

Category Theory for Agent-based Modeling & Simulation

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Objectives

- ❖ Bring Awareness of Category Theory.
 - General, we can't accomplish too much.
- ❖ Propose as a Language for Scientific Discourse – ala Tarantola & Chen
- ❖ Give a Practical Example,
and finally,
- ❖ Discuss why is it important to ABM&S



What is Category Theory?

- ❖ “In mathematics, category theory deals in an abstract way with mathematical structures and the relationships between them.” – *Stanford Encyclopedia of Philosophy*
- ❖ “Category theory arose as an organizing framework for expressing the naturality of certain constructions in algebraic topology. Its subsequent applicability, both as a language for simply expressing complex relationships between mathematical structures and as a mathematical theory in its own right, is remarkable. Categorical principles have been put to good use in virtually every branch of mathematics, in most cases leading to profound new understandings.” – *Blute, Scott – Category Theory for Linear Logicians*
- ❖ A “Rosetta Stone” – *Baez, Stay – Physics, Topology, Logic & Computation: A Rosetta Stone*



Category Theory

- ❖ Category theory has come to occupy a central position in contemporary mathematics and theoretical computer science, and is also applied to mathematical physics. Roughly, it is a general mathematical theory of structures and of systems of structures.

Stanford Encyclopedia of Philosophy – Category Theory

- ❖ Can we consider agents as structures?
What is an agent-based program?



What is Category Theory?

“The conceptual clarity gained from a categorical understanding of some particular circumstance in mathematics enables one to see how a computation of **relevant entities** can be carried out for special cases. When the special case is itself very complex, as frequently is the case, then it is a tremendous advantage to know exactly what one is trying to do and in principle how to carry out the computation. The idea of mechanizing such computations is very intriguing. The present book, of course, does not enable one to do this, but it can be viewed as an essential precursor of developments that will lead to such mechanization.”

-- Rydeheard, Burstall – *“Computational Category Theory”*



What is Category Theory?

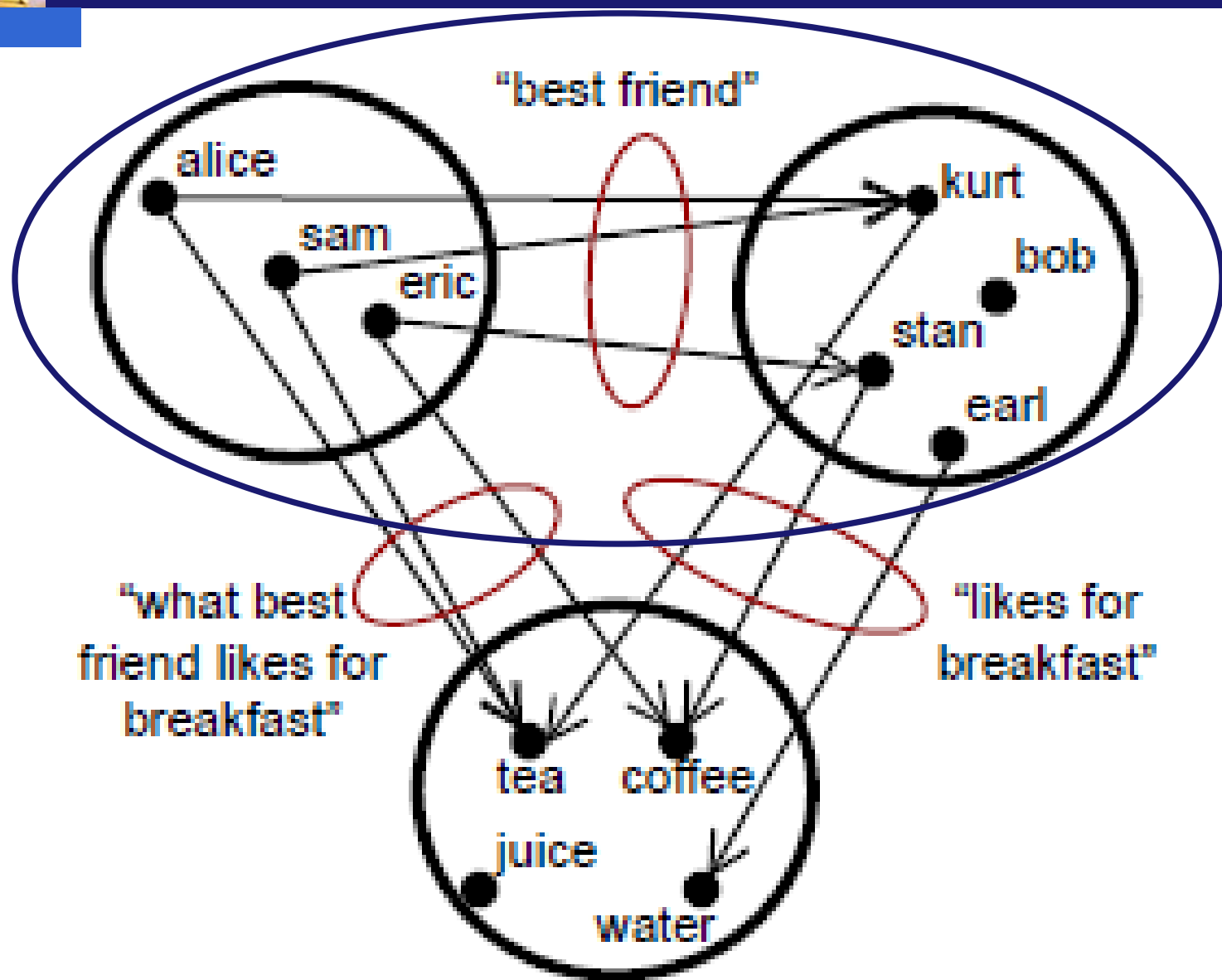
❖ Categories

- Categories of objects (including categories)
- The relationships between objects (structure).
- Behavior & structure classified by the category.
- Morphism of objects, structure, behavior and their relationships.

❖ Functors

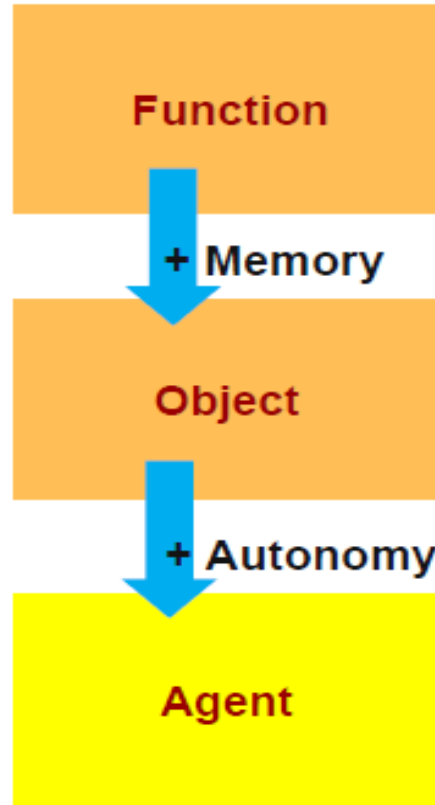
- A category of functional objects and categories.
- Usually structure preserving.

This is it (albeit simple)!



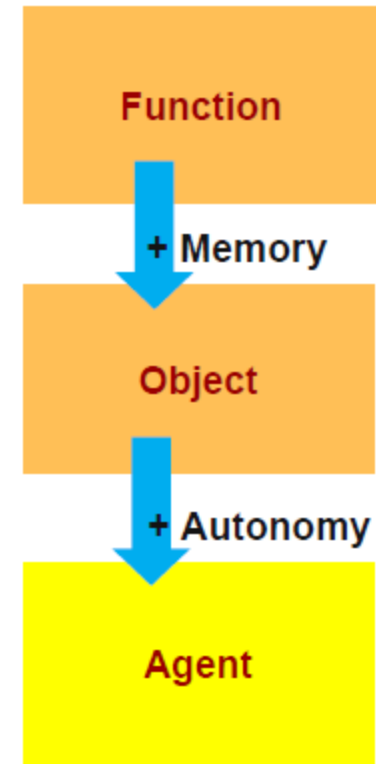
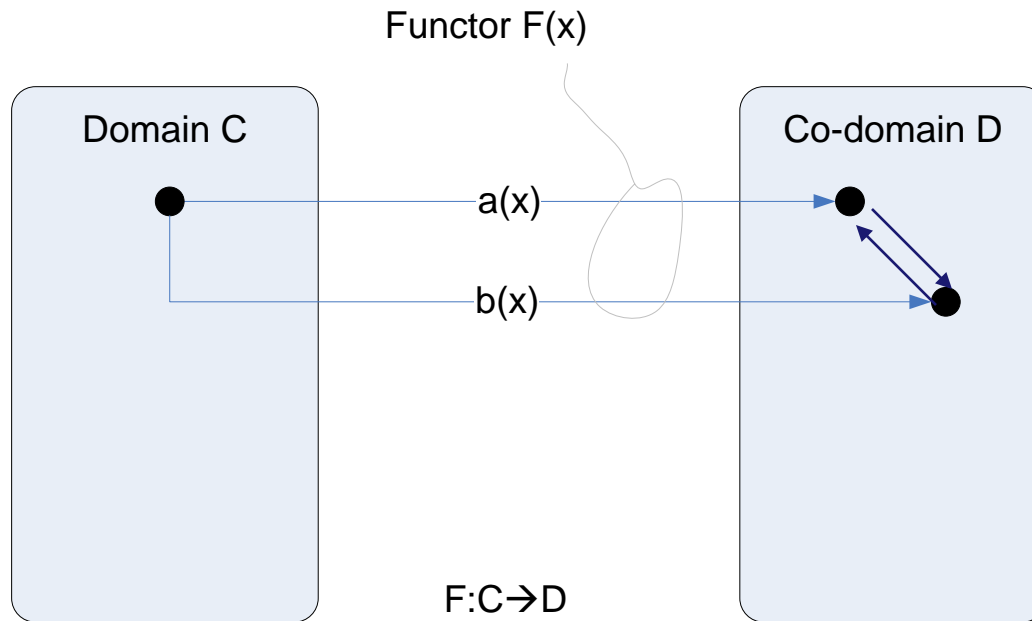
Functional Objects & Agents

What Is an “Agent?”



From Macal, North – Introduction to Agent Based Modeling and Simulation ppt

Functional Objects & Agents

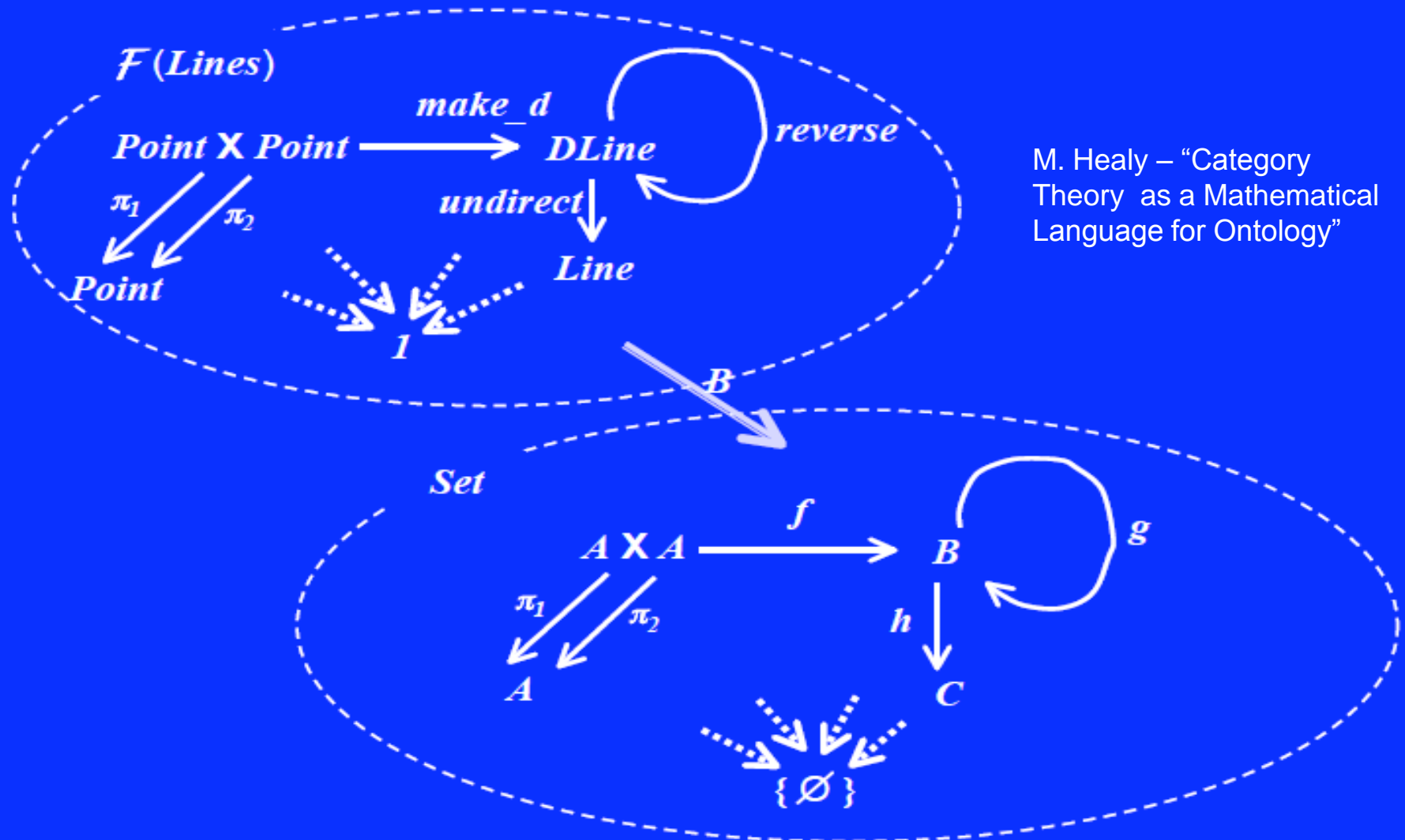


Functors are like structure preserving computer programs (methods of types)

Ibid.

In Agent Based Modeling ...

A Model is now a Functor



Abstracting a System of Agents

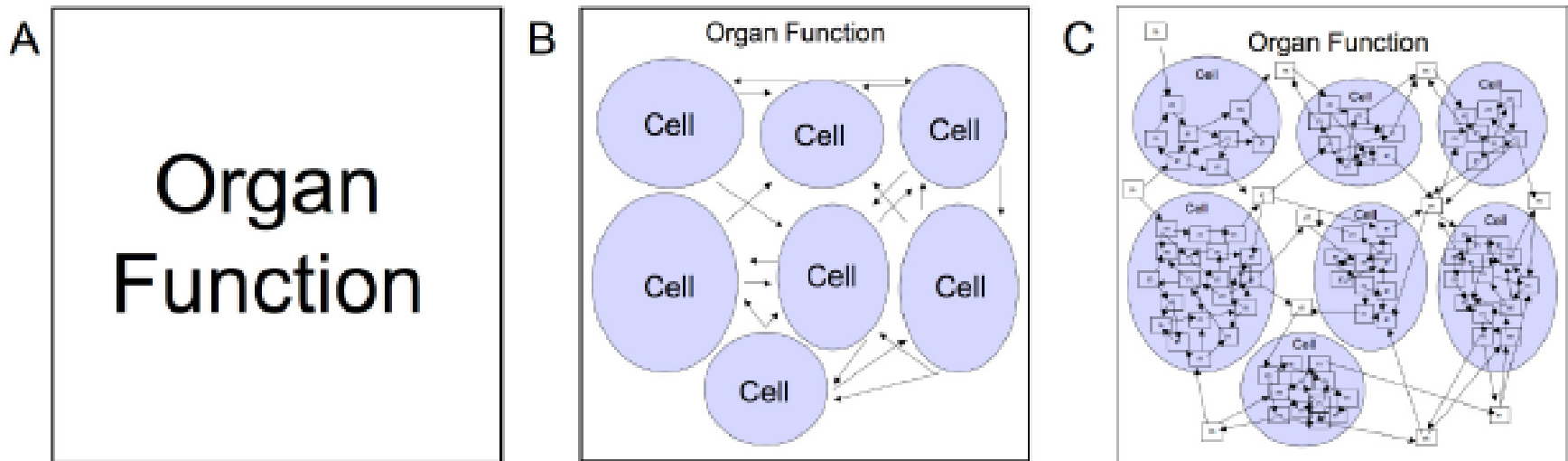
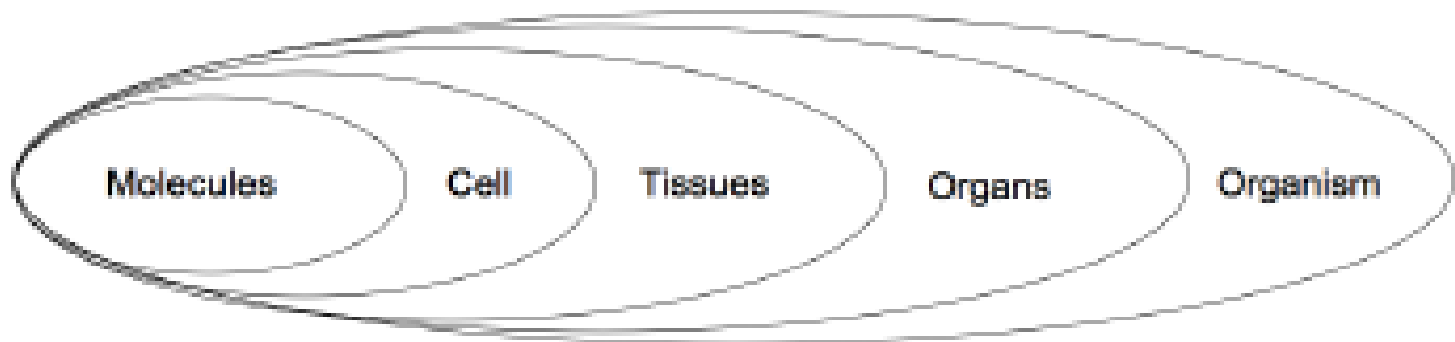


Figure 1

Abstract demonstration of the expansion of information resulting from reductionist investigation of multi-scale biological systems. Figure 1a shows the highest level of clinically observed phenomenon at the organ level. Figure 1b demonstrates graphically the mechanistic knowledge that organ function results from the interactions of multiple cells and types of cells. Figure 1c illustrates what a conceptual mechanistic model would look like when a further finer grained level of resolution is used. Figure 1c represents where the overwhelming bulk of biomedical research is currently being conducted, particularly with respect to the search for drug candidates and mechanisms of disease. Note that the "indistinctness" of Figure 1c is intentional: attempts to "zoom in" on the Figure may increase local clarity, but at the cost of being able to see the range of potential consequences to a particular manipulation.

Problem Domain

Levels of Biological Organization



Molecular
Biology

Cell
Biology

Tissue
Biology

Organ
Physiology

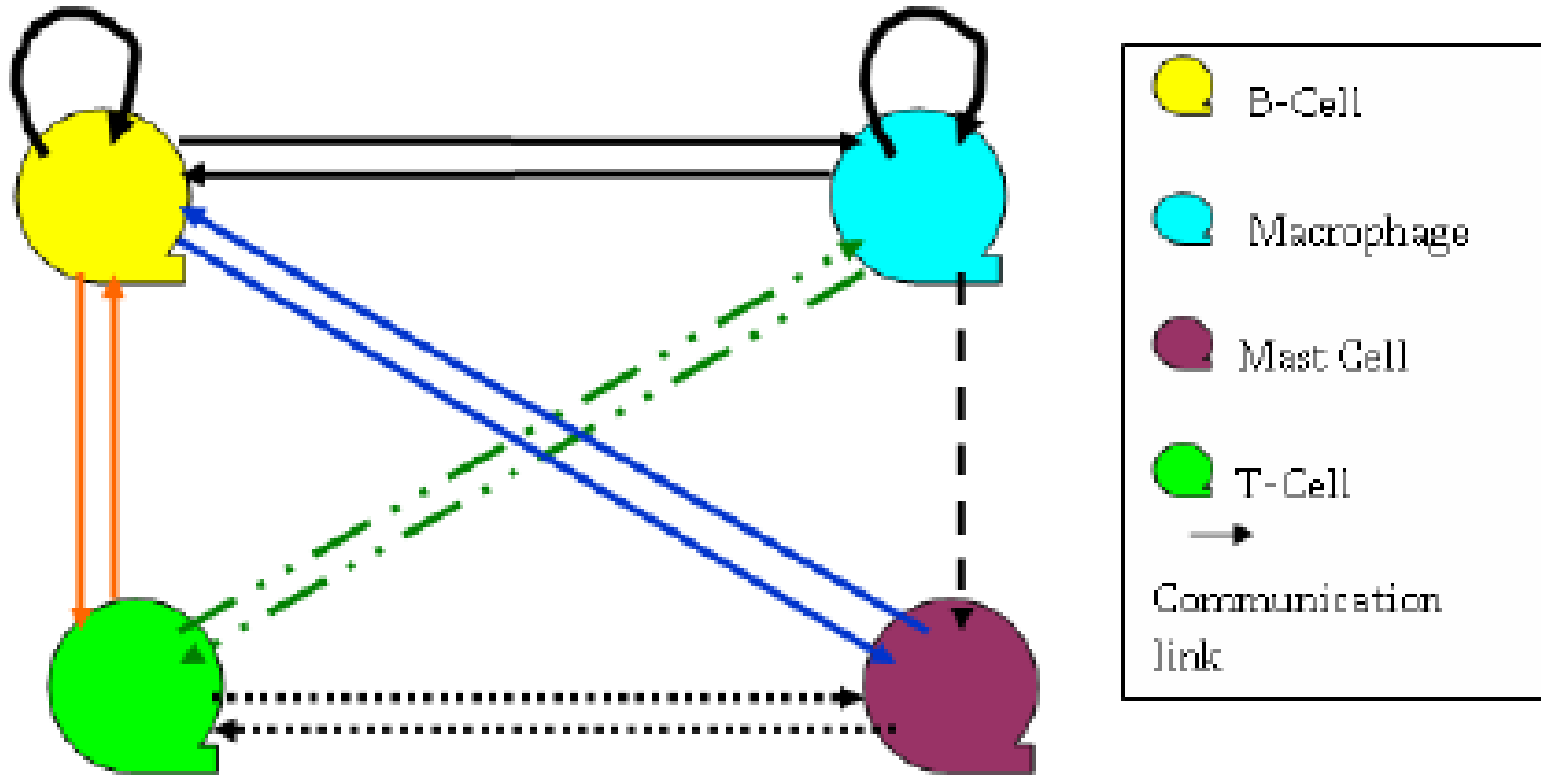
Clinical
Medicine



Multi-scale ABM Architecture

Gary An, MD – An Agent-based Multi-scale Modular Architecture
for Dynamic Knowledge Representation of Acute Inflammation

Cytokine Communication Agents



Cytokine-like “danger” signals proposed in a wireless mobile network
Mawjoon, Agbinya, Chackzo, *Replicating Cytokines in Modelling Signal Exchange Between Nodes in Wireless Mesh Networks*, 2009



Discussion

“However, the interpretation of [agent-based] simulations tends to be ad hoc, often with little theoretical justification. Related to this is the fact that there currently exists no universal formalism for describing specific emergent properties in multi-agent systems in terms of agent properties even though significant work has been done to formalise emergence, both from a multi-agent systems perspective ... and from an information theoretic perspective.”

“A hypothesis can be computationally validated by simulation if, by executing any subset of the ABM’s epistemologically unique simulations, it is possible to determine whether or not the hypothesis is true.”

Chen - A Process Interpretation of agent-based simulation and its epistemological implications, 2008

Does a Category Theoretic application of Inverse Theory provide an adequate, scientific formalism for Agent-based Modeling and Simulation?

The author (Lloyd) argues it does.

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Contact

Paper:

Lloyd – A Category-Theoretic Approach to Agent-based Modeling and Simulation, 2010

Available at: www.wattsys.com/publications

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