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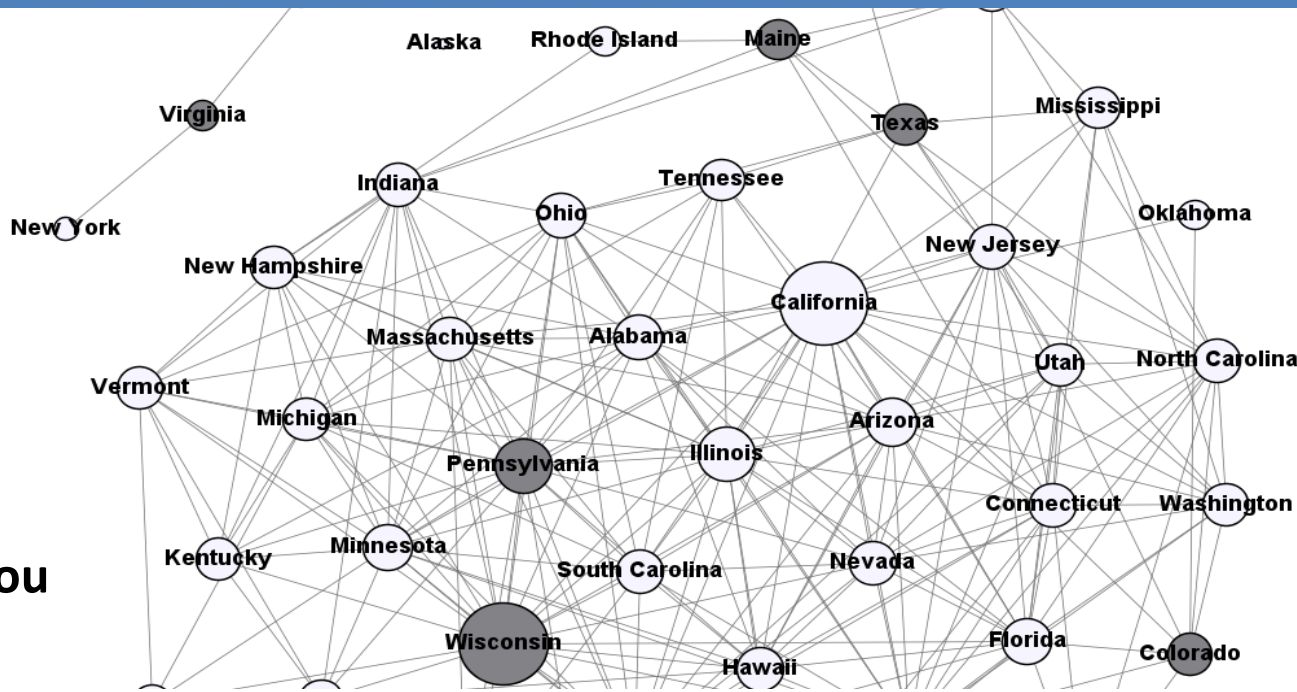



**Periklis Gogas**
**Theophilos Papadimitriou**

# A Complex Network Analysis of the U.S. Gross State Product

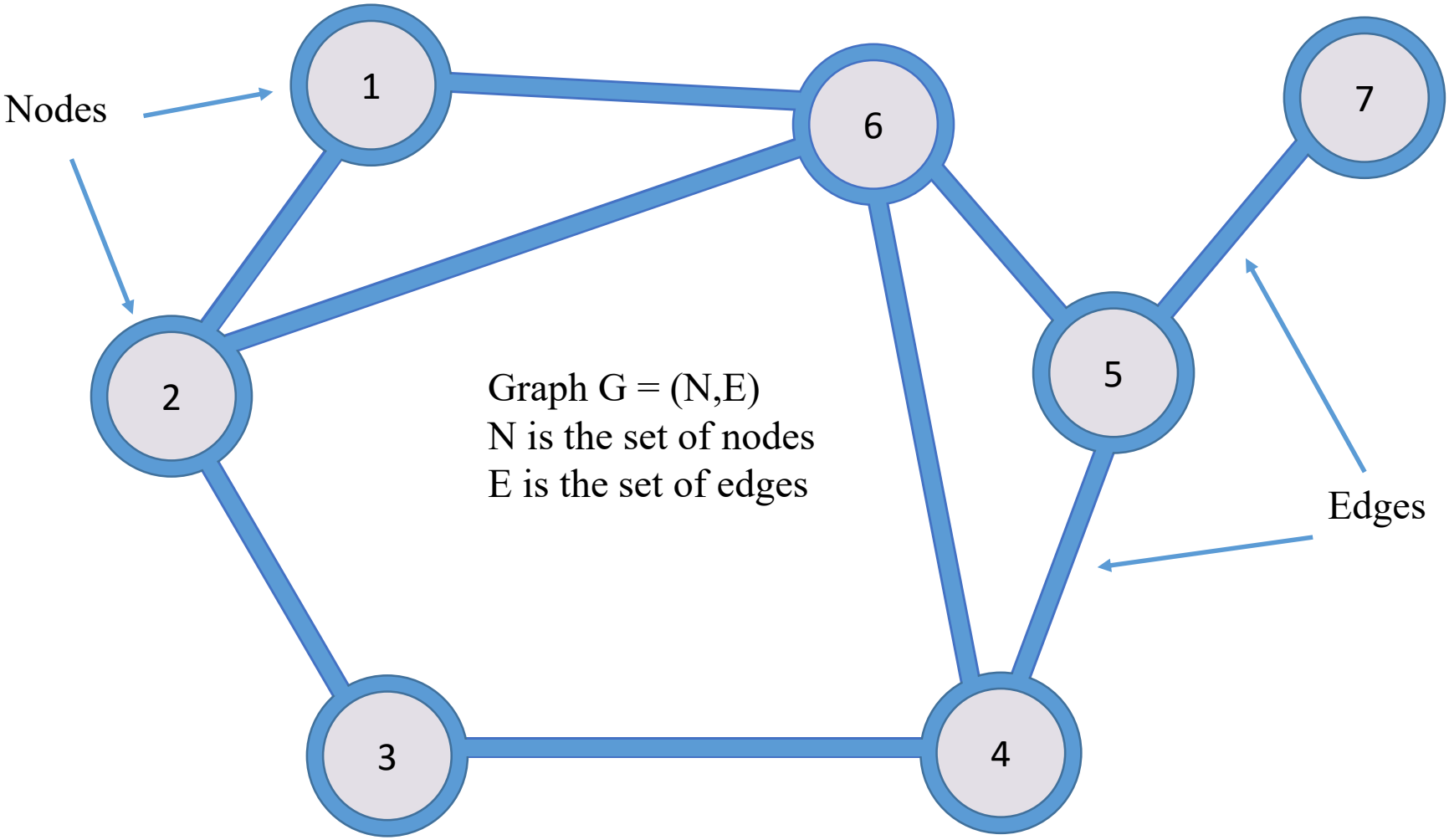
European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS, CULTURE & SPORTS
MANAGING AUTHORITY

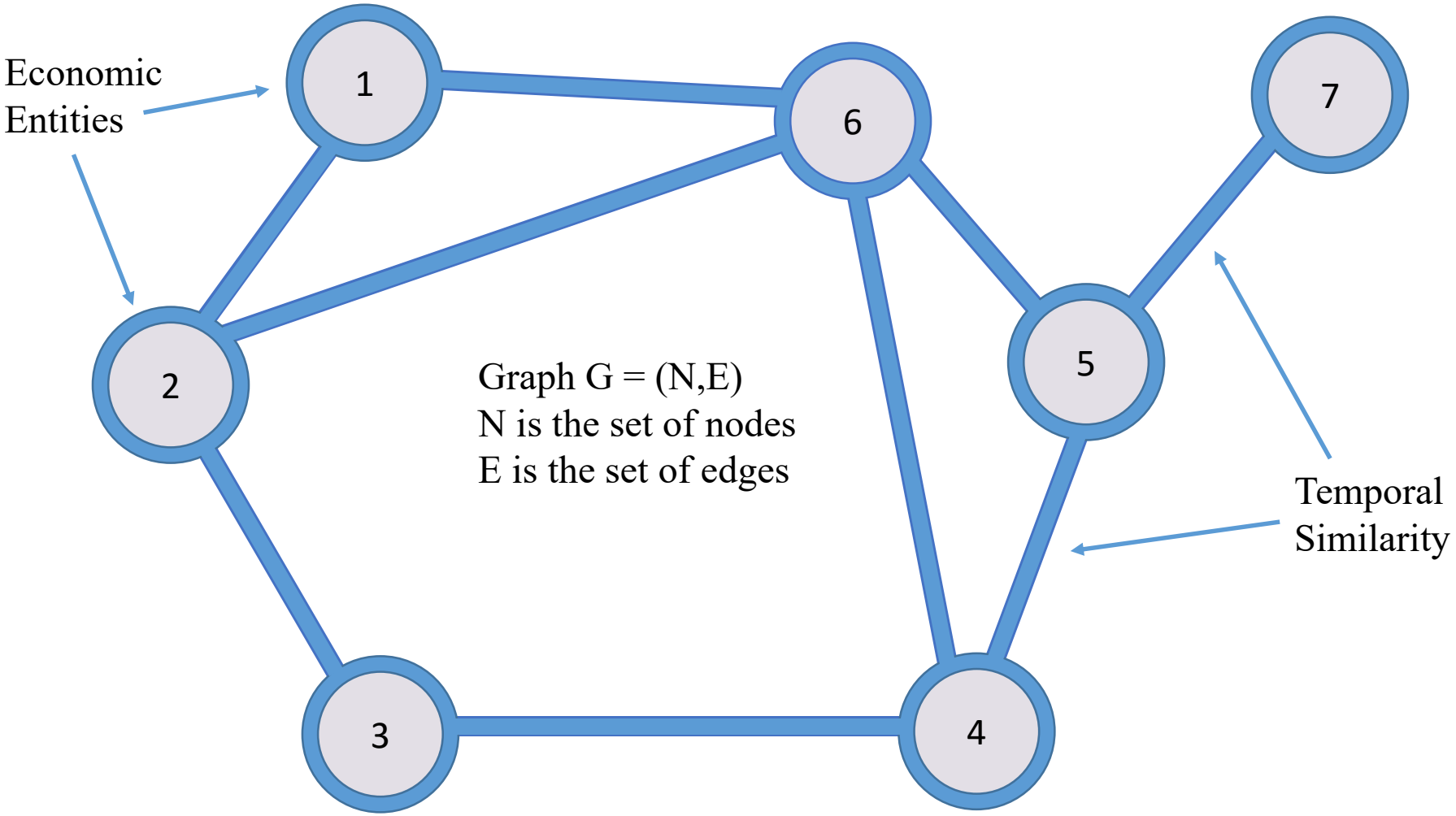
NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND

Co-financed by Greece and the European Union

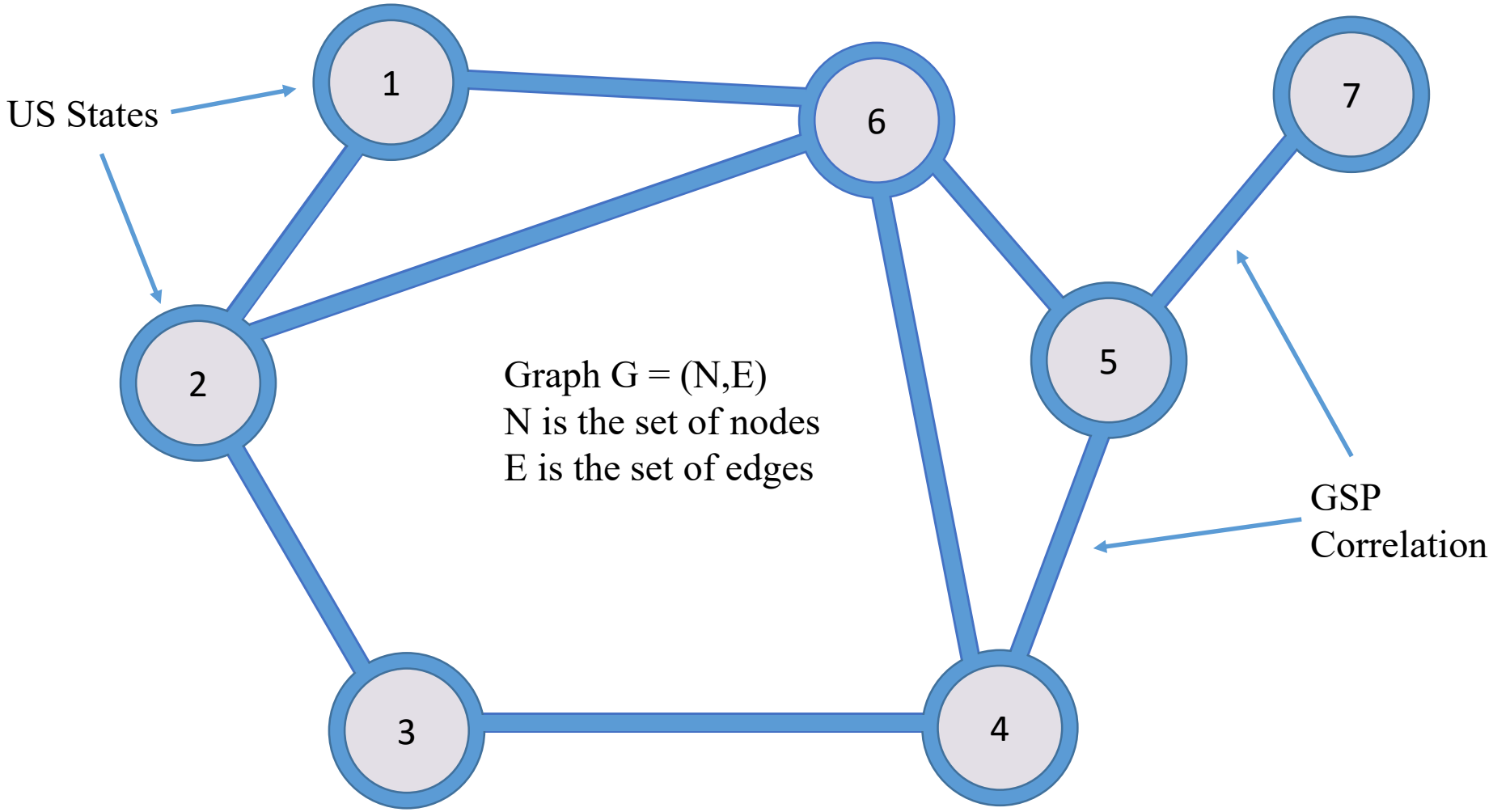
# Graph


Nodes
1
2
3
4
5
6
7
Graph G = (N,E)
N is the set of nodes
E is the set of edges
Edges

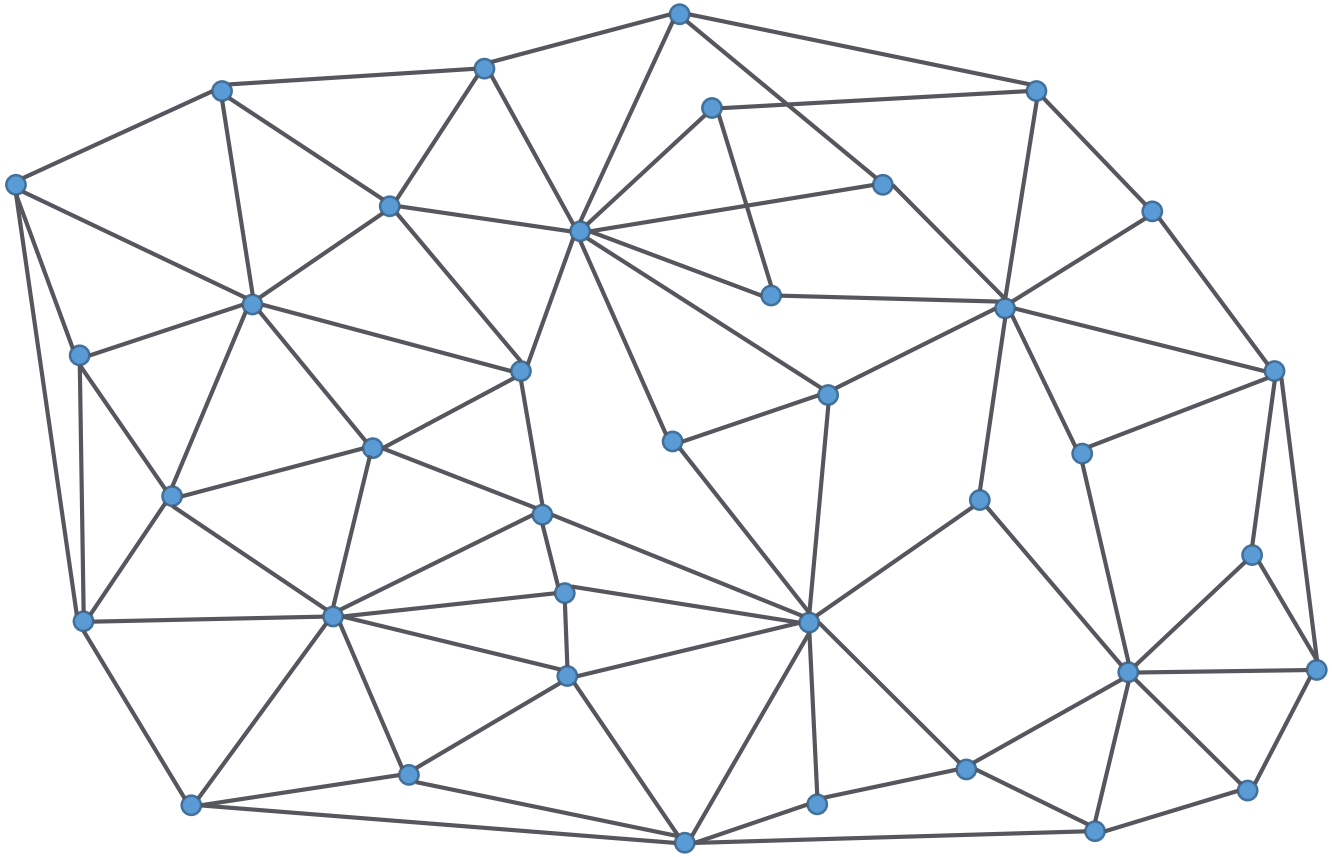
# Graph


Economic
Entities
1
2
3
4
5
6
7
Graph G = (N,E)
N is the set of nodes
E is the set of edges
Temporal
Similarity

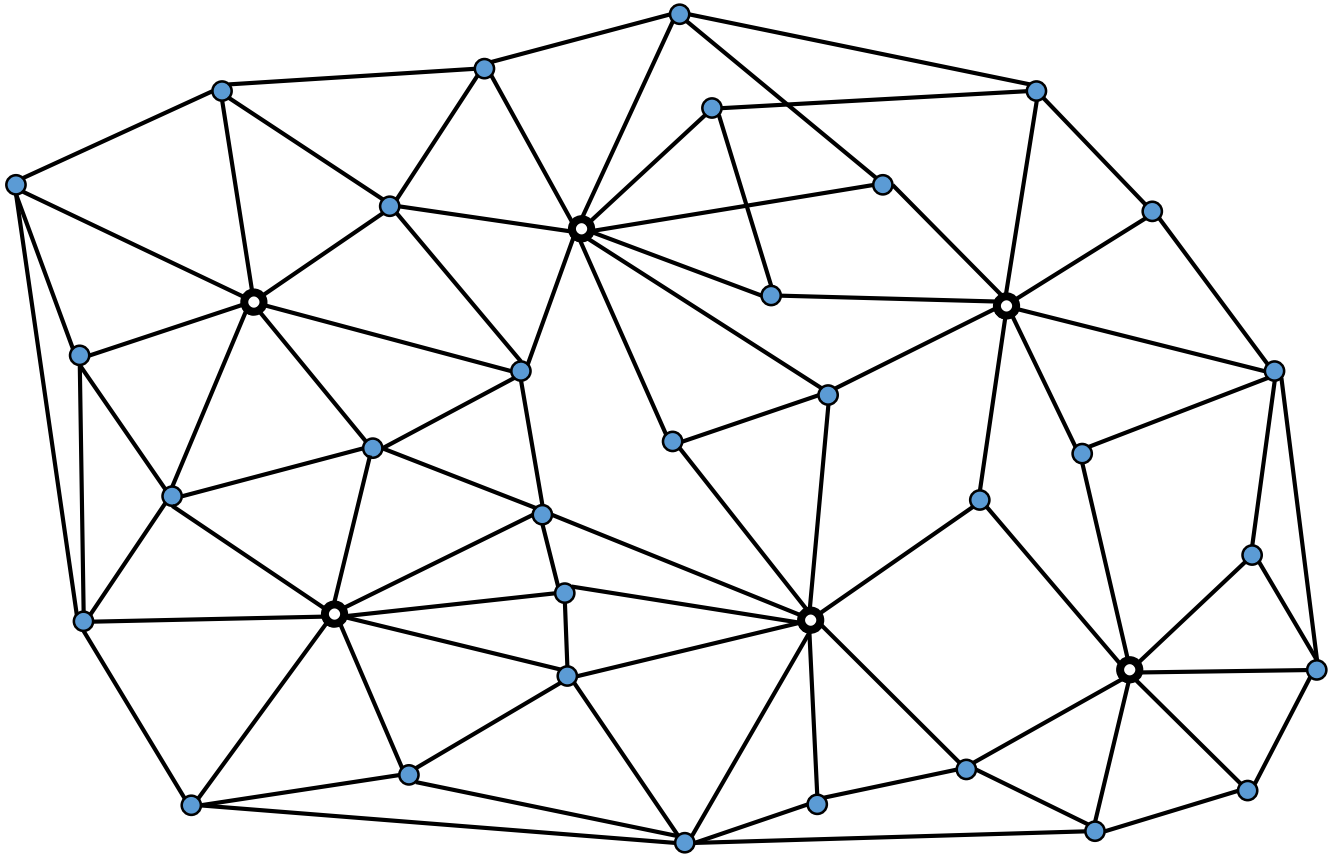
# Graph


US States
1
2
3
4
5
6
7
Graph G = (N,E)
N is the set of nodes
E is the set of edges
GSP
Correlation

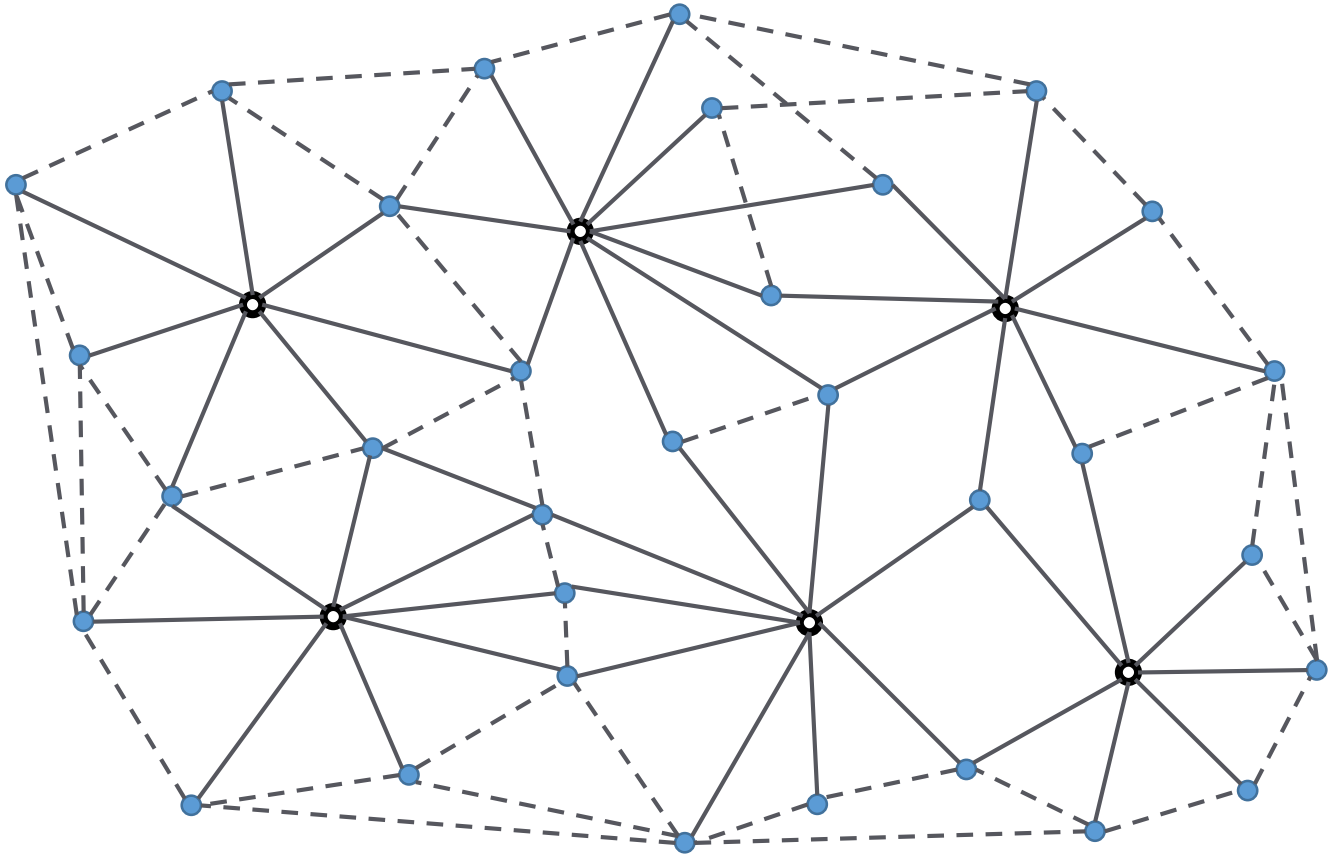
# Representation



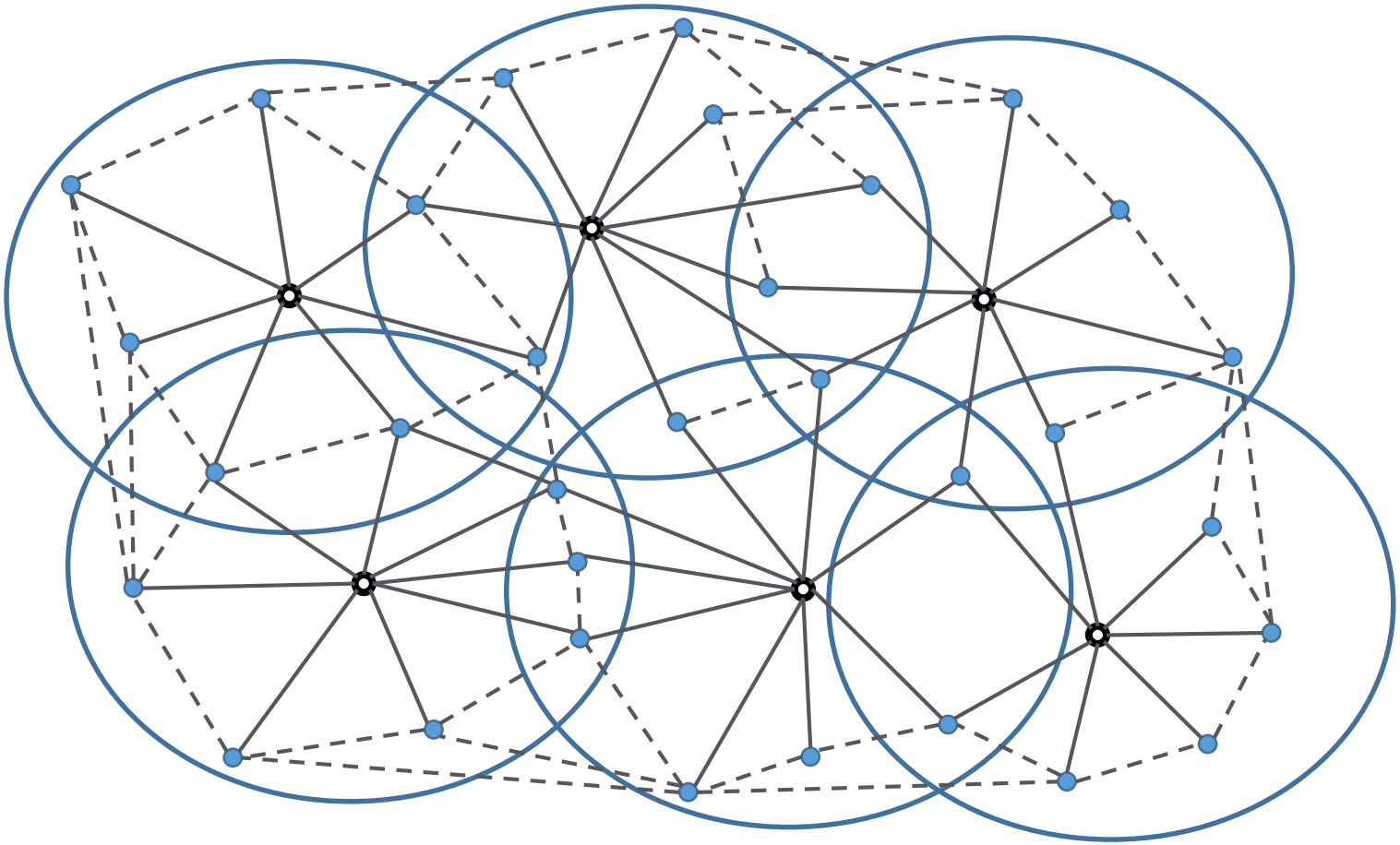
# Representation



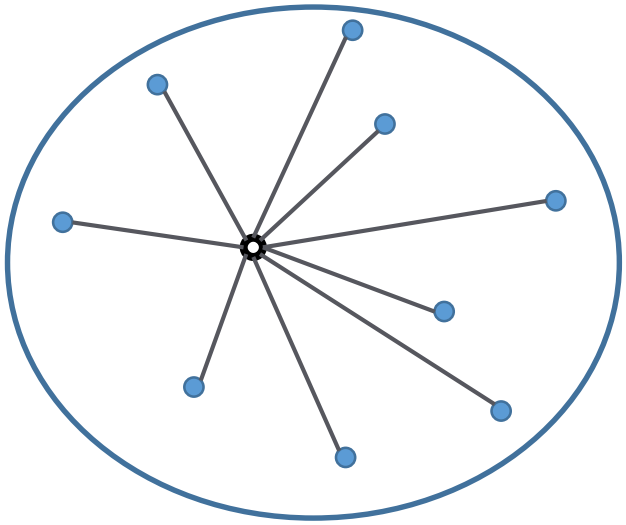
# Representation



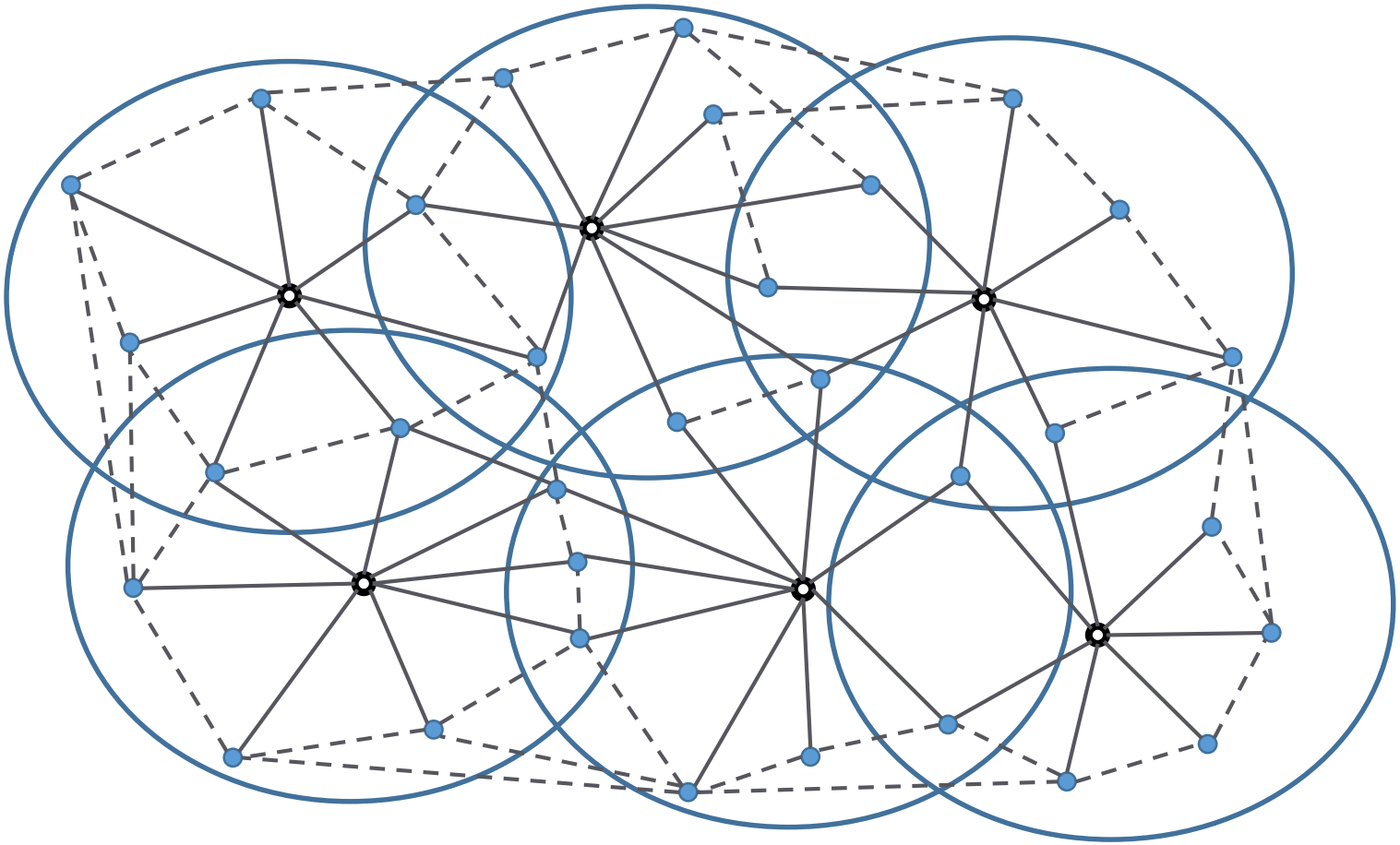
# Neighborhoods



# Neighborhoods



# Neighborhoods



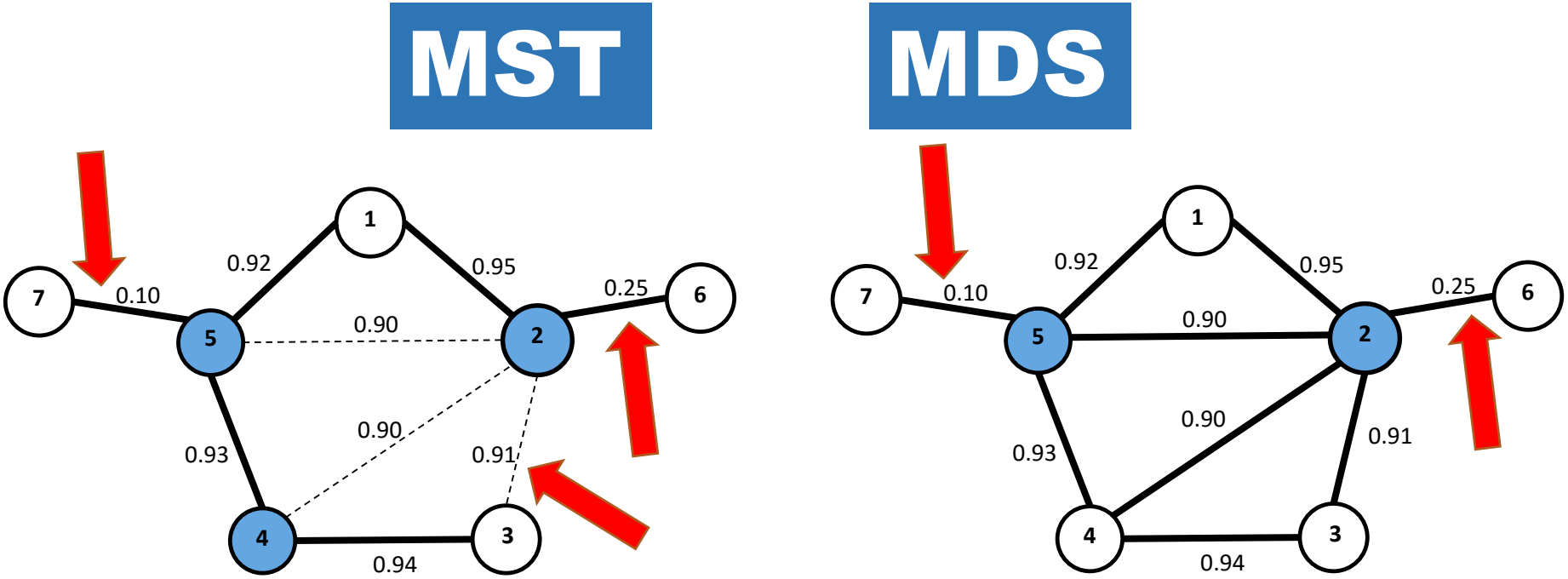
# Representation Goal

a) Identify a reduced version of the initial network
b) retaining the necessary information
c) to control and analyze the network.

Current Solution:
Minimum Spanning Tree + Heuristics

# Methodology

Widely used in the literature:



# Methodology

## Minimum Dominating Set

Given a graph G=(N,E) where N is the set of nodes and E is the set of edges,

a subset S⊆N is a **Dominating Set** of G if every node u∈N is either included in S or is adjacent to one or more nodes of S

MDS is the Dominating Set with minimum cardinality

# Methodology

## Threshold Minimum Dominating Set

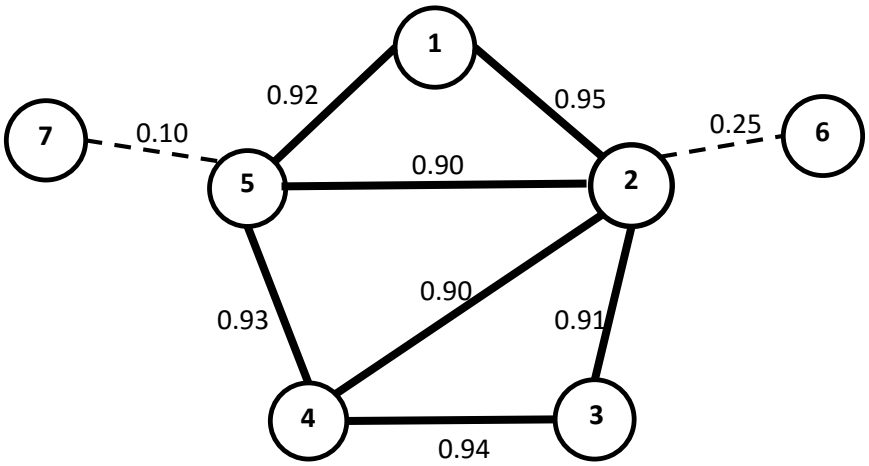
A 2-step methodology consisting of:

1. Imposing a **threshold** on the edges
2. Identifying the MDS on the thresholded network

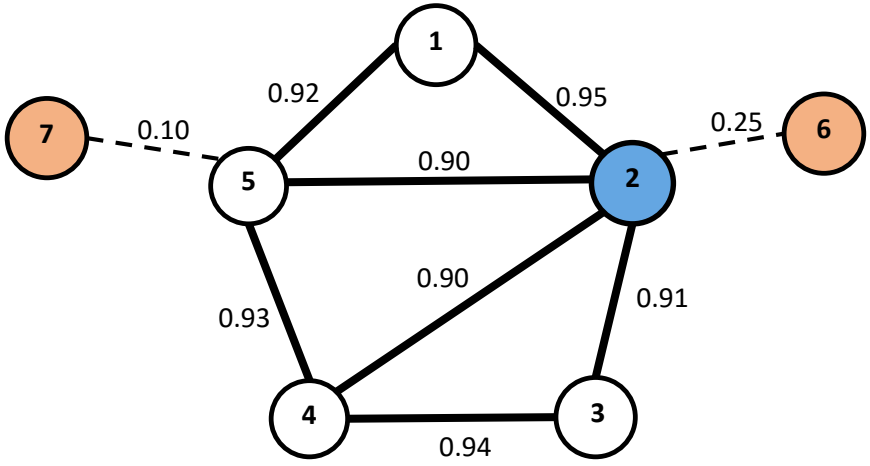
# Methodology

## T-MDS

### Step 1




### Step 2



# Research objectives

## Primary

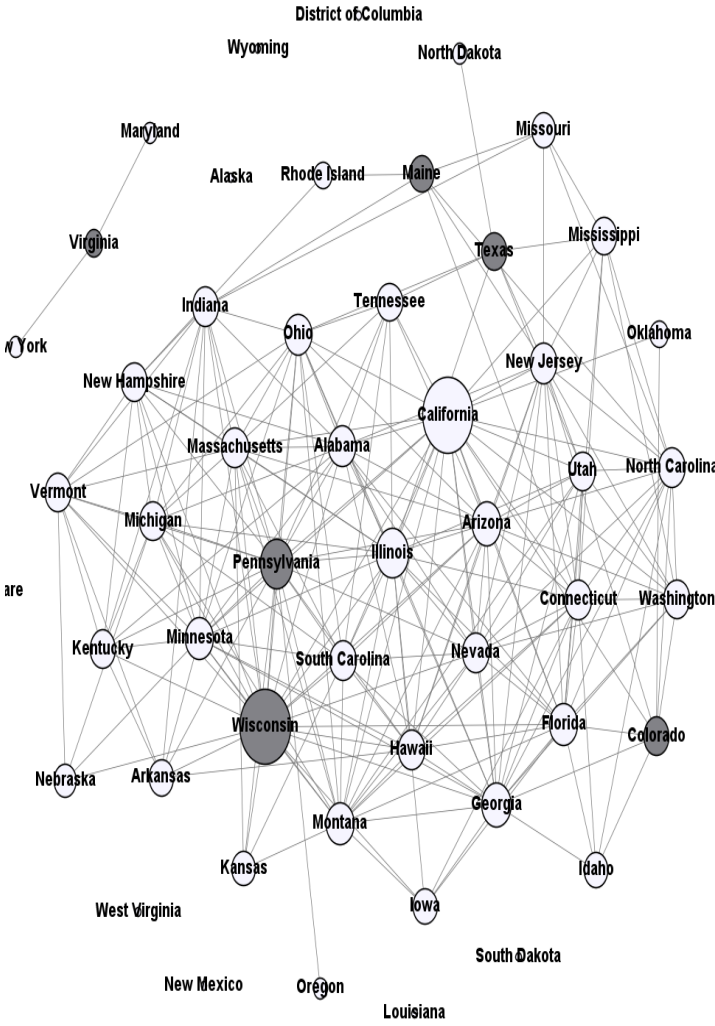
- Examine the **evolution** of business cycle synchronization in the U.S. states

## Secondary

- **Identify** groups of U.S. states with similar macroeconomic behavior
- Possibly construct a map of **contagion** paths

# The data

- **Real Gross State Product** of 51 U.S. states (50 states plus the District of Columbia)
- Source: Bureau of Economic Analysis, U.S. Department of Commerce
- Data availability: annual, 1963 onwards
  - Year 1997: **change of methodology** in measuring GSP
  - The Bureau strongly advises **against** mixing the series
- Selected dataset: GSP of 51 U.S. states, 1997-2013, **annual** frequency



# Empirical application

- **Graph Theory** - Network construction
- Nodes: **51 U.S. states**
- Edges: **similarity** of the Gross State Product patterns
- Implement the **Threshold – Minimum dominating Set** (T-MDS)
- Identify:
  - the **Dominant** states
  - their **neighborhoods**
  - **Isolated** states

# Similarity Measures

## Similarity Measures

### A. Pearson's Correlation Coefficients

- On the GSP **growth** rates

### B. Sign Concordance Indices (SCI)

- Extract **cyclical component** with HP filter
- **Percentage** of times that both cyclical components are above or below trend

## Versions

### 1. Simple

- All observations have the same weight

### 2. Weighted

- Assign **exponentially** heavier weights to more **recent** observations

### Inference

- **Comparison** of the two versions provides evidence on **convergence**

# Evidence on Convergence

**More specifically:**

- Compare the weighted and standard versions of the network
- If weighted version is denser and T-MDS cardinality lower
- Indicates higher GSP growth similarity in recent years
- Interpreted as empirical evidence of business cycle convergence

# Network Metrics

- **T-MDS metrics**
  a. Dominant states
  b. Isolated states
  c. T-MDS Cardinality = a + b

- **Standard Network metrics**
  a. **Node degree**: number of direct neighbors
     Measuring the **connectivity** (synchronization) of each individual state
  b. **Network density**: ratio of existing edges to maximum possible number of edges
     Measuring the **connectivity** (synchronization) of the U.S. states as a **whole**

# Empirical Results

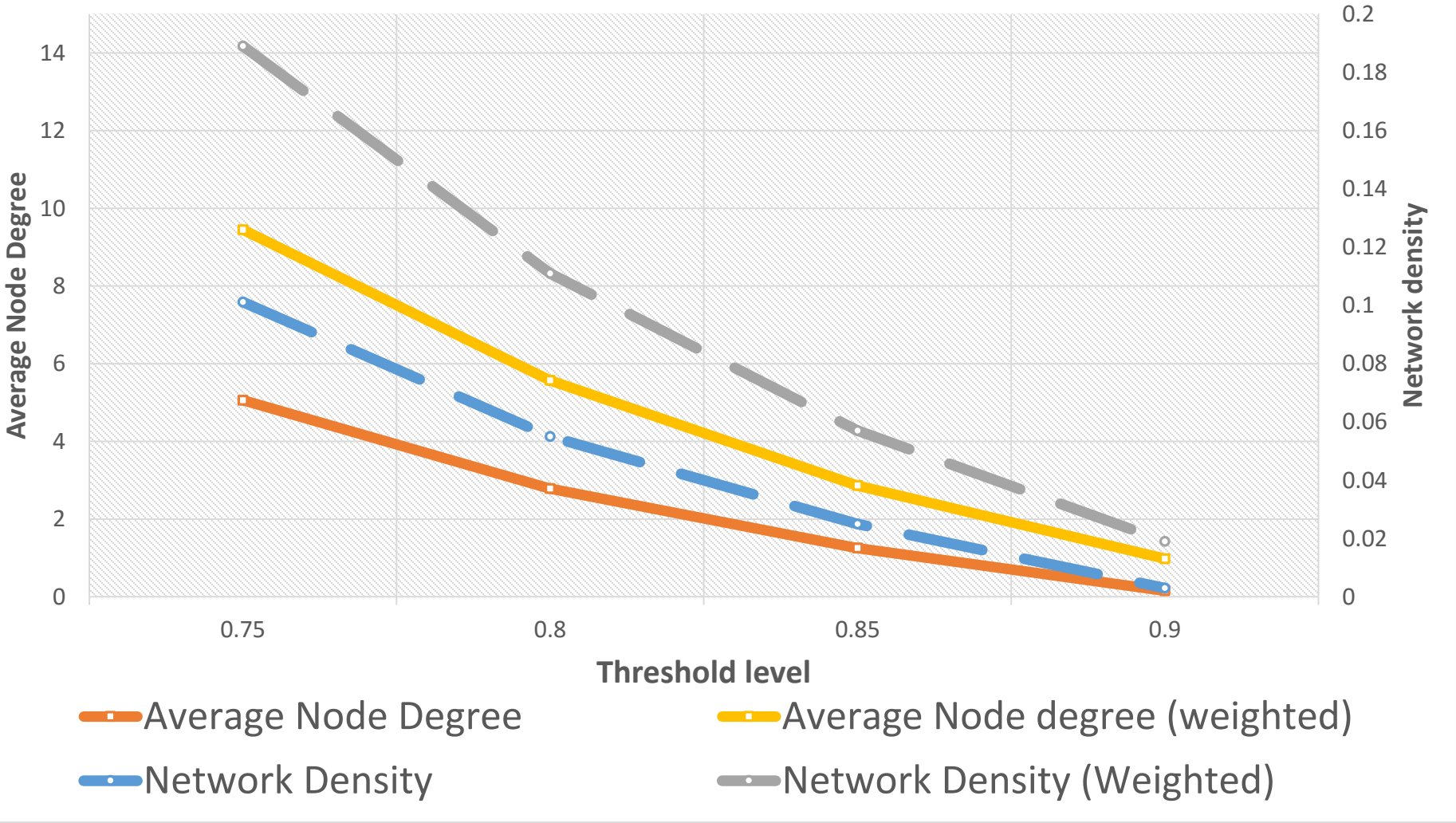
## A. Correlation Coefficient

| Network Metrics | Standard Version | | | | | Weighted Version | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Threshold level** | **0.75** | **0.80** | **0.85** | **0.90** | | **0.75** | **0.80** | **0.85** | **0.90** |
| Network Density | 0.10 | 0.05 | 0.02 | 0.01 | | 0.18 | 0.11 | 0.05 | 0.02 |
| Average Node Degree | 5.05 | 2.78 | 1.25 | 0.15 | | 9.45 | 5.56 | 2.86 | 0.98 |
| Isolated nodes | 18 | 19 | 27 | 43 | | 8 | 14 | 18 | 26 |
| Dominant nodes | 7 | 8 | 8 | 4 | | 6 | 8 | 8 | 10 |
| T-MDS cardinality | 25 | 27 | 35 | 47 | | 14 | 22 | 26 | 36 |

In the weighted version:

- Network **density** and node **degree** higher
- **Less** isolated nodes
- **Smaller** T-MDS cardinality
- The whole network **represented** by **less** states

# Empirical Results




- Both metrics **higher** in weighted versions
- Similarity **increased**

# Empirical Results

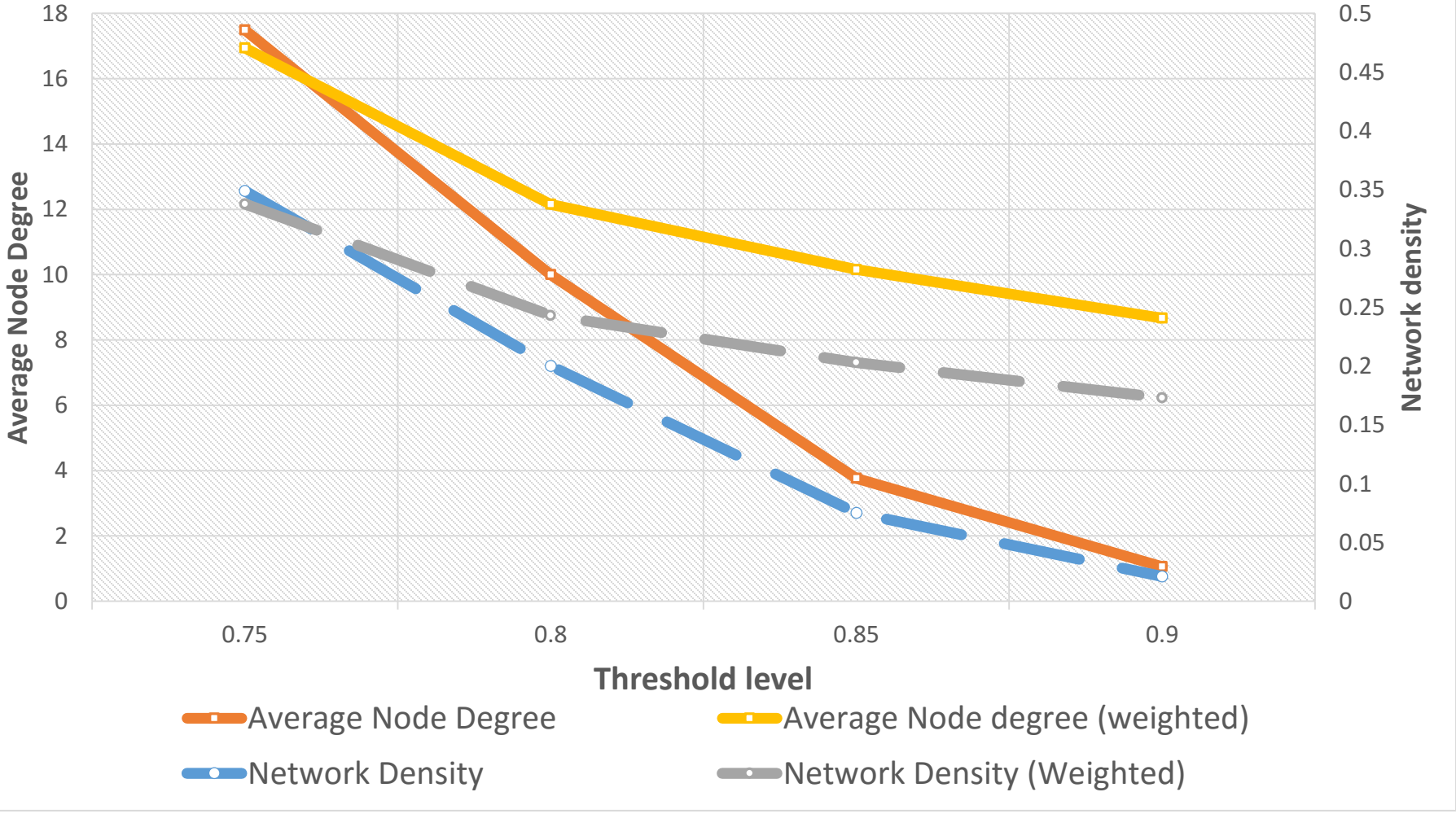
## B. Sign Concordance Index

| | Standard Version | | | | | Weighted Version | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Threshold** | **0.75** | **0.80** | **0.85** | **0.90** | | **0.75** | **0.80** | **0.85** | **0.90** |
| Network Density | 0.34 | 0.20 | 0.07 | 0.02 | | 0.33 | 0.24 | 0.20 | 0.17 |
| Aver. Node Degree | 17.49 | 10.05 | 3.76 | 1.06 | | 16.94 | 12.15 | 10.15 | 8.66 |
| Isolated nodes | 3 | 6 | 11 | 28 | | 1 | 2 | 5 | 7 |
| Dominant nodes | 5 | 6 | 8 | 8 | | 5 | 6 | 6 | 6 |
| T-MDS cardinality | 8 | 12 | 19 | 36 | | 6 | 8 | 11 | 13 |

In the weighted version:

- Network **density** and node **degree** higher
- **Less** isolated nodes
- **Smaller** T-MDS cardinality
- The whole network **represented** by **less** states

# Empirical Results




- Both metrics **higher** in weighted versions
- Similarity **increased**

# Interpretation of the results

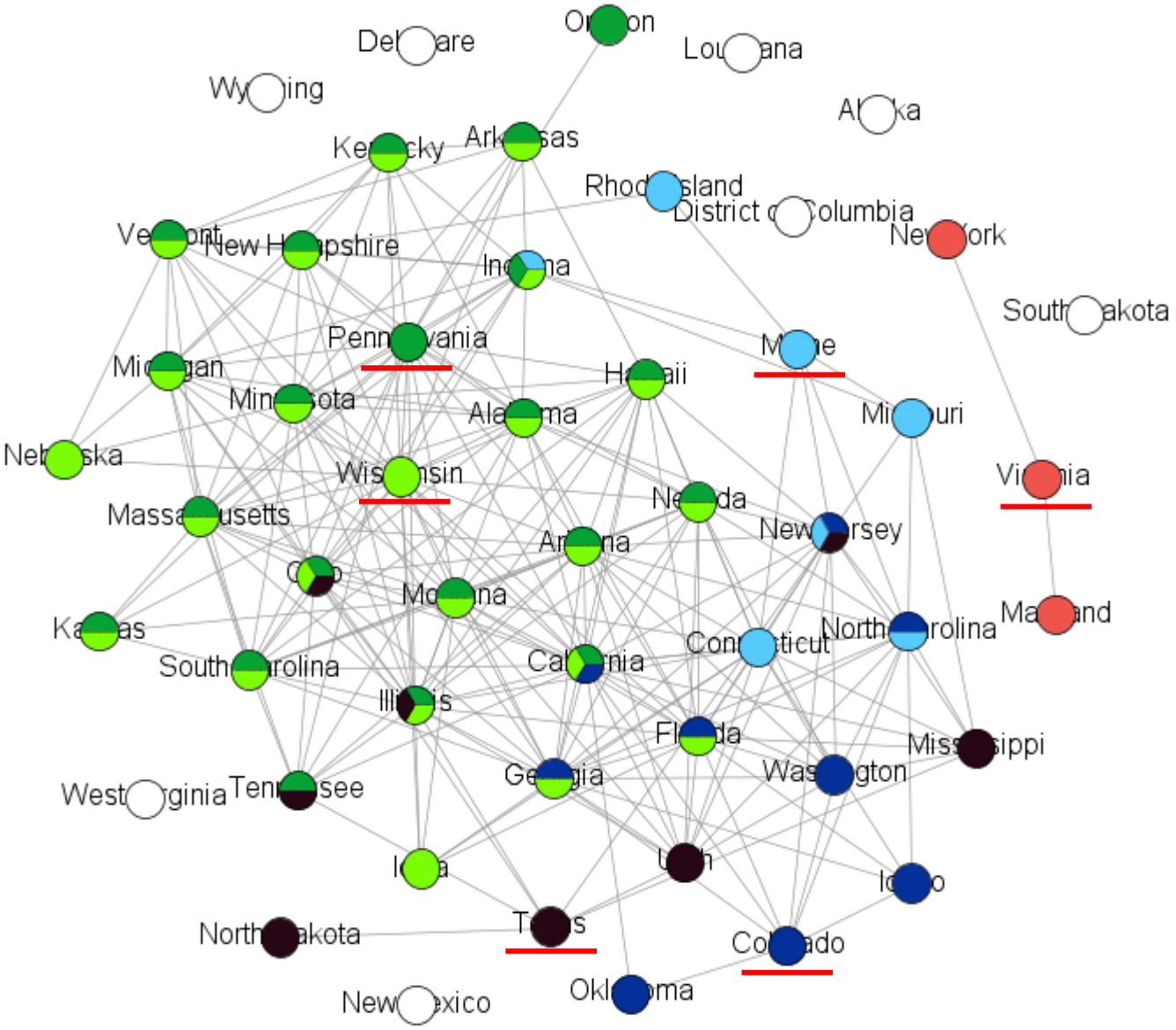
- Both similarity measures present qualitatively **similar** results.
- **Denser** network in weighted cases
- **Less** isolated nodes in weighted cases
- T-MDS cardinality is **smaller**

Taking into account 

The weighted versions assign **heavier** weights to more **recent** GSP observations

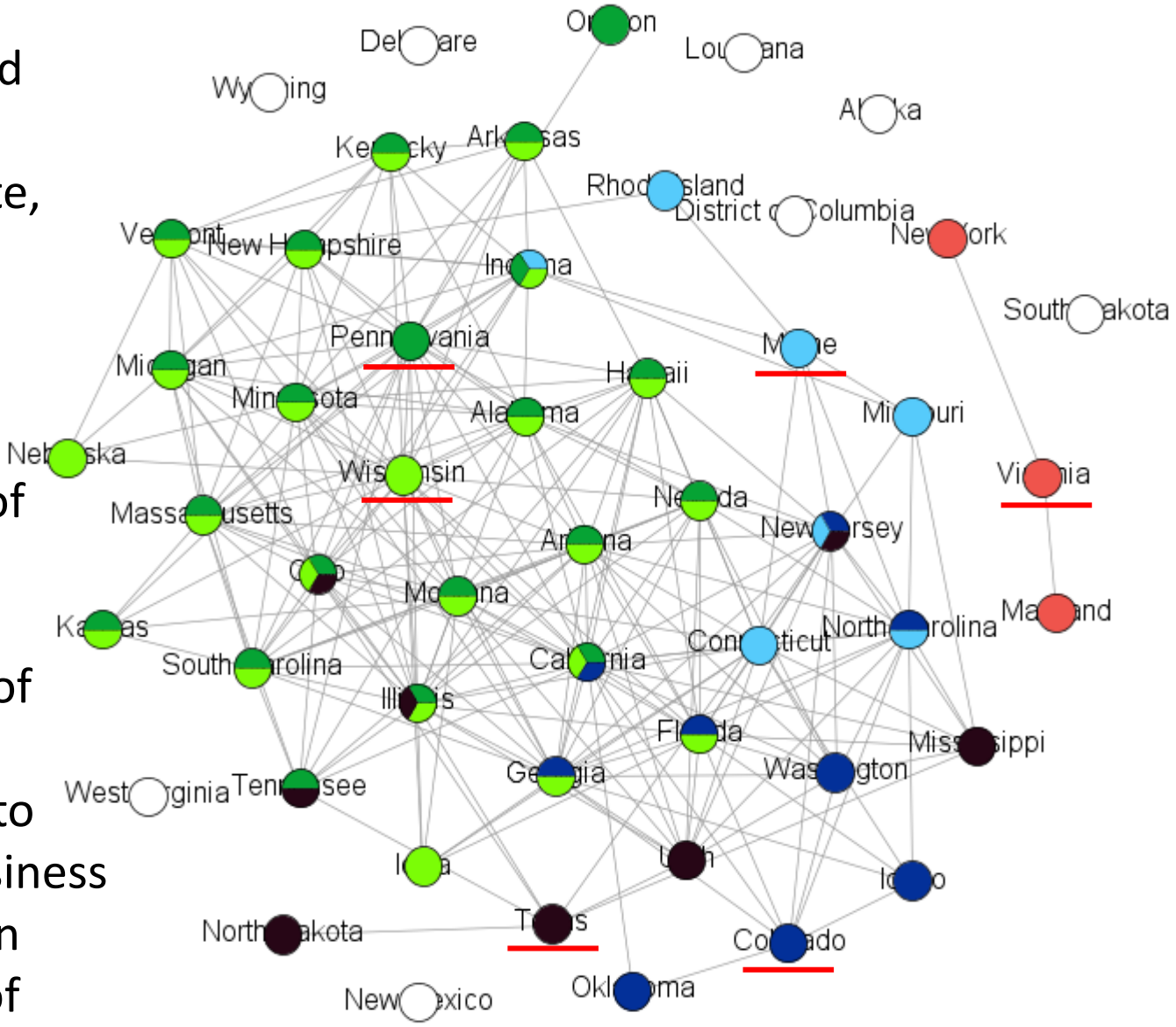
Evidence of recent **convergence** of US GSP growth rates

# The Network overview



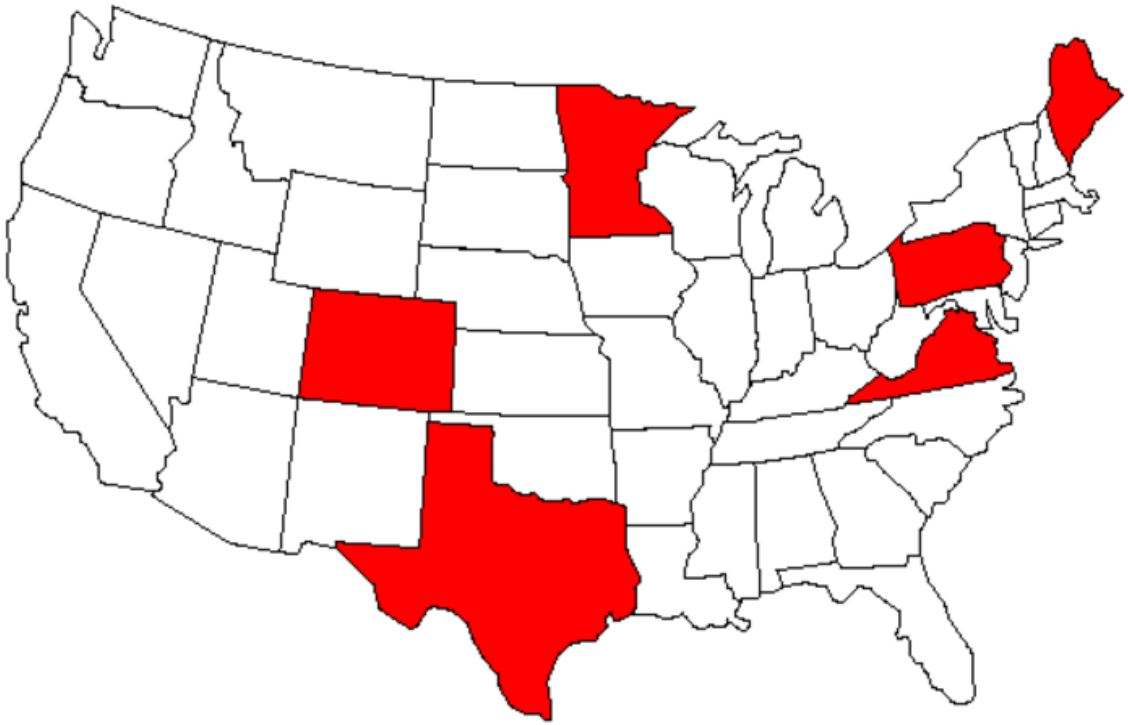
# The Network overview

- **Dominant states:** red underlined
- **Isolated states**: white, Highly idiosyncratic behavior
- **Color:** indicates neighborhood
- Observe formation of closely behaving **neighborhoods**
- Identify the **drivers** of these patterns
- Implement **policies** to sustain/increase business cycle synchronization
- Examine the **paths** of macro contagion



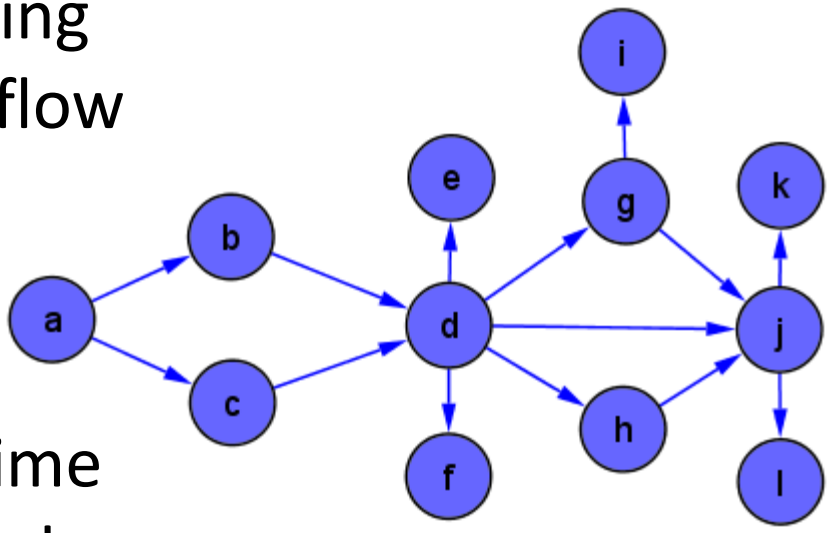
# Empirical Results - Neighborhoods

| Dominant | Colorado | Maine | Texas | Virginia | Pennsylvania | Wisconsin |
|---|---|---|---|---|---|---|
| Neighbors | California | Connecticut | Illinois | Maryland | Alabama | Alabama |
| | Florida | Indiana | Mississippi | New York | Arizona | Arizona |
| | Georgia | Missouri | New Jersey | | Arkansas | Arkansas |
| | Idaho | New Jersey | North Dakota | | California | California |
| | New Jersey | North Carolina | Ohio | | Hawaii | Florida |
| | North Carolina | Rhode Island | Tennessee | | Illinois | Georgia |
| | Oklahoma | | Utah | | Indiana | Hawaii |
| | Washington | | | | Kansas | Illinois |
| | | | | | Kentucky | Indiana |
| | | | | | Massachusetts | Iowa |
| | | | | | Michigan | Kansas |
| | | | | | Minnesota | Kentucky |
| | | | | | Montana | Massachusetts |
| | | | | | Nevada | Michigan |
| | | | | | New Hampshire | Minnesota |
| | | | | | Ohio | Montana |
| | | | | | Oregon | Nebraska |
| | | | | | South Carolina | Nevada |
| | | | | | Tennessee | New Hampshire |
| | | | | | Vermont | Ohio |
| | | | | | Wisconsin | Pennsylvania |
| | | | | | | South Carolina |
| | | | | | | Vermont |



# Future research paths

- Construct a **directed** network using **Granger causality** (examine the flow of macroeconomic changes)




- Construct the network using **lagged similarity** (examine the time lag before a shock propagates and possibly use the T-MDS in forecasting)

- **Dynamically** simulate the **patterns** and **speed** of **dispersion paths** of an economic shock

# Thank you

***Acknowledgments***

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: **THALES**. Investing in knowledge society through the European Social Fund.

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