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Inter-Organizational Networks of the EuroGroups Register

A Supervised Clustering Algorithm for Network Data

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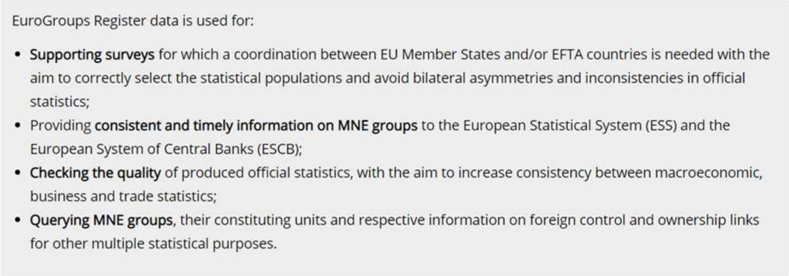
TABLE OF CONTENTS

- Introduction and Motivation
- Literature Review: Main Lines
- SUWAN Algorithm
- EGR Network
- Implementation
- Conclusions and Limitations
- Bibliography

INTRODUCTION AND MOTIVATION

Together with the national statistical business registers (NSBRs), the EuroGroups Register is part of the **European Framework of business registers**.
The EuroGroups Register exchange confidential data on legal units, enterprises and enterprise groups containing information on **multinational enterprises (MNE)** groups operating in Europe.



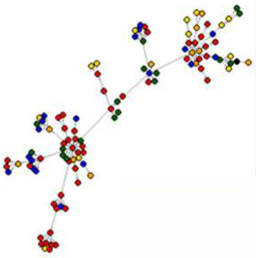
EuroGroups Register data is used for:

- **Supporting surveys** for which a coordination between EU Member States and/or EFTA countries is needed with the aim to correctly select the statistical populations and avoid bilateral asymmetries and inconsistencies in official statistics;
- Providing **consistent and timely information on MNE groups** to the European Statistical System (ESS) and the European System of Central Banks (ESCB);
- **Checking the quality** of produced official statistics, with the aim to increase consistency between macroeconomic, business and trade statistics;
- **Querying MNE groups**, their constituting units and respective information on foreign control and ownership links for other multiple statistical purposes.

Source: Eurostat

INTRODUCTION AND MOTIVATION

- **Multinational enterprise (MNE) groups can be seen as networks**



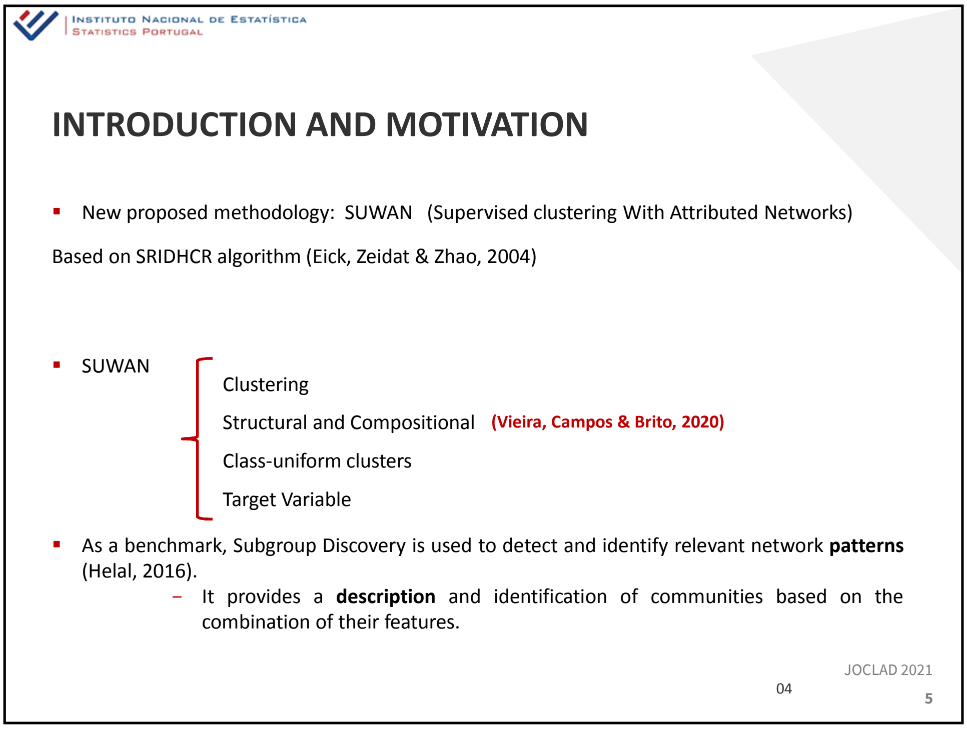
- **Goal: Distinguishing characteristics of social networks: propensity for displaying community structure**

Community Detection

- Find cohesive subgraphs of nodes
- **Structural Aspects** (Harenberg et al., 2014)

Clustering

- Divide a set of objects into homogeneous groups
- **Compositional Characteristics**

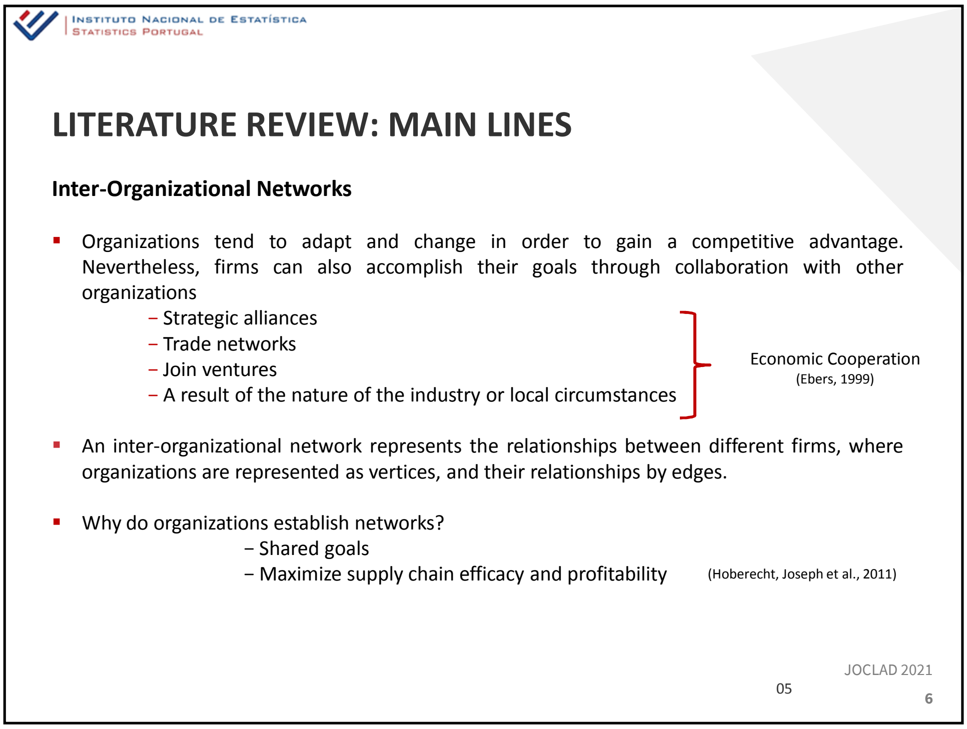


INTRODUCTION AND MOTIVATION

- New proposed methodology: SUWAN (Supervised clustering With Attributed Networks)

Based on SRIDHCR algorithm (Eick, Zeidat & Zhao, 2004)

- SUWAN
  - Clustering
  - Structural and Compositional **(Vieira, Campos & Brito, 2020)**
  - Class-uniform clusters
  - Target Variable
- As a benchmark, Subgroup Discovery is used to detect and identify relevant network **patterns** (Helal, 2016).
  - It provides a **description** and identification of communities based on the combination of their features.



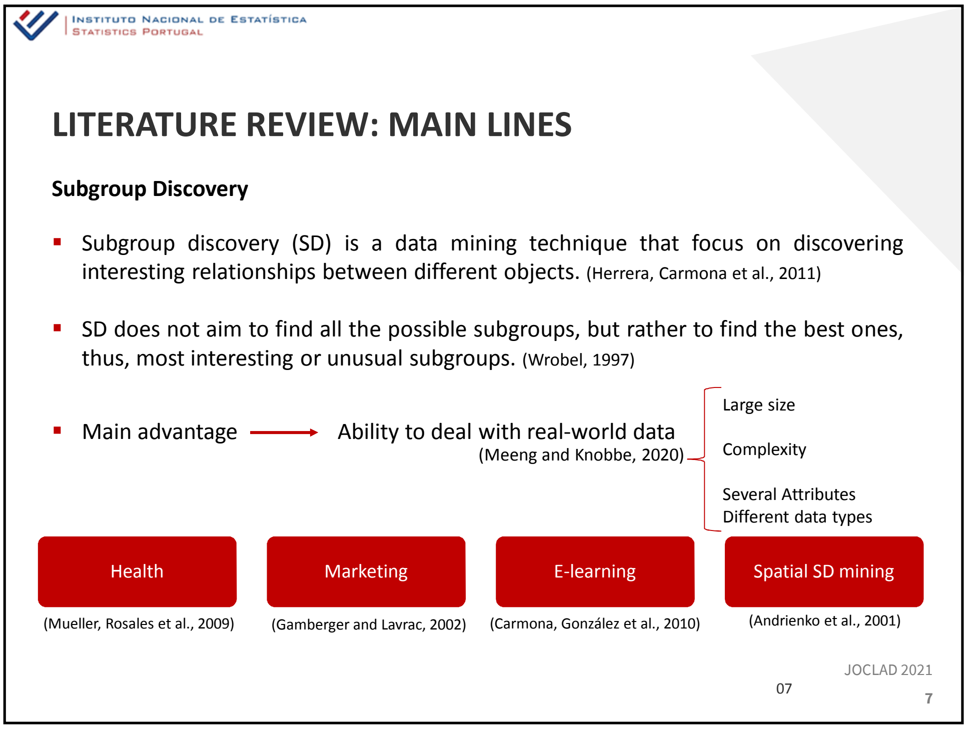
LITERATURE REVIEW: MAIN LINES

Inter-Organizational Networks

- Organizations tend to adapt and change in order to gain a competitive advantage. Nevertheless, firms can also accomplish their goals through collaboration with other organizations
  - Strategic alliances
  - Trade networks
  - Join ventures
  - A result of the nature of the industry or local circumstances

Economic Cooperation
(Ebers, 1999)

- An inter-organizational network represents the relationships between different firms, where organizations are represented as vertices, and their relationships by edges.
- Why do organizations establish networks?
  - Shared goals
  - Maximize supply chain efficacy and profitability (Hoberecht, Joseph et al., 2011)



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LITERATURE REVIEW: MAIN LINES

Subgroup Discovery

- Subgroup discovery (SD) is a data mining technique that focus on discovering interesting relationships between different objects. (Herrera, Carmona et al., 2011)
- SD does not aim to find all the possible subgroups, but rather to find the best ones, thus, most interesting or unusual subgroups. (Wrobel, 1997)
- Main advantage → Ability to deal with real-world data (Meeng and Knobbe, 2020)

Large size

Complexity

Several Attributes
Different data types

Health (Mueller, Rosales et al., 2009)

Marketing (Gamberger and Lavrac, 2002)

E-learning (Carmona, González et al., 2010)

Spatial SD mining (Andrienko et al., 2001)

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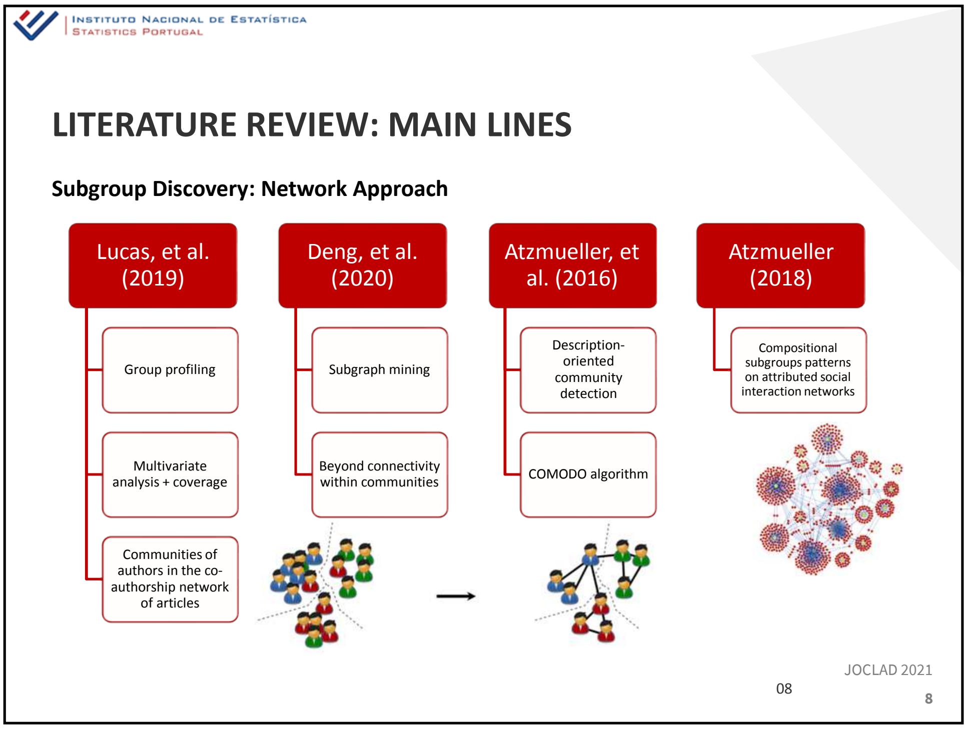
7



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LITERATURE REVIEW: MAIN LINES

Subgroup Discovery: Network Approach

Lucas, et al. (2019)
- Group profiling
- Multivariate analysis + coverage
- Communities of authors in the co-authorship network of articles

Deng, et al. (2020)
- Subgraph mining
- Beyond connectivity within communities

Atzmueller, et al. (2016)
- Description-oriented community detection
- COMODO algorithm

Atzmueller (2018)
- Compositional subgroups patterns on attributed social interaction networks

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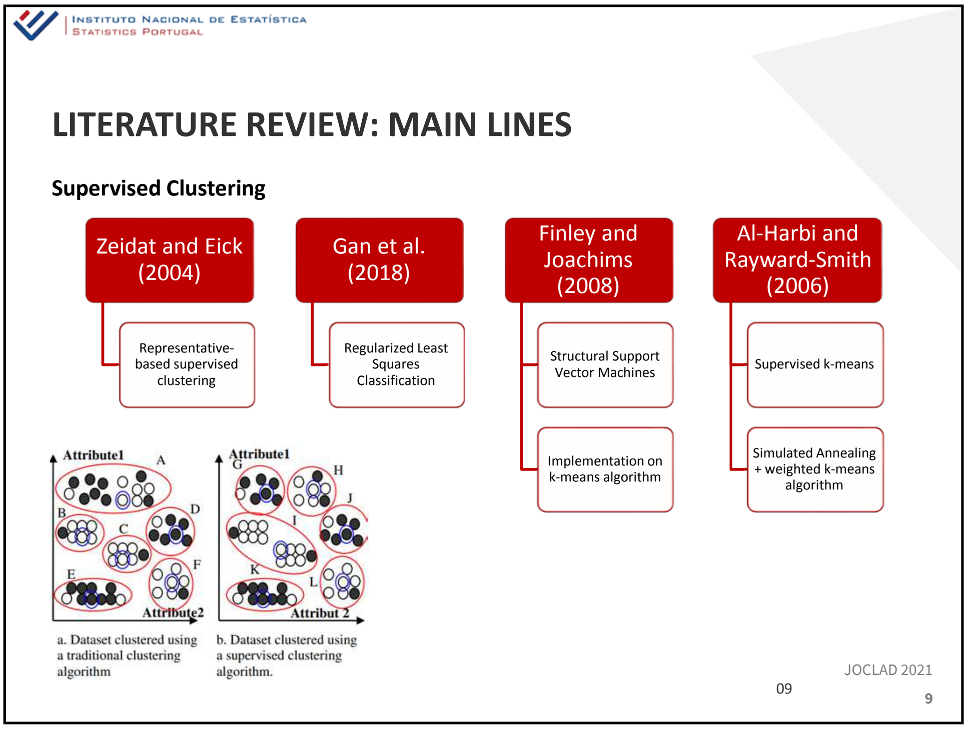
8



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Attribute1
A
B
C
D
E
F
Attribute2
Attribute1
G
H
I
J
K
L
Attribut 2

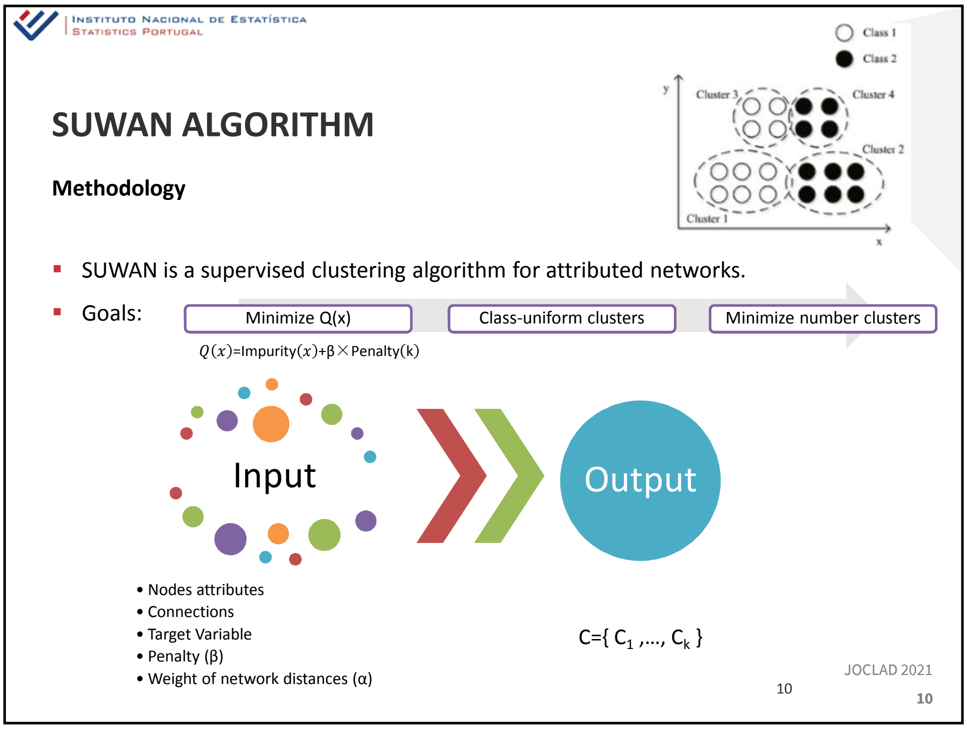
LITERATURE REVIEW: MAIN LINES

Supervised Clustering

- Zeidat and Eick (2004)
  - Representative-based supervised clustering
- Gan et al. (2018)
  - Regularized Least Squares Classification
- Finley and Joachims (2008)
  - Structural Support Vector Machines
  - Implementation on k-means algorithm
- Al-Harbi and Rayward-Smith (2006)
  - Supervised k-means
  - Simulated Annealing + weighted k-means algorithm

a. Dataset clustered using a traditional clustering algorithm

b. Dataset clustered using a supervised clustering algorithm.



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Class 1
Class 2
y
Cluster 3
Cluster 4
Cluster 2
Cluster 1
x

SUWAN ALGORITHM

Methodology

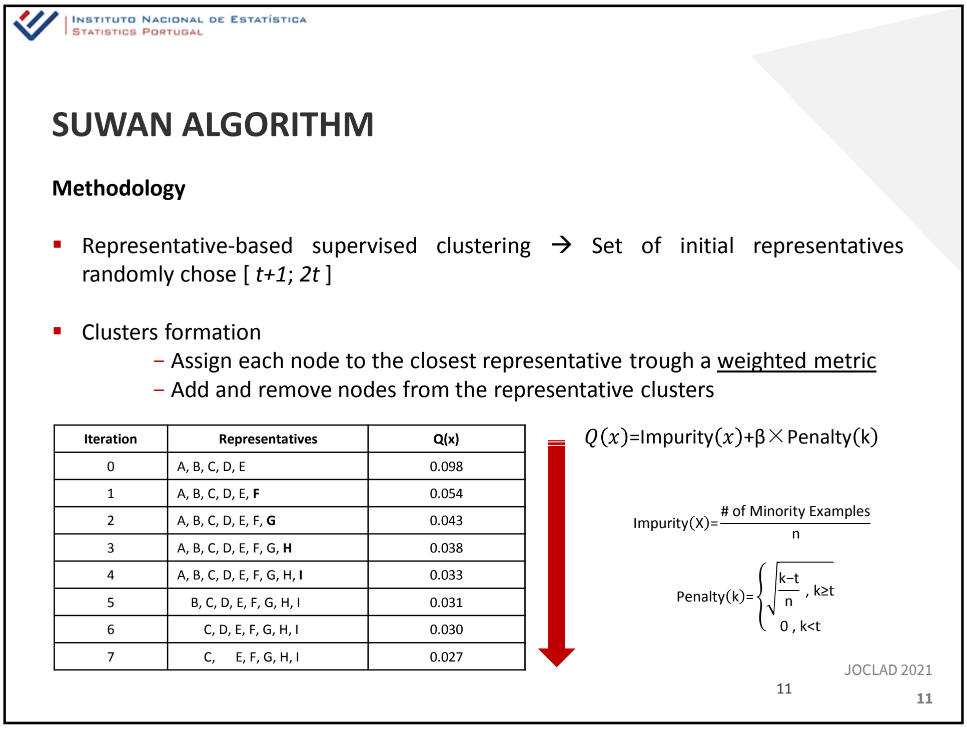
- SUWAN is a supervised clustering algorithm for attributed networks.
- Goals: Minimize Q(x) → Class-uniform clusters → Minimize number clusters

$Q(x)$=Impurity(x)+β×Penalty(k)

Input → Output

- Nodes attributes
- Connections
- Target Variable
- Penalty (β)
- Weight of network distances (α)

C={ C_1 ,…, C_k }



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SUWAN ALGORITHM

Methodology

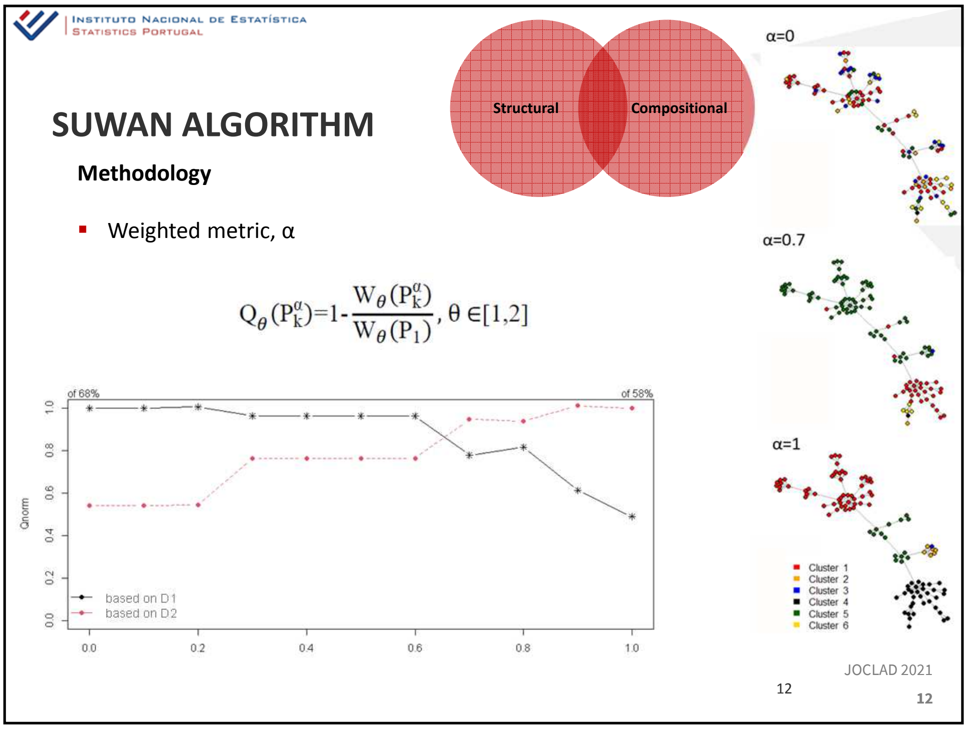
- Representative-based supervised clustering → Set of initial representatives randomly chose [*t+1*; *2t*]
- Clusters formation
  - Assign each node to the closest representative trough a weighted metric
  - Add and remove nodes from the representative clusters

Iteration	Representatives	Q(x)
0	A, B, C, D, E	0.098
1	A, B, C, D, E, **F**	0.054
2	A, B, C, D, E, F, **G**	0.043
3	A, B, C, D, E, F, G, **H**	0.038
4	A, B, C, D, E, F, G, H, **I**	0.033
5	B, C, D, E, F, G, H, I	0.031
6	C, D, E, F, G, H, I	0.030
7	C, E, F, G, H, I	0.027

$$Q(x)=\text{Impurity}(x)+\beta\times\text{Penalty}(k)$$

$$\text{Impurity}(X)=\frac{\#\text{ of Minority Examples}}{n}$$

$$\text{Penalty}(k)=\begin{cases}\sqrt{\frac{k-t}{n}}, & k\geq t\\ 0, & k<t\end{cases}$$



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SUWAN ALGORITHM

Methodology

- Weighted metric, α

$$Q_{\theta}(P_k^{\alpha})=1-\frac{W_{\theta}(P_k^{\alpha})}{W_{\theta}(P_1)}, \theta\in[1,2]$$

Structural
Compositional
of 68%
of 58%
Qnorm
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
based on D1
based on D2
α=0
α=0.7
α=1
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6

SUWAN ALGORITHM

Evaluation Measures

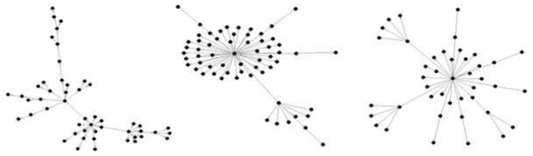
- The implemented methodology works around labeled data hence, the cluster evaluation can be accomplished through the purity of the clusters.
- This way, a new measure of the overall quality based on the cluster's purity is determined to achieve the quality of the clustering.

$$\text{Purity}(C_k) = \max_i (PR_k(t_i))$$

Where $PR_k(t_i)$ is the proportion of class t_i in cluster C_k

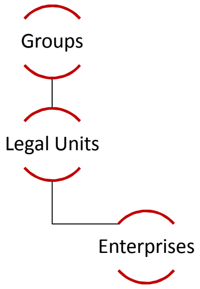
$$\text{Purity}_{\text{total}}(C) = \sum_{k=1}^{j} \frac{|C_k|}{|C|} \times \text{Purity}(C_k)$$

EGR Network



Data

- The database to be explored is provided by INE (Statistics Portugal) and it is denominated by EuroGroups Register (EGR).
- The EGR is a network of register that contains information about multinational enterprise groups, which have statistically relevant financial and non-financial transnational operations in at least one of the European countries (Eurostat, 2010).



Groups

Legal Units

Enterprises

Attribute	Description
LEU_LEID	ID of the Legal Unit
TYPE	List of type of Legal Unit (Brach or not)
LFORM	List of legal forms of Legal Units
COUNTRY_CODE	List of 2-digit ISO country codes
SIZE_CLASS	Size of the enterprise based on persons employed
TURNOVER_CLASS	Turnover class based on the enterprise turnover values
NACE_DIV	2-digit NACE Rev. 2 activity codes for the main activity of enterprises

IMPLEMENTATION

SUWAN VS Subgroup Discovery (SD)

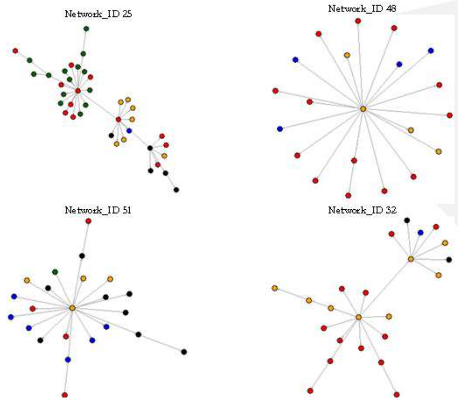
- A Multinational Enterprise Groups represents a network
- Analysis performed on 67 networks with the following characteristics
  - Group Head based in Portugal
  - > 20 connections → # 3 848 Legal Units

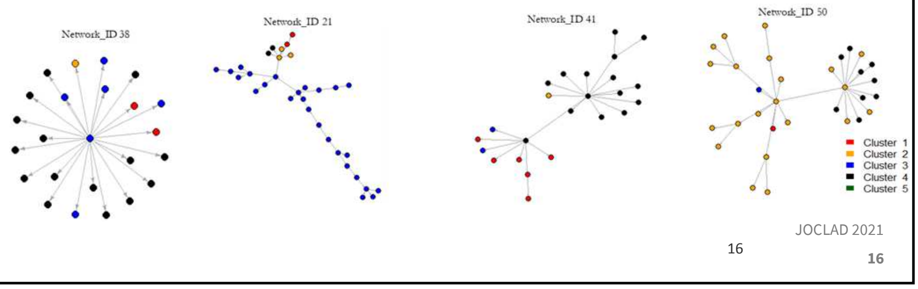
Algorithm	Average #Clusters/Subgroups	Average Overall Quality
SUWAN	3,299	0,532
SD	3,761	0,726

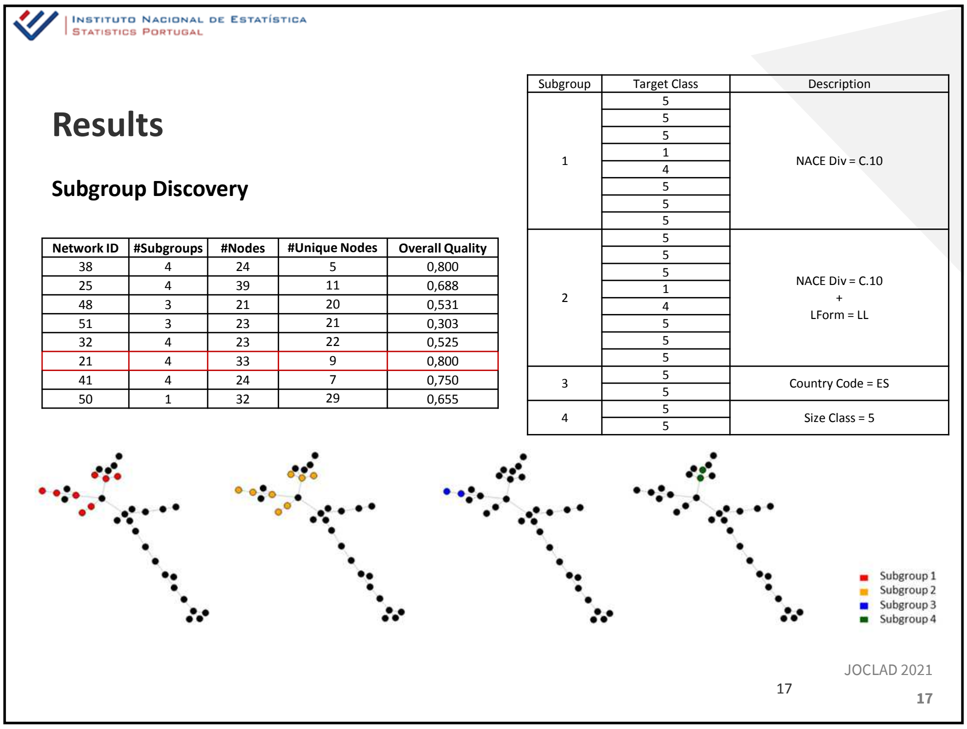
Results

SUWAN

Network ID	#Clusters	#Nodes	Overall Quality
38	4	24	1
25	5	39	0,923
48	3	21	0,905
51	5	23	0,870
32	4	23	0,783
21	4	33	0,758
41	4	24	0,750
50	4	32	0,719







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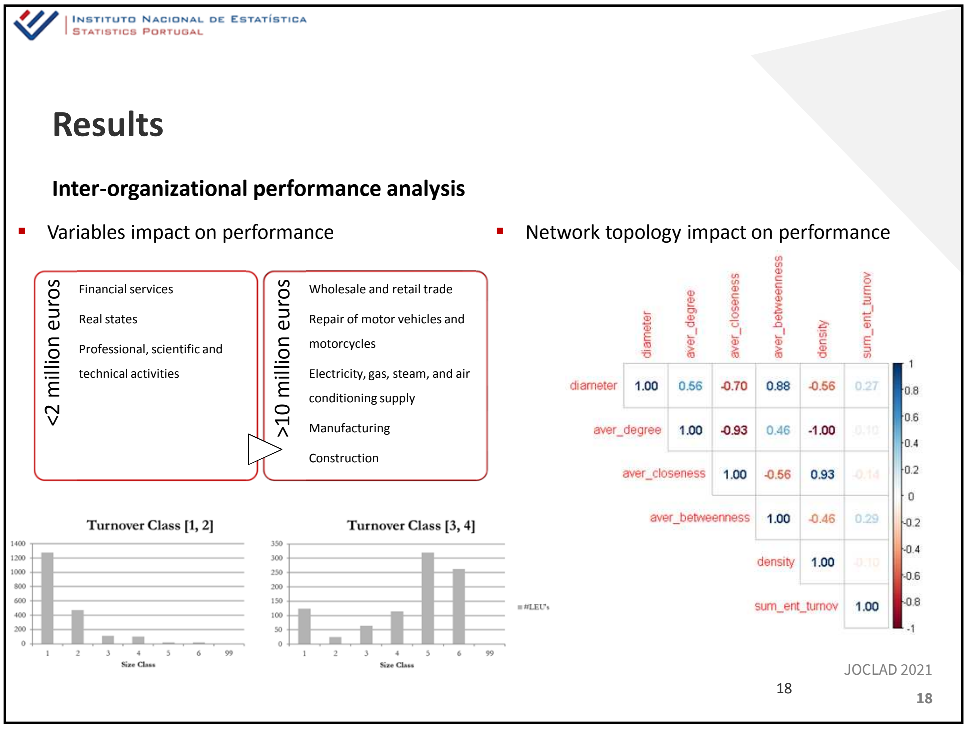
Results

Subgroup Discovery

Network ID	#Subgroups	#Nodes	#Unique Nodes	Overall Quality
38	4	24	5	0,800
25	4	39	11	0,688
48	3	21	20	0,531
51	3	23	21	0,303
32	4	23	22	0,525
21	4	33	9	0,800
41	4	24	7	0,750
50	1	32	29	0,655

Subgroup	Target Class	Description
1	5	NACE Div = C.10
	5	
	5	
	1	
	4	
	5	
	5	
	5	
2	5	NACE Div = C.10 + LForm = LL
	5	
	5	
	1	
	4	
	5	
	5	
	5	
3	5	Country Code = ES
	5	
4	5	Size Class = 5
	5	

- 🟥 Subgroup 1
- 🟧 Subgroup 2
- 🟦 Subgroup 3
- 🟩 Subgroup 4



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Results

Inter-organizational performance analysis

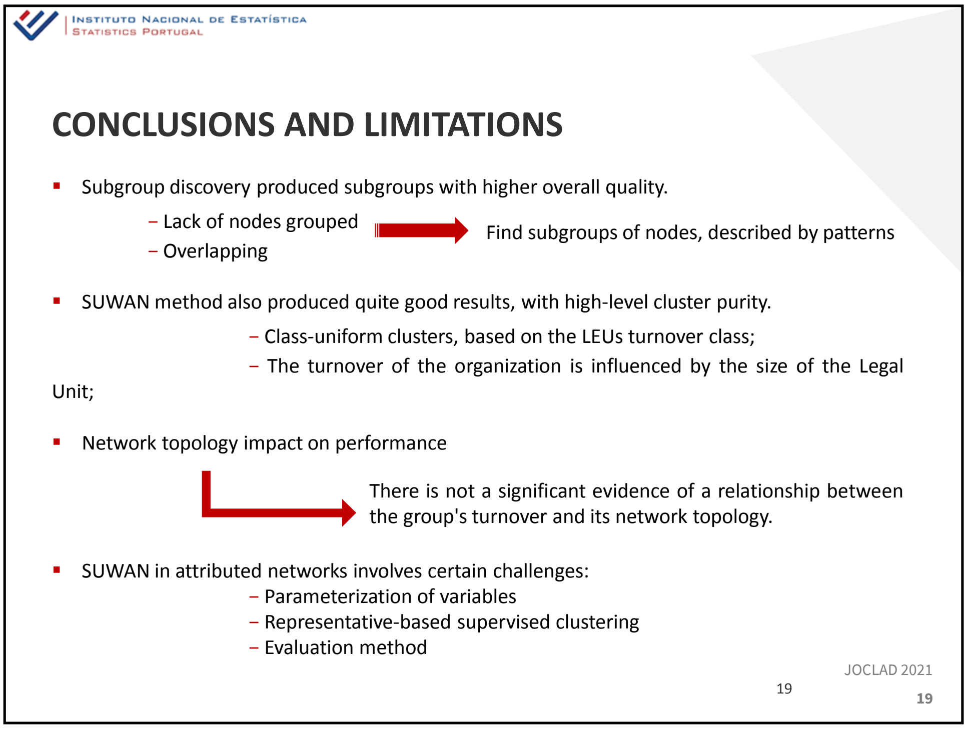
- Variables impact on performance

<2 million euros
Financial services
Real states
Professional, scientific and technical activities

>10 million euros
Wholesale and retail trade
Repair of motor vehicles and motorcycles
Electricity, gas, steam, and air conditioning supply
Manufacturing
Construction

- Network topology impact on performance

	diameter	aver_degree	aver_closeness	aver_betweenness	density	sum_ent_turnov
diameter	1.00	0.56	-0.70	0.88	-0.56	0.27
aver_degree		1.00	-0.93	0.46	-1.00	0.10
aver_closeness			1.00	-0.56	0.93	-0.14
aver_betweenness				1.00	-0.46	0.29
density					1.00	-0.10
sum_ent_turnov						1.00



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CONCLUSIONS AND LIMITATIONS

- Subgroup discovery produced subgroups with higher overall quality.
  - Lack of nodes grouped
  - Overlapping

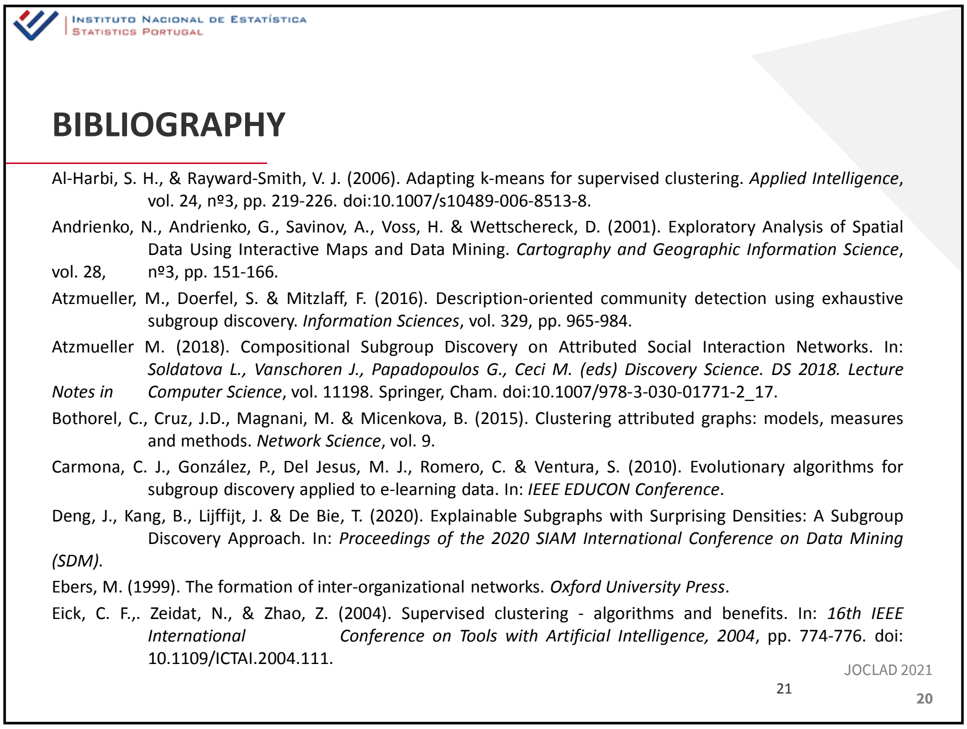
  → Find subgroups of nodes, described by patterns

- SUWAN method also produced quite good results, with high-level cluster purity.
  - Class-uniform clusters, based on the LEUs turnover class;
  - The turnover of the organization is influenced by the size of the Legal Unit;

- Network topology impact on performance

  → There is not a significant evidence of a relationship between the group's turnover and its network topology.

- SUWAN in attributed networks involves certain challenges:
  - Parameterization of variables
  - Representative-based supervised clustering
  - Evaluation method



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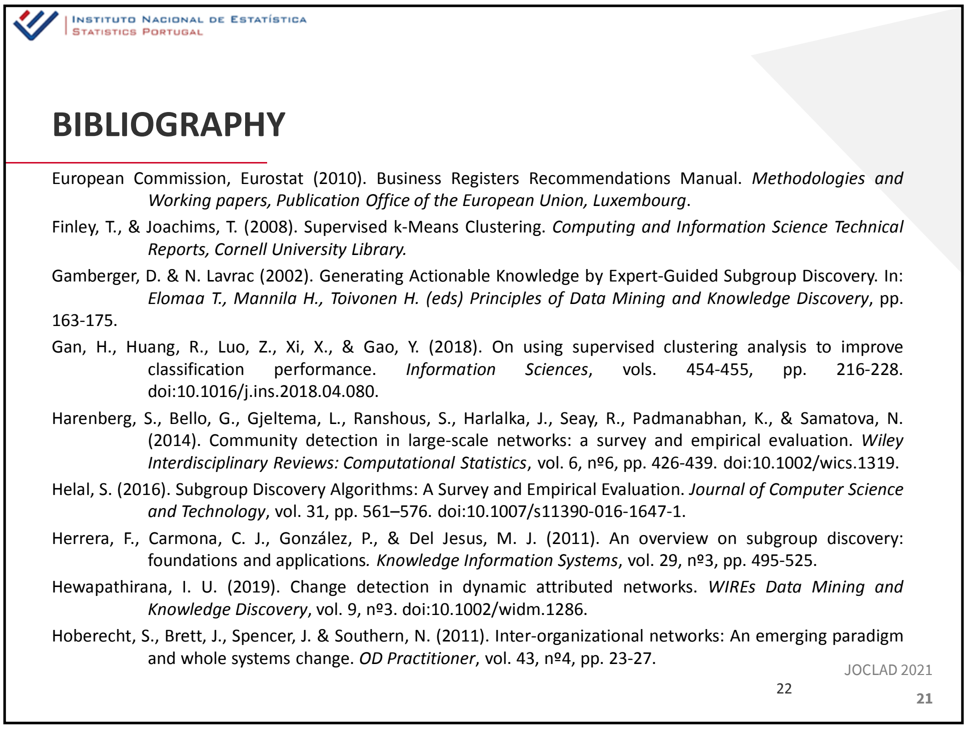

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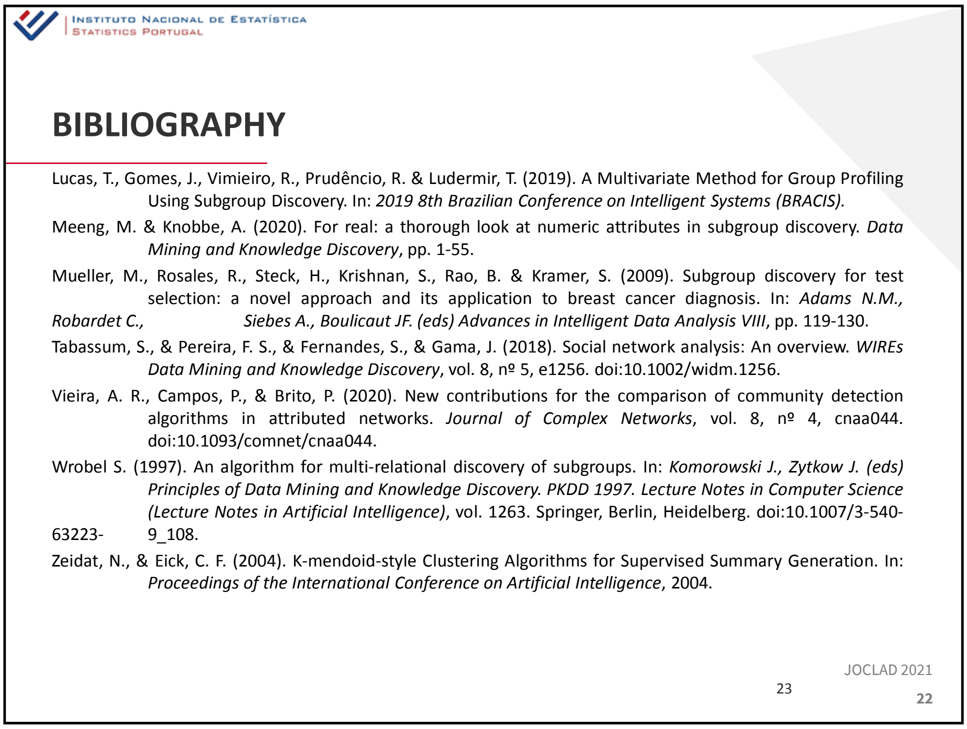

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