Lecture 11

Conditions for Self-Organized Pillars

• Will not produce regularly spaced pillars if:
  – density of termites is too low
  – rate of deposition is too low
• A homogeneous stable state results

\[ C_0 = \frac{\Phi}{k_1}, \quad H_0 = \frac{\Phi}{k_4}, \quad P_0 = \frac{\Phi}{k_2} \]

Interaction of Three Pheromones

• Queen pheromone governs size and shape of queen chamber (template)
• Cement pheromone governs construction and spacing of pillars & arches (stigmergy)
• Trail pheromone:
  – attracts workers to construction sites (stigmergy)
  – encourages soil pickup (stigmergy)
  – governs sizes of galleries (template)

NetLogo Simulation of Deneubourg Model

Run Pillars3D.nlogo

Wasp Nest Building and Discrete Stigmergy

Structure of Some Wasp Nests

Fig. from Solé & Goodwin
Part 3: Autonomous Agents

Adaptive Function of Nests

How Do They Do It?

Lattice Swarms

(developed by Theraulaz & Bonabeau)

Discrete vs. Continuous Stigmergy

- Recall: **stigmergy** is the coordination of activities through the environment
  - **Continuous or quantitative stigmergy**
    - quantitatively different stimuli trigger quantitatively different behaviors
  - **Discrete or qualitative stigmergy**
    - stimuli are classified into distinct classes, which trigger distinct behaviors

Discrete Stigmergy in Comb Construction

- Initially all sites are equivalent
- After addition of cell, qualitatively different sites created

Numbers and Kinds of Building Sites

Fig. from Self-Org. Biol. Sys.
Lattice Swarm Model
- Random movement by wasps in a 3D lattice – cubic or hexagonal
- Wasps obey a 3D CA-like rule set
- Depending on configuration, wasp deposits one of several types of “bricks”
- Once deposited, it cannot be removed
- May be deterministic or probabilistic
- Start with a single brick

Cubic Neighborhood
- Deposited brick depends on states of 26 surrounding cells
- Configuration of surrounding cells may be represented by matrices:

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{pmatrix}
\]

\[
\begin{pmatrix}
1 & 0 & 0 \\
0 & 0 & 1 \\
0 & 0 & 0
\end{pmatrix}
\]

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{pmatrix}
\]

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{pmatrix}
\]

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{pmatrix}
\]

\[
\begin{pmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{pmatrix}
\]

Hexagonal Neighborhood

Example Construction

Another Example

A Simple Pair of Rules
Part 3: Autonomous Agents

Result from Deterministic Rules

Result from Probabilistic Rules

Example Rules for a More Complex Architecture
The following stimulus configurations cause the agent to deposit a type-1 brick:

\[
\begin{bmatrix}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 0
\end{bmatrix},
\begin{bmatrix}
0 & 0 & 0 \\
1 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
\]

Result

• 20×20×20 lattice
• 10 wasps
• After 20,000 simulation steps
• Axis and plateaus
• Resembles nest of *Parachartergus*

Second Group of Rules
For these configurations, deposit a type-2 brick

Architectures Generated from Other Rule Sets

Fig. from Bonabeau & al., *Swarm Intell.*
### An Interesting Example
- Includes
  - central axis
  - external envelope
  - long-range helical ramp
- Similar to *Apicotermes* termite nest

![Fig. from Theraulaz & Bonabeau (1995)](image)

### Similar Results with Hexagonal Lattice
- 20x20x20 lattice
- 10 wasps
- All resemble nests of wasp species
- (d) is (c) with envelope cut away
- (e) has envelope cut away

![Fig. from Bonabeau & al., Swarm Intell.](image)

### More Hexagonal Examples

![Figs. from IASC Dept., ENST de Bretagne.](image)