Nest Building and Self-Assembly

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Nest Building in Social Insects

- Social Insects are capable of generating complex functional patterns in time and space
- Demonstrates greatest difference between individual and collective levels
- First hypotheses explaining complex nest building were anthropomorphic: individuals were assumed to possess a representation of the global structure

Nest likely created by Polistes wasps

A Decentralized System

- Organization departs radically from anthropomorphic model
- Decentralized system composed of cooperative, autonomous units
  - Distributed in the environment
  - Exhibit simple probabilistic stimulus-response behavior
  - Have access to local information
- Equipped with sensory-motor system to respond to stimuli
- Signals do not have symbolic value, but are attractive or repulsive - activating or inhibiting behavior

Stimulating Construction

A giant termite mound

- Initial stimuli may be simple and limited
- As construction proceeds, stimuli become more complex and numerous, inducing new behavior
- Morphogenetic process where past construction sets the stage for new building actions
- As nest gets bigger - encompasses more signals and cues

Templates and Stigmergy

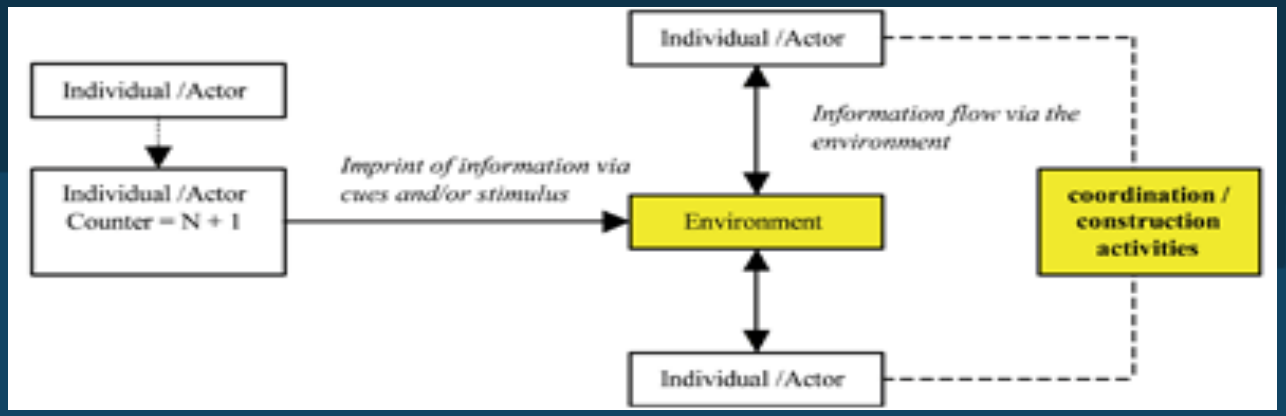
- Templates used to coordinate building activities
- "Blueprint" of nest "already exists" in the environment as physical or chemical heterogeneities

- Single action by an insect results in small modification to environment which influences actions of other insects

- Colonies of a given species build qualitatively similar architectural patterns
- Stigmergy just mediates worker-worker interactions
  - Must be supplemented with mechanism that uses these interactions to coordinate collective building
    - Self-organization and discrete stigmergy

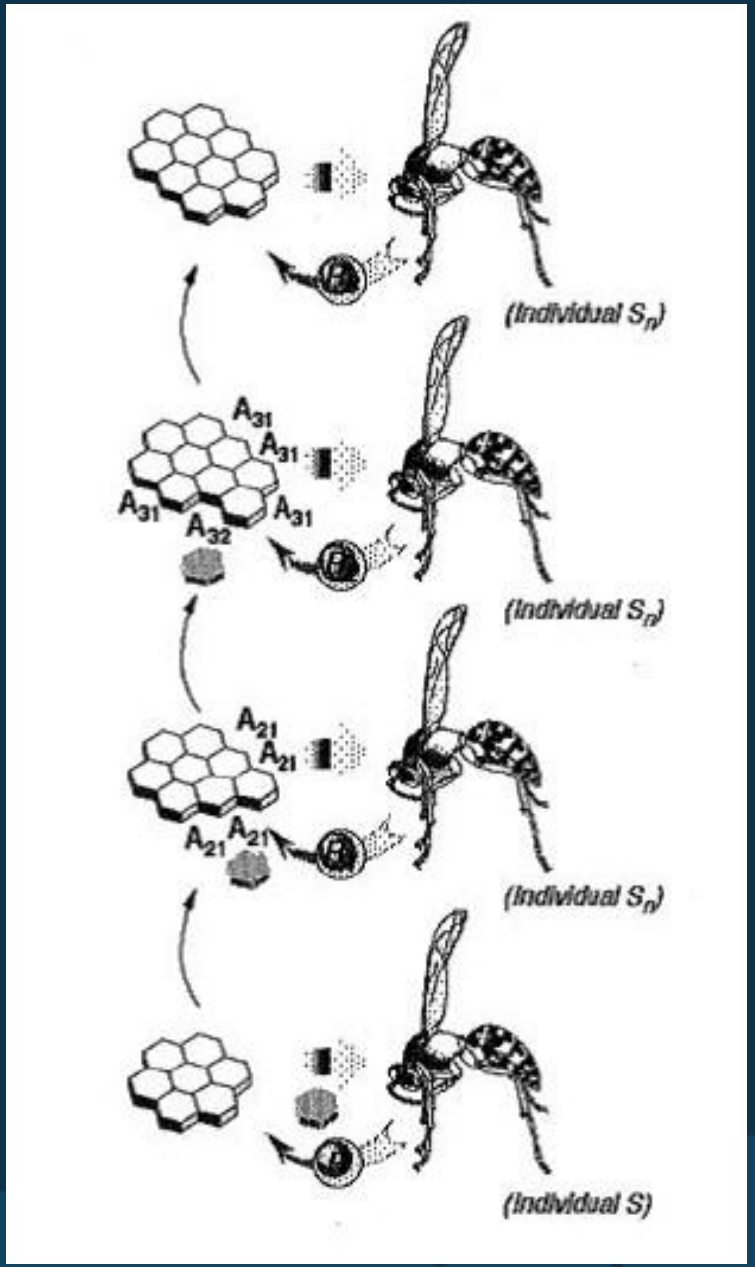
Stigmergy and Self-Organization

- A main ingredient of self-organization is multiple interactions
  - direct or indirect
- Stigmergy covers the indirect interactions through the environment
- The more intense the interactions (e.g. pheromone concentration) the more likely the SO effect (snowball effect) is to engage.
- Stigmergy and Self-orgnization is *quantitative stigmergy*



Discrete Stigmergy

- Qualitative stigmergy
  - Individuals interact through qualitative or discrete stimuli
- Stimuli are qualitatively different
  - No positive feedback can intensify a stimulus
  - A stimulus is transformed to another by insect
- In reality - both types of stigmergy likely coexist



Responses to qualitative stimuli in wasp building behavior

Model of Self-Assembly

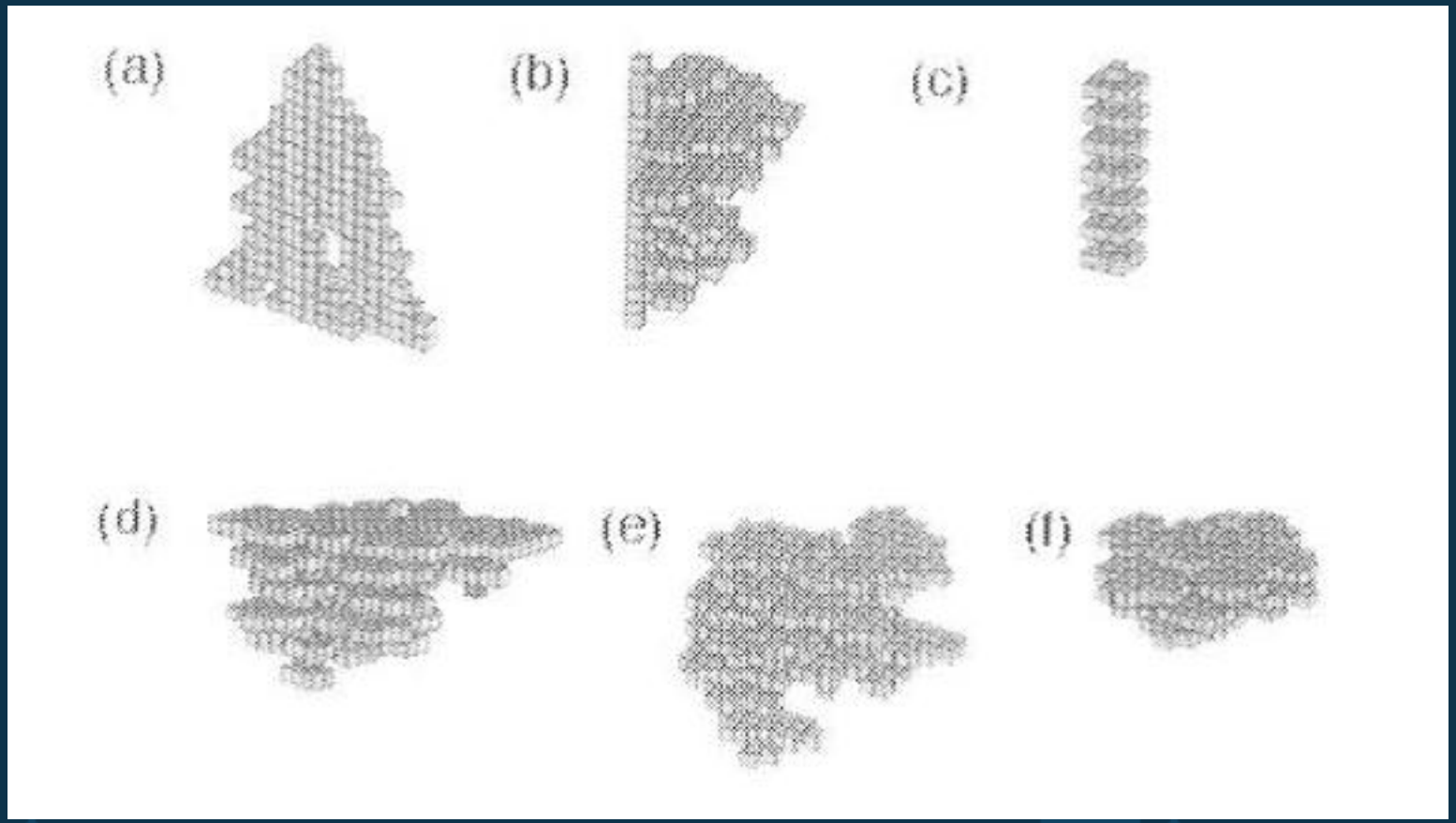
- To explore the potential of discrete stigmergy
  - Introduced an ensemble of algorithms
- Asynchronous automata that move in 3D discrete space, behave locally, and work on pure stimulus-response basis
- Construction of block architectures by qualitative stigmergy
- Building is an individual behavior, but that behavior has to be organized so that a group of agents can produce the same architecture
  - Individual activities have to be coordinated to ensure coherent construction

Algorithm 6.3 High-level description of the construction algorithm

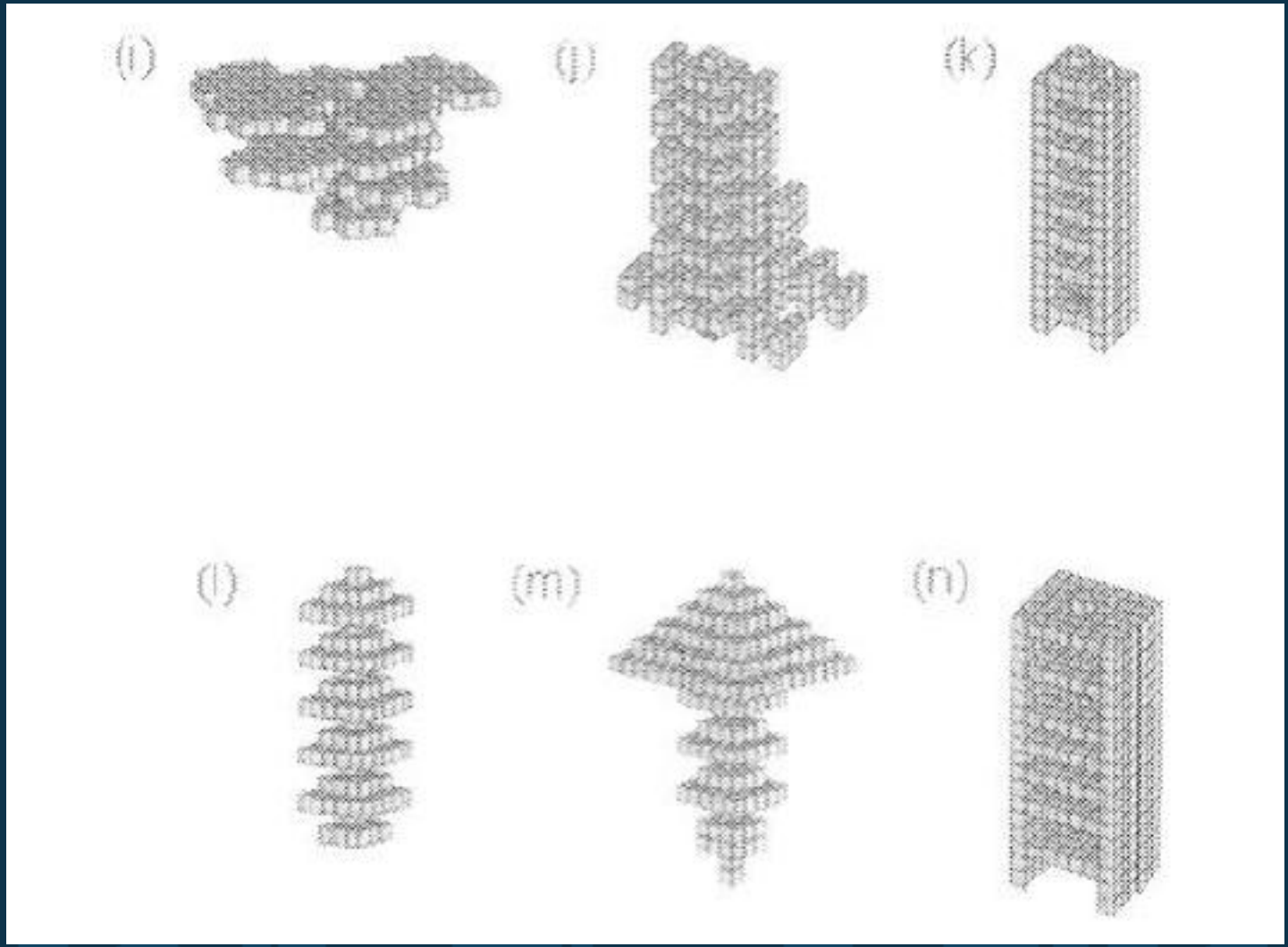
```
/* Initialization */
Construct lookup table /* identical for all agents */
Put one initial brick at predefined site /* top of grid */
For k = 1 to m do
  assign agent k a random unoccupied site /* distribute the m agents */
End For
/* Main loop */
For t = 1 to t_max do
  For k = 1 to m do
    Sense local configuration
    If (local configuration is in lookup table) then
      Deposit brick specified by lookup table
      Draw new brick
    Else
      Do not deposit brick
    End If
    Move to randomly selected, unoccupied, neighboring site
  End For
End For
/* Values of parameters used in simulations */
m = 10
```

Posing Constraints

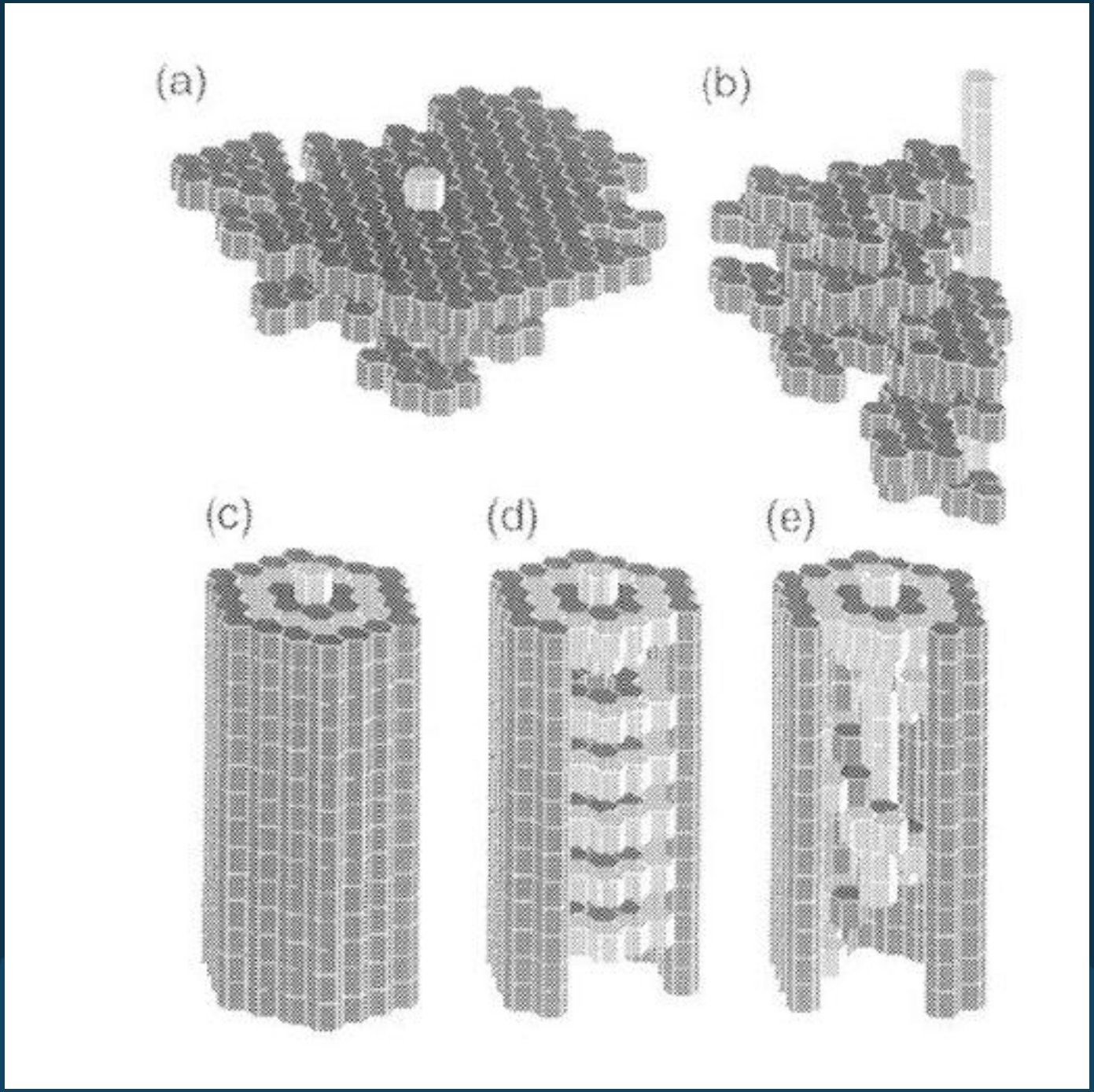
- Random exploration of algorithmic space yielded no interesting results
- Working backward from natural structures
  - Discovered that structured shapes can only be built with special algorithms characterized by emergent coordination
- Stimulating configurations corresponding to different building stages must not overlap
  - Implicit handshakes and interlocks at every stage act as constraints for consistent structural development
- Parallelism introduces potential for building conflicts
- Nest itself can act as constraints on stigermergic building behavior



Simulations of collective building on a 3D cubic lattice



More simulations of collective building on a 3D cubic lattice



Simulations of collective building on a 3D hexagonal lattice

Questions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In my day, it was 50% soldiers and 50% workers...
Now, it is 50% soldiers, 20% managers,
20% admin and only 10% workers...