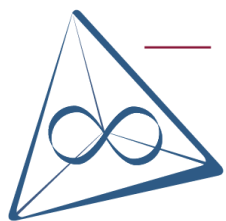# Macroscopic Observation of Large-scale Multi-agent Systems

Robin Lamarche-Perrin[1], Yves Demazeau[2], and Jean-Marc Vincent[2]

[1] Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany
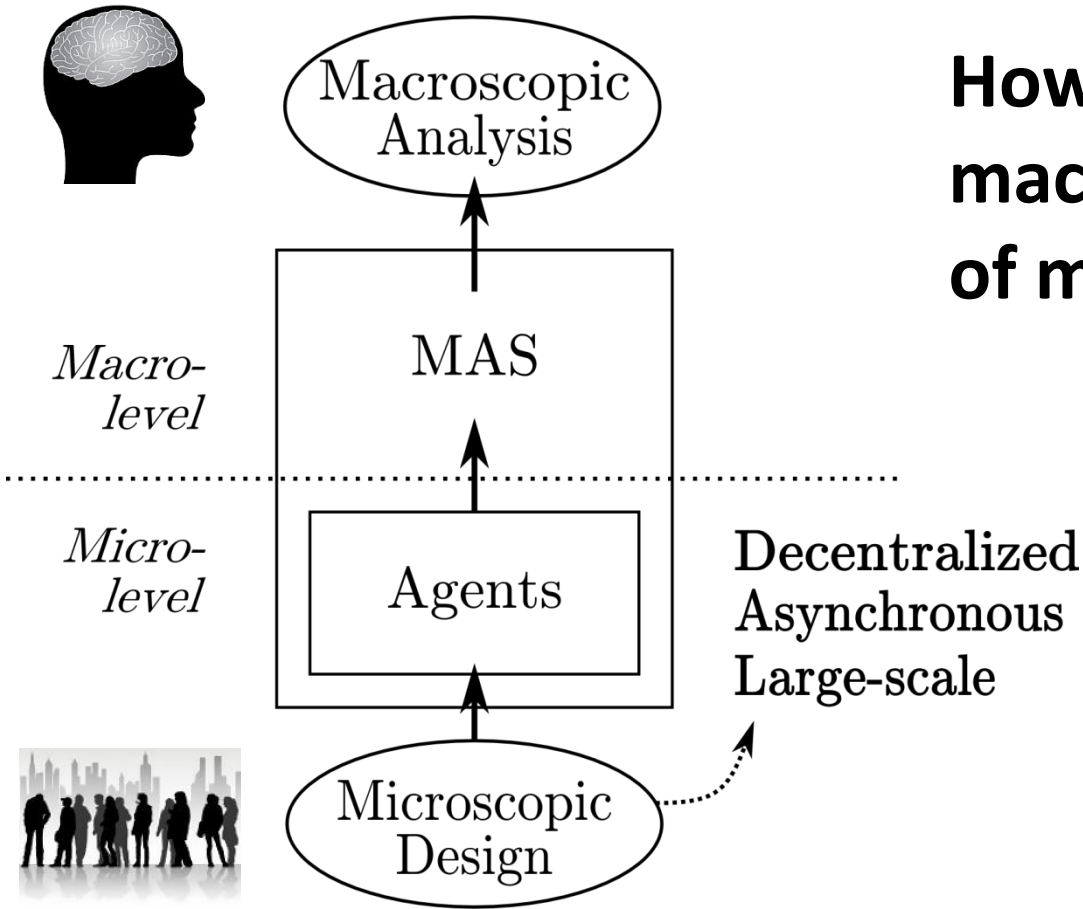[2] Laboratoire d'Informatique de Grenoble, France

Max Planck Institute for Mathematics in the Sciences

L I G
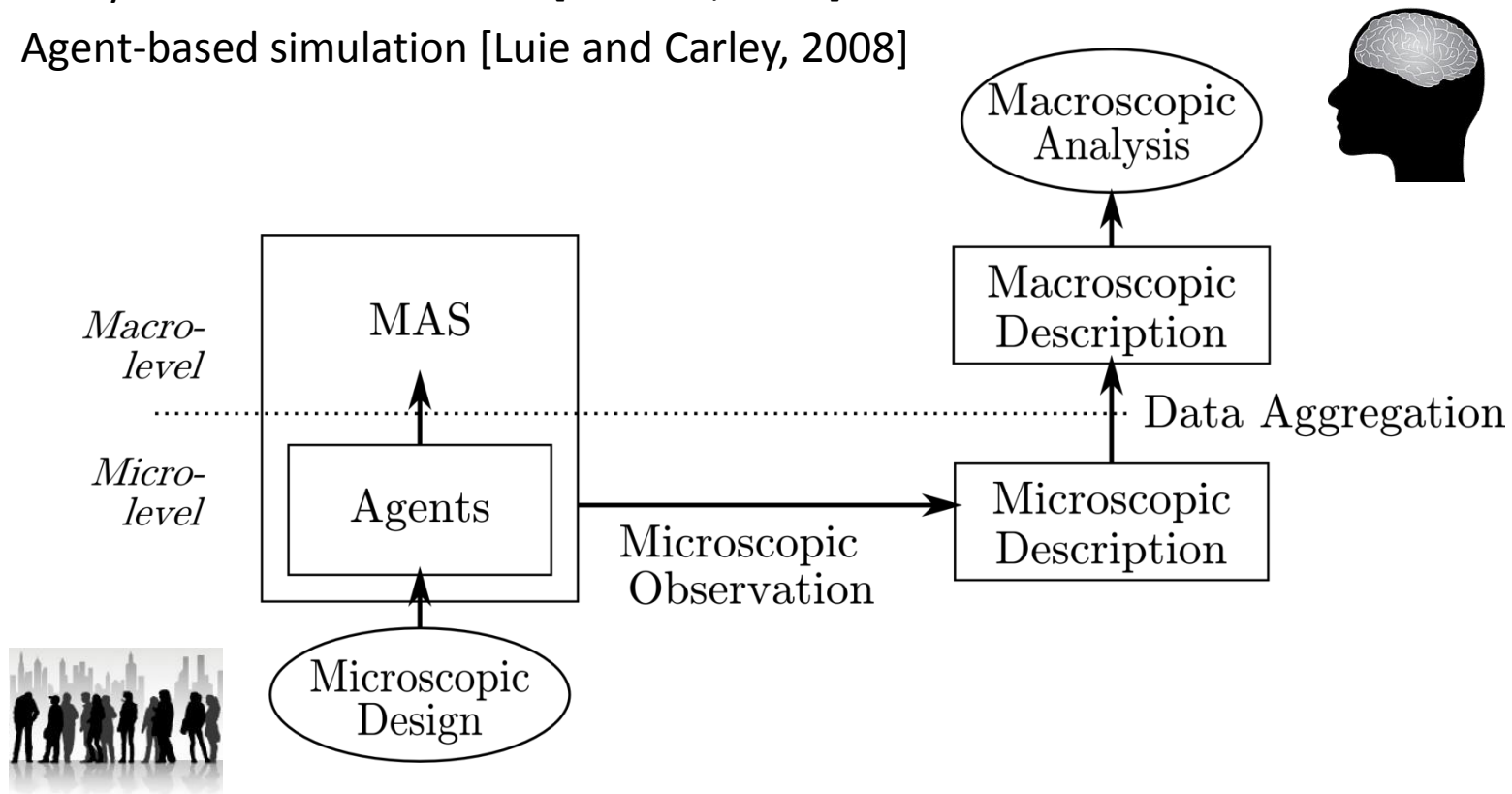
The Analysis of Large-scale MAS

How to provide a macroscopic overview of microscopic processes?
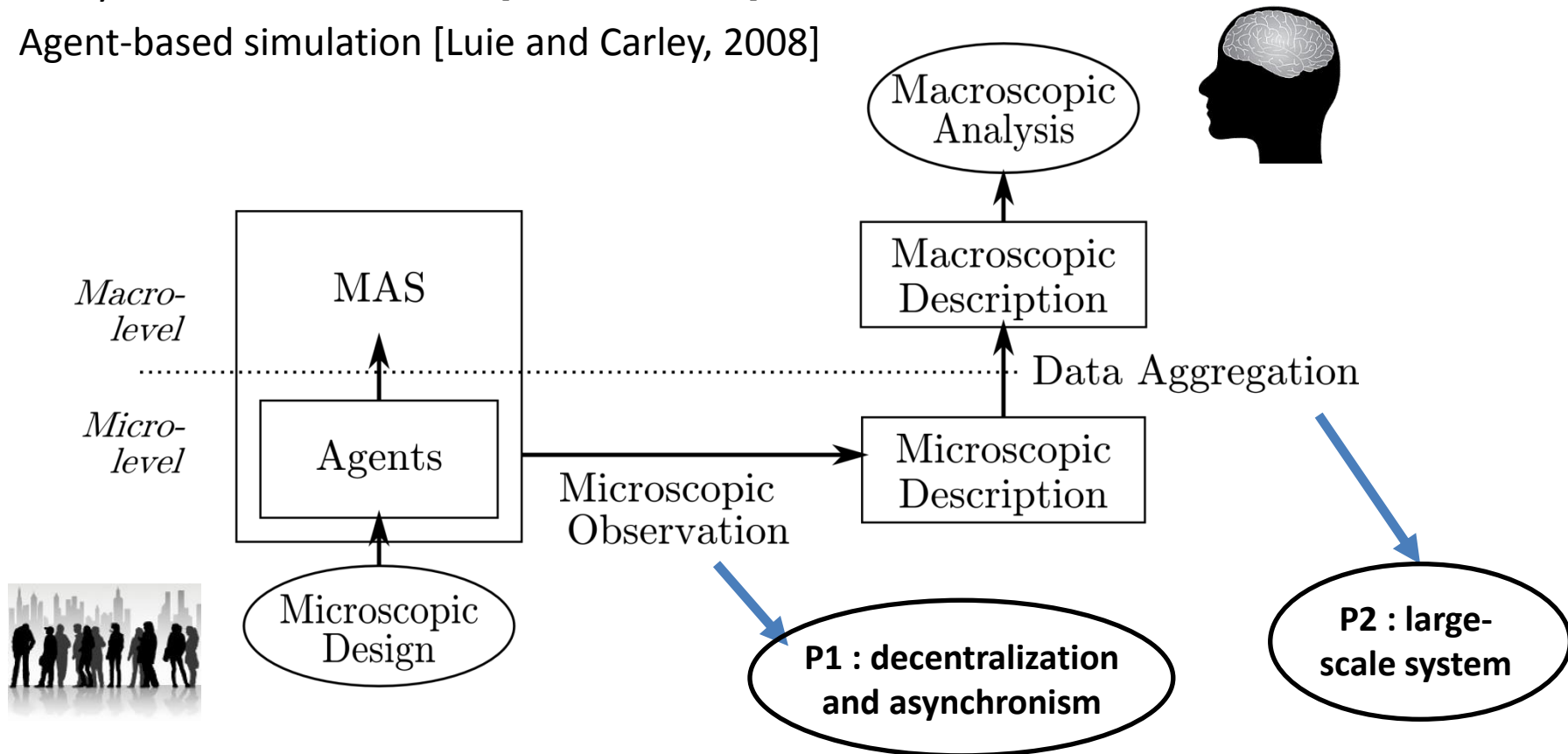
Microscopic Observation

Examples:

- Analysis of execution traces [Joumaa, 2009]
- Agent-based simulation [Luie and Carley, 2008]
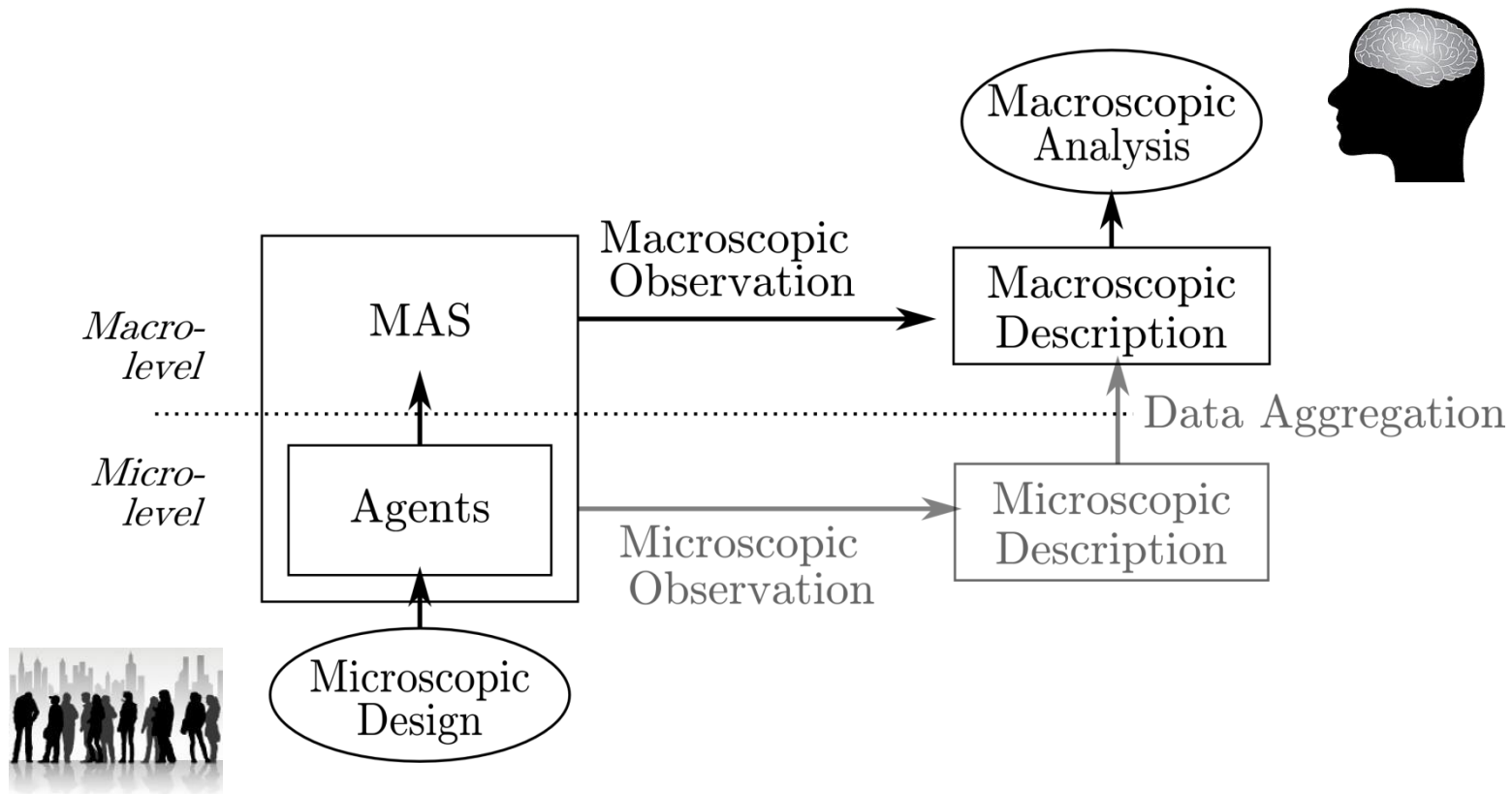
Microscopic Observation

Examples:

- Analysis of execution traces [Joumaa, 2009]
- Agent-based simulation [Luie and Carley, 2008]

Macroscopic Observation

- No precedence to the best of our knowledge

Complexity and Emergence

[Bonabeau and Dessalles, 1997]
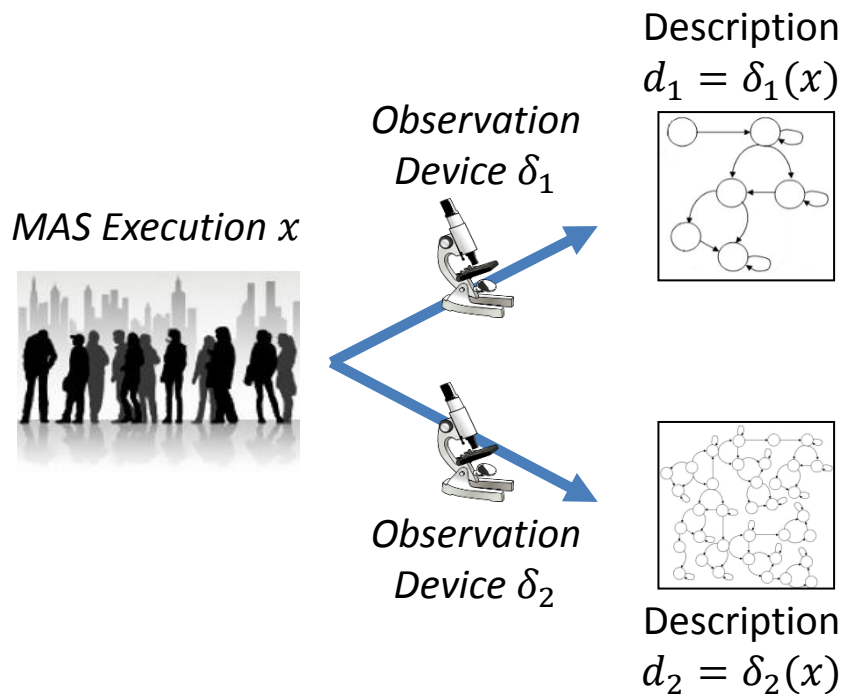« Emergence is associated with a decrease of the relative complexity. »

MAS Execution x

Complexity and Emergence

[Bonabeau and Dessalles, 1997]
« Emergence is associated with a decrease of the relative complexity. »

MAS Execution x

Observation Device δ_1

Description
$d_1 = \delta_1(x)$

Observation Device δ_2

Description
$d_2 = \delta_2(x)$

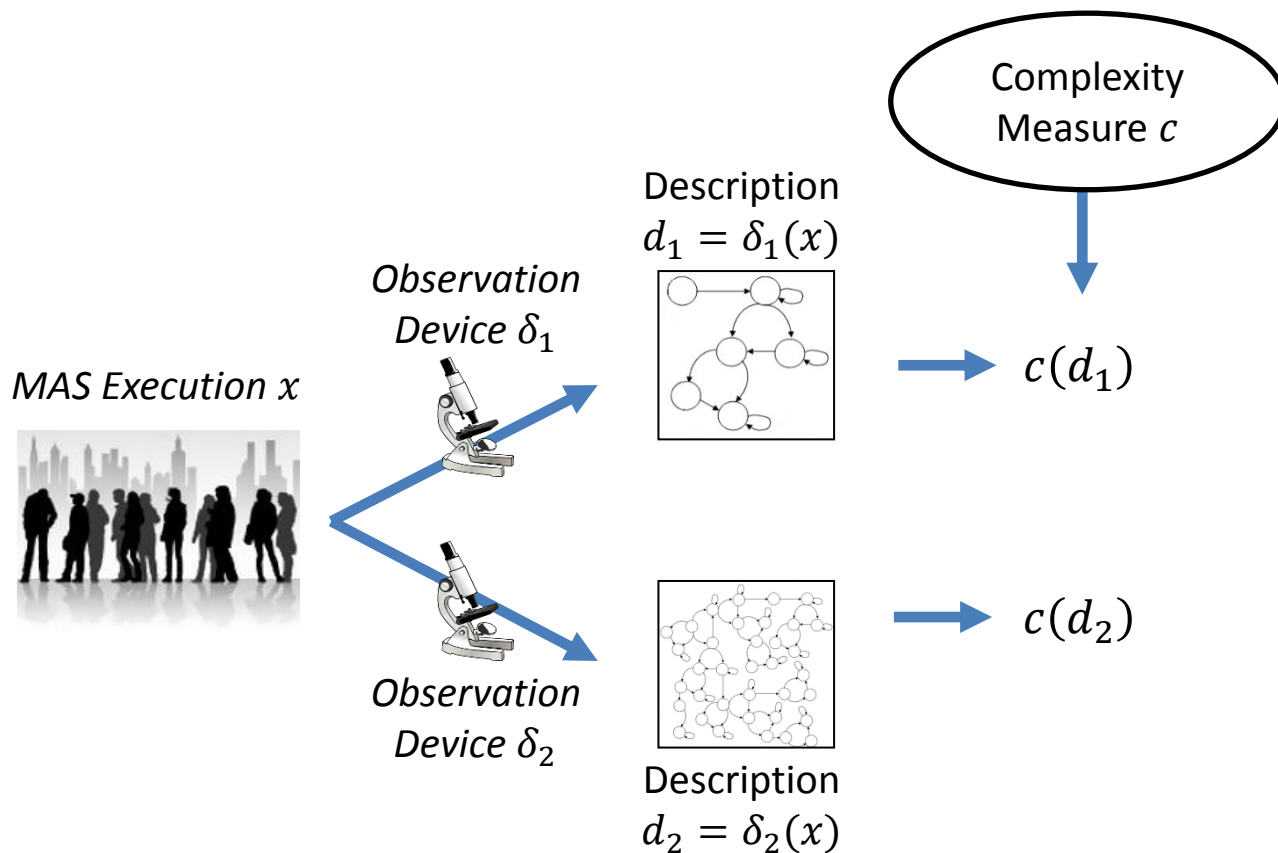# Complexity and Emergence
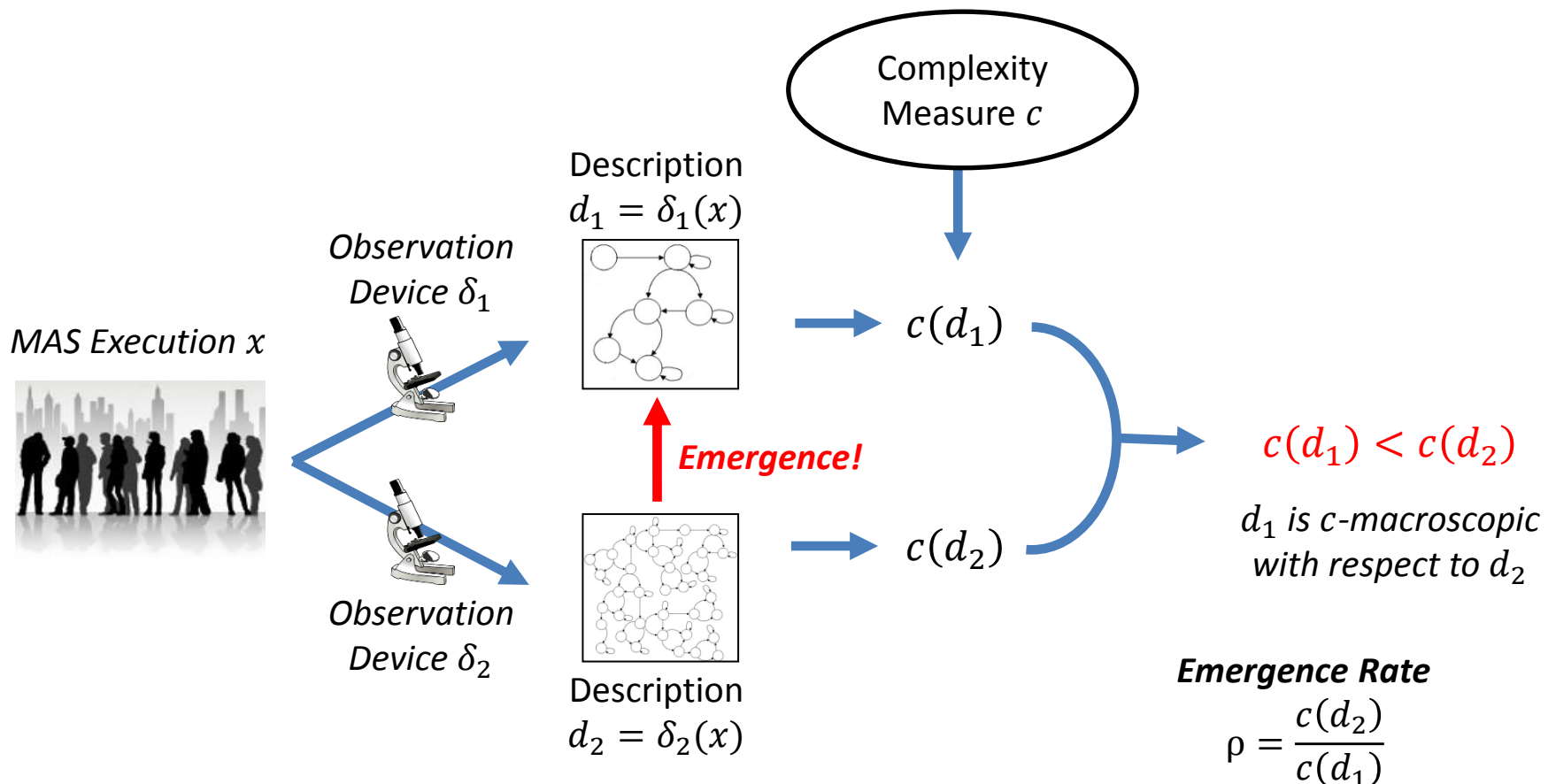
[Bonabeau and Dessalles, 1997]
« Emergence is associated with a decrease of the relative complexity. »
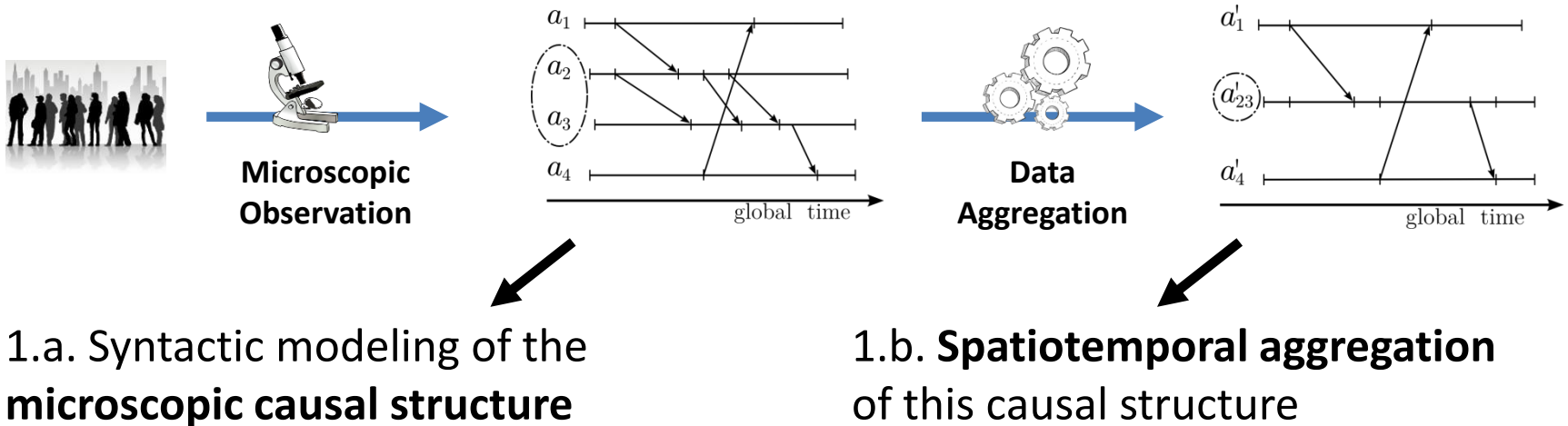
Complexity and Emergence

[Bonabeau and Dessalles, 1997]
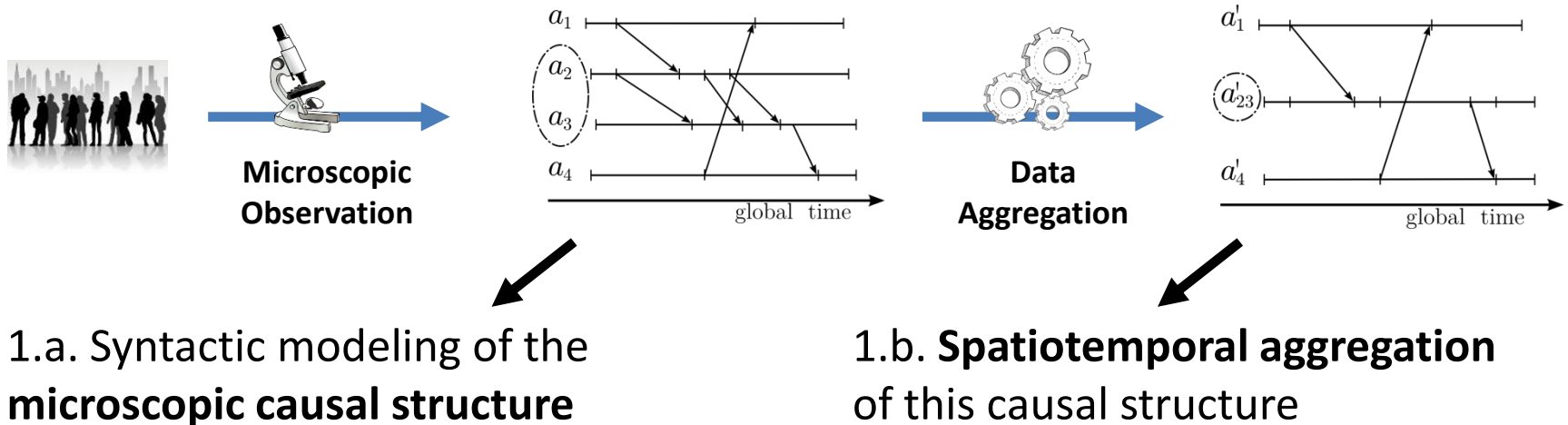« Emergence is associated with a decrease of the relative complexity. »

Complexity Measure c

Description $d_1 = \delta_1(x)$

Observation Device δ_1

MAS Execution x

$c(d_1)$

Emergence!

Observation Device δ_2

Description $d_2 = \delta_2(x)$

$c(d_2)$

$c(d_1) < c(d_2)$

d_1 is c-macroscopic with respect to d_2

Emergence Rate
$$\rho = \frac{c(d_2)}{c(d_1)}$$

A Two-parts Talk

1. Aggregating Microscopic Causal Descriptions

Microscopic Observation

Data Aggregation

1.a. Syntactic modeling of the **microscopic causal structure**

1.b. **Spatiotemporal aggregation** of this causal structure

A Two-parts Talk

1. Aggregating Microscopic Causal Descriptions

1.a. Syntactic modeling of the **microscopic causal structure**

1.b. **Spatiotemporal aggregation** of this causal structure

How to provide a macroscopic description without computing the microscopic description?

A Two-parts Talk
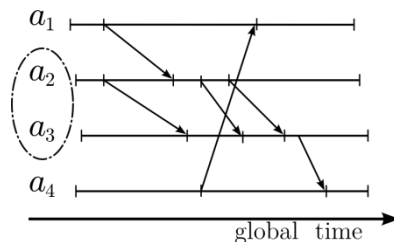
1. ## Aggregating Microscopic Causal Descriptions
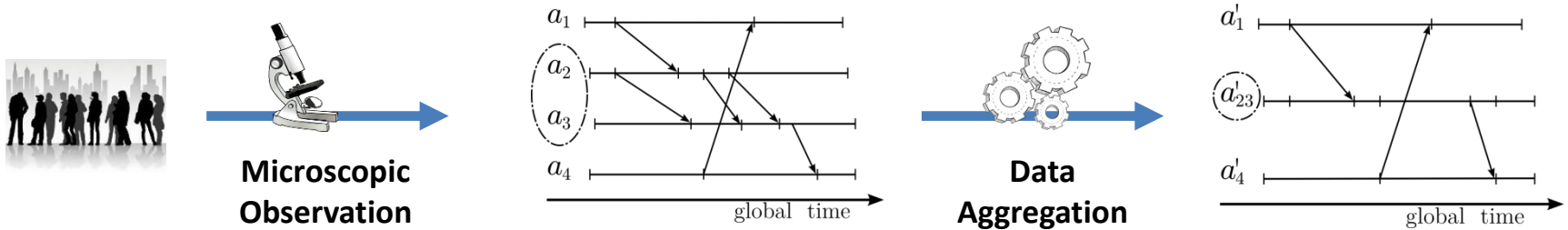
Microscopic Observation

Data Aggregation

2. ## Macroscopic Observation of an Ant Colony

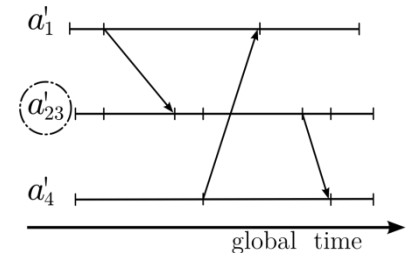**Macroscopic Observation**

Aggregating Microscopic Causal Descriptions
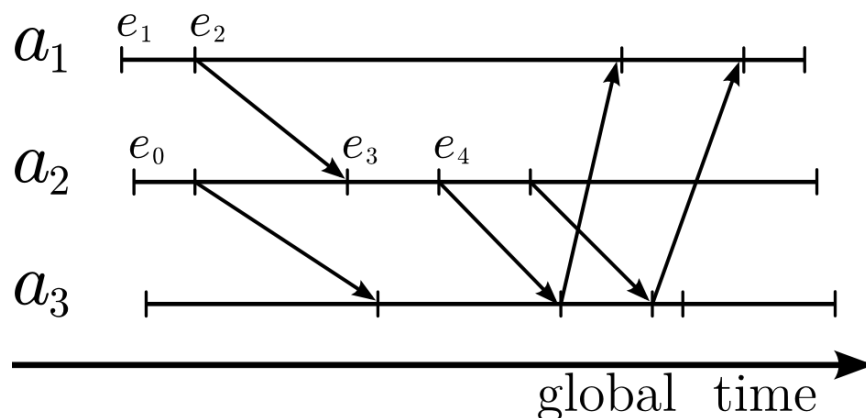

Microscopic Observation

Data Aggregation

Causal Descriptions of MAS

Generic modeling of the execution **causal structure**
- to focus on the **syntax** of agent interactions
- to abstract away the **semantics** of interactions

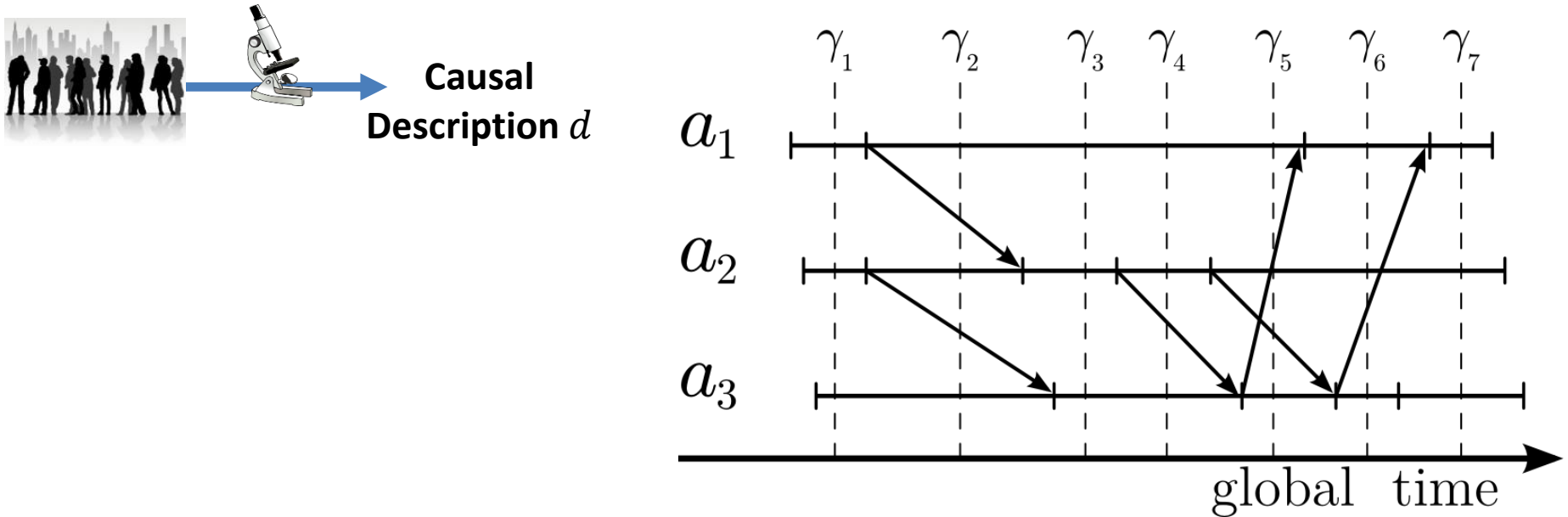**Interaction diagrams** adapted from Distributed Systems [Mattern, 1989] to Multi-agent Systems

Causal dependence:
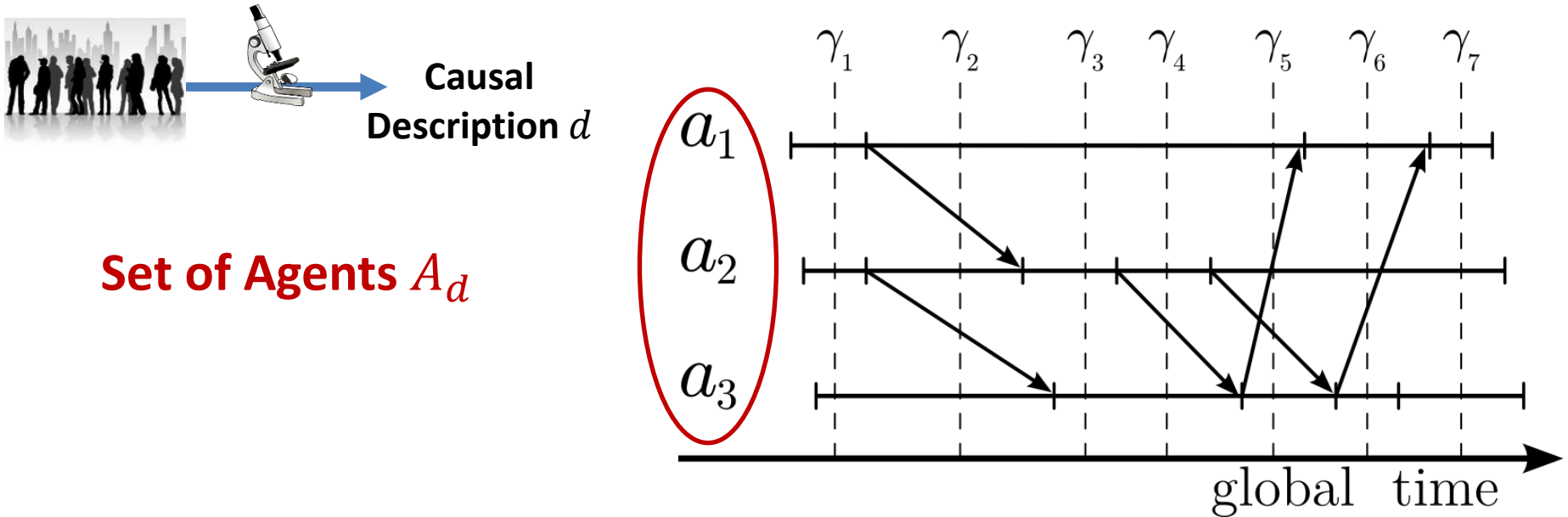$$e_1 < e_2 < e_3 < e_4$$

Independence:
$$e_0 \parallel e_1$$

Complexity of Causal Descriptions

Causal Description d

How to **measure** the complexity
of an interaction diagram?

Complexity of Causal Descriptions

Causal Description d

Set of Agents A_d

- Spatial complexity

$$c_s(d) \sim |A_d|$$

Complexity of Causal Descriptions

Causal Description d
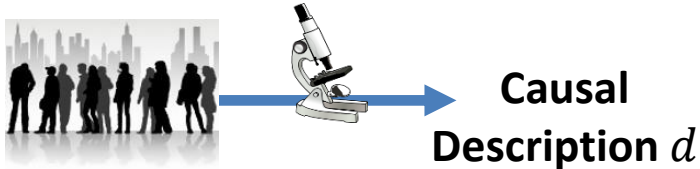
Set of Time Cuts Γ_d
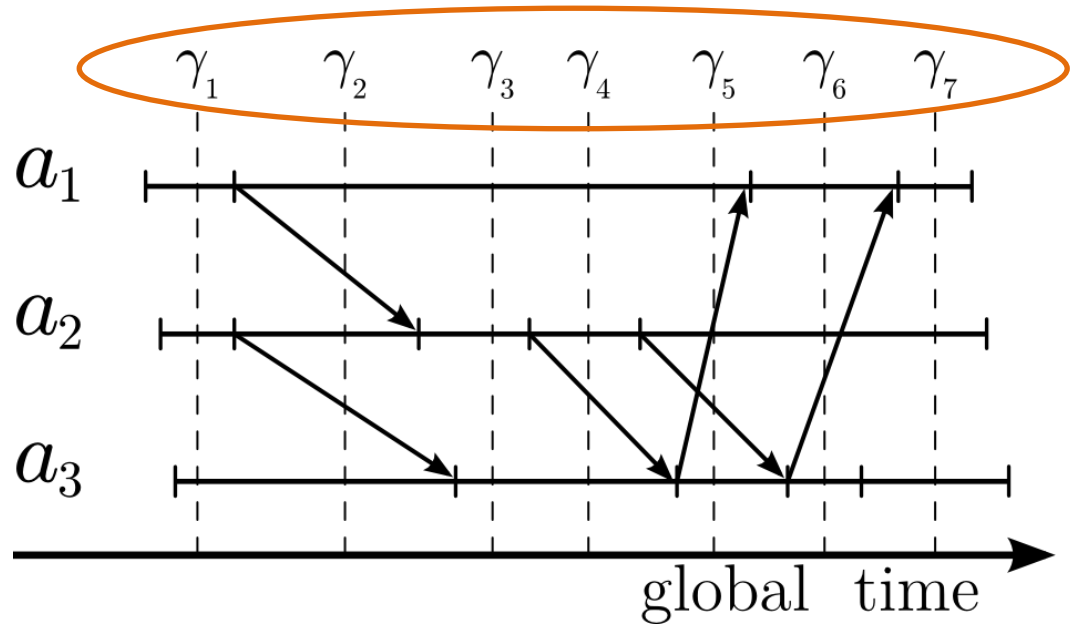
- Spatial complexity $\qquad c_s(d) \sim |A_d|$
- Temporal complexity $\qquad c_t(d) \sim |\Gamma_d|$

Complexity of Causal Descriptions
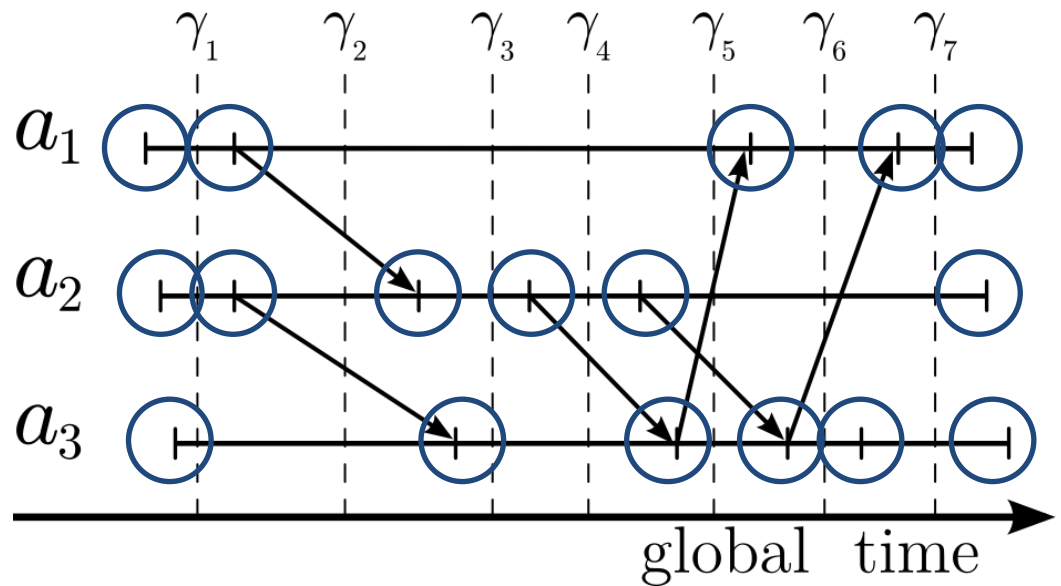
Causal Description d

Set of Events E_d

- Spatial complexity $\qquad\qquad\quad c_s(d) \sim |A_d|$
- Temporal complexity $\qquad\qquad\, c_t(d) \sim |\Gamma_d|$
- Spatio-temporal complexity $\quad\; c_{st}(d) \sim |E_d|$

Complexity of Causal Descriptions

Causal Description d
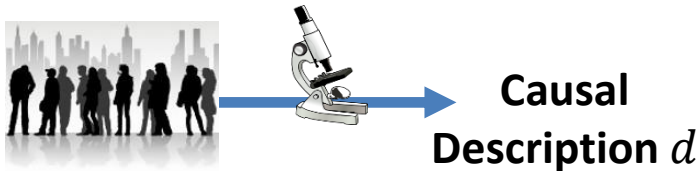
Set of Interactions I_d
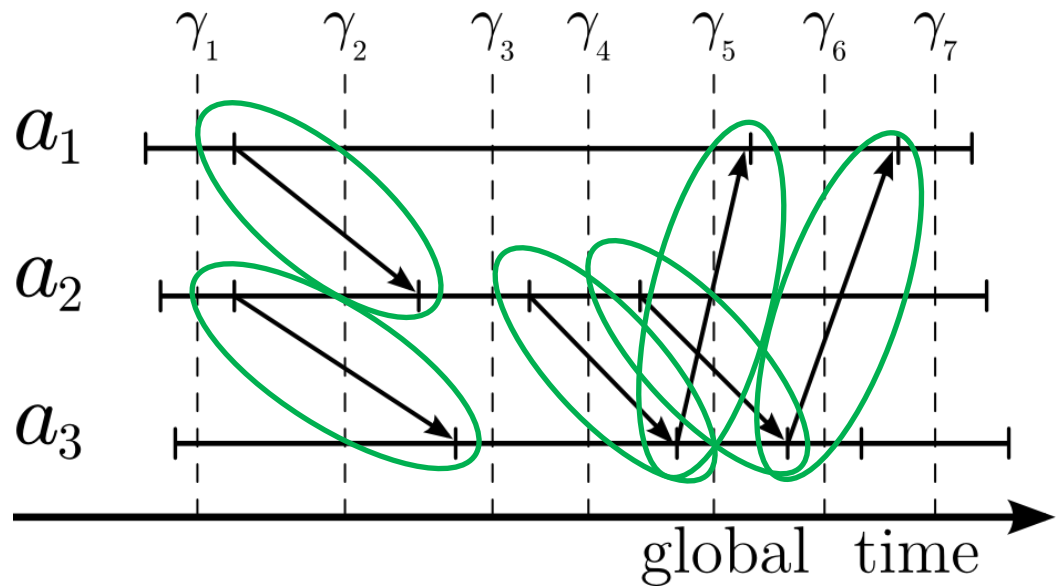
- Spatial complexity $\qquad c_s(d) \sim |A_d|$
- Temporal complexity $\qquad c_t(d) \sim |\Gamma_d|$
- Spatio-temporal complexity $\quad c_{st}(d) \sim |E_d|$
- Interaction complexity $\qquad c_i(d) \sim |I_d|$

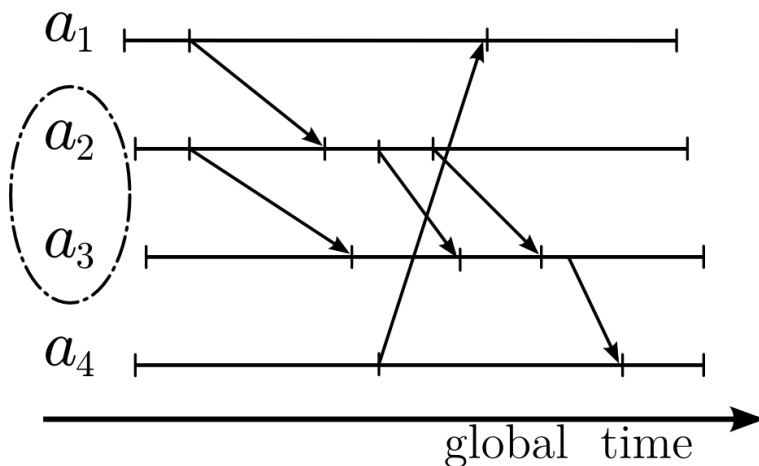# Complexity of Causal Descriptions

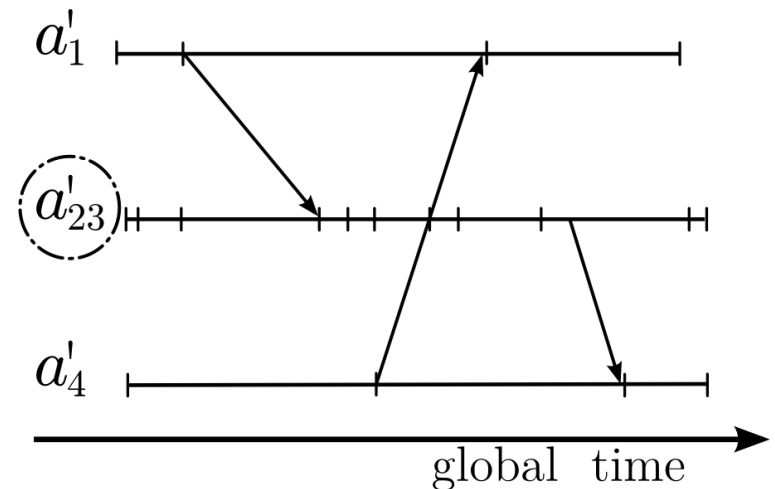**Causal Description** d
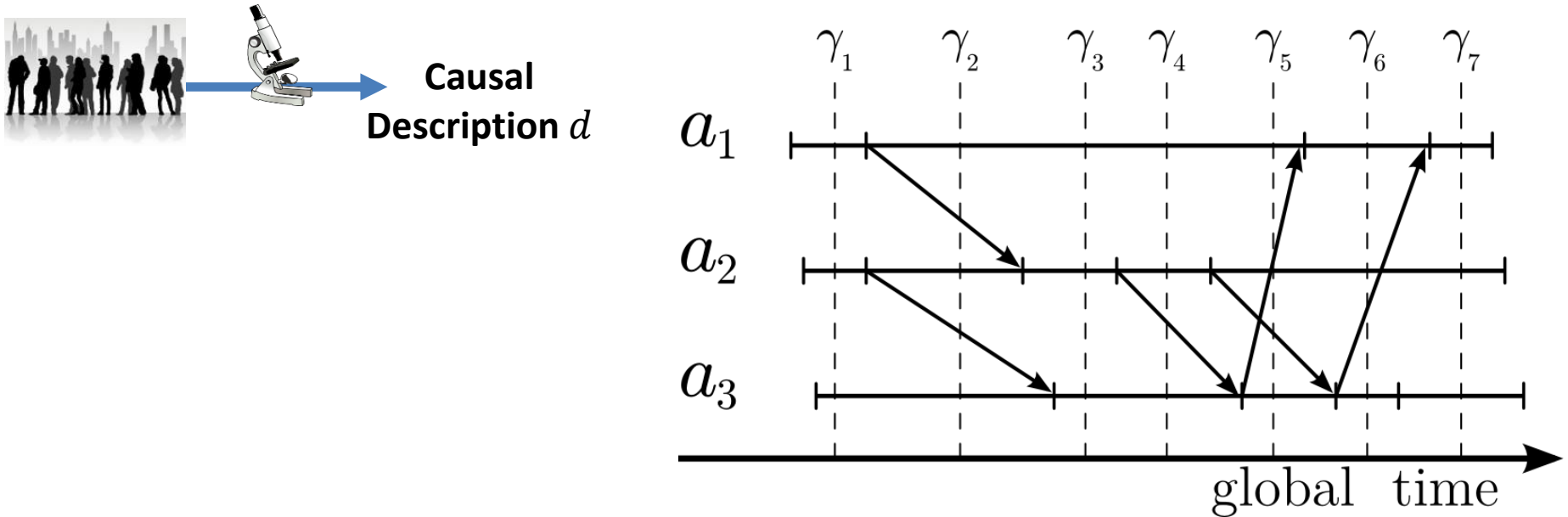
How to **reduce** the complexity
of an interaction diagram?

Spatial Aggregation
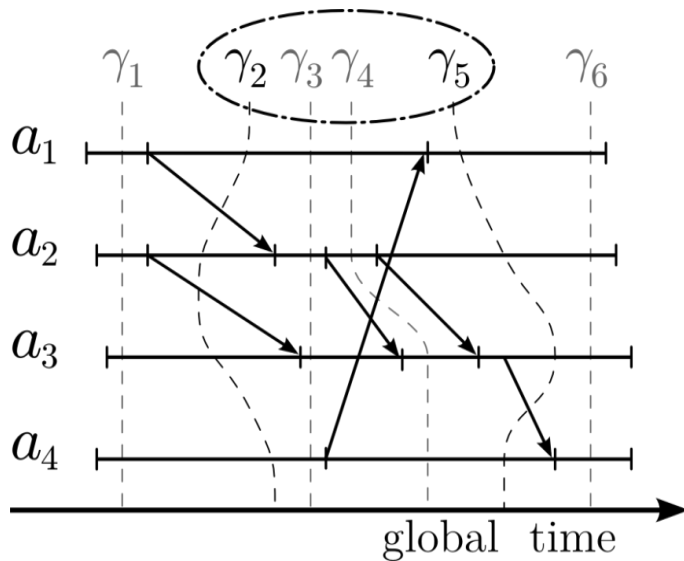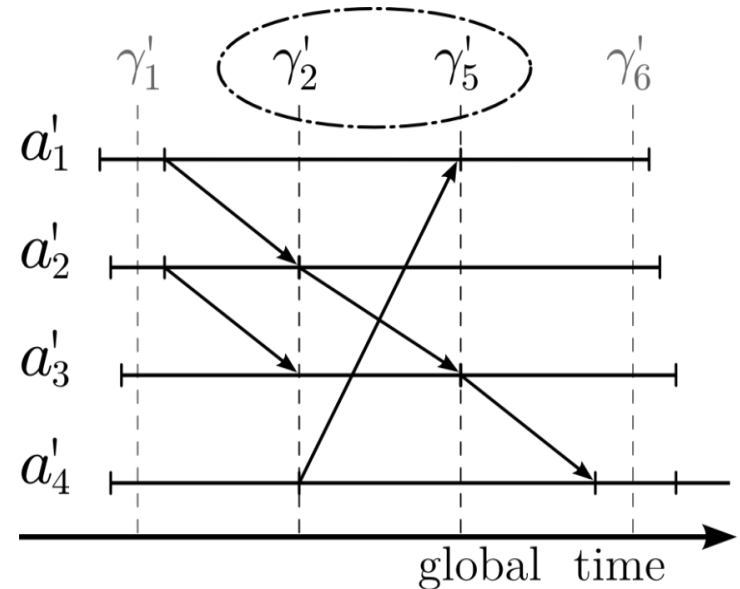
Micro-description → **Macro-description**

- Reduction of **spatial complexity**

- Potential reduction of **interaction complexity**

- Conservation of **temporal complexity**

Temporal Aggregation
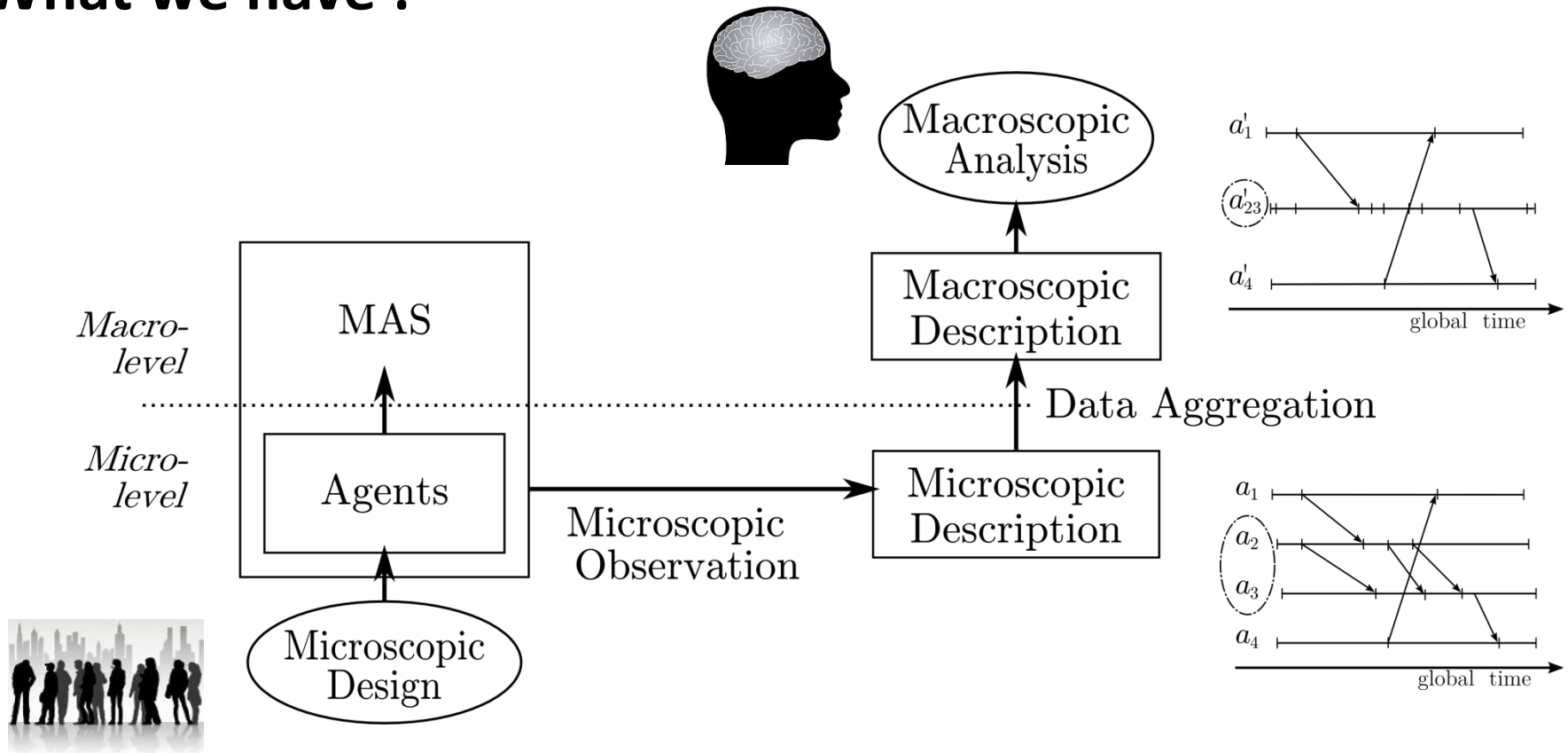
Micro-description → **Macro-description**

- Reduction of **temporal complexity**
- Potential reduction of **interaction complexity**
- Conservation of **space complexity**
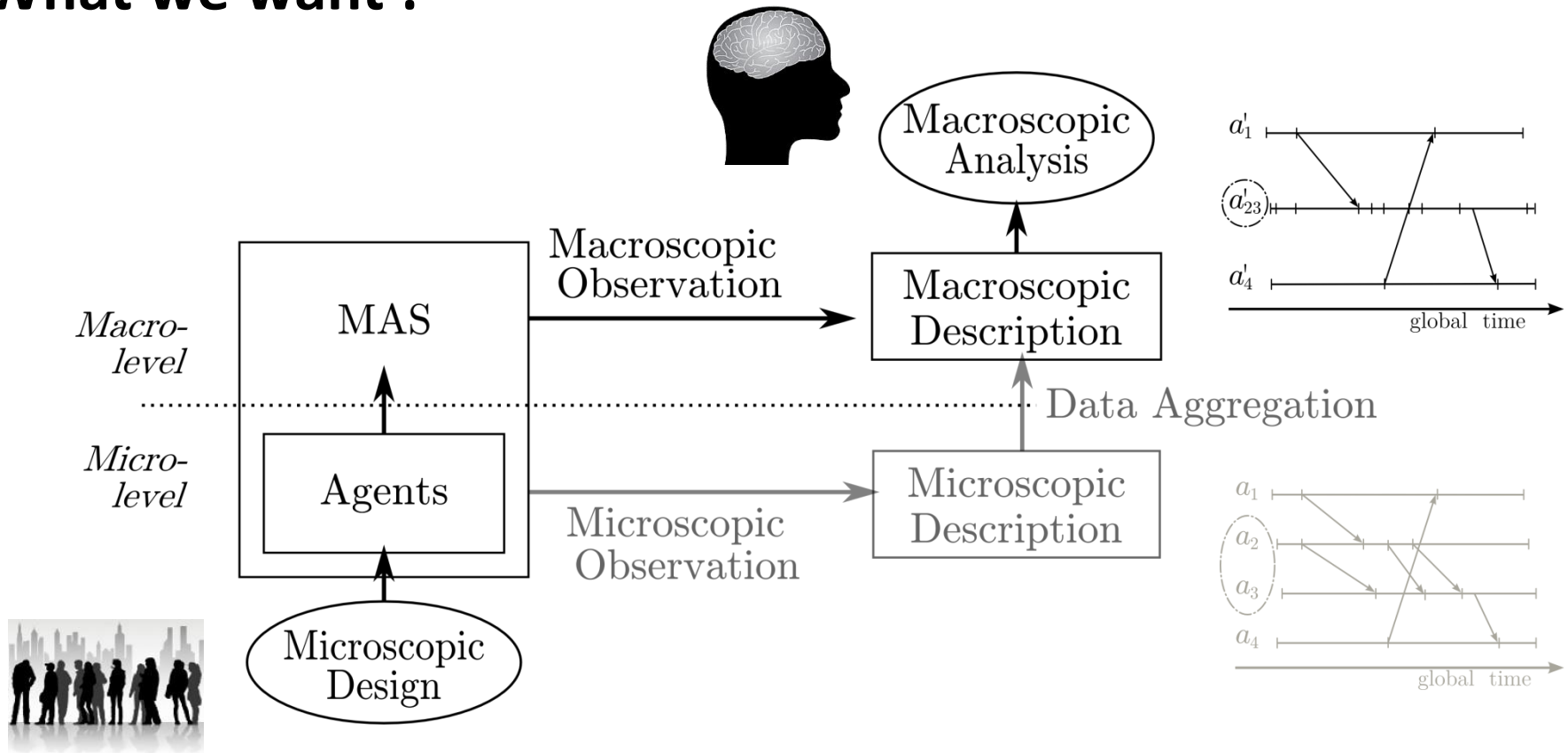
Macroscopic Observation of Causal Structures

What we have :
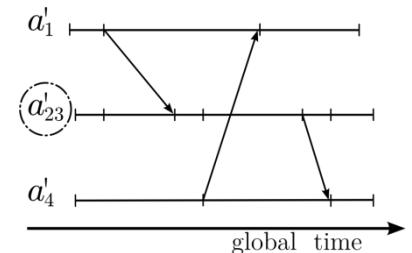
# Macroscopic Observation of Causal Structures

What we want :

Macroscopic Observation of an Ant Colony

Macroscopic Observation
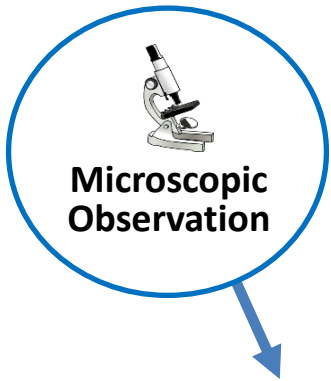
Macroscopic Observation

- Incorporate the observation process within the MAS execution

- Distribute in space and time the computation of aggregated causal descriptions

→ The agents support their own macro-observation process, that becomes itself an emergent process

Observation of an Ant Colony
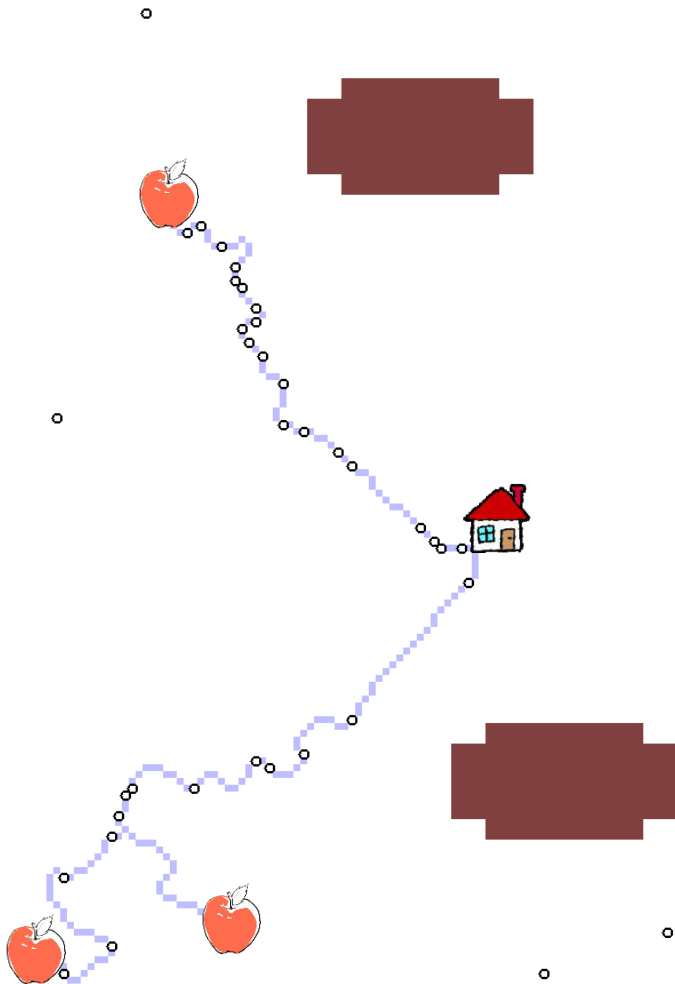
- *AntsForage* on MASON [Luke *et al.*, 2005]
  Micro-observation device
  Macro-observation device

- Emergent phenomena
  Creation of pheromone tracks
  Exploitation of food sources

- Justification of this application
  – Classical and well-known MAS
  – Pedagogical objectives
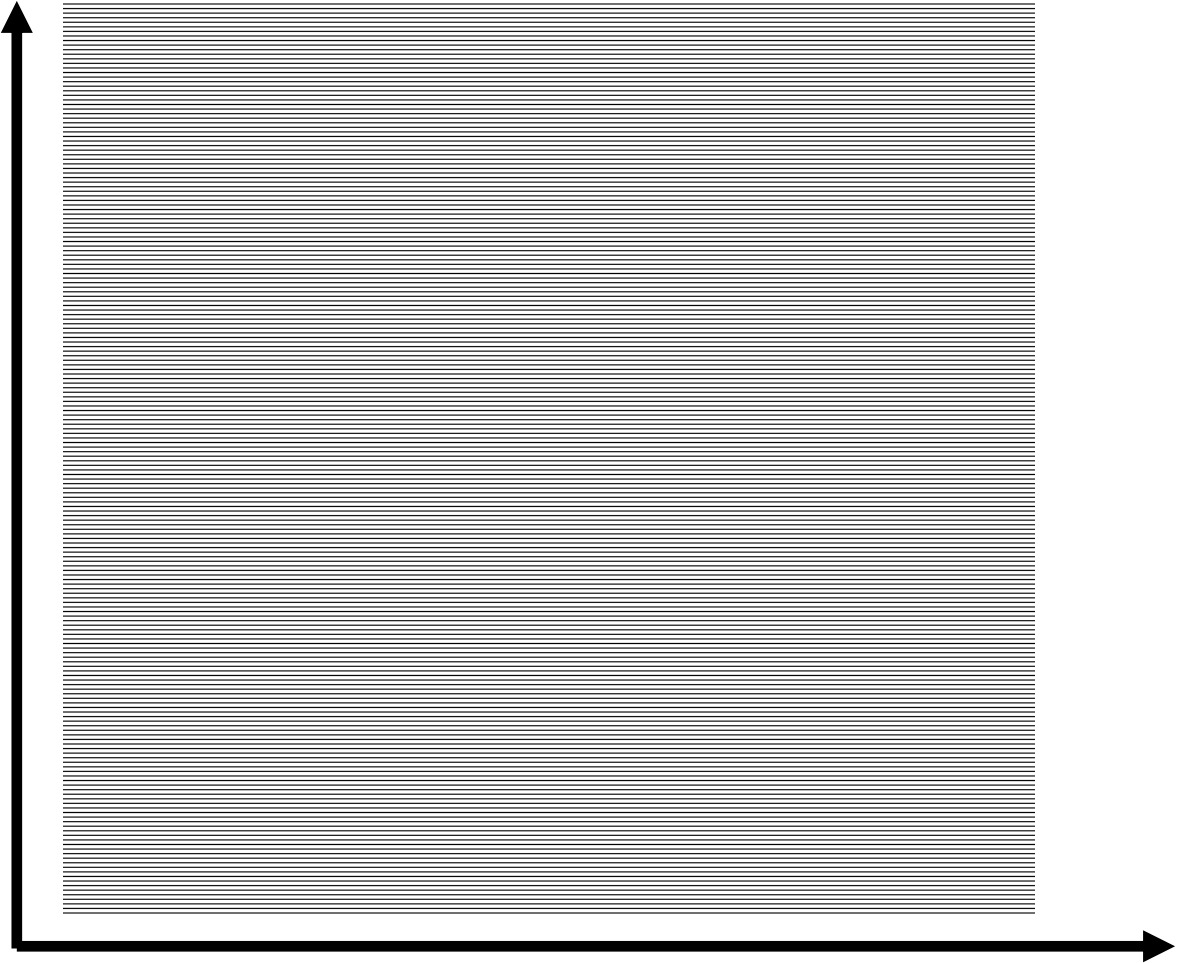 – First evaluation of the approach

Microscopic Observation

Microscopic Observation

Microscopic Interaction Diagram
one probe per ant
one cut per time step

200 ants

40 steps

Microscopic Observation

Microscopic Observation

Microscopic Interaction Diagram
one probe per ant
one cut per time step

200 ants

a_1

Pheromones deposit

γ_1

40 steps

Microscopic Observation

Microscopic Observation

Microscopic Interaction Diagram
one probe per ant
one cut per time step

200 ants

a_2

Pheromones detection

Interaction

a_1

Pheromones deposit
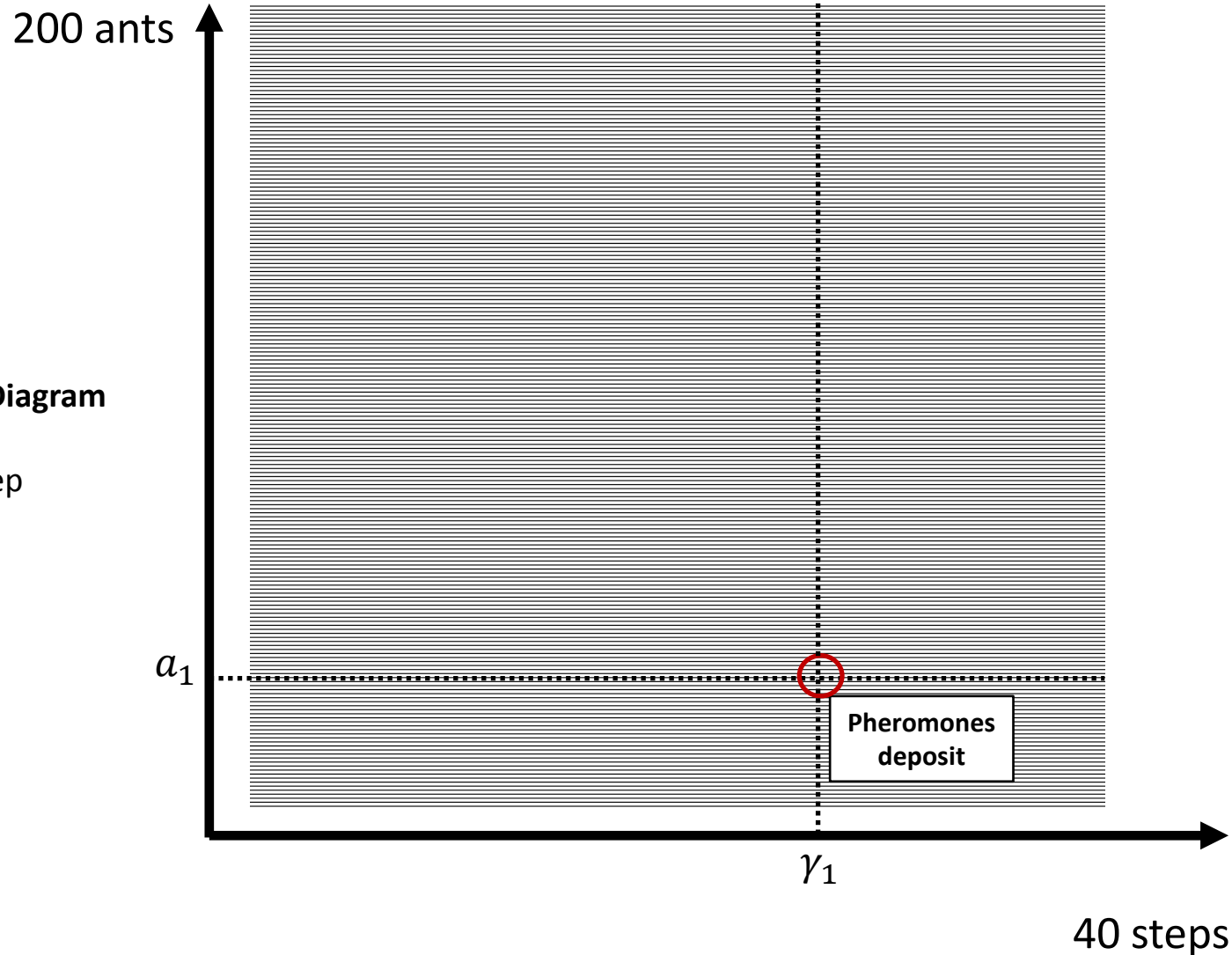
γ_1 γ_2

40 steps

Microscopic Observation

Microscopic Observation

Microscopic Observation

Microscopic Interaction Diagram
one probe per ant
one cut per time step

200 ants

a_2

a_1

γ_1 γ_2

100 steps

Microscopic Observation

Microscopic Observation

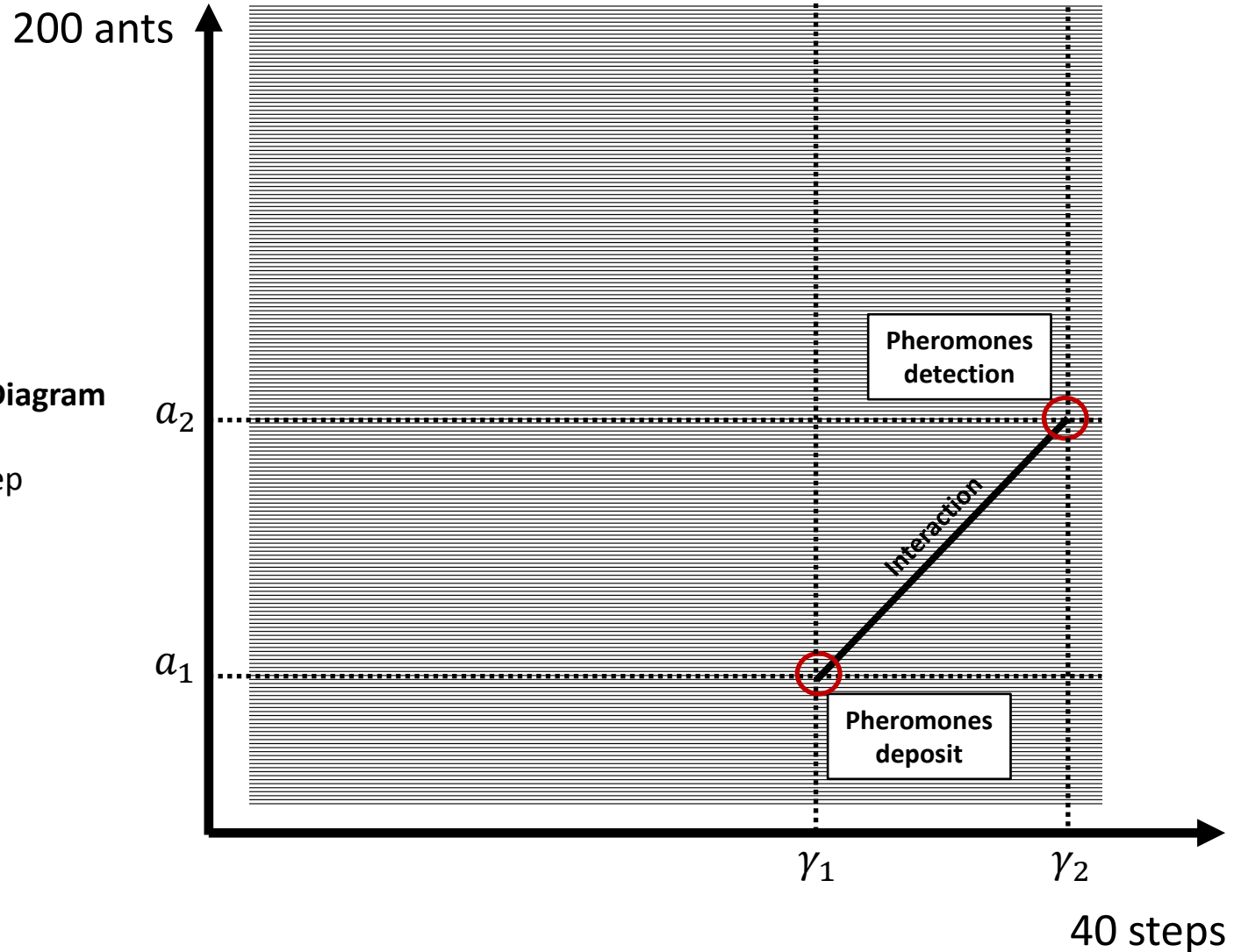Microscopic Interaction Diagram
one probe per ant
one cut per time step

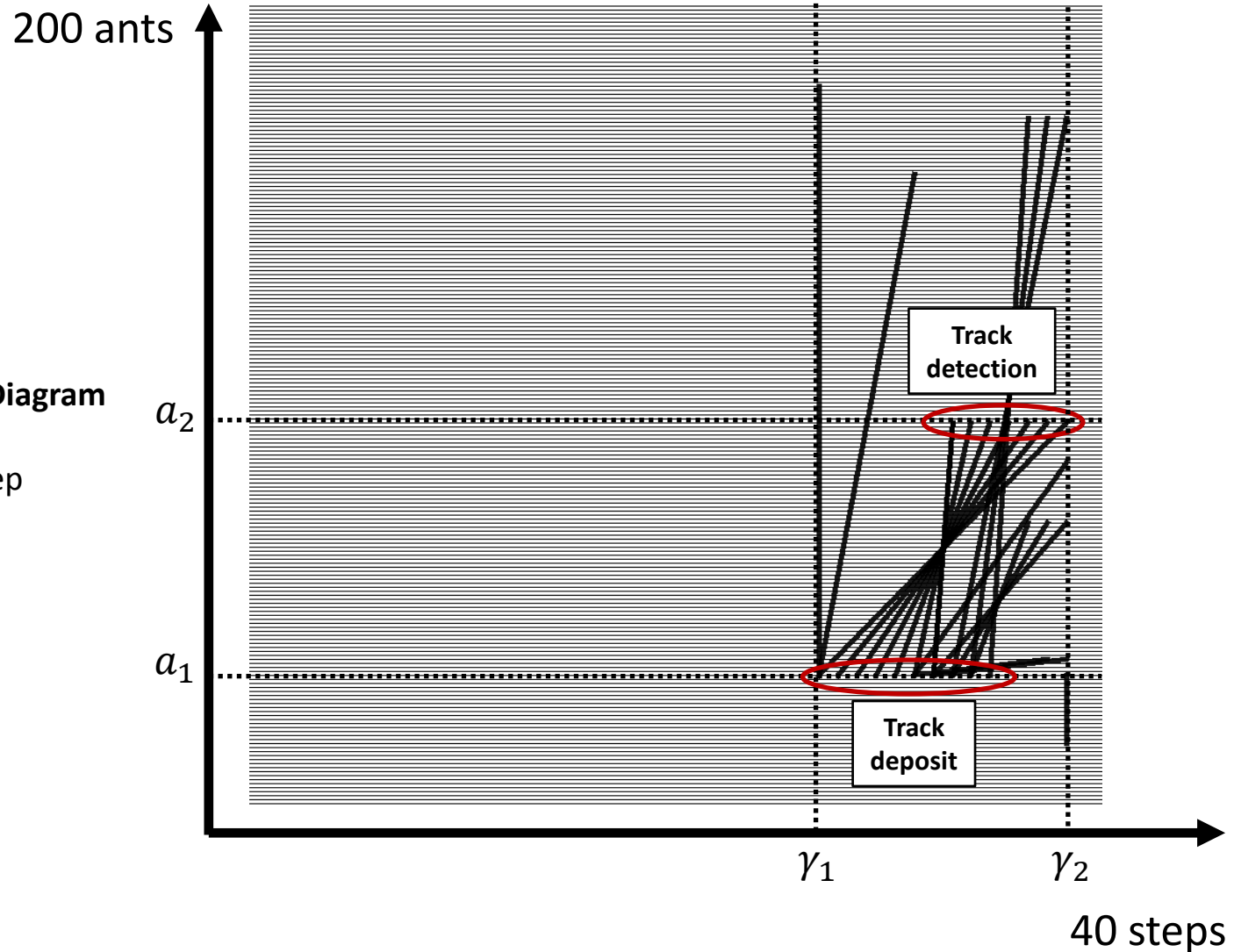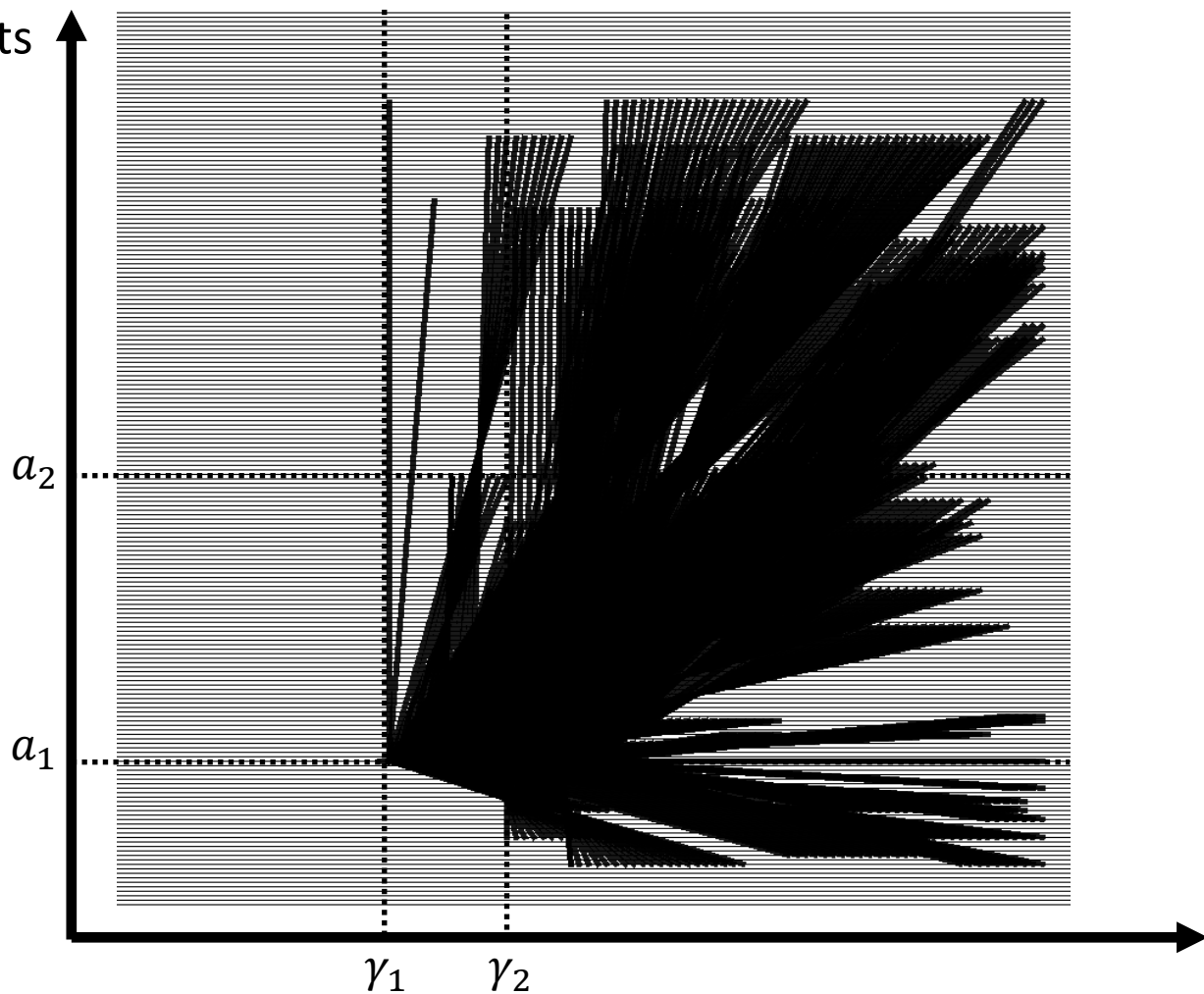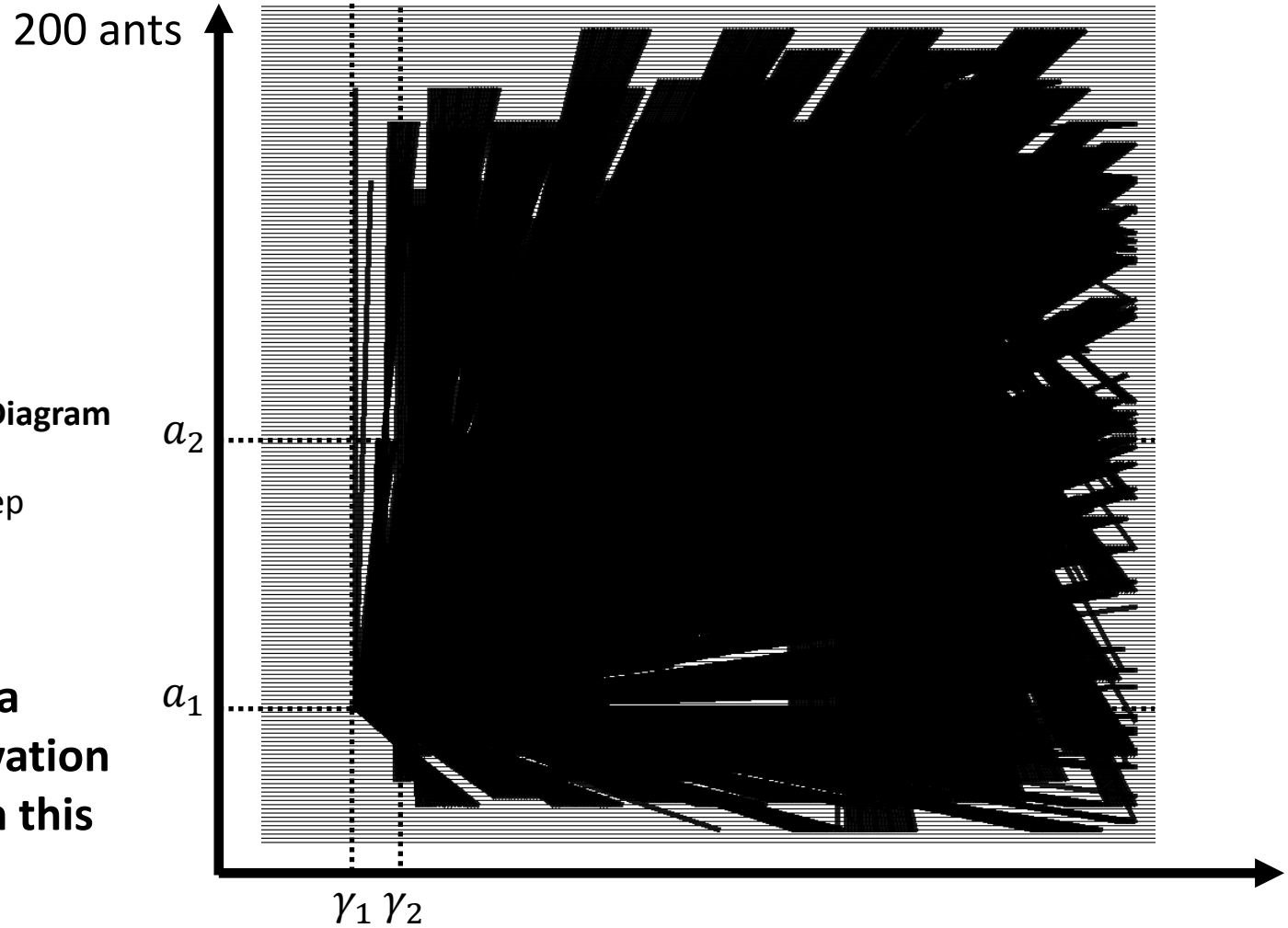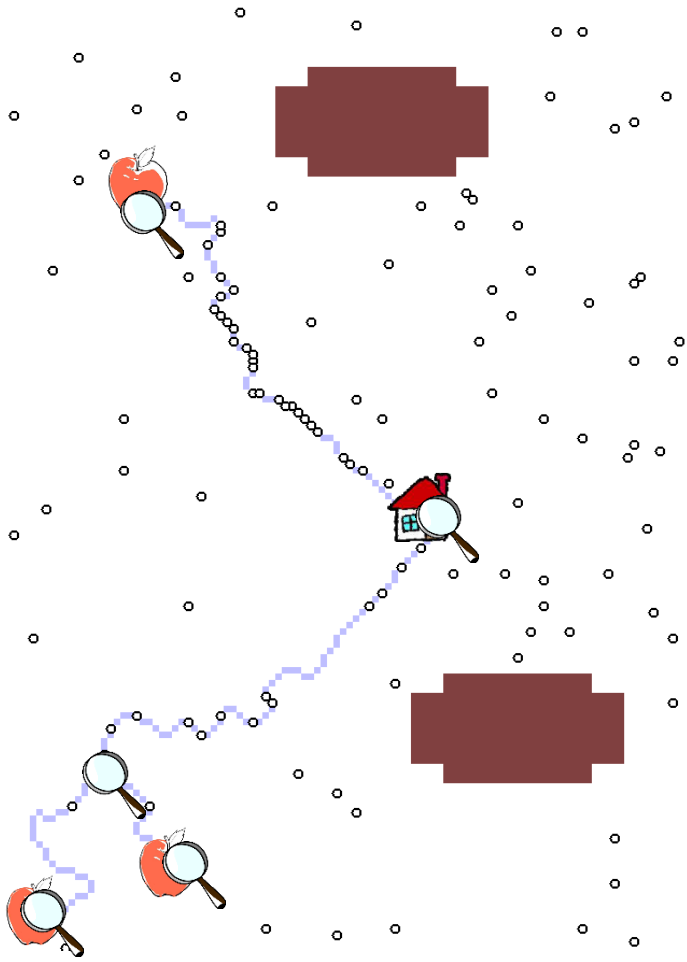**How to design a macroscopic observation design to deal with this complexity?**

200 ants

a_2

a_1

$\gamma_1\ \gamma_2$

280 steps

Macro-probes for Spatial Aggregation

Adapted from *distributed sensor networks*

Macro-probes: sensors located in decisive places (home, food sources, track forks) in order to centralize spatial information

Aggregated Agents: all ants are associated to the last probe they visited

Probe Interactions: transfer of an ant from a track to another one

Distributed Cuts and Temporal Aggregation
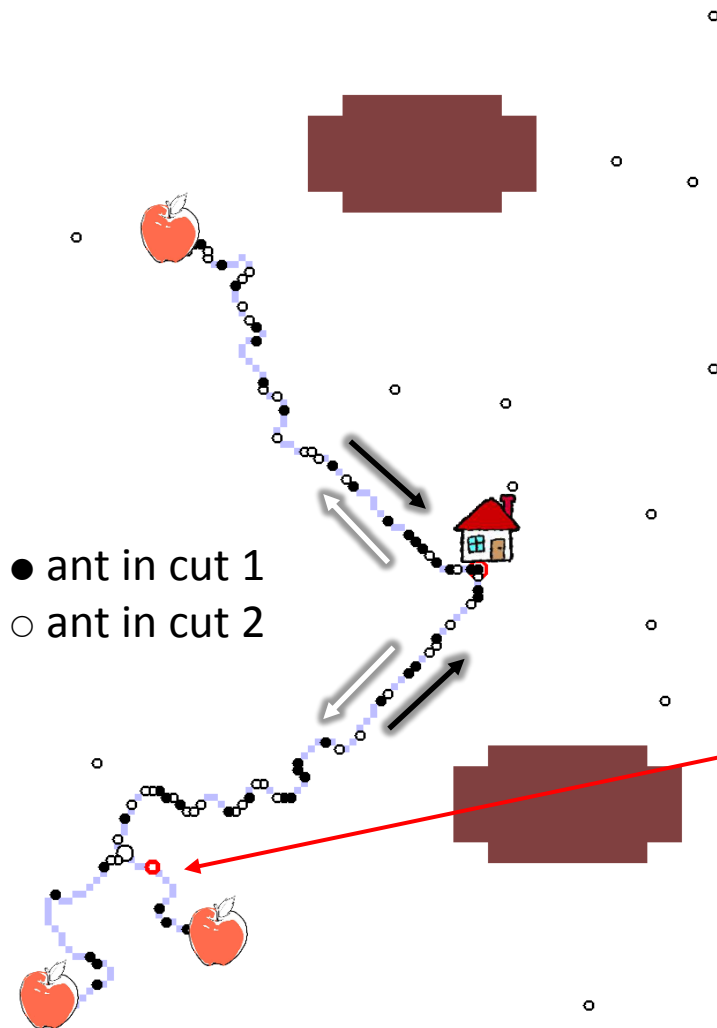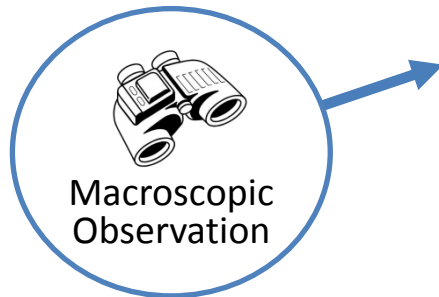
Adapted from the *snapshot algorithm* [Chandy and Lamport, 1985]

Macro-cuts: abstract time intervals synchronizing temporal information

Aggregated Cuts: all interactions happening during the round-trip of a given ant of reference

Probe Interactions: ant transfers aggregated for each round-trip

● ant in cut 1
○ ant in cut 2

Macroscopic Observation

Macroscopic
Observation

Macroscopic Observation

Discovery of food source 1

Discovery of food sources 2 and 3

Macroscopic Observation

Macroscopic Observation

Discovery of food source 1

Exploitation of food source 1

Macroscopic Observation

Discovery of food sources 2 and 3

Macroscopic Observation

Discovery of food source 1 — Exploitation of food source 1

Macroscopic Observation

Discovery of food sources 2 and 3 — Exploitation of food sources 2 and 3

Macroscopic Observation

Discovery of food source 1   Exploitation of food source 1
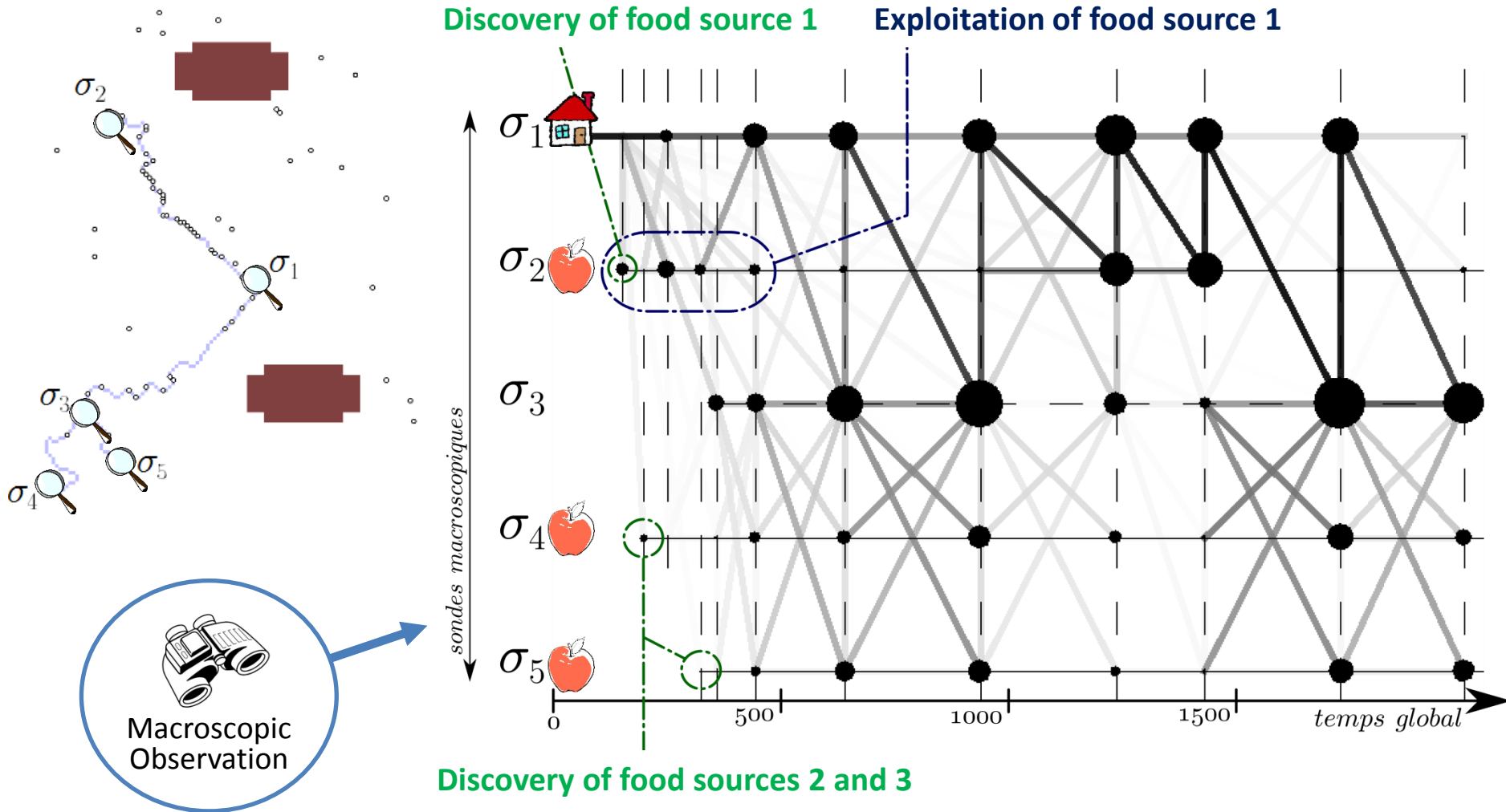
Macroscopic Observation

Discovery of food sources 2 and 3   Exploitation of food sources 2 and 3

Macroscopic Observation

Discovery of food source 1   Exploitation of food source 1

Macroscopic Observation

Discovery of food sources 2 and 3   Exploitation of food sources 2 and 3

Results

- Getting the macroscopic description is less expensive
  - **100 simulations** with **6400 ants** and **6400 time steps**
  - **220×200 grid** with **10 food sources** and **4 obstacles**

	Average emergence rate	Std. dev.
Spatial Complexity	$\bar{\rho}_s = 300$	$\sigma_s = 1,4$
Temporal Complexity	$\bar{\rho}_t = 180$	$\sigma_t = 1,2$
Interaction Complexity	$\bar{\rho}_i = 14000$	$\sigma_i = 1,5$
Relative Complexity	$\overline{\rho_r} = 58$	$\sigma_r = 1,5$

- It is tractable, and yet **emergent phenomena of interest are still fully described by the macroscopic observation**

Results

Spatial Complexity
wrt the number of agents

Temporal Complexity
wrt execution time

Conclusion and Perspectives

Conclusion and Perspectives

Macroscopic Analysis

Macroscopic Observation

Macroscopic Description → **Emergence**
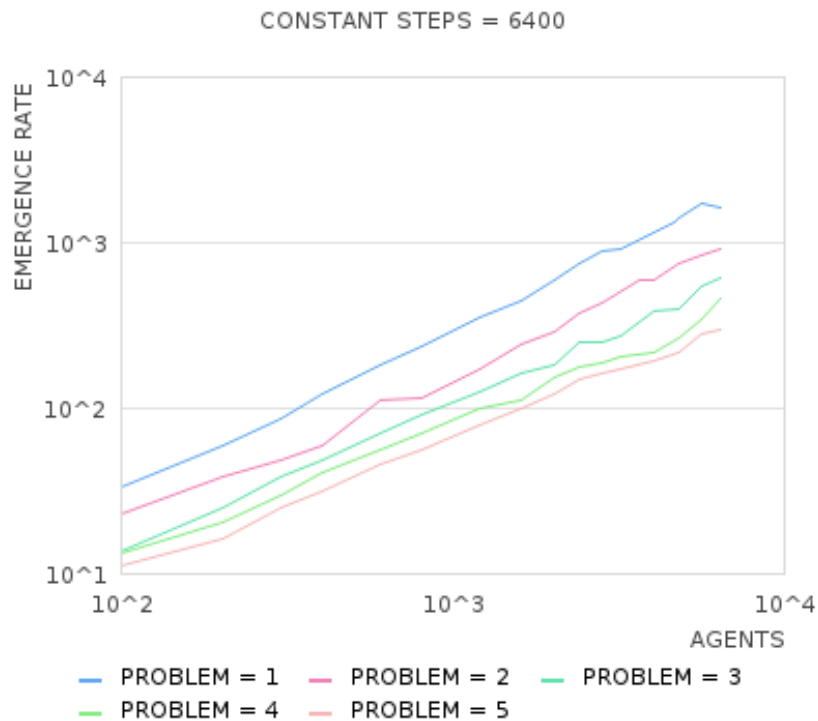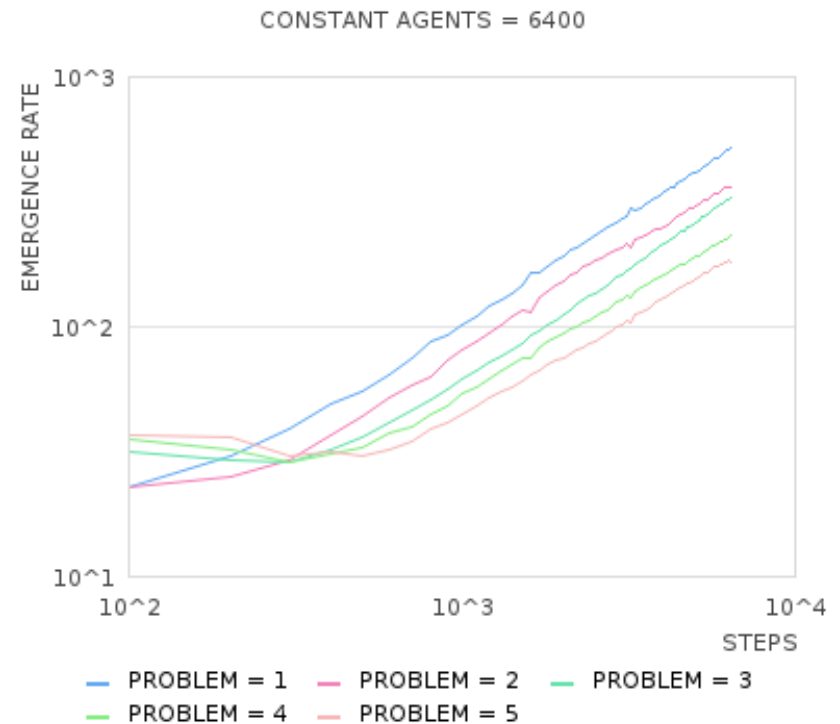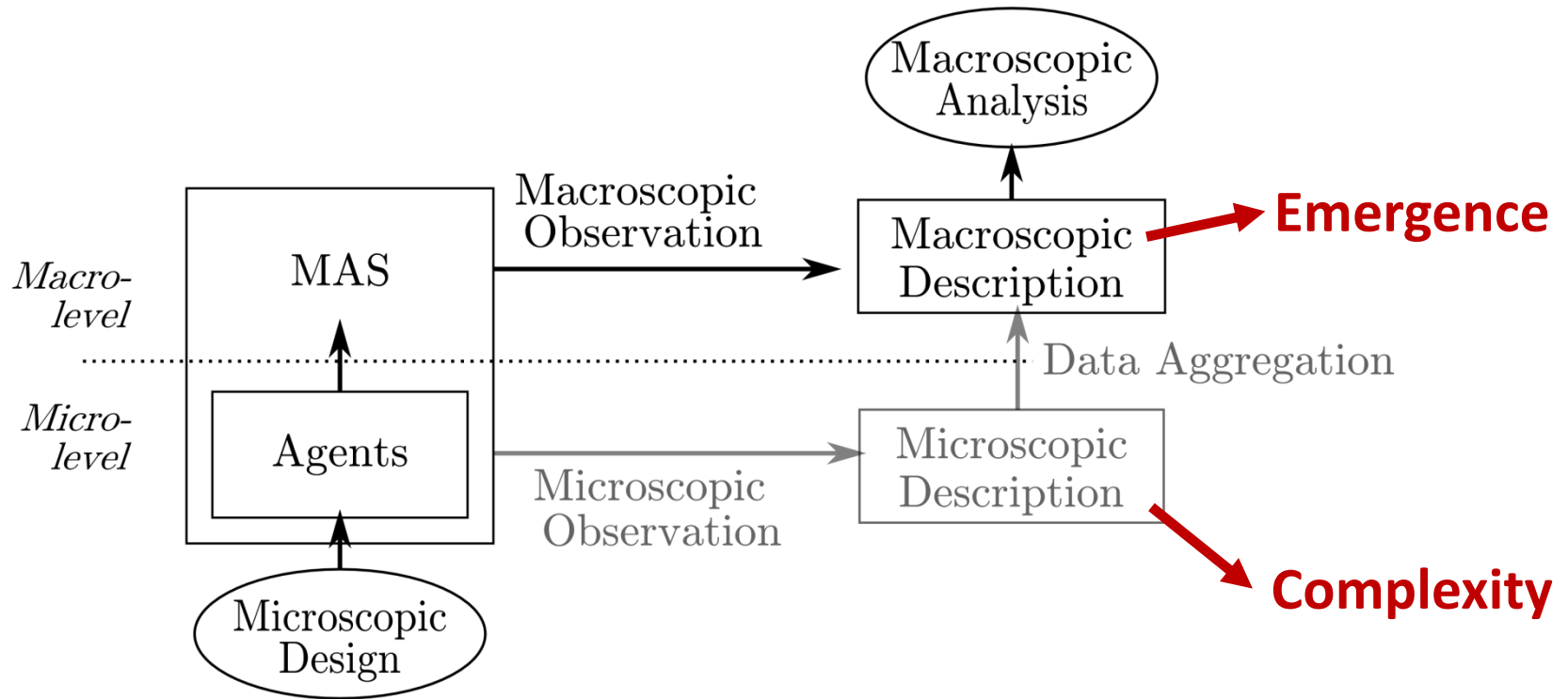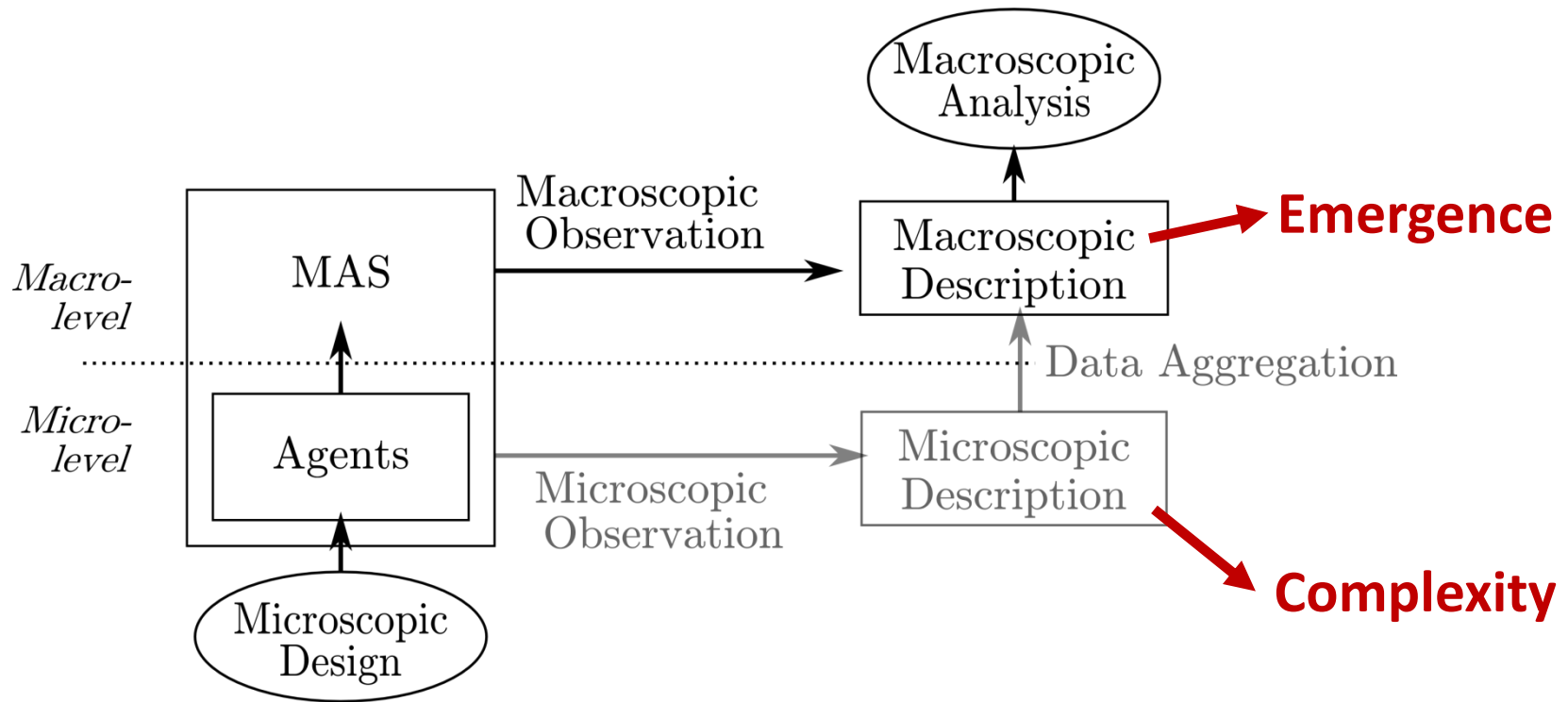
MAS

Macro-level

Micro-level

Agents

Microscopic Observation

Data Aggregation

Microscopic Description → **Complexity**

Microscopic Design

	Internal	External
Macro	**MAS**	**Emergence**
Micro	**Agents**	**Complexity**

Any other interpretation or exploitation of this diagram?

Thank you for your attention

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Yves Demazeau   `Yves.Demazeau@imag.fr`

Jean-Marc Vincent   `Jean-Marc Vincent@imag.fr`