Situated Cellular Agents and Immune System Modeling

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11/06/2003 WOA 2003 – Villasimius (CA)
Simulating the Immune System (1)

• The IS constitutes the defence mechanism of higher level organisms to molecular and microorganismic invaders

• Why simulating the IS?
  – In machina experiments
  – Educational purposes

• Issues
  – Very large numbers \(10^{12} - 10^{13}\) cells
  – Very complex scenario (different cell types and functions, knowledge still not complete)
Simulating the Immune System (2)

- Typical approaches to IS modelling
  - Analytical models
    - Main issue: distance from immunologist language
  - Cellular Automata
    - Main issues: transition rule uniformity, very large cell state

- Advantages of a SCA approach
  - Explicit and precise spatial representation
  - Direct correspondance between domain and model entities

- Why agents?
Very short description of the IS
IS entities

• IS entities are thus
  – Located and roaming in an environment
  – Autonomous and interacting according to their state, position and circumstances
  – Cooperating in order to obtain a global system characterized by
    • Adaptation/learning mechanisms
    • Decentralization and robustness
    • Memory
Situated Cellular Agents (SCA)

- A formal and computational framework where to describe, represent and simulate complex systems that require
  - spatial features to be explicitly considered
  - different forms of interaction to be integrated
- SCA relaxes constraints on uniformity, locality and closure of CA

Open systems can be modeled

- Heterogeneous agents
  - Not homogeneous agent environment
  - Different forms of interaction

Interaction involving spatially not adjacent agents
SCA

• \(<Space, F, A>\)
  – \(Space\): graph of sites representing the spatial structure of agent environment
  – \(F\): set of fields propagating throughout the Space
  – \(A\): set of situated agents

• Agent heterogeneity \(\rightarrow\) agent types
  \(A_\tau =< \sum_\tau, Perception_\tau, Action_\tau >\)

• \(\sum_\tau\) the set of states that agents of type \(\tau\) can assume

• \(Perception_\tau\) is a function associating to each agent state the vector of pairs representing the receptiveness coefficient and the agent sensibility threshold to a certain field

• \(Action_\tau\) denotes the set of actions that agents of type \(\tau\) can perform
SCA and IS modelling

- Agents represent cells (epitelial, generic IS, specific IS)
- Fields represent viruses, antigens, antibodies and other umoral signals
- Interactions can involve
  - Agents and fields (emissions, perceptions and changes in agent state)
  - Only agents (reactions between adjacent entities)
Sample interactions

Cell infection

action : trigger\( (s_{Gen}, f; s'_{Gen}) \)
condit : \( f < virus; k >, s_{Gen} \rightarrow cl; ll; v; alive >, cl < ll - 1, position(p) \)
effect : \( s'_{Gen} \rightarrow cl + 1; ll; f; alive >, F_p = F_p - f \)

Cell burst

action : emit\( (s_{Gen}, f; p) \)
condit : \( s_{Gen} \rightarrow cl; ll; f; dead >, f < virus; k >, cl > 0, position(p) \)
effect : \( s_{Gen} \rightarrow cl - 1; ll; f; dead >, added(f, p) \)

Infected cell removal

action : react\( (s_{Gen}; a_{TK_k}; s'_{Gen}) \)
condit : \( s_{Gen} \rightarrow cl; ll; f; alive >, f < virus; k > \)
effect : \( s'_{Gen} \rightarrow 0; ll; f; dead > \)
Simulation screenshots
Conclusions

• Results for Computer Science?
  – Biological inspiration for adaptation, coordination, security models
    • Current information systems have blurred and fading boundaries, but growing need of security and robustness
  – A few warnings
    • Inspiration must be followed down
    • Adaptation must be based on really fundamental concepts