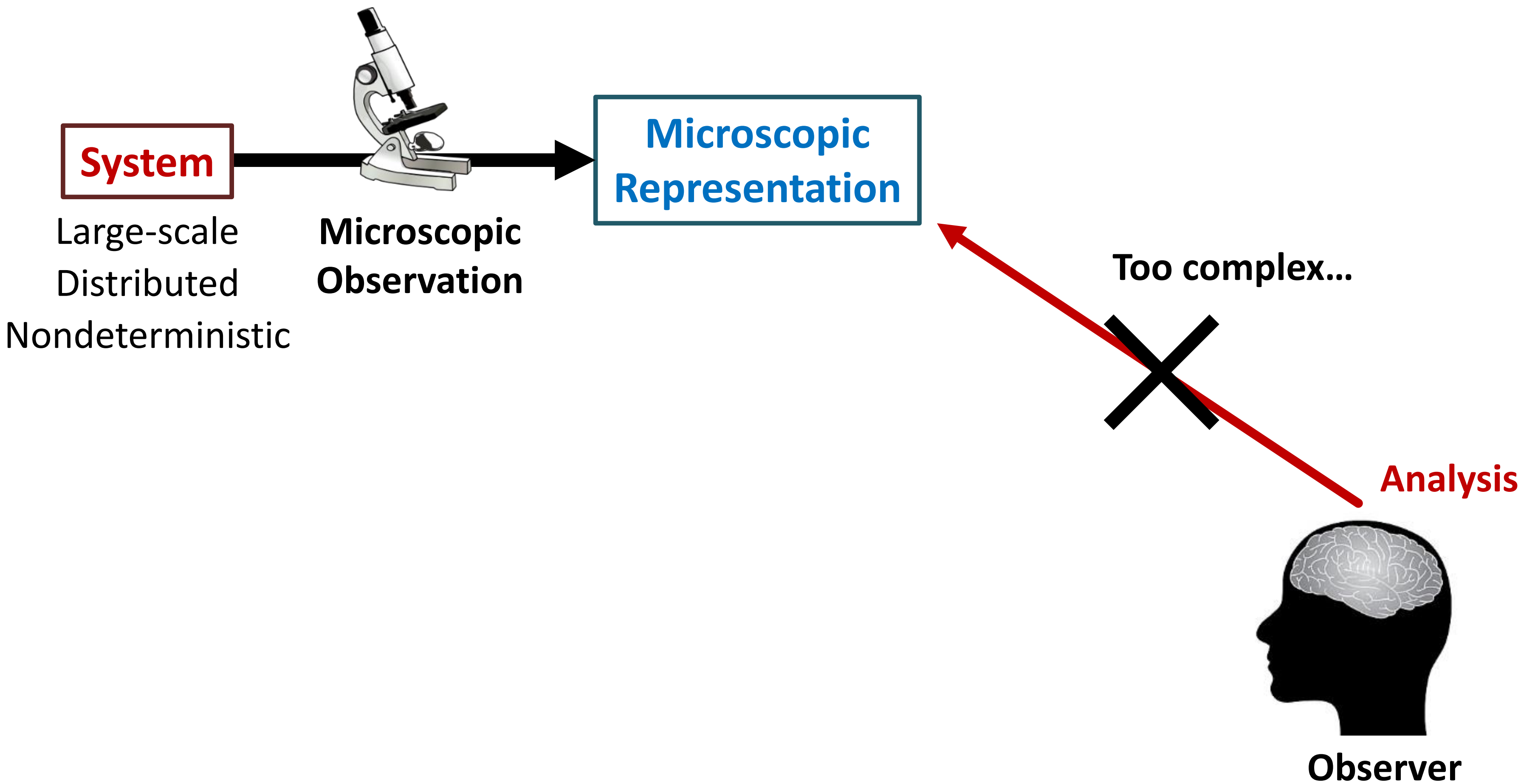
Grenoble, the 14th of October 2013
Thesis from the University of Grenoble

Macroscopic Analysis of Large-scale Systems

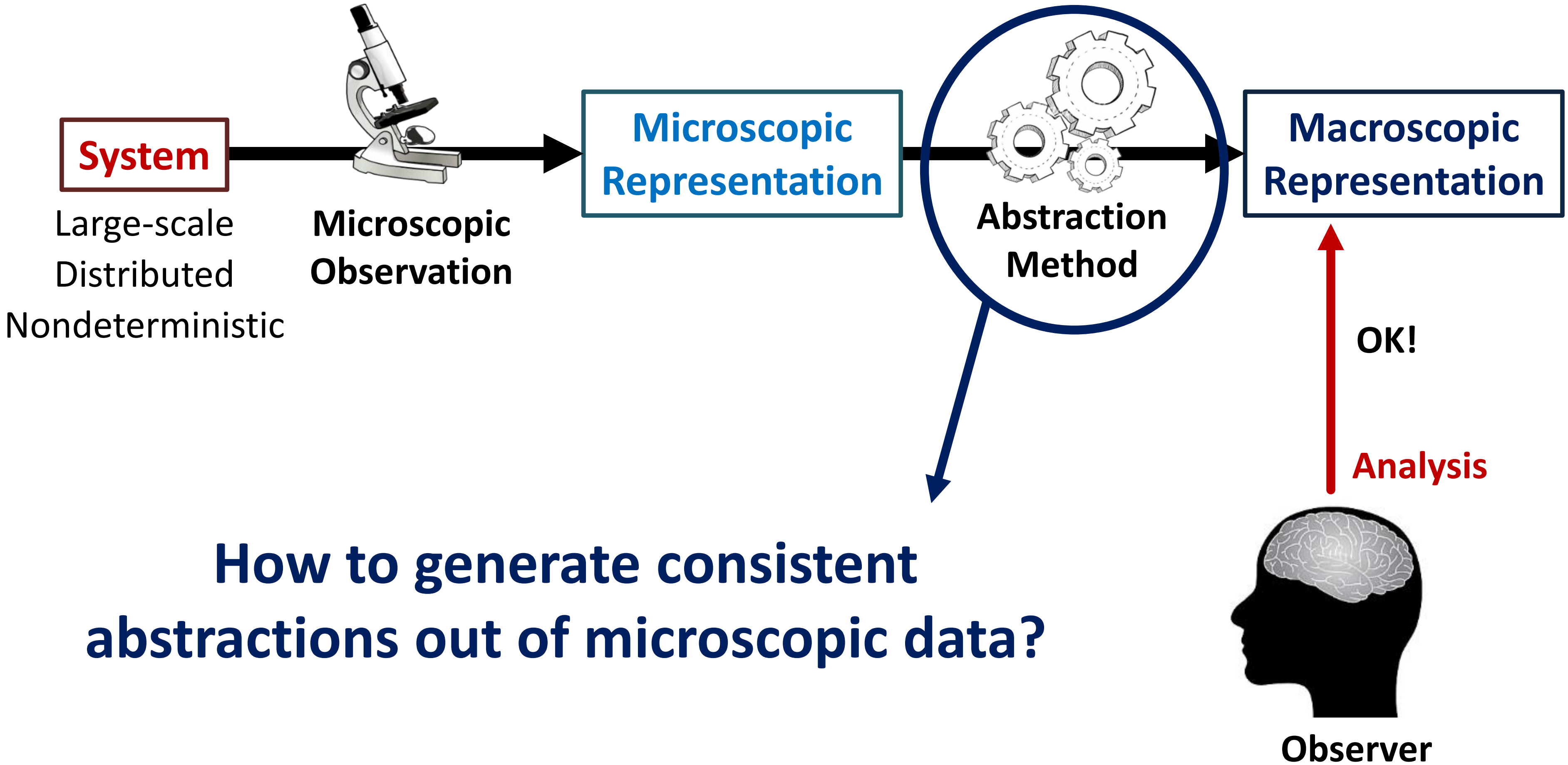
Robin Lamarche-Perrin

Reviewers: Bernard Moulin and Éric Fleury
Examiners: Salima Hassas and Brigitte Plateau
Supervisors: Yves Demazeau and Jean-Marc Vincent

The Analysis of Large-scale Systems



The Analysis of Large-scale Systems



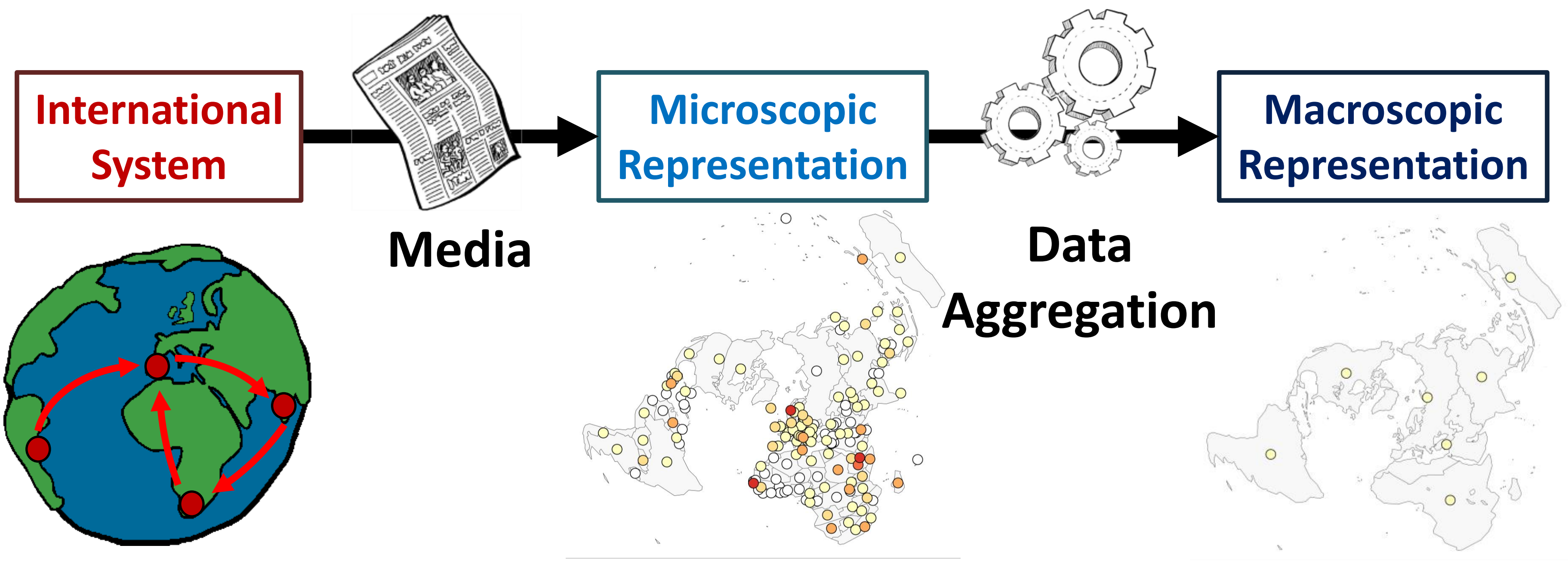
How to generate consistent abstractions out of microscopic data?

Analysis of International Relations

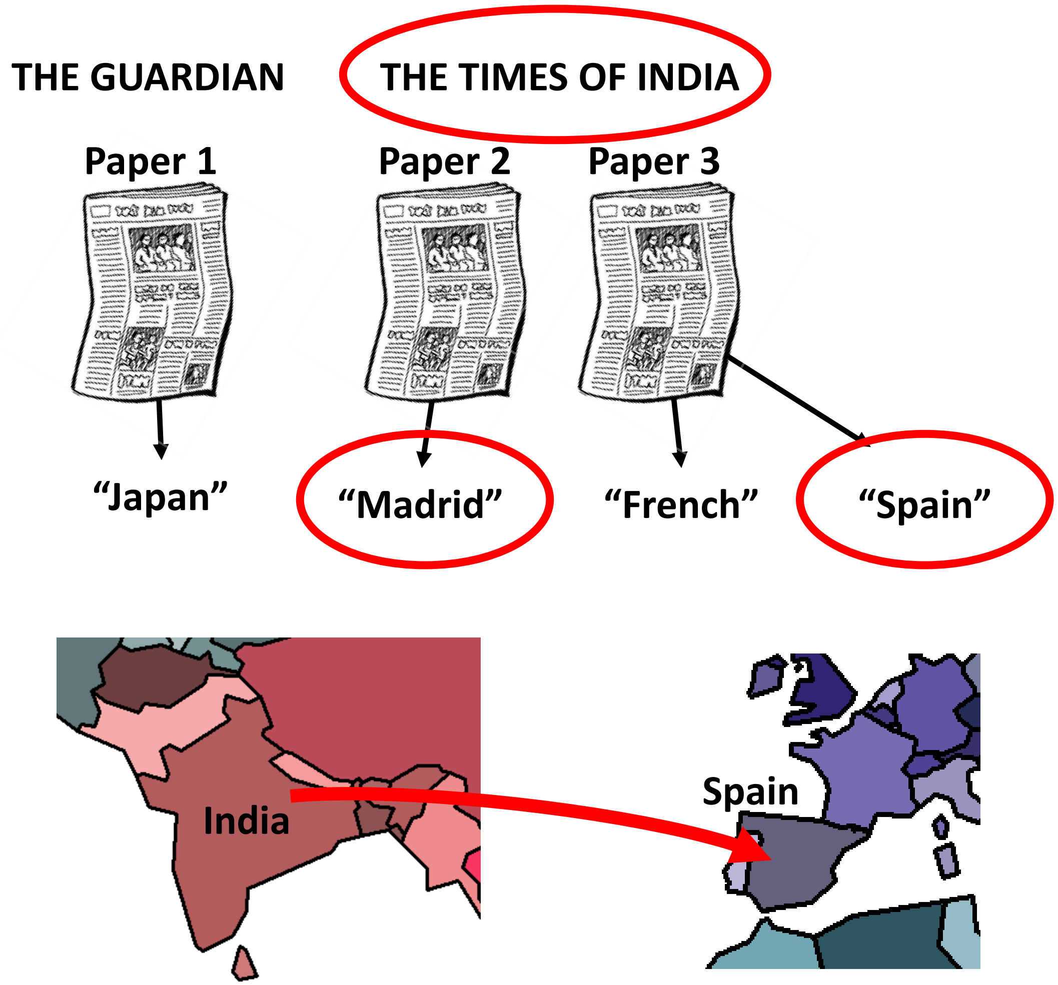
Hypothesis: media constitute an adequate instrument to observe the national level

[Grasland *et al.*, 2011]

Geographer



Data from Print Media



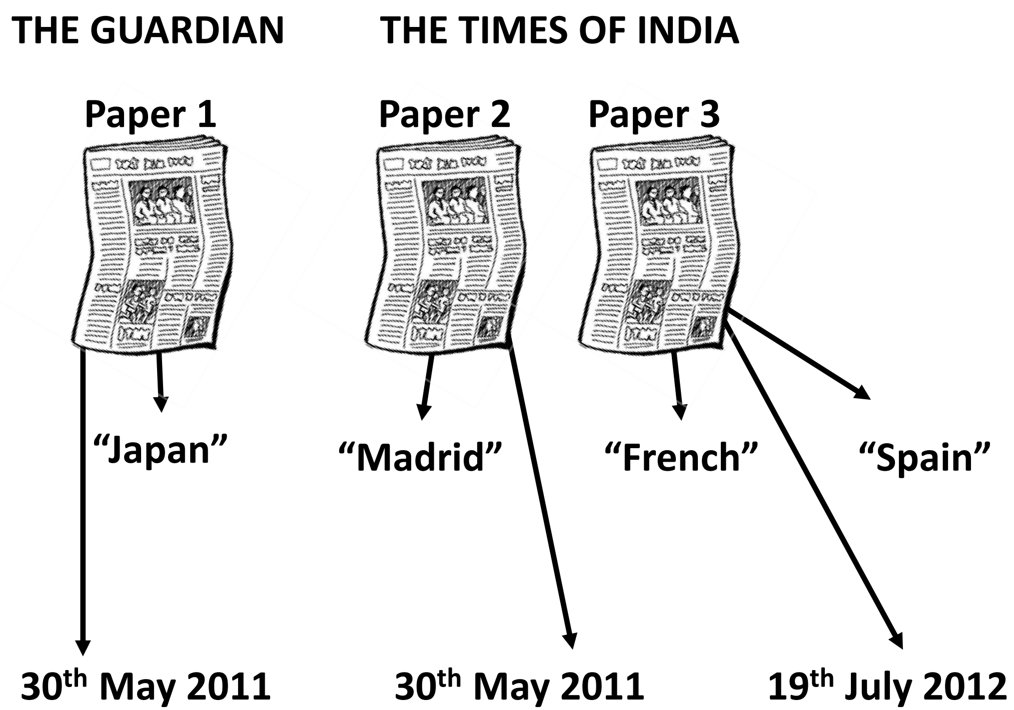
The GEOMEDIA Database
(ANR CORPUS GUI-AAP-04)

150 newspapers

1,944,000 papers

GEOGRAPHIC INFORMATION
193 countries (UN members)

Data from Print Media



The GEOMEDIA Database
(ANR CORPUS GUI-AAP-04)

150 newspapers

1,944,000 papers

GEOGRAPHIC INFORMATION

193 countries (UN members)

TEMPORAL INFORMATION

889 days / 127 weeks

(from the 3rd May 2011 to today)

Microscopic Representation of the International System

Newspaper LE MONDE

π **Space**

t **Time**

	USA	Libya	Syria	France	Israel	…	Total
2 May	25	12	11	10	4	…	**142**
9 May	14	6	12	12	5	…	**108**
16 May	20	11	12	6	9	…	**142**
23 May	15	9	6	13	5	…	**120**
30 May	10	16	17	9	4	…	**137**
6 June	14	16	16	9	4	…	**114**
13 June	15	14	17	9	6	…	**119**
20 June	17	13	12	12	7	…	**123**
27 June	7	6	7	20	2	…	**103**
4 July	12	13	8	10	6	…	**129**
11 July	21	10	10	14	3	…	**107**
18 July	7	3	8	4	5	…	**61**
25 July	16	7	6	13	4	…	**128**
1 Aug.	21	1	9	7	4	…	**88**
…	…	…	…	…	…	…	**…**
Total	**423**	**308**	**260**	**248**	**153**	**…**	**3520**

Number of observed citations

$v(\pi, t)$

$v(., t)$

$v(\pi, .)$

$v(., .)$

Number of expected citations

$$v^*(\pi, t) = \frac{v(\pi, .)\, v(., t)}{v(., .)}$$

Geographical Representation

Space (columns) — **Time** (rows, t)

	USA	Libya	Syria	France	Israel	...	Total
2 May	25	12	11	10	4	...	142
9 May	14	6	12	12	5	...	108
16 May	20	11	12	6	9	...	142
23 May	15	9	6	13	5	...	120
30 May	10	16	17	9	4	...	137
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13 June	15	14	17	9	6	...	119
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27 June	7	6	7	20	2	...	103
4 July	12	13	8	10	6	...	129
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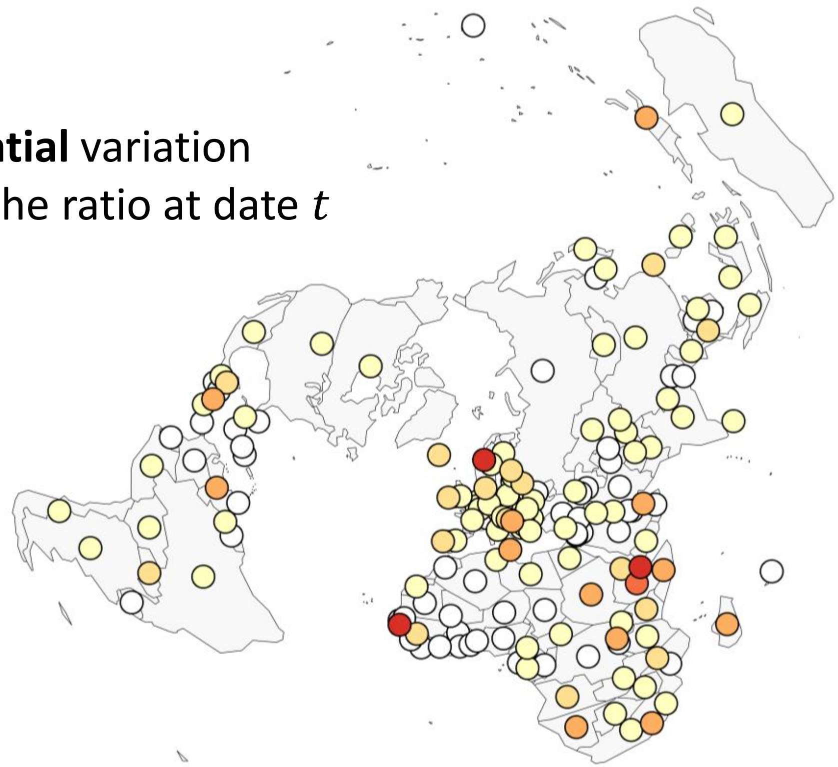
1 Aug.	21	1	9	7	4	...	88
...	...	...	...	...	...	...	...
Total	423	308	260	248	153	...	3520

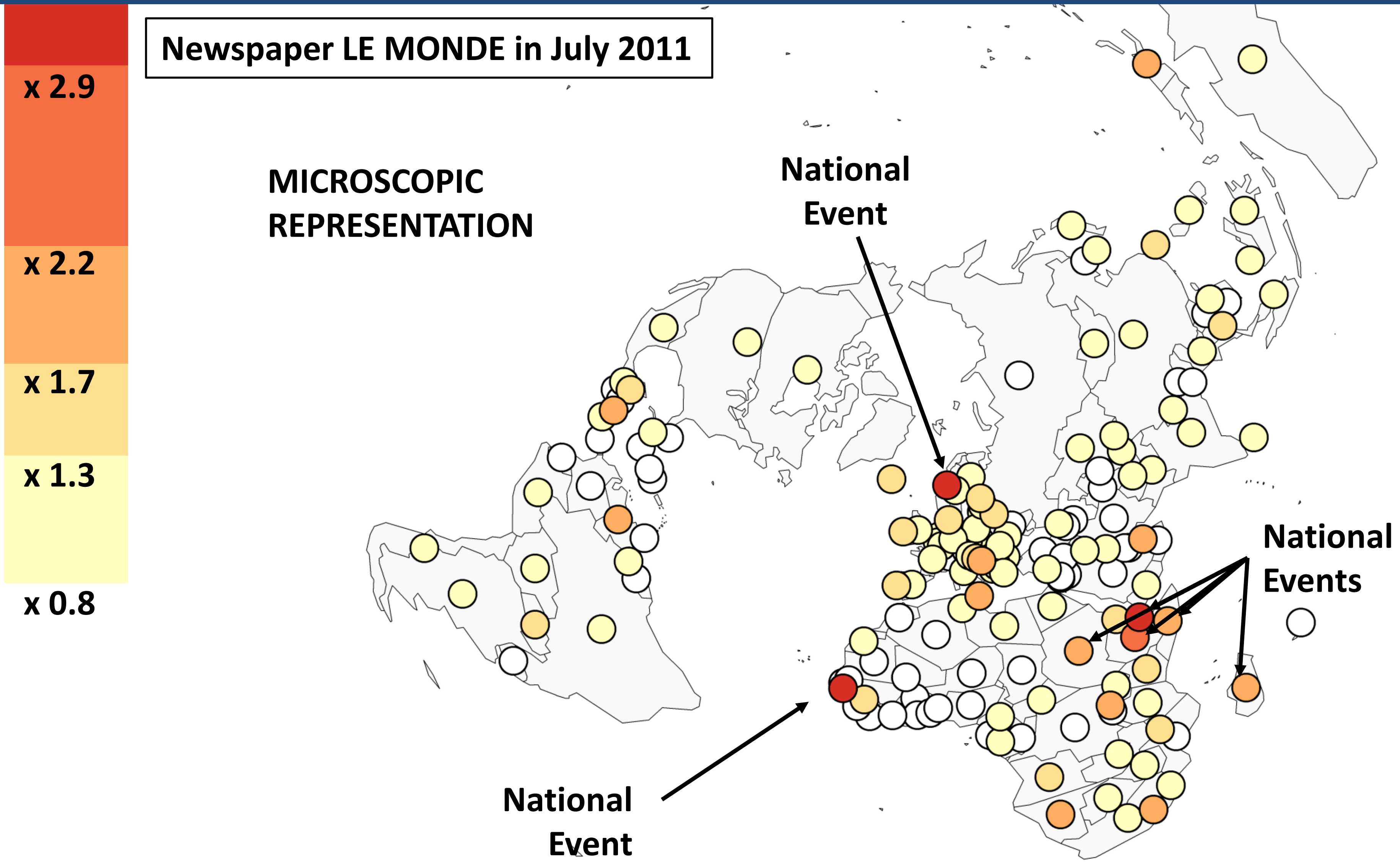
Observed-to-expected ratio of citation number

$$\rho(\pi,t) = \frac{v(\pi,t)}{v^*(\pi,t)} = \frac{v(\pi,t)\, v(.,.)}{v(\pi,.)\, v(.,t)}$$

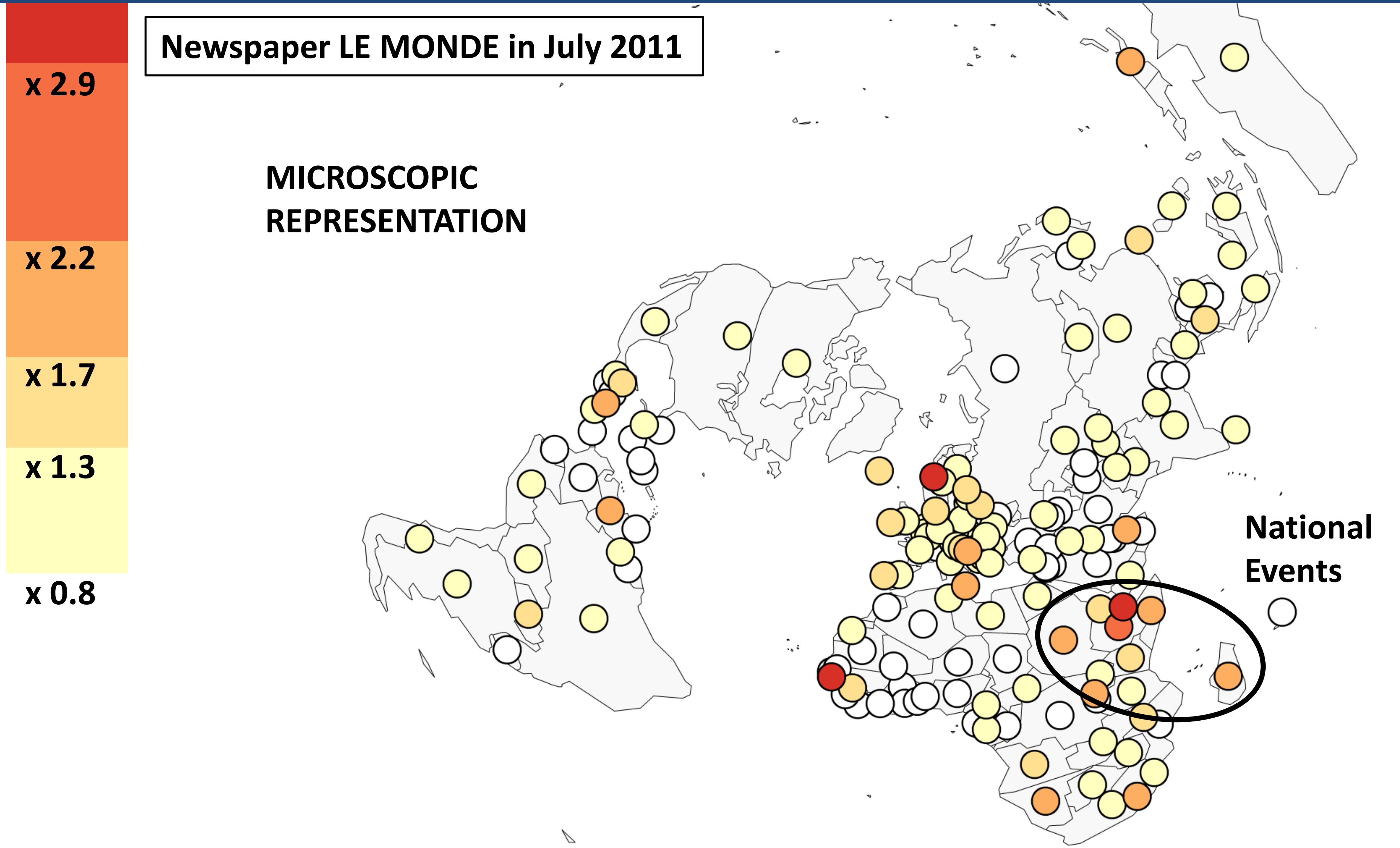
Spatial variation of the ratio at date t



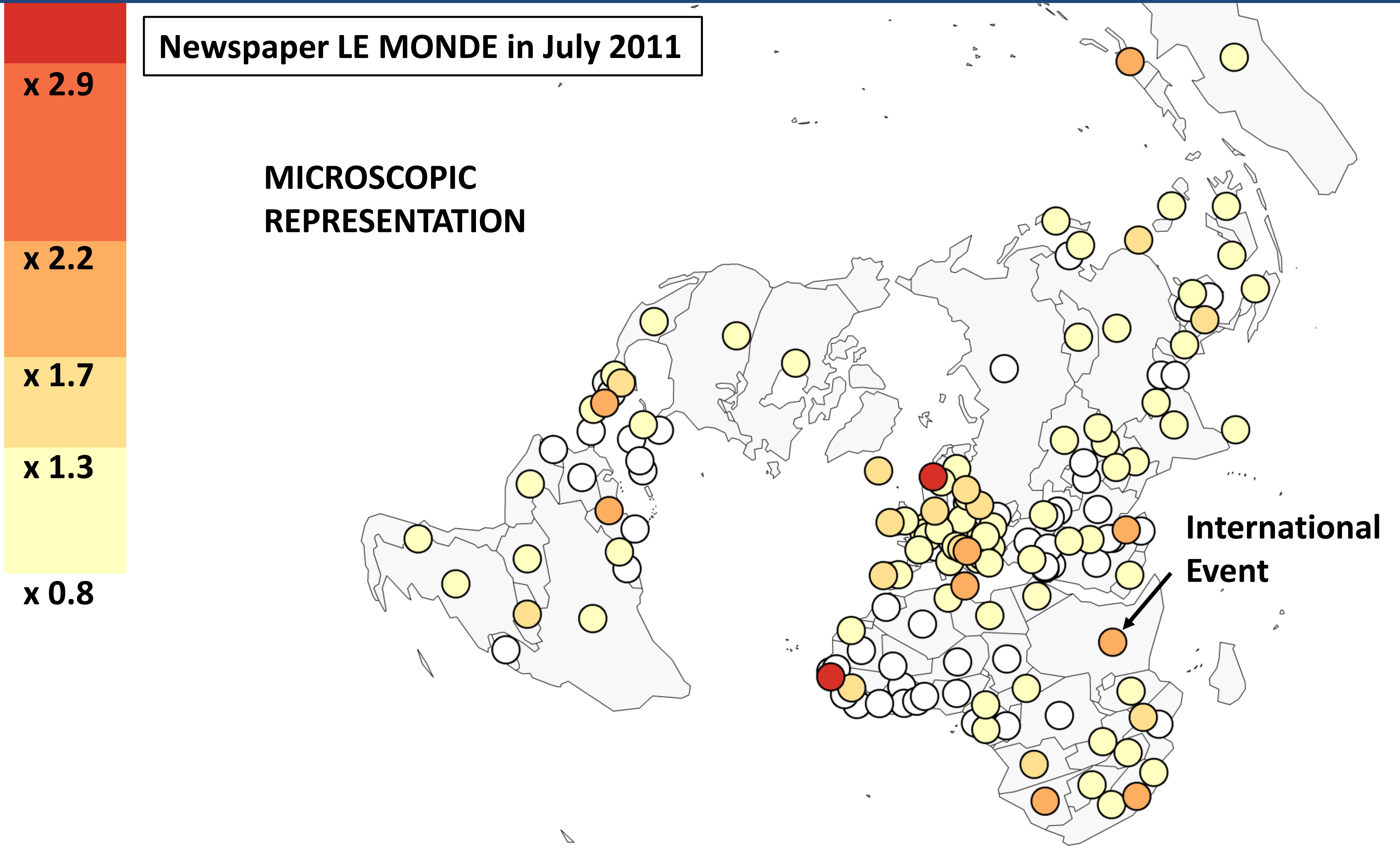
Detection of Media Events



Detection of Media Events



Detection of Media Events



Data Aggregation

Space

π_1 π_2 π_3

Time

t

	USA	Libya	Syria	France	Israel	...	Total
2 May	25	12	11	10	4	...	142
9 May	14	6	12	12	5	...	108
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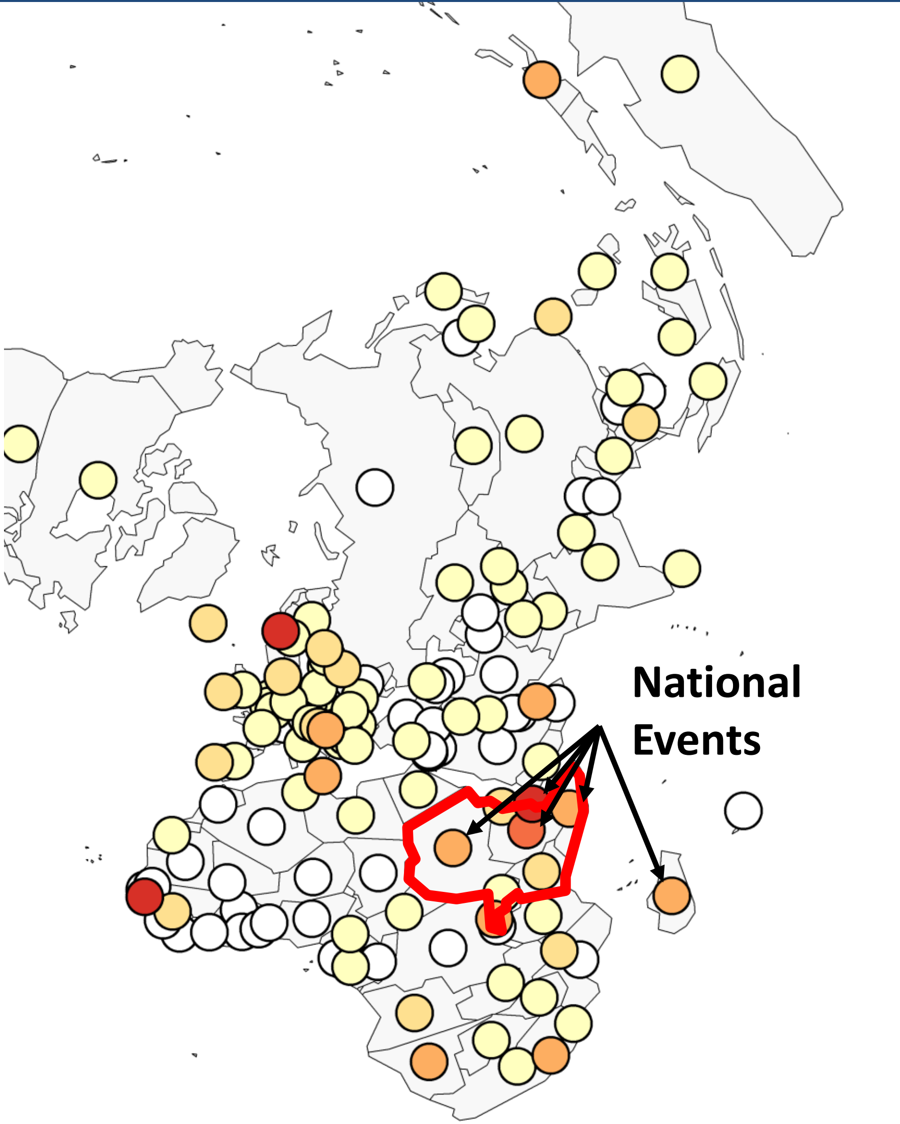
Total	423	308	260	248	153	...	3520



Data Aggregation

π_1 π_2 π_3 **Space**

Time t

	USA	Aggregate	Israel	...	Total
2 May	25	13+11+10	4	...	**142**
9 May	14	6+12+12	5	...	**108**
16 May	20	11+12+6	9	...	**142**
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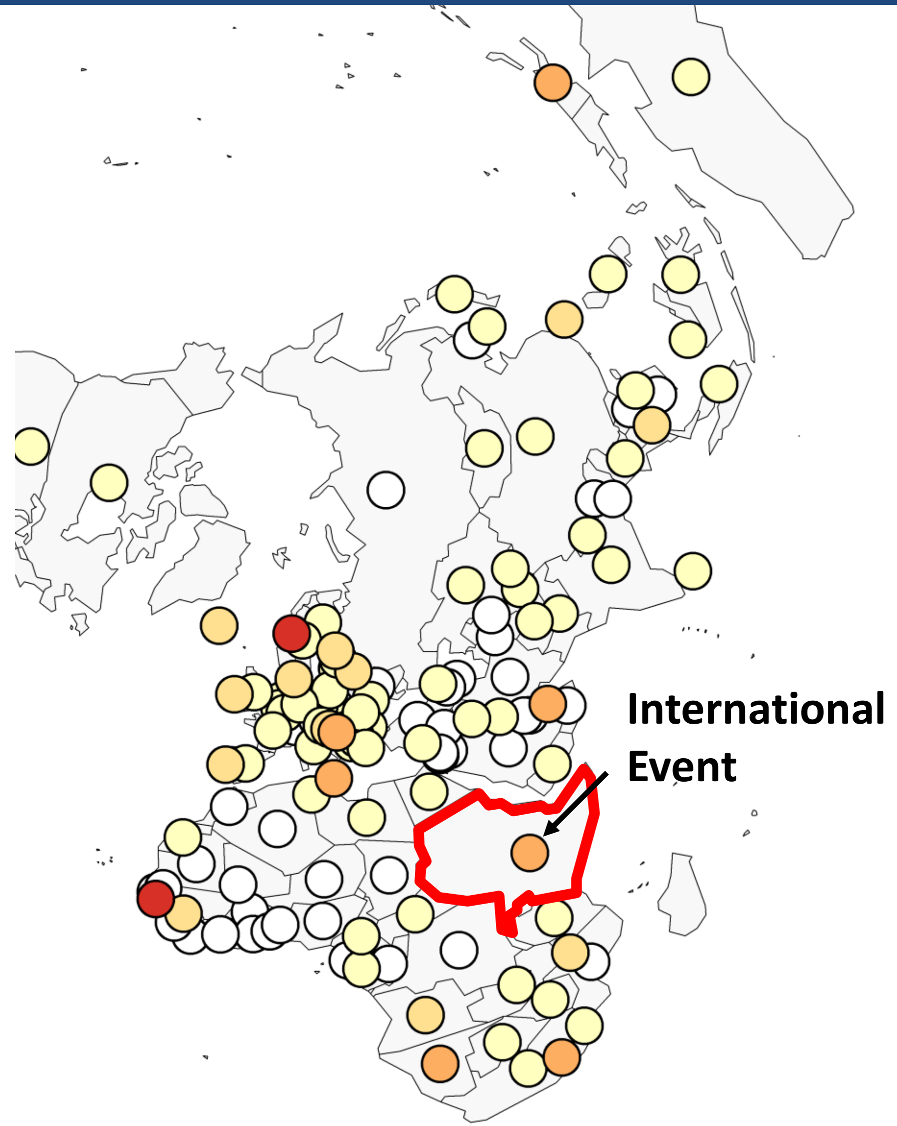
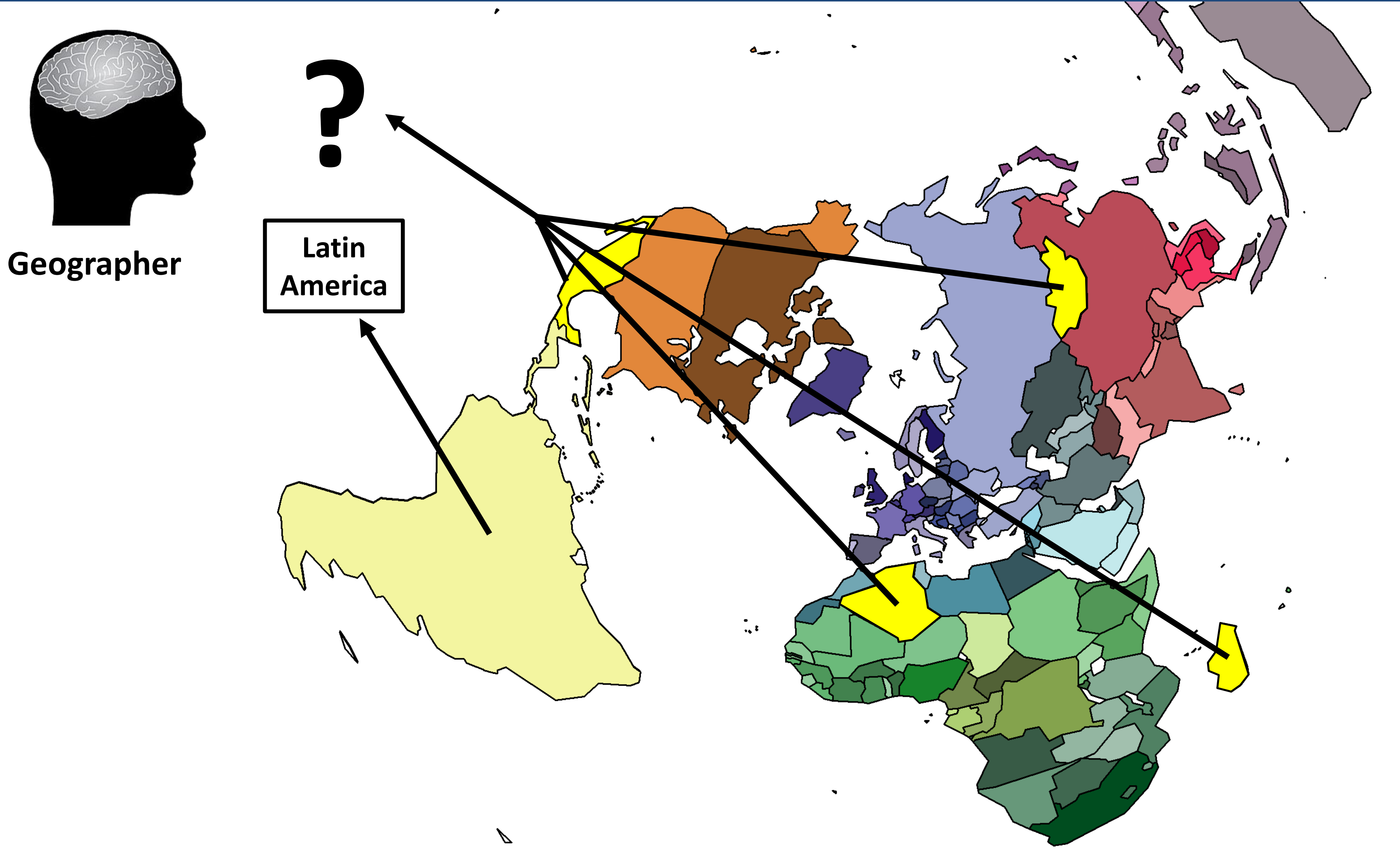


P1: The Semantics of Geographical Aggregates



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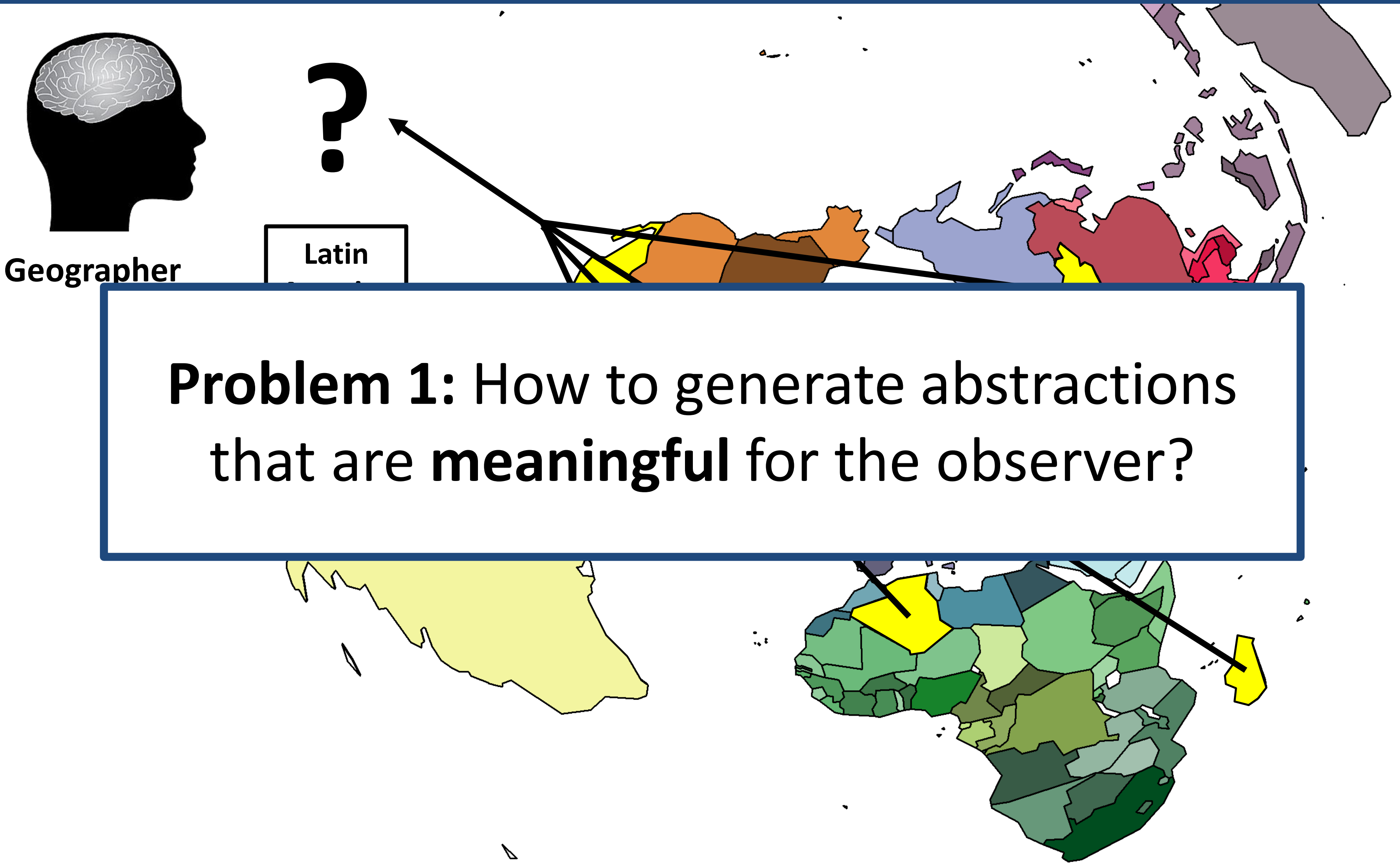
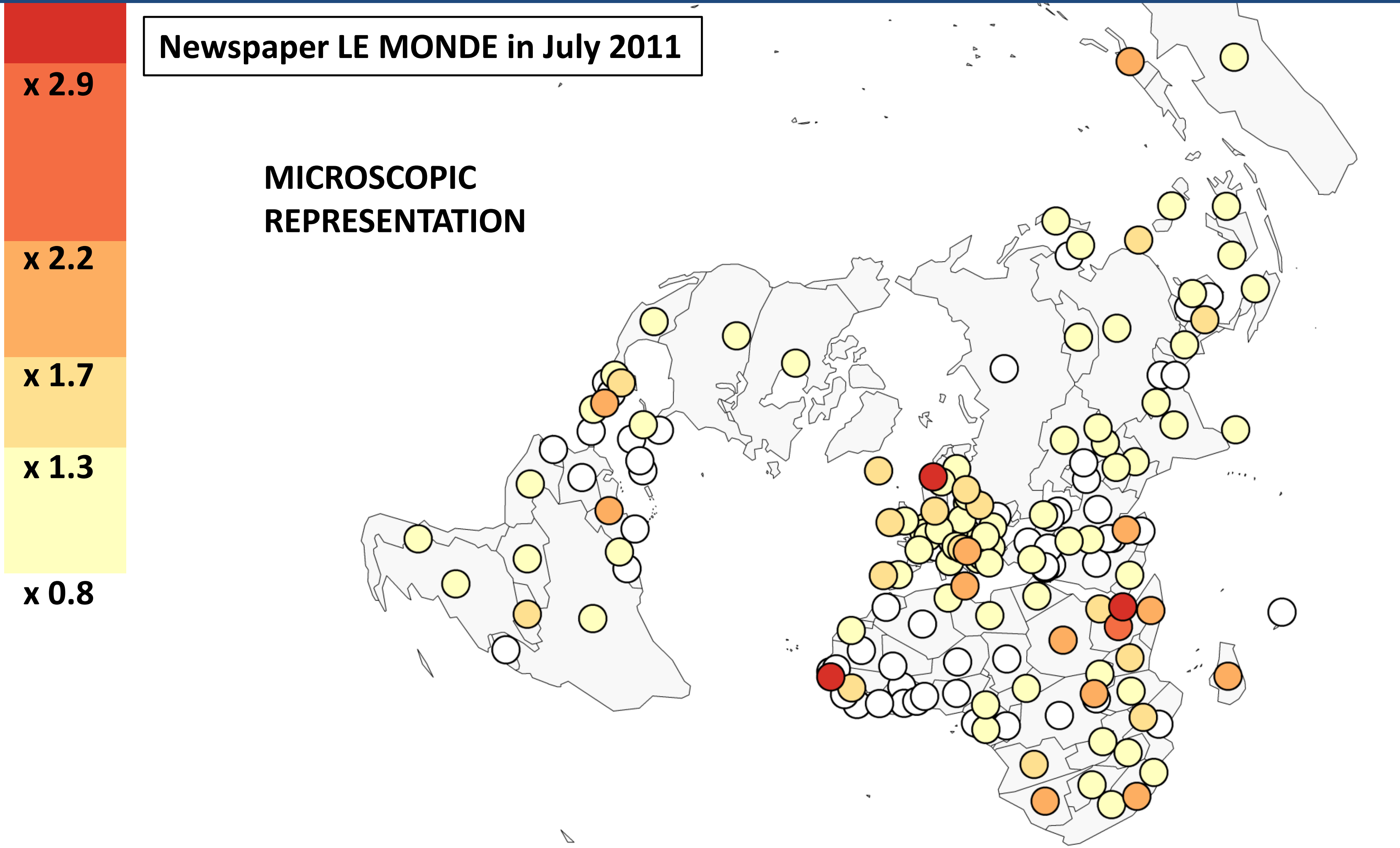
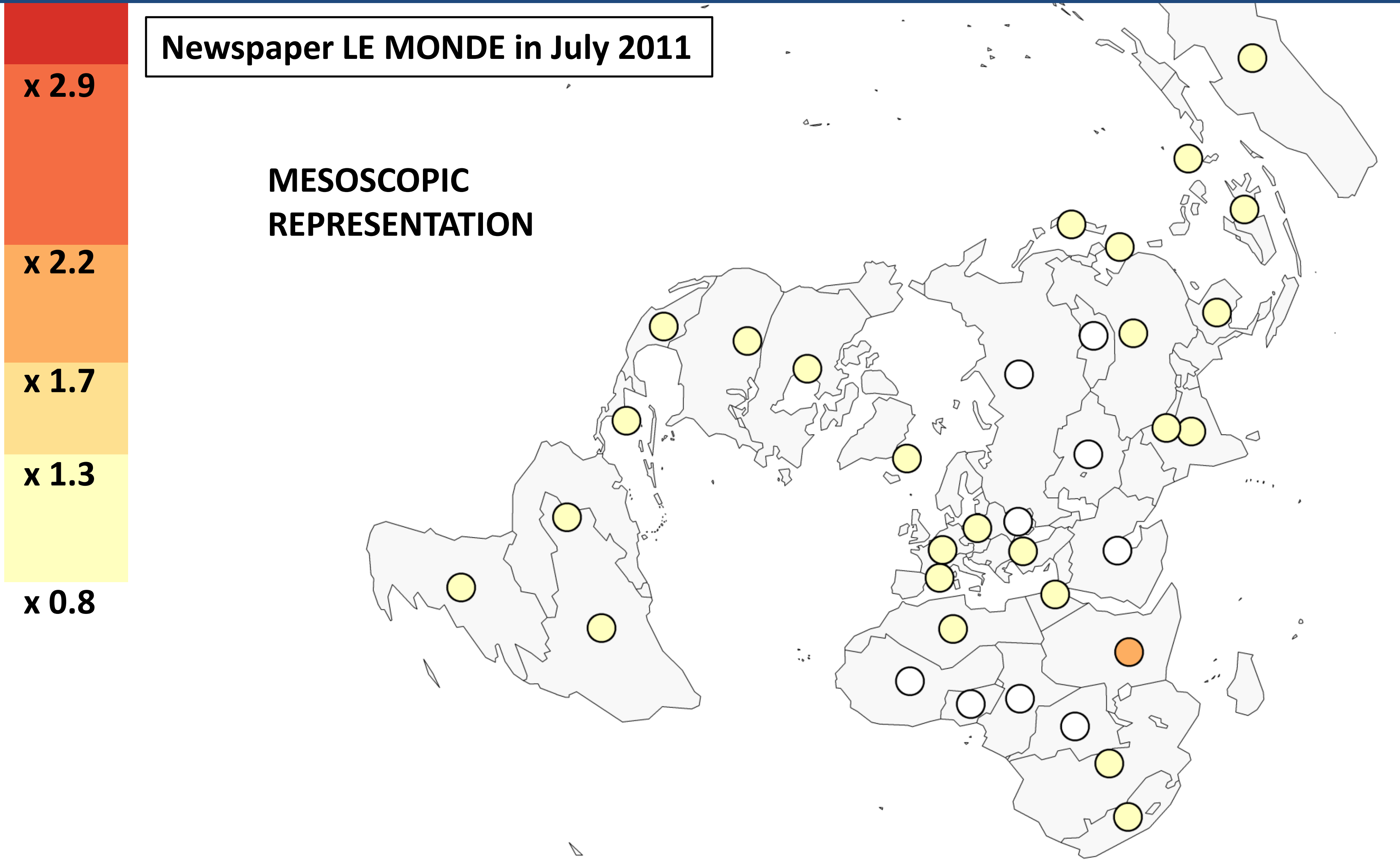


Problem 1: How to generate abstractions that are **meaningful** for the observer?

P2: The Levels of Representation



P2: The Levels of Representation



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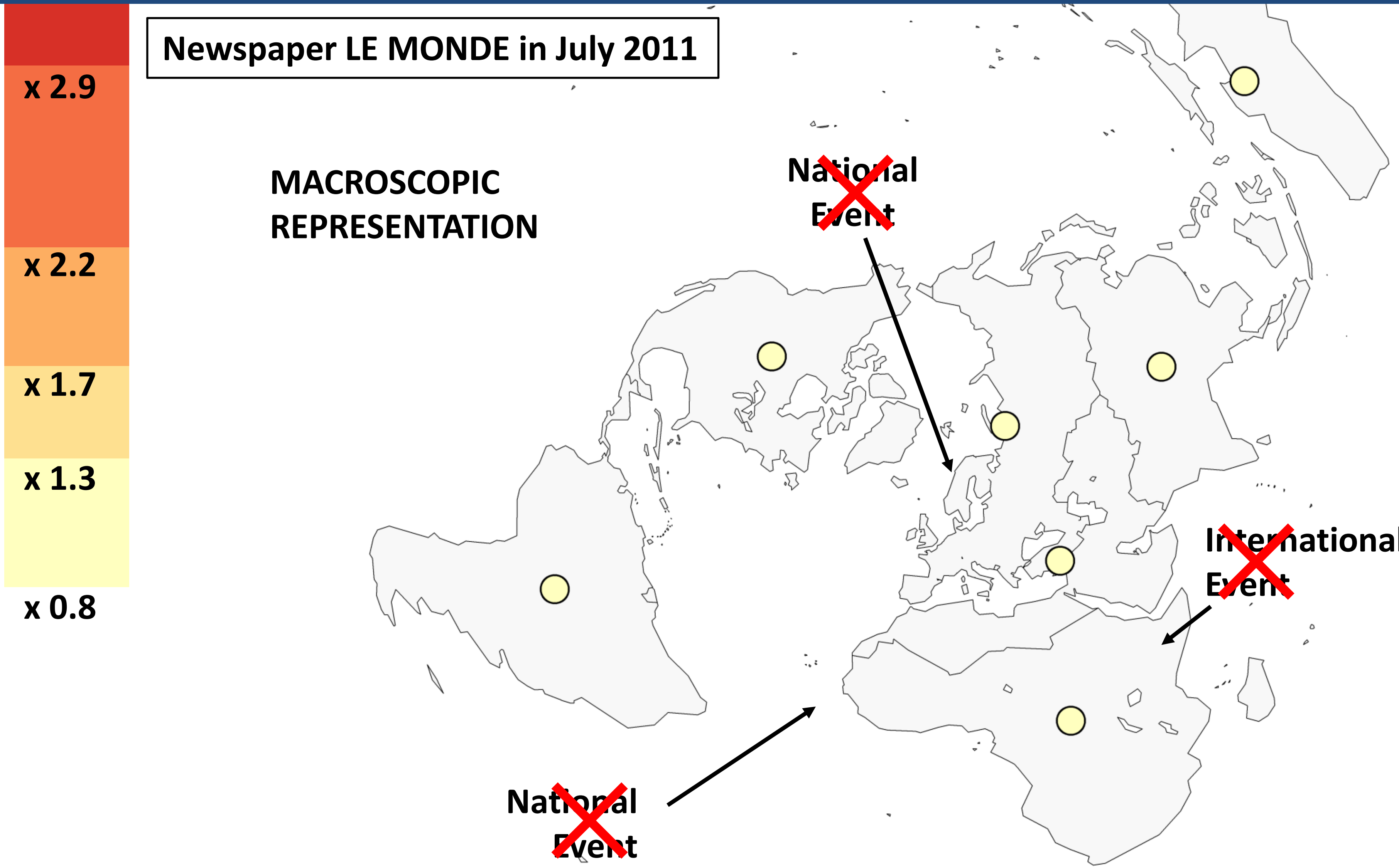

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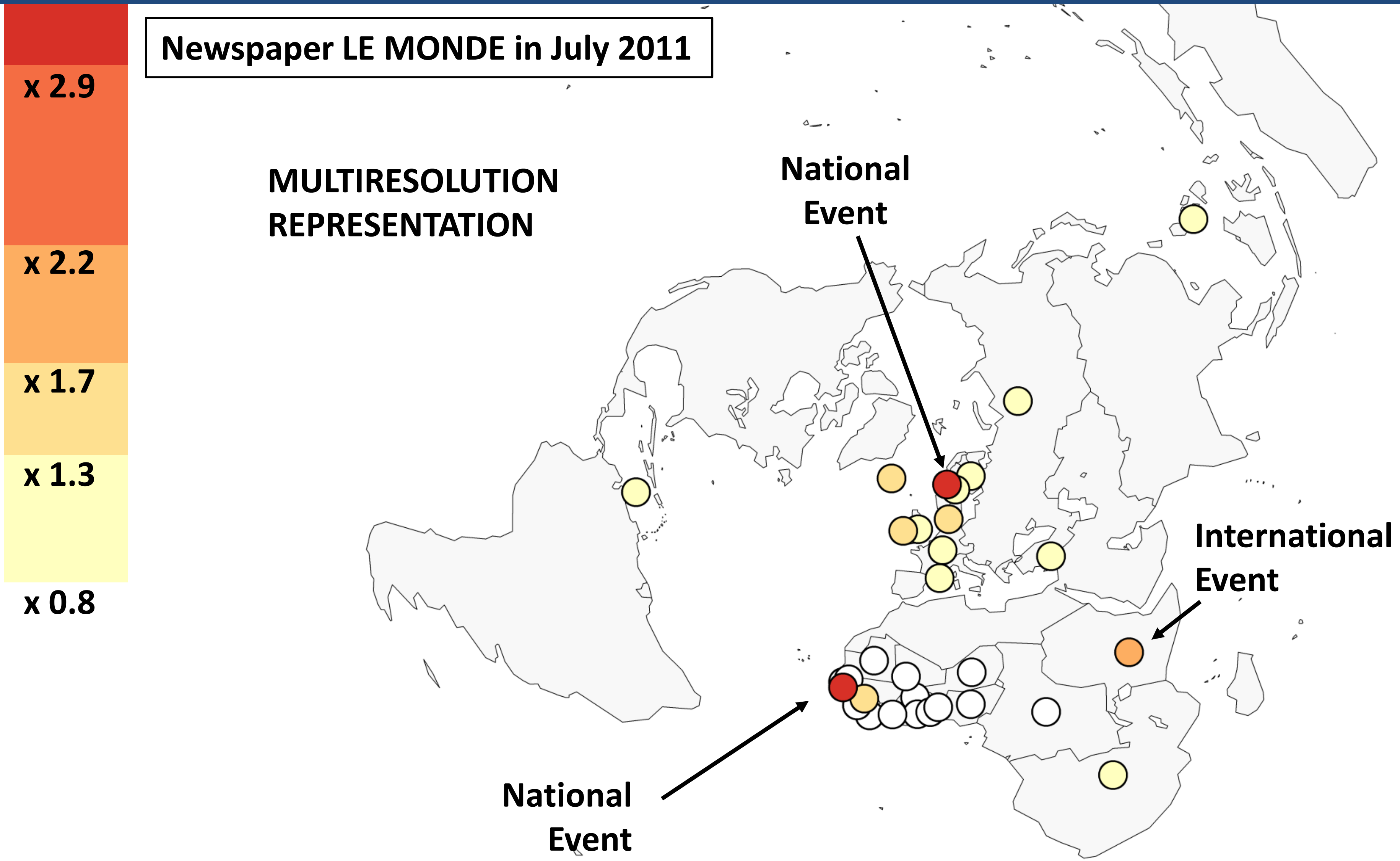
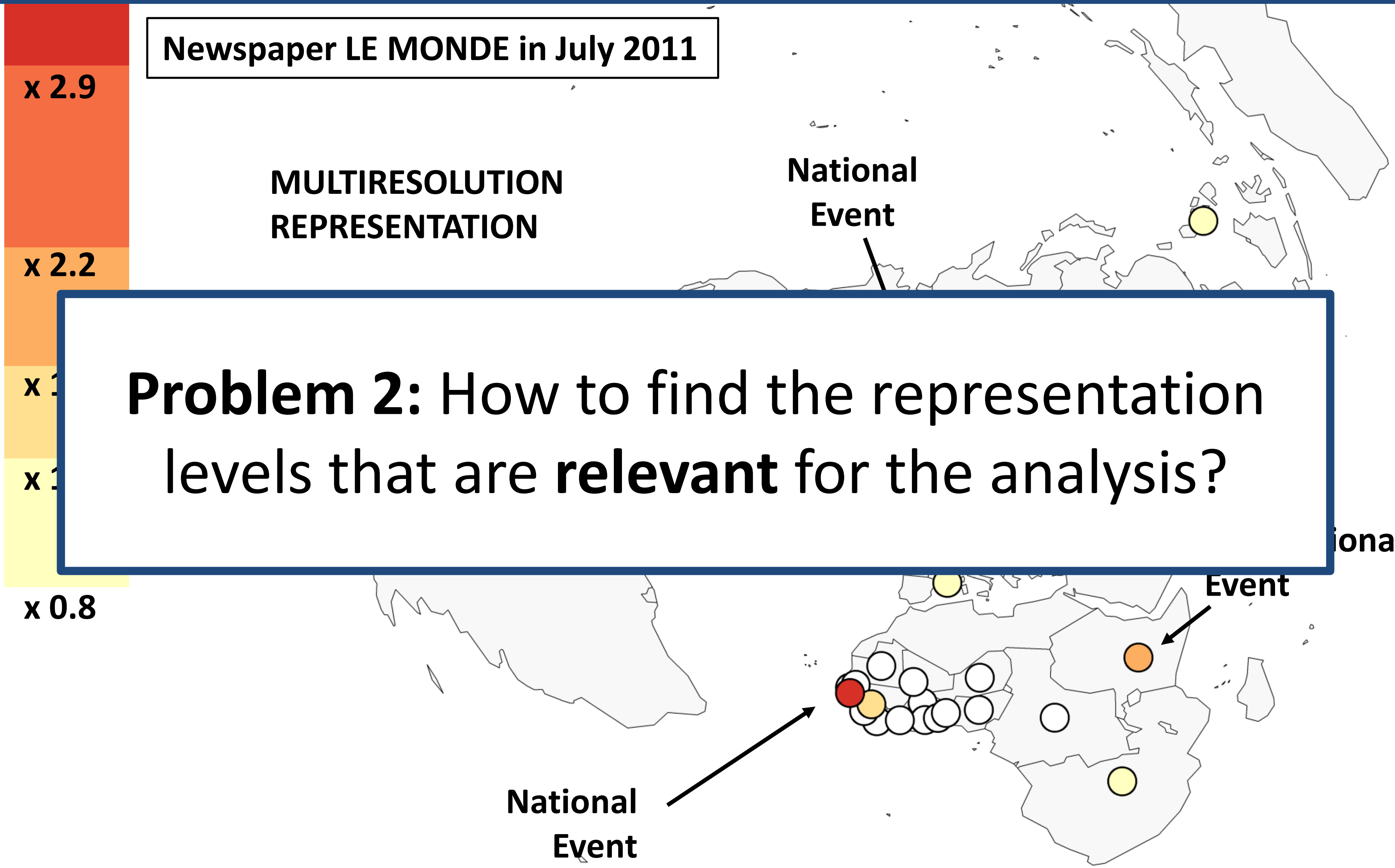
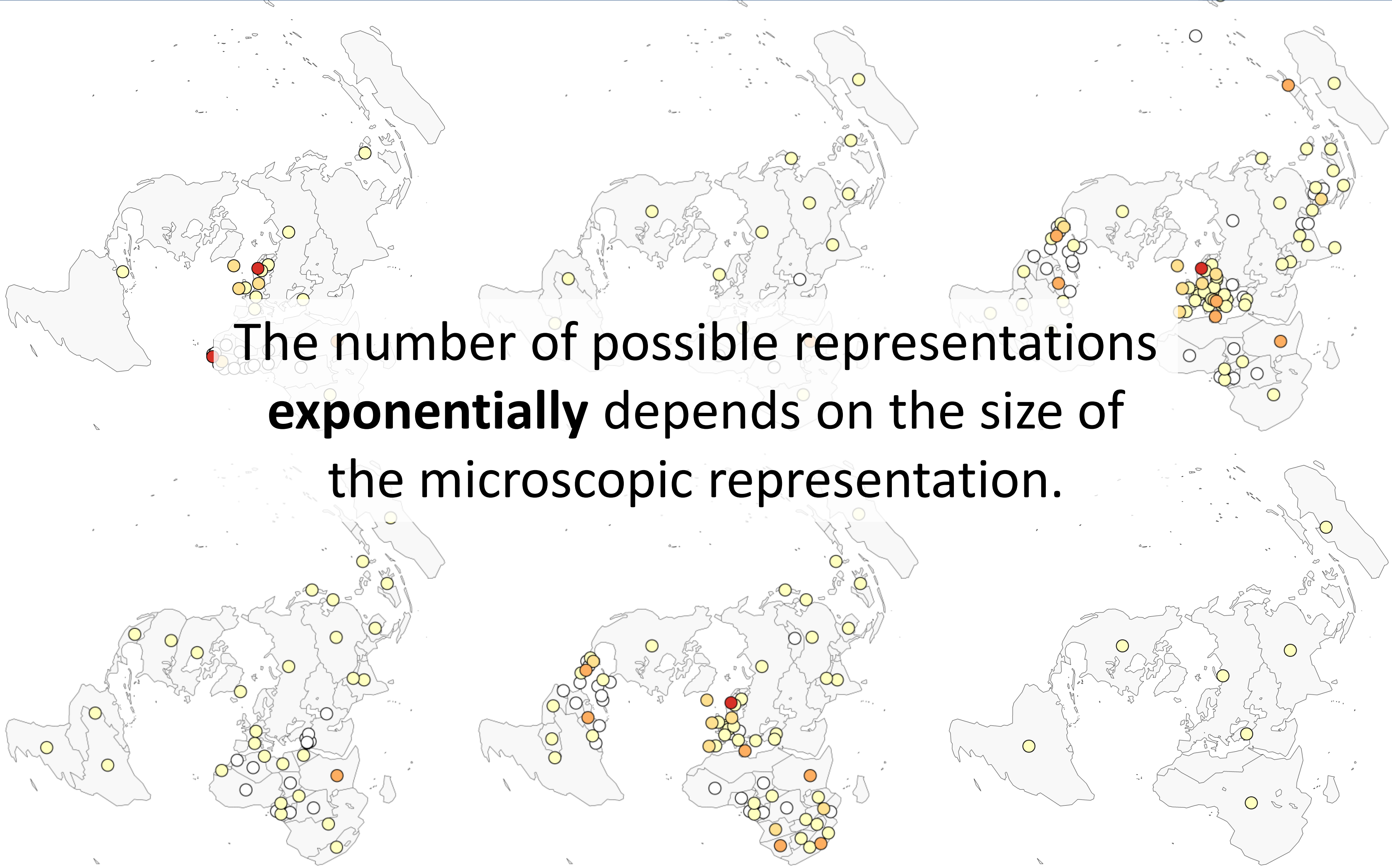


P2: The Levels of Representation



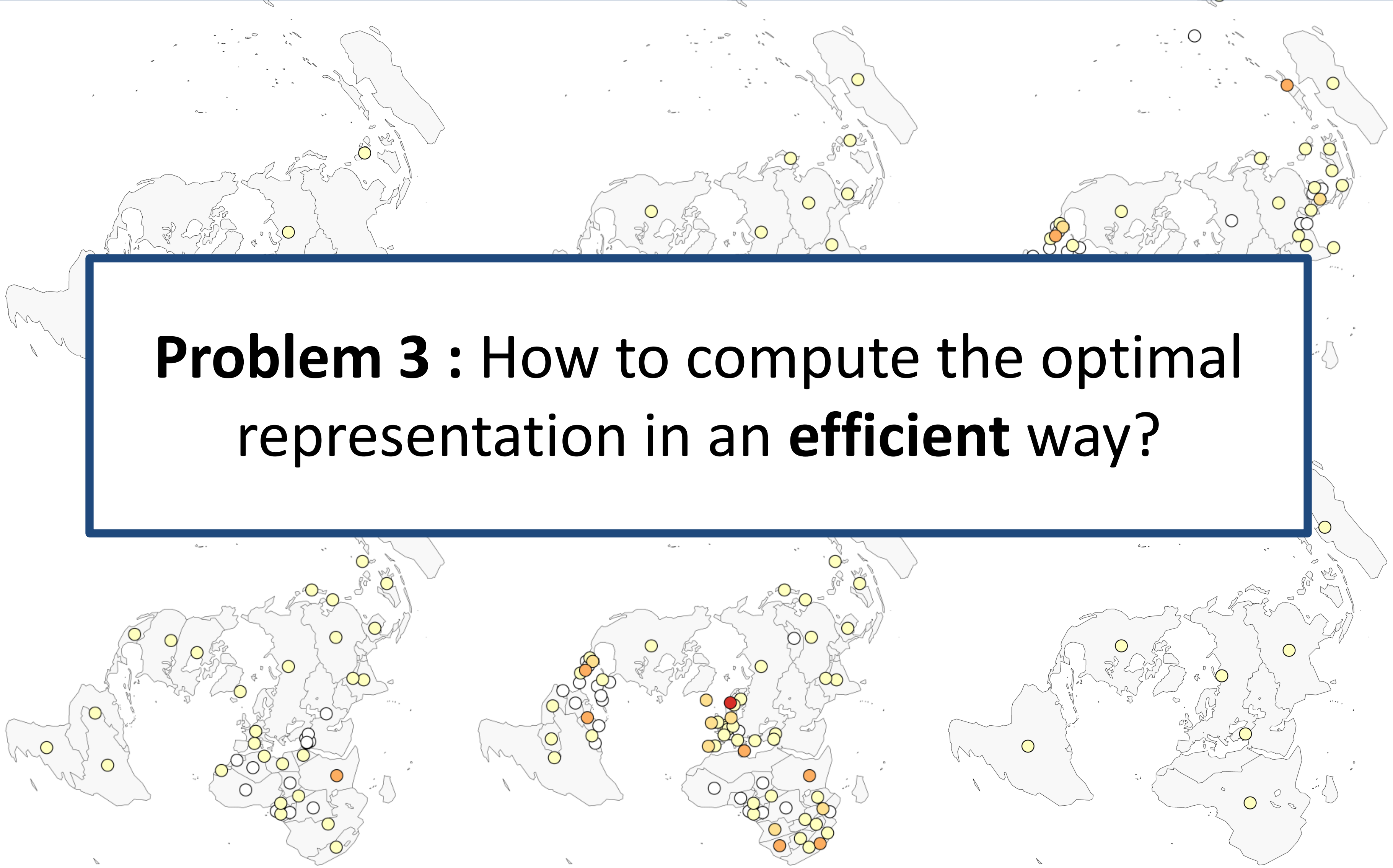
Problem 2: How to find the representation levels that are **relevant** for the analysis?

P3: The Computation of the Best Representations



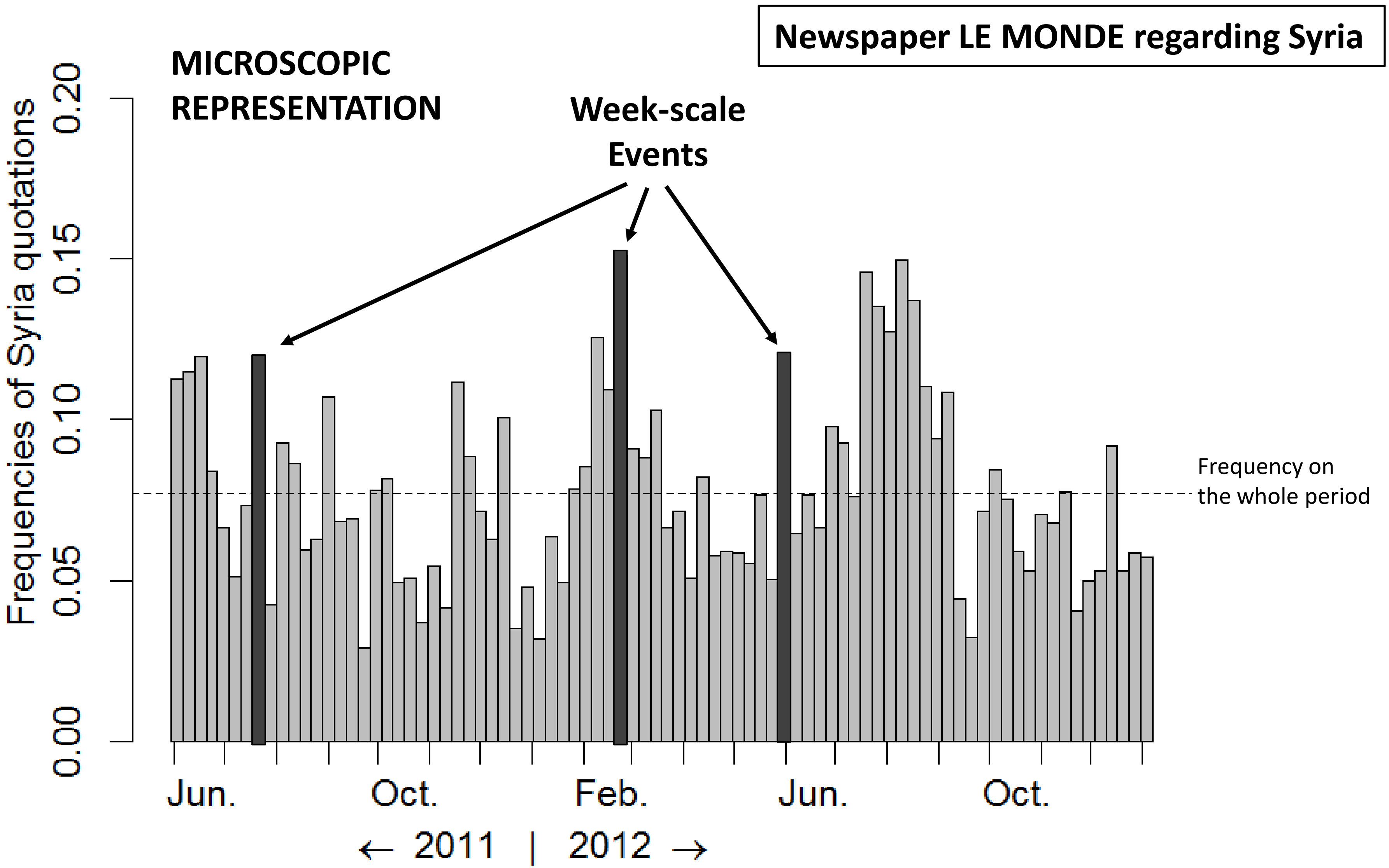
The number of possible representations **exponentially** depends on the size of the microscopic representation.

P3: The Computation of the Best Representations

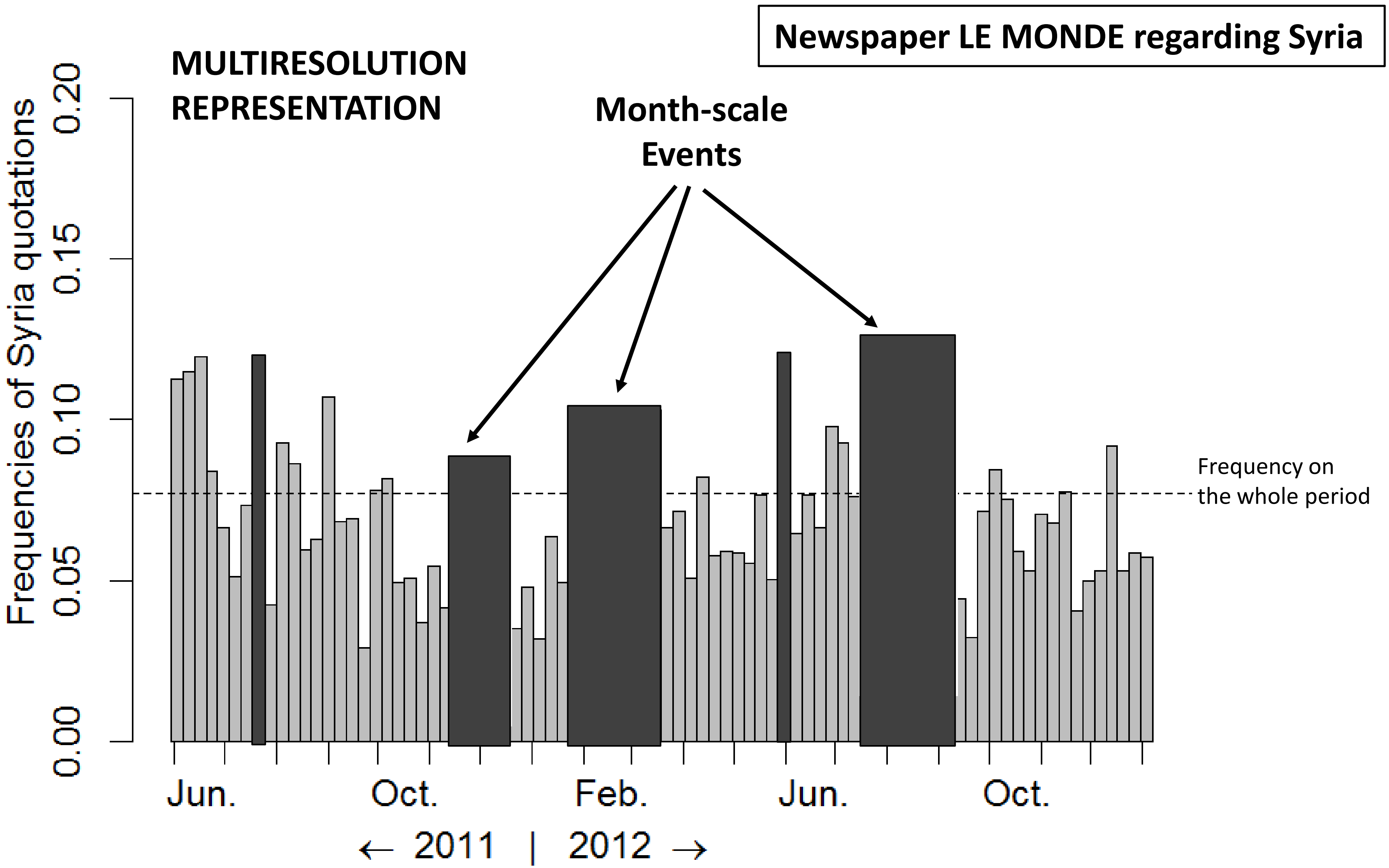


Problem 3 : How to compute the optimal representation in an **efficient** way?

And for Other Dimensions?



And for Other Dimensions?



My Approach

P0 To characterize the aggregation process

→ The algebra of possible partitions

P1 To preserve the system's semantics

→ A constrained partitioning method

To aggregate according to several dimension

→ Some constraints expressing the system's topology

P2 To evaluate and compare the representations

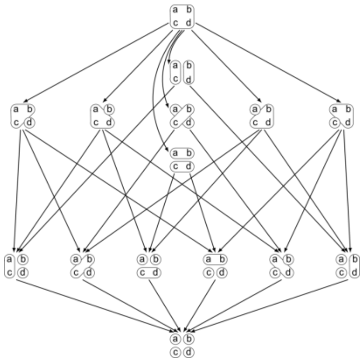
→ Some measures of complexity and information

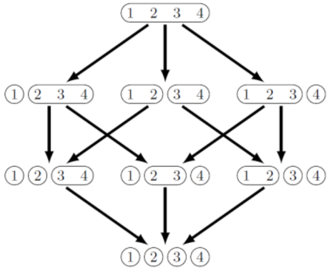
To offer several granularity levels

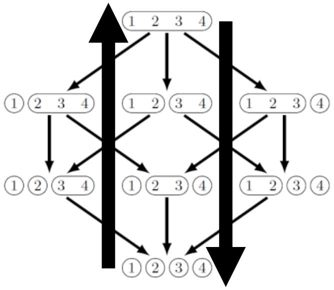
→ The optimization of a compromise

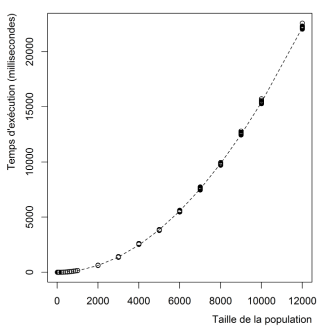
P3 To compute the best representations

→ A generic algorithm of constrained optimization





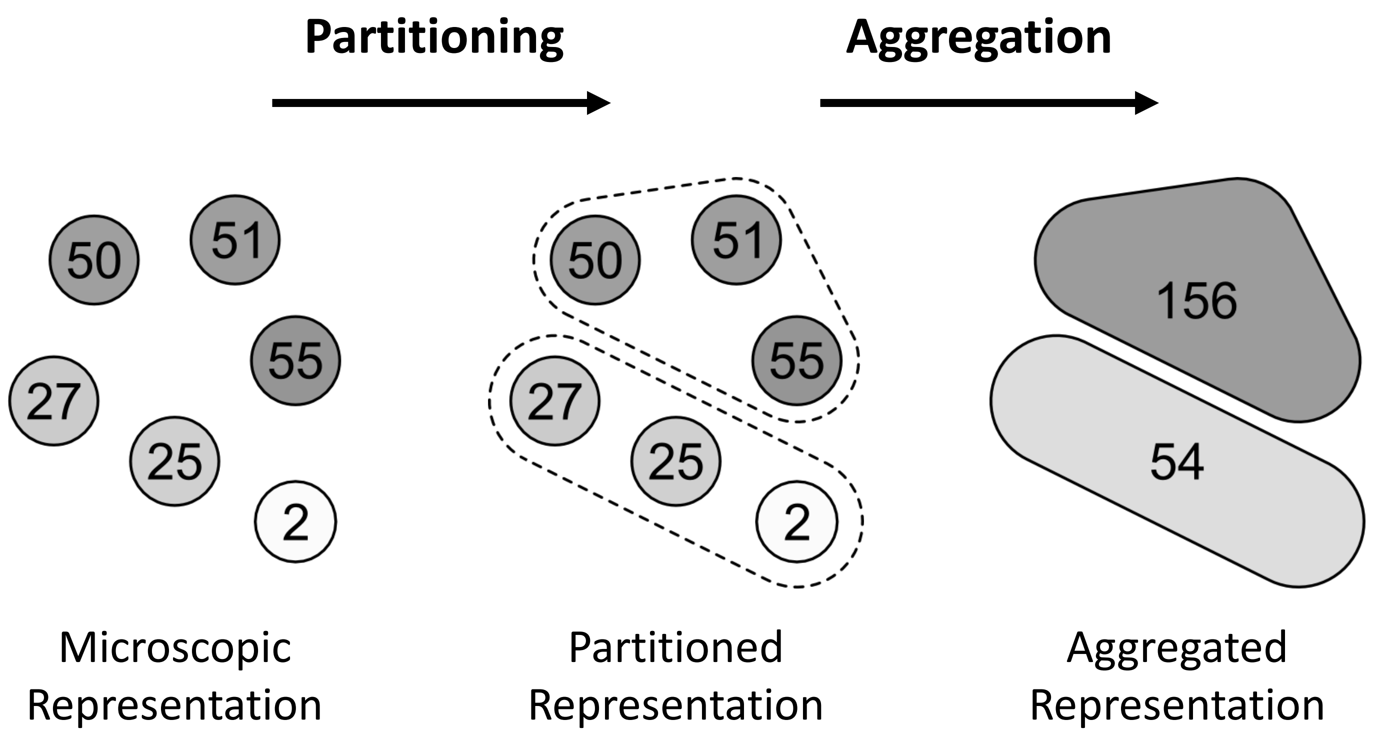




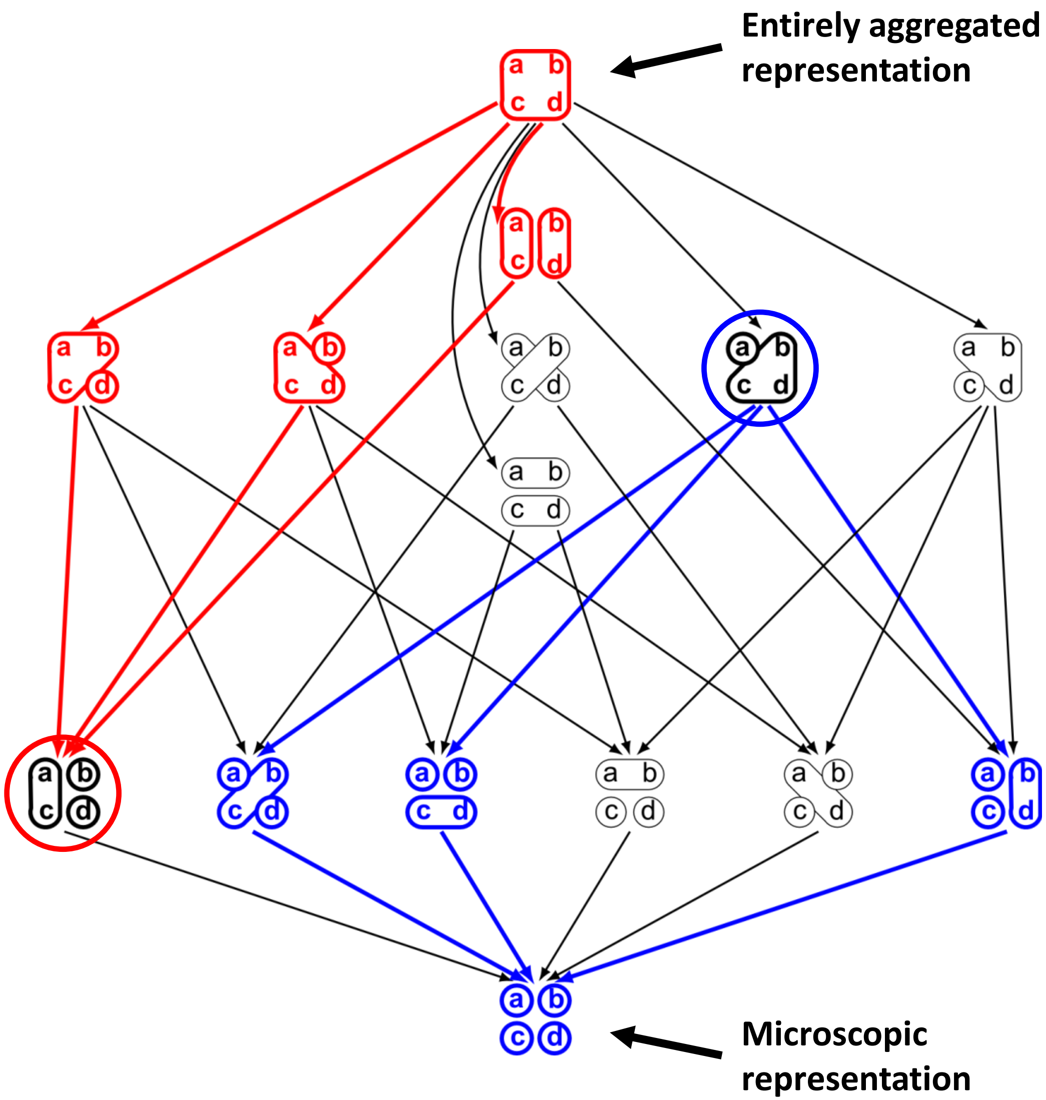
My Approach

P0	To characterize the aggregation process → The algebra of possible partitions
P1	To preserve the system's semantics → A constrained partitioning method To aggregate according to several dimension → Some constraints expressing the system's topology
P2	To evaluate and compare the representations → Some measures of complexity and information To offer several granularity levels → The optimization of a compromise
P3	To compute the best representations → A generic algorithm of constrained optimization

The Aggregation Process



Set of Possible Partitions

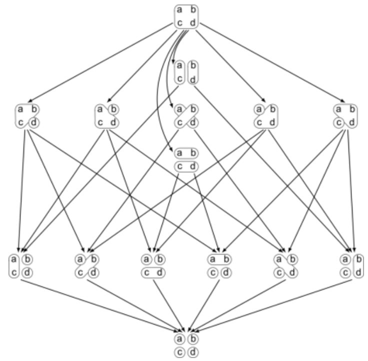


Algebraic Structure

A partial order on the set of possible partitions

→ **the refinement relation**

My Approach



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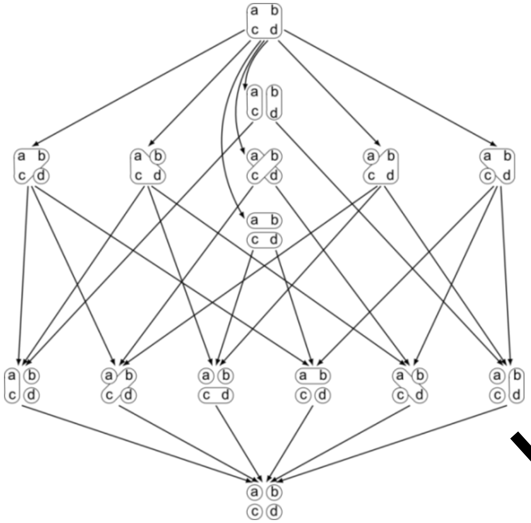
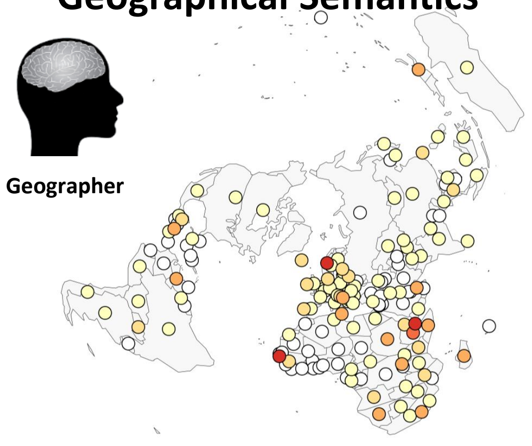
→ A generic algorithm of constrained optimization

Problems and Objectives

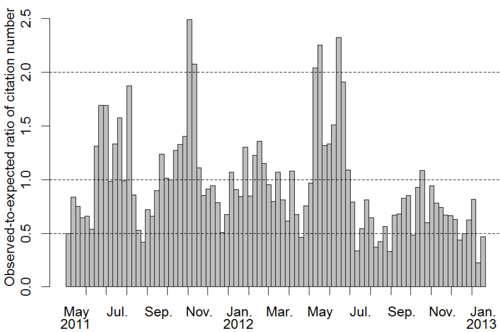
Set of possible partitions



Geographical Semantics

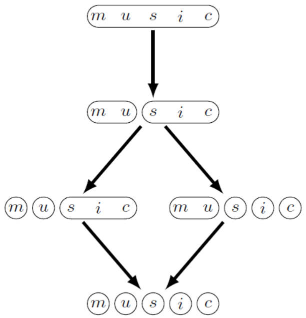


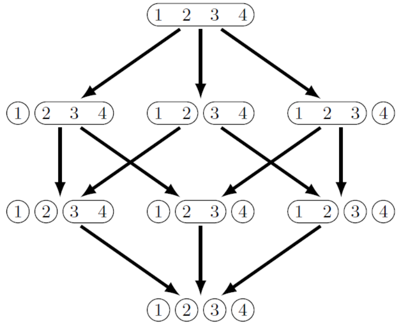
Temporal Semantics



Constraints

Set of admissible partitions

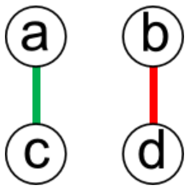




Constrained Partitioning

At the instances level

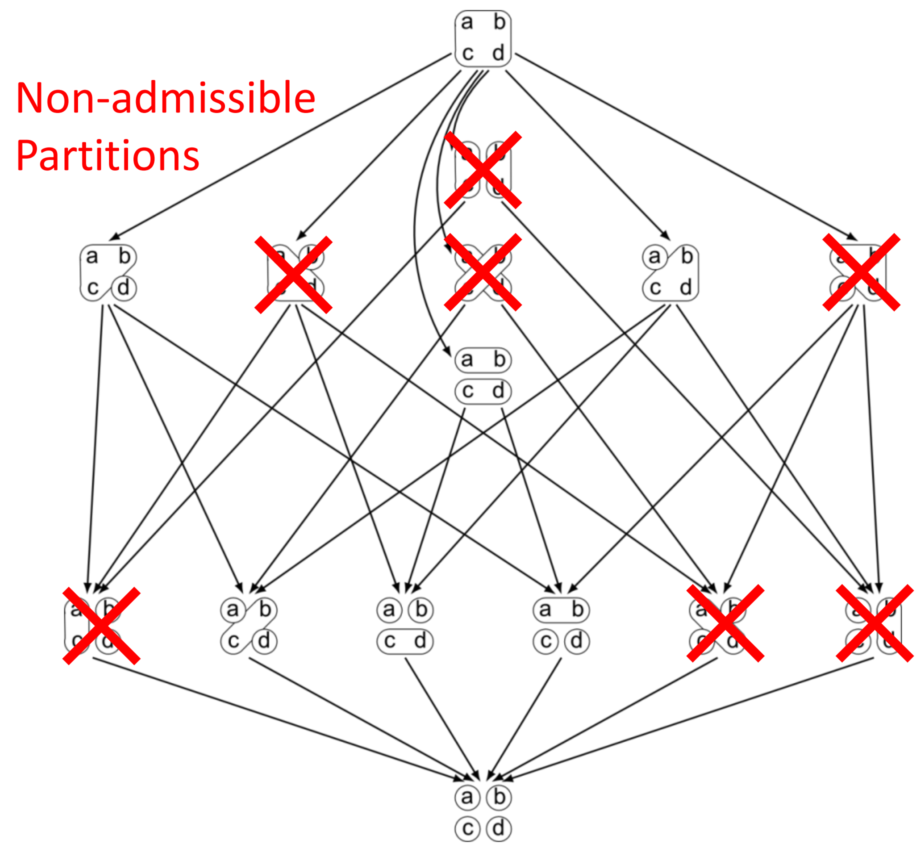
[Davidson and Basu, 2007]



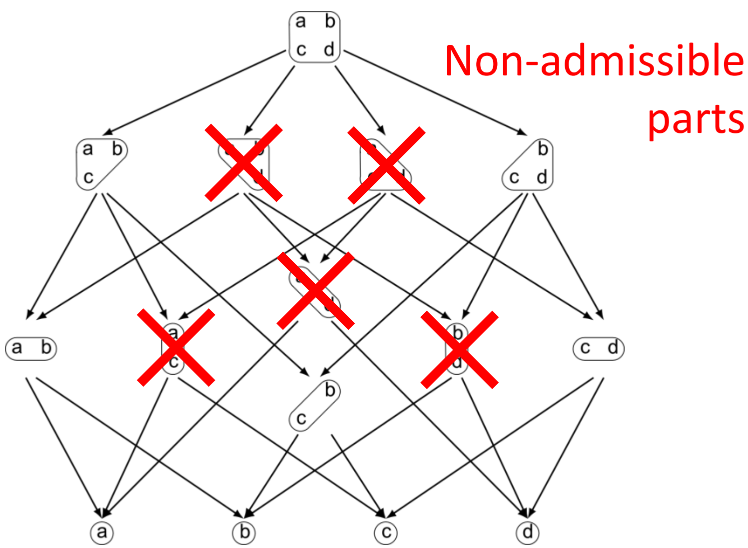
Constrained Partitioning

At the instances level
[Davidson and Basu, 2007]

At the partitions level
[Lamarche-Perrin *et al.*, IAT 2013]

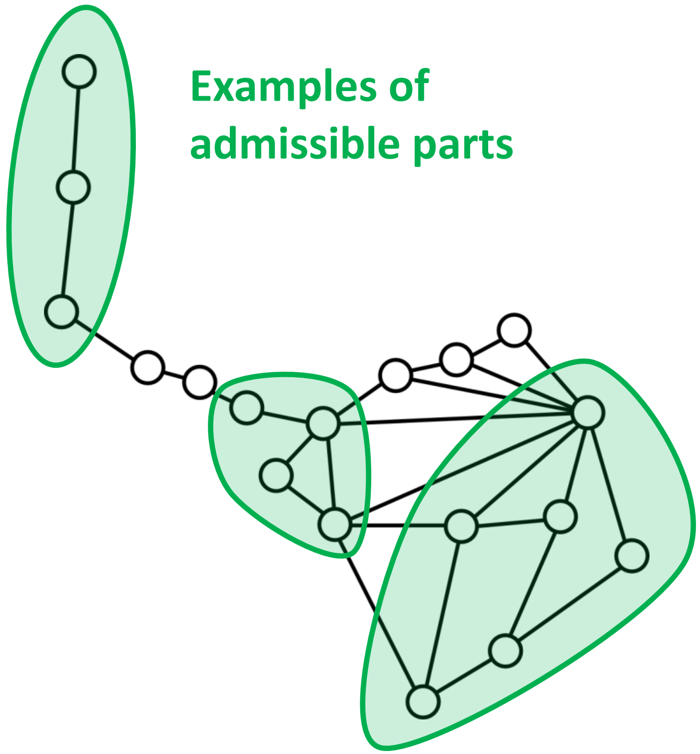


At the parts level
[Lamarche-Perrin *et al.*, IAT 2013]



Preserving the Neighborhood Relation

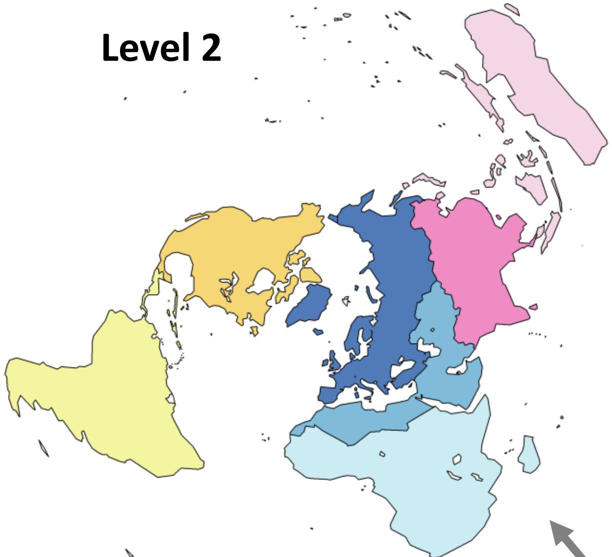
Admissible Parts: set of connected countries regarding the adjacency graph



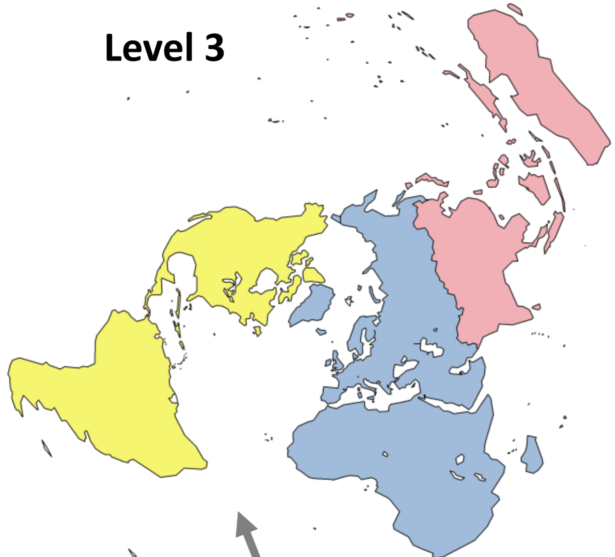
The WUTS Hierarchy

[Grasland and Didelon, 2007]

Level 2

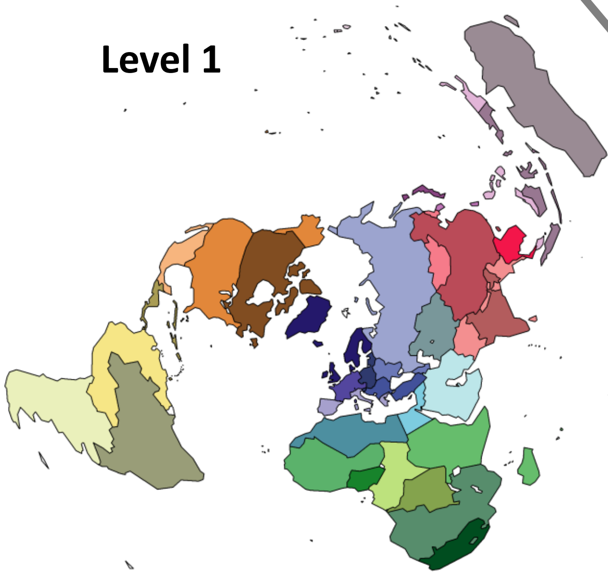


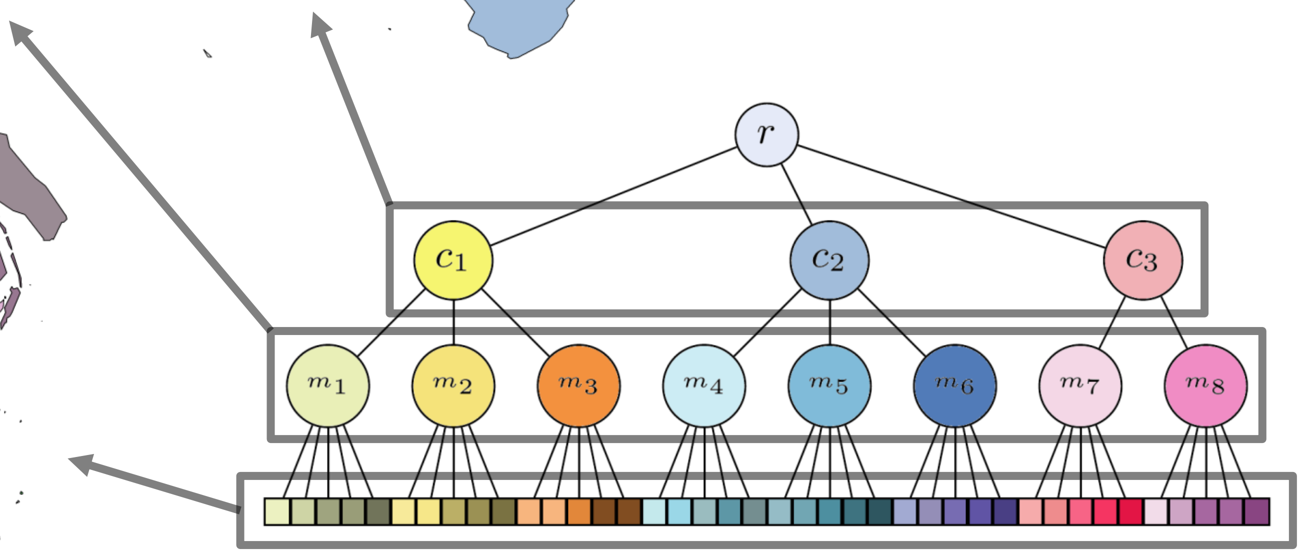
Level 3



Admissible Parts:
set of countries that are politically, culturally and economically consistent

Level 1

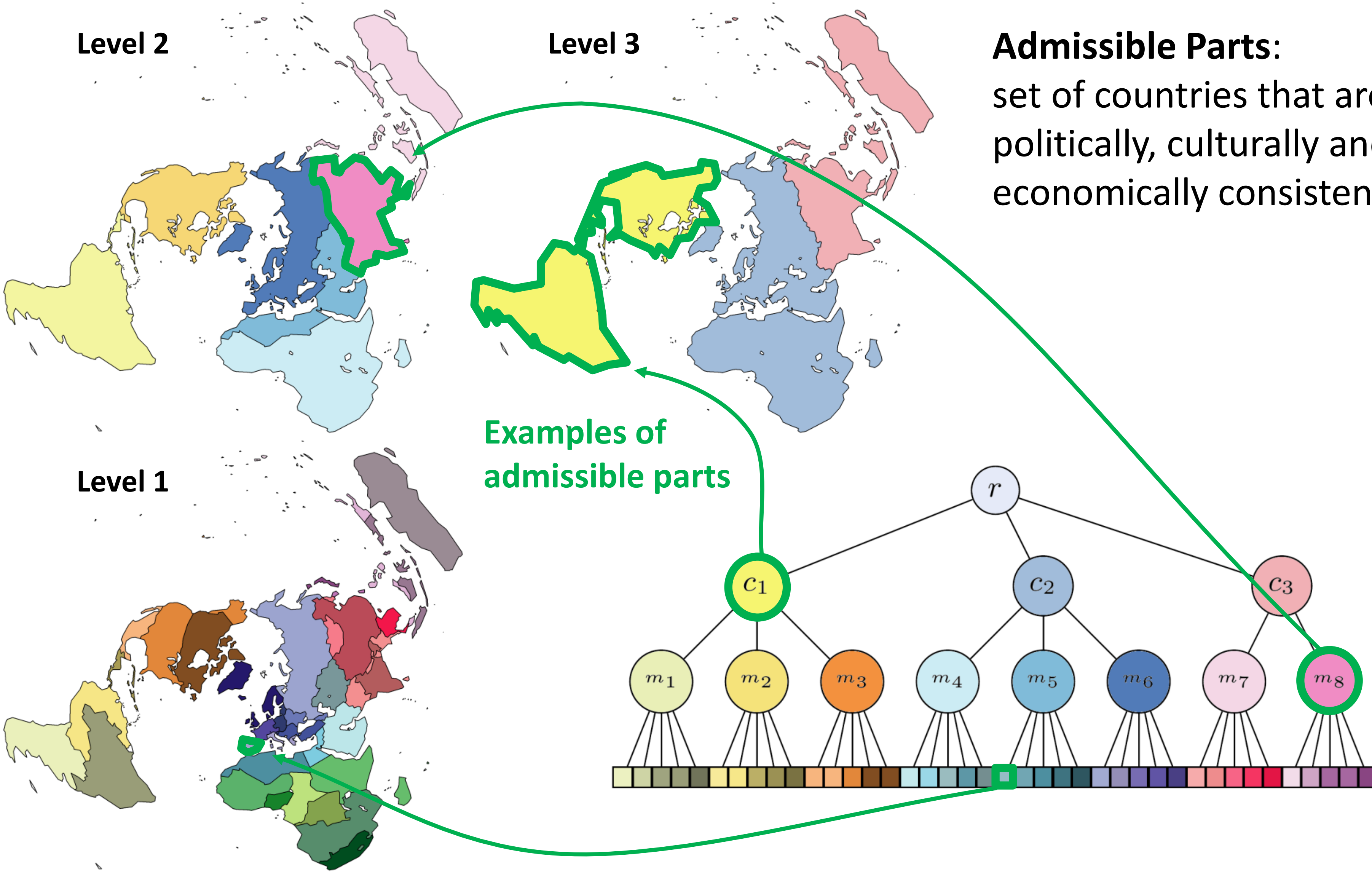




The WUTS Hierarchy

[Grasland and Didelon, 2007]

Admissible Parts: set of countries that are politically, culturally and economically consistent



Aggregating according to a Hierarchy

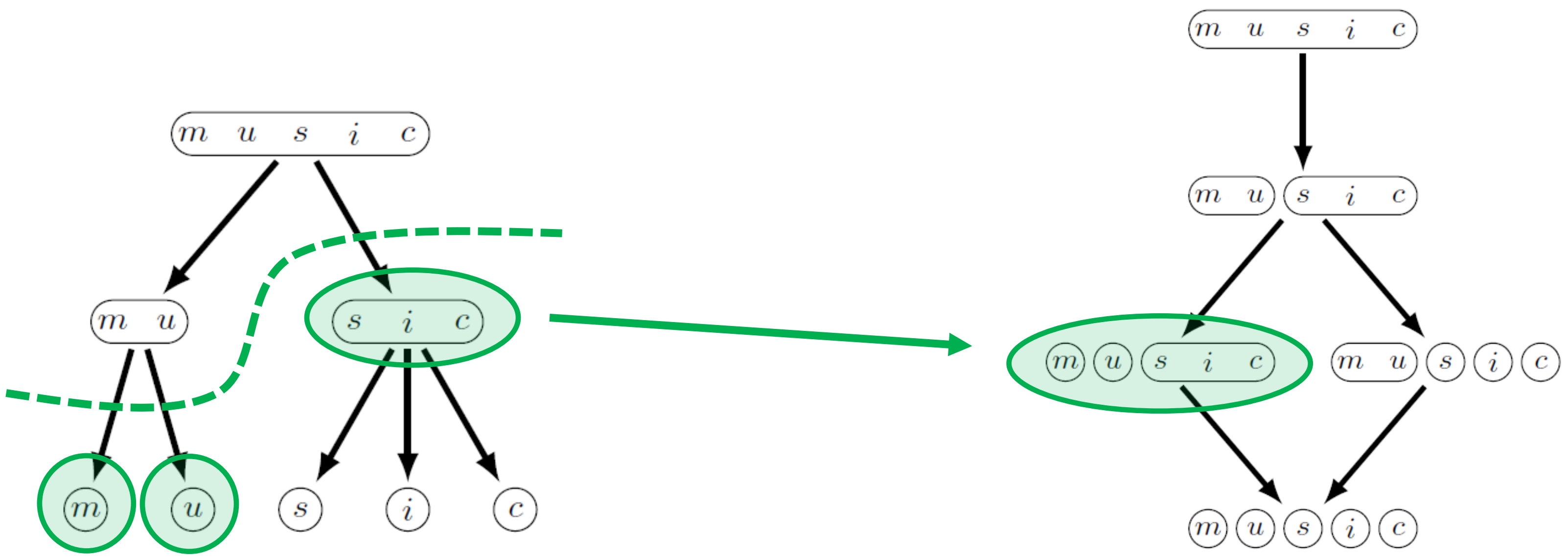
Admissible Parts
(nodes of the hierarchy)

Admissible Partitions
(cuts of the hierarchy)

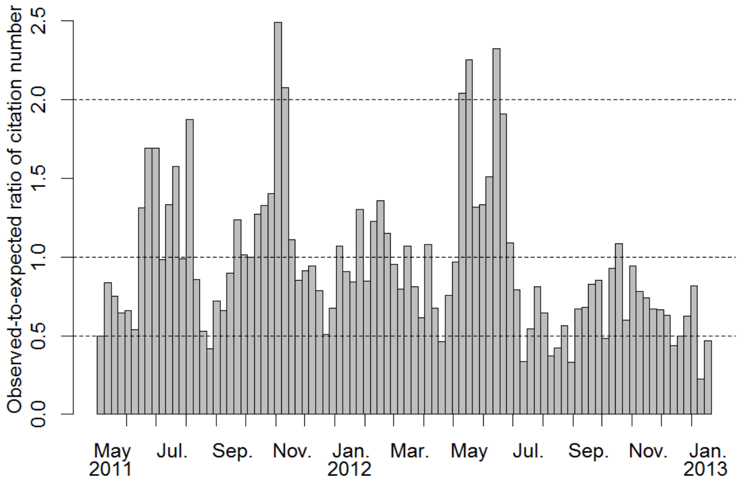
Aggregating according to a Hierarchy

Admissible Parts
(nodes of the hierarchy)

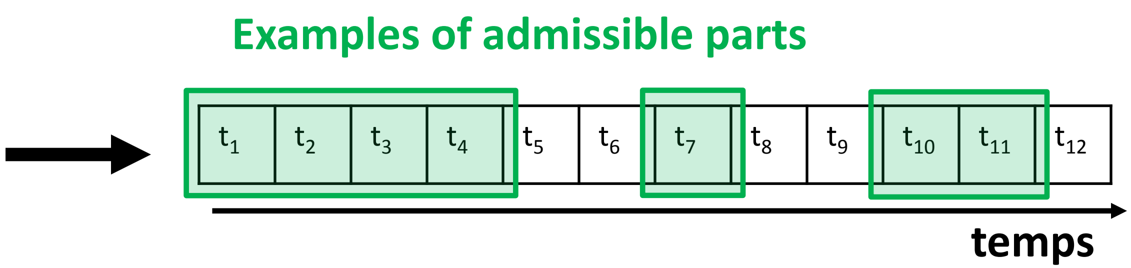
Admissible Partitions
(cuts of the hierarchy)



Preserving the Order of Time

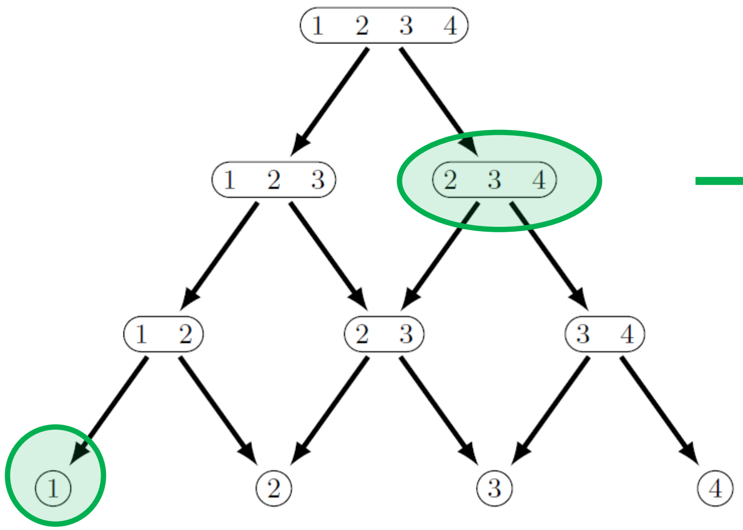


Admissible Parts:
time intervals

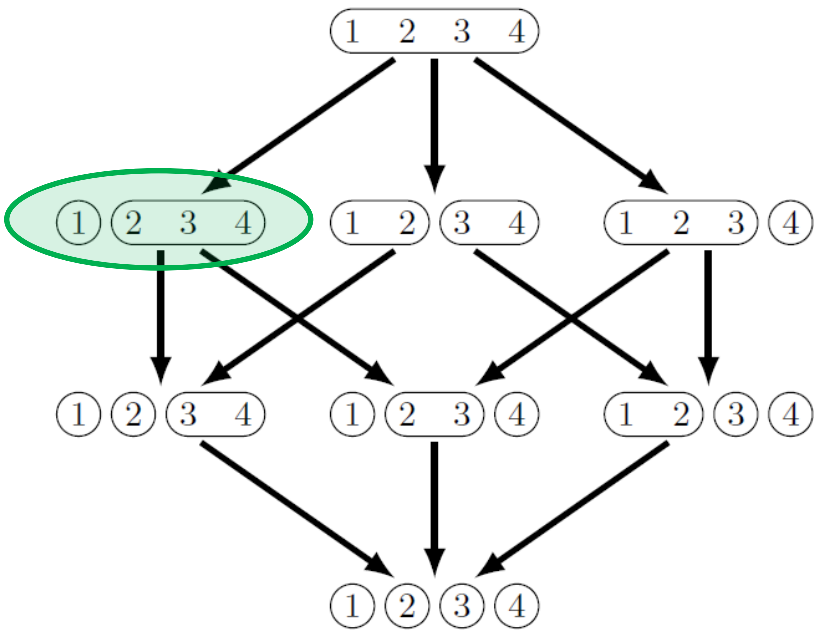


Aggregating according to a Total Order

Admissible Parts
(time intervals)

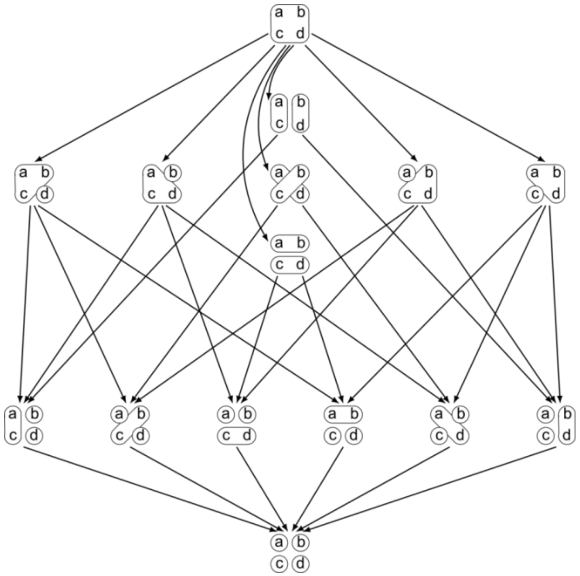


Admissible Partitions
(interval sequences)

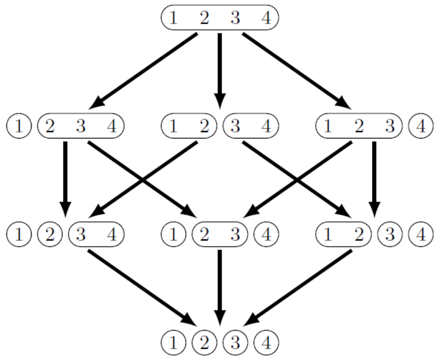


Complexity of Algebraic Structures

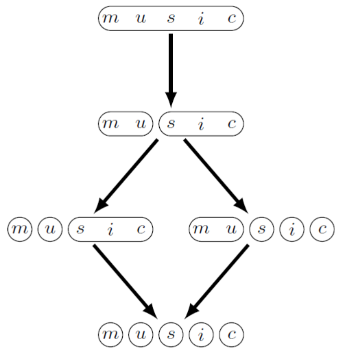
Non-constrained partitions



Admissible partitions according to a **total order**



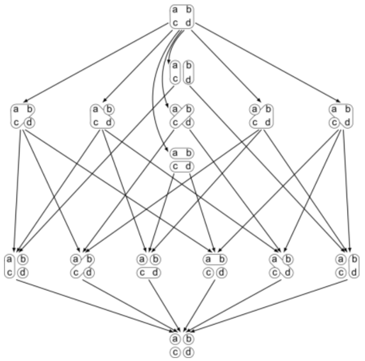
Admissible partitions according to a **hierarchy**

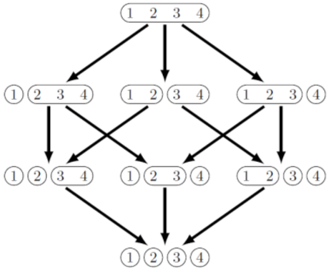


Less constrained | **More constrained**

More complex | **Less complex**

My Approach





P0 To characterize the aggregation process

→ The algebra of possible partitions

P1 To preserve the system's semantics

→ A constrained partitioning method

To aggregate according to several dimension

→ Some constraints expressing the system's topology

P2 To evaluate and compare the representations

→ Some measures of complexity and information

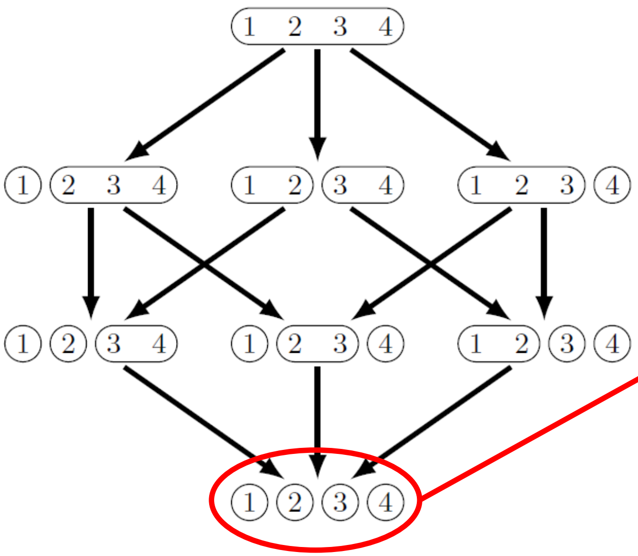
To offer several granularity levels

→ The optimization of a compromise

P3 To compute the best representations

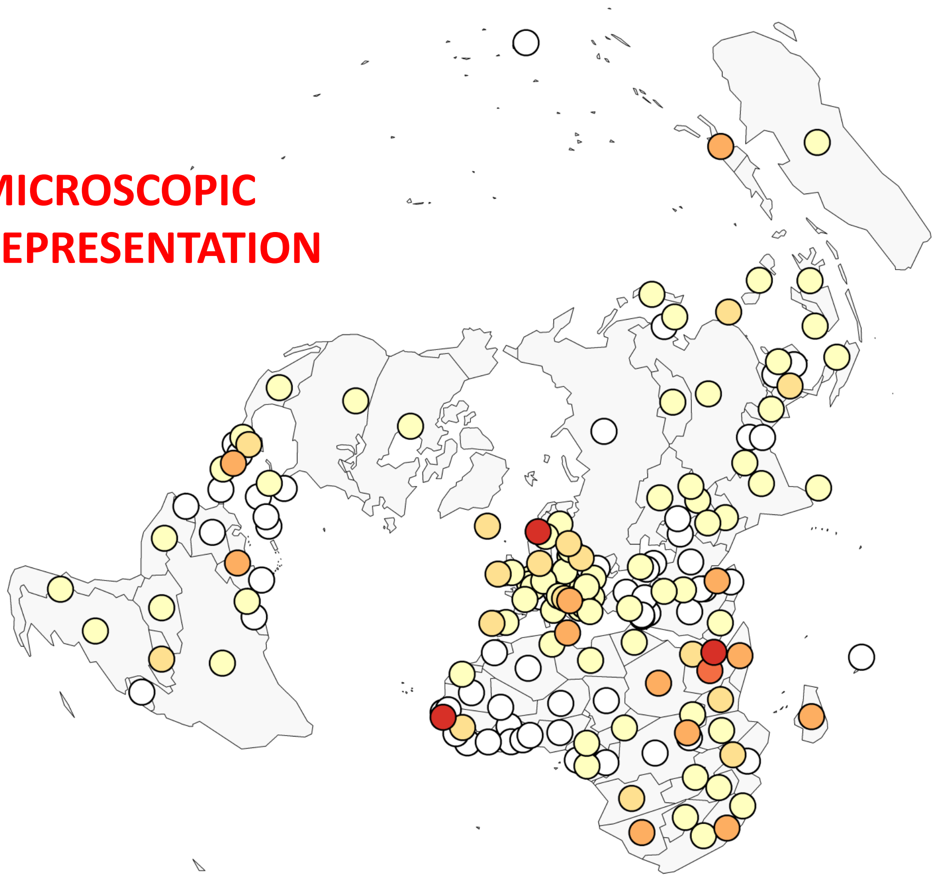
→ A generic algorithm of constrained optimization

Objectives and Difficulties



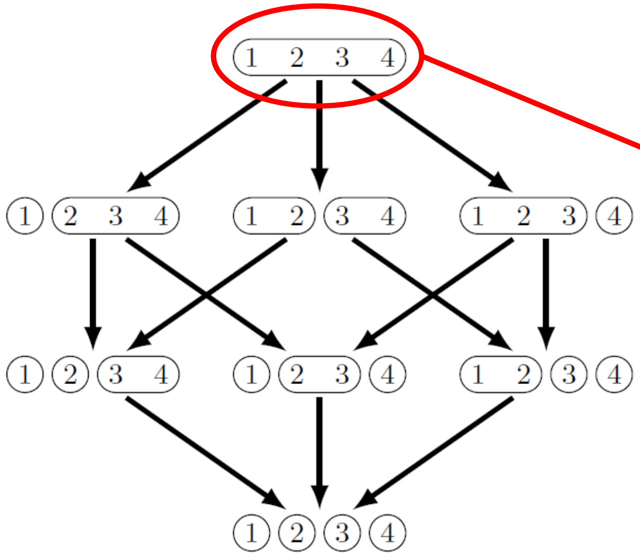
Which **admissible partition** is the **best partition** for a particular dataset?

MICROSCOPIC REPRESENTATION



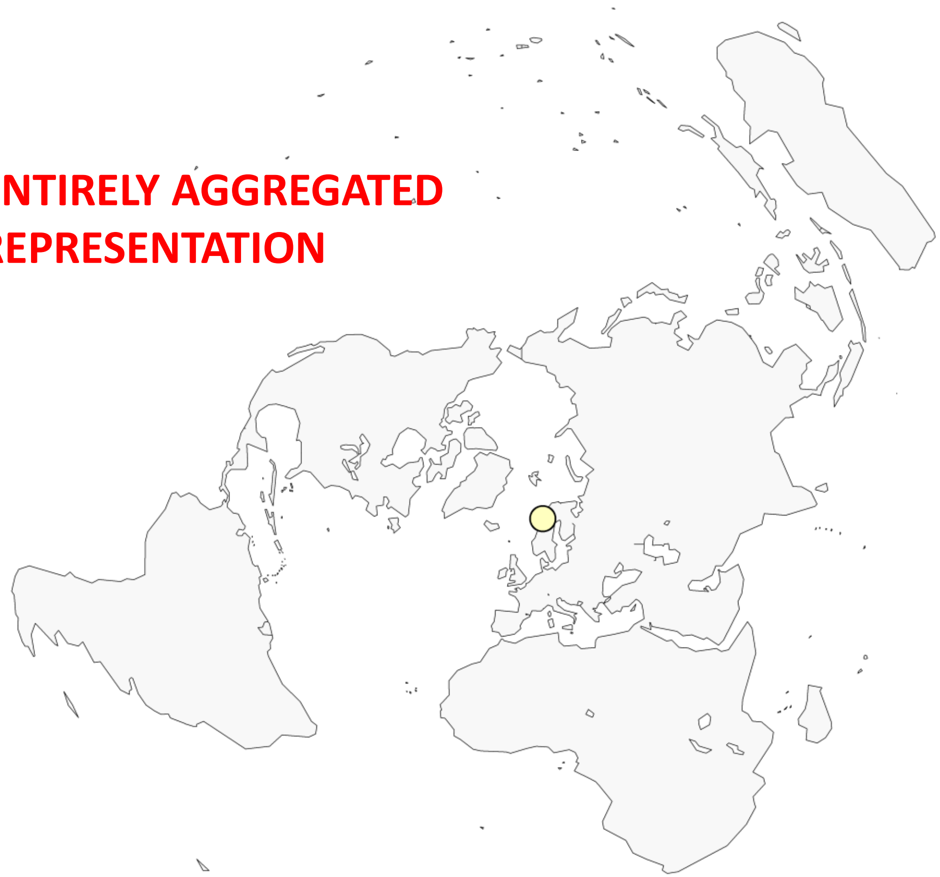
→ TOO COMPLEX TO SCALE-UP

Objectives and Difficulties



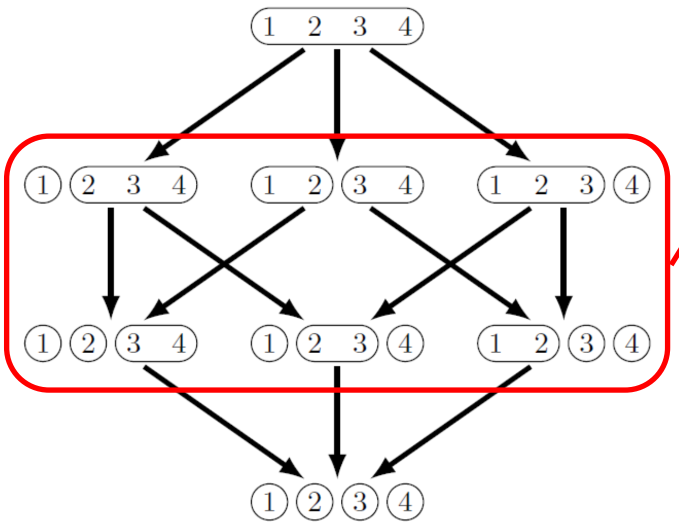
ENTIRELY AGGREGATED REPRESENTATION

Which **admissible partition** is the **best partition** for a particular dataset?

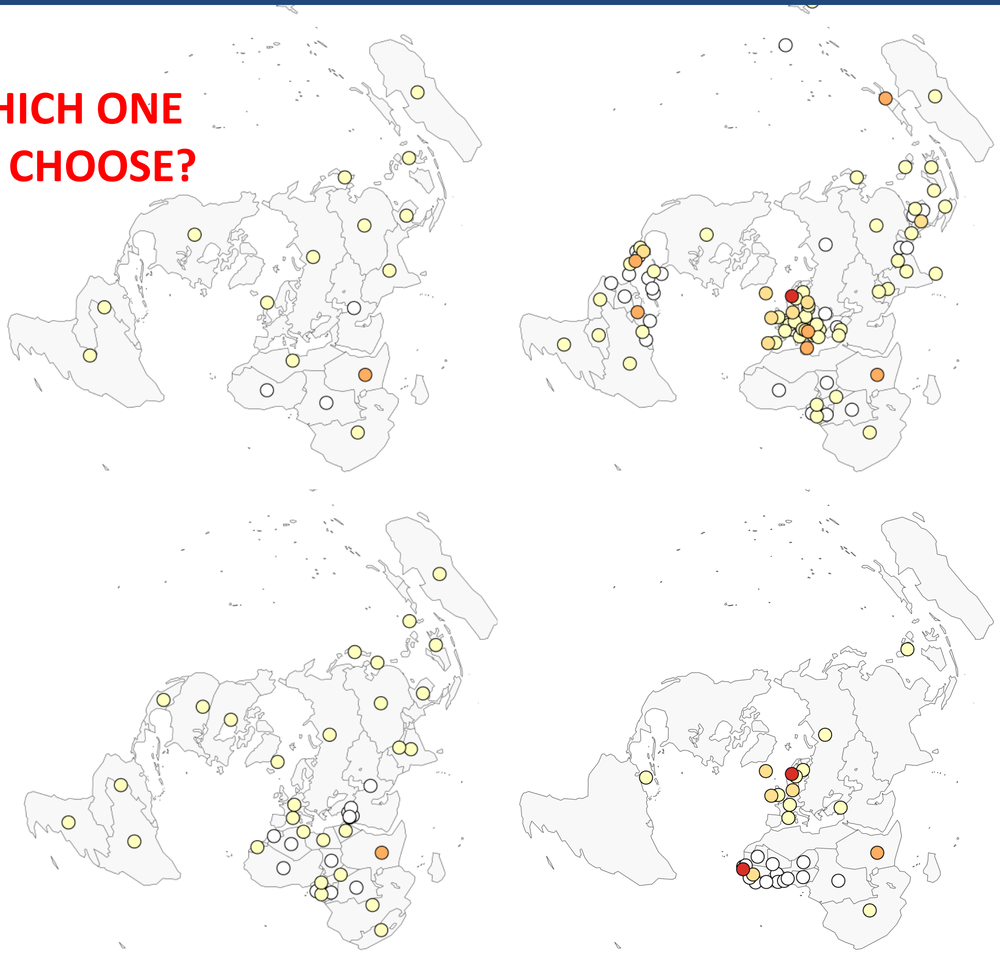


→ GIVES TOO FEW INFORMATION

Objectives and Difficulties

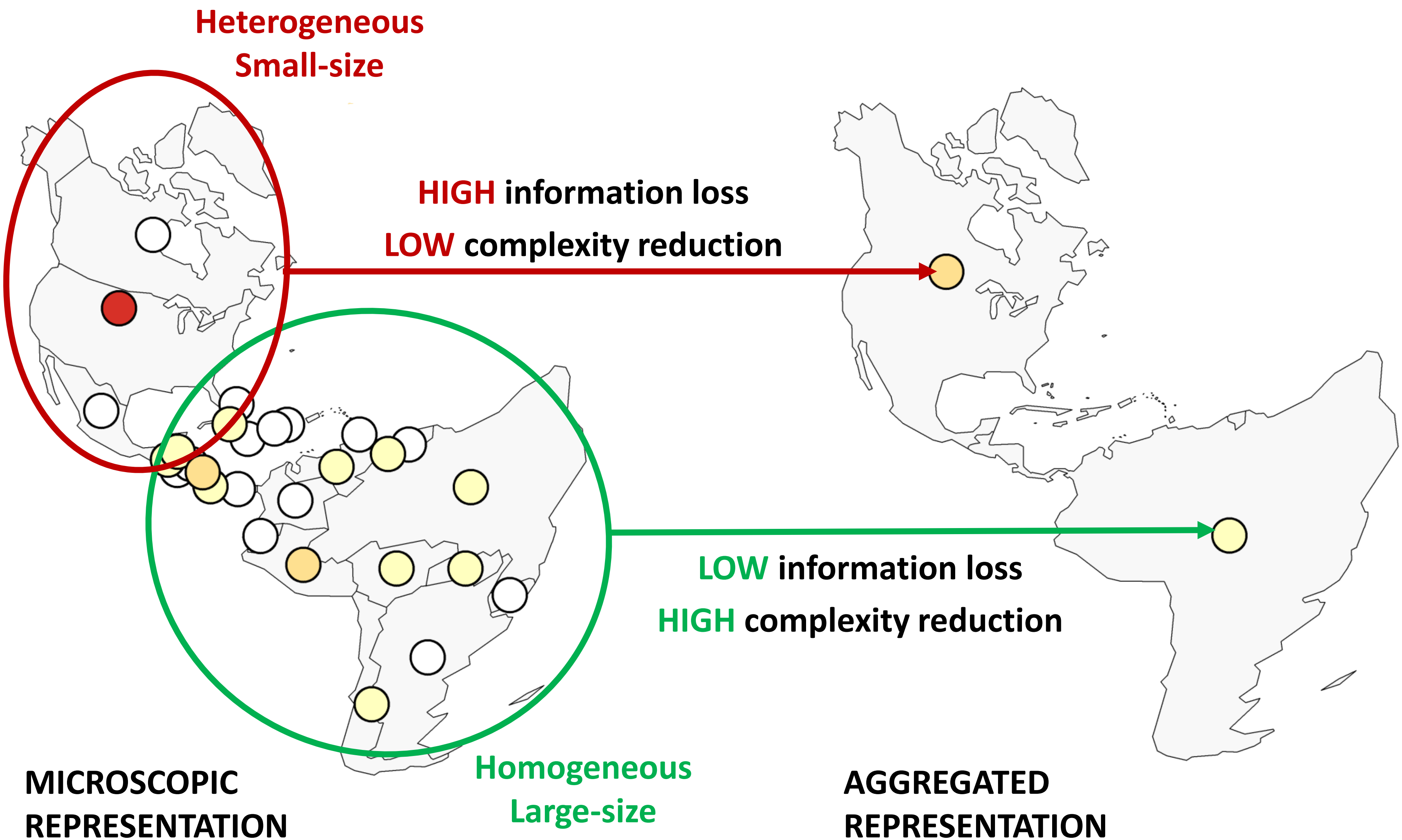


WHICH ONE TO CHOOSE?

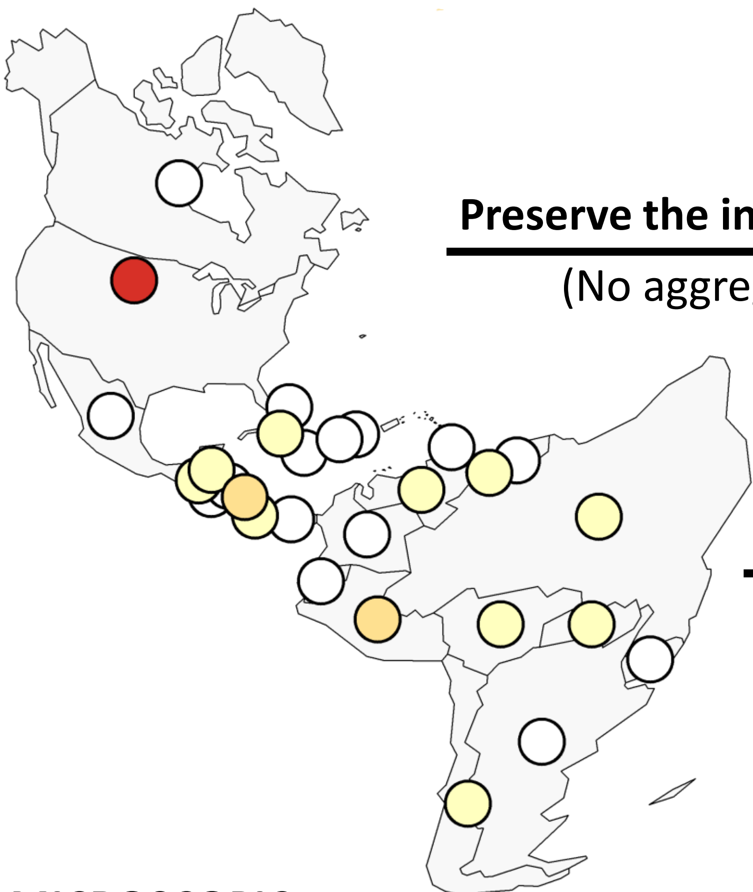


Which **admissible partition** is the **best partition** for a particular dataset?

Complexity and Information



Complexity and Information

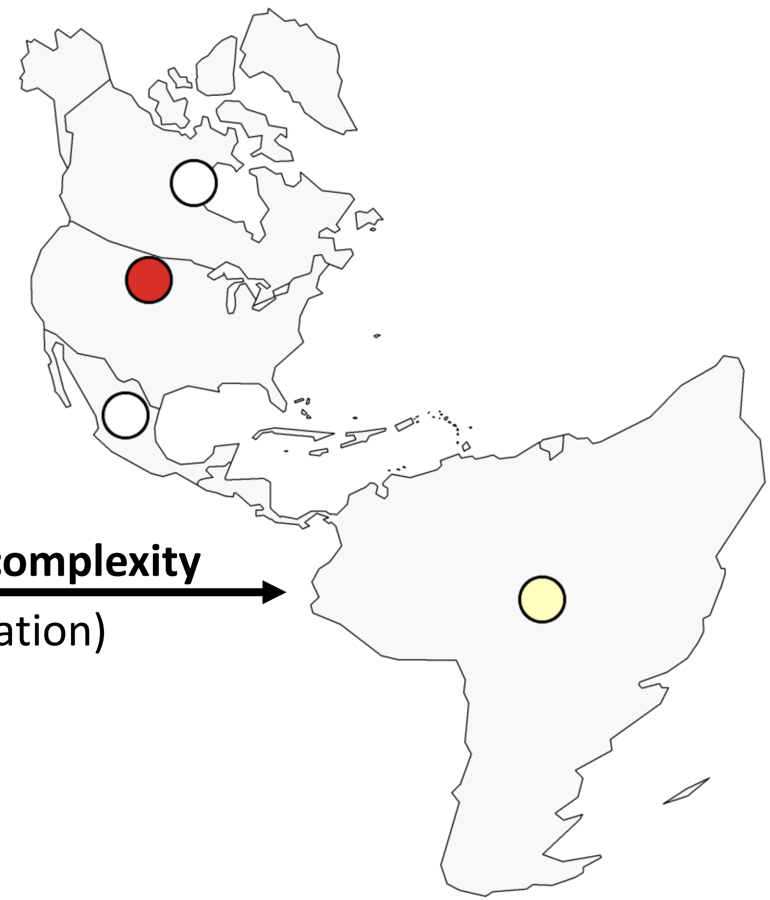


Preserve the information

(No aggregation)

Reduce the complexity

(Aggregation)



MICROSCOPIC REPRESENTATION

AGGREGATED REPRESENTATION

Quality Measures

[Lamarche-Perrin *et al.*, ECCS 2012]

Complexity depends on the **tasks** we want to fulfill and the **description tools** that are available to do so

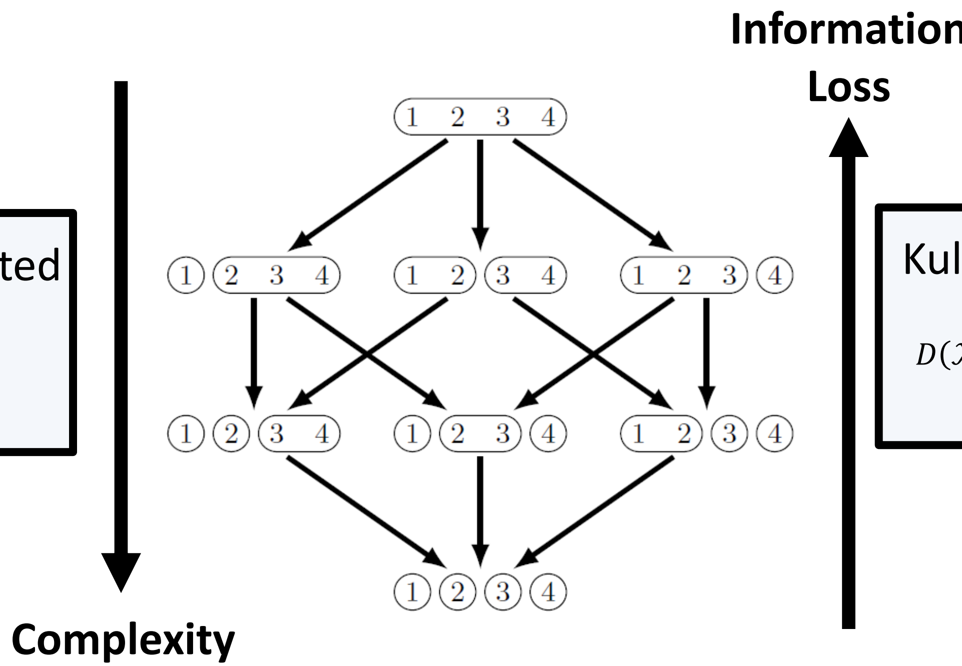
[Bonabeau and Dessalles, 1997]

Information loss is measured by the **KL-divergence** between two probabilistic distributions

[Kullback et Leibler, 1951]

Number of represented aggregates:

$$T(\mathcal{X}) = |\mathcal{X}|$$



Kullback-Leibler Divergence

$$D(\mathcal{X}) = \sum_{X \in \mathcal{X}} \sum_{x \in X} \frac{v(x)}{v(\Omega)} \log_2 \left(\frac{v(x)\,|X|}{v(X)} \right)$$

Measures Decomposability

Number of represented aggregates:

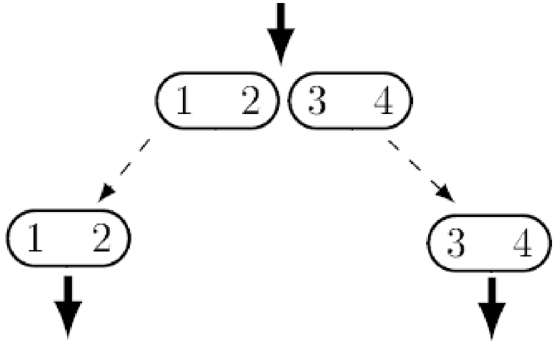
$$T(\mathcal{X}) = |\mathcal{X}|$$

Kullback-Leibler Divergence

$$D(\mathcal{X}) = \sum_{X \in \mathcal{X}} \sum_{x \in X} \frac{v(x)}{v(\Omega)} \log_2 \left(\frac{v(x)\,|X|}{v(X)} \right)$$

Additive Decomposability: The quality of a partition is the sum of the qualities of its parts

[Jackson *et al.*, 2005] [Csiszár, 2008]



$$Q\{\{1,2\},\{3,4\}\}$$

$$=$$

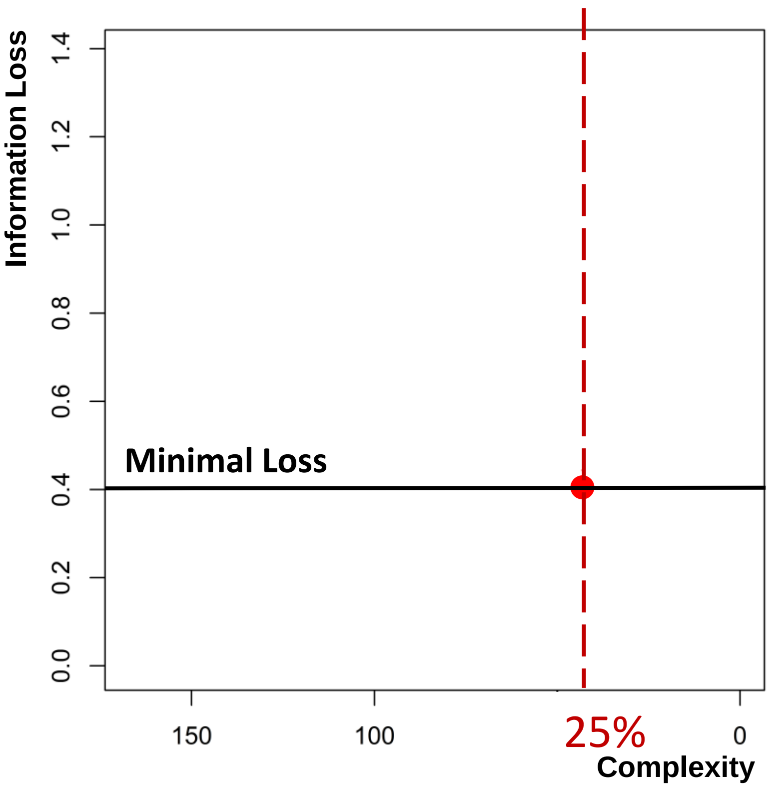
$$Q\{1,2\} + Q\{3,4\}$$

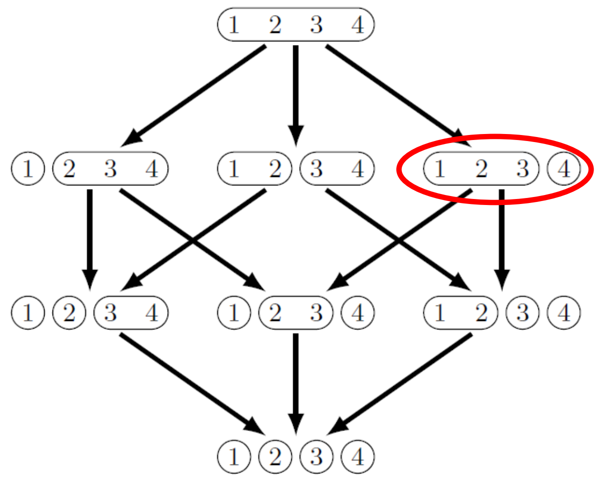
Optimizing the Partition Qualities

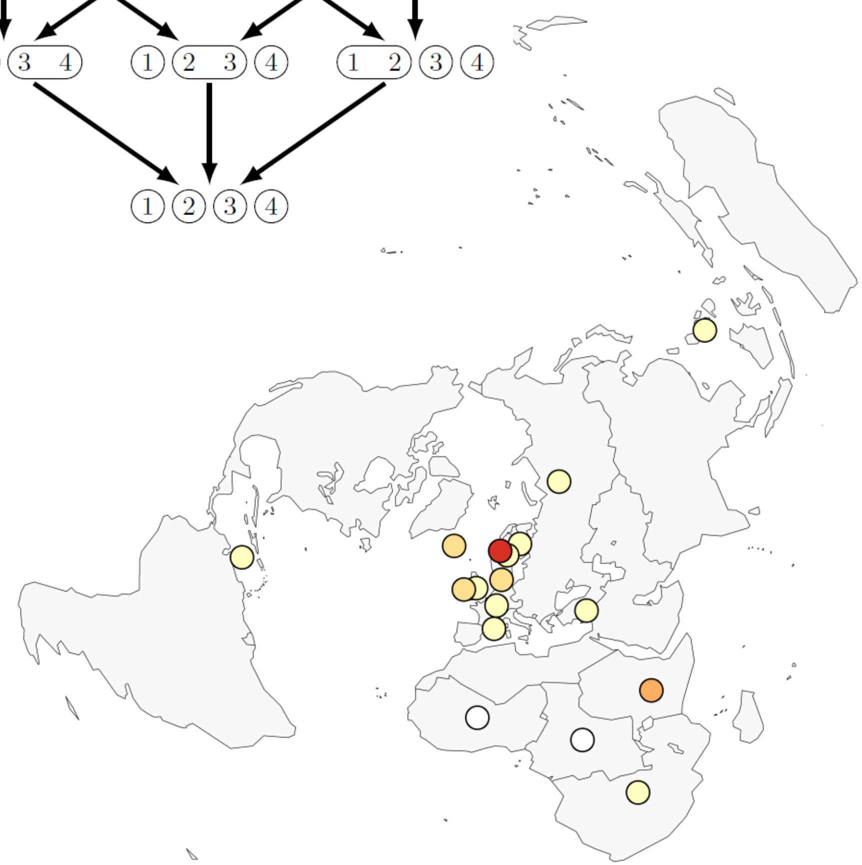
Two criteria that should be optimized

Compromise of Quality:

$$CQL_\alpha = \alpha \frac{\Delta T}{\Delta T_{\max}} - (1-\alpha)\frac{D}{D_{\max}}$$







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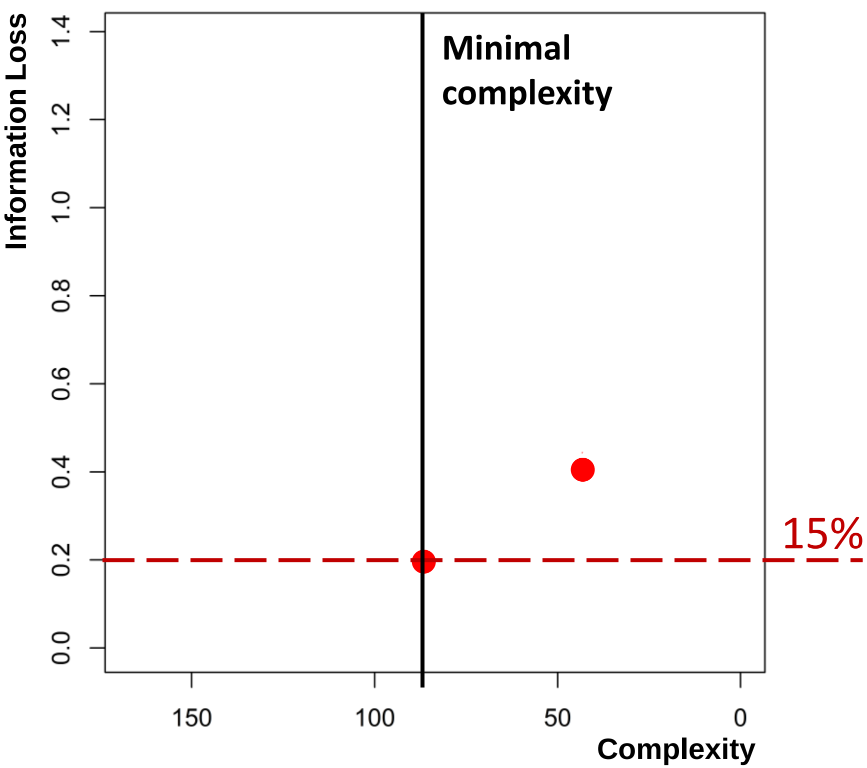

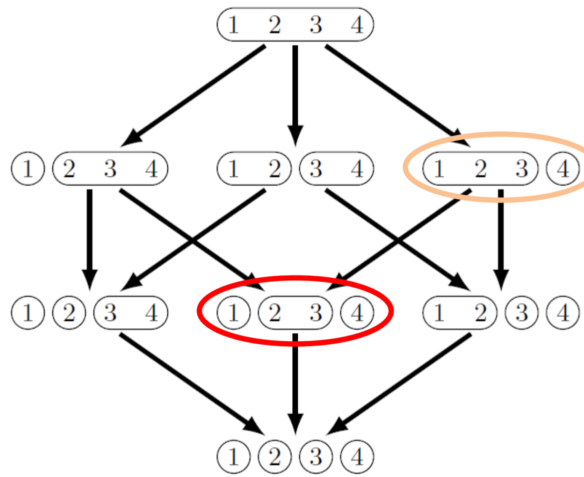

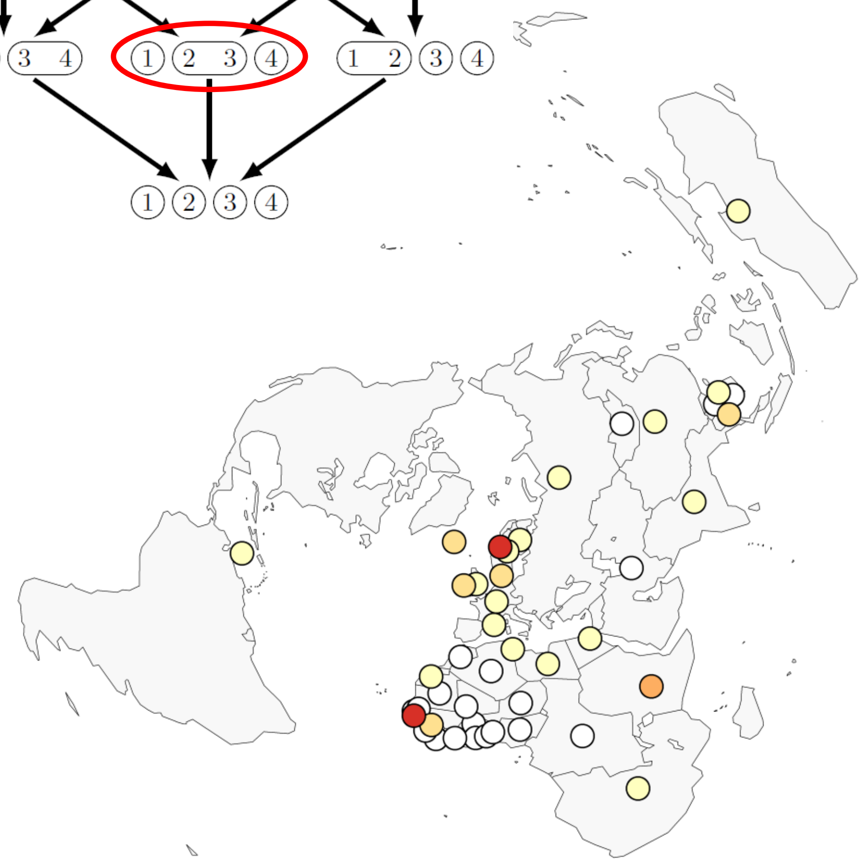

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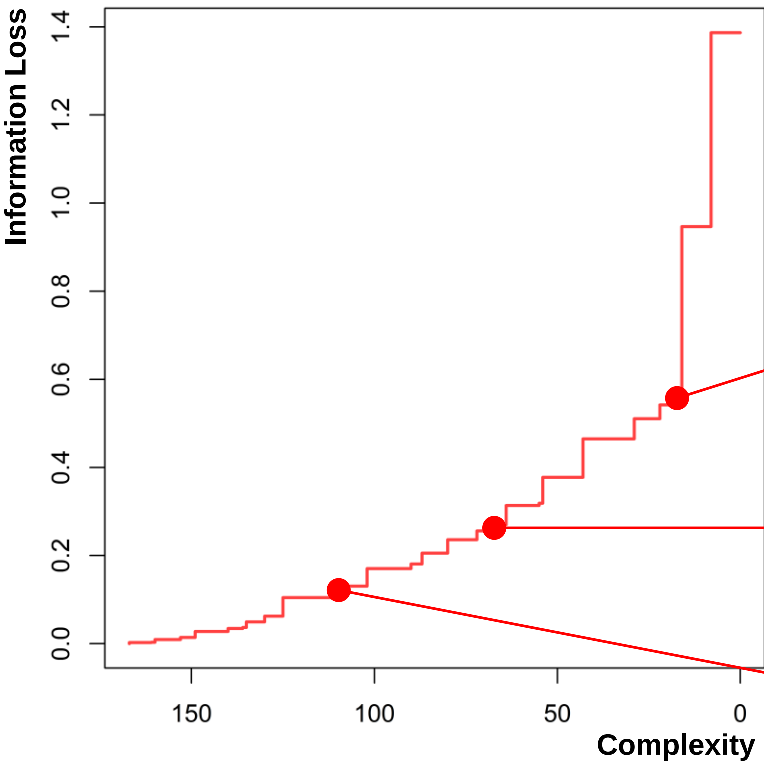
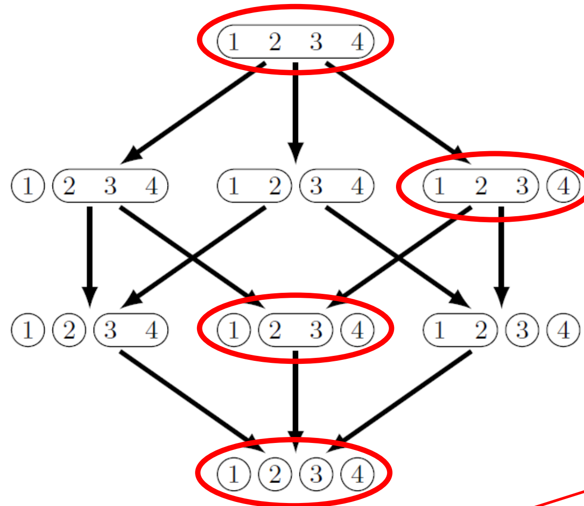
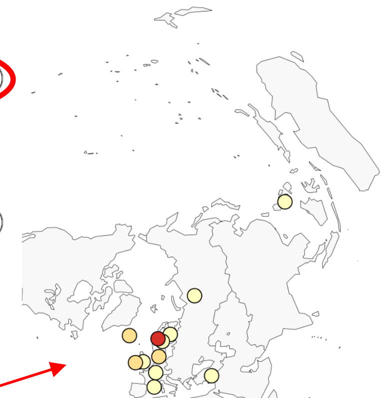
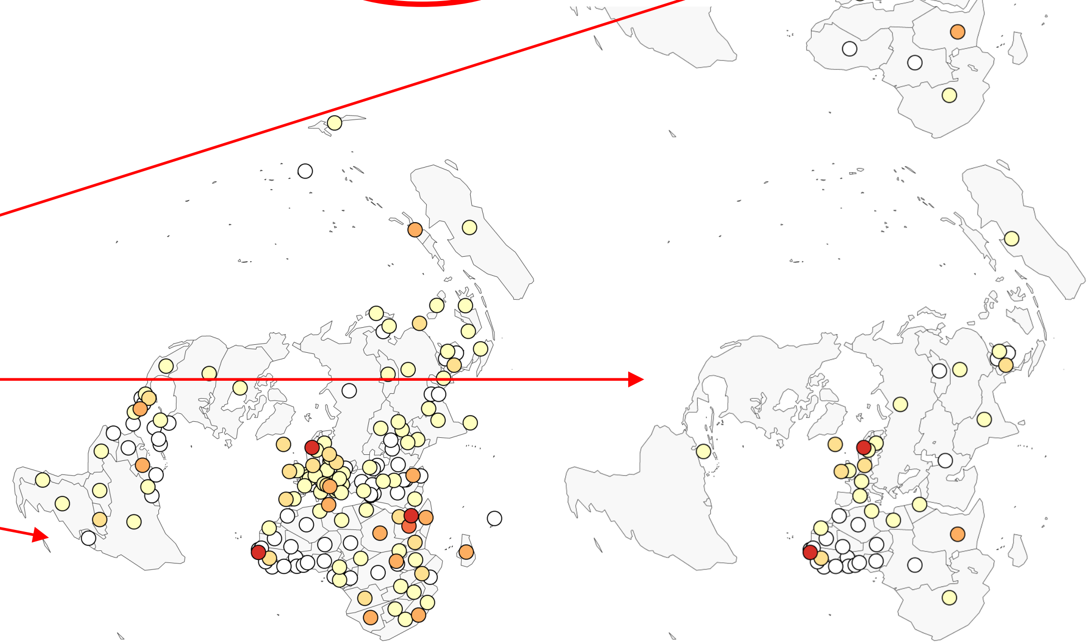




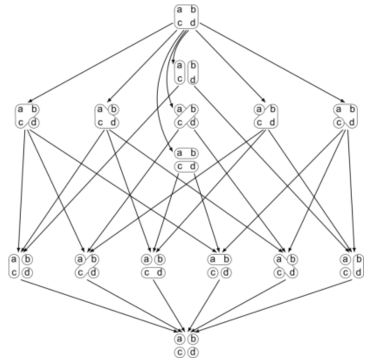




My Approach

P0 To characterize the aggregation process

→ The algebra of possible partitions

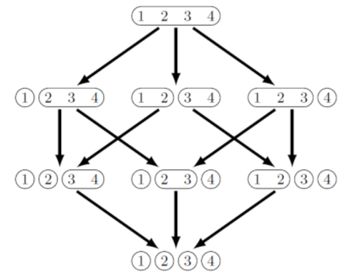


P1 To preserve the system's semantics

→ A constrained partitioning method

To aggregate according to several dimension

→ Some constraints expressing the system's topology

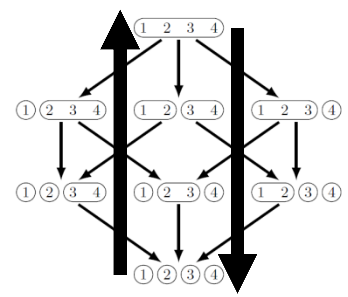


P2 To evaluate and compare the representations

→ Some measures of complexity and information

To offer several granularity levels

→ The optimization of a compromise

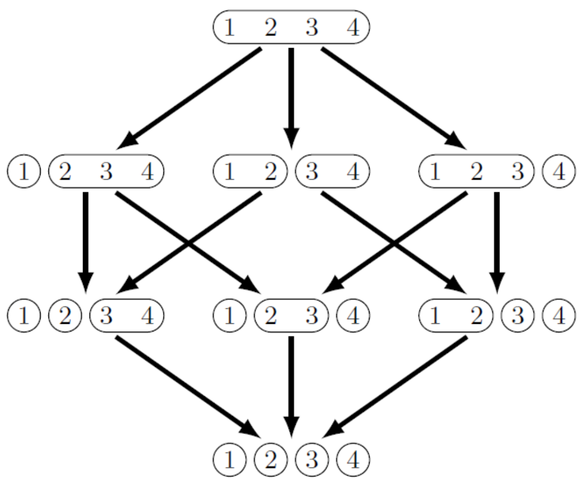


P3 To compute the best representations

→ A generic algorithm of constrained optimization

Objectives

Set of admissible partitions



Quality Measures

$$\Delta T(\mathcal{X}) = |\Omega| - |\mathcal{X}|$$

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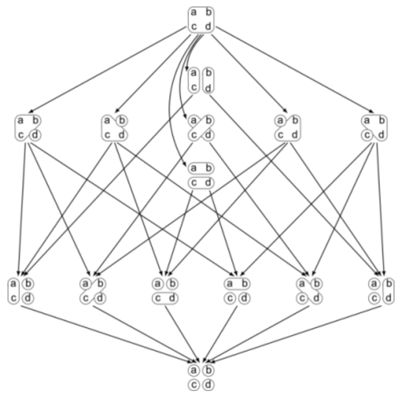
$$CQL_\alpha = \alpha \frac{\Delta T}{\Delta T_{\max}} - (1-\alpha) \frac{D}{D_{\max}}$$

The Admissible Optimal Partitions Problem: Which admissible partitions optimize a given compromise of quality?

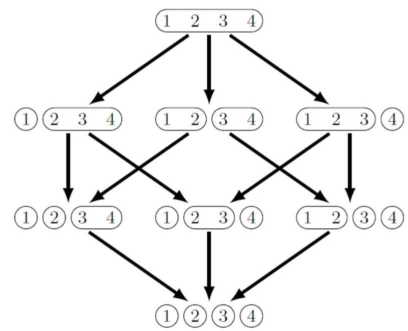
→ A well-known constrained optimization problem

Exponential Algorithmic Complexity

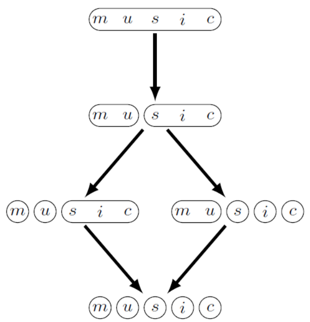
Non-constrained Set



Ordered Set



Hierarchical Set



Number of admissible partitions
(n = size of the system)

$$\Theta\left(e^{n \log n}\right)$$

$$\Theta(2^n)$$

$$\Theta(c^n)$$

[Berend and Tassa, 2010]

[Lamarche-Perrin *et al.*, IAT 2013]

Toward an Efficient Algorithm

- **Classical clustering techniques** uses some heuristics to find local optima [Halkidi *et al.*, 2001]

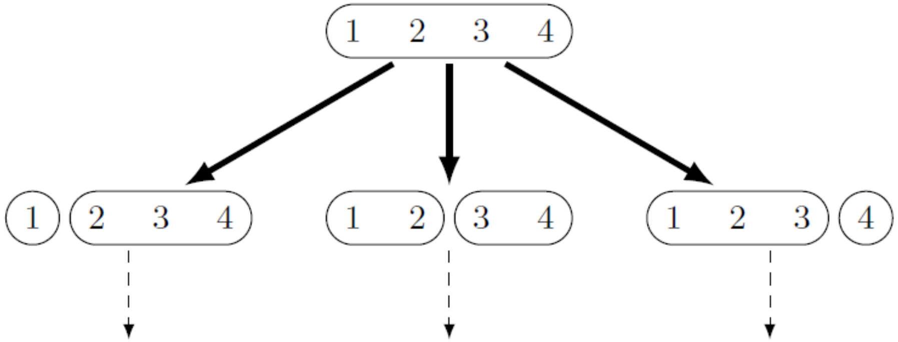
- **In our case:**
  - The **admissibility constraints** allow to reduce the complexity of the optimization problem
  - The **algebraic properties** of the quality measures allow to efficiently compare the partitions

→ **We look for the global optima**

Idea of the Algorithm

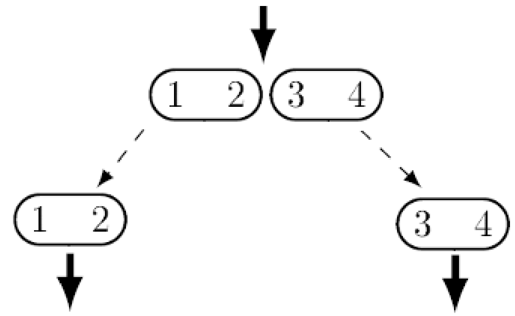
DIVIDE…

Decomposition according to the refinement relation



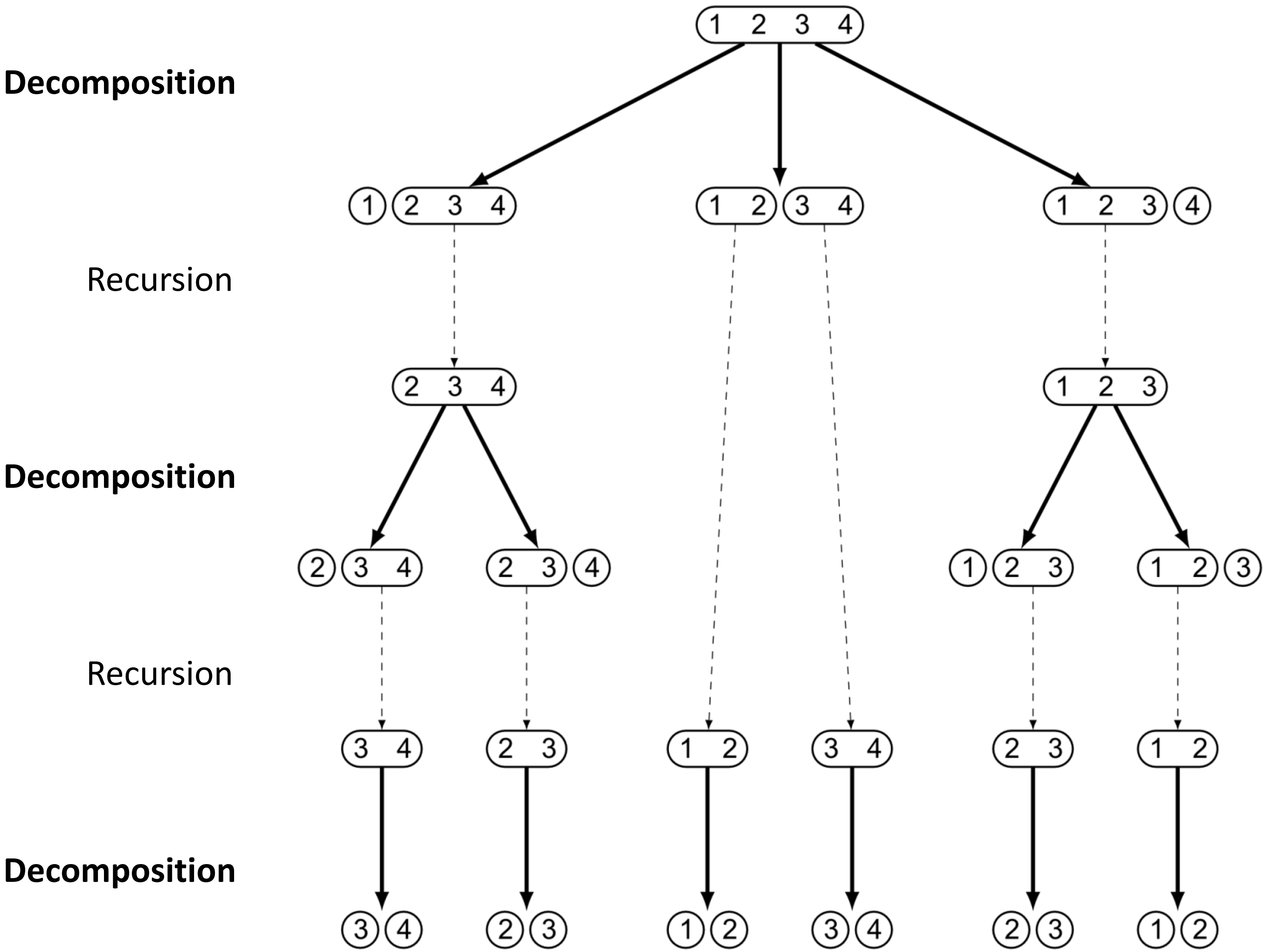
…AND CONQUER

Recursion according to the decomposability of measures



[Lamarche-Perrin *et al.*, IAT 2013]

Execution of the Algorithm



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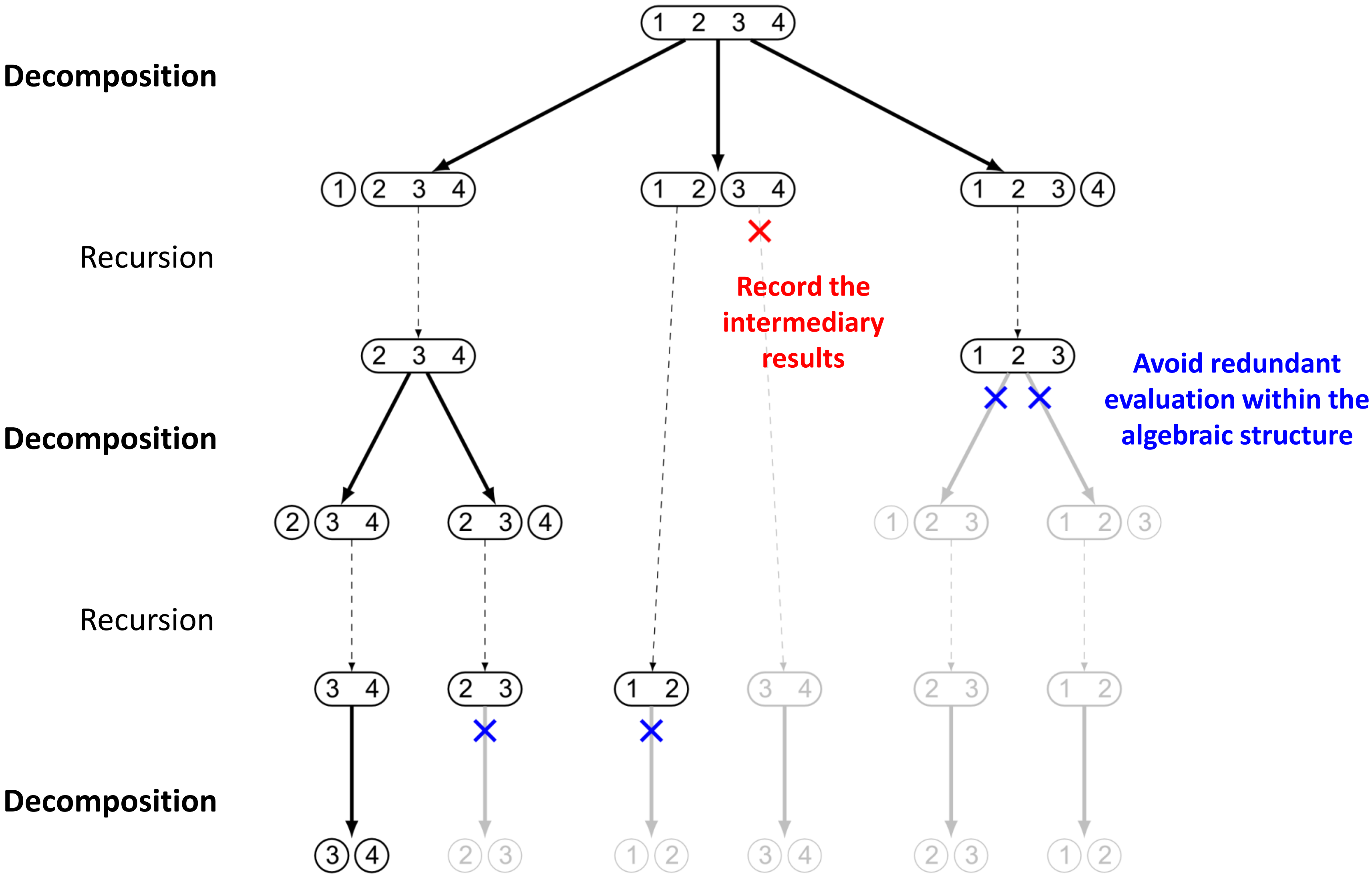
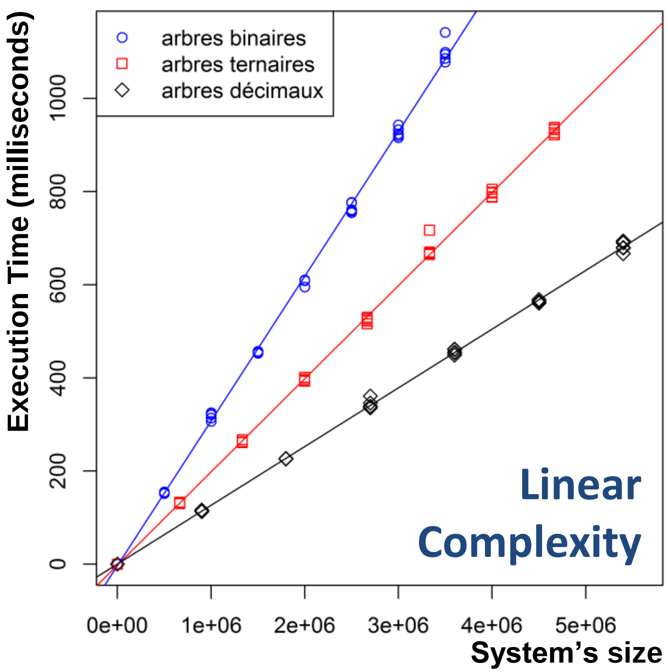


Complexity of the Algorithm

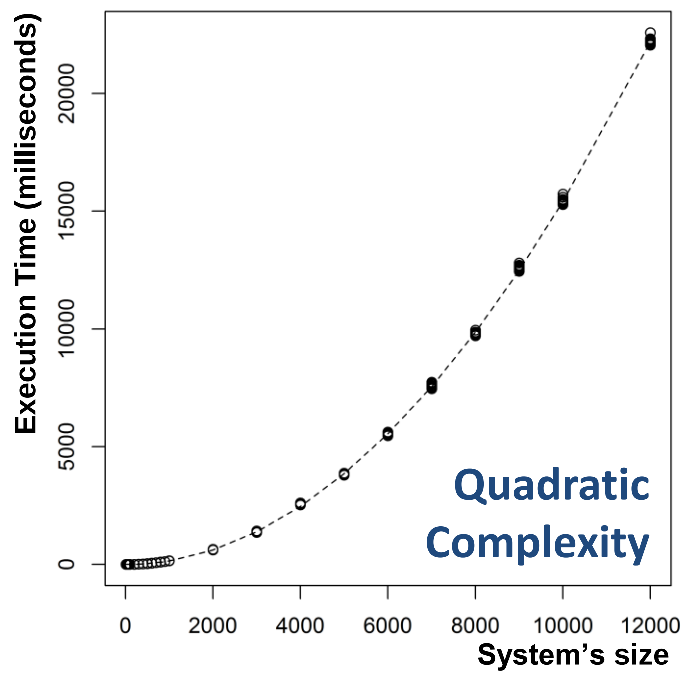
The algorithm spatial and temporal complexity directly depend on the algebraic properties of the set of admissible partitions

the more constrained, the less complex

According to a hierarchy



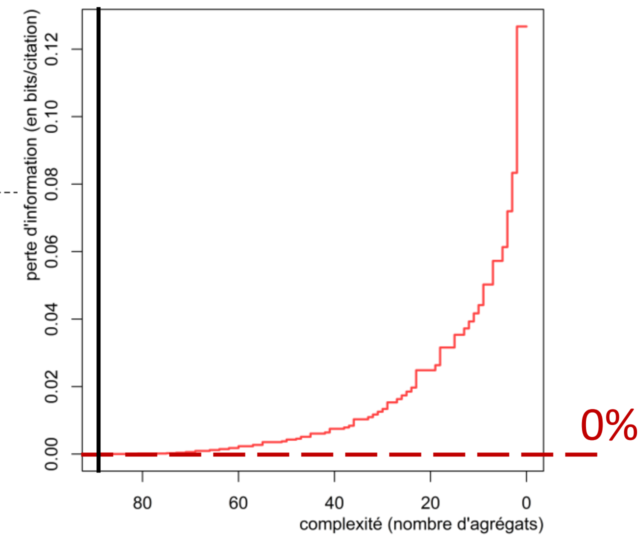
According to a total order

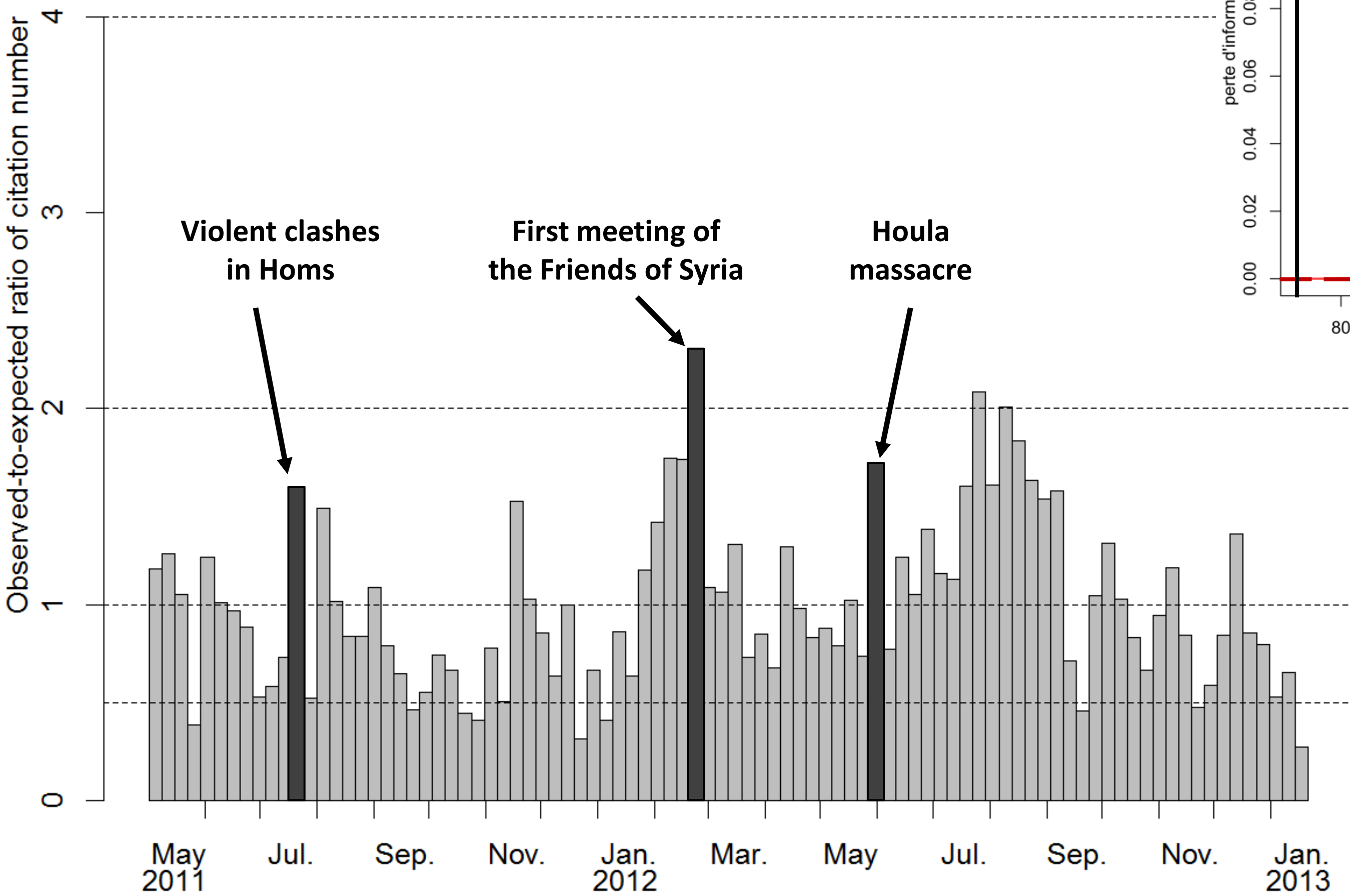


EXPERIMENTS AND RESULTS

The Syrian civil war according to LE MONDE

[Giraud, Grasland, Lamarche-Perrin *et al.*, ECTQG 2013]





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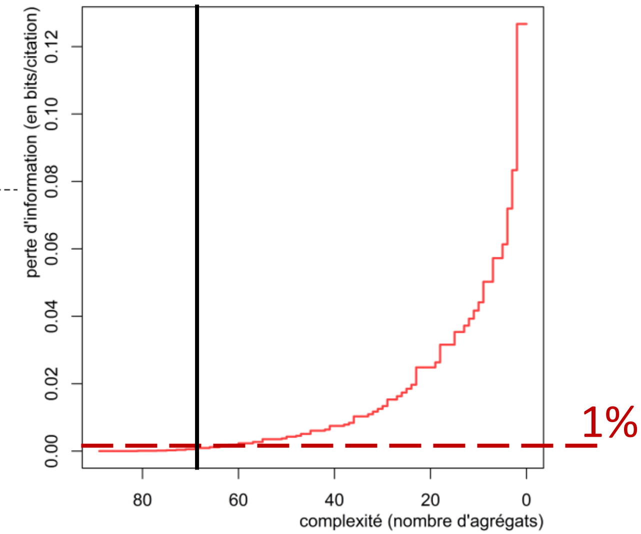

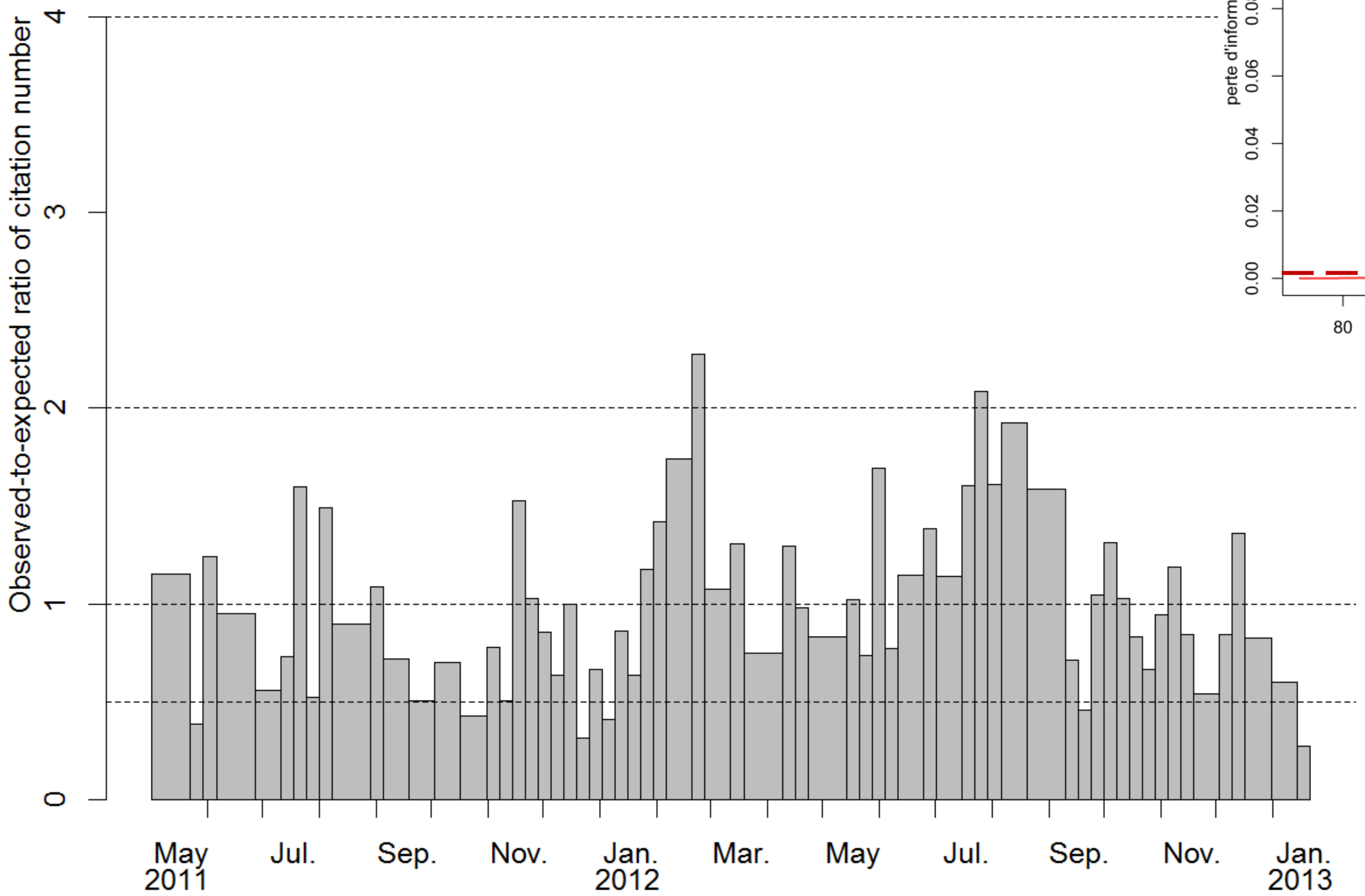

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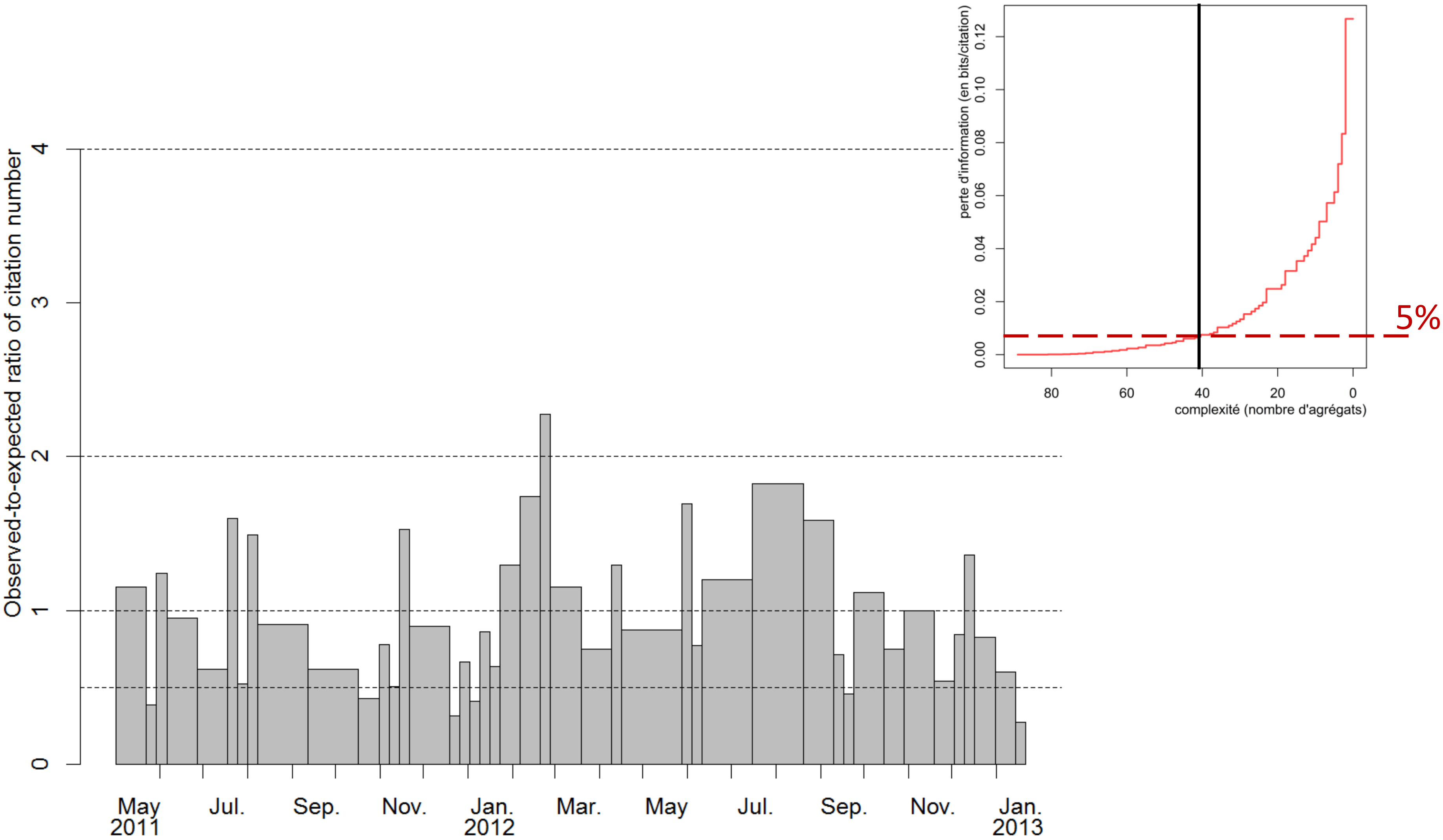

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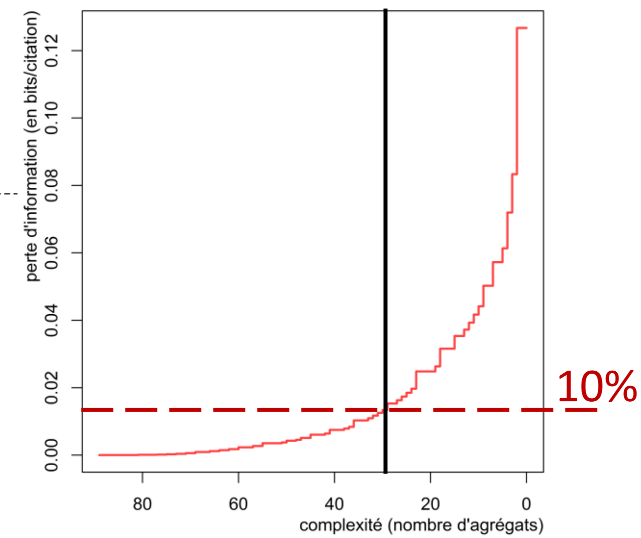

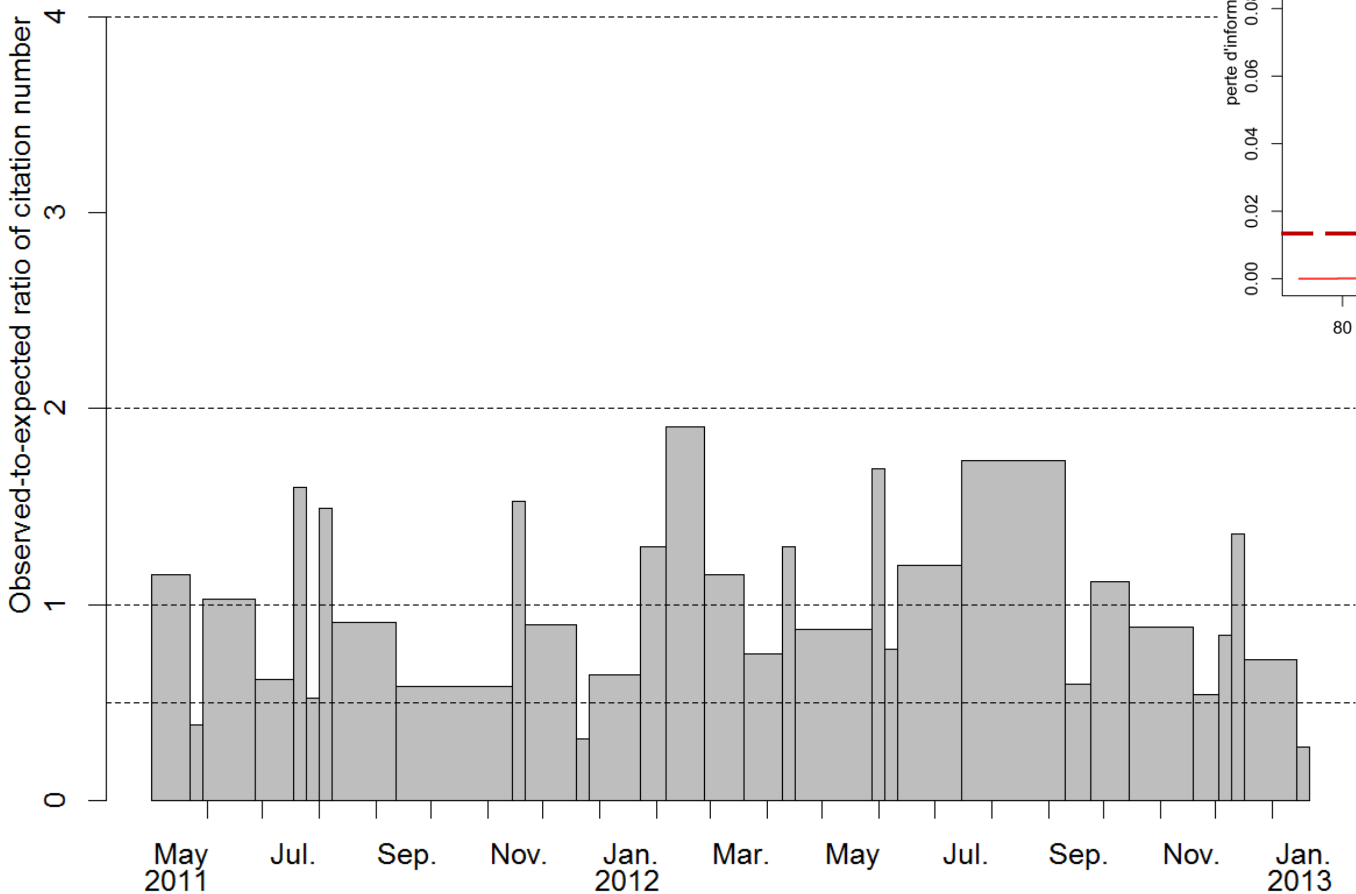

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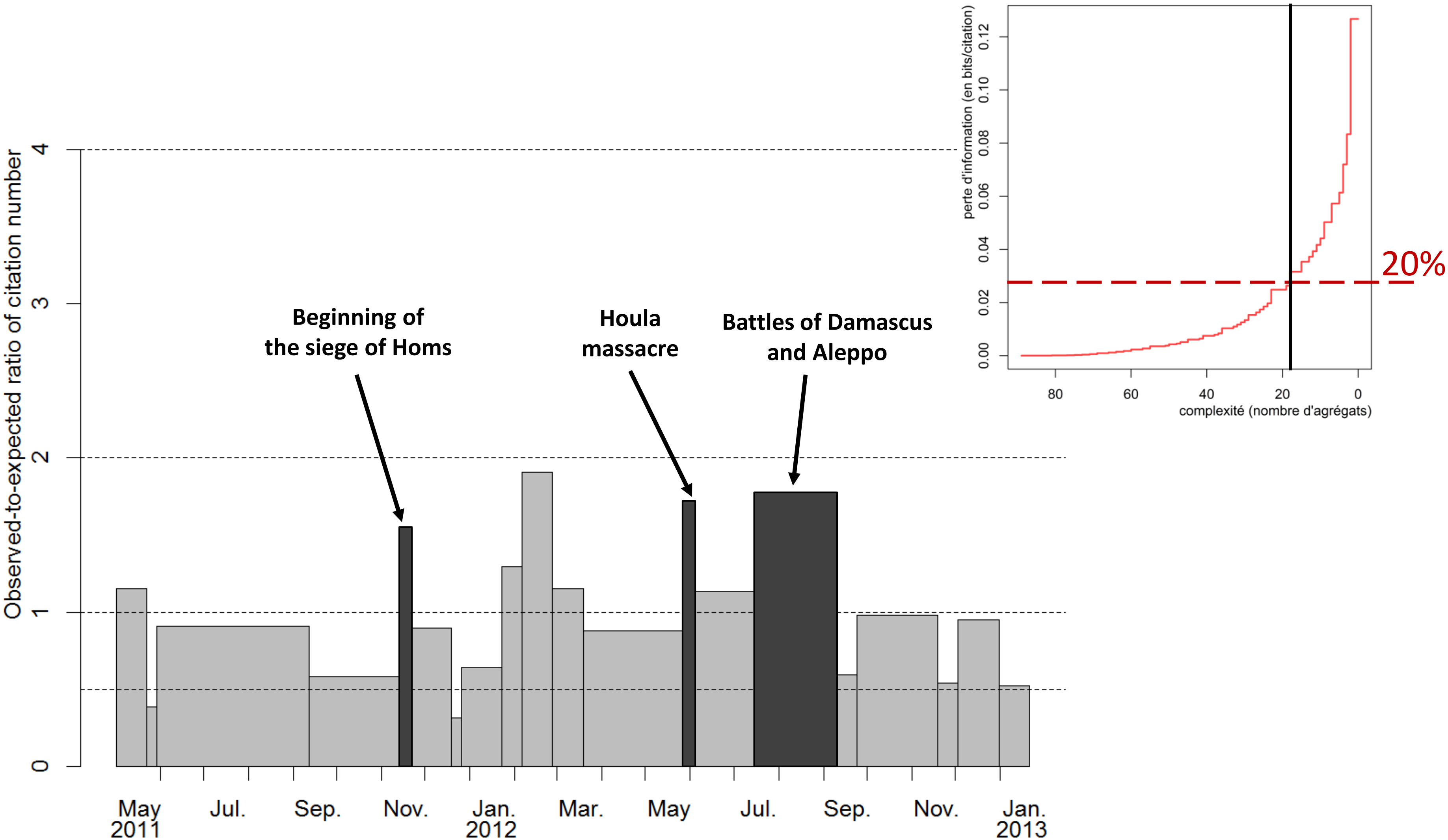
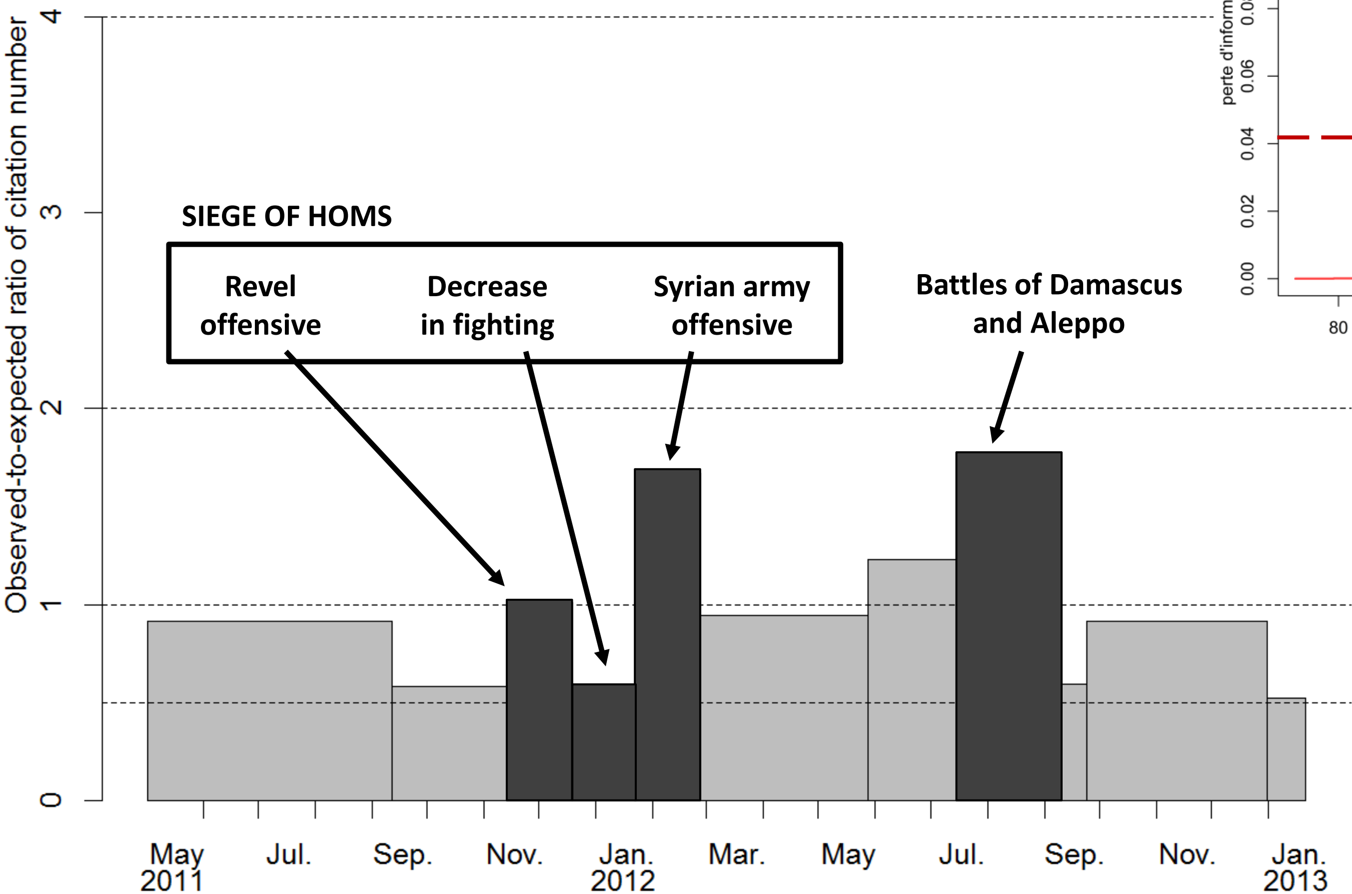
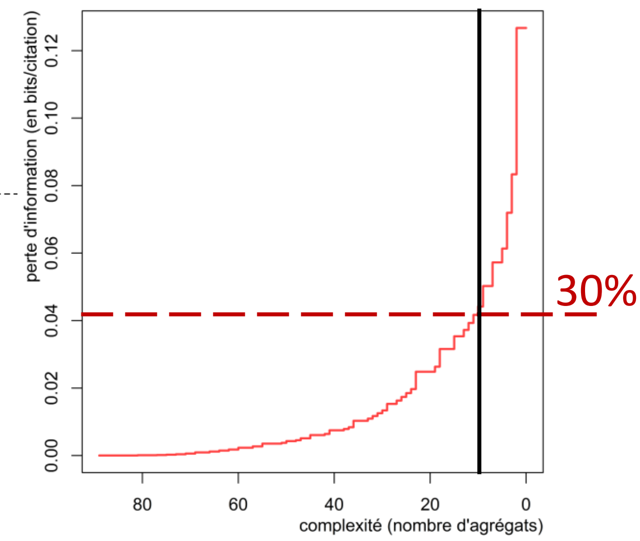


The Syrian civil war according to LE MONDE

[Giraud, Grasland, Lamarche-Perrin *et al.*, ECTQG 2013]

Source: Wikipedia
Timeline of the Syrian civil war
Siege of Homs





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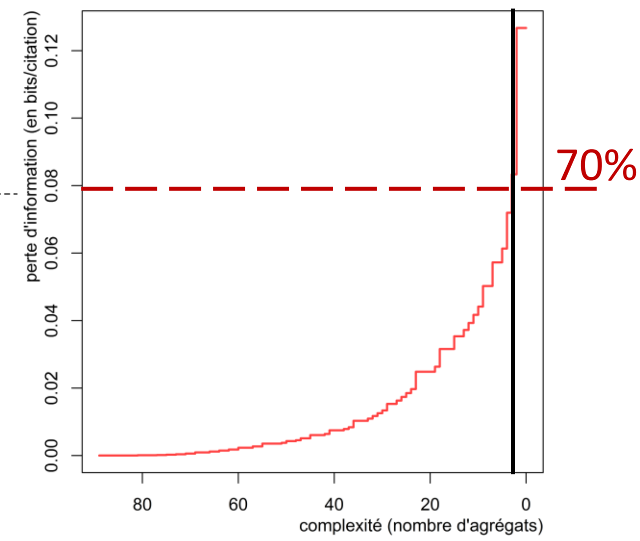
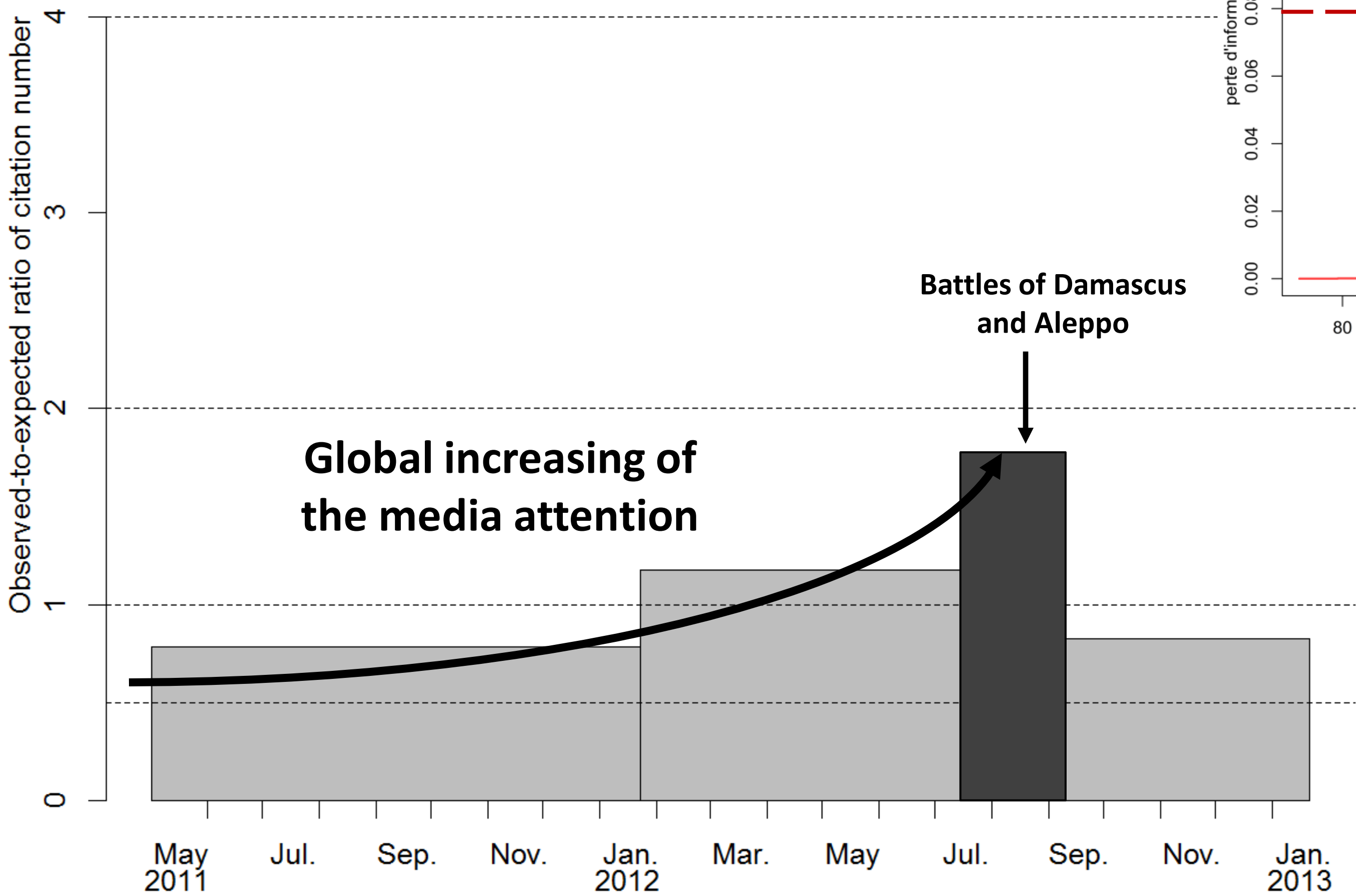
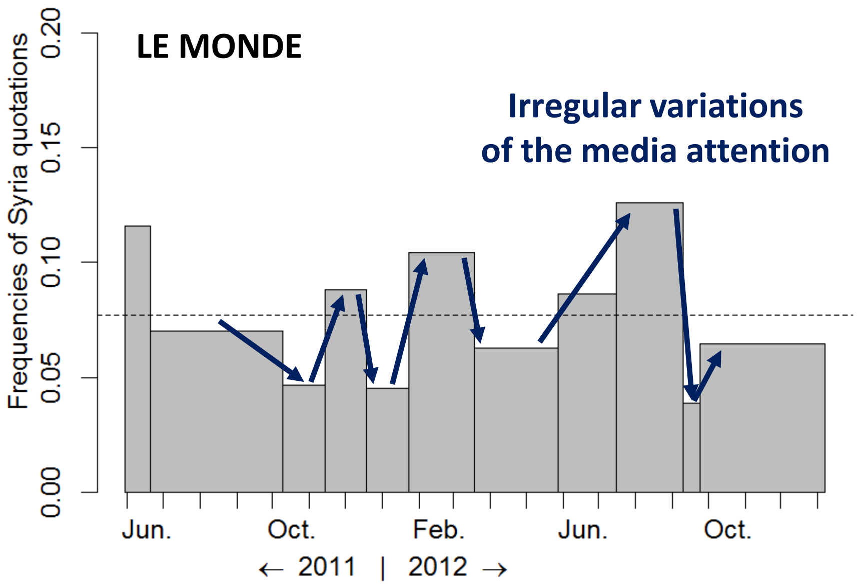
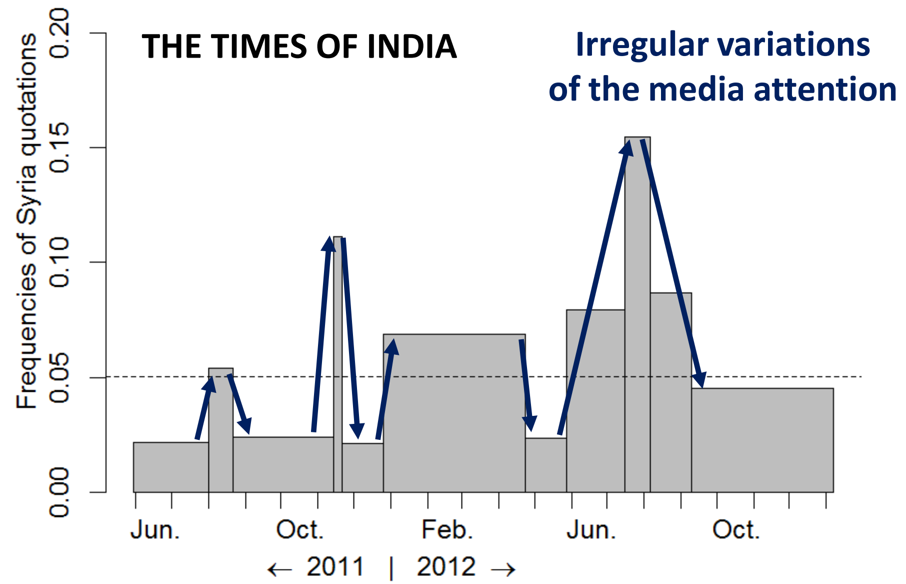


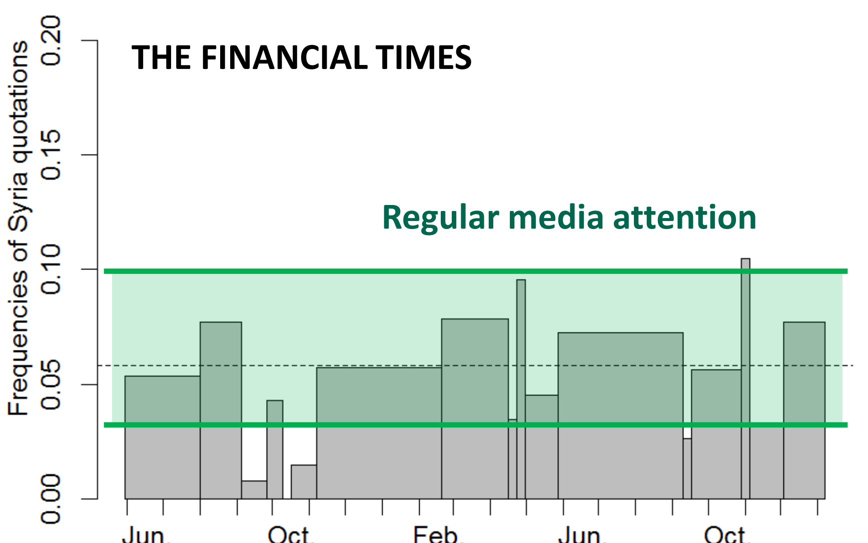


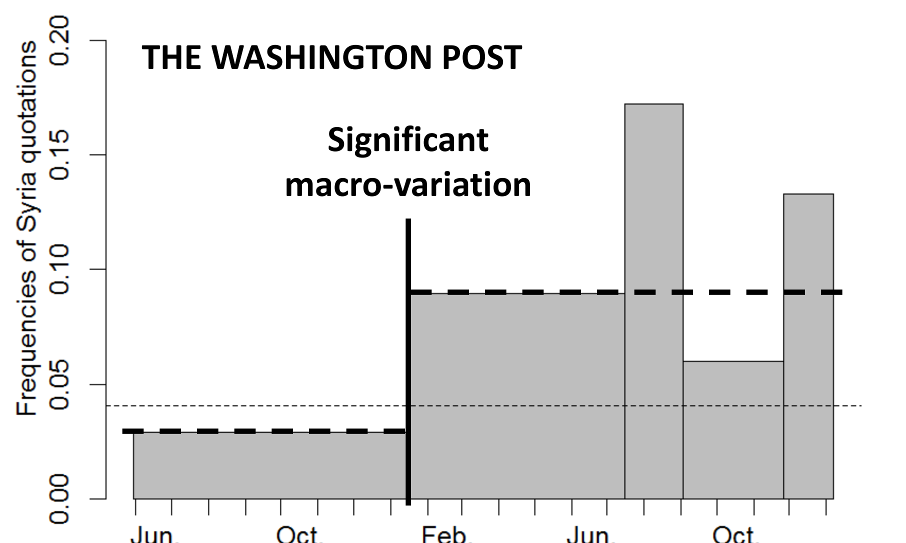
The Syrian civil war according to 4 newspapers

[Giraud, Grasland, Lamarche-Perrin *et al.*, ECTQG 2013]

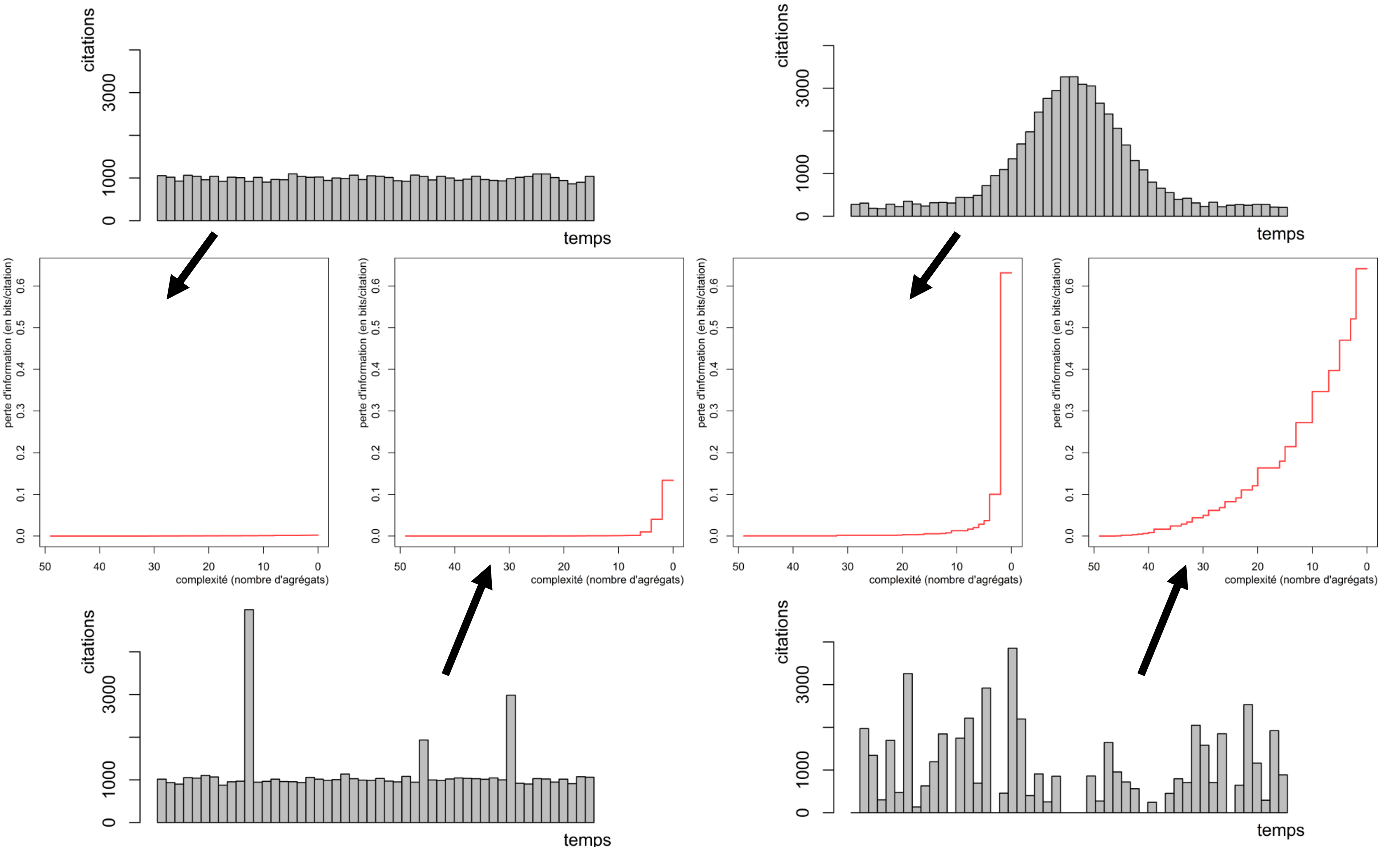








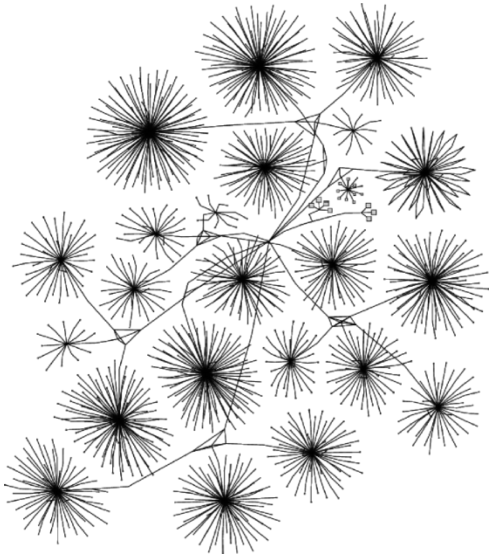
Characterizing Different Datasets



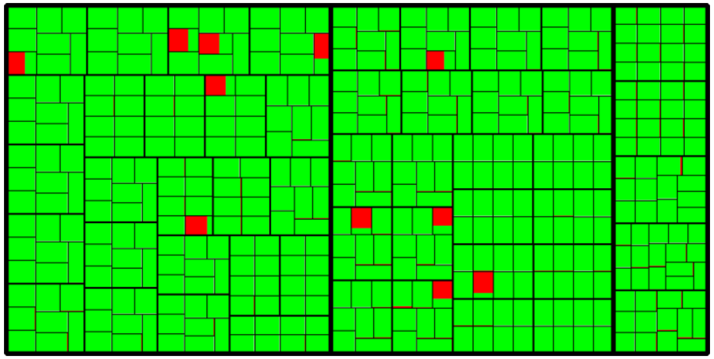
Aggregation of Execution Traces

[Lamarche-Perrin, Schnorr *et al.*, TSI 2013]

Hierarchical structure of the grid computing
[Schnorr *et al.*, 2013]

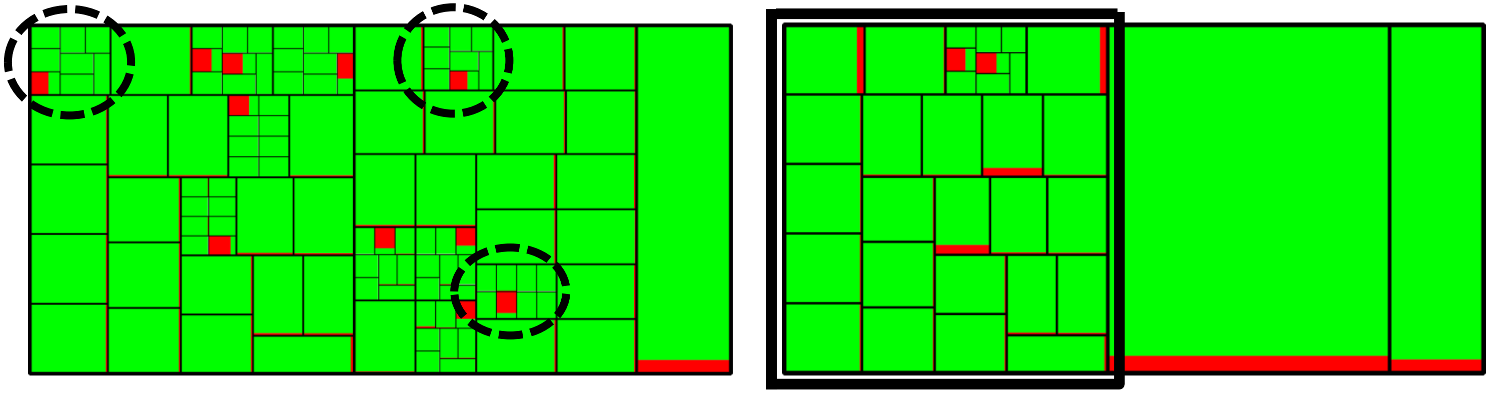


Microscopic treemap representation



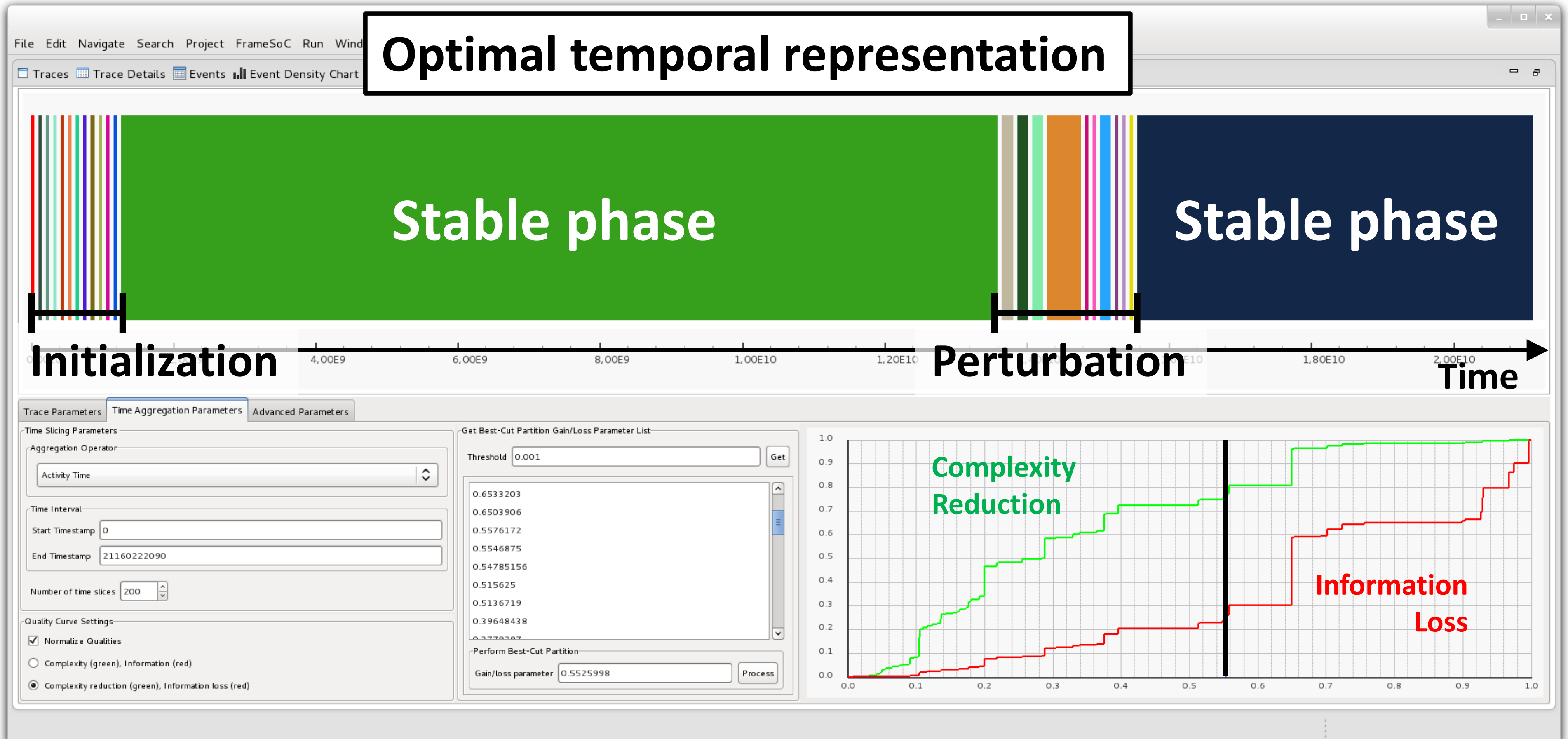
Aggregated treemap representations

Detection of multi-scale anomalies



Aggregation of Execution Traces

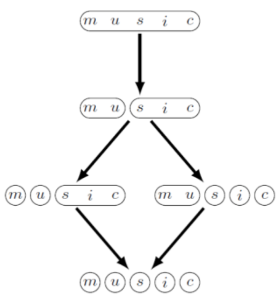
[Pagano, Dosimont *et al.*, 2013]

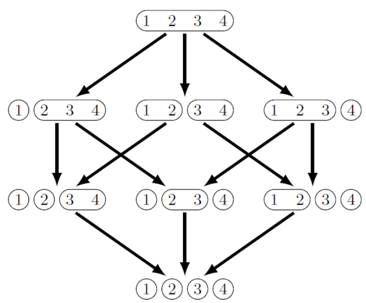


OUTCOMES AND PERSPECTIVES

Summary of the Contributions

P1 Algebraic structures that express the **system's semantic properties**

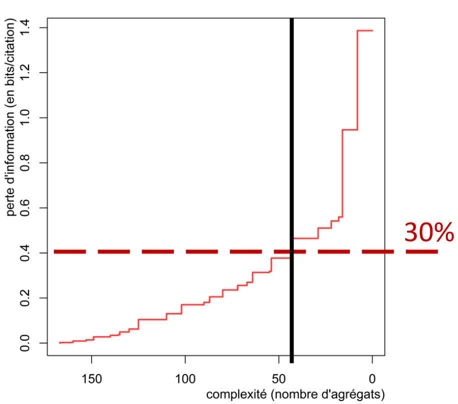




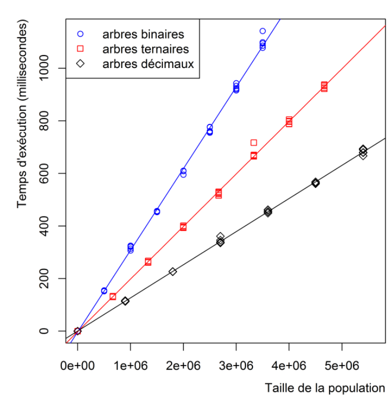
P2 A compromise of quality to generate **multi-resolution representations**

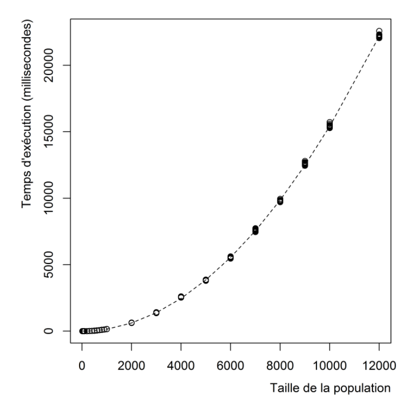
$$CQL_\alpha = \alpha \frac{\Delta T}{\Delta T_{\max}} - (1 - \alpha) \frac{D}{D_{\max}}$$

P2 Graphs of quality to choose the **representations granularity**



P3 A generic aggregation algorithm with **polynomial complexity**





Summary of the Hypotheses

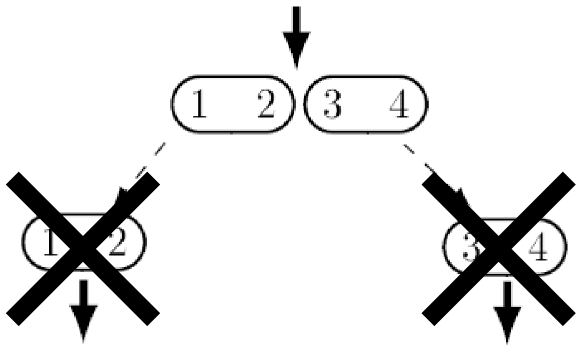
Microscopic observation tools

P0 Aggregation according to **partitions**

P1 **Hierarchical** or **ordered** systems

P2 **Decomposable** quality measures

Non-decomposable Measures



$$Q\{\{1,2\},\{3,4\}\}$$

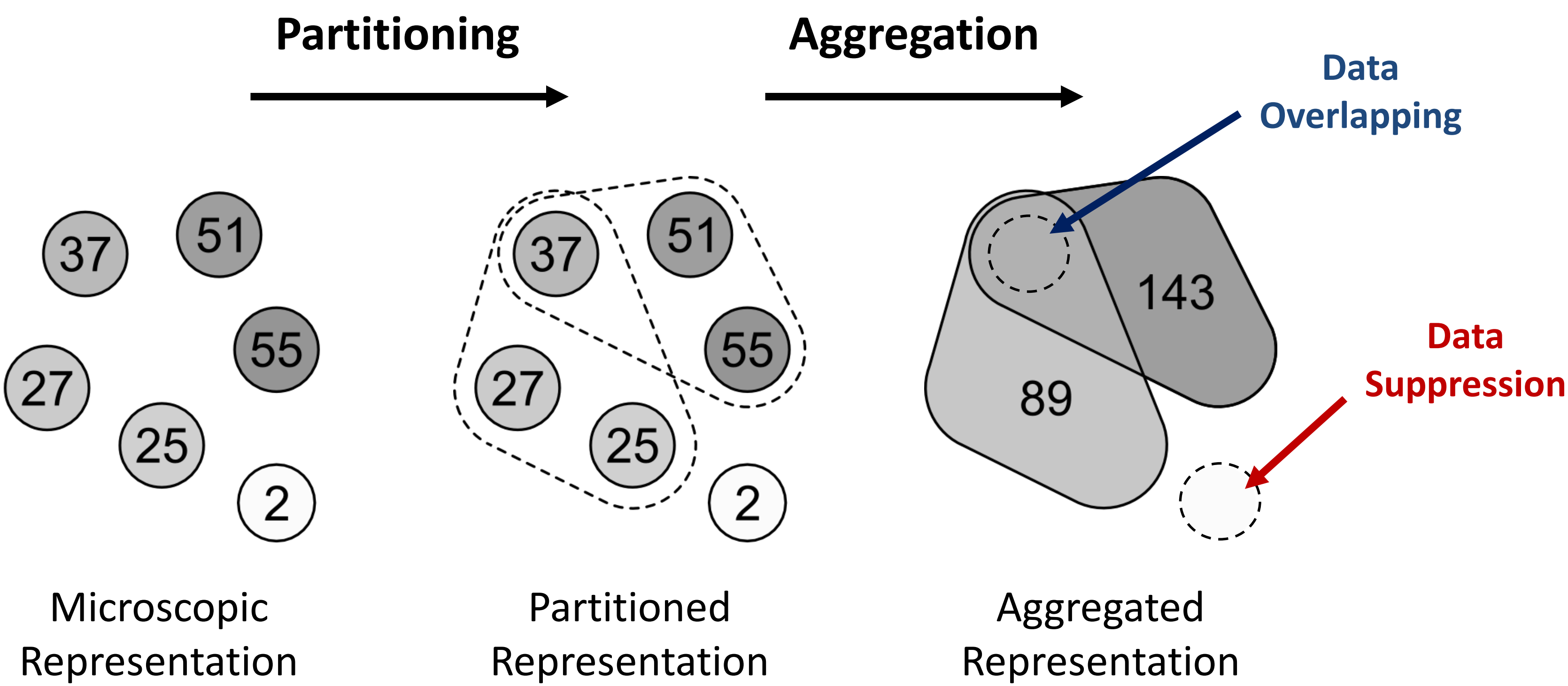
$$\neq$$

$$Q\{1,2\} + Q\{3,4\}$$

- The recursive approach is no longer possible
- The quality of a part cannot be defined

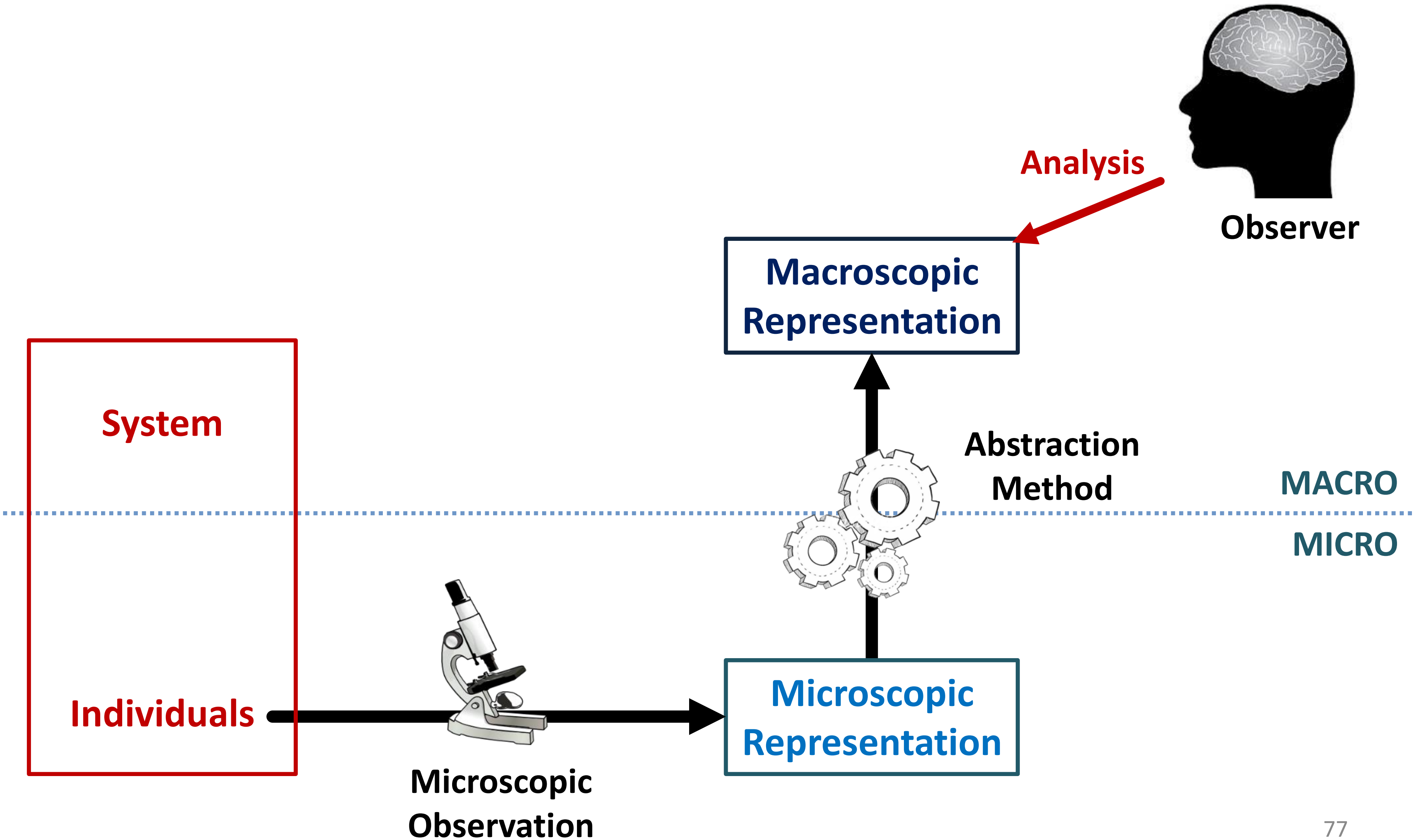
→ Do non-decomposable quality measures have a meaning to evaluate the aggregation process?

Non-disjoint and Non-covering Parts

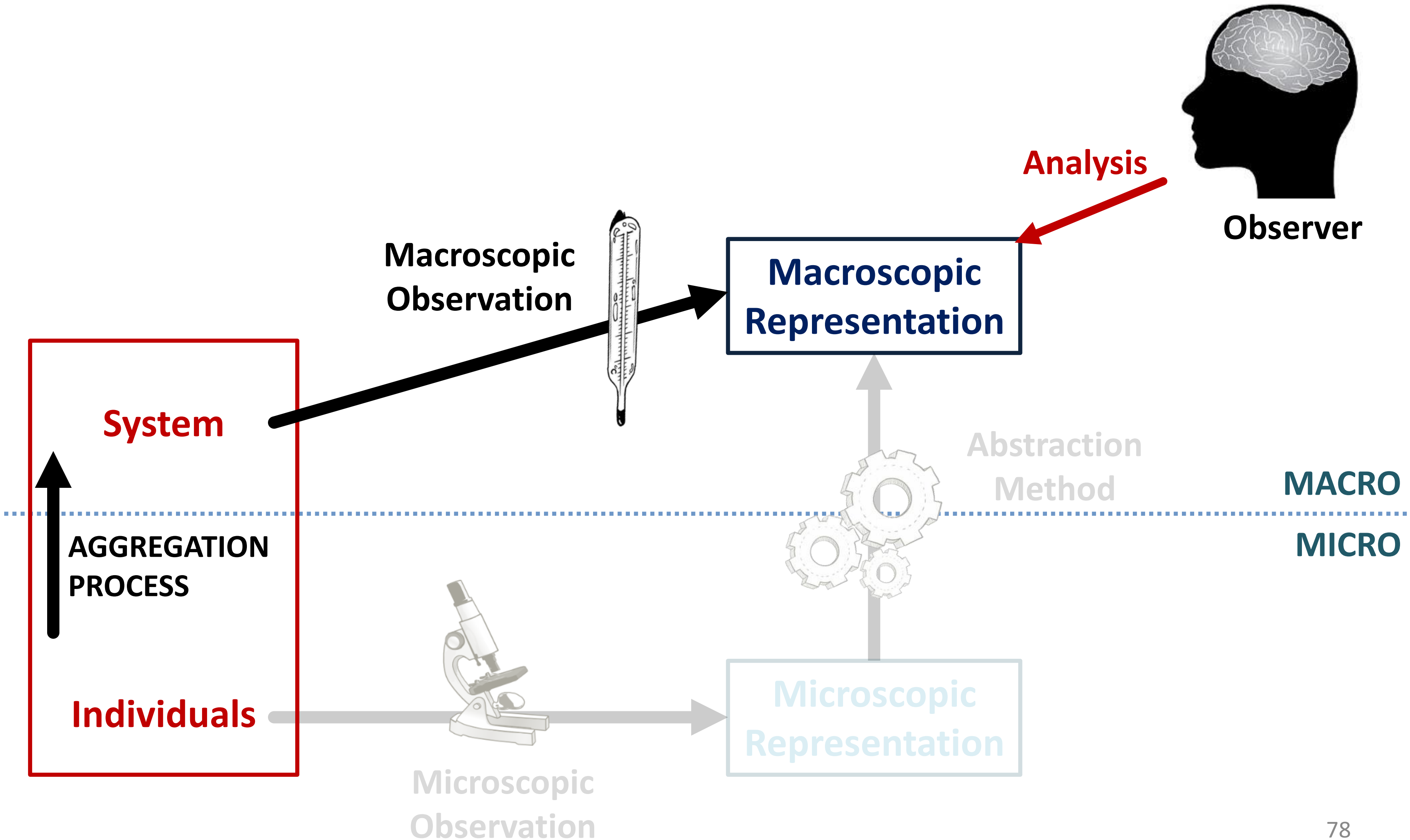


→ Effect on the algorithmic complexity?

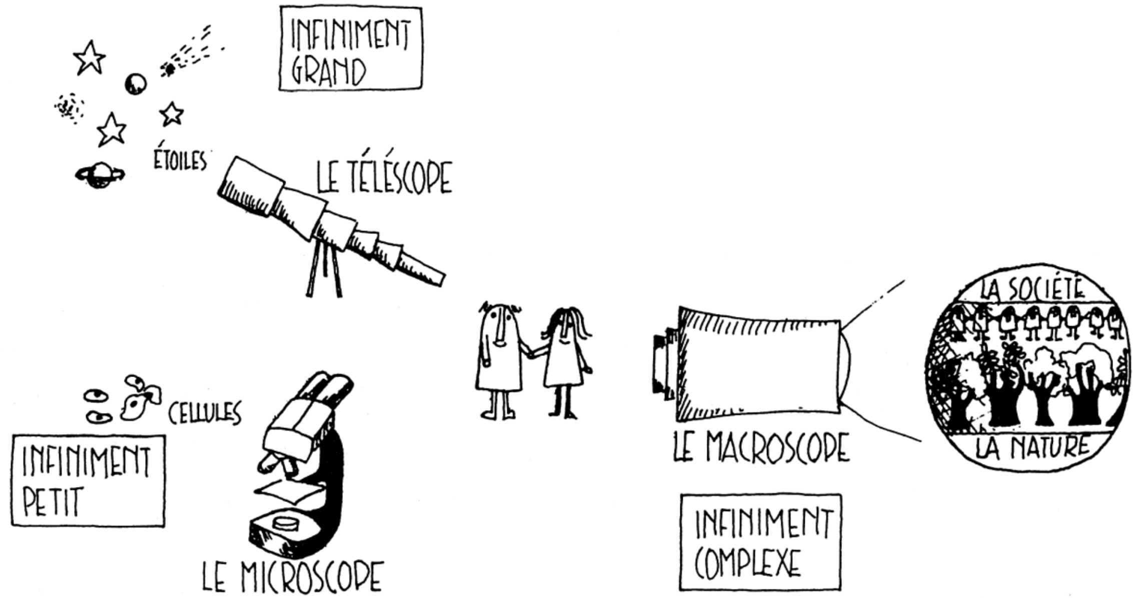
Macroscopic Observation



Macroscopic Observation



THANKS FOR YOUR ATTENTION



« Aujourd'hui nous sommes confrontés à un autre infini :
l'infiniment complexe. Mais cette fois, plus d'instrument. »

Joël de Rosnay, *Le macroscope*, 1975

LIST OF PUBLICATIONS

Peer-reviewed Journals (being accepted)

Lamarche-Perrin, Demazeau et Vincent. **Building the Best Macroscopic Representations of Complex Multi-Agent Systems.** *Transaction on Computational Collective Intelligence (TCCI)*, 2014.

Lamarche-Perrin, Schnorr, Vincent et Demazeau. **Agrégation de traces pour la visualisation de grands systèmes distribués.** *Technique et Science Informatiques (TSI)*, 2014.

International Peer-reviewed Conferences with Proceedings

Lamarche-Perrin, Demazeau et Vincent. **The Best-partitions Problem: How to Build Meaningful Aggregations.** *Intelligent Agent Technology (IAT)*, Atlanta, 2013.

Giraud, Grasland, Lamarche-Perrin, Demazeau et Vincent. **Identification of International Media Events by Spatial and Temporal Aggregation of RSS Flows of Newspapers.** *European Colloquium in Theoretical and Quantitative Geography (ECTQG)*, Dourdan, 2013.

Lamarche-Perrin, Demazeau and Vincent. **How to Build the Best Macroscopic Description of your Multi-agent System?** *Practical Applications of Agents and Multi-Agent Systems (PAAMS)*, Salamanca, 2013.

French Peer-reviewed Conferences with Proceedings

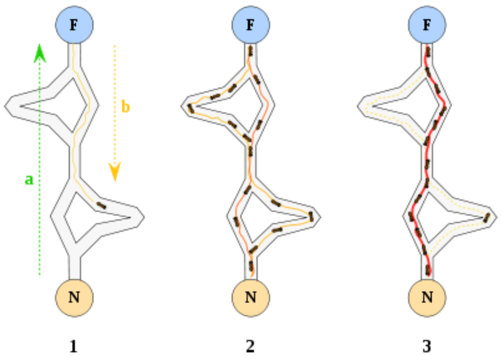
Lamarche-Perrin, Demazeau et Vincent. **Organisation, agrégation et visualisation d'informations médiatiques.** *Colloque annuel du Collège des Sciences du Territoire*, Paris, 2011.

Lamarche-Perrin, Demazeau et Vincent. **Observation macroscopique et émergence dans les SMA de très grande taille.** *Journées Francophones des Systèmes Multi-Agents (JFSMA)*, Valenciennes, 2011.

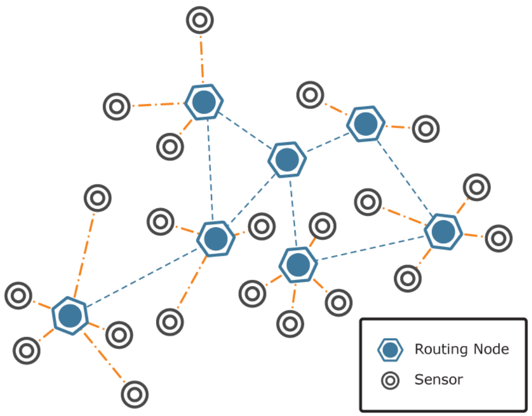
Application Perspectives

Multi-agent Systems

[Lamarche-Perrin *et al.*, JFSMA 2011]

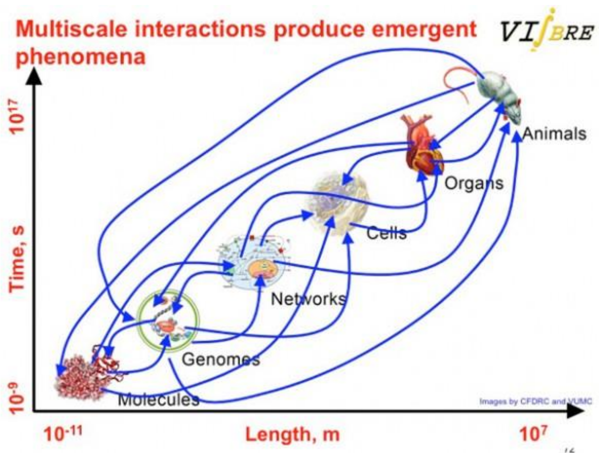


Sensor Networks



Multi-scale simulation

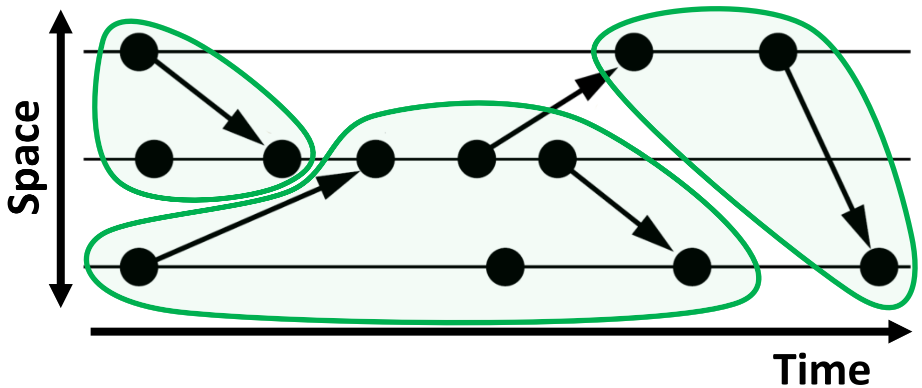
[Gil-Quijano *et al.*, 2012]



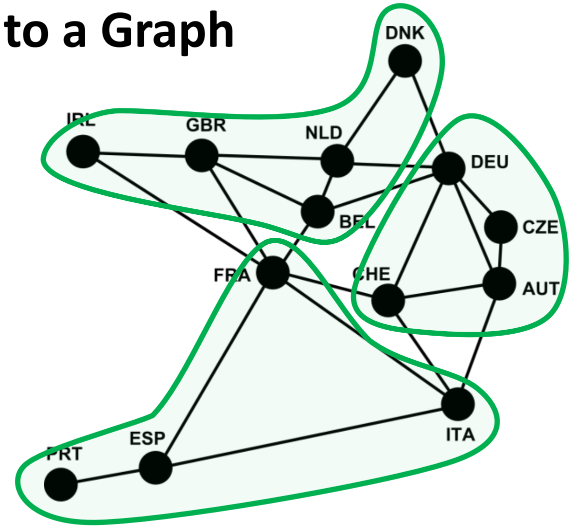
Other Topological Structures

Aggregation of Events

[Mattern, 1989]



Aggregation according to a Graph

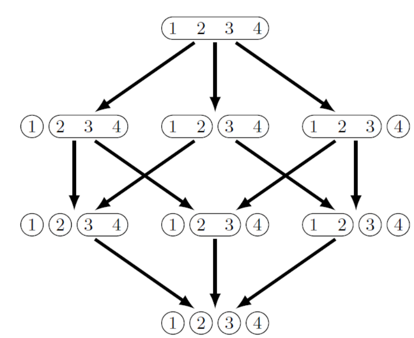


Aggregation of an Interaction Matrix

	ESP	FRA	GBR	BEL	CHE
ESP	X	12	11	10	4
FRA	14	X	12	12	5
GBR	20	11	X	6	9
BEL	15	9	6	X	5
CHE	10	16	17	9	X

[Lamarche-Perrin *et al.*, CIST 2011]

Corresponding Algebras

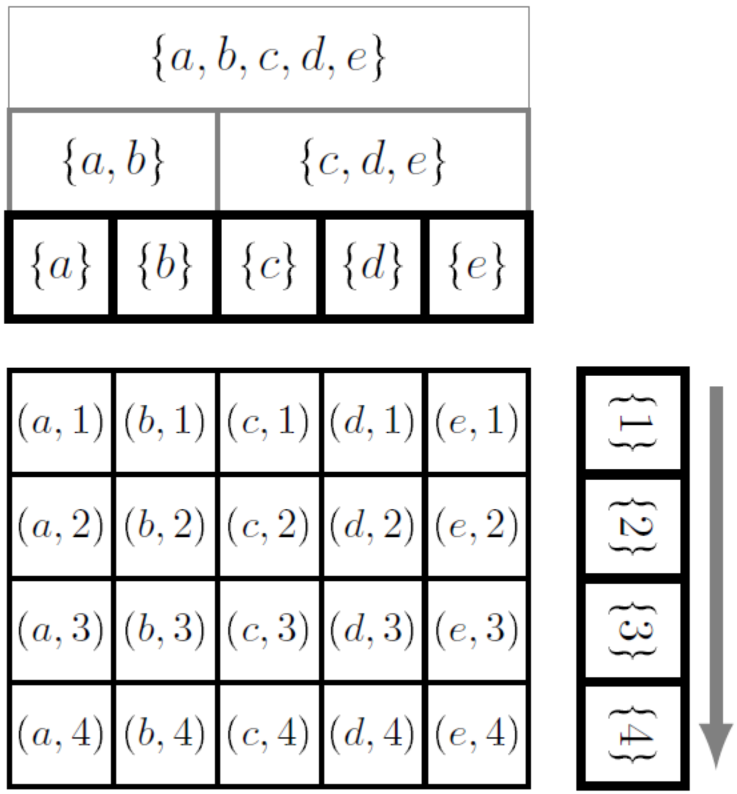


Algorithmic Complexity

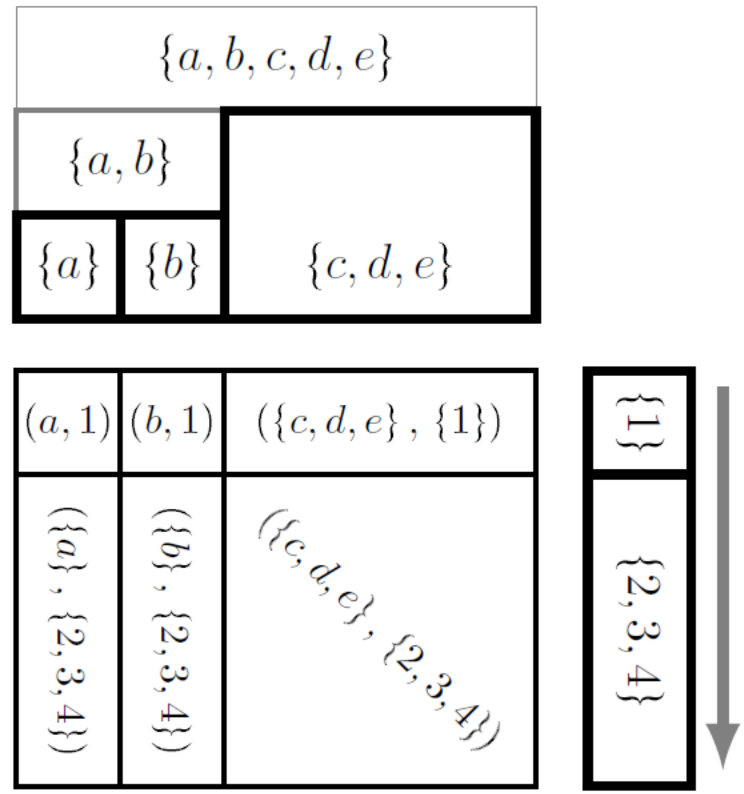
Find the complexity classes that are associated to other dimensions, other semantics, other topologies, *etc.*

Set	Admissible Parts	Admissible Partitions	Temporal Complexity	Spatial Complexity
Non-contrained	$\Theta(2^n)$	$\Theta\left(e^{n \log n}\right)$	$\Theta(3^n)$	$\Theta(2^n)$
Ordered	$\Theta(n^2)$	$\Theta(2^n)$	$\Theta(n^2)$	$\Theta(n^2)$
Hierarchical	$O(n)$	$O(\mathrm{c}^n)$	$O(n)$	$O(n)$
Other topologies	?	?	?	?

Multidimensional Aggregation



Microscopic Representation



Aggregated Representation

Aggregation of Causal Structures