A design-pattern for best-of-n collective decisions

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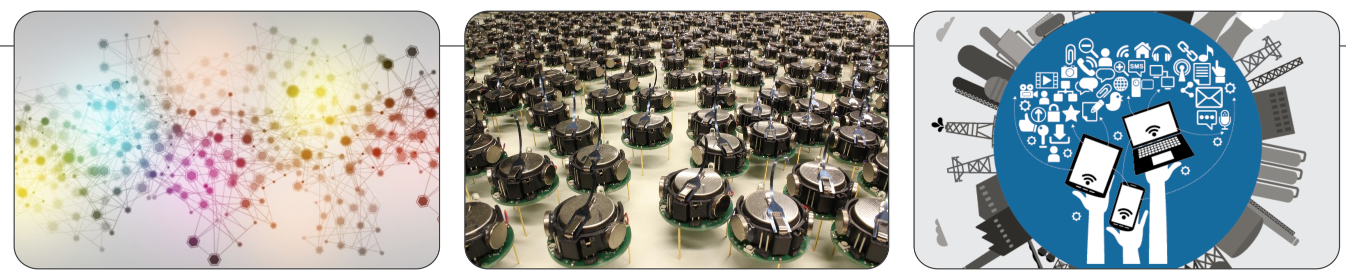
Design Problem

Macroscopic Behaviour → ? → Individual Rules



Design Pattern

Name

Problem
- purposes
- constraints
- preconditions

Design Rationale
- working principles
- origins

Solution
- multi-level description and implementation guidelines

macro model | meso model | micro model | agent rules

- rules to convert parameters
- effects of different interaction patterns

Case Study #1
Case Study #2
⋮
Case Study #n

Decentralised Decision Making

Name: Collective decisions through cross-inhibition

Problem: Best-of-*n* collective decisions
- Set of *n* options not known a priori
- Each option *i* is characterised by quality v_i
- **GOAL**: select the best (or equal-best) option

Design Rationale: Honeybee nest site selection
- Spontaneous discovery/abandonment of potential sites
- Recruitment of scouts for high quality sites
- Cross-inhibition to break decision deadlocks

+Attains near-optimal speed-accuracy tradeoff
+No need of direct comparison between options

T. D. Seeley et al., "Stop Signals Provide Cross Inhibition in Collective Decision-Making by Honeybee Swarms". Science, 335(6064):108–111, 2012.

Solution: multi-level description + implementation guidelines

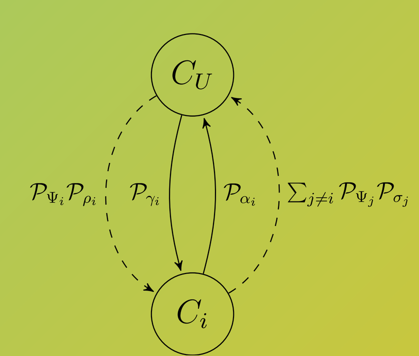
macroscopic mean-field

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

macroscopic finite-size

$$\frac{\delta}{\delta t}P(\mathbf{N},t) = \sum_{k=1}^{4n}[\beta_k - P(\mathbf{N},t)\mathcal{Q}_k], \quad \forall \mathbf{N}$$

microscopic discrete



homo vs hetero
- homogeneous system

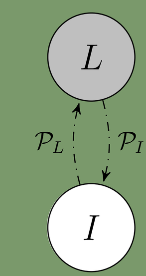
$$P_{\lambda,g}(\hat{v}_i) = \lambda_i\tau$$

- heterogeneous system

$$P_{\lambda,g}(\hat{v}_i) = \begin{cases} \mathcal{P}_{\lambda\uparrow} & \hat{v}_i > \delta_g \\ \mathcal{P}_{\lambda\downarrow} & \hat{v}_i \leq \delta_g \end{cases}$$

$$F_{\mathcal{D}_\lambda} = \frac{\lambda\tau - \mathcal{P}_{\lambda\downarrow}}{\mathcal{P}_{\lambda\uparrow} - \mathcal{P}_{\lambda\downarrow}}$$

latent vs interactive
accounting for agents unable to interact at every control cycle



$$\eta_I = \mathcal{P}_I/(\mathcal{P}_I + \mathcal{P}_L)$$

episodic discovery
accounting for stochastic discovery of available options with probability E_i:

$$\gamma_i = f_\gamma(v_i) \rightarrow \mathcal{P}_\gamma(v_i) = \frac{f_\gamma(v_i)\tau}{E_i}$$

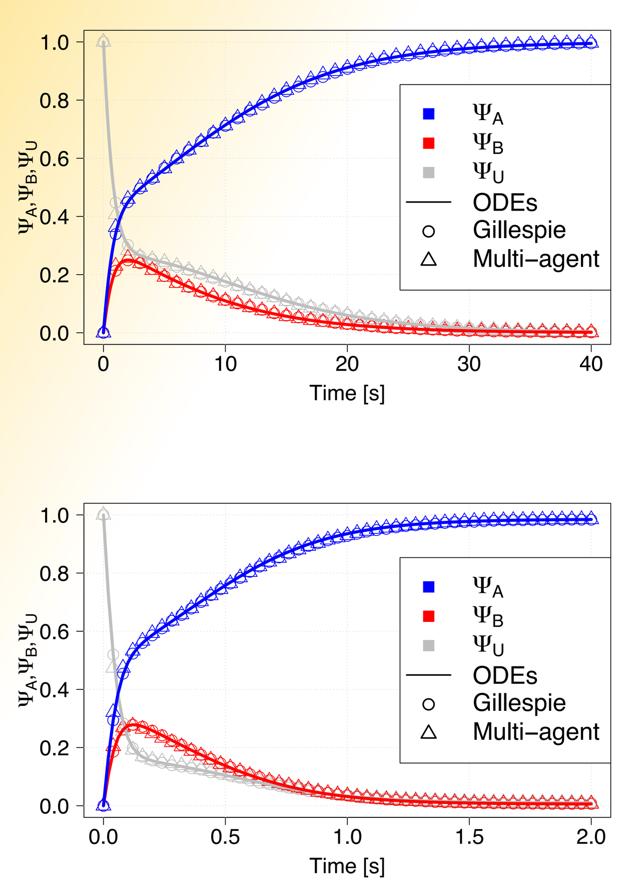
minimum speed
providing an upper bound for the agent control time-step according to the PFSM description

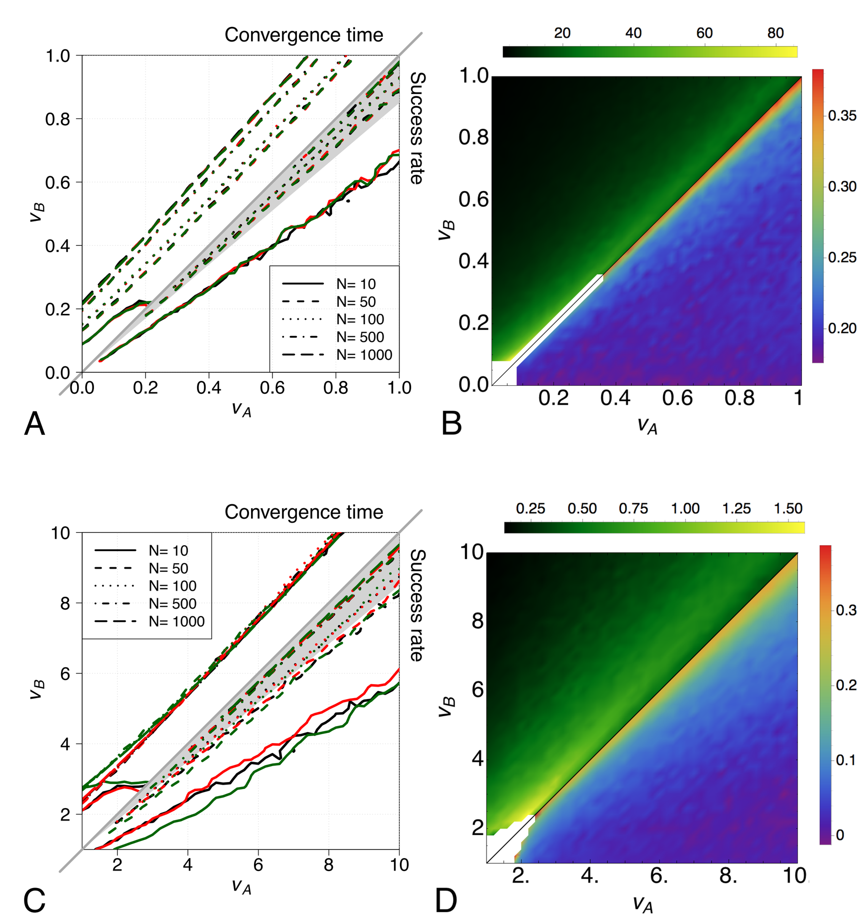
$$\begin{cases} \tau \leq (\max_{v_i} f_\rho(v_i) + \max_{v_i} f_\gamma(v_i))^{-1} \\ \tau \leq (\max_{v_i} f_\alpha(v_i) + \max_{v_i} f_\sigma(v_i))^{-1} \end{cases}$$

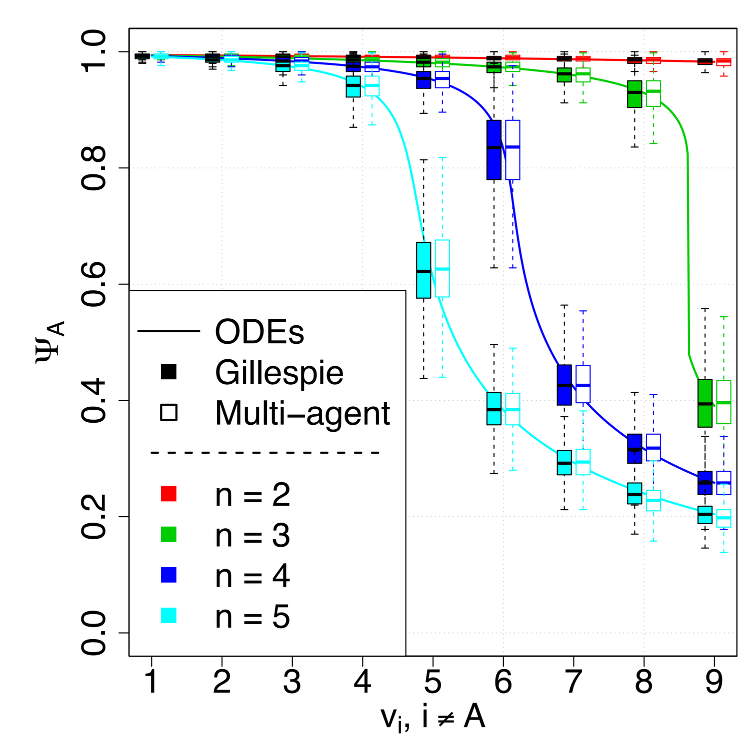
Case study 1: Collective decisions on a fully connected network

$$A: \begin{cases} \alpha = 0 \\ \gamma = hv \\ \rho = kv \\ \sigma = 1 \end{cases}$$

$$B: \begin{cases} \alpha = 1/v \\ \gamma = v \\ \rho = v \\ \sigma = 10 \end{cases}$$







Case study 2: Collective decisions in a search and exploration problem

$$\begin{cases} \alpha = 1/v \\ \gamma = v \\ \rho = v \\ \sigma = v \end{cases}$$