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

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

NetLogo Simulation of Deneubourg Model

Run Pillars3D.nlogo

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)

Wasp Nest Building and Discrete Stigmergy

Fig. from Solé & Goodwin

Structure of Some Wasp Nests

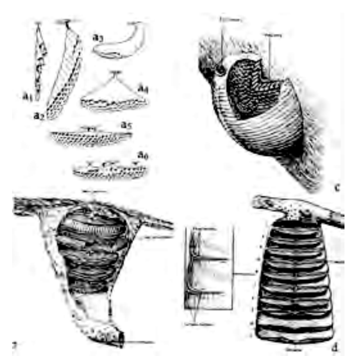
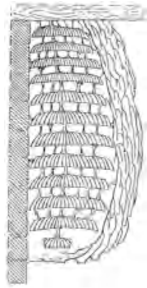


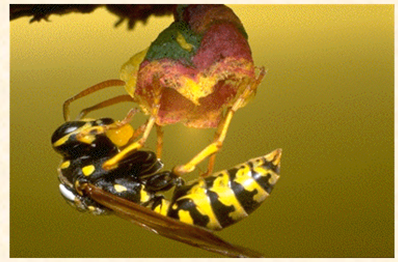
Fig. from *Self-Org. Biol. Sys.*

Adaptive Function of Nests



9/27/07 Figs. from Self-Org. Biol. Sys, 7

How Do They Do It?



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Lattice Swarms

(developed by Theraulaz & Bonabeau)

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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

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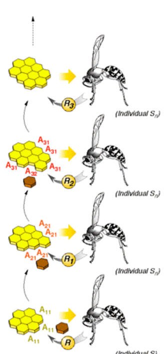
Discrete Stigmergy in Comb Construction



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

9/27/07 Fig. from *Self-Org. Biol. Sys.* 11

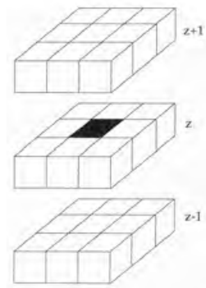
Numbers and Kinds of Building Sites

9/27/07 Fig. from *Self-Org. Biol. Sys.* 12

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

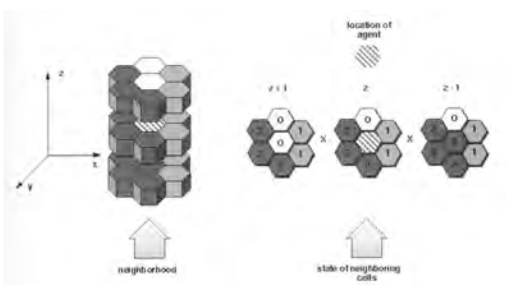
Cubic Neighborhood



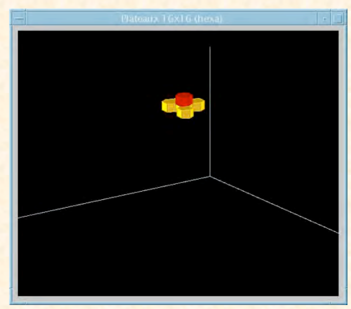
- Deposited brick depends on states of 26 surrounding cells
- Configuration of surrounding cells may be represented by matrices:

$$\begin{bmatrix}0&0&0\\1&0&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\1&\bullet&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\1&0&0\\0&0&0\end{bmatrix}$$

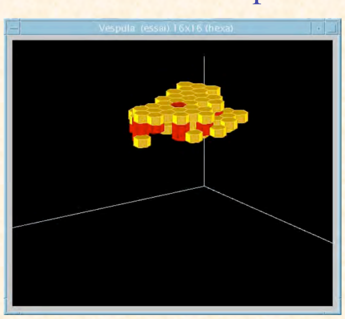
Hexagonal Neighborhood



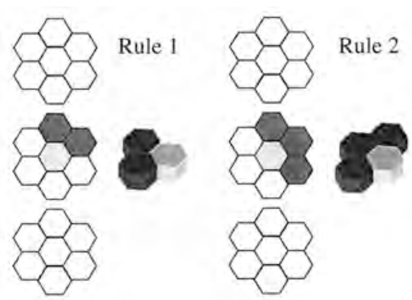
Example Construction



Another Example



A Simple Pair of Rules



Result from Deterministic Rules

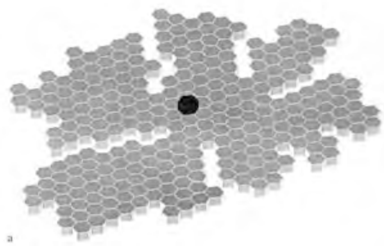


Fig. from *Self-Org. in Biol. Sys.*

Result from Probabilistic Rules

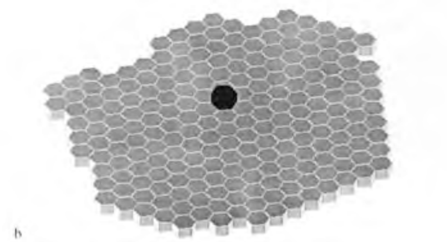


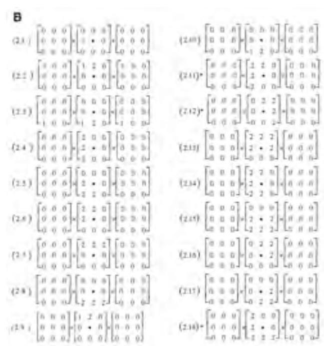
Fig. from *Self-Org. in Biol. Sys.*

Example Rules for a More Complex Architecture

The following stimulus configurations cause the agent to deposit a type-1 brick:

$$(1.1)\quad \begin{bmatrix}0&0&0\\0&1&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\0&\bullet&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix}$$

$$(1.2)\quad \begin{bmatrix}0&0&0\\1&0&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\1&\bullet&0\\0&0&0\end{bmatrix}\times\begin{bmatrix}0&0&0\\1&0&0\\0&0&0\end{bmatrix}$$



Second Group of Rules

For these configurations, deposit a type-2 brick

Result

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

Fig. from Bonabeau & al., *Swarm Intell.*

Architectures Generated from Other Rule Sets

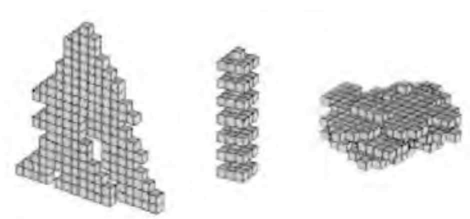
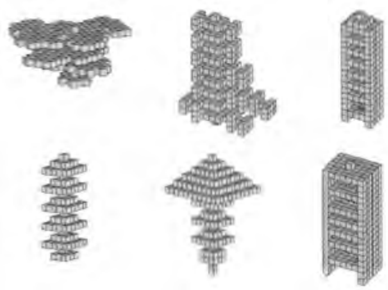


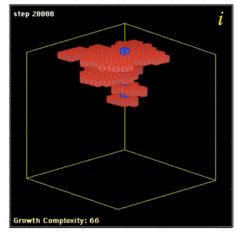
Fig. from Bonabeau & al., *Swarm Intell.*

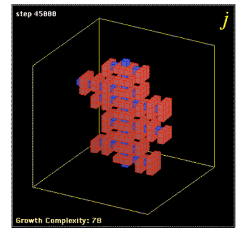
More Cubic Examples



9/27/07 Fig. from Bonabeau & al., *Swarm Intell.* 25

Cubic Examples (1)





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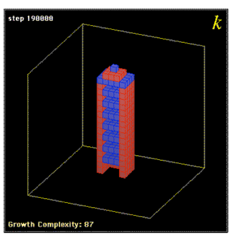
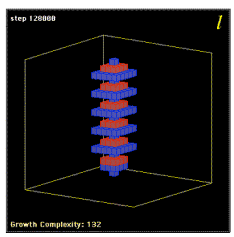
Cubic Examples (2)





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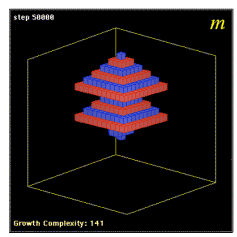
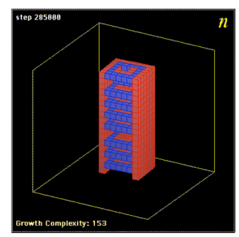
Cubic Examples (3)





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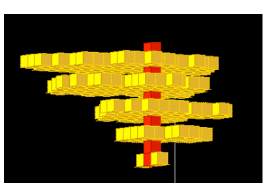
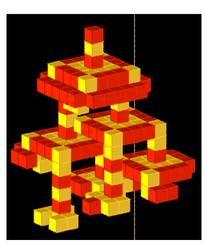
Cubic Examples (4)





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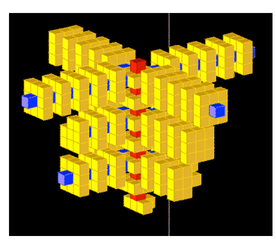
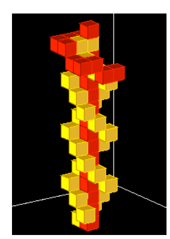
Cubic Examples (5)





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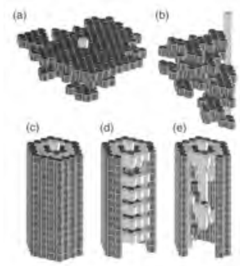
An Interesting Example

- Includes
  - central axis
  - external envelope
  - long-range helical ramp
- Similar to *Apicotermes* termite nest

Fig. from Theraulaz & Bonabeau (1995)

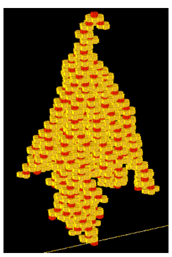
Similar Results with Hexagonal Lattice

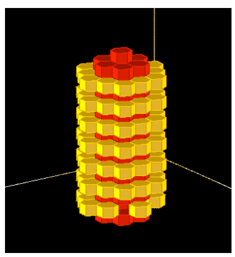


- 20×20×20 lattice
- 10 wasps
- All resemble nests of wasp species
- (d) is (c) with envelope cut away
- (e) has envelope cut away

Fig. from Bonabeau & al., *Swarm Intell.*

More Hexagonal Examples





Figs. from IASC Dept., ENST de Bretagne.