

Emergent coordination and collaboration in swarms and flocks

- Part 3 -

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Division of Labor

Definition

- **Polyethism**
Division of labor is a stable pattern of variation among workers within a colony in the tasks they perform: each worker specializes on a subset of the complete repertoire of tasks performed by the colony, and this subset varies across individual workers in the colony
- **Morphological polyethism**
The worker's size and/or shape is related to its performance of tasks
- **Temporal polyethism**
Workers change their tasks specifically as a function of their age

Morphological polyethism

The caste system in the ant *Atta laevigata*

- Gardeners-nurses (head width $\approx 0.8\text{mm}$)
- Within-nest generalists (head width $\approx 1.4\text{mm}$)

Morphological polyethism

The caste system in the ant *Atta laevigata*

- Foragers-excavators (head width $\approx 2.2\text{mm}$)
- Defenders-soldiers (head width $\approx 5\text{mm}$)

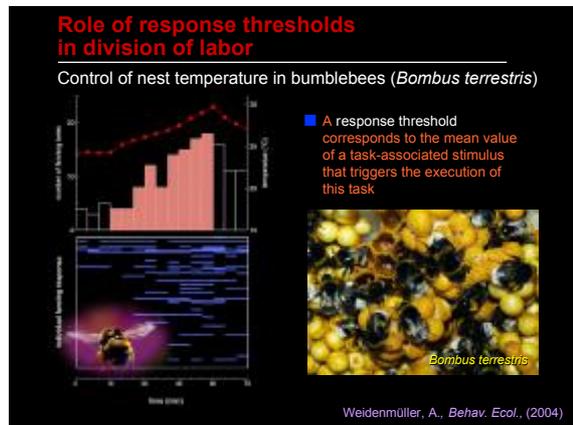
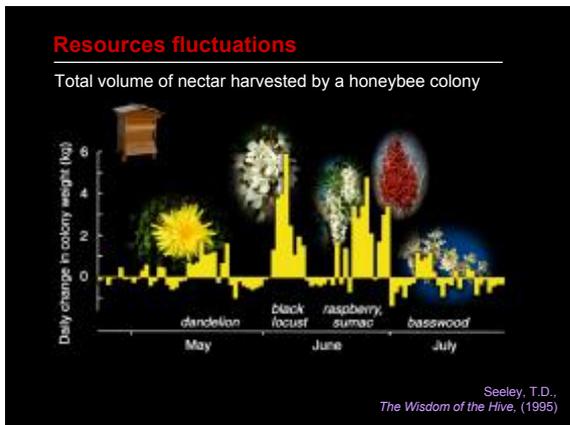
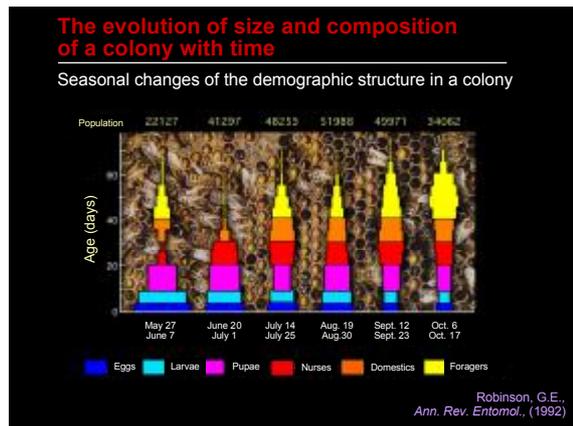
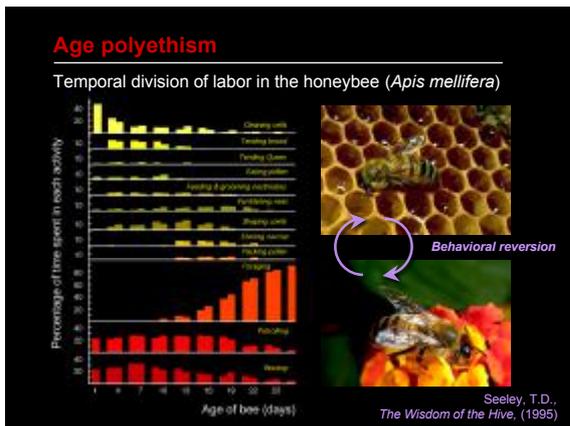
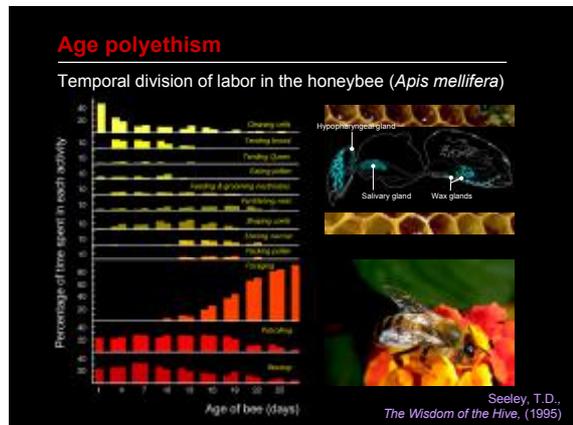
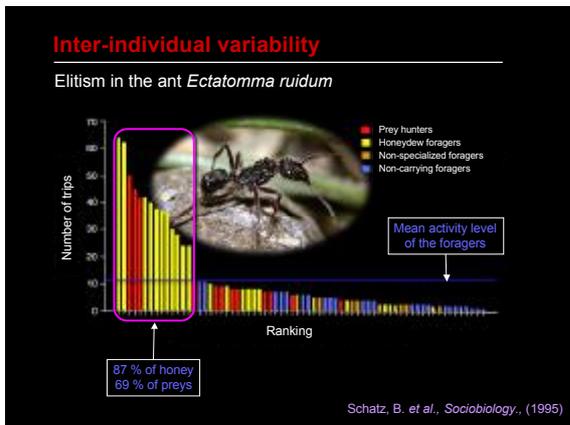
Morphological polyethism

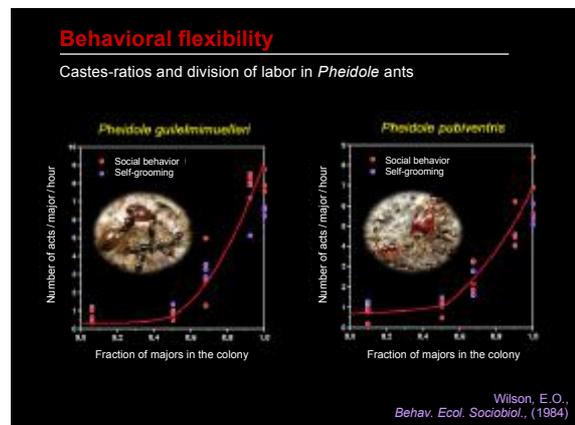
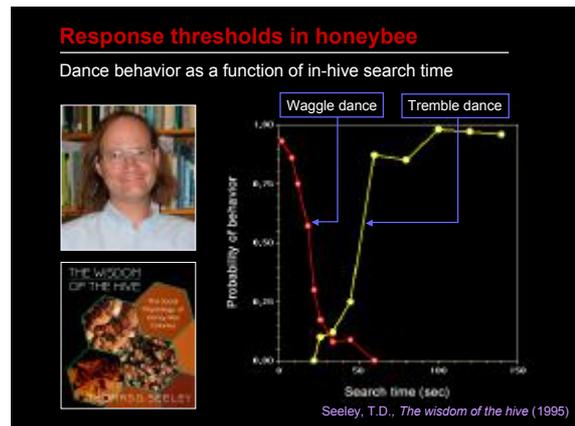
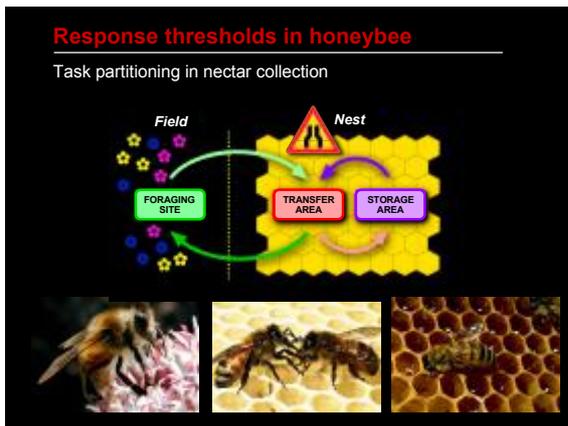
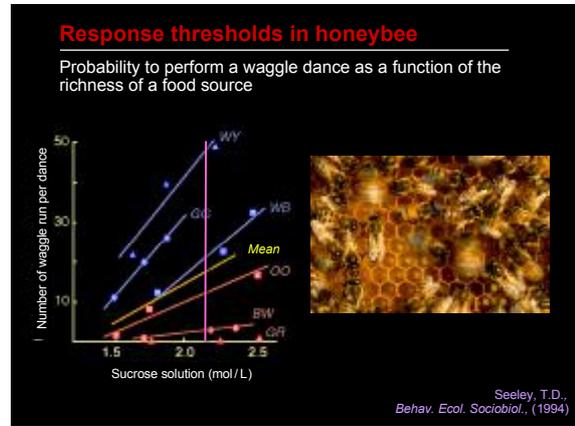
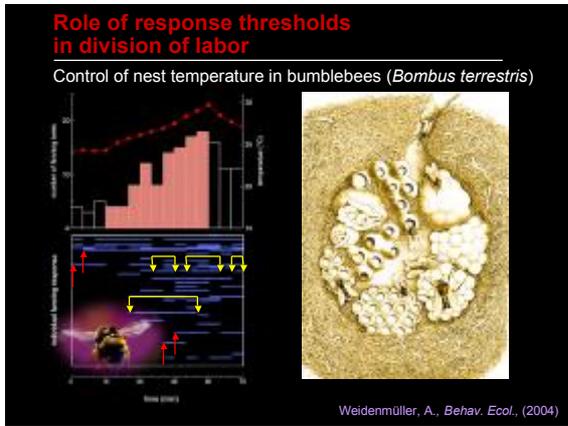
The caste system in the ant *Atta laevigata*

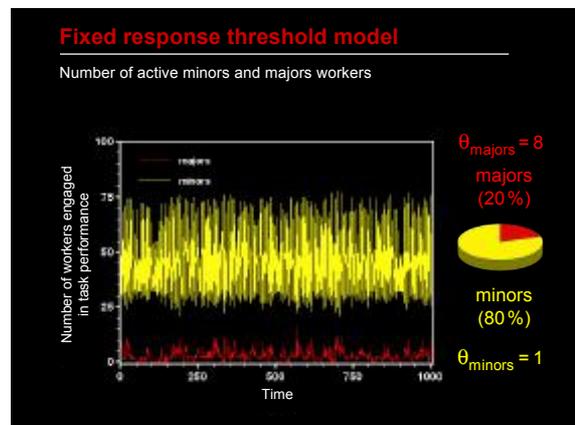
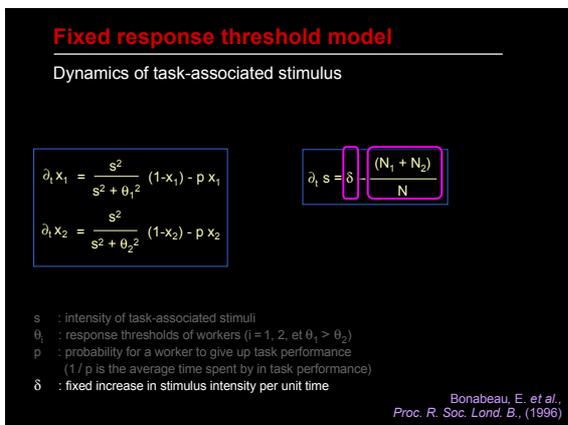
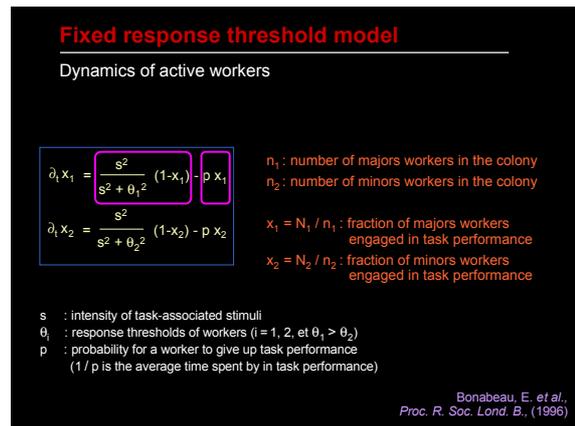
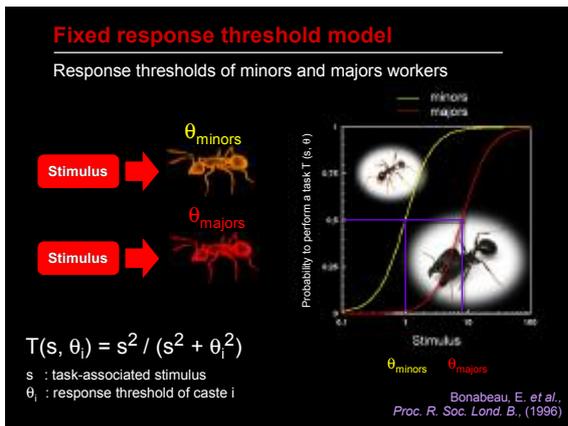
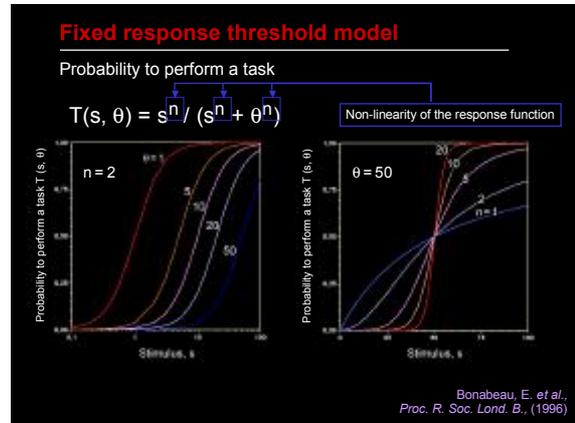
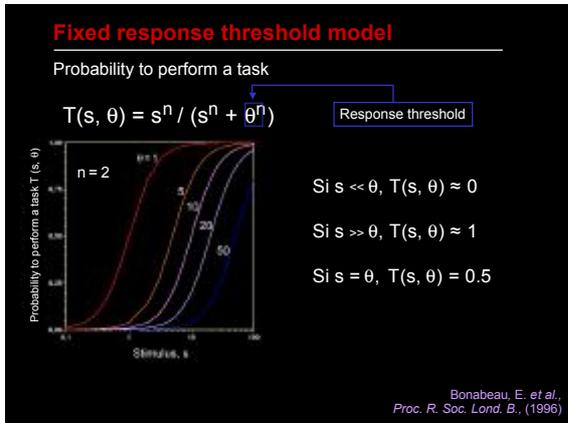
Behavioral castes

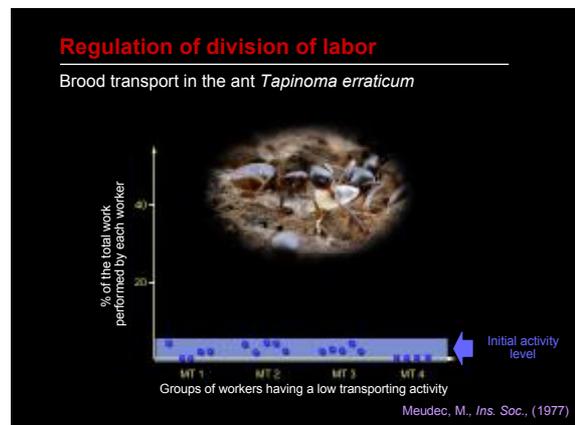
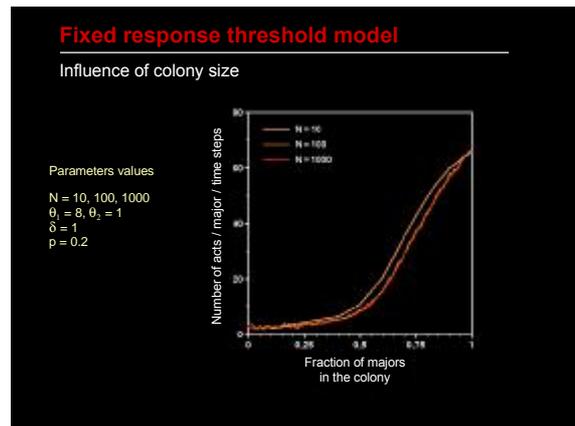
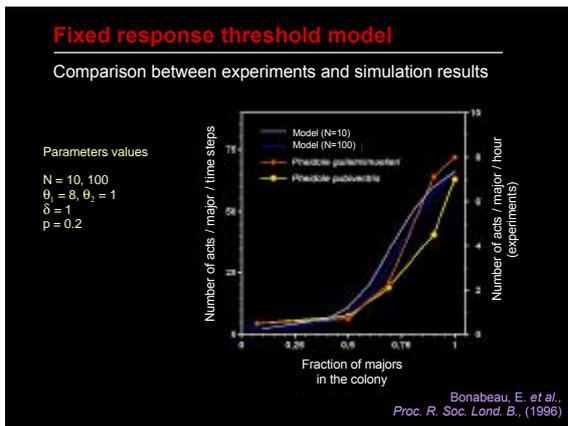
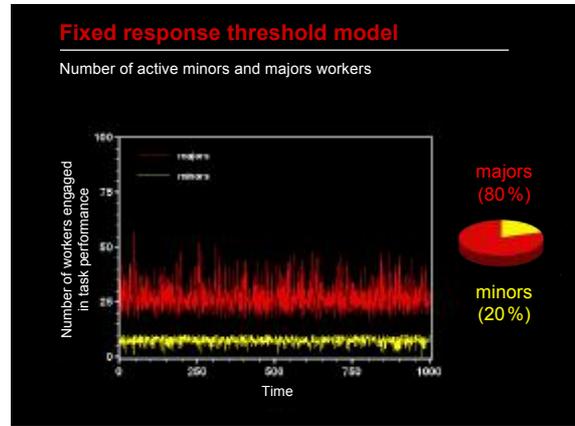
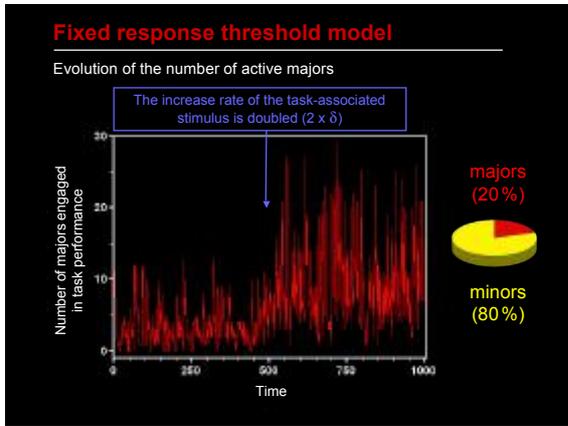
Behavioral profiles in the indian wasp *Ropalidia marginata*

Gadagkar, R. & Joshi, N.V.,
Anim. Behav., (1983)



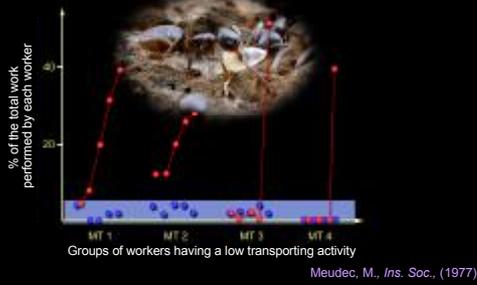






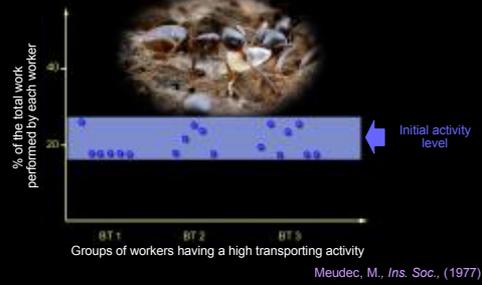
Regulation of division of labor

Brood transport in the ant *Tapinoma erraticum*



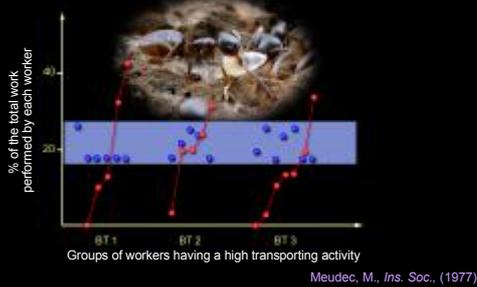
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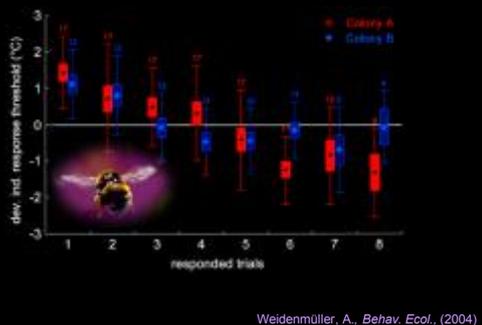
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Brood transport in the ant *Tapinoma erraticum*



Influence of learning on response thresholds

Reinforcement of response thresholds in *Bombus terrestris*



Influence of learning on response thresholds

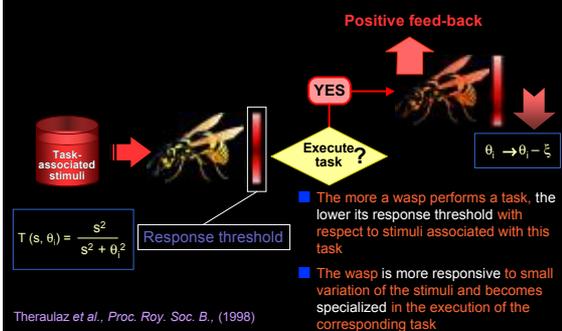
Behavioral flexibility and division of labor in *Polistes* wasps



Polistes dominulus

Self-organized division of labor

Response threshold reinforcement



Self-organized division of labor

Response threshold reinforcement

- Not performing the task induces an increase of the response threshold
- The wasp will be less responsive to the stimuli and its probability to perform the task will be lower

Response threshold reinforcement model

Model description

$$\theta_i \rightarrow \theta_i - \xi \quad \text{if worker } i \text{ performs the task}$$

$$\theta_i \rightarrow \theta_i + \phi \quad \text{if worker } i \text{ does not perform the task within a given period of time}$$

$$T(s, \theta_i) = \frac{s^2}{s^2 + \theta_i^2}$$

$$\partial_t s = \delta - \frac{1}{N} \left(\sum_{i=1}^N X_i \right)$$

Parameters

- s : intensity of the task-associated stimuli
- θ_i : response threshold of worker i , $\theta_i \in [\theta_{\min}, \theta_{\max}]$
- ξ : learning coefficient
- ϕ : forgetting coefficient
- δ : increase in stimulus intensity per unit time
- X_i : proportion of time spent by worker i performing the task

Therulaz, G. et al., Proc. Roy. Soc. B., (1998)

Response threshold reinforcement model

Dynamics of response thresholds

- Several insects are in competition to perform the task
- The total amount of work load is proportional to the size of the colony
- Division of labor at the colony level results from individual learning and competition among individuals to perform tasks

Response threshold reinforcement model

Dynamics of response thresholds

Parameters values
 $\theta_{\min} = 1$, $\theta_{\max} = 1000$
 $\delta = 1$, $p = 0.2$, $\xi = 10$, $\phi = 1$
 $N = 5$

Response threshold reinforcement model

Dynamics of response thresholds after removing one worker

Parameters values
 $\theta_{\min} = 1$, $\theta_{\max} = 1000$
 $\delta = 1$, $p = 0.2$, $\xi = 10$, $\phi = 1$
 $N = 6$

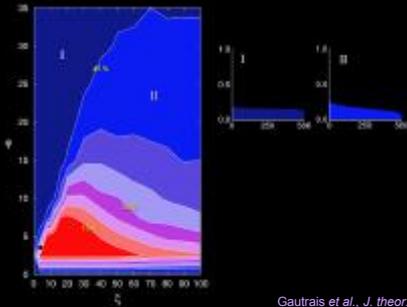
Response threshold reinforcement model

Effect of learning (ξ) and forgetting (ϕ) on activity levels

Gautrais et al., J. theor. Biol., (2002)

Response threshold reinforcement model

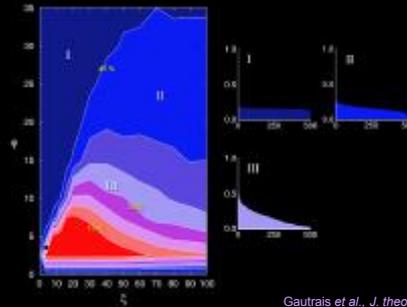
Effect of learning (ξ) and forgetting (ϕ) on activity levels



Gautrais et al., *J. theor. Biol.*, (2002)

Response threshold reinforcement model

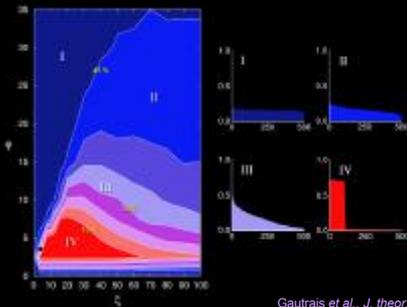
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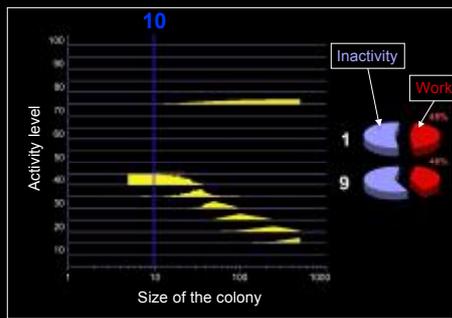
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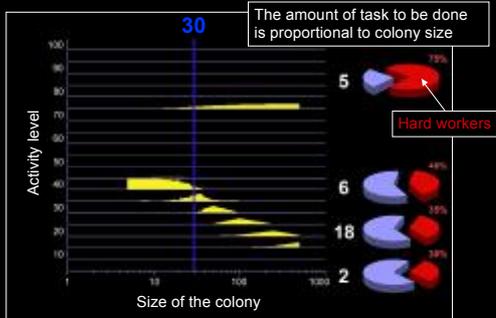


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Distribution of activity levels as a function of colony size



Distribution of activity levels as a function of colony size



Distribution of activity levels as a function of colony size

