Rich, Cognitive Agent Models for Socio-Economic Agent-Based Modeling

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Plan

- Introduction and motivations
- Reactive vs. cognitive agents
- The BDI model of agency
- Financial Markets
- Road Traffic
- Human Geography

Agent-Based Modeling

- A tool for studying complex systems
  - Alternative/complementary to mathematical tools
  - Advantage : more realistic description
- Agents
  - Discrete, autonomous entities
  - Have goals and behavior
  - May be heterogeneous
- Basic assumptions
  - Key aspects of behavior, interaction can be described
  - We can (re-)construct complex processes and systems bottom-up
- Simulation is the main tool to test models (= theories)

Reactive vs. Cognitive Agents

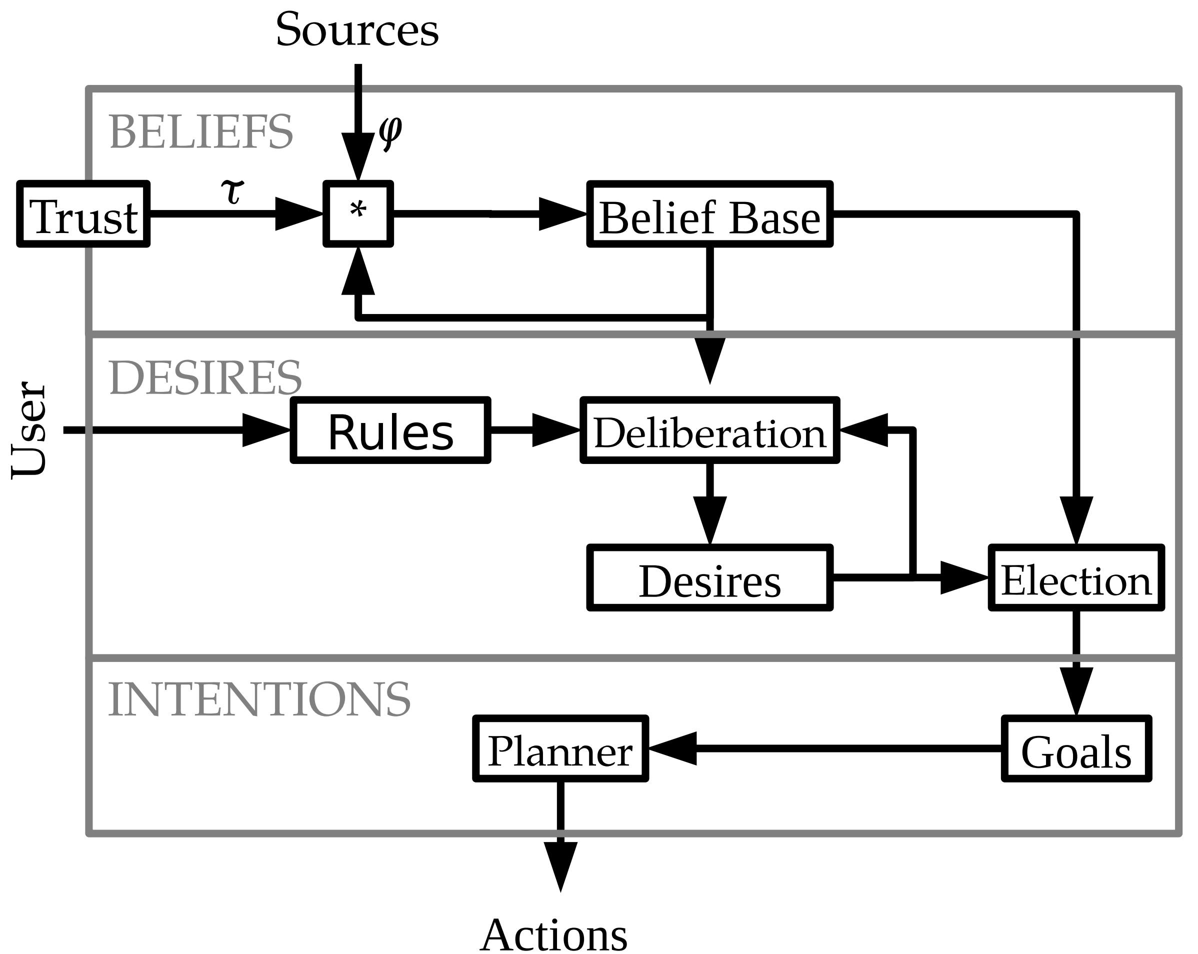
- Reactive Agents
  - Input-output mapping (sensors → actuators)
  - Simple behavior (described by fixed rules or math equations)
  - No or limited internal state

- Cognitive Agents
  - S/w artifacts that exhibit intelligent behavior in complex domains
  - Autonomous, responsive, proactive, goal-oriented, co-operative
  - Deliberation
  - Established cognitive architecture (e.g., the BDI Model)

Agent Models

- Usually, ABM of economies rely on very simple agents
- Similar to interacting particle systems
- What about using richer models, e.g., BDI agents?
- This is what we have started doing in the last few years:
  - Cognitive ABM of financial markets, with Célia da Costa Pereira and Alessia Mauri (IAT 2009, AAMAS 2012)
  - ABM of road traffic, C. da Costa Pereira, A. Bazzan, and A. Koster (IEEE ITCS)
  - Work underway with the geographers of UMR ESPACE and Los Andes University of Bogotá (TOMSA Project)

BDI Agent Model



ABM of Financial Markets

- Study the link between microscopic parameters and macroscopic phenomena (e.g., bubbles and crashes)
- Use cognitive agents for the simulation
- Realistic (albeit simplified) market structure
- Inspired by the Adaptive Market Hypothesis

Adaptive Market Hypothesis

- An interesting attempt to reconcile the EMH with the criticisms leveled against it by psychologists and behavioral economists
- The main intuition:
  - The dynamic of **evolution** determine the efficiency of the markets
- Markets would thus be in a **perennial unstable equilibrium**
- Market participants evolve against each other
  - competitive co-evolution
  - Competition, mutation, reproduction, and natural selection
  - Waxing and waning of financial institutions, investment products, and, ultimately, **fortunes**
- This **constant flux** fits very nicely with the observed reality

[Andrew W. Lo. The Adaptive Market Hypothesis. *J. of Portfolio Management*, 2004]

Market Simulator

- Asset (no dividend) + Money (no interest)
- Agents hold
  - An inventory of the asset
  - Cash
- Market value of inventory + Cash = NAV
- Trading: buy/sell *n* contracts at limit price $\in [0, +\infty)$
- Market matches orders at each period by executing a single-price auction (no fees)

Technical Indicators

26 technical indicators of several types:

- Price went up n periods ago
- Price > n-period SMA
- Price > n-period EMA
- Price / n-period SMA > m-period SMA
- Price / n-period EMA > m-period EMA
- Price / n-period SMA went up m-periods ago
- MACD

Agent Model

- Propositional language with 5 atomic propositions
  - The price is going up (u)
  - Money balance > minimum threshold (m)
  - Asset inventory > minimum threshold (a)
  - Buy (b)
  - Sell (s)
- Mental state described by a four-tuple (K, B, R, D)
  - K = knowledge (a fuzzy interpretation)
  - B = beliefs (a fuzzy interpretation)
  - R = desire-generation rules
  - D = desires (a fuzzy set of literals on {b, s})
- A belief change operator $B' = B * \alpha / \varphi$

Agent's Genome

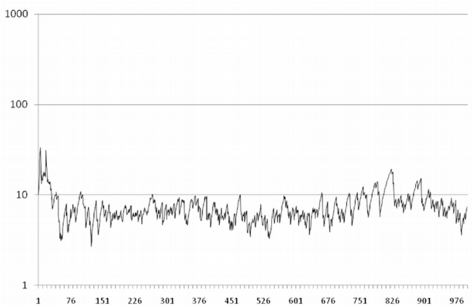
- Initial mental state (fuzzy interpretation)
- Degree of trust in each technical indicator
- Behavioral parameters
  - Fraction of money (asset) the agent is willing to invest (divest)
  - Minimum threshold for money (asset)
  - Propensity to buy (sell) if asset below (above) threshold
  - Price concession (i.e., aggressiveness of orders)
  - Price concession adaptation (i.e., if previous order not filled)

- Encoding: one floating-point number per gene

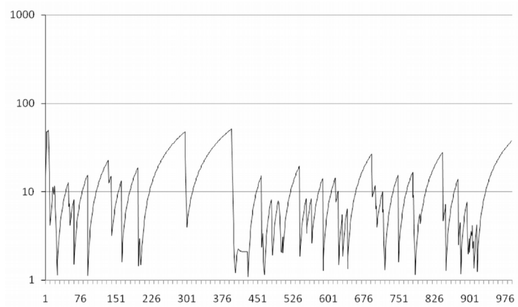
Evolutionary Algorithm

- Agents co-evolve based on their trading proficiency
- A generation at regular intervals, every *i* time steps
- Fitness = NAV
- Redistribution: worst 30% by NAV get extinct, their “fortune” is distributed to survivors, proportionally to their NAV
- Selection: survivors are selected for reproduction with a probability proportional to their NAV; elitism
- Mutation: Gaussian perturbation to every gene
- Recombination: uniform crossover

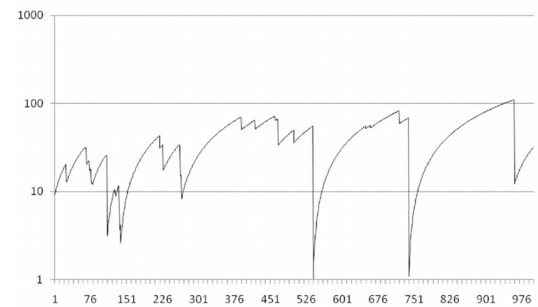
Experiments



$i = 1$

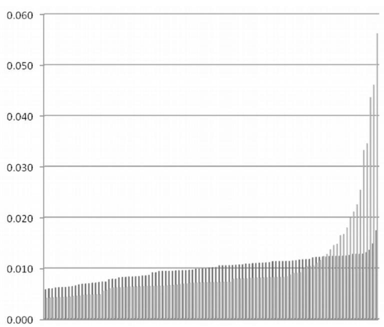


$i = 10$



$i = 100$

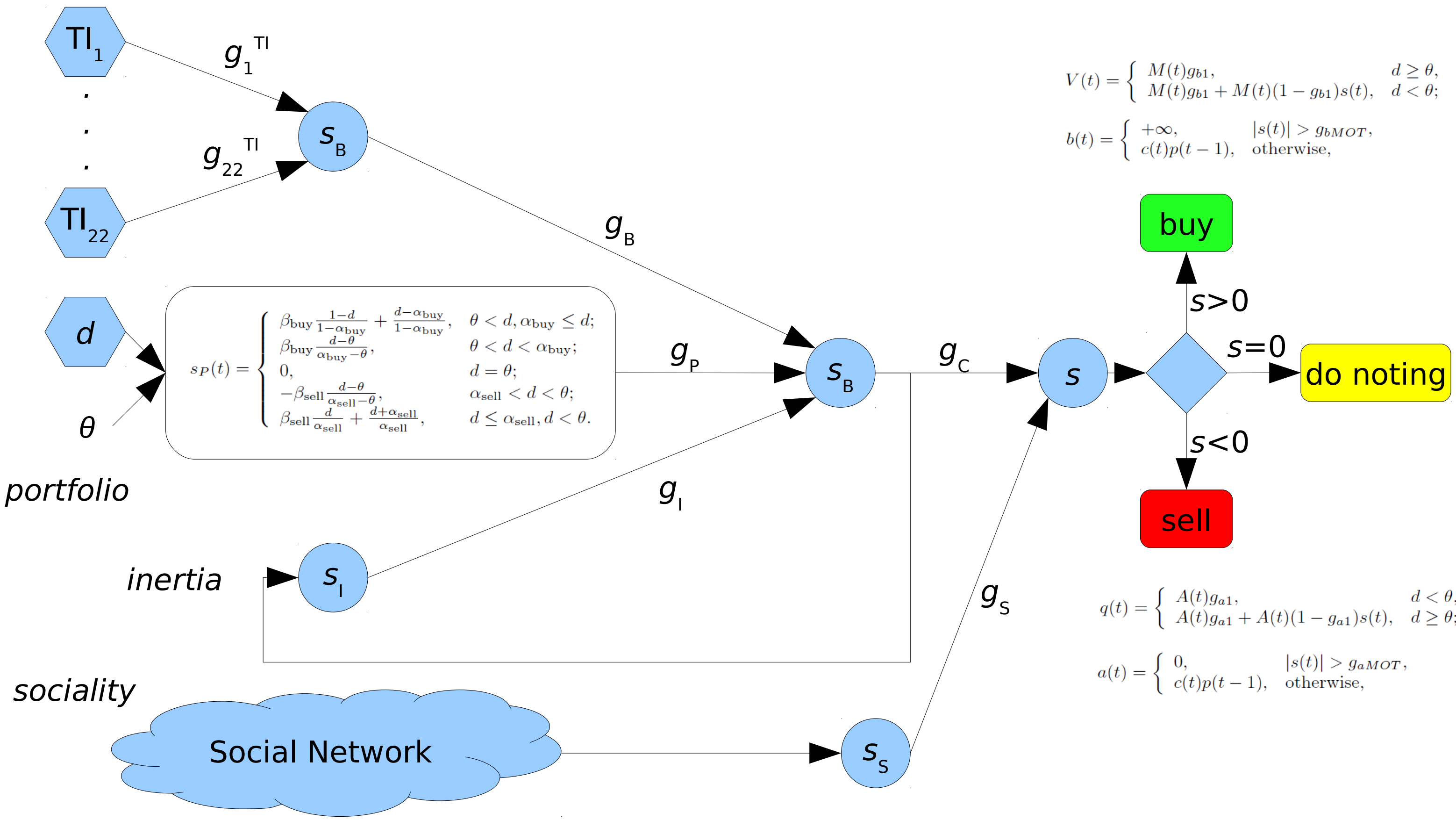
Stylized facts: lepotokurtic distribution of log-returns, volatility clustering, bubbles and crashes, mean-reverting time series



Final wealth distribution:
$i = 10$ (dark bars)
$i = 100$ (light bars)

[da Costa Pereira, Mauri, Tettamanzi. Cognitive ABM of a Financial Market. IAT 2009]

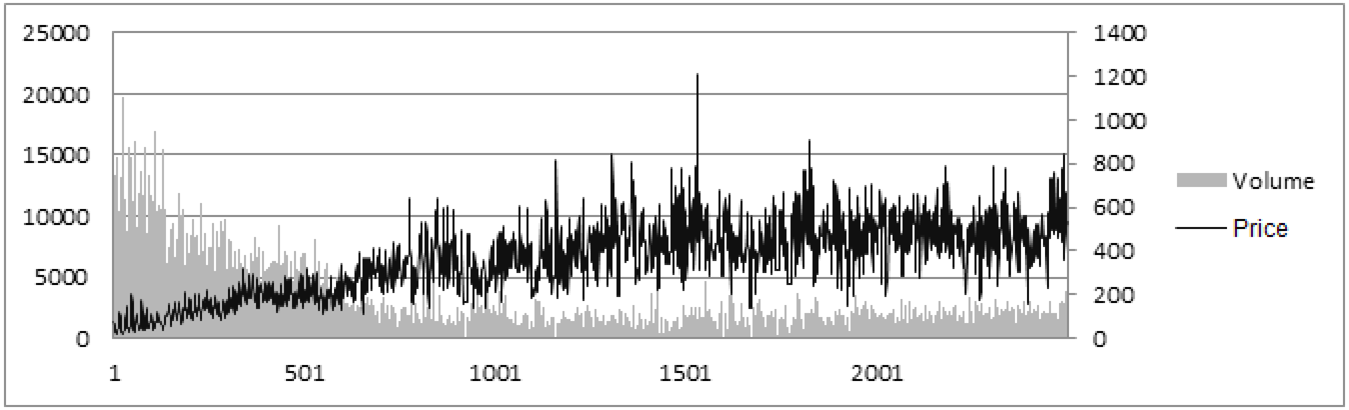
Agent Model



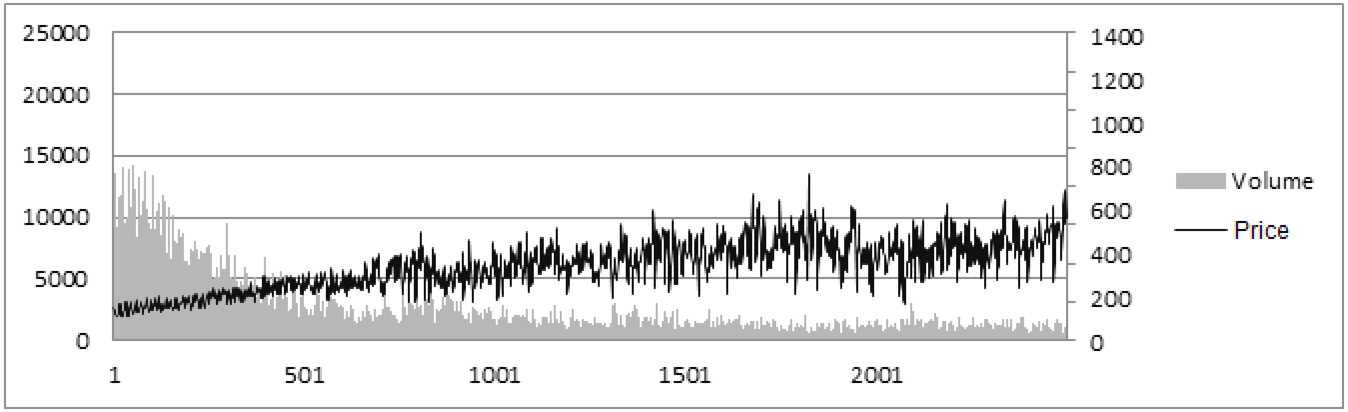
[Mauri, Tettamanzi. Investigating the Role of Social Behavior in Financial Markets through ABS. AAMAS 2012]

Simulations (no shocks)

Sociality ON

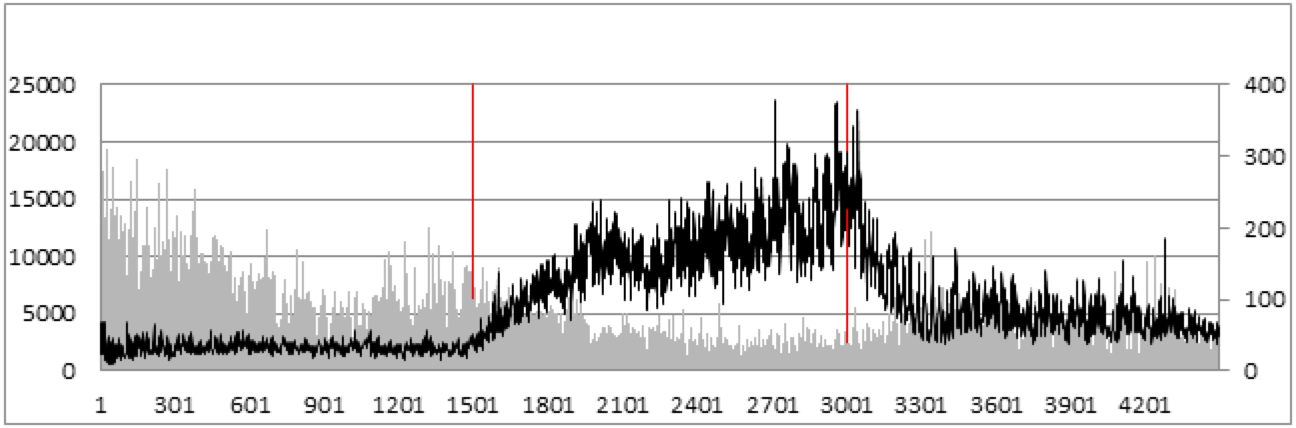


Sociality OFF

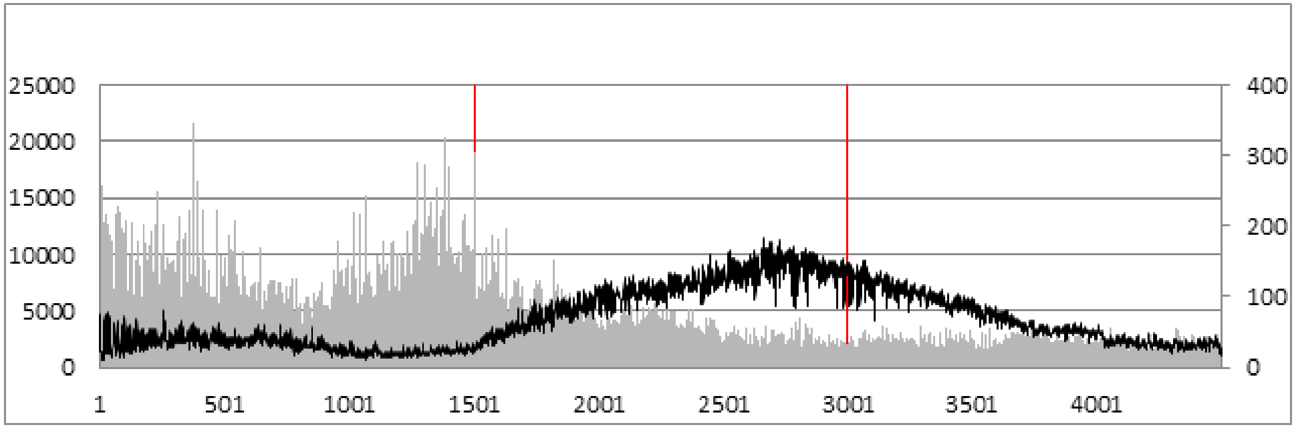


Simulations (with shocks)

Sociality
ON

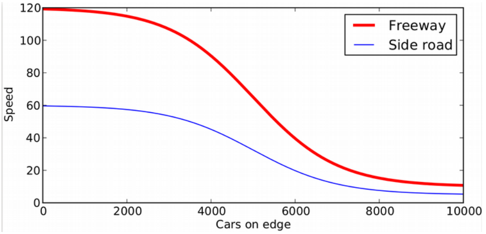


Sociality
OFF



Road Traffic with VANETs

- VANETs : vehicle-to-vehicle communication
  – Safety applications
  – Notification of road conditions
- Problem of potentially deceitful communication
- Trust model to estimate the reliability of incoming information
- Possibilistic BDI model to reason about uncertainty
- Application scenario:
  – Information provision about congestion
  – Propositional messages: a road is congested
  – Agents desire to avoid congestions when planning roads
  – IF B(congested) THEN take_sideroad



Possibilistic BDI Agent Model

Possibility distribution

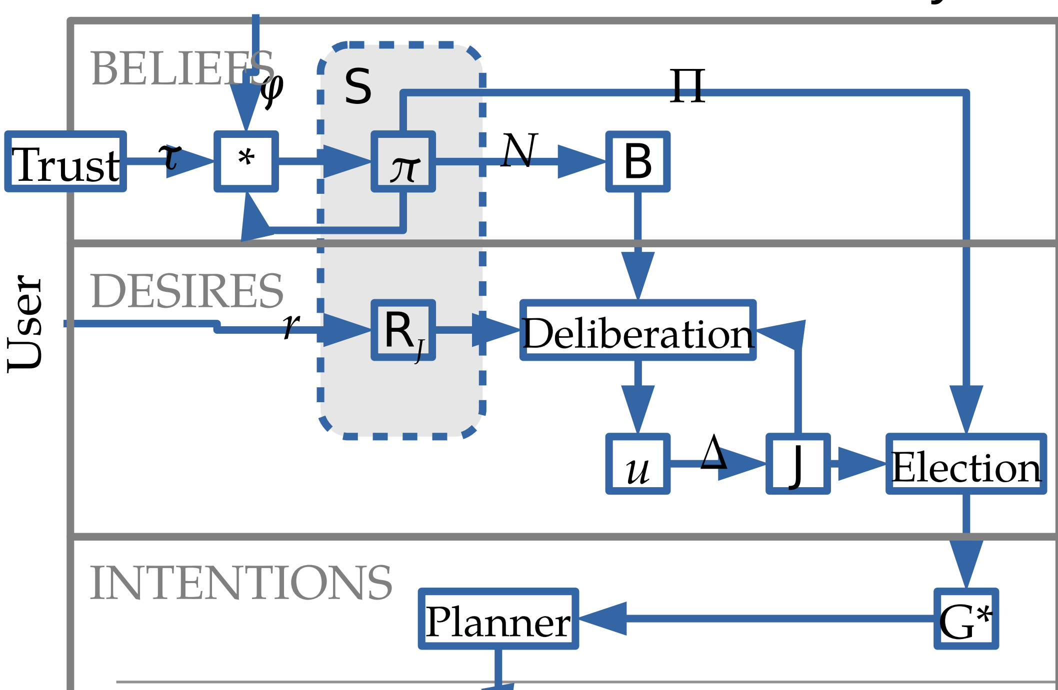
$\pi : \Omega \to [0,1]$

$$\pi' = \pi * \frac{\tau}{\phi}$$

Possibilistic belief revision operator *

$$\pi'(\mathcal{I}) = \begin{cases} \frac{\pi(\mathcal{I})}{1-\mathbf{B}(\neg\phi)}, & \text{if } \mathcal{I} \models \phi \text{ and } \mathbf{B}(\neg\phi) < 1; \\ 1, & \text{if } \mathcal{I} \models \phi \text{ and } \mathbf{B}(\neg\phi) = 1; \\ \min\{\pi(\mathcal{I}), 1-\tau\}, & \text{if } \mathcal{I} \not\models \phi. \end{cases}$$

Theorem : * obeys the AGM postulates



$$\mathbf{B}(\phi) = 1 - \max_{\mathcal{I} \not\models \phi} \pi(\mathcal{I})$$

$$\mathcal{R}_J = \{\beta_i, \psi_i \Rightarrow_D^+ \phi_i\}$$

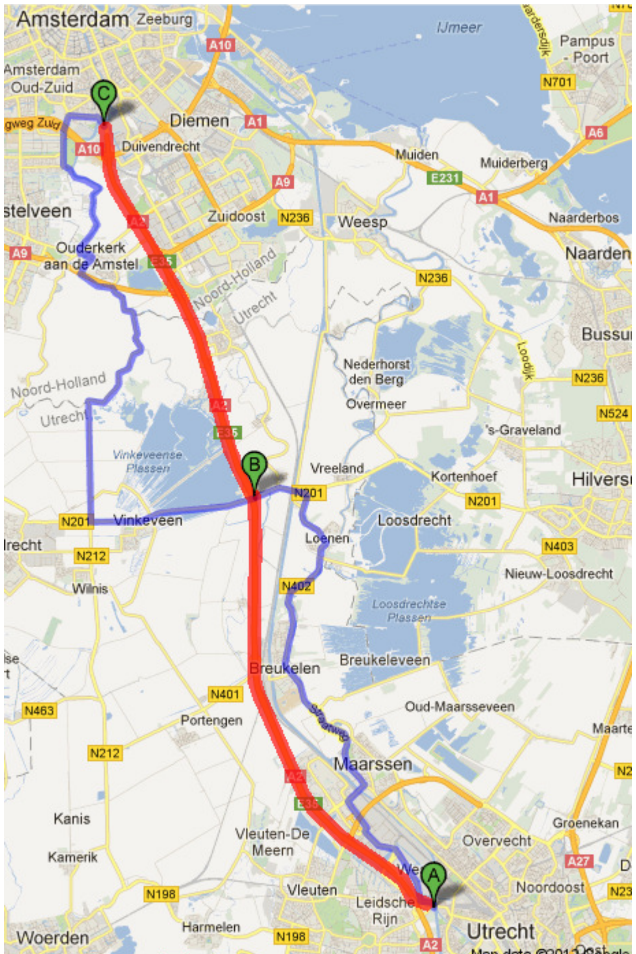
$$u : \Omega \to [0,1]$$

$$\mathbf{J}(\phi) = \min_{\omega \models \phi} u(\omega).$$

$$G^* = G_{\gamma^*}, \text{ where } \gamma^* = \max_{G_\gamma \neq \emptyset} \gamma$$

[da Costa Pereira & Tettamanzi (AAMAS'10, ECAI'10)]

Experiments



Macrosimulation:

- Twice a choice between main road and side road
- Communication
  - before A
  - On the way to B
- Use trust in VANET for second choice
- Deceitful agents
  - 60% of the agents will cheat if they think it benefits them
  - Other 40% are always truthful
- Agents take the freeway unless they believe it is congested

Results

- Deceitful information has a negative influence on traffic flow
- Overall flow in the network diminishes compared with situation with only truthful communication
- Deceitful agents do slightly better. Honest agents far worse
- Taking trust into account mitigates this influence

[A. Koster, C. da Costa Pereira, A. Tettamanzi, A. Bazzan. Using Trust and Possibilistic Reasoning to Deal with Untrustworthy Communication in VANETs". IEEE-ITSC 2013]

TOMSA Project

- Transport Oriented Modeling for urban denSification Analysis
- Work underway with the geographers of UMR ESPACE and Los Andes University of Bogotá
- Households and Real-Estate Developers modeled as possibilistic BDI agents
- Developers decide if and where to buy land and build
- Households may rent or buy a dwelling; if they are landlords, they may decide to let it out or occupy it
- Inputs include the location, amenities, transportation facilities, distance from workplace, and attractiveness of neighborhood
- A simulator for the city of Bogotá is under development

Thanks for your attention!