Self-Organization and Templates

Qijun Jiang and Xianshun Jiang

Overview

- Two Theories:
  - Template Mechanism
  - Positive Feedback Mechanism
- Two Models:
  - Royal Chamber
  - Wall Building
- Application

Self-Organization

- Lies in attractivity of corpuses or items of different types that could lead to formation of clusters of specific items
- Snowball effects: larger cluster is more likely to attract more items
- Combined template mechanism in the process of clustering

Template Mechanism

- Prepattern in the environment used to organize activities
    - Affected by natural gradient (temperature, humidity), fields, or heterogeneities exploited by the colony
    - E.g. Acantholepsis custodiens

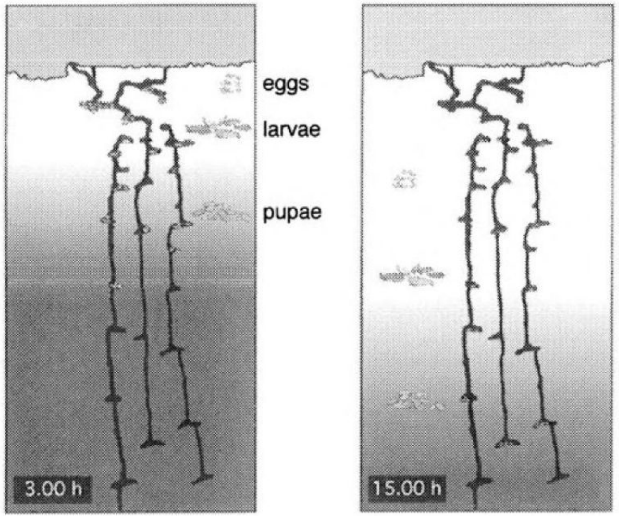
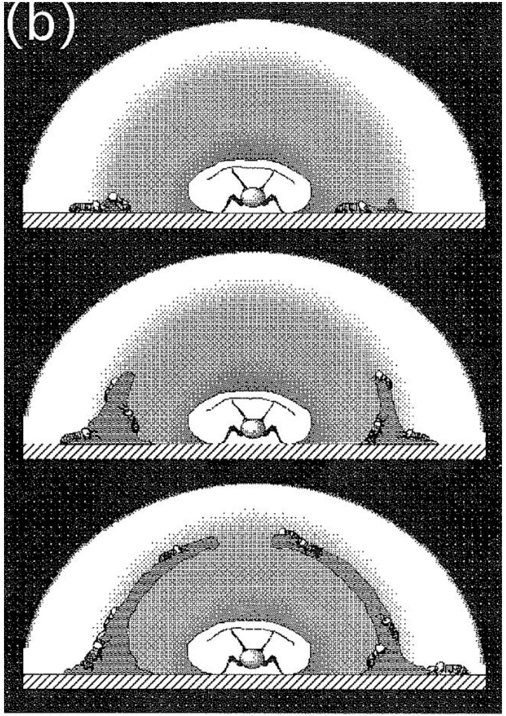


FIGURE 5.1 The spatial distribution of eggs, larvae, and pupae in the ant *Acantholepsis custodiens* depends on the temperature gradient along the depth axis. The gradient changes between 3:00 a.m. (left) and 3:00 p.m. (right).

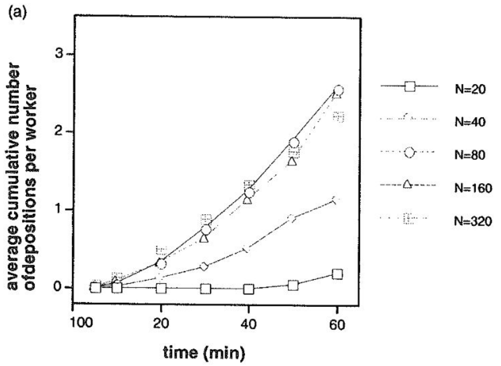
Template Mechanism

- Prepattern could also be the body shape of the animal
  - Physogastric queen of Macrotermes subhylinus emits pheromone that creates pheromonal templates in the form of decreasing gradient around her (right figure)
  - Freshly-killed physogastric queen could also cause the phenomenon, but a wax dummy of the queen doesn't stimulates the construction
- Other facts also plays a role
  - Tactile stimuli
  - Other pheromones such as cement and trail pheromones



Limitation of Template Mechanism

- Walls are not uniformly built
  - Pillars built first, then the space between is filled
- Rate of building increases rapidly (right figure)
  - 20 workers: 0.2 deposition / worker
  - 80 workers: 2.5 deposition / worker (same time interval as above)
  - 80 workers reach the maximum build rate per worker.



Positive Feedback Mechanism

- Cement pheromone trigger chemotactic behavior from workers and spatial
    - Small obstacles attract nearby workers and stimulates their behavior to deposit pallets.
    - The more pallets at one location, the more termites attracted

Model of Positive Feedback Mechanism

$H(r, t)$ = concentration at location r, time t, of the pheromone

- k_2 = amount of pheromone emitted per unit of deposited material per unit time
- P = amount of deposited material still active
- $-k_4H$ = pheromone decay
- $D_H \nabla^2 H$ = pheromone diffusion
- D_H = diffusion coefficient

$$\partial_t H = k_2 P - k_4 H + D_H \nabla^2 H$$

Model of Positive Feedback Mechanism

C: density of the attractiveness of the cement pheromone

- $\gamma\nabla(C\nabla H)$ = attractiveness of the pheromone gradient
- γ = intrinsic strength of attractiveness(positive, the greater γ is, the greater the attractiveness)
- $D_C\nabla^2C$ = random component in individual motion
- D_C = "diffusion" constant of termites
- ϕ = flow of loaded termites into the system

$$\partial_t C = \Phi - k_1 C + D_C \nabla^2 C - \gamma \nabla (C \nabla H)$$

Model of Positive Feedback Mechanism

Dynamics of the active material P:

- k_1C = amount of material P deposited per unit time
- k_2P = rate of disappearance

$$\partial_t P = k_1 C - k_2 P \,.$$

Model of Positive Feedback Mechanism

$$C_0 = \frac{\Phi}{k_1}, \qquad H_0 = \frac{\Phi}{k_4}, \qquad P_0 = \frac{\Phi}{k_2}.$$

$$\gamma_c = \frac{\left((k_4 D_C)^{1/2} + (k_1 D_H)^{1/2}\right)^2}{\Phi}$$

Model of Positive Feedback Mechanism

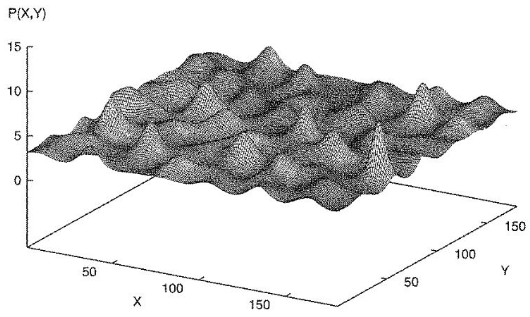


FIGURE 5.5 Spatial distribution of P for a 2D system (180×180) and $k_1 = k_2 = k_4 = 0.8888$, $D_C = 0.01$, $D_H = 0.000625$, $\Phi = 3$, $\gamma = 0.004629$, $t = 100$. The distribution of pillars is only statistically regular, because of the random initial distribution of P. The initially fastest-growing modes do not necessarily continue to be dominant after some time, as structures can emerge locally and modify the physics of the system.

Model of Pheromonal Template

T(x, y): amount of queen pheromone at location (x, y)

- λ_x, λ_y = characteristic distances for the decay of the pheronmal pattern (assume to be the proportional to the size of the queen in the x and y direction)

$$T(x,y) = e^{-[((x-x_0)/\lambda_x)^2+((y-y_0)/\lambda_y)^2]}$$

Model of Pheromonal Template

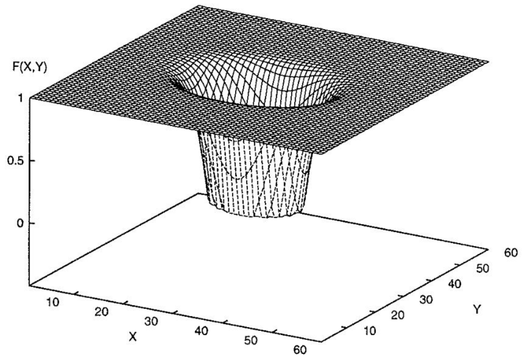


FIGURE 5.6 Simulated pheromonal template created by the queen. $T(x,y) = \exp(-[((x-x_0)/\lambda_x)^2+((y-y_0)/\lambda_y)^2])$, $\lambda_x = 7$, $\lambda_y = 5$, $x_0 = y_0 = 30$, $F(x,y) = 1-T(x,y)$ where $T(x,y) = \exp(-[((x-x_0)/\lambda_x)^2 + ((y-y_o)/\lambda_y)^2])$.

Model of combination of Positive Feedback Mechanism and Pheromonal Template

Full equation:

- v = force of attraction of the queen pheromonal template

$$\partial_t C = \Phi - k_1 C + D_C \nabla^2 C - \gamma \nabla (C \nabla H) - v \nabla (C \nabla T)$$

When pheromone intensity is too large:

- F(x, y) = 1 - T(x, y)

$$\partial_t C = \Phi - F k_1 C + D_C \nabla^2 C - \gamma \nabla (C \nabla H) - v \nabla (C \nabla T)$$

$$\partial_t P = F k_1 C - k_2 P \,.$$

Model of combination of Positive Feedback Mechanism and Pheromonal Template

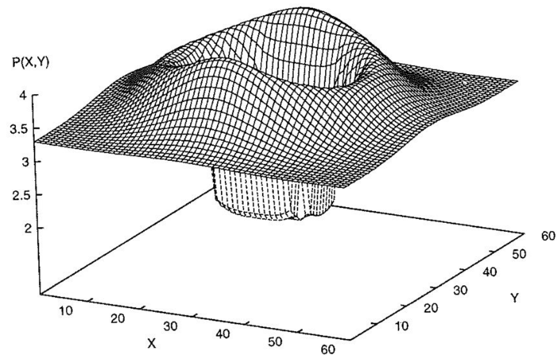


FIGURE 5.7 Spatial distribution of P at $t = 100$ for a 2D system and $k_1 = k_2 = k_4 = 0.8888$, $D_C = 0.01$, $D_H = 0.000625$, $\Phi = 3$, $\gamma = 0.004629$, added chemotactic motion toward the pheromonal template represented in Figure 5.6, with $v = 0.02$. A chamber forms around the simulated template.

WALL BUILDING IN Leptothomx Albipennis

•Leptothomx albipennis’s nest walls

(aggregated grains of sand, or fragments of stone, or particles of earth)

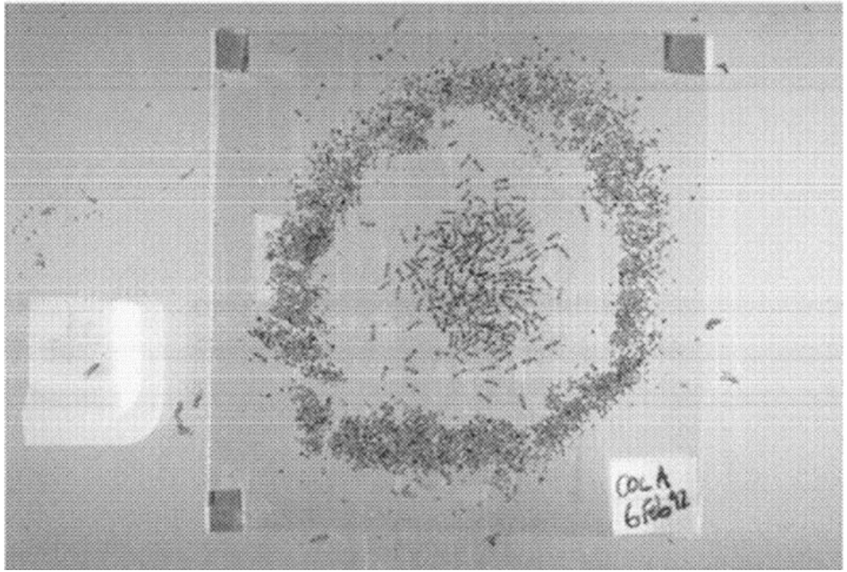
•serves as a chemical or physical template

•Nature of template unknown

•Template allows the size of nest regulated related to colony size

•stigmergic self-organizing mechanism (grains attract grains)

•deposition behavior: the local density of grains + the distance from the cluster of ants and nest



Franks and Deneubourg (double mechanism (template + self-organization)

$$\partial_t S = D(r)G(S)L\left(1 - \frac{S}{K}\right) - P(r)F(S)SU \,.$$

Picking-Up Rate

•P(r) represents the influence of the template.

•F(S): decreasing function of # of grains (g1+g2S)^-1

•S: the density of grain

•U: the density of unladen ant

•L: the density of pick it up and become a laden ant

•Rate of transformation from U to L is P(r)US

•g1 and g2: parameters of grain dropping and dropping next to another grain

$$\partial_t S = D(r)G(S)L\left(1 - \frac{S}{K}\right) - P(r)F(S)SU\,.$$

Dropping Rate

•D(r): direct influence of template

•L: the density of pick it up and become a laden ant

•S: the density of grain

•K: carrying capacity per unit area

•G(S): linearly increasing of # of grains (g1+g2S)

•g1 and g2: parameters of grain dropping and dropping next to another grain

$$\partial_t S = D(r)G(S)L\left(1 - \frac{S}{K}\right) - P(r)F(S)SU\,.$$

$$\eta = \frac{S}{(g_1 + g_2 S)^2}\left(1 - \frac{S}{K}\right)^{-1},$$

$$\eta \equiv \frac{D(r)L}{P(r)U}\,.$$

Eta is tendency to build wall in a particular area

D(r), P(r) are influenced by template

U: higher the density of individual in nest→ wall goes further away (grain deposits are prevented when population density is large) → lower U

1. When $g_1/g_2 > 0.125K$, the solution of S is unique, and S grows with η (Figures 5.11(a) and 5.11(c)).
2. When $g_1/g_2 < 0.125K$, several solutions can be reached for $\eta > \eta_c(g_1/g_2)$, depending on the history of the system (Figure 5.11(b)). This phenomenon is called hysteresis.

- carrying capacity per unit area (K)
- the density of grain (S)

Application

- data analysis
- graph partitioning models

Non-parametric → Parametric

Thank you!

Questions?