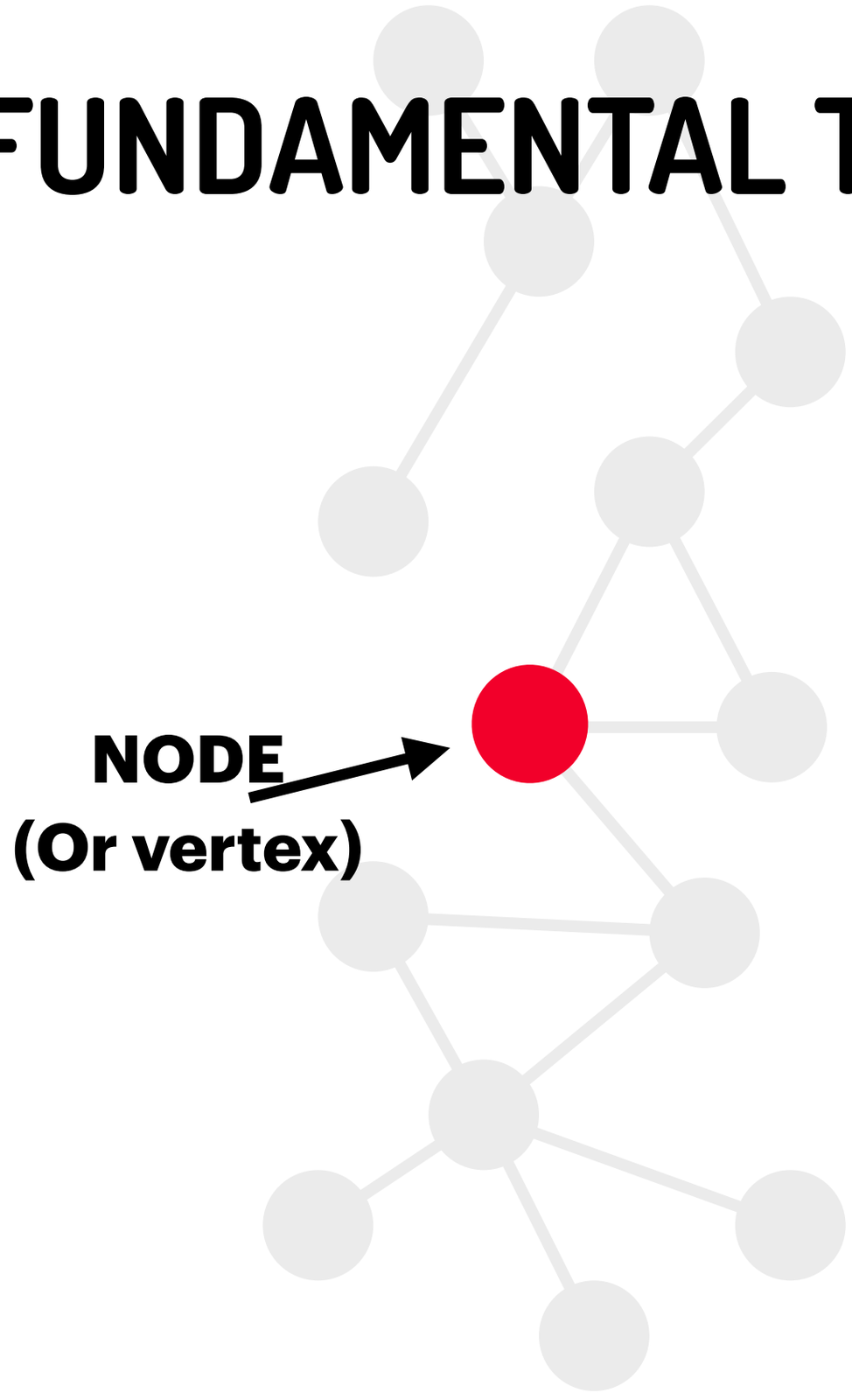
Network elements

LEARNING OUTCOMES

Get to know network **terminology**
Explore the different **types of networks**
See some network **applications**

FUNDAMENTAL TERMS

FUNDAMENTAL TERMS



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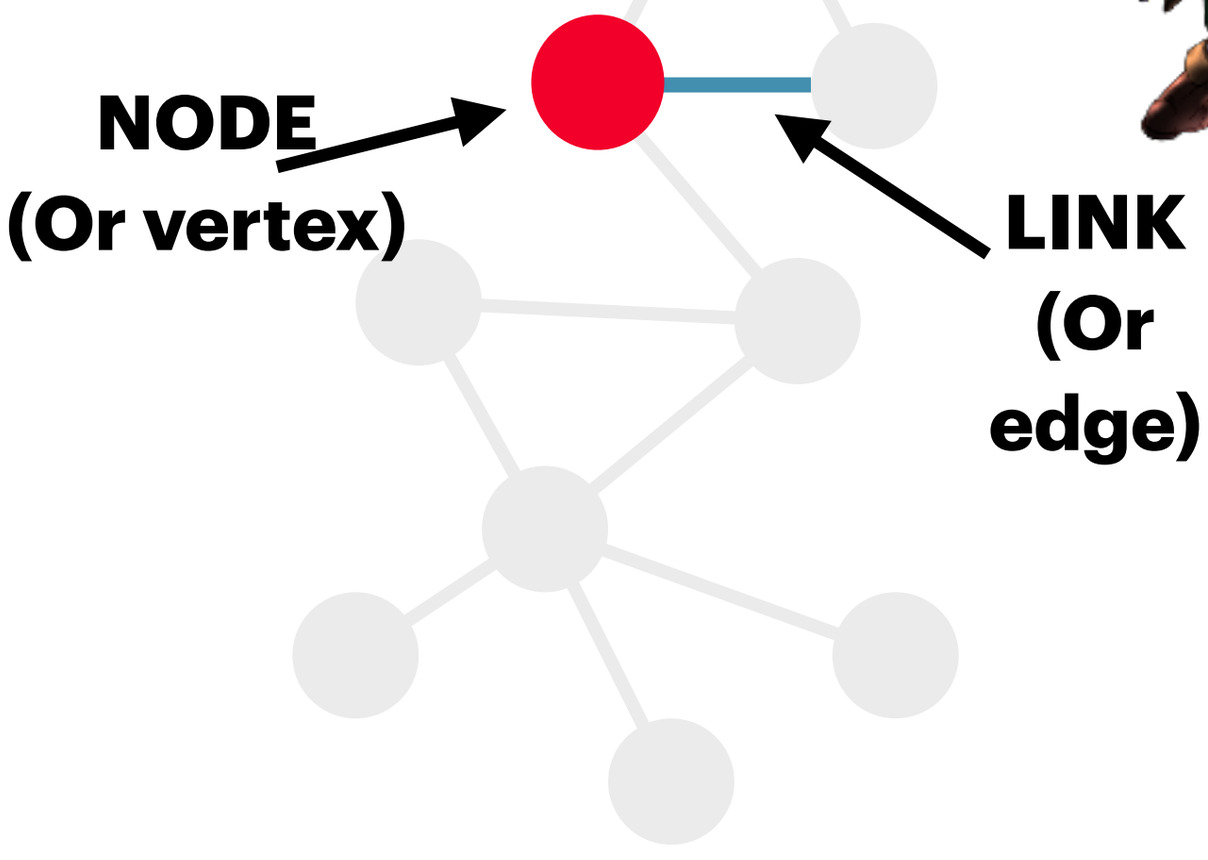
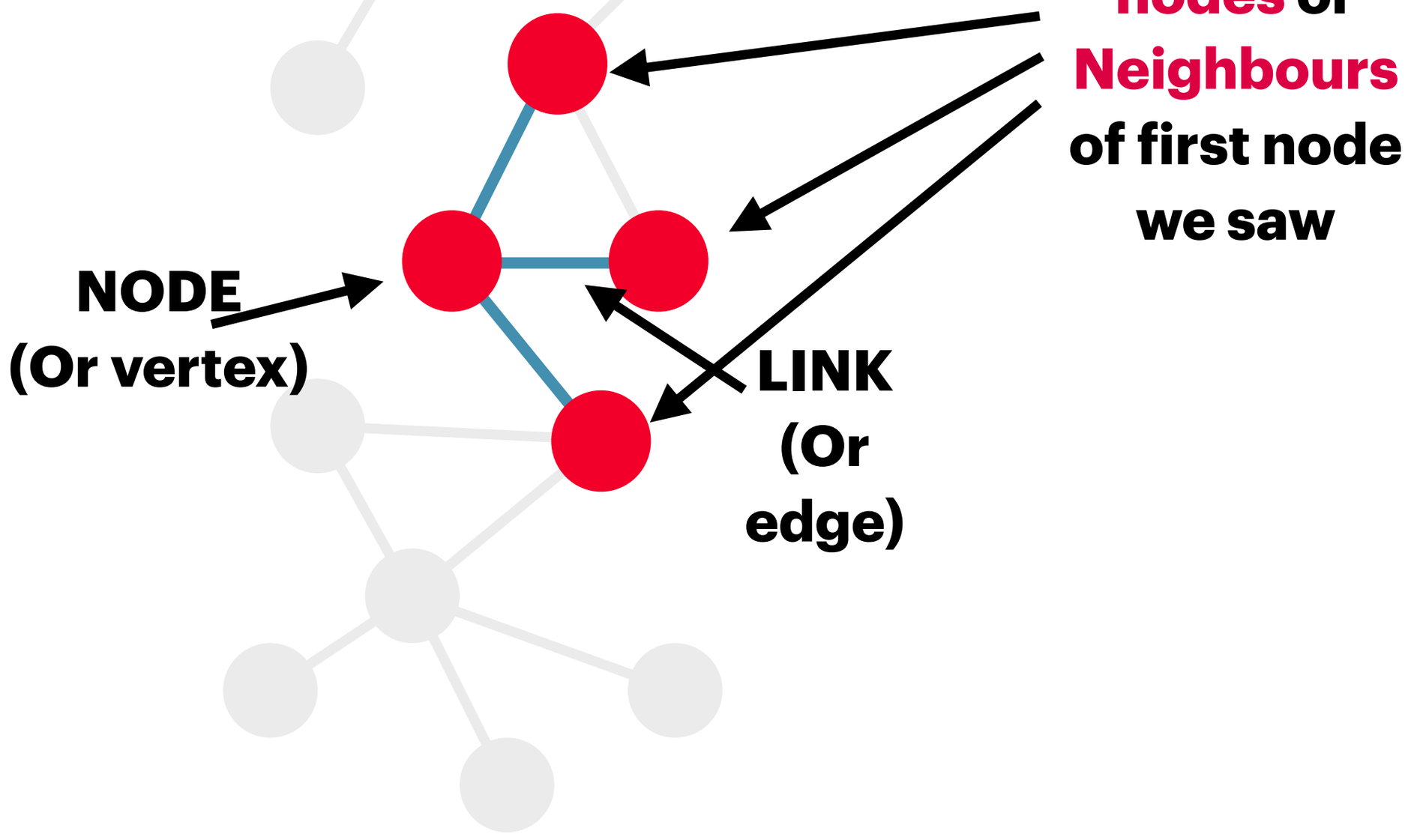


NODE
(Or vertex)

LINK
(Or edge)

FUNDAMENTAL TERMS



FUNDAMENTAL NOTATION

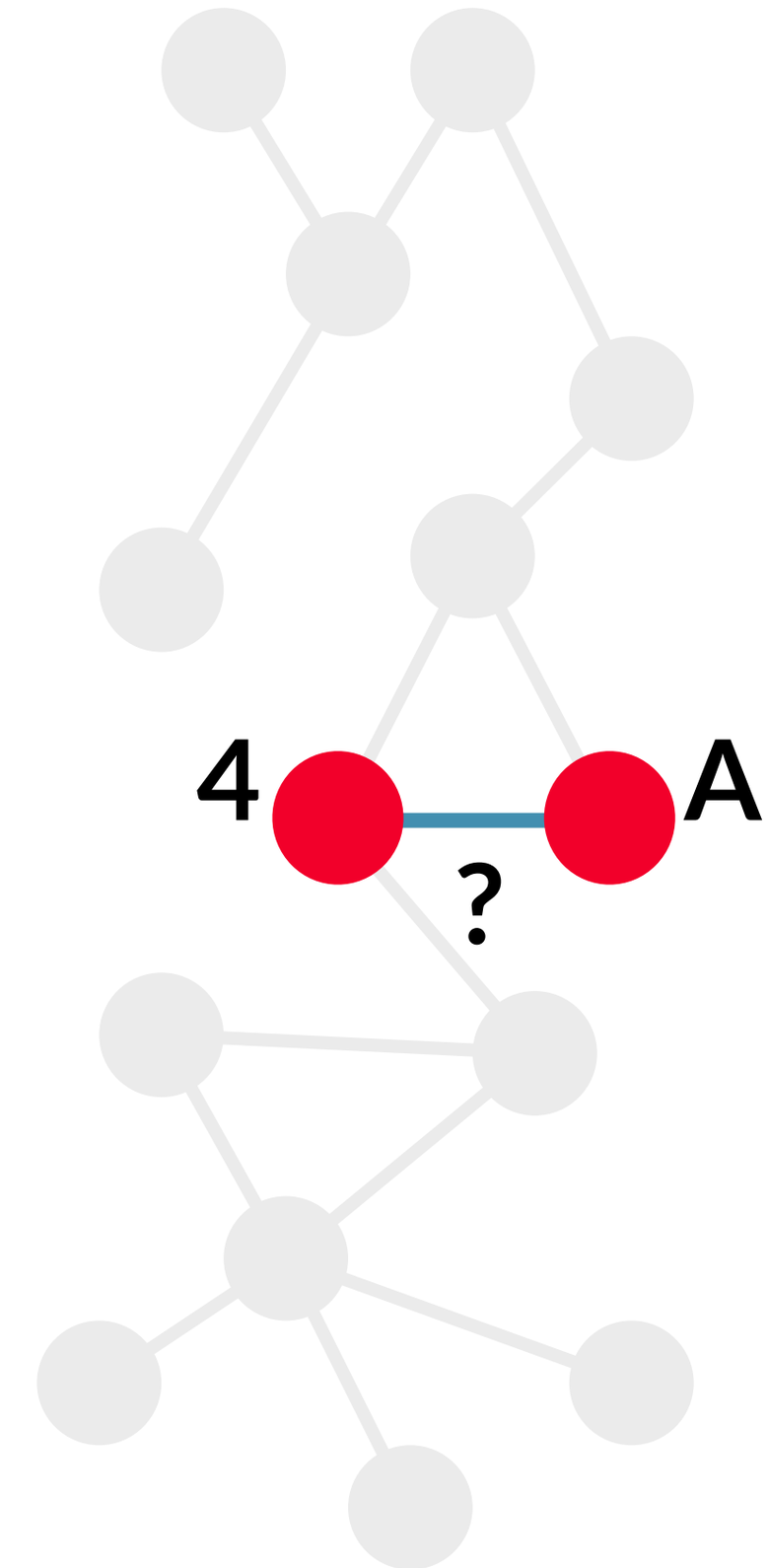
A NETWORK **G** IS A SYSTEM COMPOSED OF TWO PARTS:

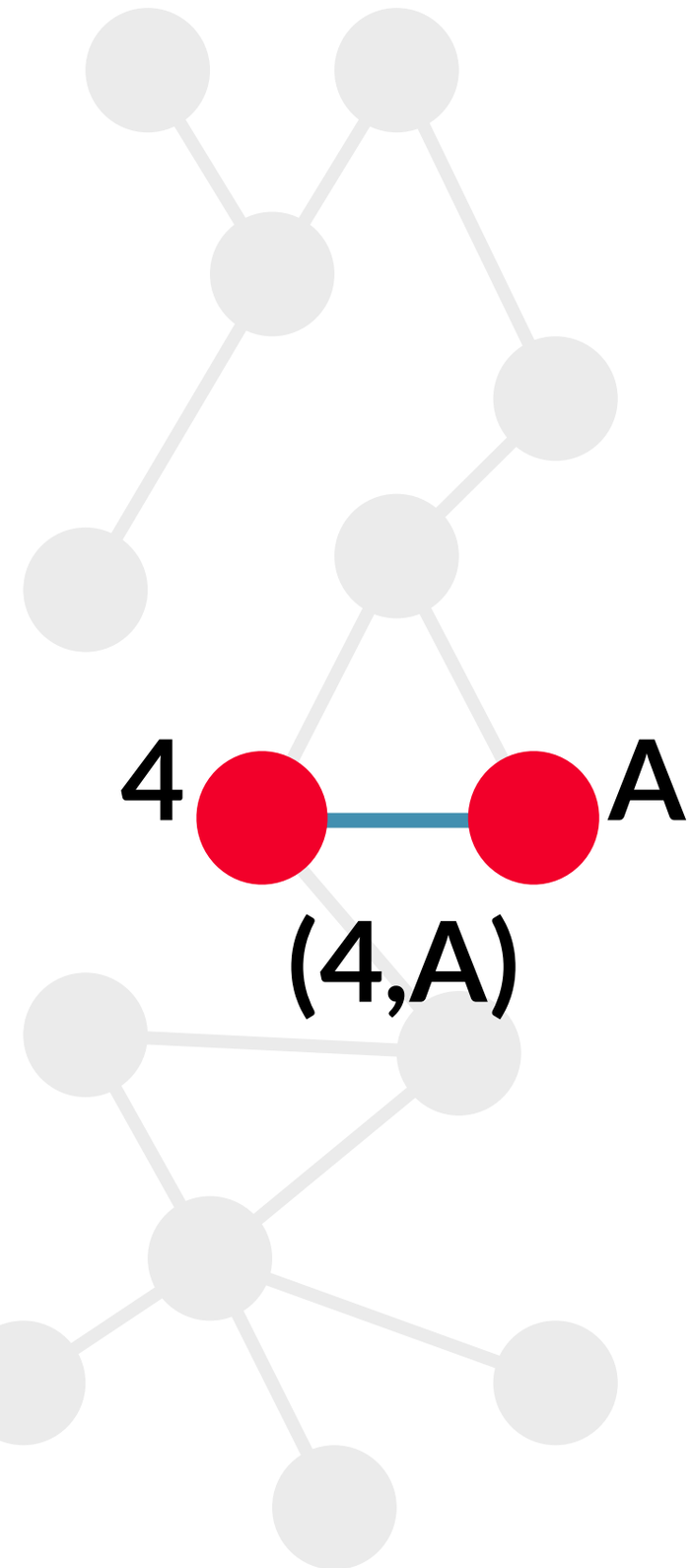
A SET **N** OF ELEMENTS (NODES) CONNECTED BY **L** LINKS.

The link **(i,j)** connects the node i to the node **j**

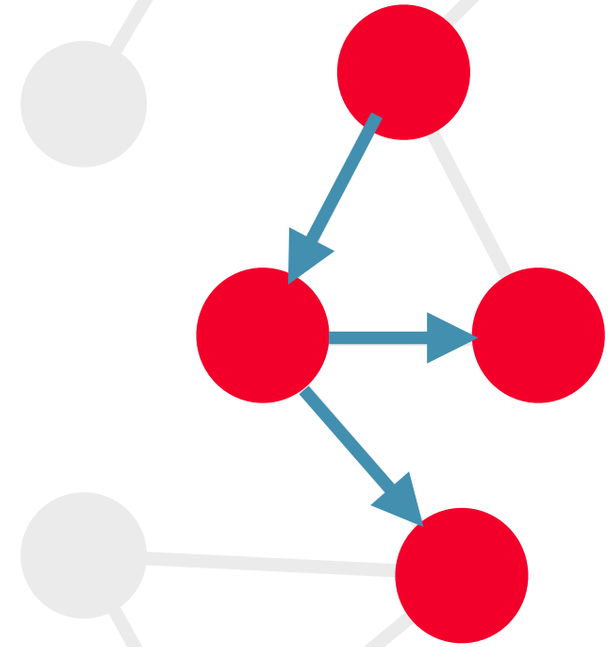
|N|=14

|L|=15

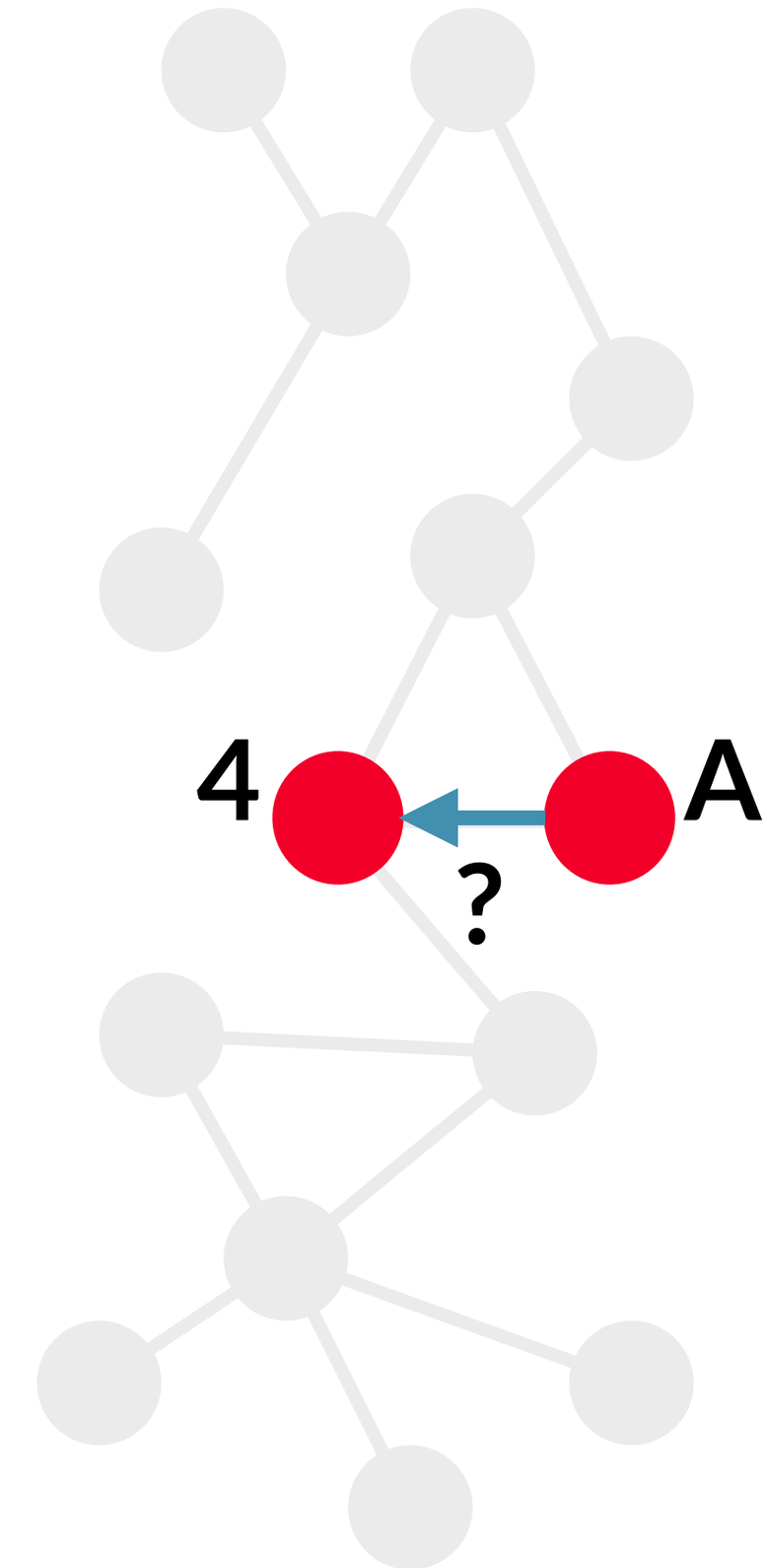

4
A
?

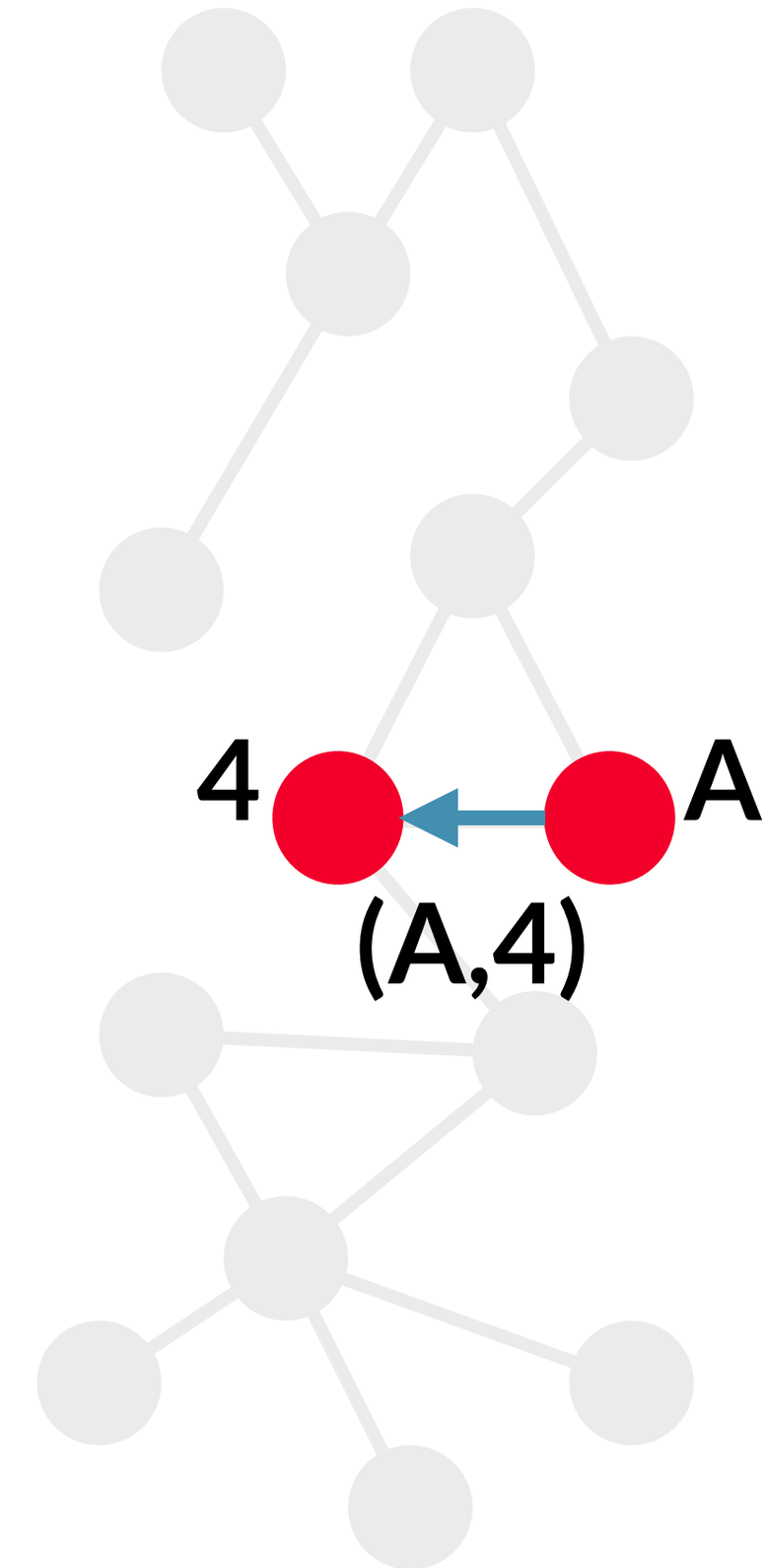

4
A
(4,A)

FUNDAMENTAL NOTATION

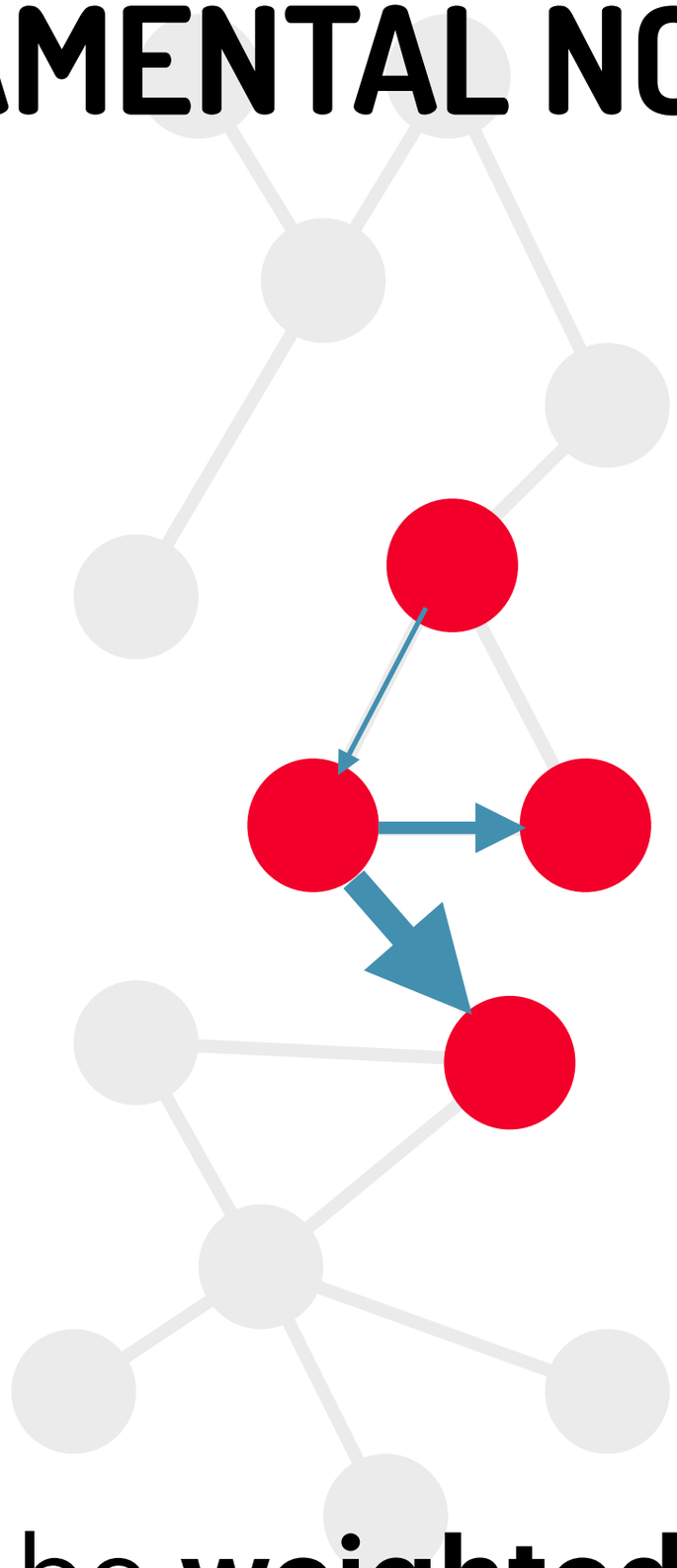


A network **G** can be directed or undirected. A directed network has directed links.


4
A
?

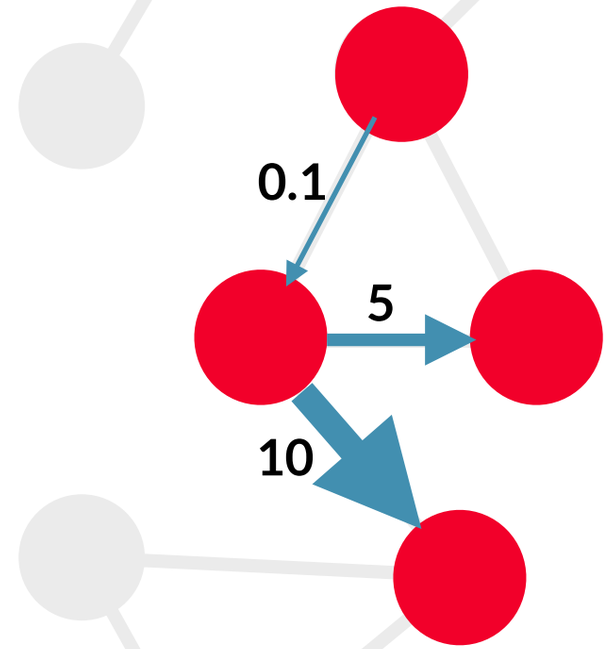

4
A
(A,4)

FUNDAMENTAL NOTATION



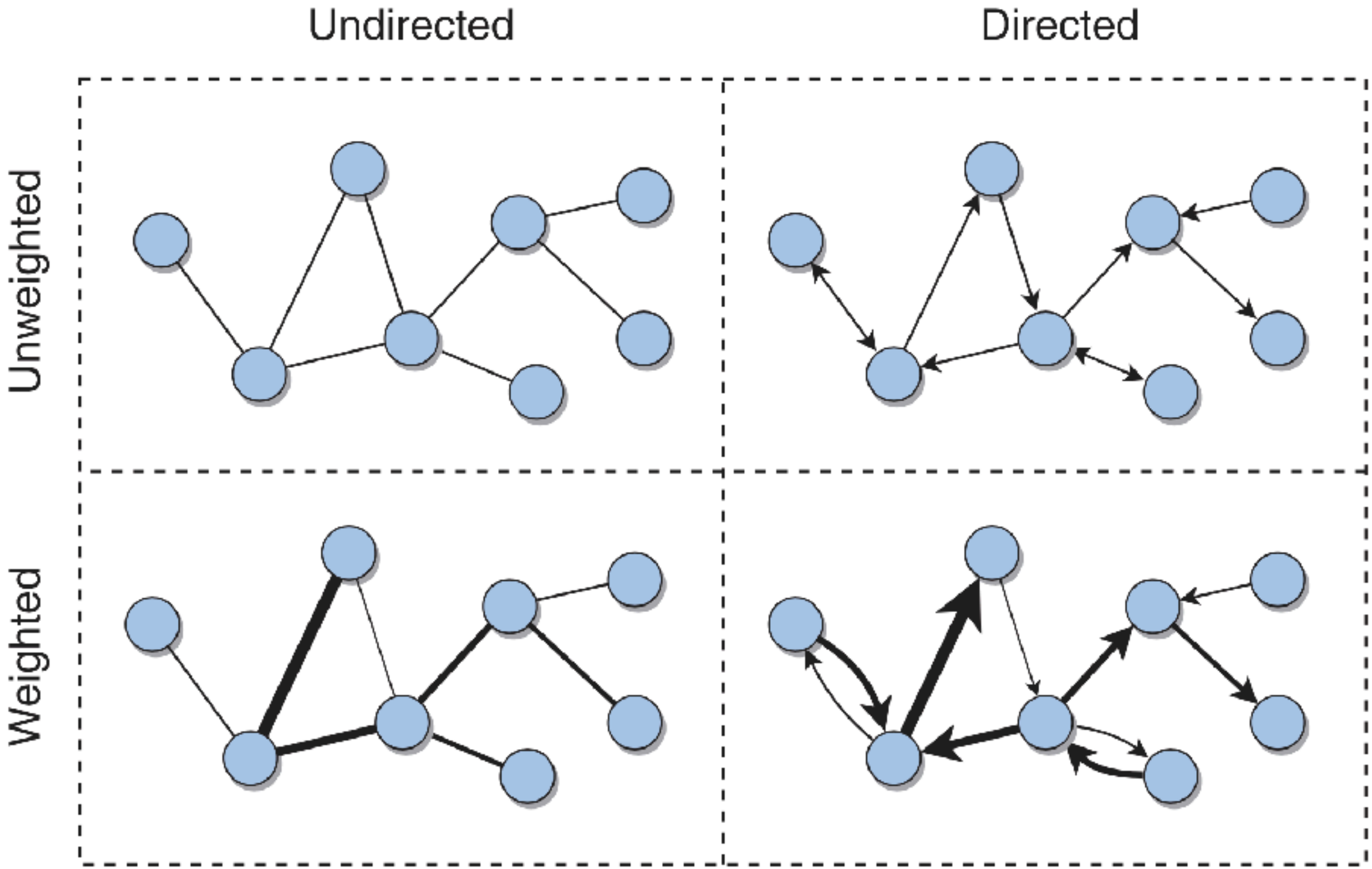
Links can also be **weighted** or **unweighted**

FUNDAMENTAL NOTATION



Weighted links are associated with a weight **w**, so they are described by **(i,j,w)**

FUNDAMENTAL NOTATION

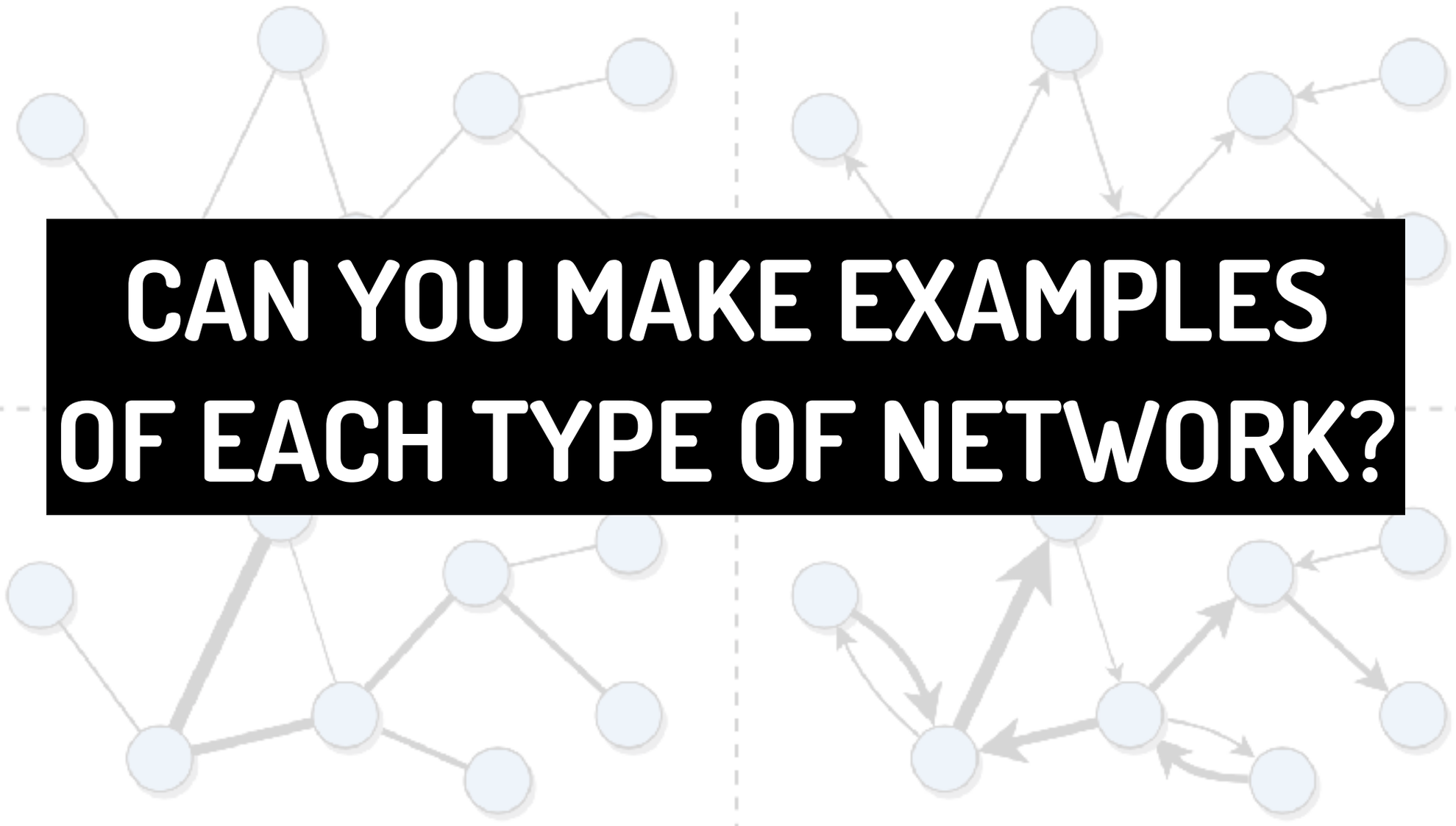


Undirected

Directed

Unweighted

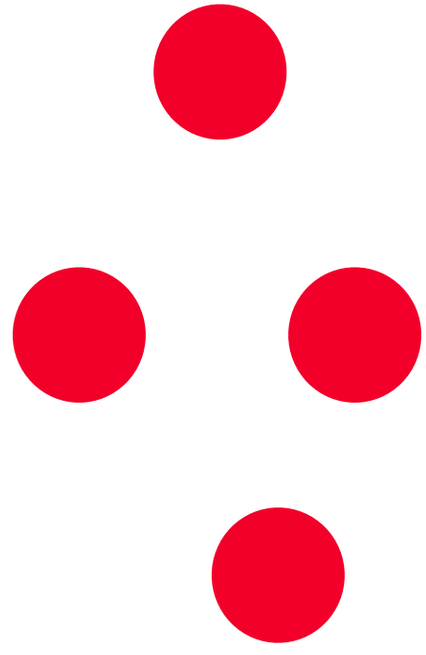
Weighted



CAN YOU MAKE EXAMPLES OF EACH TYPE OF NETWORK?

MAXIMUM NUMBER OF LINKS

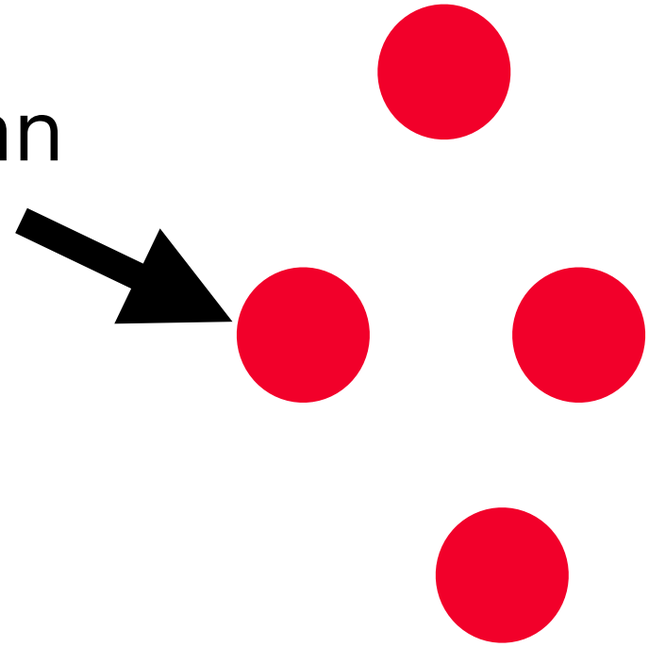
If we have 4 nodes in an undirected network, what is the **maximum possible number** of links between them?



MAXIMUM NUMBER OF LINKS

If we have 4 nodes in an undirected network, what is the **maximum possible number** of links between them?

How many links can this node have?



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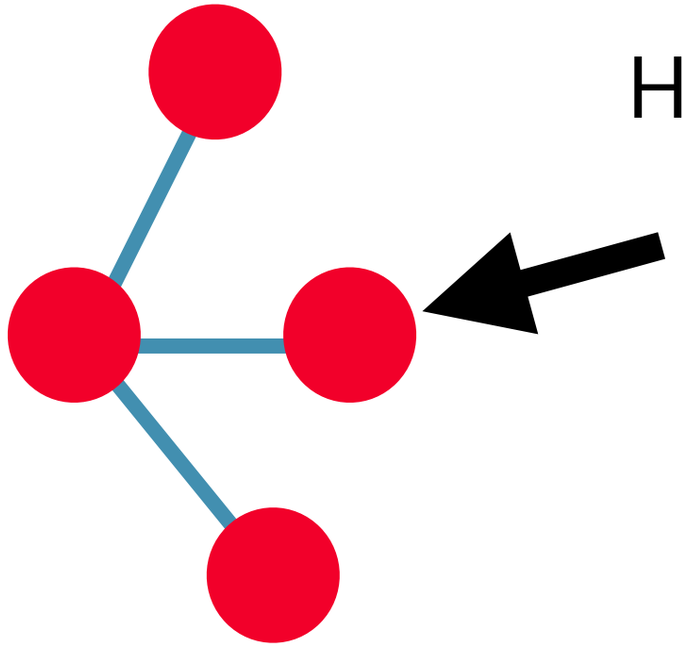
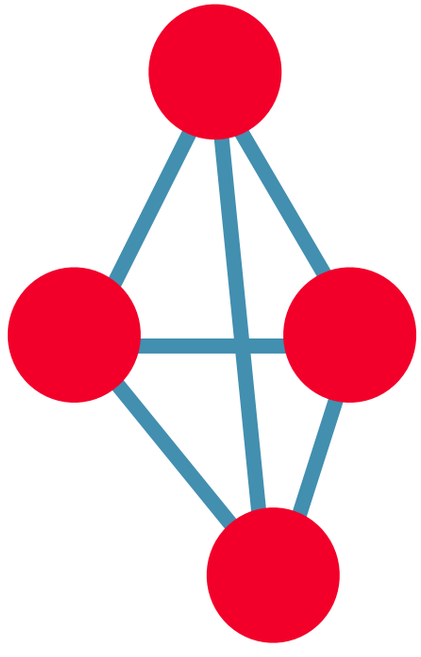


MAXIMUM NUMBER OF LINKS

Every node of the N nodes that we have **can connect to any other except from itself**
This means it can connect to **n-1 nodes**



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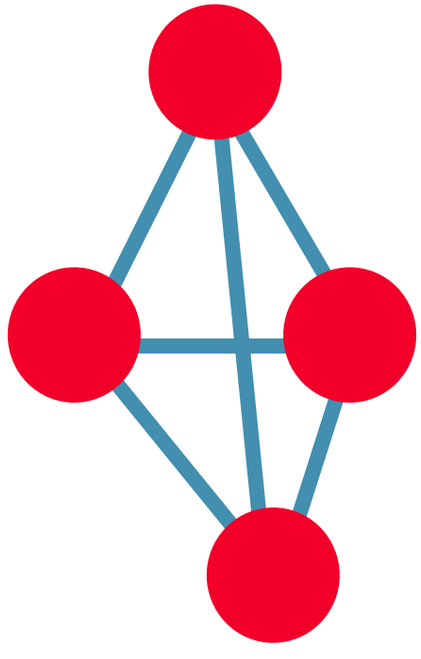


Then, the maximum number of links is N(N-1) right?

WRONG!!!
WE ARE COUNTING LINKS TWICE THIS WAY!

If the network is undirected, then the link (i,j) is equivalent to the link (j,i)

MAXIMUM NUMBER OF LINKS

$$L_{max} = \binom{N}{2} = \frac{N(N-1)}{2}$$

WHAT IS THE MAXIMUM NUMBER OF LINKS IN A DIRECTED NETWORK?

$$L_{max} = ?$$

WHAT IS THE MAXIMUM NUMBER OF LINKS IN A DIRECTED NETWORK?

$$L_{max} = N(N-1)$$

DENSITY

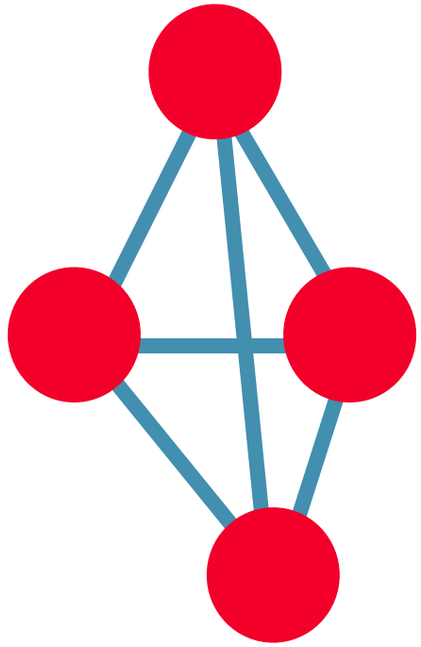
$$d = \frac{L}{L_{max}}$$

Network	Type	Nodes (N)	Links (L)	Density (d)
Facebook Northwestern Univ.		10,567	488,337	0.009
IMDB movies and stars		563,443	921,160	0.000006
IMDB co-stars	W	252,999	1,015,187	0.00003
Twitter US politics	DW	18,470	48,365	0.0001
Enron email	DW	87,273	321,918	0.00004
Wikipedia math	D	15,220	194,103	0.0008
Internet routers		190,914	607,610	0.00003
US air transportation		546	2,781	0.02
World air transportation		3,179	18,617	0.004
Yeast protein interactions		1,870	2,277	0.001
C. elegans brain	DW	297	2,345	0.03
Everglades ecological food web	DW	69	916	0.2

DEGREE

In an undirected network, the degree **k** of a node is the number of links a node has

This is equivalent of saying that k is the number of **neighbours** a node has



The **average degree** of a network is $\langle k \rangle = \frac{\sum_i k_i}{N}$

DEGREE

In a directed network, there are three types of degree:

In-degree: k_{in} Out-degree: k_{out} Total-degree: k_{tot}

DEGREE

In a weighted network, instead of a degree, a node has a **strength**:

$$s_i = \sum_j w_{ij}$$

DEGREE

In a weighted network, instead of a degree, a node has a **strength**:

$$s_i = \sum_j w_{ij}$$

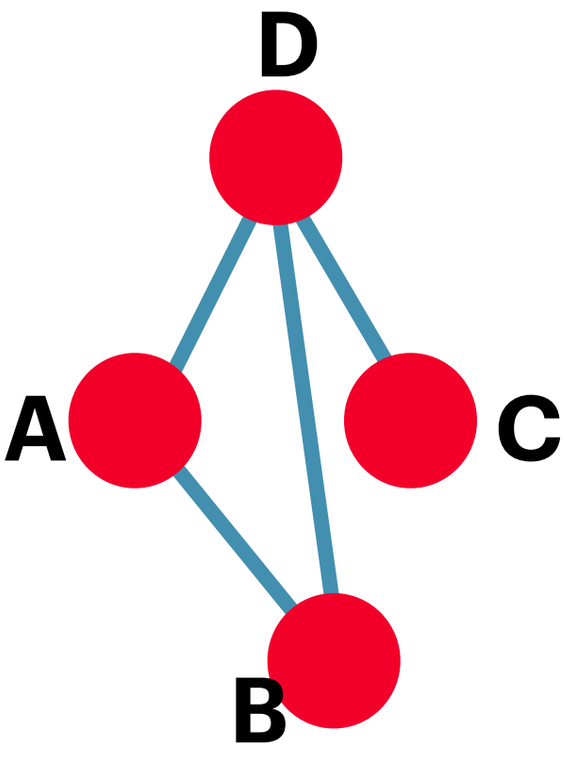
In a directed weighted network, a node has an **in-strength** and an **out-strength**:

$$s_i^{in} = \sum_j w_{ji}$$

$$s_i^{out} = \sum_j w_{ij}$$

MATHEMATICAL REPRESENTATION

How do we represent networks mathematically and for computers?

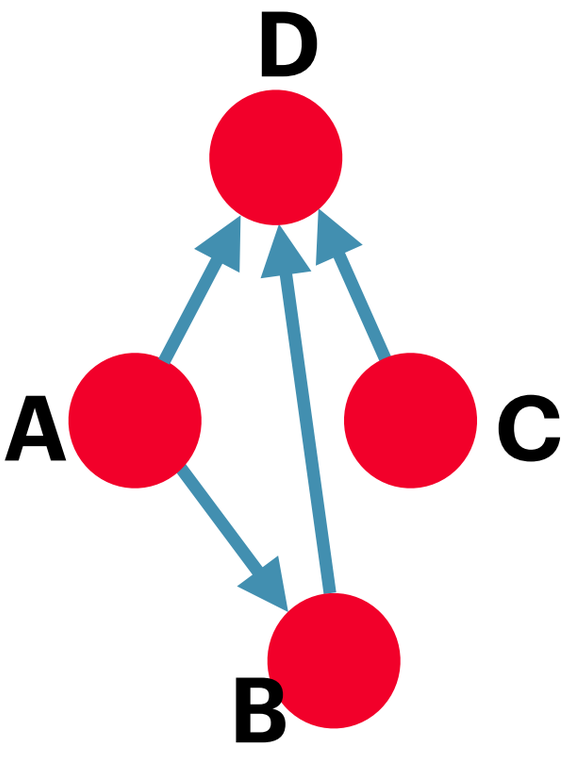


$$\begin{array}{c} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cccc} A & B & C & D \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix} \end{array}$$

ADJACENCY MATRIX

MATHEMATICAL REPRESENTATION

How do we represent networks mathematically and for computers?



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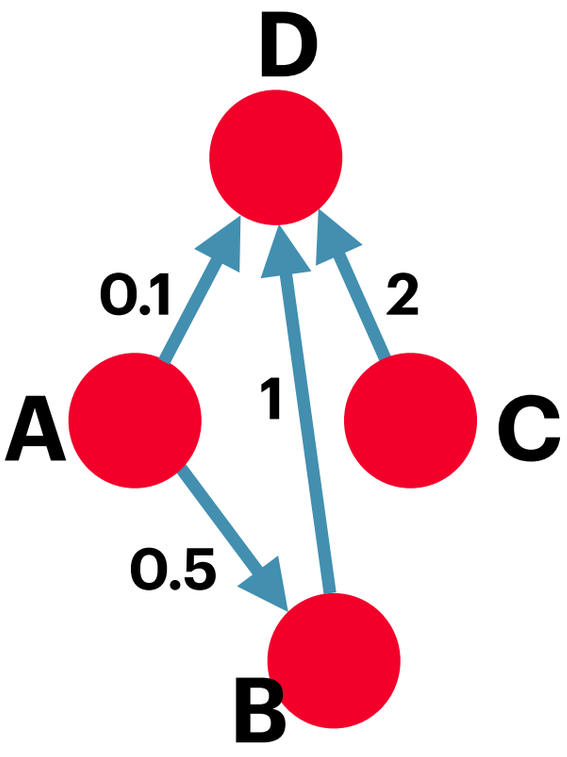
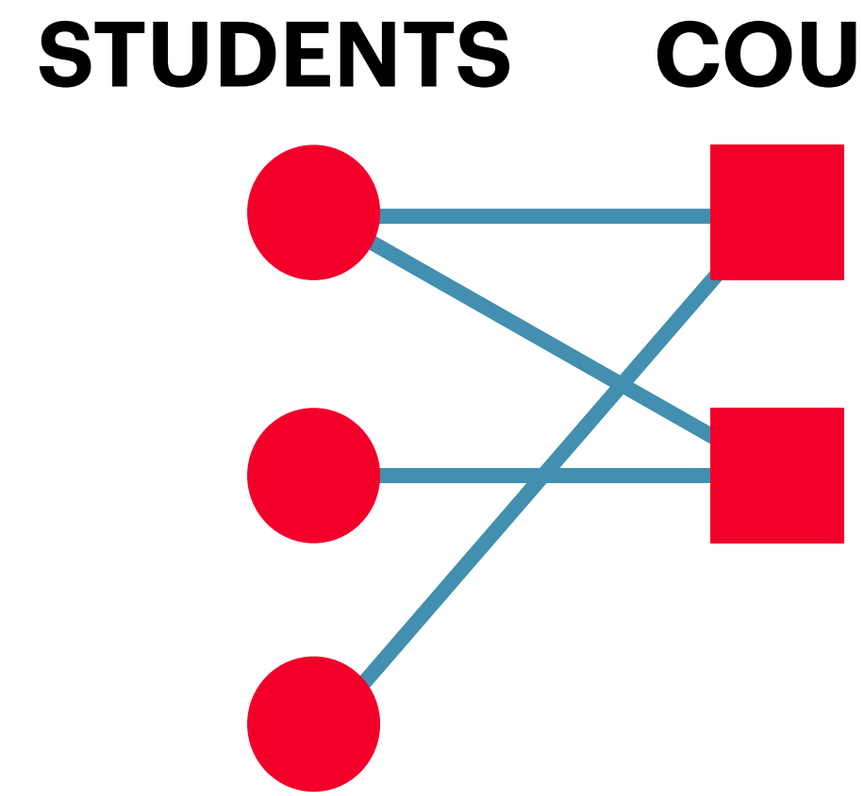


$$\begin{array}{c} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cccc} A & B & C & D \end{array} \\ \begin{bmatrix} 0 & 0.5 & 0 & 0.1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

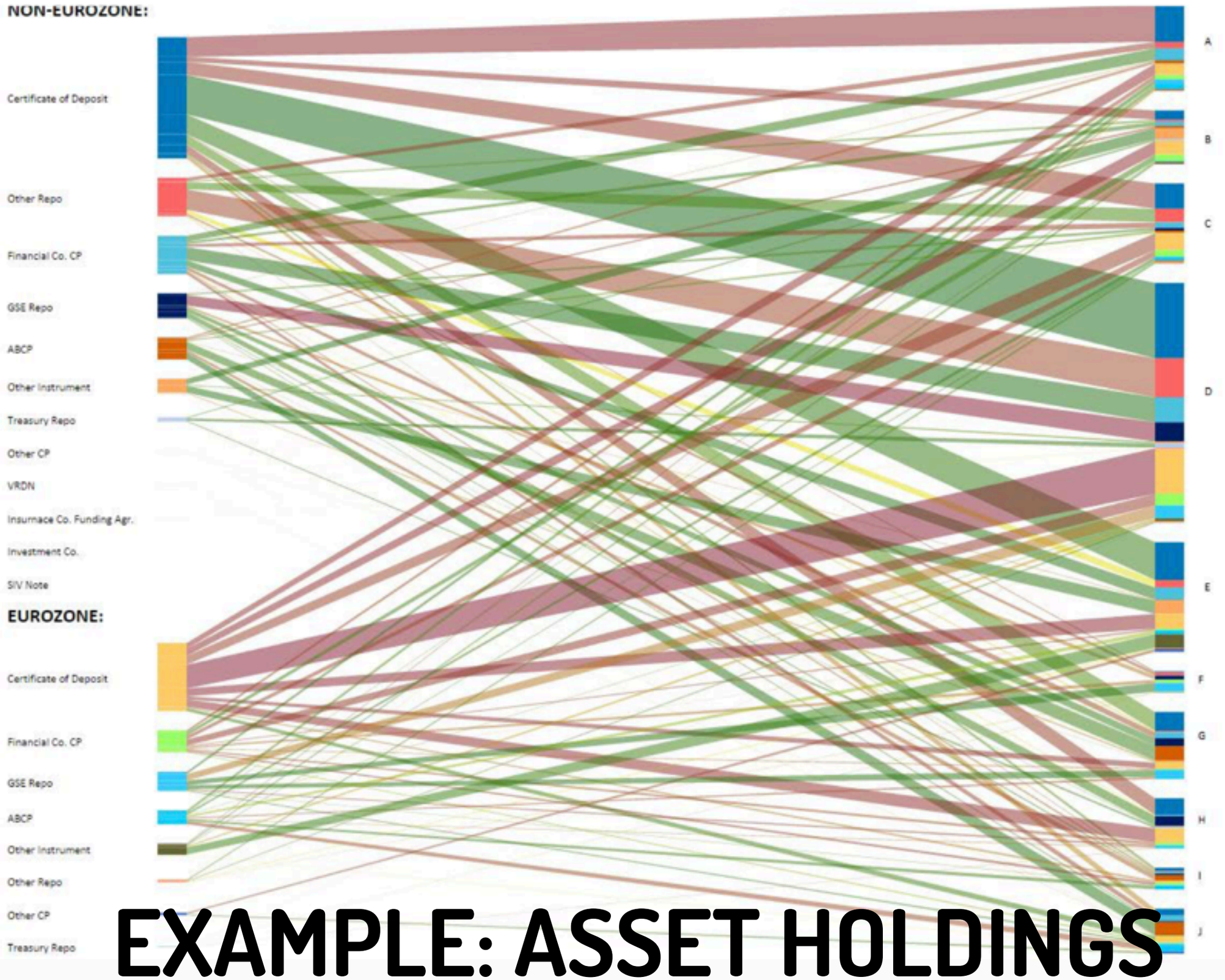
ADJACENCY MATRIX

OTHER NETWORK TYPES



BIPARTITE NETWORK

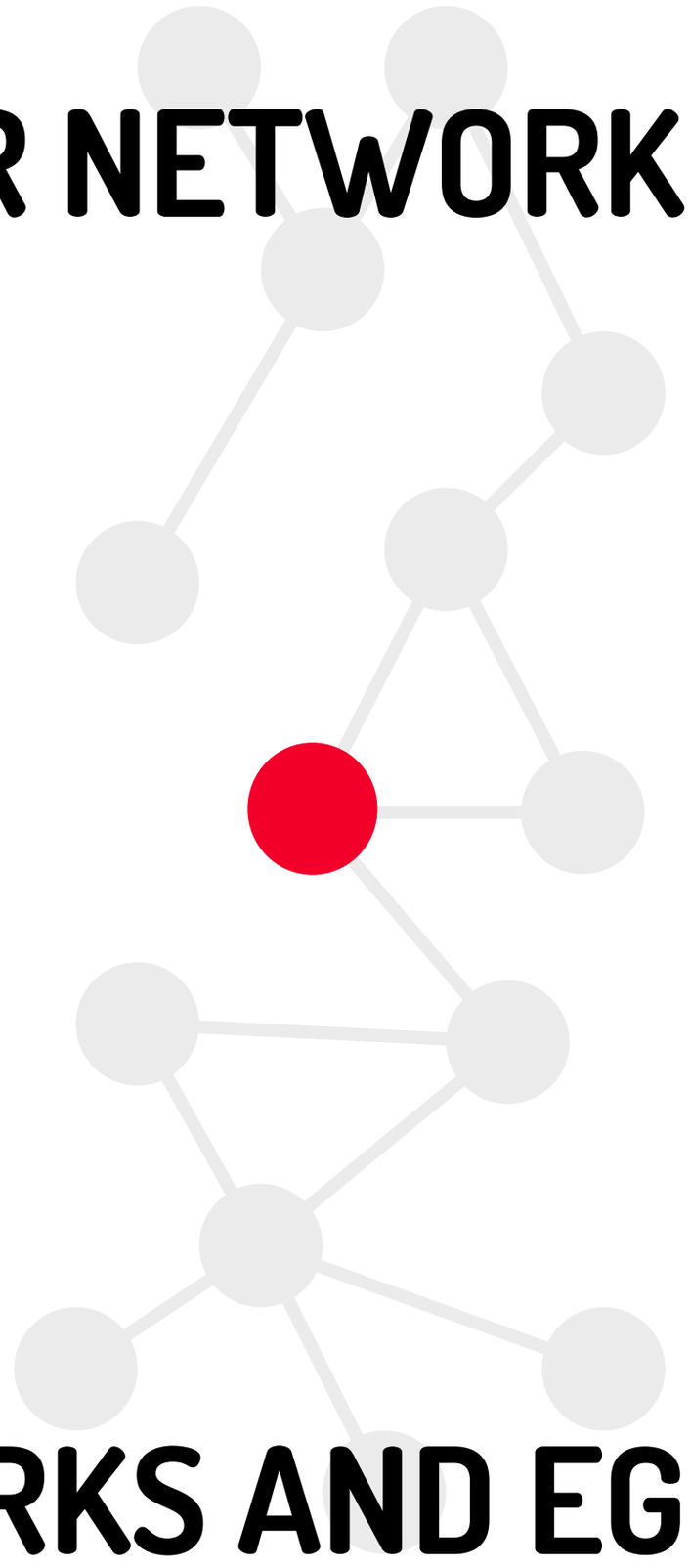
July-August, 2011



EXAMPLE: ASSET HOLDINGS

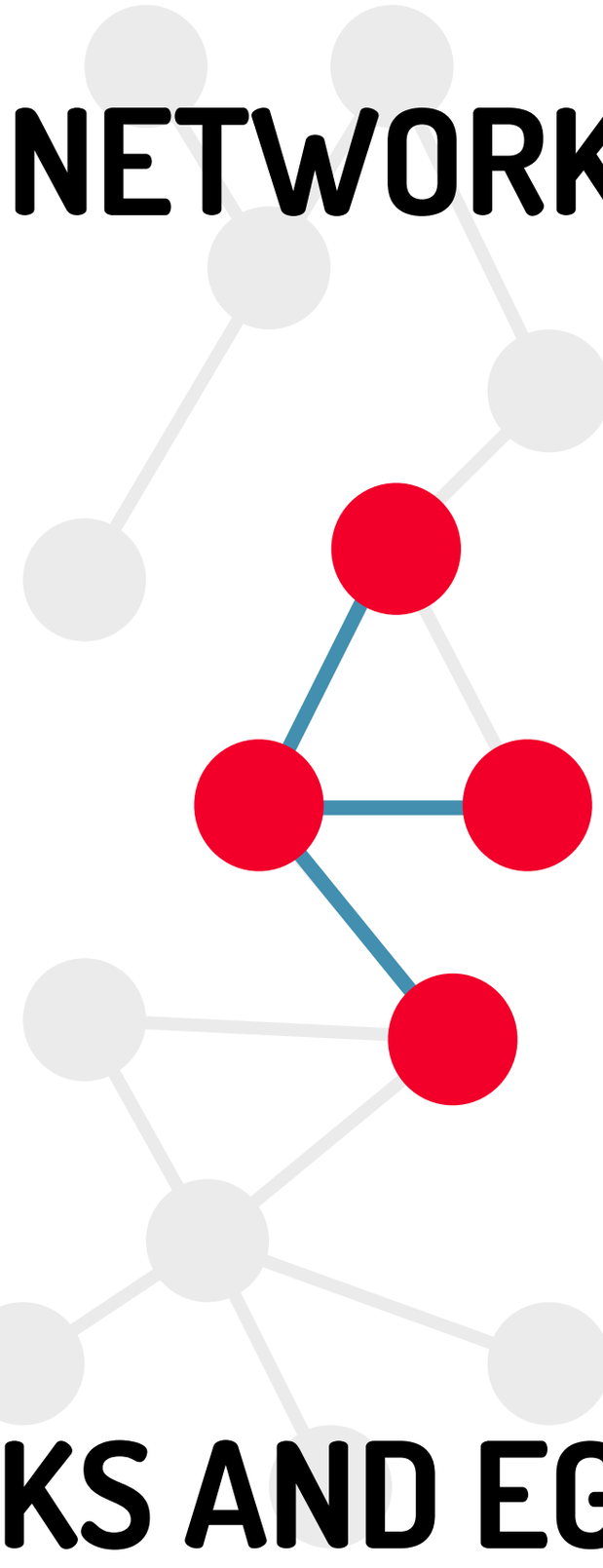
Image source : SEC N-MFP, OFR analysis

OTHER NETWORK TYPES



SUB-NETWORKS AND EGO-NETWORKS

OTHER NETWORK TYPES



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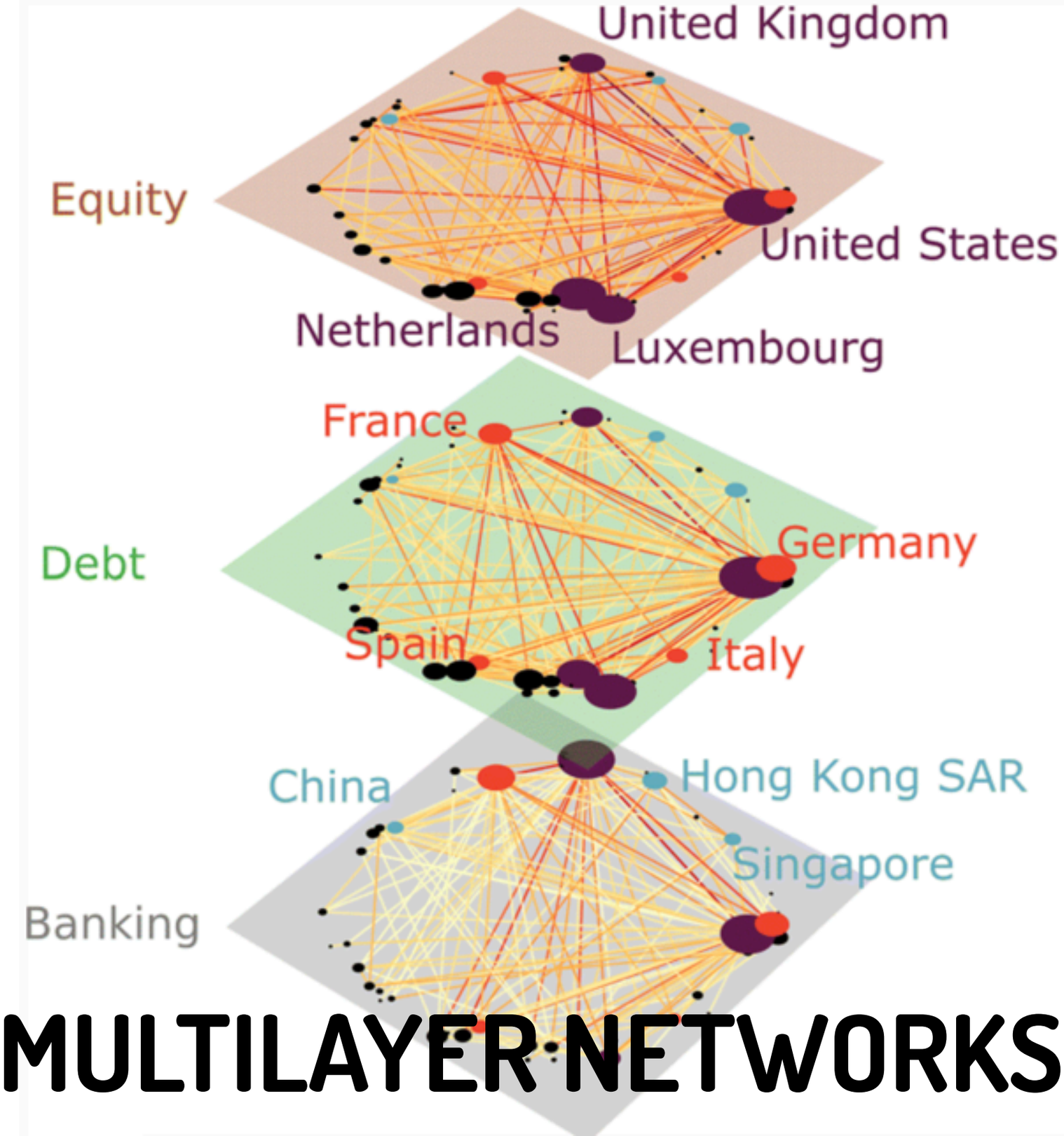
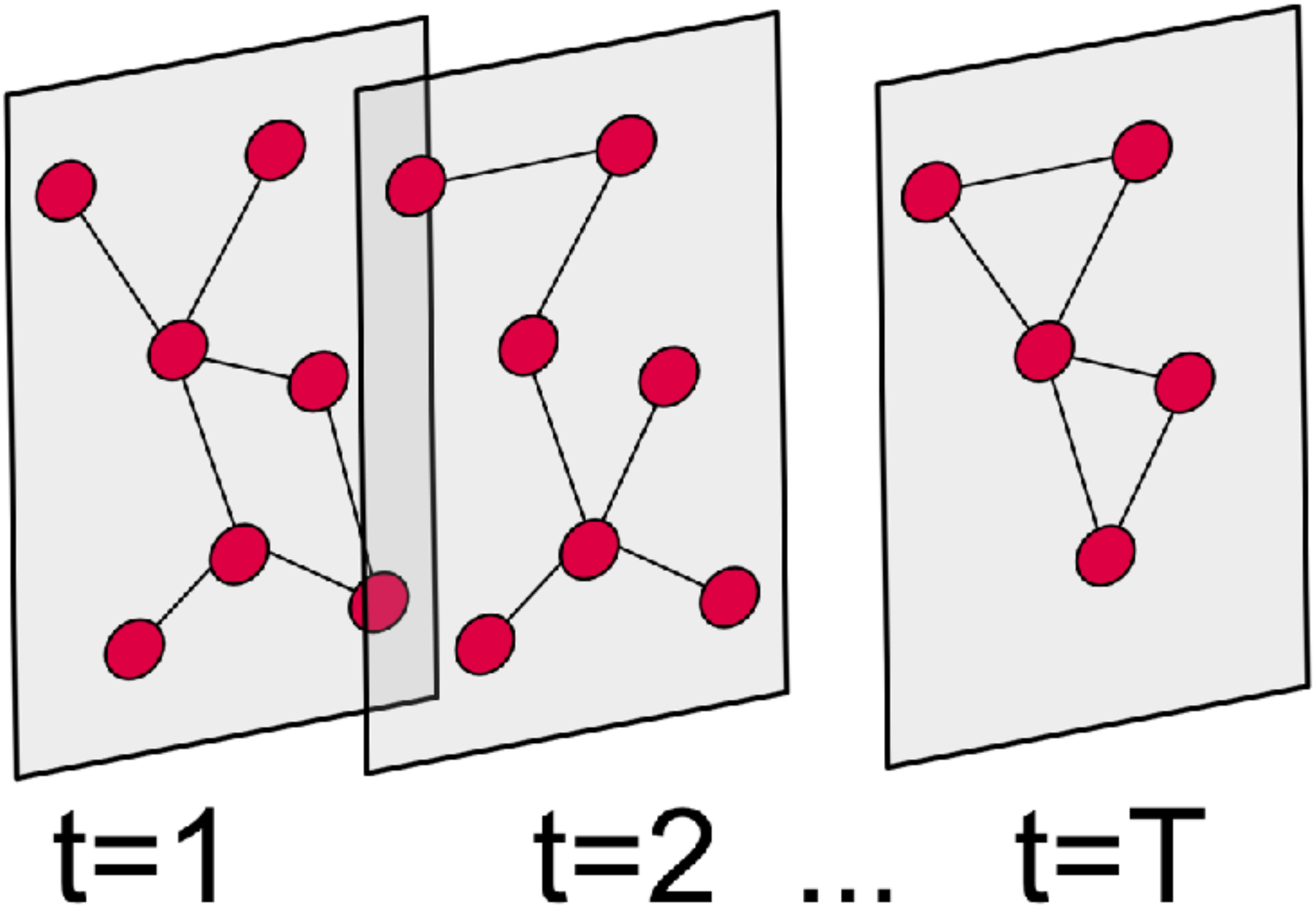


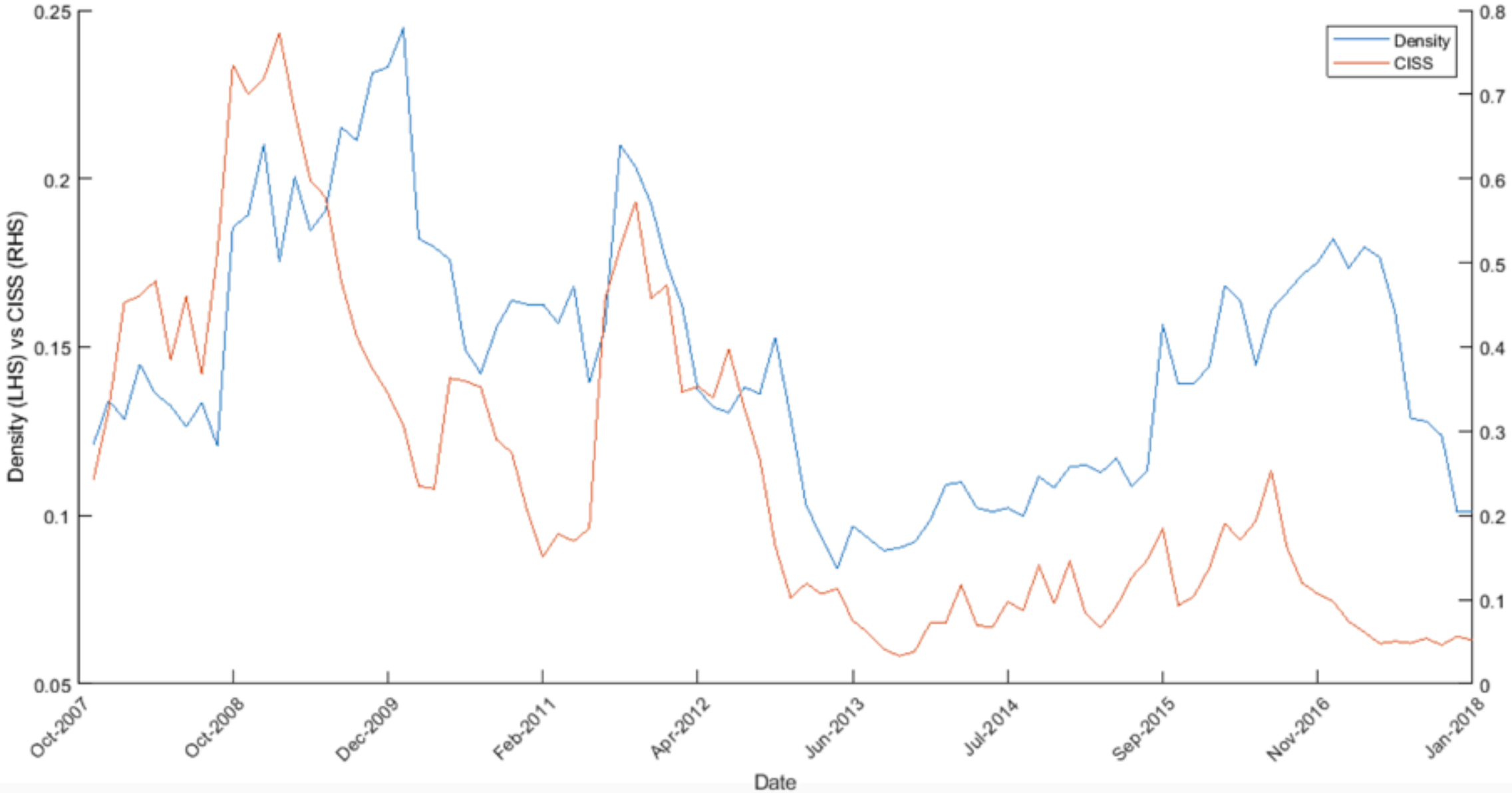
MULTILAYER NETWORKS

OTHER NETWORK TYPES



TEMPORAL NETWORKS

OTHER NETWORK TYPES



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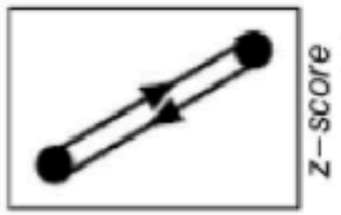
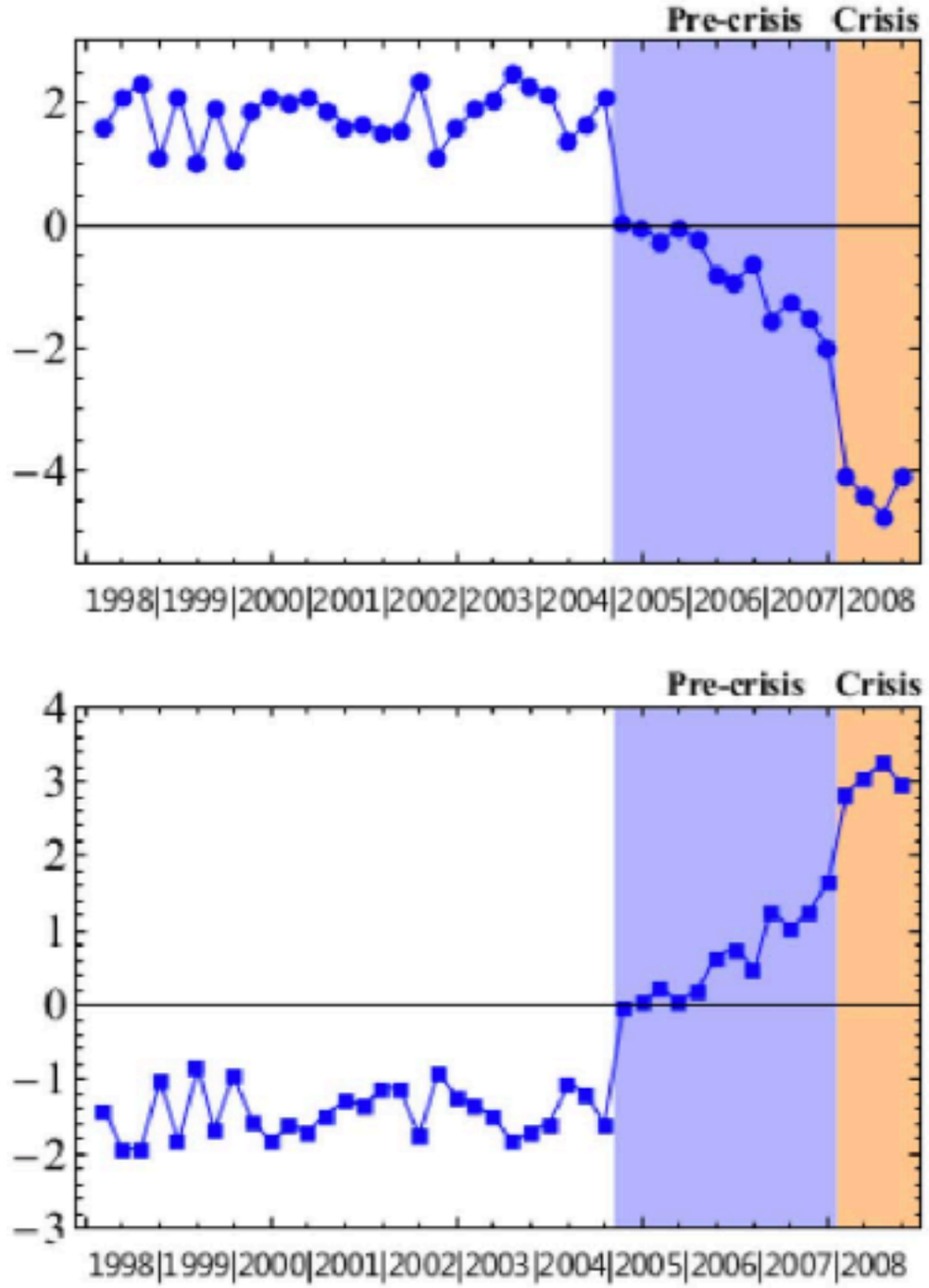
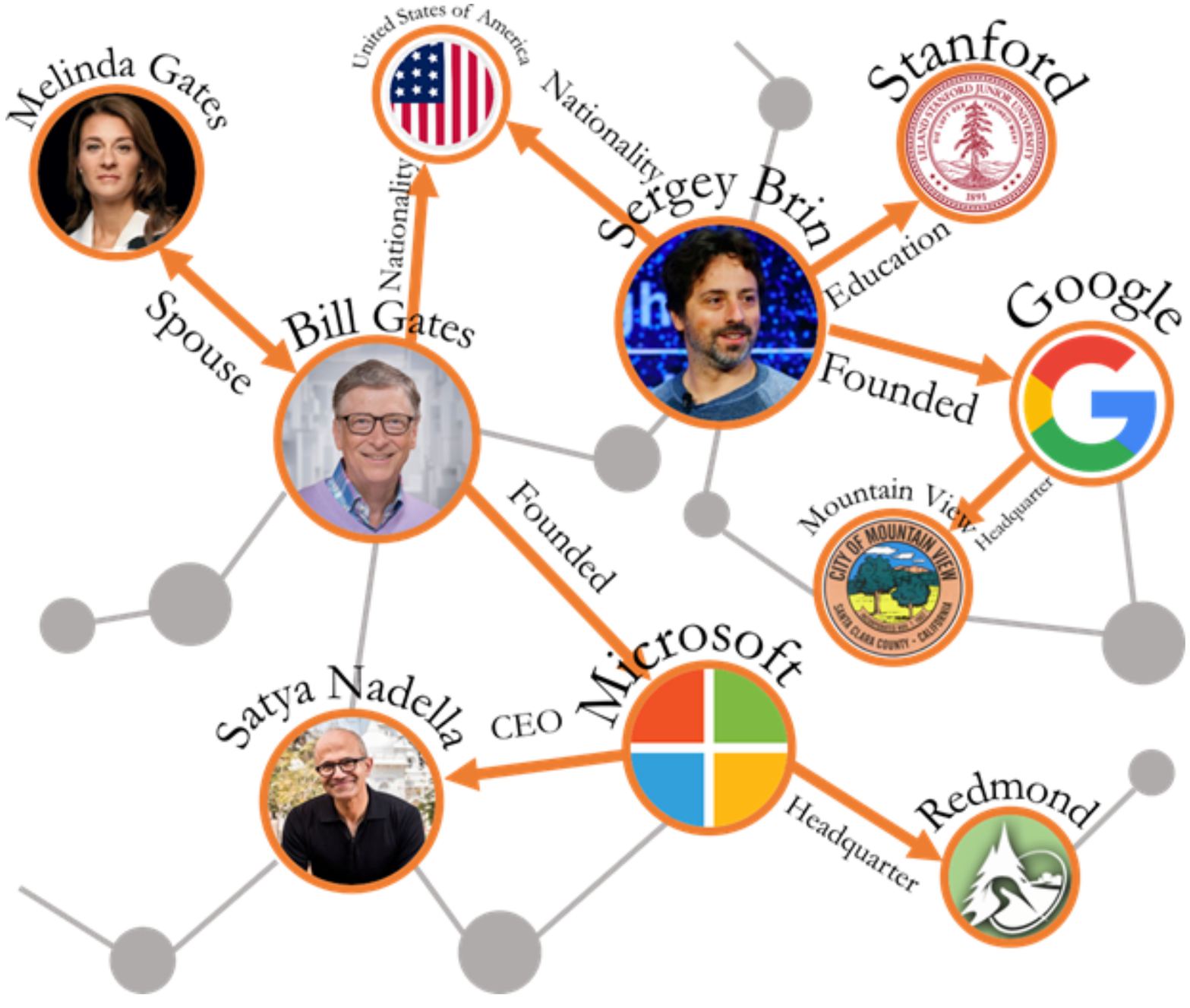




TEMPORAL NETWORKS

KNOWLEDGE GRAPHS



SUMMARY

We learned how to **characterise network elements**

We learned how to **choose** the most appropriate **type of links**

We have **seen different types of networks**