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Modeling and Simulation of Information Flow: A Study of Infodynamic Quantities

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Topic 6: Modeling and Simulation

Presentation Topic Outline

- Causal Measures and Physical Equivalents
  - Visibility of information (Vi) – attractive force (push)
  - Visibility of the need for information (Vn) – info pull
  - Empowerment of people (Ep) – “mass” of particle
  - Barriers to communication (Bc) – a repulsive force
  - Perception of risk (Pr) – repulsive force
  - Human-to-human communication (Hc) - repulsive force
- Effect of Information-Flow Components
  - Effect of information-flow promoters: Vi, Vn and Ep
  - Effect of information-flow inhibitors: Bc, Pr, and Hc
- Simulating the Behavior of Aggregates of Particles
  - NetLogo M&S environment where “particles” are agents
- Preliminary Results
- Ongoing and Future Research

Agent-Based Model Patterned after Chemical Molecular Dynamics Simulations

- Past research demonstrates that an analytical solution for information velocity is intractable.
- Purpose of current research: Understand factors that affect the rate of information flow.
- Agent-Based Model: Information providers and consumers are modeled as particles, as in well-known molecular-dynamics studies.
- Information interactions and exchanges are modeled as physical properties and processes, such as collisions with energy transfer.
- Factors that enable information transfer are modeled as attractive intermolecular forces.
- Factors that inhibit information flow are modeled as repulsive intermolecular forces.

Causal Measures & Physical Equivalents: Information-Flow Promoters: (Vi)

Vi = Visibility of information

- One kind of particle, *I*, represents information.
- Another kind of particle, *D*, represents the decision maker who needs the information.
- *D* and *I* collide and interact in the model like two different kinds molecules in a fluid (e.g. gas or liquid).
- High Vi increases information exchange.
  - Information exchange is equivalent to energy, momentum, or electron transfer in matter.
- *I* Particles with Vi = 0 interact like molecules in an ideal gas, i.e. no intermolecular forces.
  - Information flow is restricted but the model is simpler.

Causal Measures & Physical Equivalents: Information-Flow Promoters: (Vn)

Vn = Visibility of the need for information

- A *D* particle with a high value for Vn is like an *I* particle with a high value for Vi.
- Particles with high Vi or Vn are like atoms or molecules with large collision cross sections.
  - High Vi and high Vn both increase collision frequency and increases information exchange.
- *D* Particles with Vn = 0 interact like molecules in an ideal gas, i.e. no intermolecular forces.
  - Information flow is restricted, same as Vi = 0
- Information flow improves if the need for information is visible.

Causal Measures & Physical Equivalents: Information-Flow Promoters: (Ep)

Ep = Empowerment of people
– like the mass of a particle

- Force = mass x acceleration.
- More massive particles represent empowered people in the simulation, e.g. admirals & generals.
- Work = force x distance.
- Po = dW/dt **Power** = rate at which work is done.
- Massive particles transfer more energy and momentum. They produce work faster.
- Empowered people overcome obstacles, transfer more information and work more efficiently.

Causal Measures & Physical Equivalents: Information-Flow Inhibitors (Bc)

Barriers to communication (Bc)

- We model the magnitude of Bc as the amount of force and energy (i.e. effort) necessary to enable an information exchange.
- Bc is the inverse of Ep. Empowered people do not need to exert an inordinate amount of force to communicate information.
- Barriers to communication inhibit information flow and impede information sharing.
- Examples:
  - Dates after which no information sharing is allowed
  - Formal requirements for information submissions
  - Approval chains
  - Mandatory use of user-hostile & disfunctional web sites.

Causal Measures & Physical Equivalents: Information-Flow Inhibitors (Pr)

Perception of risk (Pr)

- Pr is like a very high pressure in a gas mixture.
- Pressure on simulated "gas" can separate *D* and *I* components into two immiscible liquid phases.
- Almost no *D* particles will be near the *I* particles.
- Interface = only opportunity for information transfer.
- Pr separates decision makers from info they need.
- People who perceive significant personal risk for sharing info will not share for fear it will affect their:
  - Reputation, performance ratings, promotions
- Decision makers do not want to accept information they think is high risk, such as information that is:
  - Irrelevant, incomplete, incorrect, stale, misleading, useless

Causal Measures & Physical Equivalents: Information-Flow Inhibitors (Hc)

Hc = Human-to-human communication

- Examples:
  - Face-to-face meetings, teleconferences
  - Phone calls, email
  - In writing, in a paper submitted for approval through a sequential chain of command
- Most inefficient communication is direct one-on-one exchange (E). (Better: blogs => low Hc)
- This exchange does not scale. (N**2-N)/2
- Hc, a proximity measure, can be modeled as an inverse power law for inter-particle interaction:
- Potential energy, P(E) α C / r**Hc   r = distance
- The higher the Hc, the closer the *D* and *I* particles need to be to exchange information.

Effect of Information-Flow Components

Information-Flow Promoters:

- Vi and Vn are like attractive forces or other vector quantities that specify a given direction of motion.
  - Velocity ($\vec{w}$) and its time derivatives are vectors.
  - Ep is like mass, M.
  - $F = M\vec{A}$ becomes $F\ (\text{info exchange}) = Ep\ \overrightarrow{(dw/dt)}$

Information-Flow Inhibitors :

- Bc, Pr, & Hc are quantities that describe repulsive forces like those between molecules in a fluid that keep *D* and *I* particles separated.
- More momentum is needed for information flow.
- Likelihood of information exchange decreases as Bc, Pr, & Hc increase.

Experiment Simulating Information Flow with Aggregates of Particles

- Particles with information to share: green agents
- Decision makers with insufficient information: red.
- Information flow is like the diffusion of a green gas consisting of *I* particles.
- Information exchange between particles is like:
  - Momentum and energy transfer in a collision
  - Electron exchange in a chemical reaction
- Red particles turn green after they receive the information they need.
- Color change = change in state of decision maker from high uncertainty to lower uncertainty.
- Experimenter controls the rate of information transfer by varying the information flow-components, **Vi, Vn, Ep, Bc, Pr, & Hc.**

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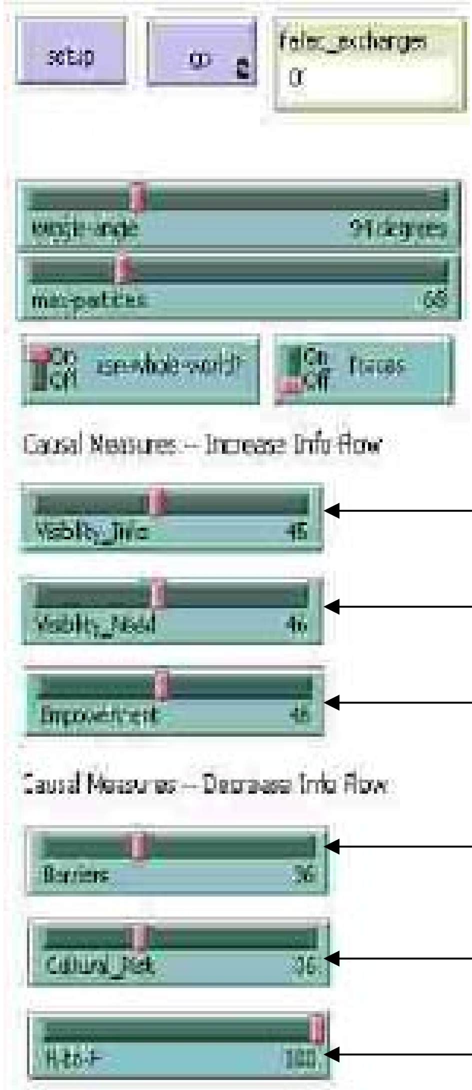
Net-Logo
Modeling & Simulation Environment



- NetLogo has intuitive interface to model complex systems that develop over time.
- Users can change independent variables during run time and observe the emergent behavior in real time using sliders:

Visibility of information (Vi)

Visibility of need for information (Vn)

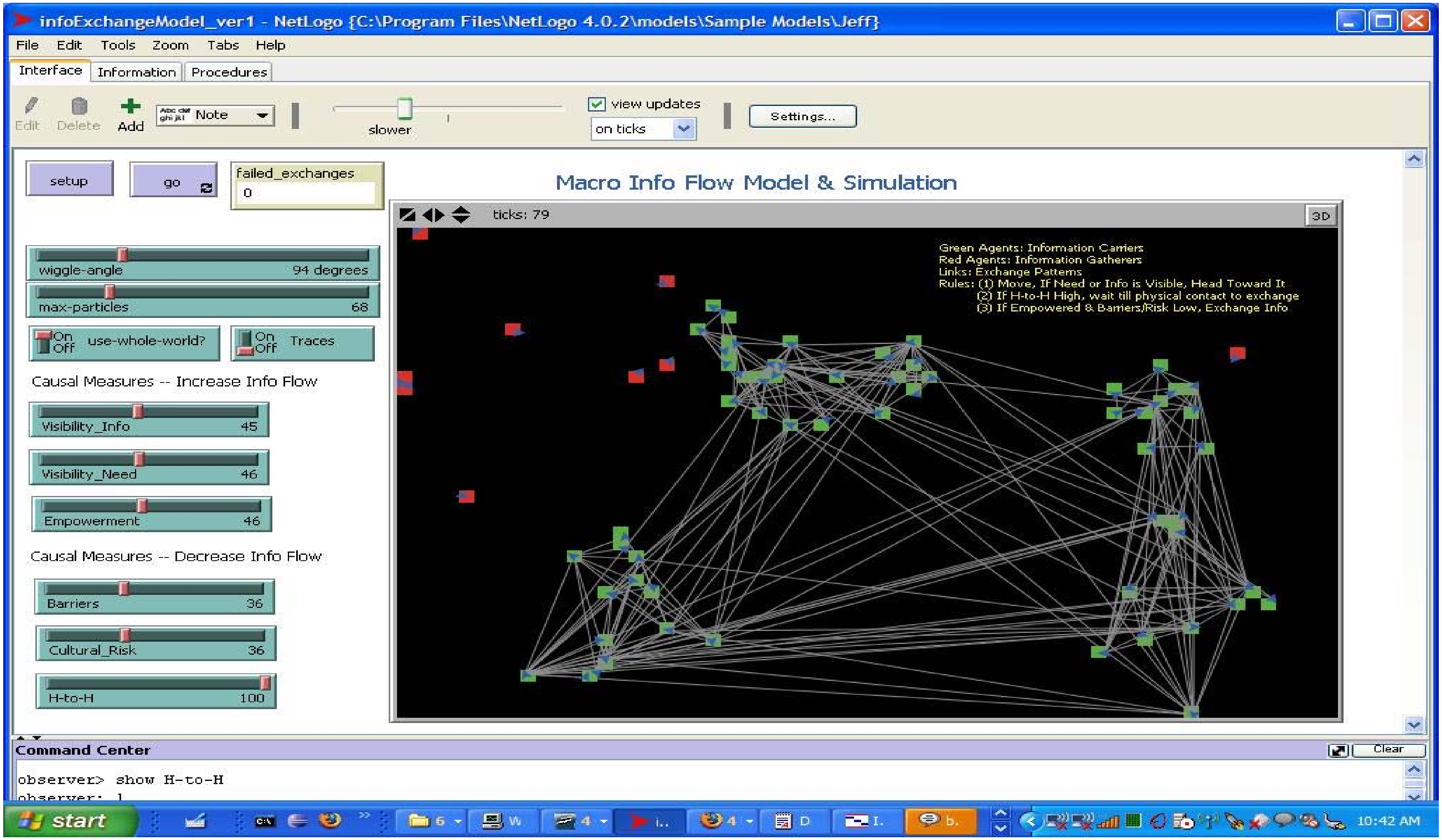
Empowerment of people (Ep)

Barriers to communication (Bc)

Perception of risk (Pr)

Human-to-human communication (Hc)

Agent-Based Model to Understand Information Flow



Ongoing and Future Research:

Model enhancements & attributes of particles

- Information flow can be modeled as a set of interacting particles representing decision makers and information providers.
- Future enhancements to model include:
  - Deadlines and dynamic perishable data
  - Dependence on specific information requirements
  - Partial information exchanges
  - Data fusion modeled as three-way collisions or more
  - Confidence measures and uncertainty
- Confidence measure $Cd(t) = 1 – U(t)$
- $U(t) = n^-(t = t_d) / n^-(t = 0)$
- $U(t)$ is time-dependent uncertainty.
- n^- = amount of information needed at time, t
- t_d = decision deadline

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Backup pages

Ongoing and Future Research:
Levels of Data Persistence and Perishability

- Confidence and uncertainty can change dynamically during the simulation due to incremental transfer of information.
- Distributions of deadlines, t_d, can be selected to simulate various degrees of data persistence.
  - t_d is a property of *D* particles.

Data-duration type	**Example**	**Typical t_e**
Static	Port location	500 years
Semi Static	Ship's OPCON	5 months
Dynamic	Aircraft location	5 minutes

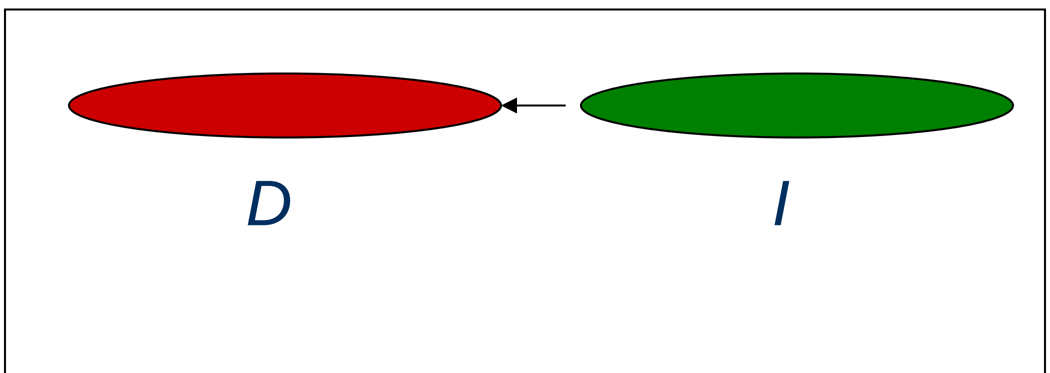
Ongoing and Future Research:

Information Annealing as a Metric for Information Flow

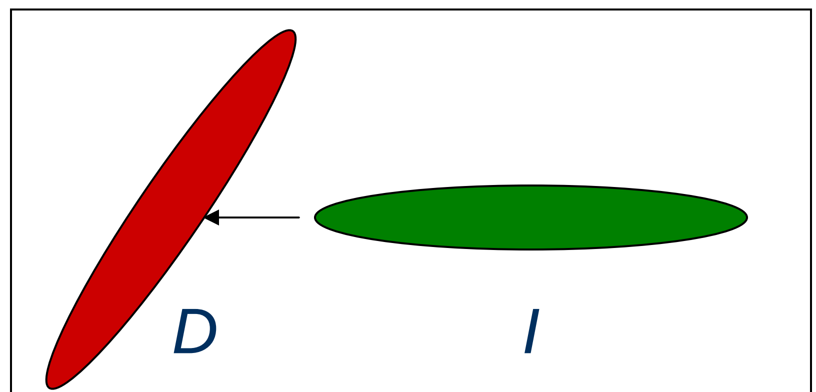
- A period of time is needed for the system to absorb new information, during which entropy fluctuates.
- **Physical annealing**: Multiple iterations of physical “heating” and “cooling” enable each atom to find its optimal place in a physical solid structure.
- Confidence and uncertainty fluctuate during the decision process. **Infodynamic annealing** is characterized by increases and decreases in entropy & uncertainty.
- Proposed metrics: How often and how quickly do members of organization adjust confidence in decisions based on new information?

Future Research:
Particle Anisotropy

- Force of information flow is greatest when people are empowered and information-flow direction and information-inquiry direction are in opposite directions moving toward each other. See **a.** below.
- Force between the *D* and *I* particles could be anisotropic (depending on their orientation at the time of collision), like a fluid of linear molecules instead of isotropic point particles. Compare a. & b.



a.



b.