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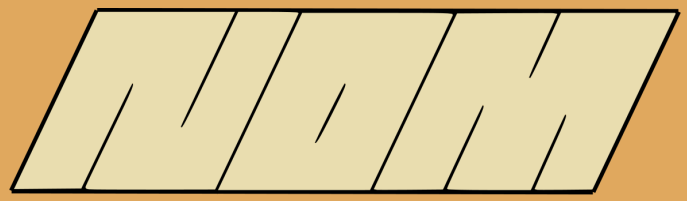


Network-based Operational Modelling

Introduction to network analysis

Dr Sean Manzi - University of Exeter, UK

Health Service Modelling Associates Programme 4

Session structure

- 0930 – 0950 Network analysis and its uses
- 0950 – 1005 Components of a network
- 1005 – 1030 Transforming data into a network representation
- 1030 – 1045 Comfort break
- 1045 – 1130 Transforming data into a network representation
- 1120 – 1220 Building a network graph (NetworkX)

Learning objectives

- Understand what a network graph is and how it is constructed
- Be able to transform raw data into a format suitable for conducting a network analysis
- Know how to create a simple network graph in Python using NetworkX

Network analysis and its uses

What is a network

Network graphs are used to:

- Study the function of large and/or complex systems
- Visualise relationships and interactions in a intuitive way
- Represent abstract concepts in a concrete way

Exemplar uses

EXAMPLES OF NETWORKS AND THEIR COMPONENTS

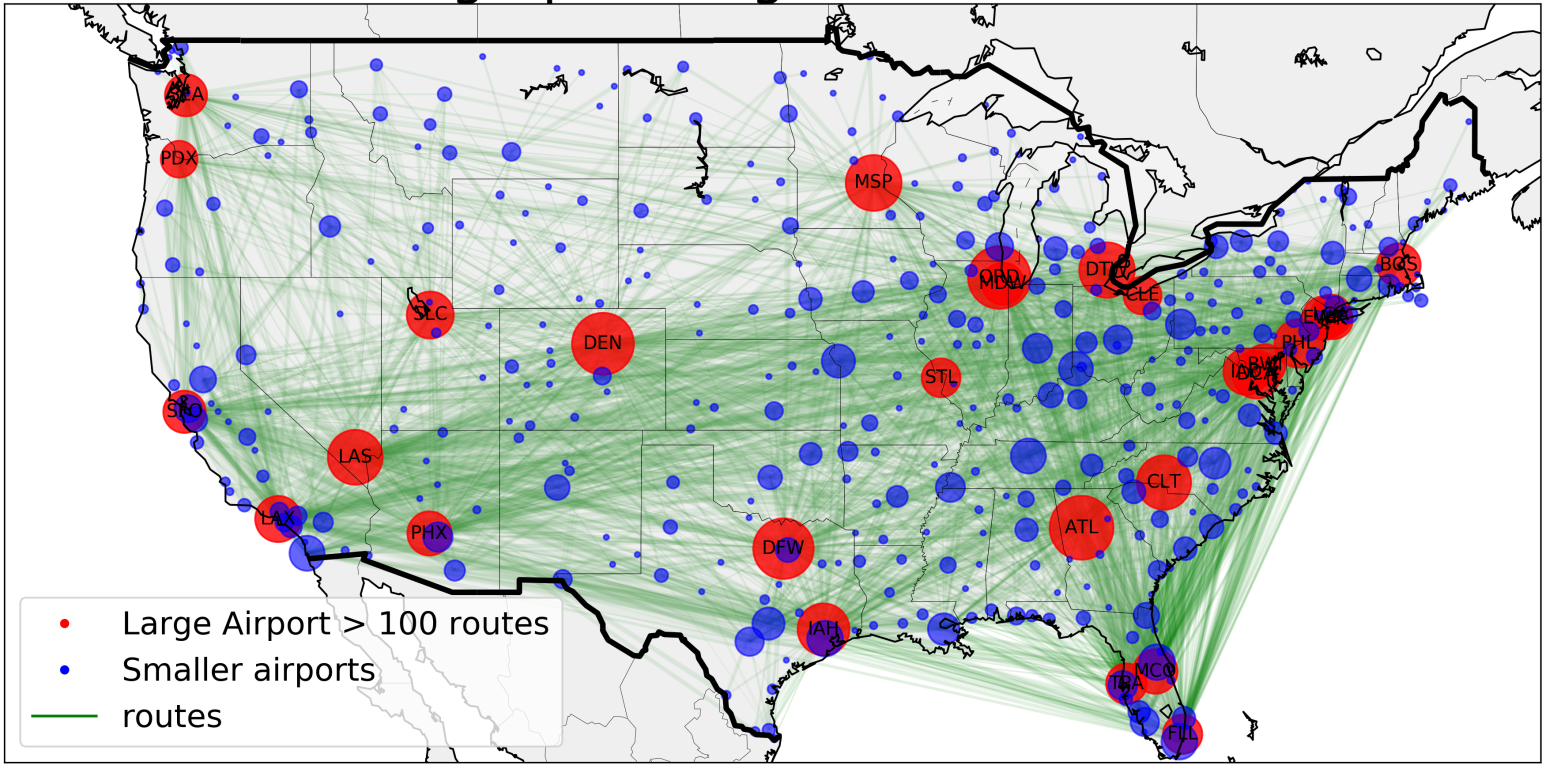
NETWORK	VERTICES	VERTEX ATTRIBUTES	EDGES	EDGE ATTRIBUTES
Airlines Network	**Airports**	Footfall, Terminals, Staff, City population, International/Domestic, Freight, Hangar capacity	**Airplanes / Routes**	Frequency, # Passengers, Plane Type, Fuel Usage, Distance covered, Empty seats
Banking Network	**Account Holders**	Name, demographics, KYC Document, Products, Account status, balance and other details	**Transactions**	Type, Amount, Authentication (pass/OTP), Time, Location, Device
Social Network	**Users**	Name, demographics, # connections, likes, circles belong to, subscriptions	**Interactions**	Medium (like/comment/direct message), time, duration, type of content, topic
Physician Network	**Doctors**	Demographics, speciality, experience, affiliation (type and size), Weekly patient intake	**Patients**	Demographics, Diagnosis history, visit frequency, purpose, referred to, insurance
Supply Chain Network	**Warehouses**	Location, size, capacity, storage type, connectivity, manual/automated	**Trucks**	Load capacity, # wheels, year of make, geographical permit, miles travelled. Maintenance cost, driver experience

TheMathCompany

Credit: https://www.analyticsvidhya.com/blog/2018/04/introduction-to-graph-theory-network-analysis-python-codes/

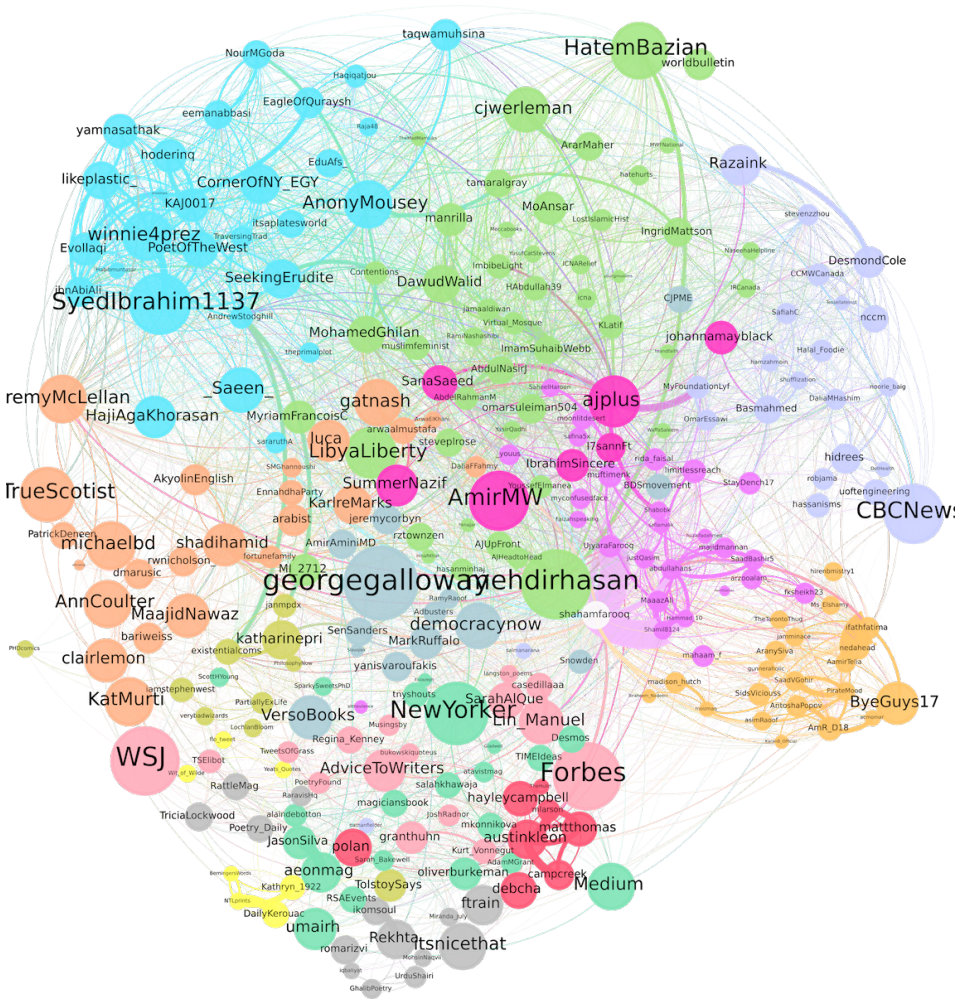
Example 1

Network graph of flight routes in the USA



Credit: towardsdatascience.com

Example 2



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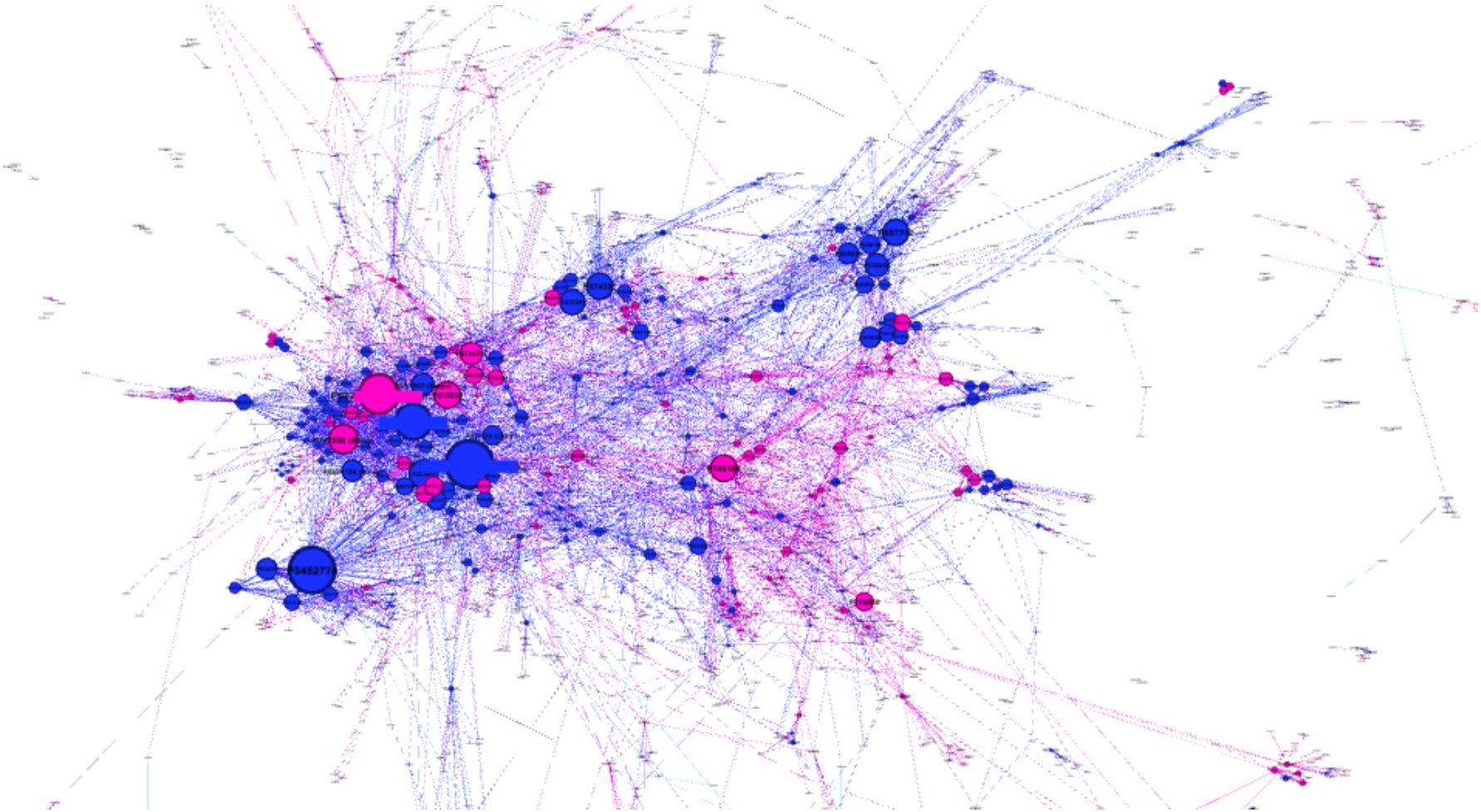
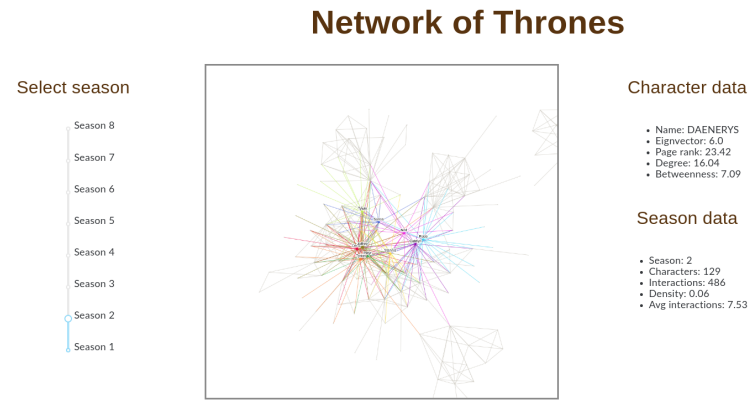
HSMA 3 – Understanding the relationships between o

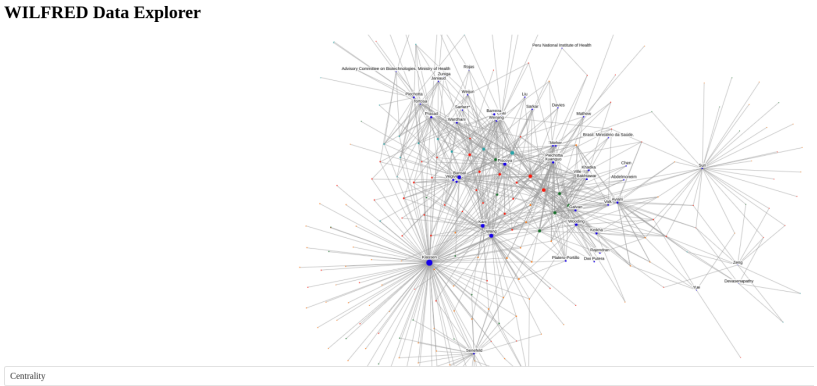


Credit: Jenna Thomas and Charley Bartlett, Devon and Cornwall Police

Interactive examples



https://got-network-app.herokuapp.com/



https://wilfred-data-explorer.herokuapp.com/

Network-based Operational Modelling

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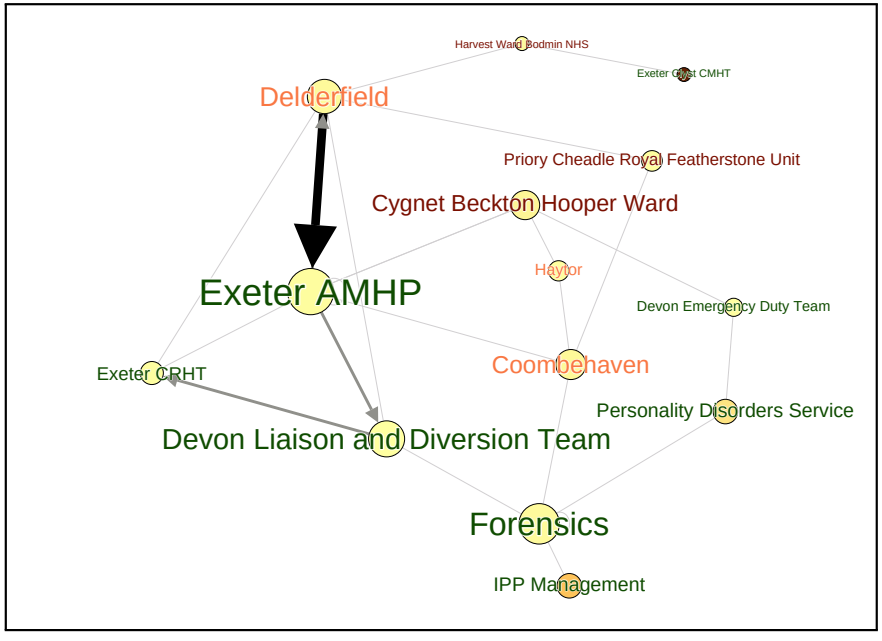
Network-based operational modelling for healthcare

- Graph as service structure
- Node as service
- Edge as patient movement
- Edge weight as number of patients
- Node attributes as improvement measures



Components of a network

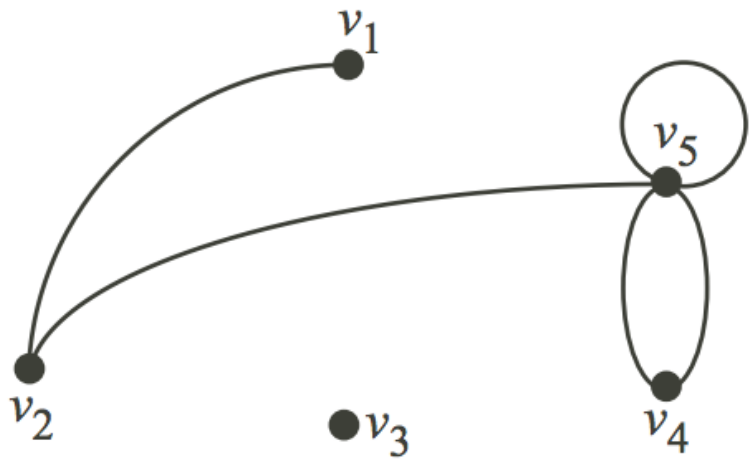
What is a network

A network graph is:

- A graph based representation of a system
- Based on pairwise relationships between entities
- Quantitatively encodes the properties of the system within the network structure

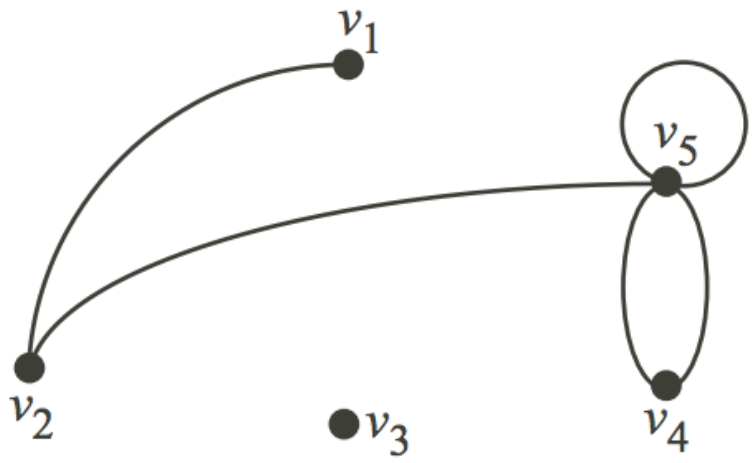
Components of a network graph

- Node/vertex
- Edge
- Graph - unordered pairs of nodes
- DiGraph - ordered pairs of nodes
- Edge weight
- Node attributes



Some terminology

- Parallel edges
- Loop
- Adjacent edges
- Adjacent nodes



Required input data

Data required to build a network graph

- Node list: ID, Label, n-attributes
- Edge list: Source, Target, n-attributes (e.g. Weight)

Data transformation

Data transformation process

1. Start with the raw data table - patient level data
2. Clean the data - category consistency, negative dates, erroneous whitespace
3. Order the data - by patient then by date
4. Create an adjacency matrix - more on this shortly
5. Iterate over the interaction matrix to create edge list - source, target, weight
6. Use unique instances as nodes - depends on the resolution of the data and how you want to subset your data

Data cleaning

Some things to consider

- Capitalisation inconsistencies
- Spelling mistakes
- Erroneous whitespace - leading, trailing, multiples
- Incorrect date entries - reversed, missing
- Missing data

Order the data

Order the data by patient then by date. This allows you to iterate over the data row by row to create the adjacency matrix.

	A	B	C	D	E	F	G
1	ClientID	ReferralDate	ReferralDischarge	ReferralSource	WardTeam	GenSpecialty	ICD10
2	14	27/02/2011	19/05/2016	Internal referral	Link Centre Area 1	ADULT MENTAL ILLNESS	F603
3	14	13/10/2011	NA	Internal referral	Area 31 Adult Community Sector C	ADULT MENTAL ILLNESS	F603
4	14	23/01/2015	01/01/2016	Internal - Community Mental Health Team (Adult Mental Health)	Area 23 PPT	PSYCHOTHERAPY	F603
5	14	07/11/2016	NA	Community Mental Health Team (Adult)	Link Centre Area 1	ADULT MENTAL ILLNESS	F603
6	64	25/11/2014	12/04/2016	Internal - Community Mental Health Team (Adult Mental Health)	Area 23 PPT	PSYCHOTHERAPY	F606
7	64	28/02/2015	14/09/2015	Other	Area 23 MHAR	ADULT MENTAL ILLNESS	F606
8	64	05/07/2016	04/09/2017	Community Mental Health Team (Adult)	Area 23 PPT	PSYCHOTHERAPY	F606
9	64	11/07/2016	21/08/2016	Choose and Book (GP)	Area 24 MHAT	ADULT MENTAL ILLNESS	F606
10	64	27/05/2016	NA	Community Mental Health Team (Adult)	Area 12 CMHT	ADULT MENTAL ILLNESS	F606
11	64	20/08/2017	NA	Community Mental Health Team (Adult)	Link Centre Area 1	ADULT MENTAL ILLNESS	F606
12	89	05/06/2008	NA	Other	Area 26 CMHT	ADULT MENTAL ILLNESS	F609
13	89	19/03/2013	27/07/2015	Internal - Inpatient Service (Adult Mental Health)	Personality Disorders Service	PSYCHOTHERAPY	F609
14	89	06/01/2015	06/01/2015	Other Acute secondary care specialty	Area 30 Liaison Service	LIAISON PSYCHIATRY	F609
15	89	08/02/2015	08/02/2015	Other Acute secondary care specialty	Area 30 Liaison Service	LIAISON PSYCHIATRY	F609
16	89	09/05/2015	09/05/2015	Accident And Emergency Department	Area 30 Liaison Service	LIAISON PSYCHIATRY	F609
17	89	03/03/2015	11/03/2015	Accident And Emergency Department	Area 30 Liaison Service	LIAISON PSYCHIATRY	F609
18	89	24/02/2015	24/02/2015	Internal - Community Mental Health Team (Adult Mental Health)	Area 30 Liaison Service	LIAISON PSYCHIATRY	F609
19	89	22/06/2015	23/06/2015	Community Mental Health Team (Adult)	Area 30 AMHP	ADULT MENTAL ILLNESS	F609
20	89	19/07/2015	20/07/2015	Emergency Medical Unit	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
21	89	29/06/2015	07/07/2015	Inpatient Service (Adult)	Area 30 CRHT	ADULT MENTAL ILLNESS	F609
22	89	05/08/2015	06/08/2015	DGH Wards	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
23	89	16/09/2015	19/09/2015	Inpatient Service (Adult)	Area 30 CRHT	ADULT MENTAL ILLNESS	F609
24	89	06/09/2015	07/09/2015	Emergency Medical Unit	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
25	89	31/10/2015	01/11/2015	Emergency Medical Unit	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
26	89	29/09/2015	29/09/2015	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
27	89	16/09/2015	16/09/2015	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
28	89	20/09/2015	08/04/2016	DGH Wards	Personality Disorders Service	PSYCHOTHERAPY	F609
29	89	17/11/2015	19/11/2015	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
30	89	08/03/2016	08/03/2016	Community Mental Health Team (Adult)	Area 30 AMHP	ADULT MENTAL ILLNESS	F609
31	89	04/06/2016	NA	General Medical Practitioner	Gender Identity and Sexual Therapy	ADULT MENTAL ILLNESS	F609
32	89	22/06/2016	23/06/2016	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
33	89	22/06/2016	24/06/2016	Community Mental Health Team (Adult)	Area 30 AMHP	ADULT MENTAL ILLNESS	F609
34	89	03/06/2016	04/06/2016	Emergency Medical Unit	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
35	89	31/07/2016	31/07/2016	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
36	89	22/07/2016	23/07/2016	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609
37	89	11/06/2016	11/06/2016	Accident And Emergency Department	Liaison Psychiatry Area 30	LIAISON PSYCHIATRY	F609

Adjacency matrix

	0	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
2	0	1	1	1	0	1	0	0	0
3	0	0	1	1	0	0	0	0	0
4	0	0	0	0	1	0	0	0	0
5	0	0	1	1	0	9	2	0	0
6	0	0	0	0	0	2	1	0	0
7	0	0	0	0	0	1	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	5	3	0	0

- Create a matrix of zeros n-services by n-services in size
- For each patient iterate over their data slecting the first service then the next and increment the location in the matrix referring to those services
- Source in row, target in column, frequency count in cell

Node list

Index	ID	Label	MeanLoS	MedianLoS	Setting
0	0	All OOA services	30.4444	26	OOA
1	1	Area 10 AMHP	23	23	Community
2	2	Area 10 CRHT	4.625	3	Community
3	3	Area 10 Community Mental Health	1286.5	176.5	Community
4	4	Area 10 OPMH Community	505	234	Community
5	5	Area 11 MHAT	81.1143	58	Community
6	6	Area 12 CMHT	793.818	300	Community
7	7	Area 13 MHAR	1909.33	928	Community
8	8	Area 14 CMHT	550	550	Community
9	9	Area 15 CMHT	227.5	227.5	Community
10	10	Area 15 OPMH Community	173.429	85	Community
11	11	Area 16 Community Mental Health	449.5	234.5	Community
12	12	Area 17 CMHT	764	764	Community
13	13	Area 18 PPT	421	294	Community
14	14	Area 19 CMHT	1090	1090	Community
15	15	Area 20 OPMH Community	241	241	Community

- Required: ID - a unique numerical identifier
- Optional: Label - a text string descriptor, continuous and discrete attributes of any type

Edge list

Index	Source	Target	Type	Id	Weight
0	37	0	Directed	0	1
1	49	0	Directed	1	1
2	57	0	Directed	2	1
3	58	0	Directed	3	1
4	59	0	Directed	4	1
5	69	0	Directed	5	1
6	73	0	Directed	6	1
7	83	0	Directed	7	1
8	2	1	Directed	8	1
9	2	2	Directed	9	1
10	3	2	Directed	10	1
11	5	2	Directed	11	1
12	47	2	Directed	12	1
13	49	2	Directed	13	1
14	56	2	Directed	14	1
15	86	2	Directed	15	1

- Required: Source - unique node identifier, Target - unique node identifier, ID - unique edge identifier
- Optional: Type (required for Gephi) - directed or undirected, weight - number from adjacency matrix, continuous and discrete attributes

Break time

Break time!!

When we return it will be your turn to create the node and edge data you will then use to construct a network graph

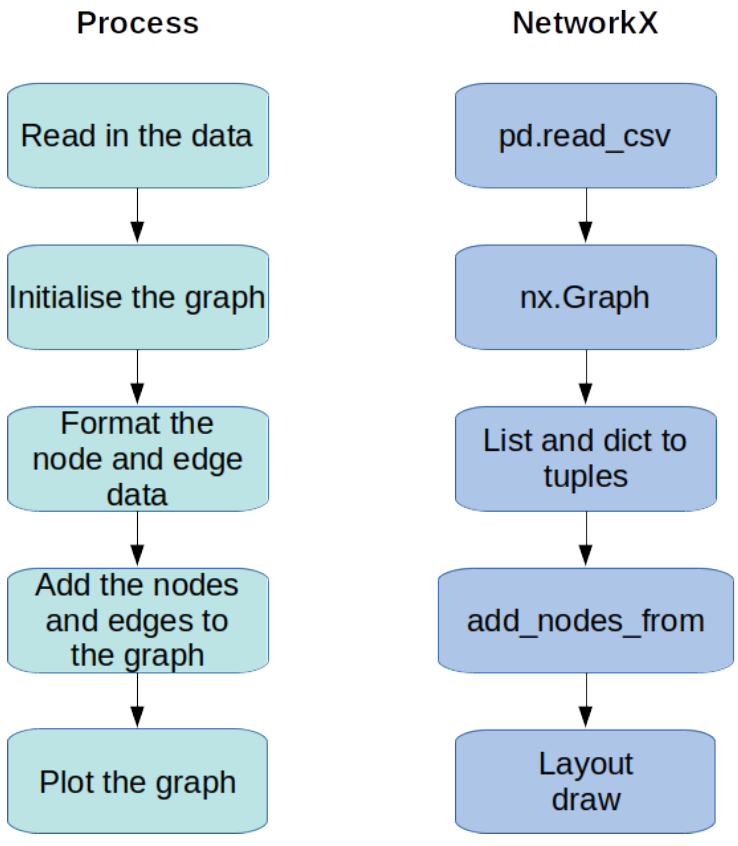
Task time

Data transformation

- Open the data_transformation_jumbled.py file in spyder
- This is an example of how to transform patient episode data for network analysis
- This example provides all of the required columns for use with multiple network analysis libraries
- However! The code has been split into 8 blocks and then jumbled up
- Task – Rebuild the code and make it work
- To be kind the package imports and data read function are in the correct position
- Don't forget to set your working directory!

Building a network graph

Building a network graph



Task time

Open Spyder and start a new script. This time I have provided you with the code in the slides but some of the column and variable names are missing. Missing names are marked with a double astrisk **. The data you require for this task are the node and edge lists produced in the previous task.

Building a network graph

Import the required libraries and the data we just created

```
import networkx as nx
import pandas as pd

nodes = pd.read_csv('data/node_list.csv',
low_memory=False)
edges = pd.read_csv(**,
low_memory=False)
```

Building a network graph

Initialise a graph object which we will assign to the variable **G**

```
** = nx.Graph()
```

Building a network graph

Node inputs are tuples of the node ID and a dictionary of attributes
Node tuples (ID, dict of attributes)

```
idList = nodes[**].tolist()
labels =  pd.DataFrame(nodes['Label'])
labelDicts = **.to_dict(orient='records')
nodeTuples = [tuple(r) for r in zip(idList,labelDicts)]
```

Building a network graph

Edge inputs are tuples of source ID, target ID and a dictionary of attributes
Edge tuples (Source, Target, dict of attributes)

```
sourceList = edges[**].tolist()
targetList = edges['Target'].tolist()
weights = pd.DataFrame(edges[**])
weightDicts = **.to_dict(orient='records')
edgeTuples =
[tuple(r) for r in zip(sourceList,**,weightDicts)]
```

Building a network graph

We add the nodes and edges to the graph object **G**

```
G.add_nodes_from(**)
G.add_edges_from(**)
```

Building a network graph

We pass the graph object to a layout algorithm to determine the node coordinates and hence the edge start and end points

```
pos = nx.kamada_kawai_layout(**)
```

Building a network graph

Finally we draw the graph passing in the graph object **G**, the position object **pos** and adjust the node size

```
plot = nx.draw(**, pos=**, node_size=100,
 with_labels=True, font_size=10)
```

Advanced network analysis

In the optional advanced sessions we will cover:

- Different types of graph
- Graph metrics and their interpretation
- How graph visualisations work
- Graph algorithms and custom layouts
- Interactive graphs with Plotly and Holoviews

Thank you

Thank you for paying attention
Hope you enjoyed the session
Checkout https://www.project-nom.com for more information and training on the use of network-based operational modelling for whole system modelling in healthcare