed edge into the graph
void addEdge(vector<int>* adjList, int u, int v)
{
   adjList[u].push_back(v);
}
// Function to print the adjacency-list representation of graph
void printGraph(vector<int>* adjList, int V)
{
   for (int v = 0; v < V; ++v)
   {
      cout << "[" << v << "] head ";
      for(int i=0; i < adjList[v].size(); i++)
         cout << "-> " << adjList[v].at(i);
      cout << endl;
   }
   cout << endl;
}
```

สมาชิกของ adj list ของ v

traverse vector

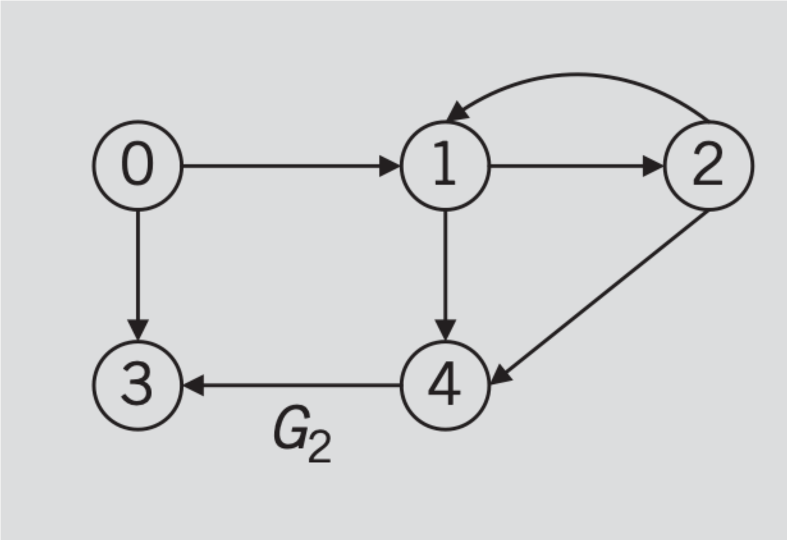
Basic Graph Operations Using Adjacency-List Representation (2)

```
// Driver code
int main()
{
   int n = 5;

   vector<int>* adjList = createGraph(n);

   //Vertex numbers should be from 0 to 4.
   addEdge(adjList, 0, 1);
   addEdge(adjList, 0, 3);
   addEdge(adjList, 1, 2);
   addEdge(adjList, 1, 4);
   addEdge(adjList, 2, 1);
   addEdge(adjList, 2, 4);
   addEdge(adjList, 4, 3);

   printGraph(adjList, n);
   return 0;
}
```




```
Lasalle:codes dmodify$ ./a.out
[0] head -> 1-> 3
[1] head -> 2-> 4
[2] head -> 1-> 4
[3] head
[4] head -> 3
```

Operation: createGraph

- createGraph(n): create the empty graph with *n* isolated vertices

```
struct Node** createGraph(int n)
{
        struct Node** adjList = malloc(sizeof(struct
Node*)*n);
        for(int i=0; i<n; i++) {
        adjList[i] = NULL;
        }
    return adjList;
}
```

```
#define NMAX 500

vector<int>* createGraph()
{
   return new vector<int>[NMAX];
}
```

```
struct Node
{
        int adj_vertex;
        struct Node* next;

};
```

Operation: addEdge

- addEdge(G,u,v): add the edge from vertex *u* to vertex *v* in the graph *G*

```
void addEdge(struct Node** adjList, int u, int v)
{
   struct Node* node = adjList[u];
   if(node == NULL) {
        node = malloc(sizeof(struct Node));
        node->adj_vertex = v;
        node->next = NULL;
        adjList[u] = node;
   } else {
        while(node->next != NULL)
        node =  node->next;
        struct Node* new_node = malloc(sizeof(struct Node));
        new_node->adj_vertex = v;
        new_node->next = NULL;
        node->next = new_node;
   }
}
```

```
void addEdge(vector<int>* adjList, int u, int v)
{
   adjList[u].push_back(v);
}
```

Operation: printGraph

- printGraph(G): print the graph *G*

```
void printGraph(struct Node** adjList, int n)
{
   for (int u = 0; u < n; u++)
   {
        printf("[%d] head: ", u);

        struct Node* node = adjList[u];

      while(node) {
        printf("-> %d ", node->adj_vertex);
        node = node->next;
      }

      printf("-> NULL \n");
   }
   printf("\n");
}
```

```
void printGraph(vector<int>* adjList, int V)
{
   for (int v = 0; v < V; ++v)
   {
      cout << "[" << v << "] head ";
      for(int i=0; i <
         adjList[v].size(); i++)
         cout << "-> " <<
            adjList[v].at(i);
      cout << "\n";
   }
}
```

Operation: removeEdge

- removeEdge(G, u, v): remove the existing edge from vertex *u* to vertex *v*

```
void removeEdge(struct Node** adjList, int u, int v)
{
   struct Node* node = adjList[u];
   if(node->adj_vertex == v) {
      adjList[u] = node->next;
      free(node);
   } else {
      struct Node* prev_node = node;
      node = node->next;
      while(node->adj_vertex != v) {
         prev_node = node;
         node = node->next;
      }
      prev_node->next = node->next;
      free(node);
   }
}
```

```
void removeEdge(vector<int>* adjList, int u, int v) {
   for(int i=0; i<adjList[u].size(); i++)
      if(adjList[u].at(i) == v) {
      adjList[u].erase(
         adjList[u].begin()+i);
         return;
      }
}
```

Operation: addVertex

- addVertex(G, u): add the new vertex *u* whose label is *n*+1 to the graph *G*

```
struct Node** addVertex(struct Node** adjList, int *n, int
u) {
   struct Node** new_adjList = createGraph(u+1);
   for (int i=0; i<*n; i++) {
      new_adjList[i] = adjList[i];
      adjList[i] = NULL;
   }
   deleteGraph(adjList, *n);
   *n = u+1;
   return new_adjList;
}
```

```
void addVertex(int &n, int u)
{
   n = u+1;
}
```

```
void deleteGraph(struct Node** adjList, int n) {
   for (int u=0; u<n; u++) {
      struct Node* node = adjList[u];
      while(node != NULL) {
         struct Node* next_node = node->next;
         free(node);
         node = next_node;
      }
   }
   free(adjList);
}
```

Operation: removeVertex

- removeVertex(G, u): remove the existing vertex *u* whose label is *n* from the graph *G*

```
void removeVertex(struct Node** adjList, int *n, int u) {

   for(int v=0; v<*n; v++) {
      if(isAdjacent(adjList, v, u) == 1)
         removeEdge(adjList, v, u);
   }
   struct Node* node = adjList[u];
   while(node != NULL) {
      struct Node* next_node = node->next;
      free(node);
      node = next_node;
   }
   adjList[u] = NULL;
   if(u < *n-1)
      return;
   (*n)--;
}
```

```
void removeVertex(vector<int>* adjList,int &n, int
u)
{
   if(u < n-1)
      return;
   for(int v=0; v<n; v++)
      removeEdge(adjList, v, u);
   adjList[u].clear();
   n--;
}
```

Operation: isAdjacent

- isAdjacent(G, u, v): check whether vertices *u* and *v* are adjacent in *G*

```
int isAdjacent(struct Node** adjList, int u, int v) {
   struct Node* node = adjList[u];
   int ret = 0;
   while(node != NULL) {
      if(node->adj_vertex == v)
         ret = 1;
      node = node->next;
   }
   return ret;
}
```

```
bool isAdjacent(vector<int>* adjList, int u, int v)
{
   for(int i=0; i<adjList[u].size(); i++)
      if(adjList[u].at(i) == v)
         return true;
   return false;
}
```

Operation: inDegree

- inDegree(*G,* u): return the in-degree of vertex *u* in G

```
int inDegree(struct Node** adjList, int n, int u) {
   int in_deg = 0;

   for(int i=0; i<n; i++) {
      struct Node* node = adjList[i];
      while(node) {
        if(node->adj_vertex == u)
           in_deg++;
        node = node->next;
      }
   }
   return in_deg;
}
```

```
int inDegree(vector<int>* adjList, const int n,  int u) {
   int count = 0;
   for(int v=0; v<n; v++)
      for(int i=0; i<adjList[v].size(); i++)
         if(adjList[v].at(i) == u)
            count++;
   return count;
}
```

Operation: outDegree

- outDegree(*G,* u): return the out-degree of vertex *u* in G

```
int outDegree(struct Node** adjList, int n, int u) {
   struct Node* node = adjList[u];
   int out_deg = 0;
   while(node != NULL) {
      out_deg++;
      node = node->next;
   }
   return out_deg;
}
```

```
int outDegree(vector<int>* adjList, int u) {
   return adjList[u].size();
}
```