

# Data Structures 2017-2: Final Project

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## Contents

<b>Introduction</b>	<b>1</b>
Definitions . . . . .	2
Theorems . . . . .	2
<b>Implementation</b>	<b>2</b>
The structure. . . . .	3
Elementary operations . . . . .	3
Additional operations . . . . .	4
The parser . . . . .	4
Random network generation script . . . . .	4
<b>Using the program</b>	<b>6</b>
Making a call . . . . .	6
Sending publicity to all clients . . . . .	7
Sending publicity to clients in a specific area code . . . . .	7
<b>Building and running the program</b>	<b>8</b>
ANT commands . . . . .	8
<b>Acknowledgements</b>	<b>8</b>

## Introduction

This program simulates a network manager for a telecommunications company. The hypothetical company offers two kinds of services: regular phone calls and video calls. All the network's clients are under a respective station. Every station has at least one client and a unique area code, links between stations allow clients within them to communicate. The specifications are as follows:

- This program allows two clients to communicate through a phone call if the stations are linked or if there's a route through a number of stations that allows the original two to connect (More formally, a trajectory or walk that omits edges), and allows clients to use the video service if said route uses less than or equal links as there are links in the whole network.
- This program also allows the company to send publicity to all the clients in order of:
  - a. Phone number.
  - b. Station's area code, then phone number.
- Finally, this program allows the company to send publicity to all the clients within a station.

The network structure itself is stored as `resources/network.xml` and is loaded from disk every time the

program launches. The subjaacent structure is a simple undirected labeled graph<sup>1 2</sup>.

## Definitions

The following definitions were taken from Gordon College's course of Discrete Mathematics MAT230 (Fall 2016) and Wolfram's Mathworld:

1. A *graph*  $G = (V, E)$  consists of a set  $V$  of vertices (also called nodes) and a set  $E$  of edges.
2. If an edge connects to a vertex we say the edge is *incident* to the vertex and say the vertex is an *endpoint* of the edge.
3. If an edge has only one endpoint then it is called a *loop edge*.
4. If two or more edges have the same endpoints then they are called *multiple or parallel* edges.
5. Two vertices that are joined by an edge are called *adjacent* vertices.
6. A *simple graph* is a graph with no loop edges or multiple edges. Edges in a simple graph may be specified by a set  $\{v_i, v_j\}$  of the two vertices that the edge makes adjacent.
7. The *degree* of a vertex is the number of edges incident to the vertex and is denoted  $\deg_G(v)$ .
8. A simple undirected graph in which all the vertices are labeled with a unique natural number is a *labeled graph*.

## Theorems

With the previous definitions we extend the following theorems:

1. A vertex can be connected to at most  $|V| - 1$  other vertices, else a loop or parallel edge occurs.

$$\forall v \in V, 0 \leq \deg_G(v) < |V|$$

2. All simple graphs have an even number of odd degree vertices, this is known as the *Handshaking Lemma*

$$\sum_{v \in V} \deg_G(v) = 2|E|$$

3. A sequence of non-negative integers  $d_1 \geq \dots \geq d_n$  can be represented as the degree sequence of a finite simple graph on  $n$  vertices if and only if  $d_1 + \dots + d_n$  is even and

$$\sum_{i=1}^k d_i \leq k(k-1) + \sum_{i=k+1}^n \min(d_i, k)$$

holds for every  $k$  in  $1 \leq k \leq n$ . This is known as the *Erdős–Gallai theorem*.

4. The  $n$  vertex graph with the maximum number of edges that is still disconnected is a complete graph (all nodes are connected to the remaining nodes) of  $n - 1$  nodes with an additional isolated vertex. Hence, there are  $\binom{n}{2} = \frac{(n-1)(n-2)}{2}$  edges in such graph and adding any other possible vertex will yield a connected graph of  $n$  nodes. Ie. The minimum number of edges needed to guarantee connectivity for an  $n$  vertex graph is:

$$\frac{(n-1)(n-2)}{2} + 1$$

## Implementation

This program has three main components:

- The command line interface (CLI), that allows the user to call upon this programs operations.
- The network structure.
- The network loader.

---

<sup>1</sup><http://mathworld.wolfram.com/LabeledGraph.html>

<sup>2</sup>[https://en.wikipedia.org/wiki/Graph\\_labeling](https://en.wikipedia.org/wiki/Graph_labeling)

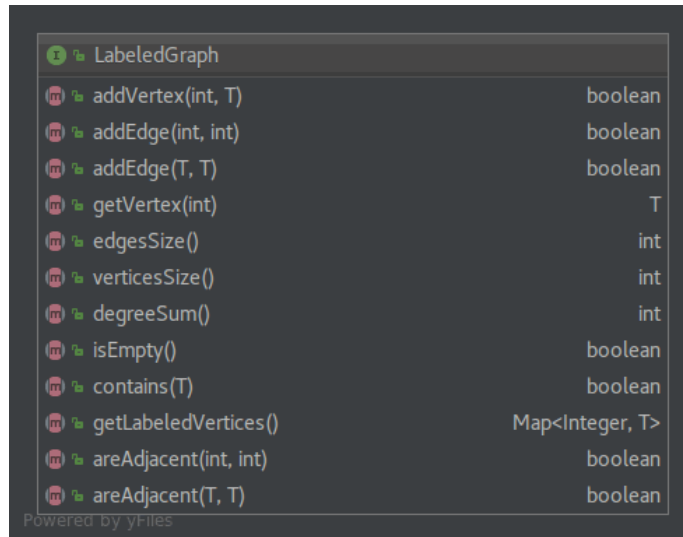
## The structure.

The most important structure in this program is the Labeled Graph in `fciencias.edatos.network.Network`, it implements the interface in *Figure 1*. It uses a HashTable to store its labeled vertices, Stations (`fciencias.edatos.network.Station` which store their neighbors in a HashSet), as area code - Station pairs.

## Elementary operations

This are the elementary operations specified by the `LabeledGraph` and some of their properties within `Netowork`:

- `addVertex(int, T) → boolean`, is  $O(n)$ , this is because if a replacement takes place, the graph has to rebuild edges using previous neighbors and newly added ones. But if no replacement takes place (unique area codes are respected) it's  $O(1)$ . In other words, addition is  $O(1)$ , replacement is  $O(n)$ .
- `addEdge(int, int) → boolean`, is  $O(1)$ .
- `addEdge(T, T) → boolean`, is  $O(1)$ .
- `getVertex(int) → T`, is  $O(1)$ .
- `edgesSize() → int`, is  $O(n^2)$  because it uses `degreeSum()`.
- `verticesSize() → int`, is  $O(n^2)$  because it exhaustively performs **BFS** on the graph to discover newly added neighbors and adds them to the graph's HashTable when counting them.
- `degreeSum() → int`, is  $O(n^2)$  because it uses `verticesSize()`. This method checks that some theorems hold and raises an exception if it detects anomalies. The theorems that are actively checked are theorems 1 and 2.
- `isEmpty() → boolean`, is  $O(1)$ .
- `contains(T) → boolean`, is  $O(1)$ .
- `getLabeledVertices() → Map<Integer,T>`, is  $O(n^2)$  because it uses `edgesSize()` to expand the graph before returning a copy of its HashTable.
- `areAdjacent(int, int) → boolean`, is  $O(1)$ .
- `areAdjacent(T, T) → boolean`, is  $O(1)$ .



LabeledGraph	
<code>addVertex(int, T)</code>	<code>boolean</code>
<code>addEdge(int, int)</code>	<code>boolean</code>
<code>addEdge(T, T)</code>	<code>boolean</code>
<code>getVertex(int)</code>	<code>T</code>
<code>edgesSize()</code>	<code>int</code>
<code>verticesSize()</code>	<code>int</code>
<code>degreeSum()</code>	<code>int</code>
<code>isEmpty()</code>	<code>boolean</code>
<code>contains(T)</code>	<code>boolean</code>
<code>getLabeledVertices()</code>	<code>Map&lt;Integer, T&gt;</code>
<code>areAdjacent(int, int)</code>	<code>boolean</code>
<code>areAdjacent(T, T)</code>	<code>boolean</code>

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Figure 1: Operations required by the interface `fciencias.edatos.util.LabeledGraph`.

## Additional operations

In addition to this elementary operations, `Network` also implements the following methods that extend its functionality ( $c$  is the number of clients within the network):

- `quickEdgesSize() → int`, is  $O(n \log(n))$  since it sorts the list of all the network's station's degrees using *Timsort*.
- `getAllClientsByPhone() → List<Client>`, is  $O(c \log(c))$ , because it uses *Timsort* on all the network's clients.
- `getAllClientsByStation() → List<Client>`, is  $O(c \log(c))$ , because it uses *Timsort* on each station's client set.
- `linearErdosGallai(List<Integer>) → boolean`, is  $O(n)$  per the theorems in **this paper**; this basically implements the Erdos-Gallai theorem.
- `getTrajectory(T, T) → List<Station>`, is  $O(n^2)$  because it uses `getTrajectory(int, int)`.
- `getTrajectory(int, int) → List<Station>`, is  $O(n^2)$  because it uses `edgesSize()` to expand the graph before extracting the trajectory.

## The parser

In order to properly load the provided `network.xml` into the structure, the `NetworkLoader` class uses DOM and a dtd file (`resources/Network.dtd`). The XML file representing the `Network` looks like this:

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE Network SYSTEM "Network.dtd">
<Network links="277" stations="25">
  <Station code="55" name="Mexico City">
    <Client name="Daniel Bermudez" phone="71416892"/>
    <Client name="Jose Arguello" phone="12297883"/>
  </Station>
  <Station code="81" name="Monterrey, Nuevo Leon">
    ...
  </Station>
  ...
  <Link stationACode="33" stationBCode="686"/>
  <Link stationACode="686" stationBCode="229"/>
  <Link stationACode="998" stationBCode="744"/>
  ...
</Network>
```

where each *Station* tag represents a chemical element with corresponding **name** (self-explanatory), and **code** (unique area code), and each *Link* tag represents a link between the stations with codes **stationACode** and **stationBCode**. Also, every *Station* tag has a number of *Client* tags which represent the station's clients and each have attributes **name** and **phone** (both, self-explanatory).

## Random network generation script

In order to create a random xml that adheres to the aforementioned `Network.dtd`, the following python script was created (source code in `resources/stations.py`):

```
from xml.etree.ElementTree import ElementTree as Tree
from xml.etree.ElementTree import Element as Elem
from random import randint
import xml.etree.ElementTree as e_tree
import os
```

```

F_NAMES = ""Luis
...
Elizabeth"".splitlines()

L_NAMES = ""Rodriguez
...
Arguello"".splitlines()

STATIONS = ""55-Mexico City
...
951-Oaxaca, Oaxaca"".splitlines()

def main():
    root = Elem('Network')
    area_codes = []
    for station in STATIONS:
        words = station.split('-')
        area_code = words[0]
        area_codes.append(area_code)

        name = words[1]
        new_station = Elem('Station')
        new_station.set('code', str(area_code))
        new_station.set('name', name)
        appendclients(new_station, randint(1, 5))
        root.append(new_station)

    min_conn = ((len(area_codes) - 1)*(len(area_codes) - 2))//2 + 1
    links = set()
    for _ in range(min_conn):
        station_a, station_b = getlink(links, area_codes)
        new_link = Elem('Link')
        new_link.set('stationACode', station_a)
        new_link.set('stationBCode', station_b)
        root.append(new_link)

    root.set('links', str(min_conn))
    root.set('stations', str(len(area_codes)))
    with open('network.xml', 'wb') as f:
        f.write(b'<?xml version="1.0" encoding="UTF-8" ?><!DOCTYPE Network SYSTEM "Network.dtd">')
        Tree(root).write(f, 'utf-8')
    ...

```

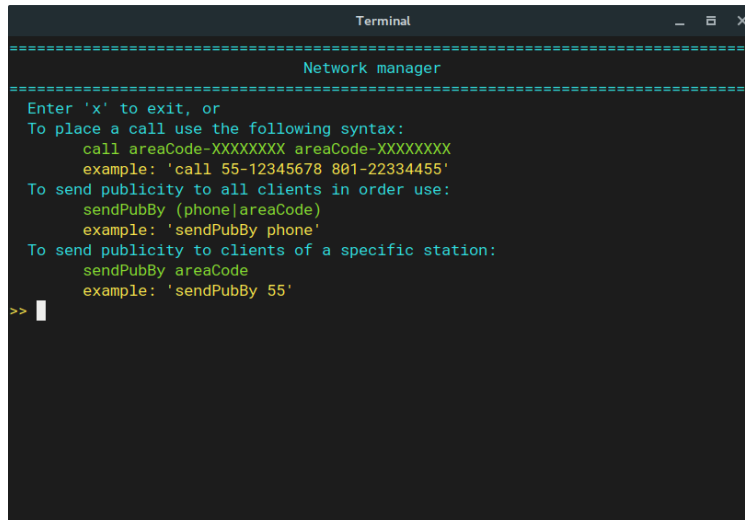
This line in particular needs some explaining, it is calculating the minimum links necessary to guarantee that the graph will be connected per theorem 4:

```
min_conn = ((len(area_codes) - 1)*(len(area_codes) - 2))//2 + 1
```

While F\_NAMES and L\_NAMES hold random first names and last names respectively, STATIONS were taken from [this page](#) and represent real life cities with their respective area codes.

## Using the program

The program explains the options available to the user when it's first launched. It uses regular expressions for all its user input validation, hence it's pretty robust, it won't accept invalid options or incorrect syntax.

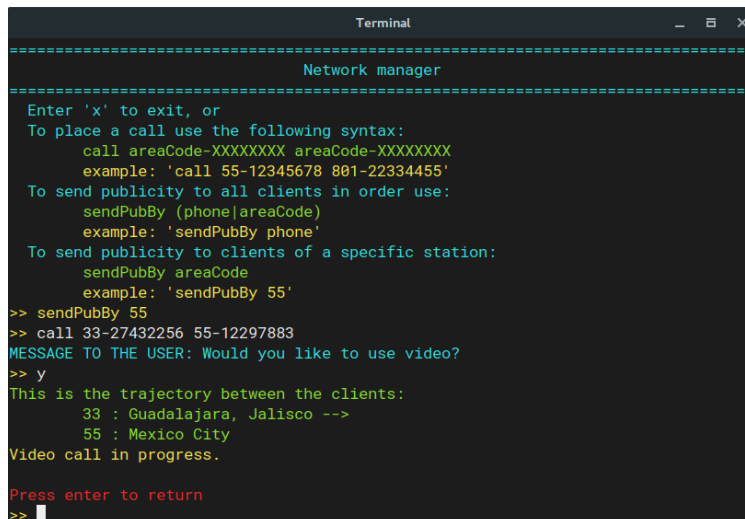


```
Terminal
=====
Network manager
=====
Enter 'x' to exit, or
To place a call use the following syntax:
  call areaCode-XXXXXXX areaCode-XXXXXXX
  example: 'call 55-12345678 801-22334455'
To send publicity to all clients in order use:
  sendPubBy (phone|areaCode)
  example: 'sendPubBy phone'
To send publicity to clients of a specific station:
  sendPubBy areaCode
  example: 'sendPubBy 55'
>> 
```

Figure 2: Welcome screen.

## Making a call

In order for a call to be successful, first of all the specified phone numbers must exist within their corresponding area codes. If both clients are accounted for by their respective stations, a route is then calculated. If the resulting route is shorter (in terms of links traversed) than or equal to the number of links within the whole network, the program asks the client if they wish to use video. Using standard yes or no answers, the call is placed with the appropriate conditions.

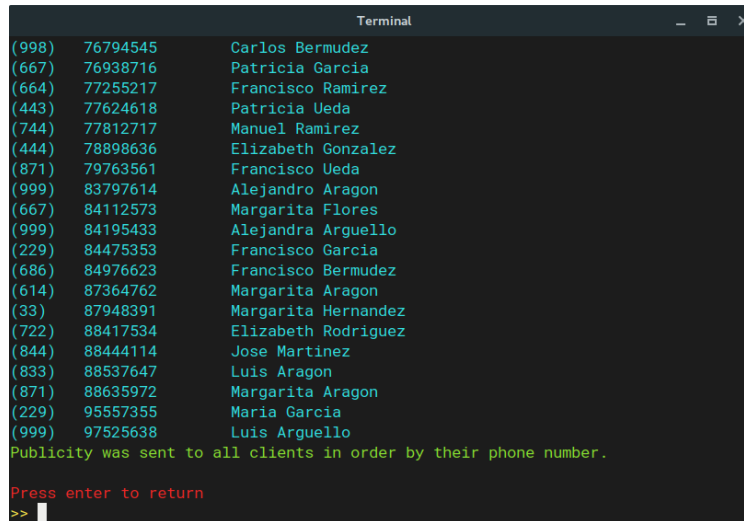


```
Terminal
=====
Network manager
=====
Enter 'x' to exit, or
To place a call use the following syntax:
  call areaCode-XXXXXXX areaCode-XXXXXXX
  example: 'call 55-12345678 801-22334455'
To send publicity to all clients in order use:
  sendPubBy (phone|areaCode)
  example: 'sendPubBy phone'
To send publicity to clients of a specific station:
  sendPubBy areaCode
  example: 'sendPubBy 55'
>> sendPubBy 55
>> call 33-27432256 55-12297883
MESSAGE TO THE USER: Would you like to use video?
>> y
This is the trajectory between the clients:
  33 : Guadalajara, Jalisco -->
  55 : Mexico City
Video call in progress.
Press enter to return
>> 
```

Figure 3: A successful video call between 33-27432256 and 55-12297883.

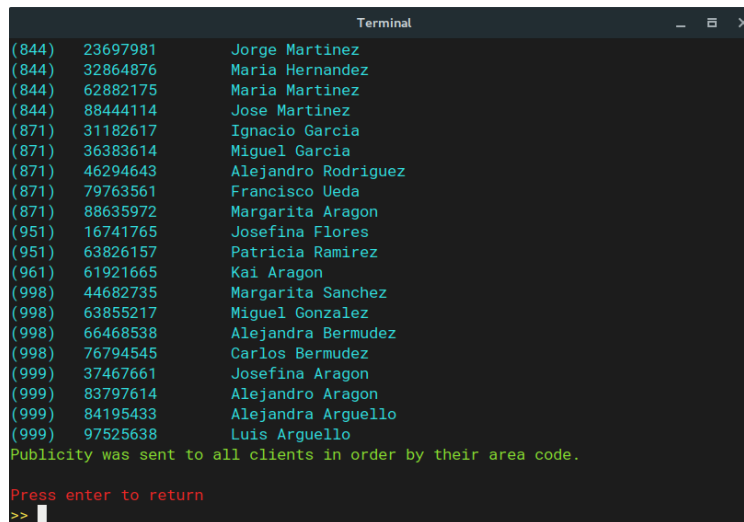
## Sending publicity to all clients

In order to send publicity to all clients in the network, two options are available. The Company can send the publicity in order by the clients' phone numbers, or in order by area code, and then by phone number.



```
Terminal
(998) 76794545 Carlos Bermudez
(667) 76938716 Patricia Garcia
(664) 77255217 Francisco Ramirez
(443) 77624618 Patricia Ueda
(744) 77812717 Manuel Ramirez
(444) 78898636 Elizabeth Gonzalez
(871) 79763561 Francisco Ueda
(999) 83797614 Alejandro Aragon
(667) 84112573 Margarita Flores
(999) 84195433 Alejandra Arguello
(229) 84475353 Francisco Garcia
(686) 84976623 Francisco Bermudez
(614) 87364762 Margarita Aragon
(33) 87948391 Margarita Hernandez
(722) 88417534 Elizabeth Rodriguez
(844) 88444114 Jose Martinez
(833) 88537647 Luis Aragon
(871) 88635972 Margarita Aragon
(229) 95557355 Maria Garcia
(999) 97525638 Luis Arguello
Publicity was sent to all clients in order by their phone number.
Press enter to return
>> 
```

Figure 4: Publicity sent to all clients in the network, ordered by their phone numbers.



```
Terminal
(844) 23697981 Jorge Martinez
(844) 32864876 Maria Hernandez
(844) 62882175 Maria Martinez
(844) 88444114 Jose Martinez
(871) 31182617 Ignacio Garcia
(871) 36383614 Miguel Garcia
(871) 46294643 Alejandro Rodriguez
(871) 79763561 Francisco Ueda
(871) 88635972 Margarita Aragon
(951) 16741765 Josefina Flores
(951) 63826157 Patricia Ramirez
(961) 61921665 Kai Aragon
(998) 44682735 Margarita Sanchez
(998) 63855217 Miguel Gonzalez
(998) 66468538 Alejandra Bermudez
(998) 76794545 Carlos Bermudez
(999) 37467661 Josefina Aragon
(999) 83797614 Alejandro Aragon
(999) 84195433 Alejandra Arguello
(999) 97525638 Luis Arguello
Publicity was sent to all clients in order by their area code.
Press enter to return
>> 
```

Figure 5: Publicity sent to all clients in the network, ordered by their area codes, and then their phone numbers.

## Sending publicity to clients in a specific area code

Lastly, the Company can also send targeted publicity to all the clients within an area code.

```
Terminal
=====
Network manager
=====
Enter 'x' to exit, or
To place a call use the following syntax:
  call areaCode-XXXXXXX areaCode-XXXXXXX
  example: 'call 55-12345678 801-22334455'
To send publicity to all clients in order use:
  sendPubBy (phone|areaCode)
  example: 'sendPubBy phone'
To send publicity to clients of a specific station:
  sendPubBy areaCode
  example: 'sendPubBy 55'
>> sendPubBy 55
(55) 71416892 Daniel Bermudez
(55) 12297883 Jose Arguello
Sent publicity to all clients in 55 : Mexico City.
Press enter to return
>> 
```

Figure 6: Publicity sent to all clients in Mexico City

## Building and running the program

The program can be built using ant, the available commands are described in the next section ANT. If you're on Linux and have python installed, then running the following command from the project's main directory will be enough to build and run the program: `ant executable; ./network`. After having run `ant executable` once, you'll only need to run `./network` to launch the program, though.

## ANT commands

The included `build.xml` provides the following commands:

1. `ant compile`, compiles the program to `build/classes/`.
2. `ant doc`, generates the program's documentation and puts it inside `doc/`.
3. `ant jar`, compiles the program and creates a jar, `build/jar/Network.jar`.
4. `ant run`, compiles the program, creates the jar and runs the application (using the awful ant logger). This is not the recommended way to run the program, use the following command to create an executable instead:
5. `ant executable`, creates a runnable file `./network` that uses a python script to run the actual jar file.
6. `ant all`, generates documentation, compiles the program, creates the jar file and the runnable file.
7. `ant clean`, deletes all files and folders except for `src/`, `resources/`, `build.xml` and `README.pdf`.

## Acknowledgements

For more information on the tools used to build, create and run this program see:

- Apache Ant.
- Document object model.
- Document type definition.
- Python.
- Regular expressions.