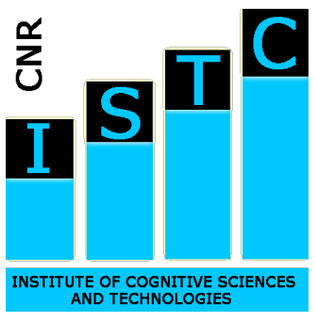
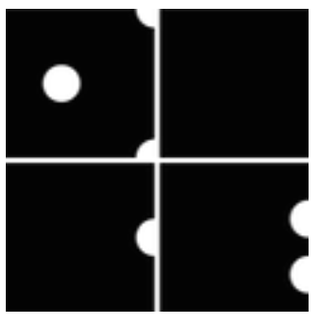
A Design Pattern for Swarm-Centric Decision Making

Vito Trianni
vito.trianni@istc.cnr.it

Tuesday, June the 7th, 2016





design of decentralised systems

- large number of interconnected agents
- distributed, decentralised
- self-organised

SWARM ROBOTICS

WIRELESS SENSOR NETWORKS

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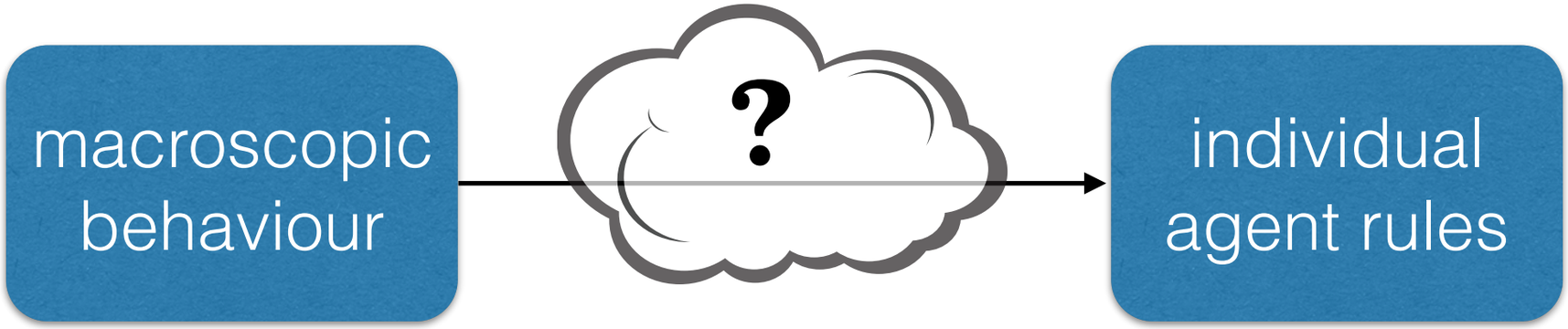

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design of decentralised systems

- large number of interconnected agents
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SWARM ROBOTICS

WIRELESS SENSOR NETWORKS

- hard to model
- heterogeneities
- domain-specific challenges

CURRENT APPROACH: tailored solution to specific problems

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design patterns

- reusable solutions for a specific class of problems
- leverage on the principled understanding of theoretical models of collective systems

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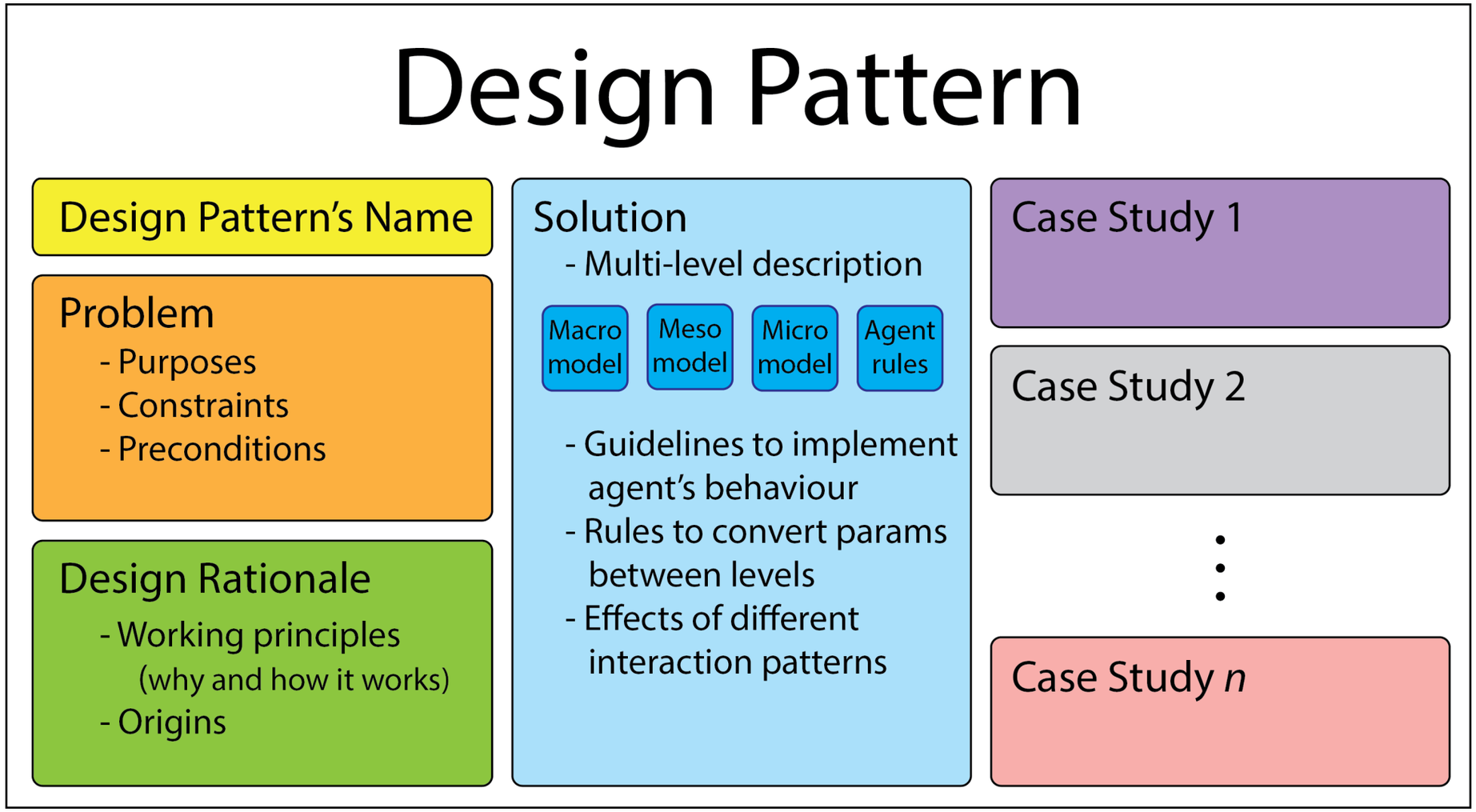

decentralised decision making

- best-of-*n* decision problem
- set of *n* options
- each option *i* has a quality v_i
- GOAL: select the best (or equal-best) option

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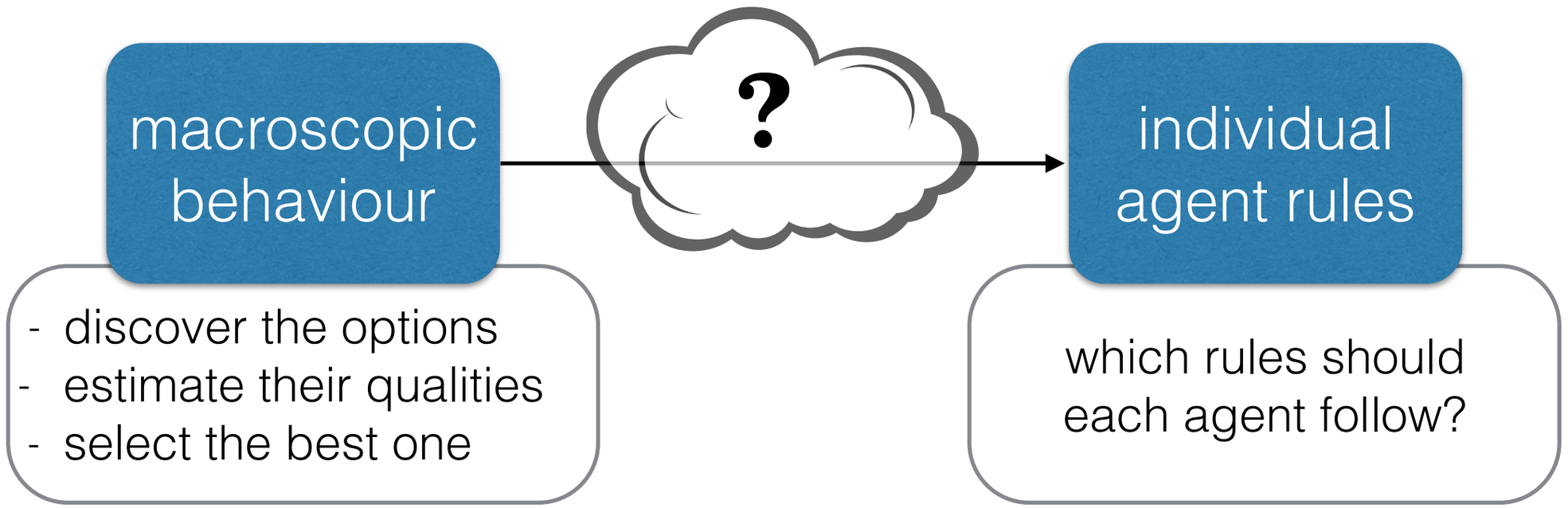

design rationale

nest-site selection in honeybees

+ attains near-optimal speed-accuracy tradeoff
+ no need of direct comparison between option qualities
+ adaptive mechanisms to tune decision speed and to break symmetry deadlocks

nest-site selection model

discovery:

$$U \longrightarrow A$$
$$U \longrightarrow B$$

abandonment:

$$A \longrightarrow U$$
$$B \longrightarrow U$$

recruitment:

$$A+U \longrightarrow A+A$$
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direct switch:

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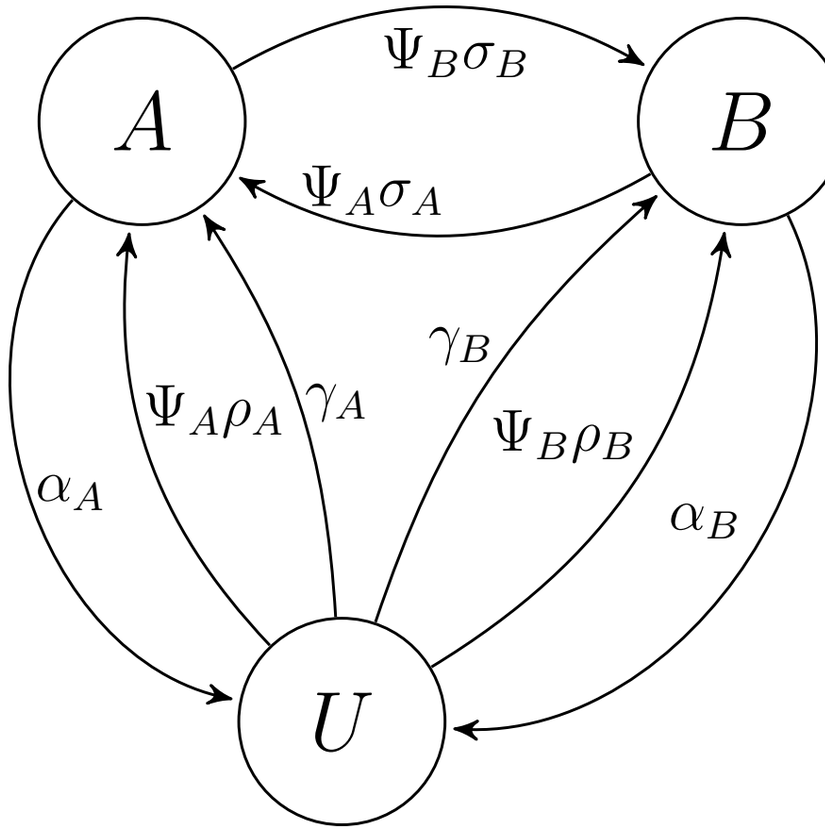

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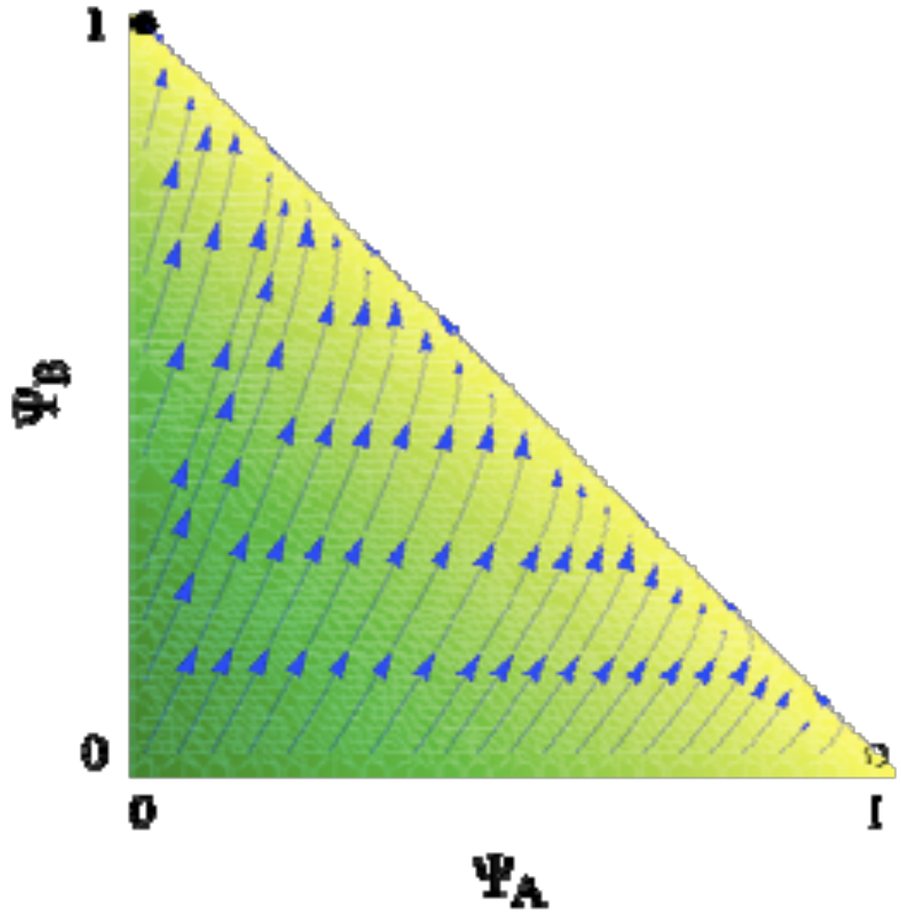

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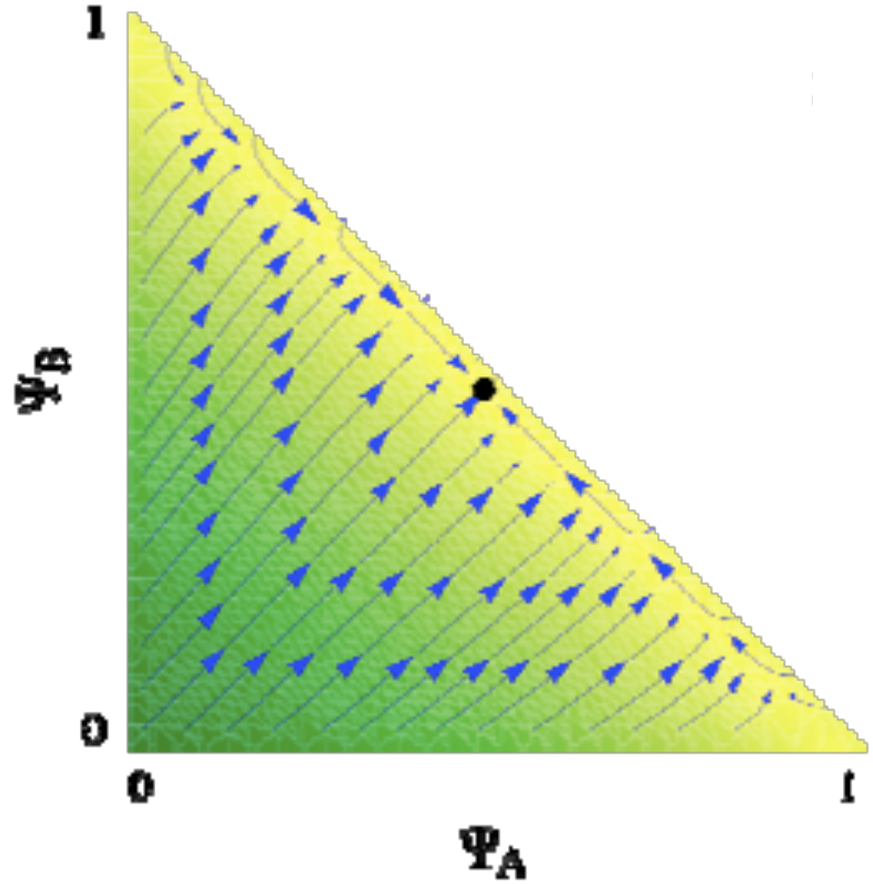

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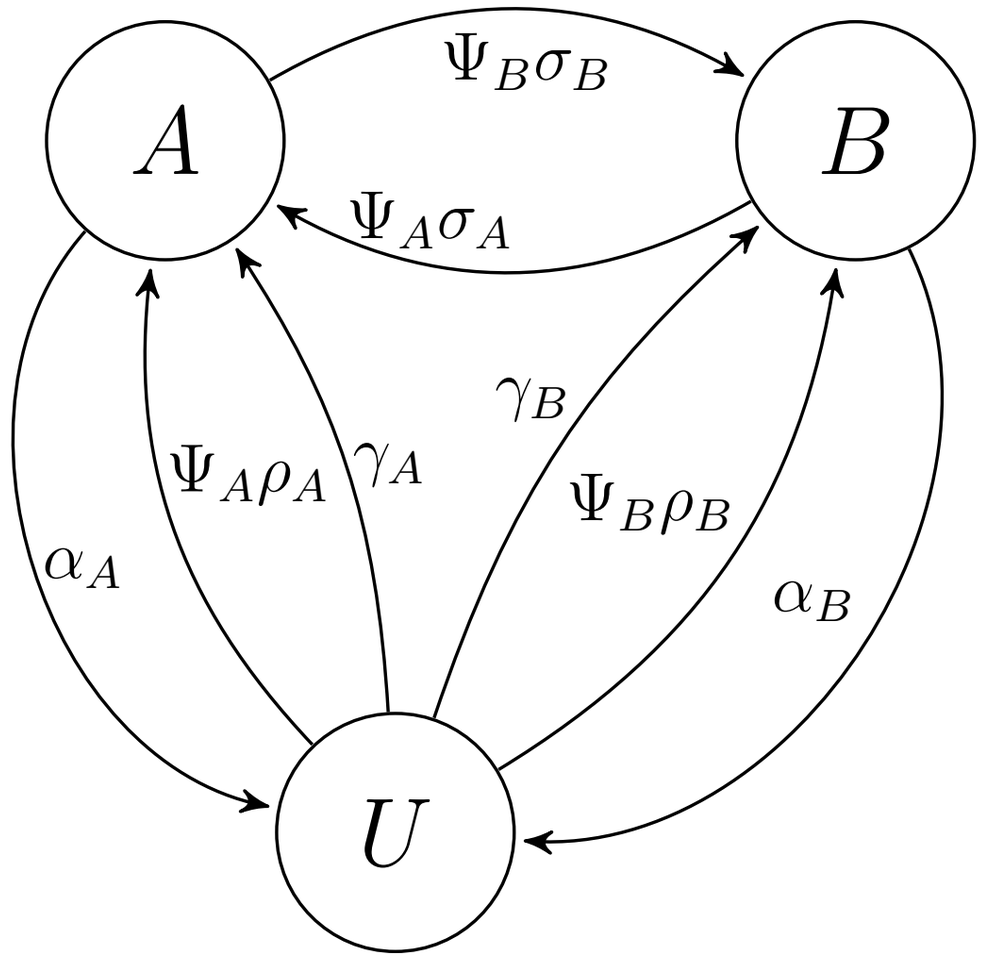

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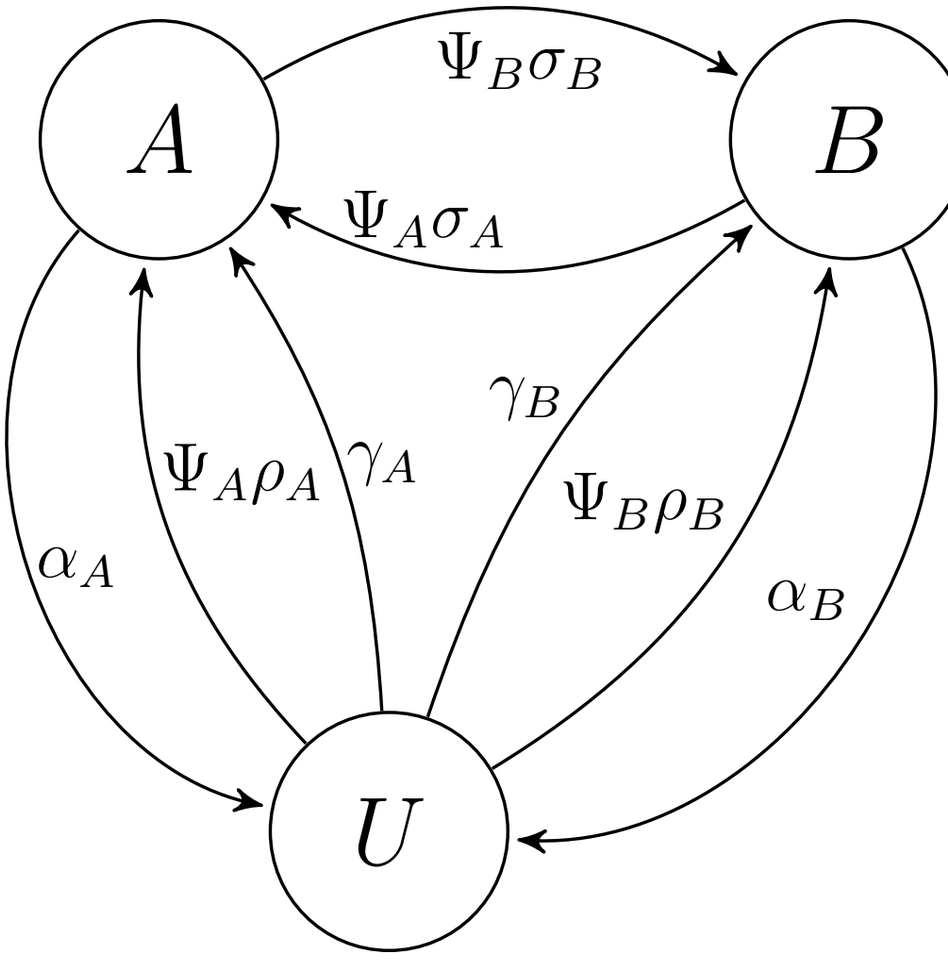
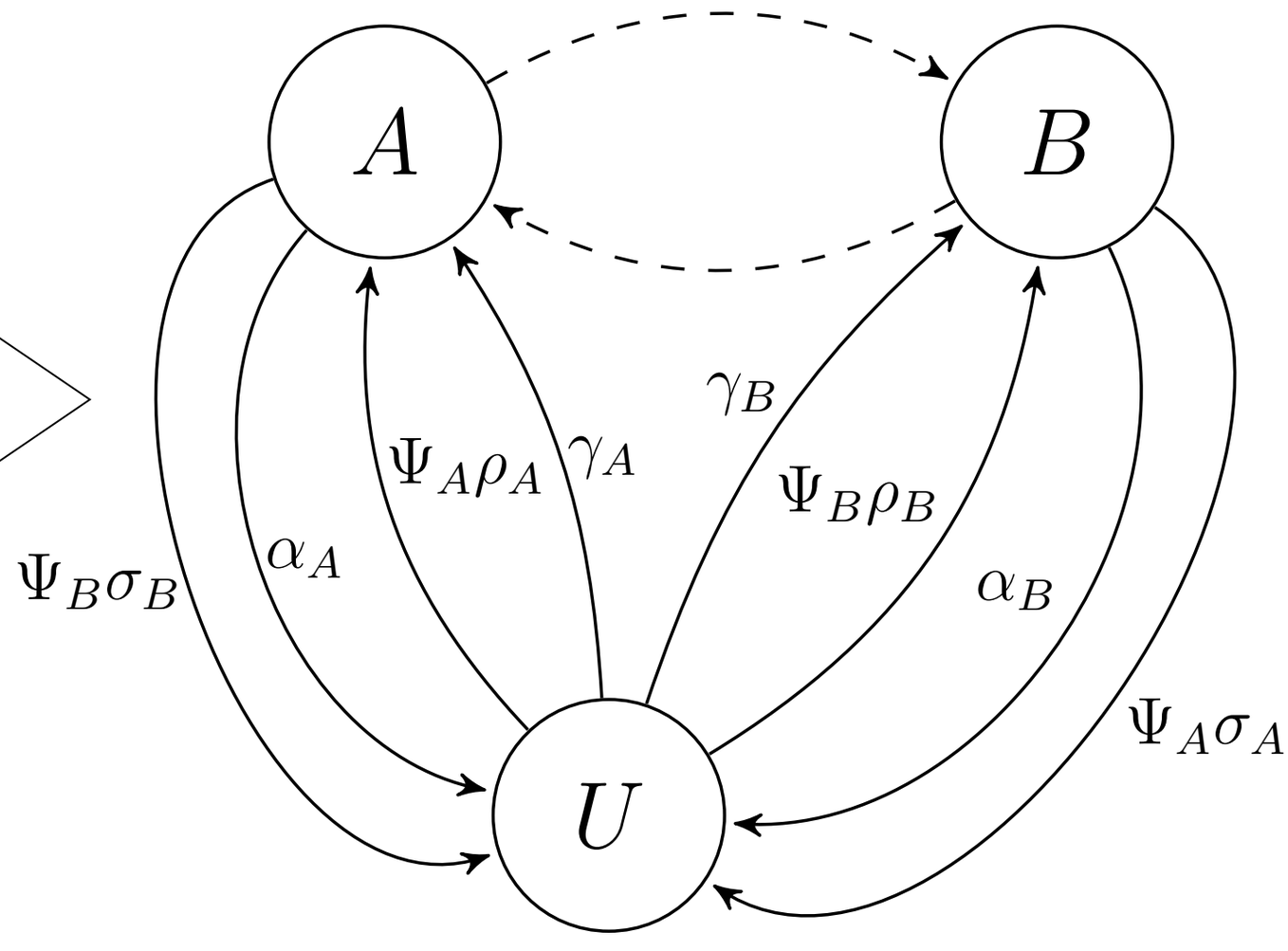


stop-signal



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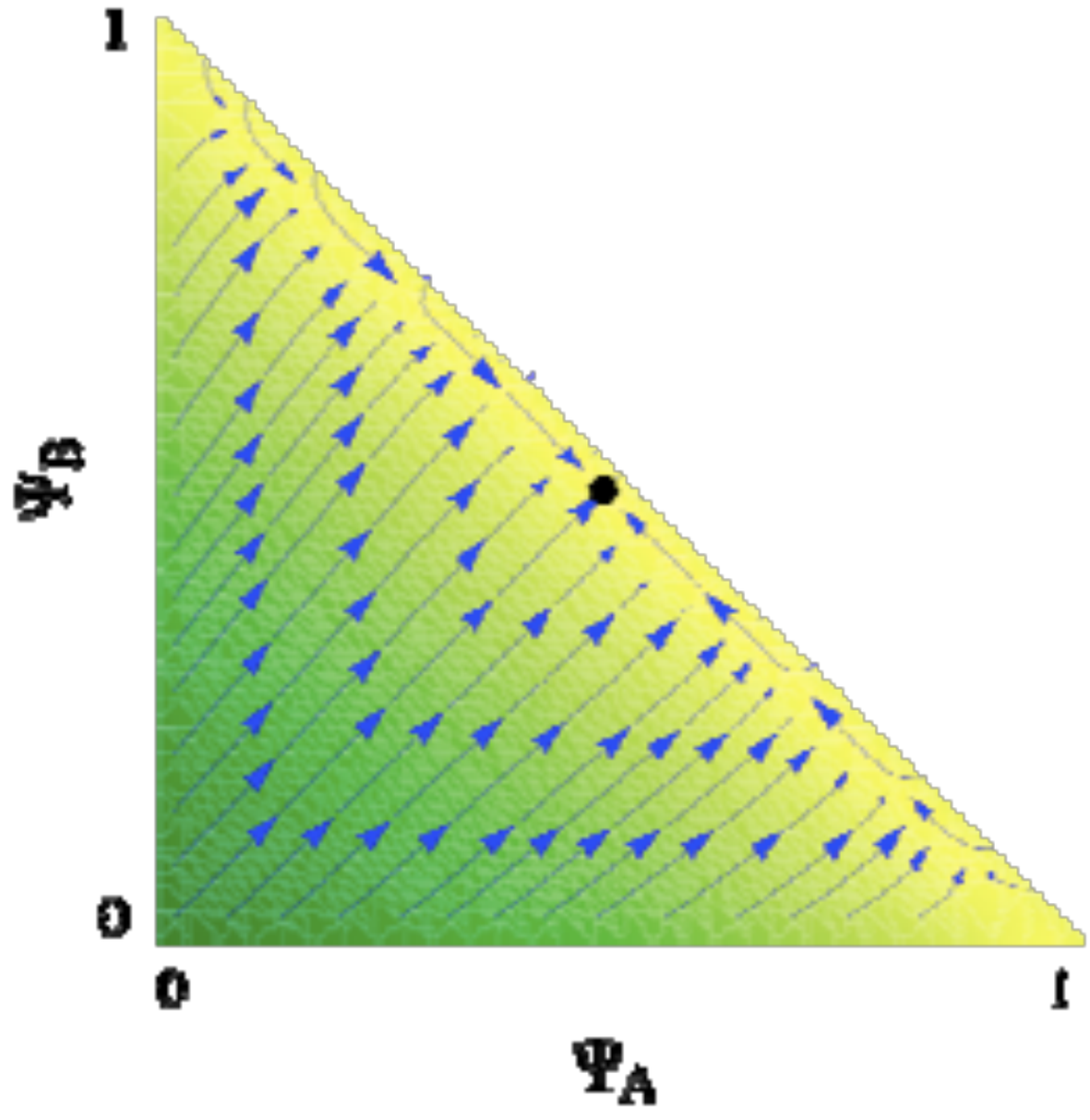

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cross-inhibition

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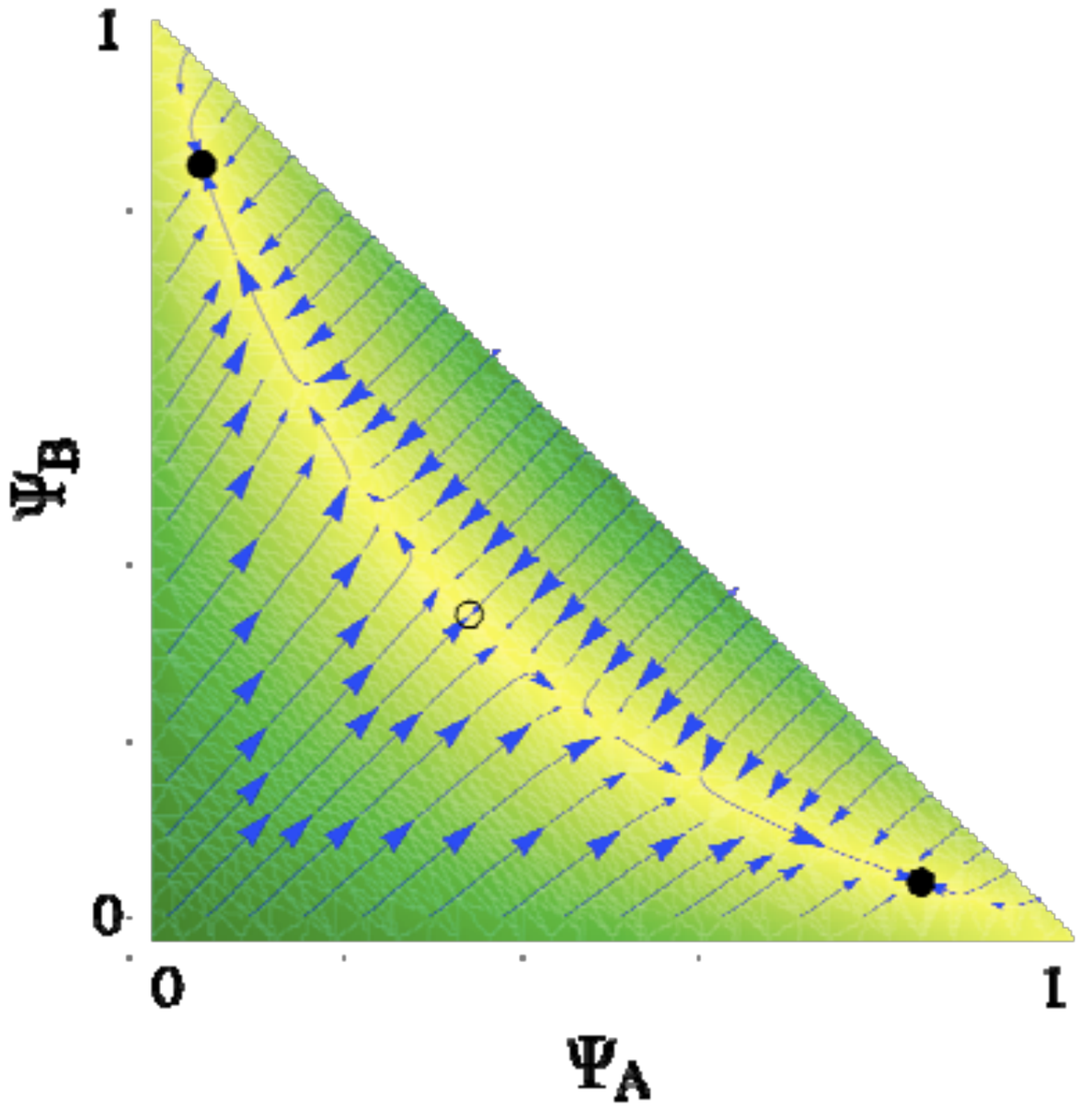

design pattern solution
multi-level description of the decision process

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design pattern solution

multi-level description of the decision process

Macroscopic description

infinite-size
deterministic
time continuous

System of ODEs

$$\begin{cases} \dot{\Psi}_i & = \gamma_i \Psi_U - \alpha_i \Psi_i + \rho_i \Psi_i \Psi_U - \sum_{j \neq i} \sigma_j \Psi_i \Psi_j \\ \Psi_U & = 1 - \sum_i \Psi_i \end{cases}$$

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design pattern solution

multi-level description of the decision process

Macroscopic description	Macroscopic description
infinite-size deterministic time continuous	finite-size stochastic time continuous
System of ODEs	Master equation
$\begin{cases} \dot{\Psi}_i &= \gamma_i \Psi_U - \alpha_i \Psi_i + \rho_i \Psi_i \Psi_U - \sum_{j \neq i} \sigma_j \Psi_i \Psi_j \\ \Psi_U &= 1 - \sum_i \Psi_i \end{cases}$	$\frac{\delta}{\delta t} P(\mathbf{N}, t) = \sum_{k=1}^{4n} [\beta_k - P(\mathbf{N}, t) \mathscr{Q}_k], \quad \forall \mathbf{N}$

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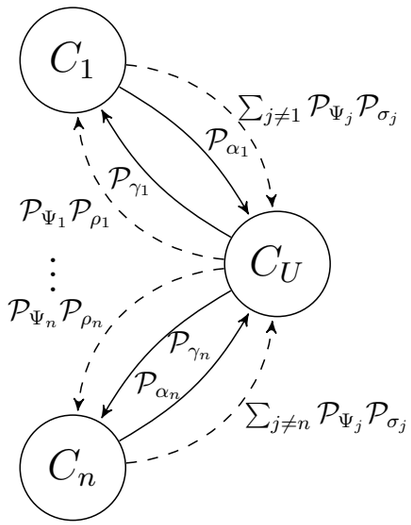
design pattern solution

multi-level description of the decision process

Macroscopic description	Macroscopic description	Microscopic description
infinite-size deterministic time continuous	finite-size stochastic time continuous	agent-based stochastic time discrete
System of ODEs	Master equation	PFSM
$\begin{cases} \dot{\Psi}_i & = \gamma_i \Psi_U - \alpha_i \Psi_i + \rho_i \Psi_i \Psi_U - \sum_{j \neq i} \sigma_j \Psi_i \Psi_j \\ \Psi_U & = 1 - \sum_i \Psi_i \end{cases}$	$\frac{\delta}{\delta t} P(\mathbf{N}, t) = \sum_{k=1}^{4n} [\beta_k - P(\mathbf{N}, t) \mathscr{Q}_k], \quad \forall \mathbf{N}$	

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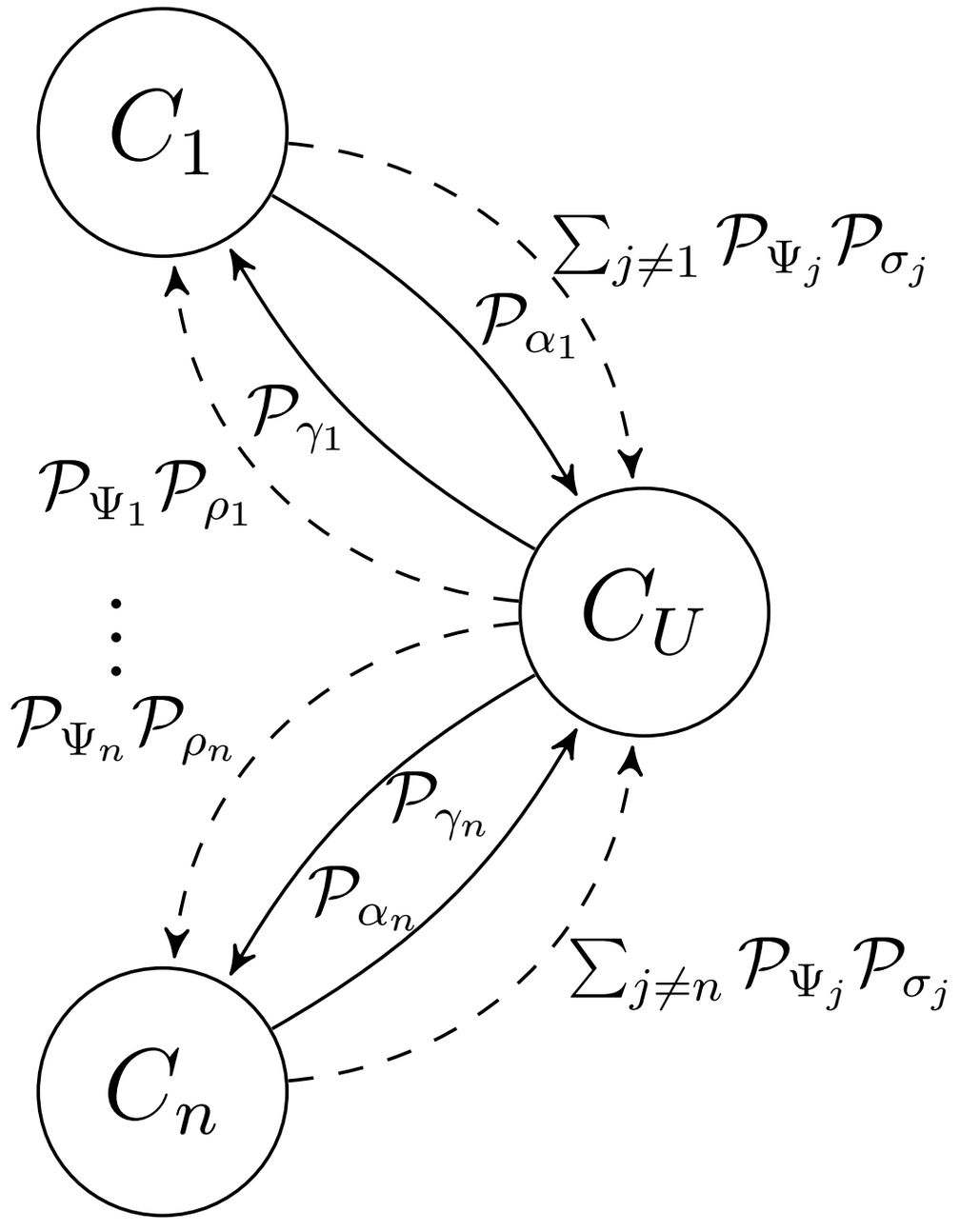

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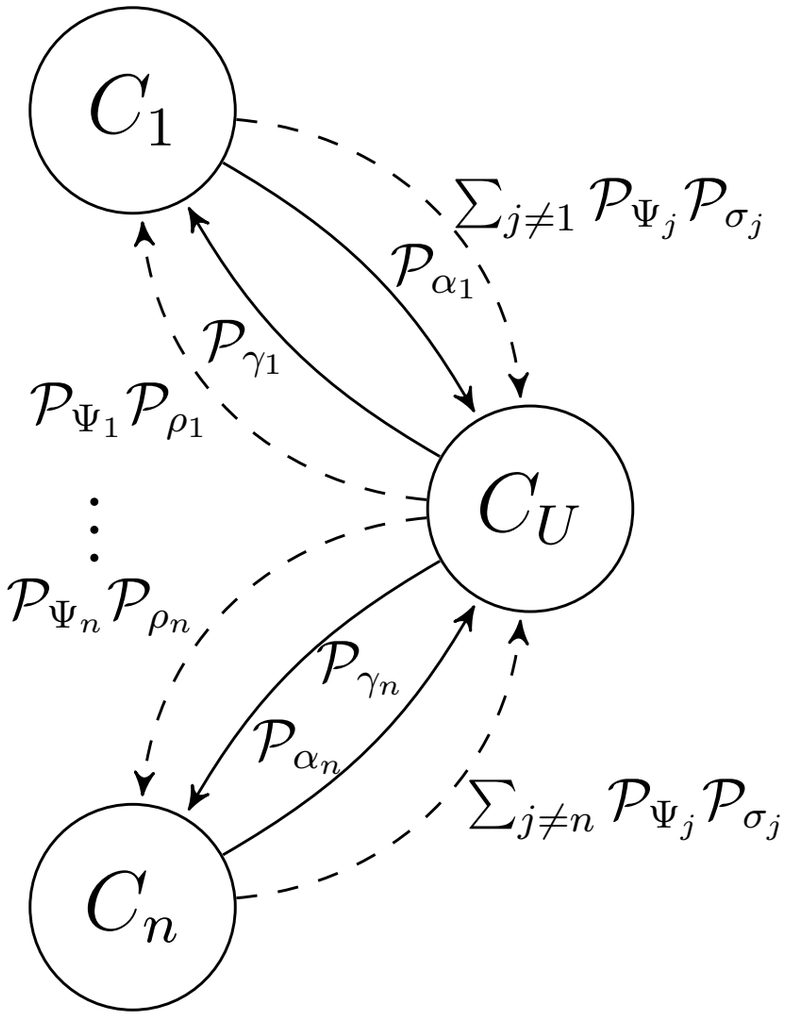
micro-macro link

transform parameters of the macroscopic model into the probabilities of the individual PFSM

$$\begin{cases} \dot{\Psi}_i = \gamma_i \Psi_U - \alpha_i \Psi_i + \\ \qquad \rho_i \Psi_i \Psi_U - \sum_{j \neq i} \sigma_j \Psi_i \Psi_j \\ \Psi_U = 1 - \sum_i \Psi_i \end{cases} \Leftrightarrow$$



design pattern: solution

implementation guidelines

Homogenous vs. heterogenous agents	Latent and interactive agents	Episodic discovery
The transition probabilities may vary in each agent	Interactions cannot take place at any moment	In many scenarios, discovery is an episodic event

Minimum speed of the process	Local interactions
The timestep length of each agent must be conveniently sized	How to estimate the population size?

We provide solutions to attain a micro-macro link in all these situations

design pattern: case studies

- showcase the usage of the design pattern
    - in simplified situations
    - in particularly challenging working conditions

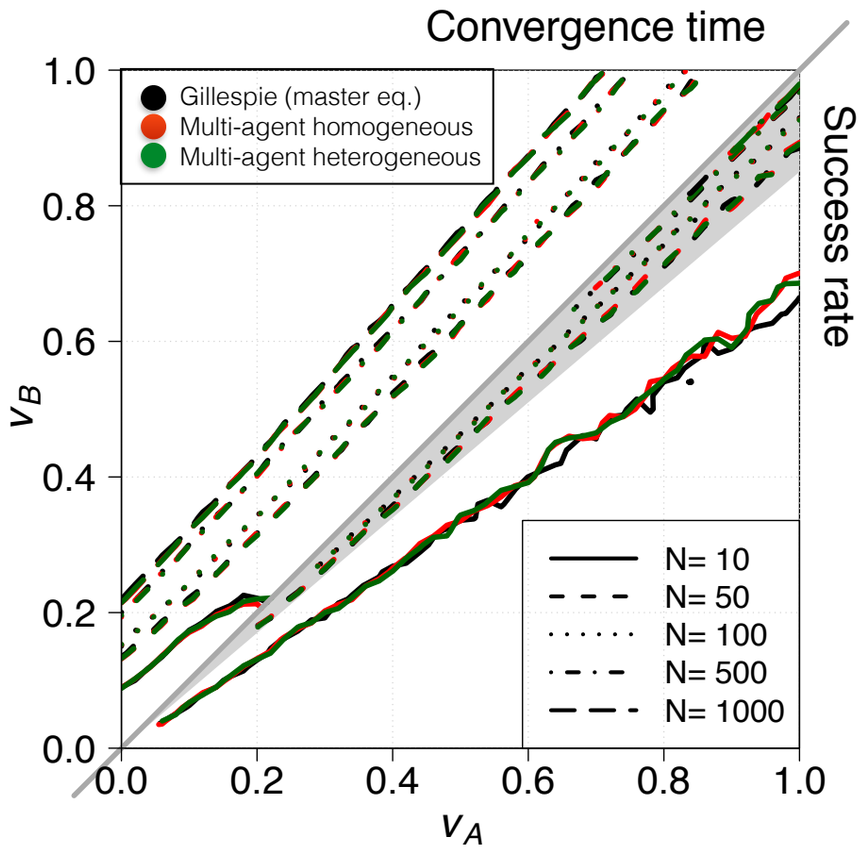
design pattern: case studies

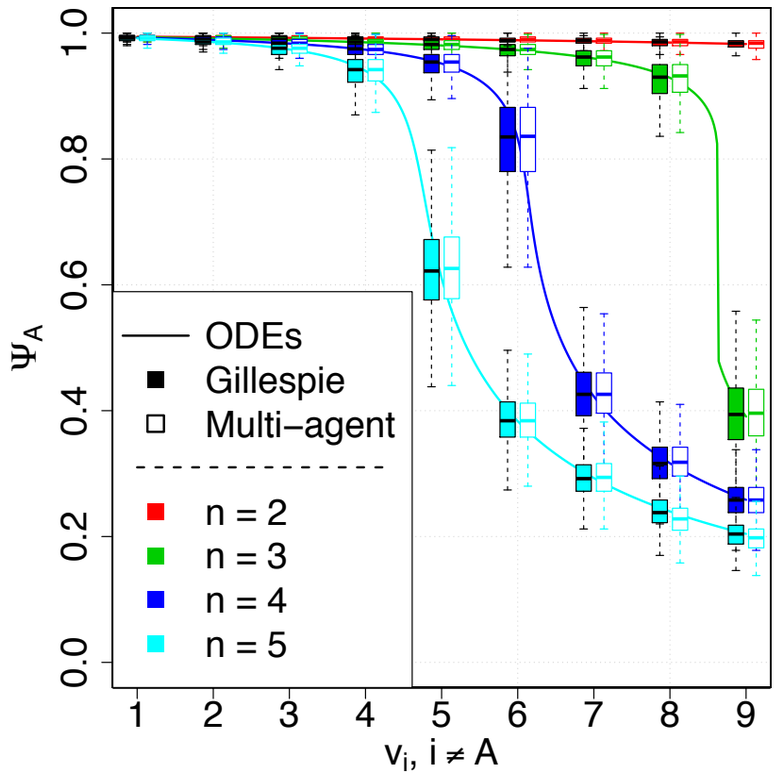
.1. Multiagent simulations on fully-connected networks	.2. Multiagent simulations for search & exploration
Basic case study to investigate several parameterisations	Mobile point-size particles capable to move in a 2D environment
.3. Swarm robotics system for search & exploration	.4. Coexistence in heterogeneous cognitive networks
Physics-based simulations to exemplify embodiment challenges	fully-decentralised solution for channel selection in cognitive radio networks

Case study #1

.1.
Multiagent simulations on fully-connected networks

Basic case study to investigate several parameterisations





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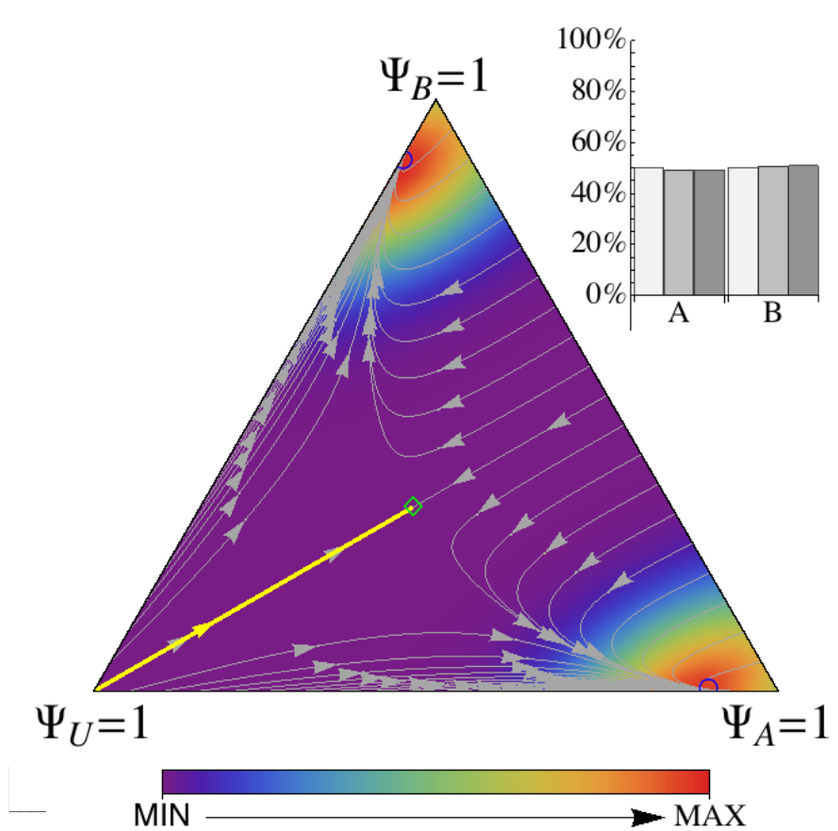
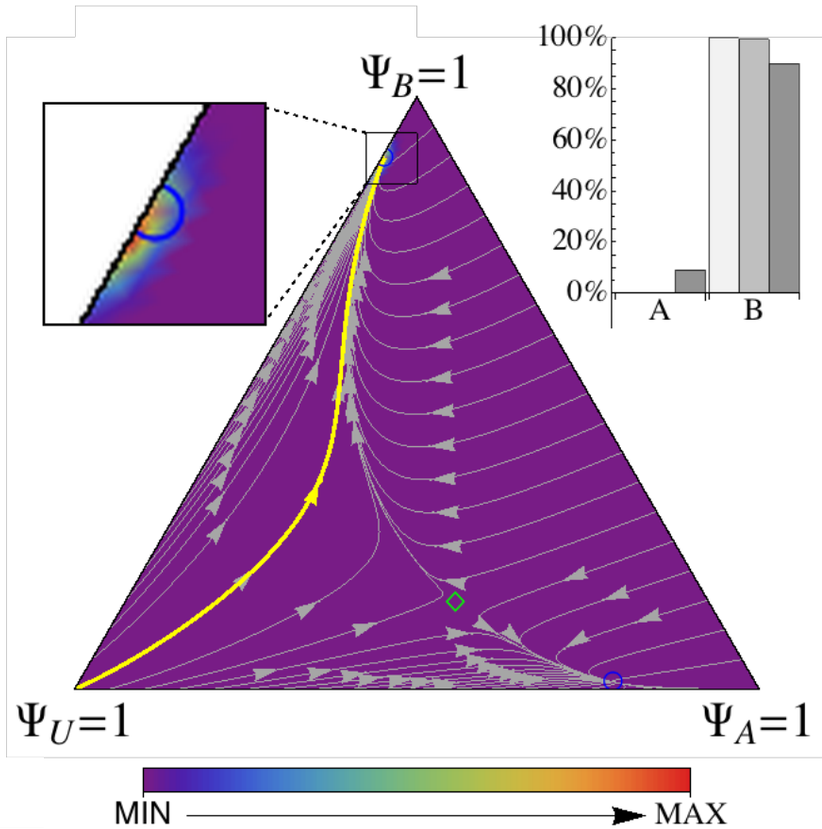
Case study #2

.2.
Multiagent simulations for search & exploration

Mobile point-size particles capable to move in a 2D environment





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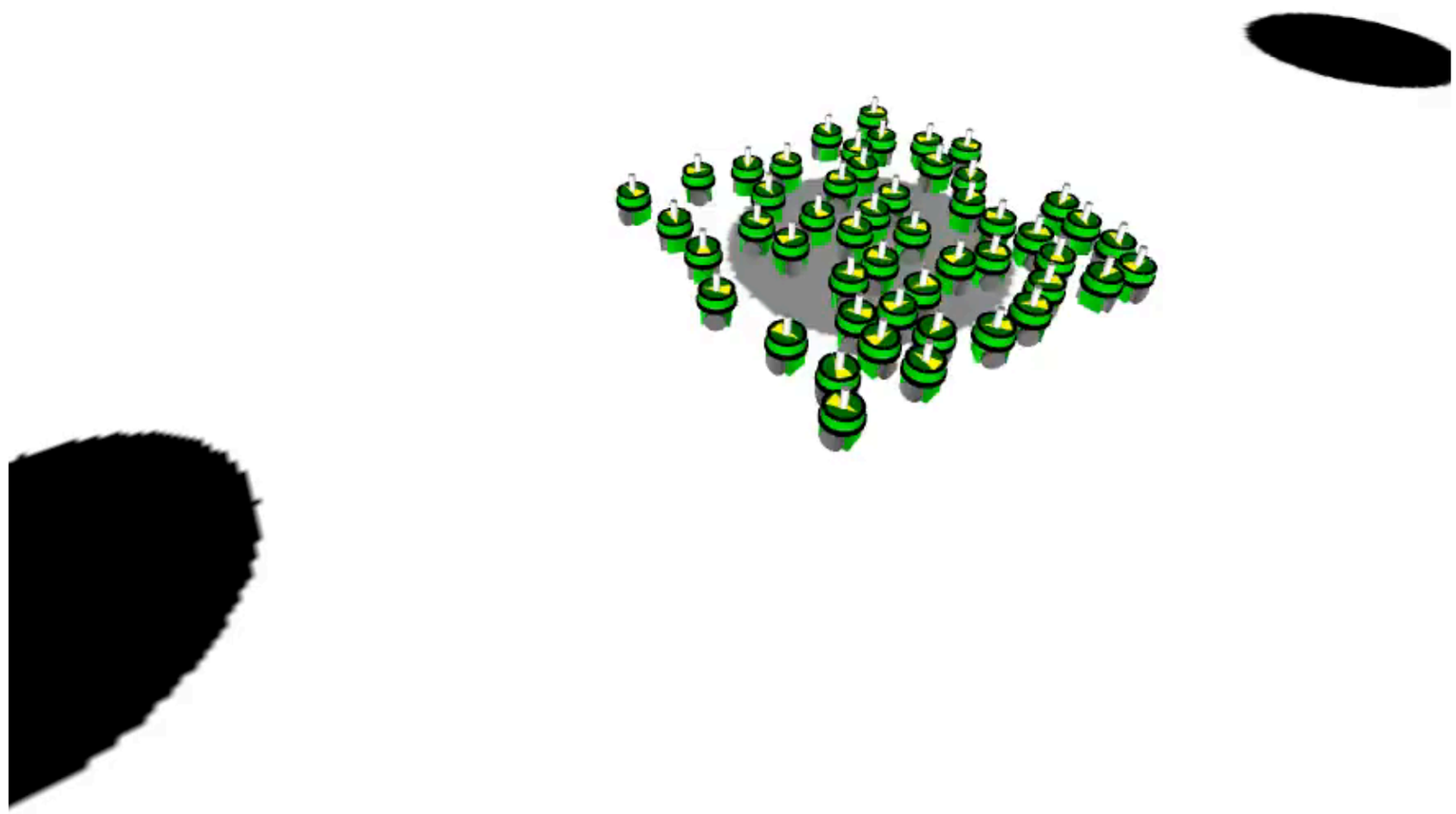
Case study #3

.3.
Swarm robotics system for search & exploration

Physics-based simulations to exemplify embodiment challenges



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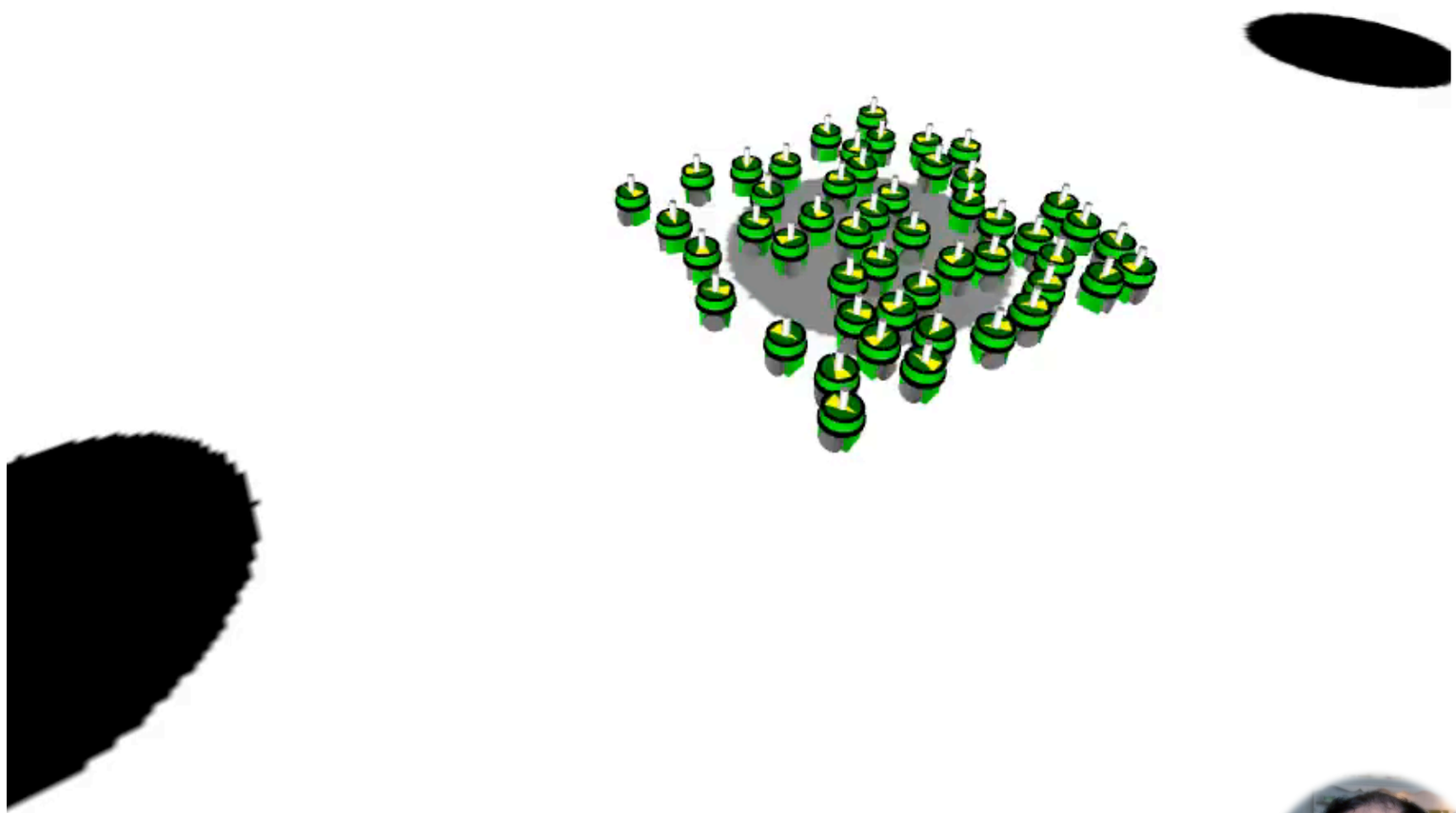

video by A. Reina

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Case Study #4

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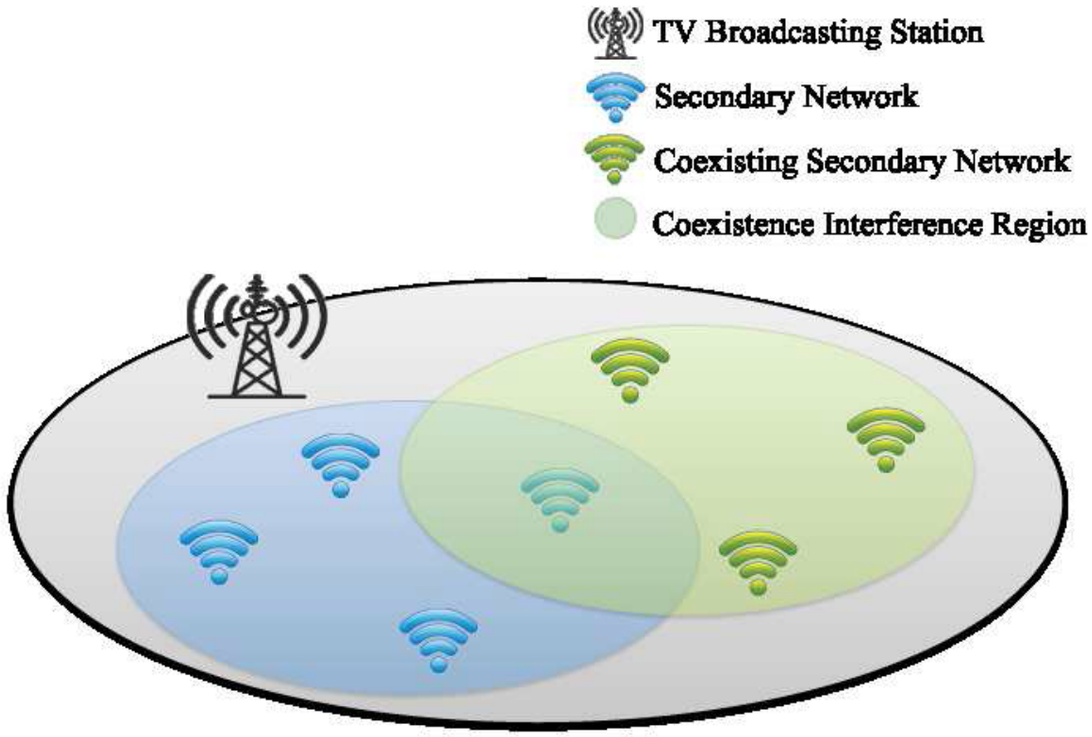
Coexistence in heterogeneous cognitive network

fully-decentralised solution for channel selection in cognitive radio networks



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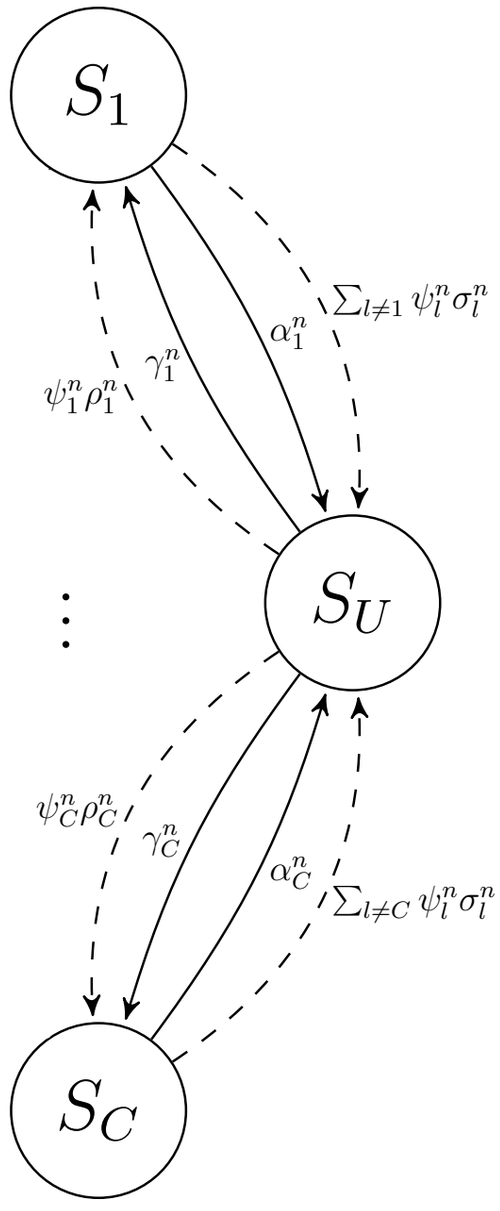

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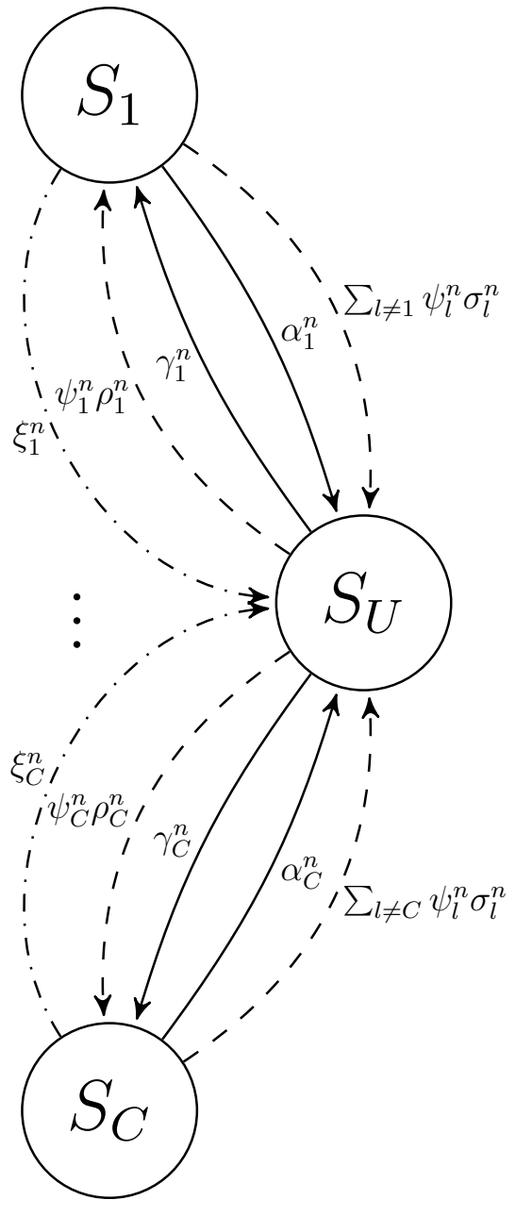

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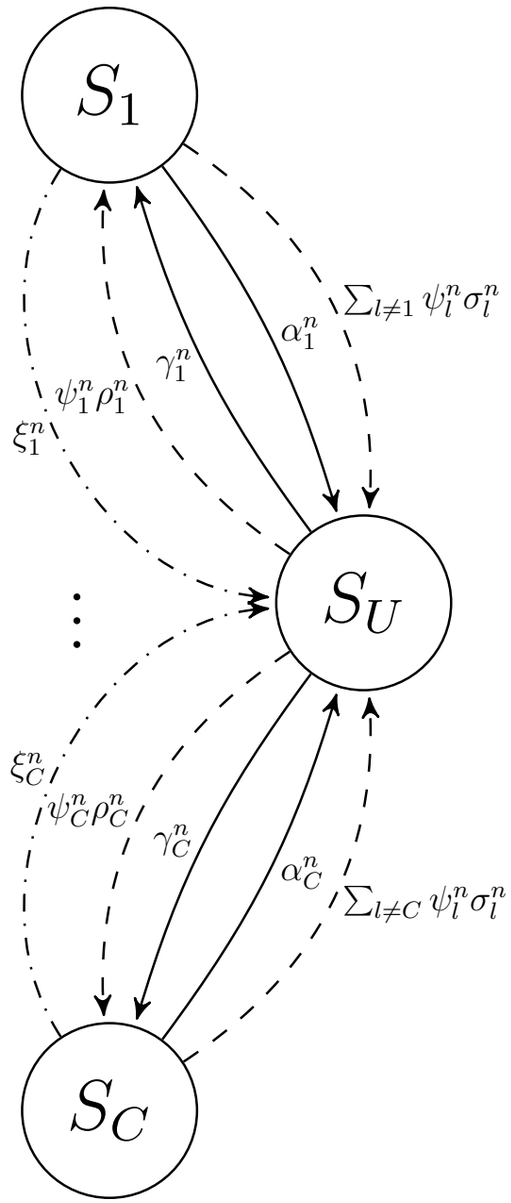

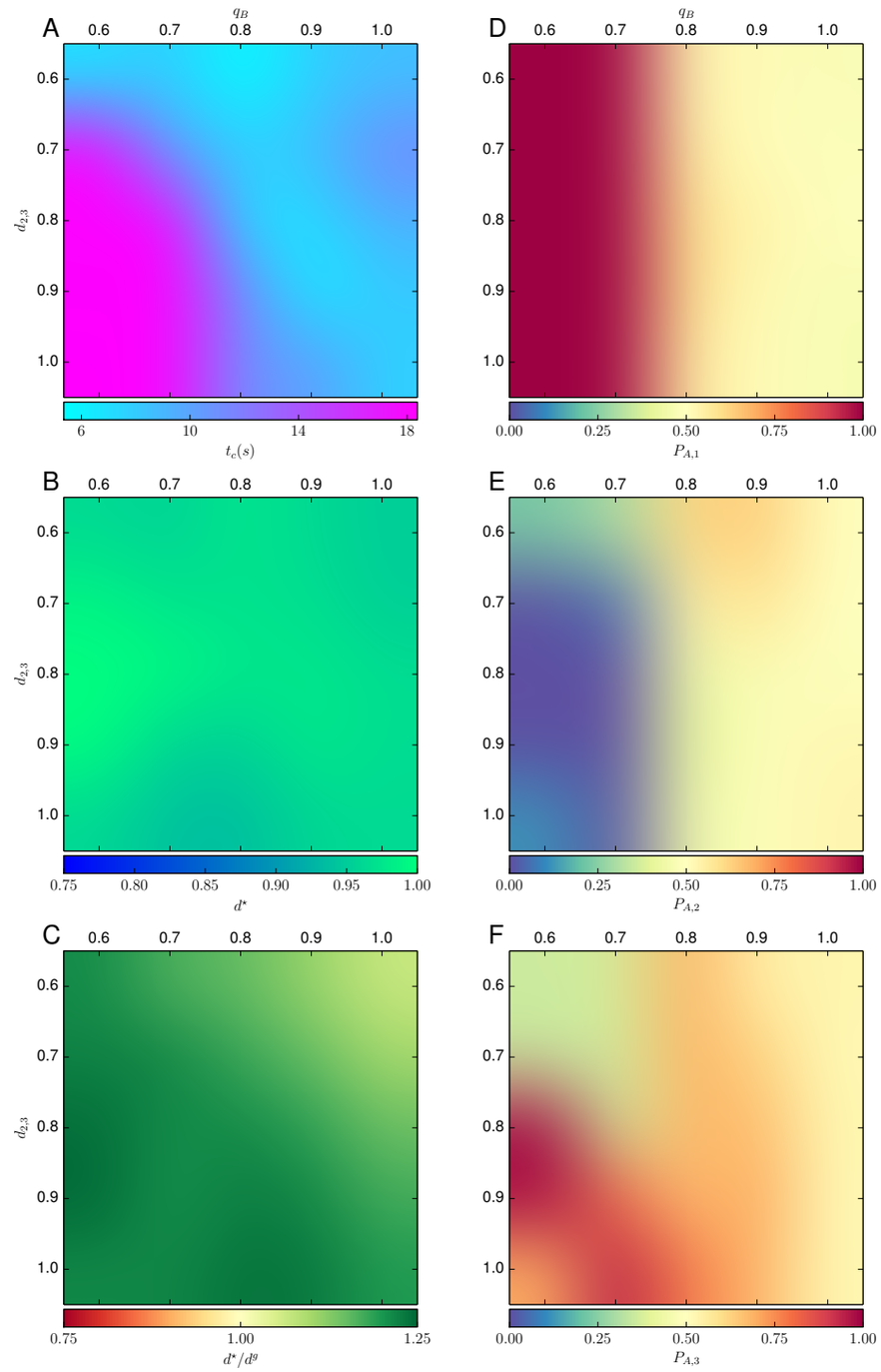

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Thanks for
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