The International Technology Alliance
in
Network and Information Sciences

KSCO 2012

Modelling the Dynamics of Team Sensemaking: A Constraint Satisfaction Approach

Paul Smart and Nigel Shadbolt
University of Southampton

February 2012

ITA Context

- Part of the International Technology Alliance (ITA) program.
- One of 18 research tasks in the ITA
- Builds on existing work in the ITA:
  - shared understanding
  - distributed problem-solving
  - cognitive extension

Research Objectives

- Understand how communication networks affect aspects of collective cognition:
  - instances where cognitive processing is distributed across multiple agents.
- Particular focus of attention is sensemaking:
  - understand how communication networks affect the interpretation of ambiguous, uncertain and conflicting environmental information.

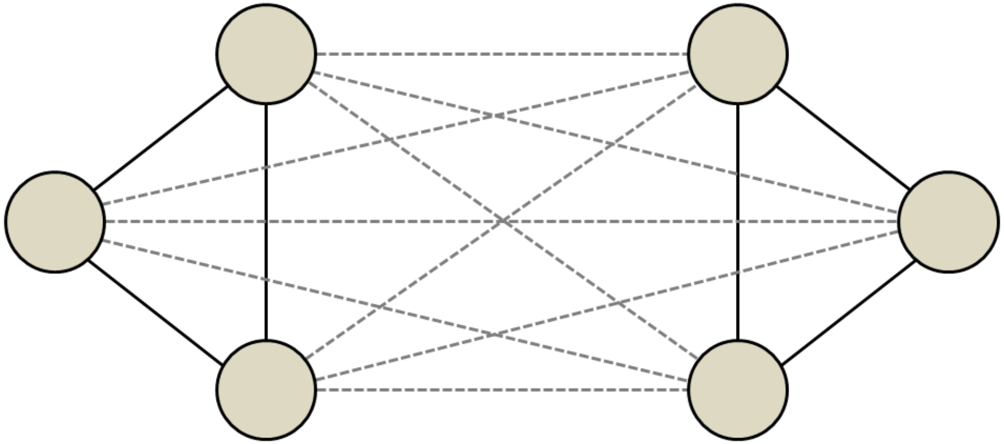
Sensemaking

- **Individual sensemaking:**
  - "a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively" (Klein et al, 2006)
- **Team sensemaking:**
  - "the process by which a team manages and coordinates its efforts to explain the current situation and to anticipate future situations, typically under uncertain or ambiguous conditions." (Klein et al, 2010)

Constraint Satisfaction Networks

- Sensemaking cast as a form of constraint satisfaction problem
  - agent is trying to match observed features to potential explanations based on background knowledge.
- Constraint satisfaction networks.
- Previous applications areas:
  - belief revision, explanation, schema completion, analogical reasoning, causal attribution, discourse comprehension, content-addressable memories, cognitive dissonance and attitude change.

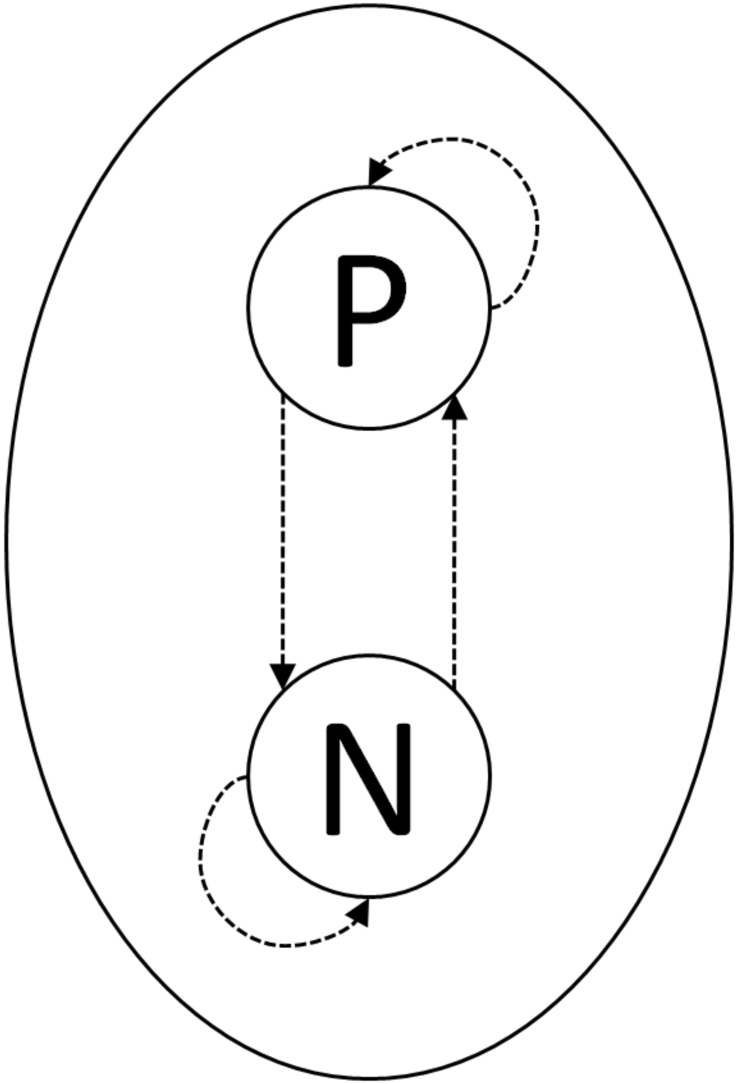
Computational Model



Schultz, T.R. and M.R. Lepper, Cognitive dissonance reduction as constraint satisfaction. Psychological Review, 1996. 103(2): p. 219-240.

- Each agent implemented as a constraint satisfaction network.
- Excitatory and inhibitory links between nodes.
- Connectivity of cognitive units reflects an agent's background knowledge about a domain.

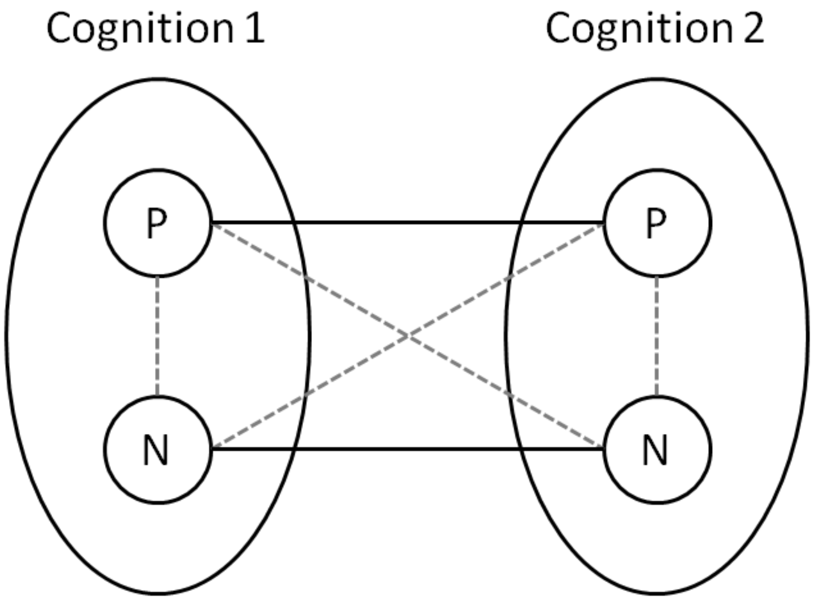
Cognitive Units



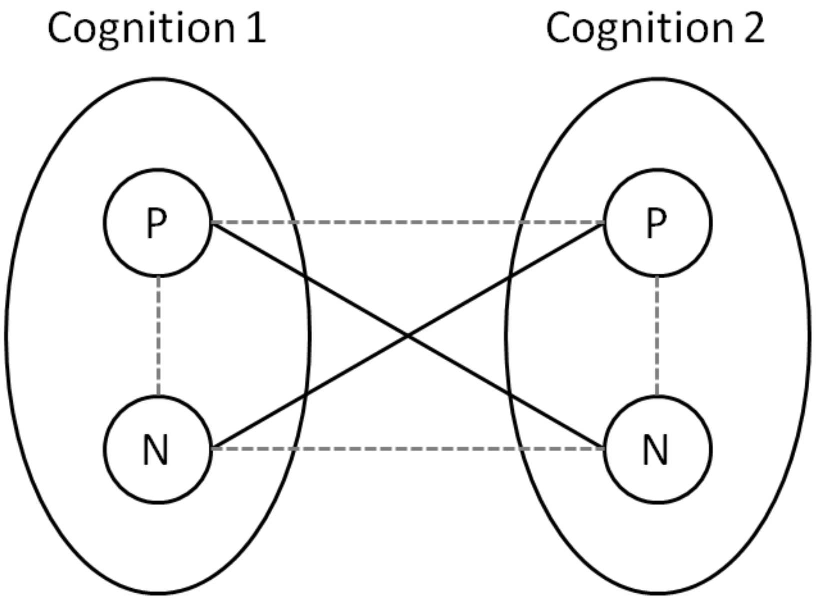
- Each node in the constraint satisfaction network is called a cognitive unit.
- Cognitive units represent the beliefs held by agents.
- Internally, each cognitive unit consists of a 'positive' (P) node and a 'negative' (N) node.
- Net activation of the cognitive unit represents the extent to which an agent holds a particular belief.

Excitatory and Inhibitory Connections

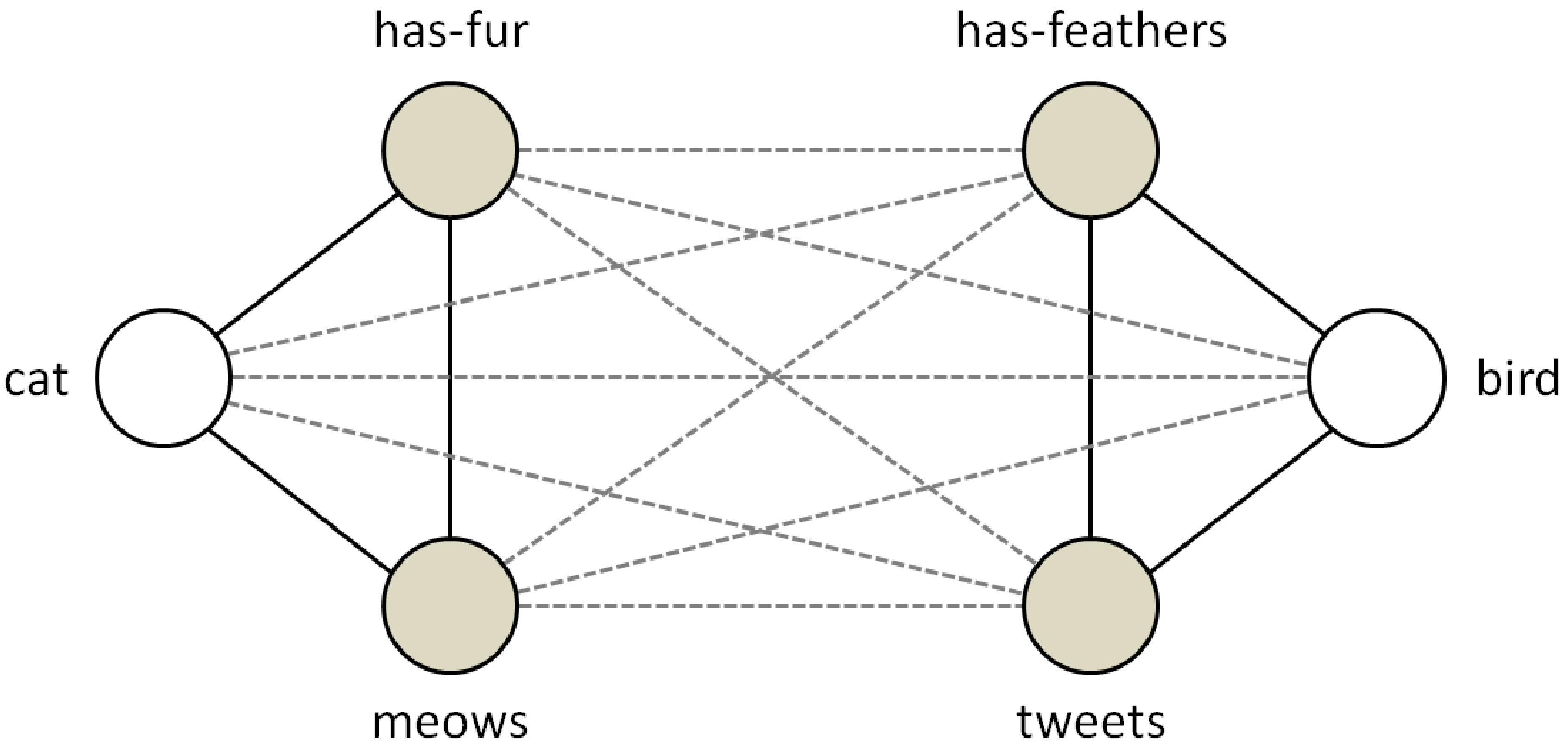
Excitatory



Inhibitory

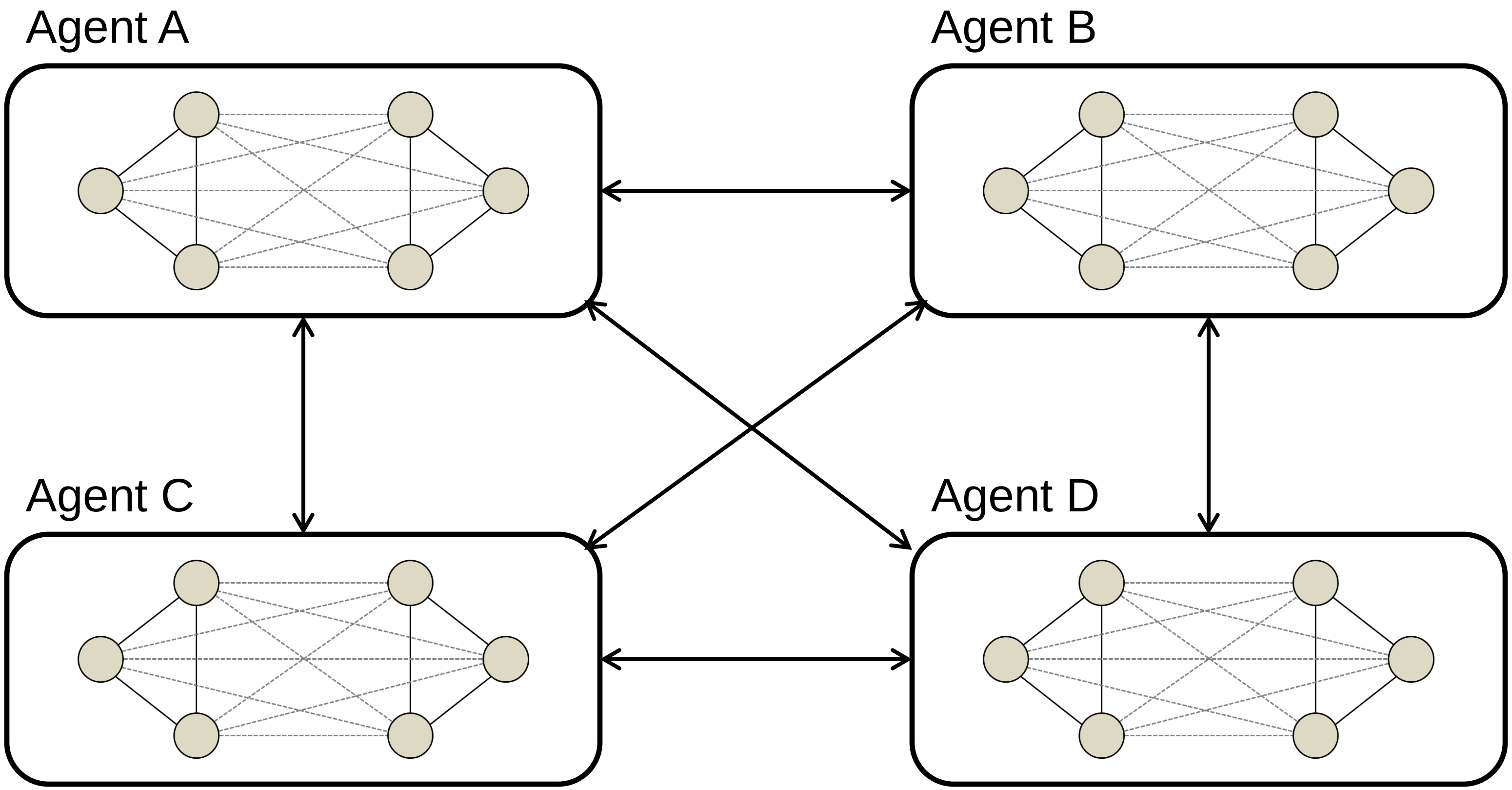


Cognitive Organization



- Interactions between nodes over successive processing cycles lead to pattern of activation.
- Reflects agent's attempt to make sense of information.

Communication Network Structure

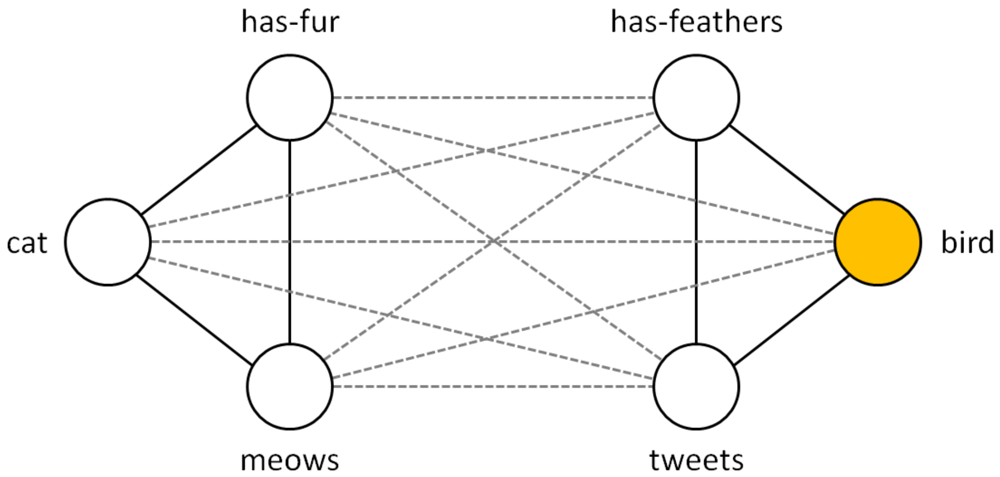


Hutchins, E., The social organization of distributed cognition, in Perspectives on Socially Shared Cognition, L. Resnick, J. Levine, and S. Teasley, Editors. 1991, The American Psychological Association: Washington DC, USA

Activation Vectors

Environmental Information

Node	Agent A	Agent B	Agent C	Agent D	Total
has-fur	0.3	0.3	0.5	0.0	1.1
meows	0.2	0.2	0.2	0.0	0.6
has-feathers	0.0	0.0	0.2	0.5	0.7
tweets	0.0	0.0	0.0	0.0	0.0



The activation of the ‘bird’ cognitive unit was set at 0.5 at the beginning of each simulation.

This represents agents’ expectations about the kind of object they expect to encounter.

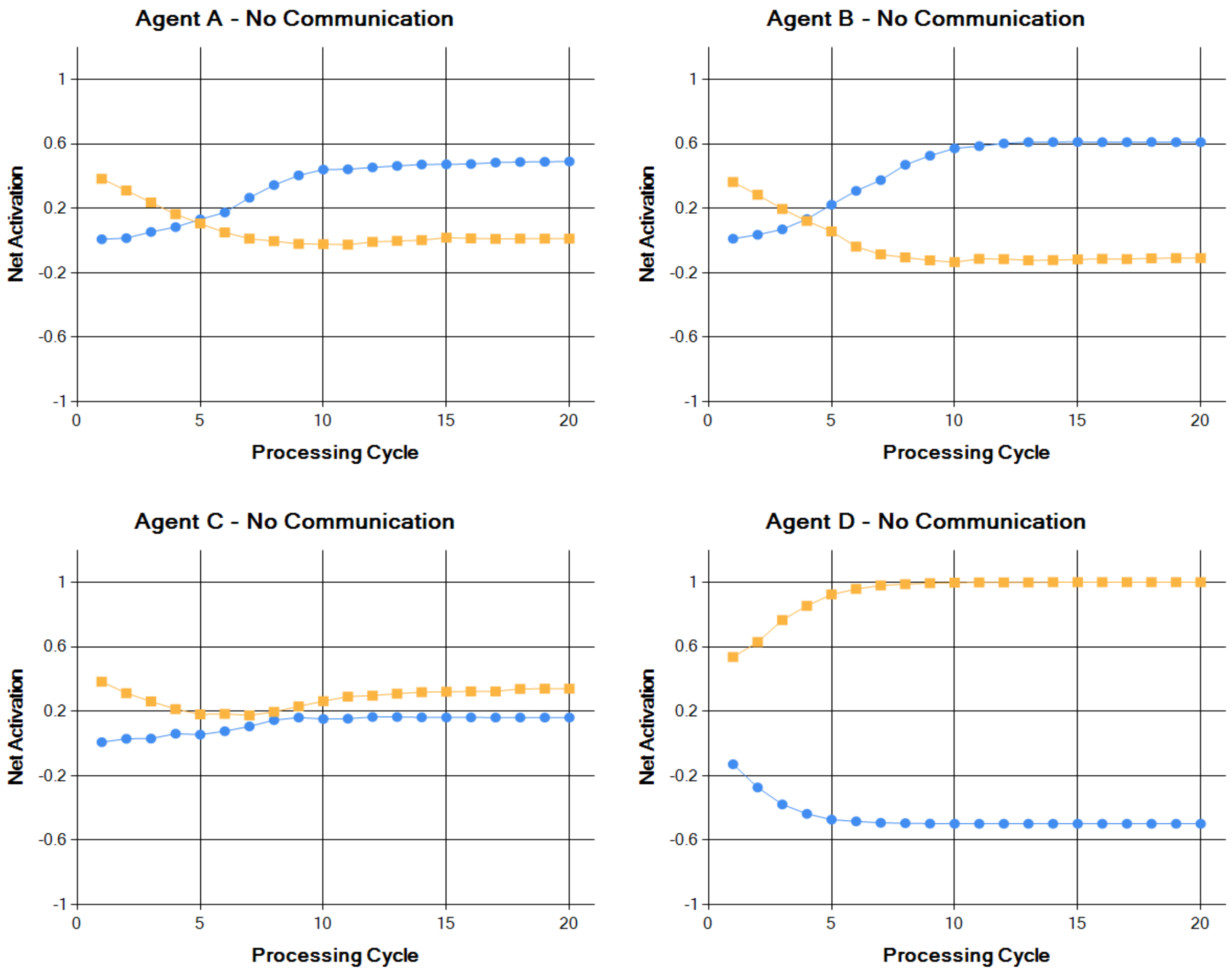
Experiments

- Experiment 1: Communication Frequency
  - How does the frequency of inter-agent communication affect agents' beliefs about the environment?
- Experiment 2: Information Type
  - How does the kind of information (object vs. feature) communicated affect agents' beliefs about the environment?
- Experiment 3: Timing of Communication
  - How does the timing of communication (early vs. late) affect agents' beliefs about the environment?

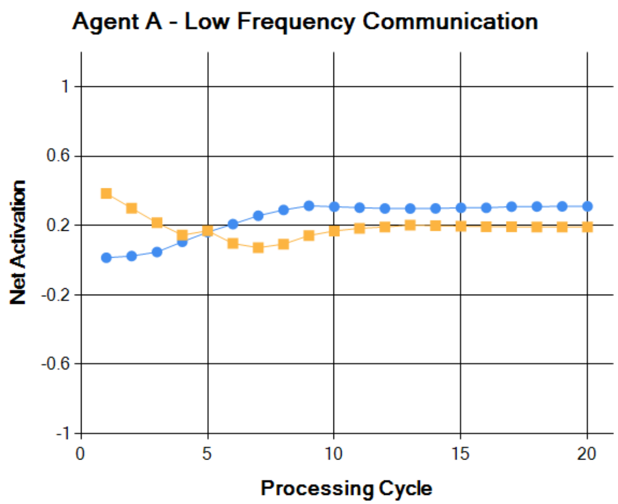
Experiment 1: Comm Frequency

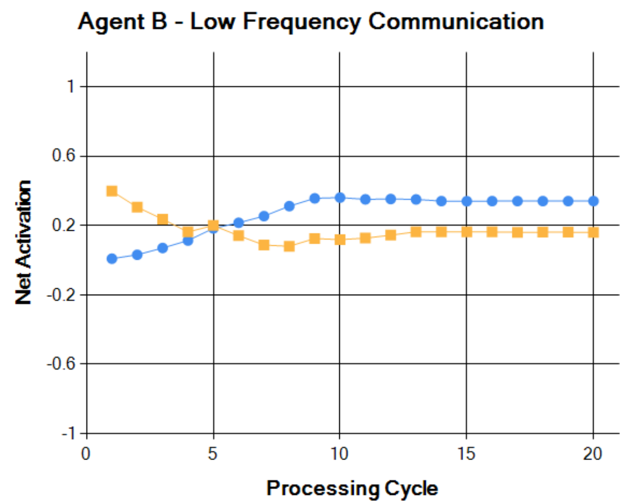
- How does communication frequency affect the temporal evolution of belief states?
- Experimental Conditions:
  - No Communication
    - no communication on any processing cycle
  - Low Frequency Communication
    - agents communicate on every 4th processing cycle
  - High Frequency Communication
    - agents communicate on every processing cycle
- 50 simulations were run in each condition.
- Each simulation lasted for 20 processing cycles.

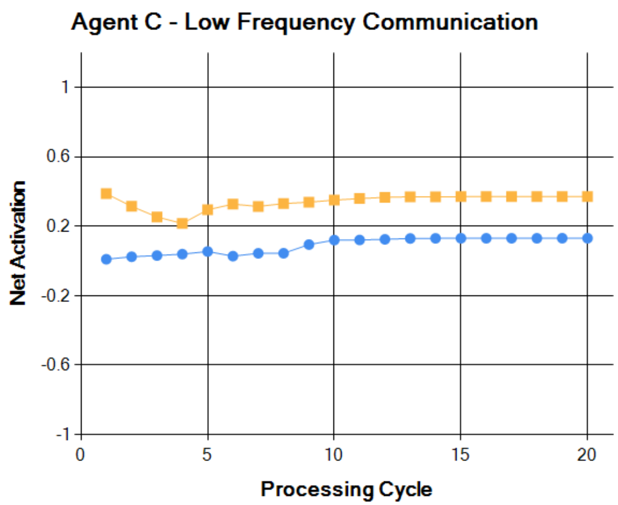
Exp 1: No Communication

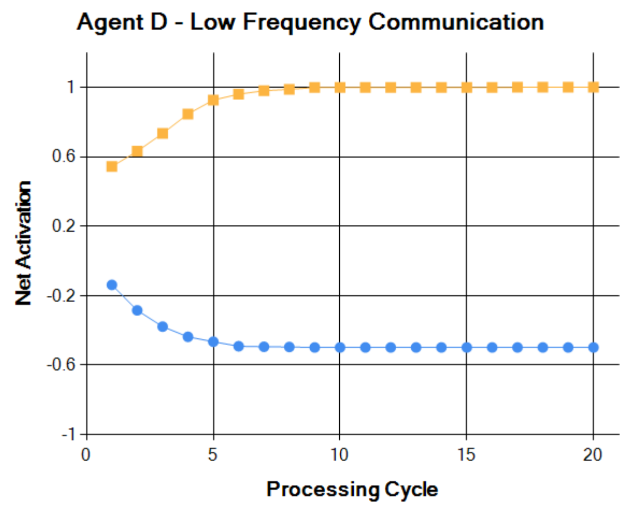


Exp 1: Low Frequency Comm

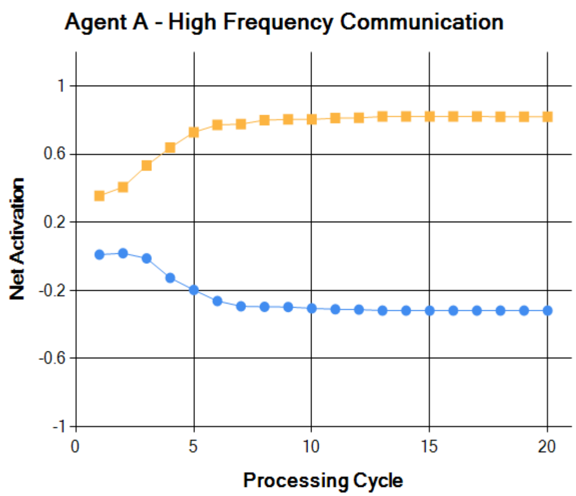


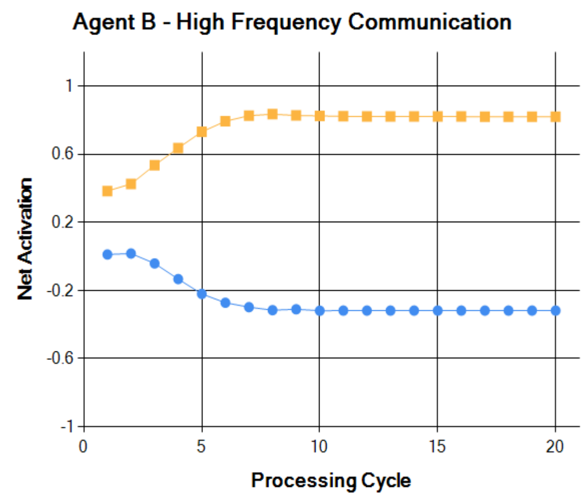


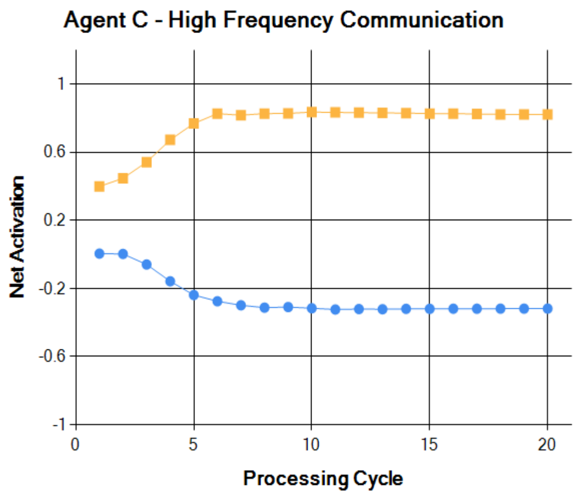


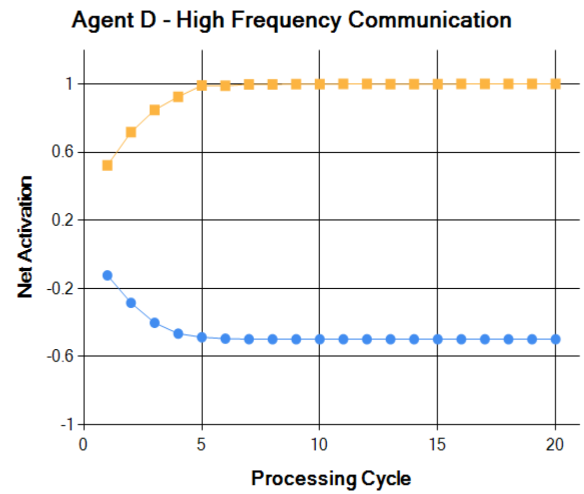


Exp 1: High Frequency Comm







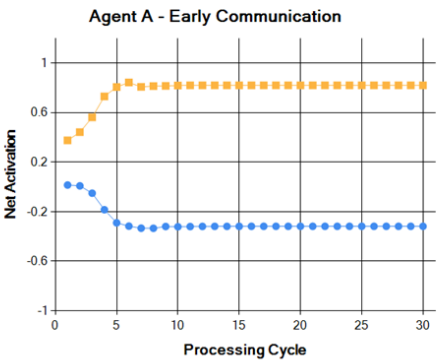


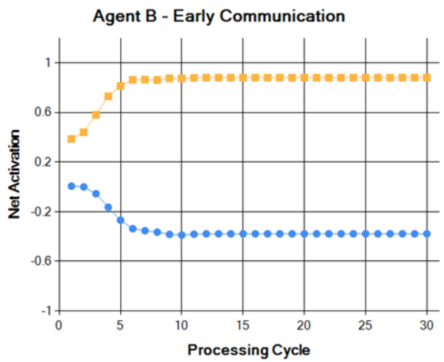
Experiment 3: Timing

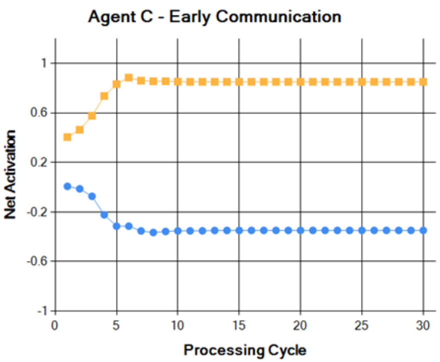
- How does the timing of inter-agent communication affect the temporal evolution of belief states?
- Experimental Conditions:
  - Early Communication
    - agents communicate only on cycles 1-5
  - Late Communication
    - agents communicate only on cycles 16-20
- 50 simulations were run in each condition.
- Each simulation lasted for 30 processing cycles

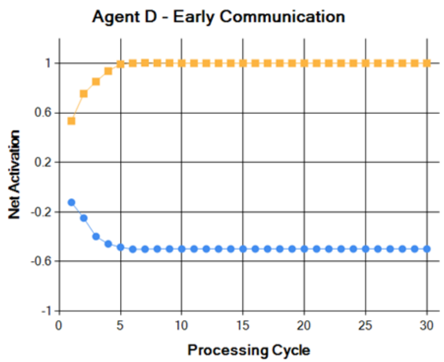
Experiment 3: Timing

Early Communication

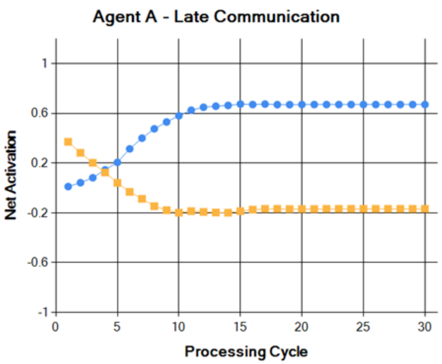


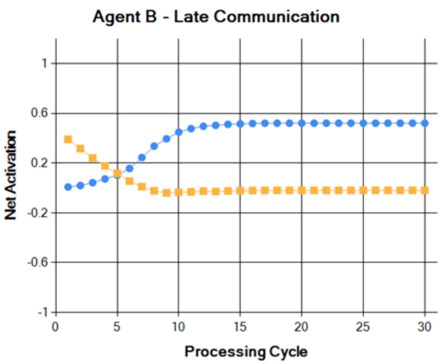


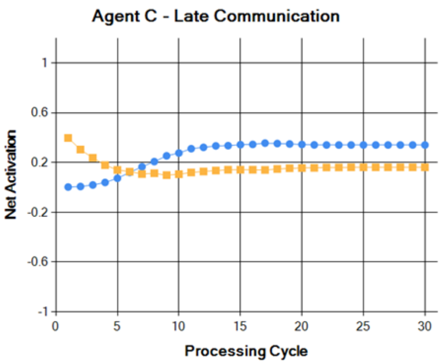


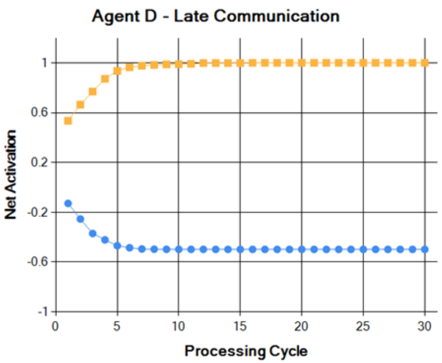


Late Communication









Conclusions

- Experiment 1:
  - As the frequency of communication increases, agents tend to rapidly converge on a common interpretation of noisy environmental information.
- Experiment 3:
  - Communication that takes place early on in a simulation tends to lead to rapid convergence on a particular interpretation of environmental information. (Not necessarily the correct one!)
  - Early communication leads agents to discount information that competes with their initial expectations.

Future Work (1)

➢ Network Topology

- more agents – investigate different network topologies.

➢ Agent Networks

- greater number of cognitive units, a greater diversity of cognitive units, and variable weightings between the units (use of training regimes).
- look at differences in background knowledge/beliefs – could be way of exploring the interactions between culturally-disparate groups.

Future Work (2)

- Inter-Agent Communication
  - variable weightings between agents.
  - reflects level of trust that agents have in one another.
- Confidence
  - confidence is represented by activation levels of cognitive units.
  - what happens if we restrict communication/information sharing based on confidence?

Summary

- Background:
  - part of the International Technology Alliance program.
  - work seeks to understand how network-mediated communication affects the dynamics of collective cognition.
- Initial Experiments:
  - precipitant forms of information sharing may affect agents' abilities to properly consider environmental information.
  - a period of independent processing prior to information sharing may help to avoid the discounting of environmental information.
- Future Work:
  - explore how features of the coalition environment affect sensemaking (trust, cultural differences, etc).