U.S. Army Research, Development and Engineering Command

Modeling trust in ELICIT-WEL to capture the impact of organization structure on the agility of complex networks

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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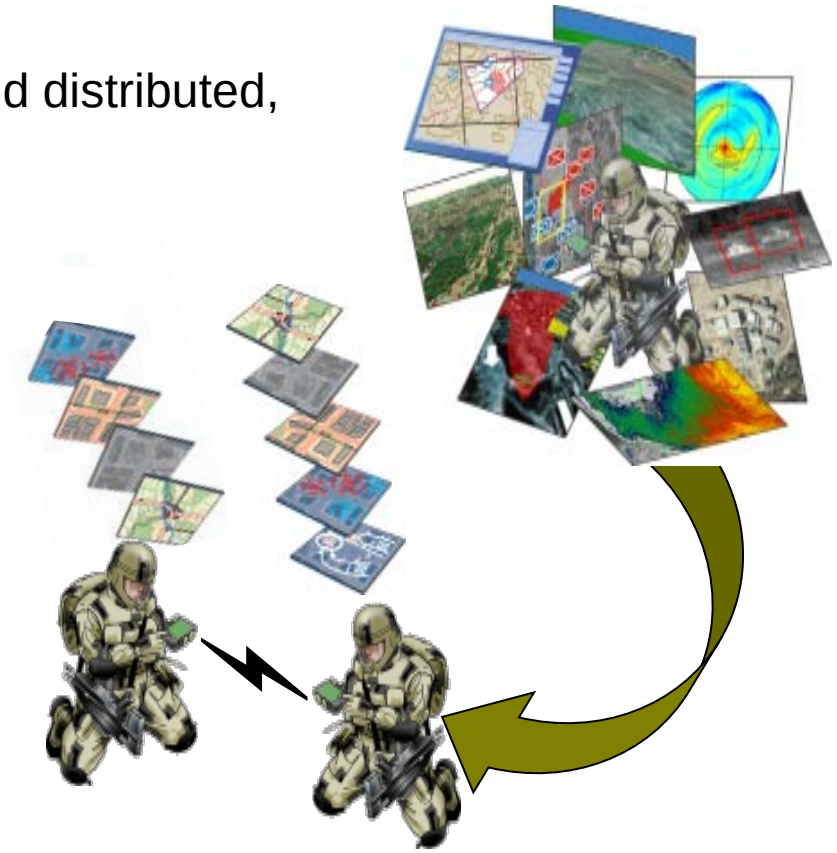
Motivation

- Information in command and control (C2) environments is growing in volume, scope and diversity
- C2 organizations are becoming more flat and distributed, less hierarchical and centralized

Requirements

- Need to be able to process, exploit and disseminate information timely, efficiently and effectively
- DoD CIO data sharing strategy
  - Post before process
  - Make data accessible
  - Enable data to be trusted



Every soldier is a sensor

- Emergence of distributed teams that must make tactical decisions without centralized command or
- Company Intelligence Support Teams (COIST)
- Small teams of soldiers to gather information make tactical decisions
  - Manage the company's lethal and non-lethal targeting
  - Supervise the company's intelligence, surveillance, and reconnaissance (ISR) program
  - Manage the patrol prebrief/debrief for the company
  - Detainee operations
  - Tactical site exploitation

Trust can benefit performance

- Create a composite trust model that quantifies trust evolution using Bayesian updates and adapts its behavior based on estimated trust of neighboring entities
- Develop an integrated experiment platform to enable validation of trust-based agent model simulations

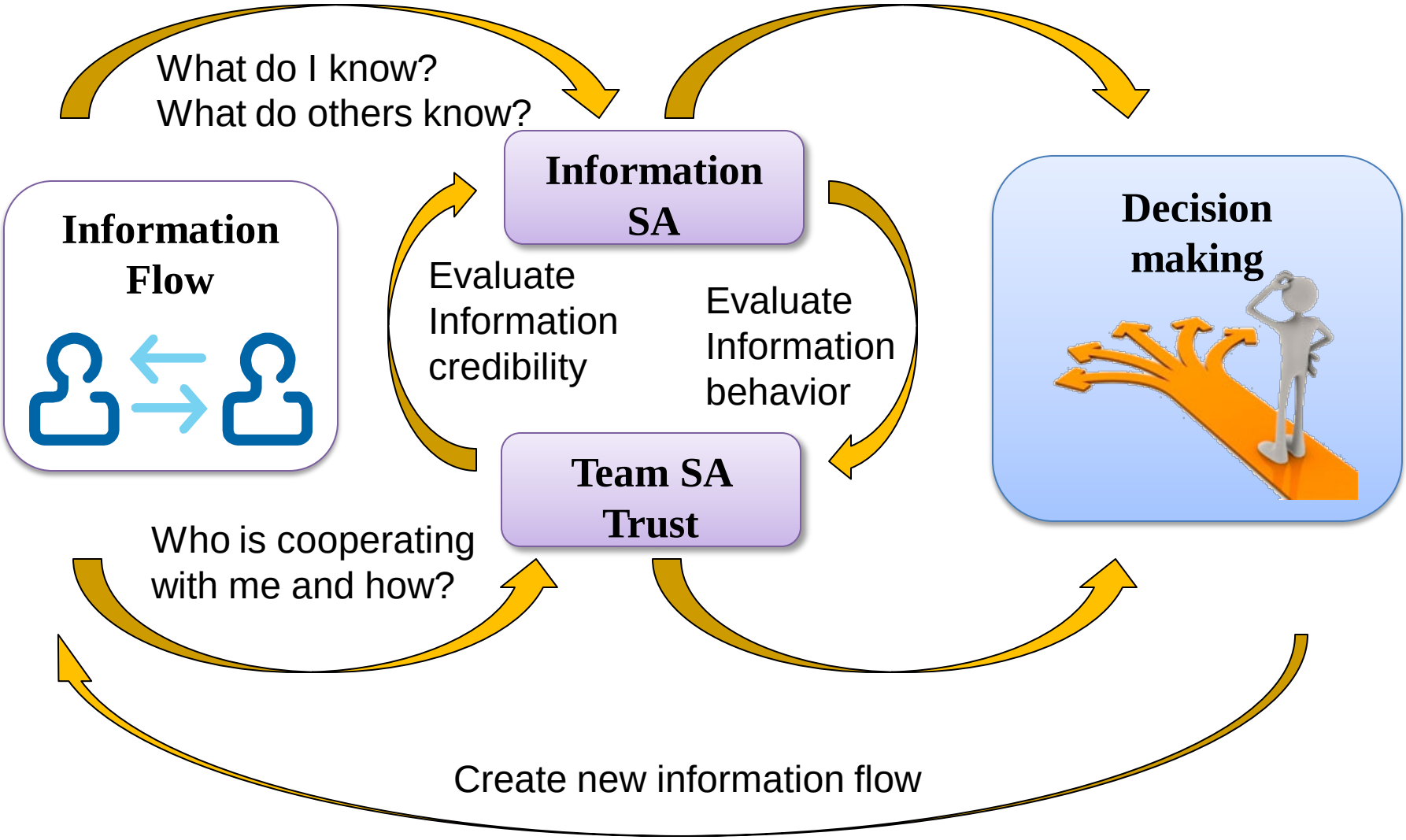
ARL's Network Science Collaborative Technology Alliance (NS CTA)

- enhance human performance for network-enabled warfare
- enhance speed and precision for complex military operations

Trust in Distributed Decision Making

- enhance distributed decision-making capabilities of the Army in the context of Network-Centric Operations, in particular, for Irregular Warfare (IW) and Counterinsurgency (COIN)
- understanding the role trust plays in composite networks that consists of large systems with complex interactions between communication, information, and social/cognitive networks

Information flow, SA and Decision making are interlinked

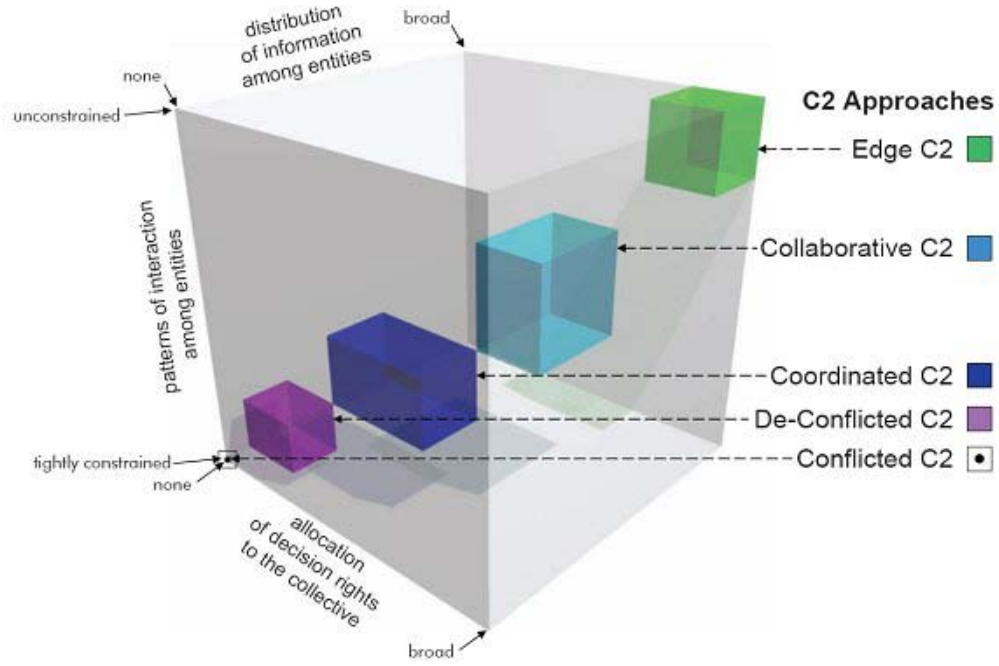


C2 maturity space

- distribution of information
- patterns of interaction
- allocation of decision rights

C2 Agility

- robustness of operating conditions
- adaptation of varying conditions



Current status

Related research

- Information sharing, SA, decision making (Yen, Endsley)
- Trust (Lee, Parasuraman)

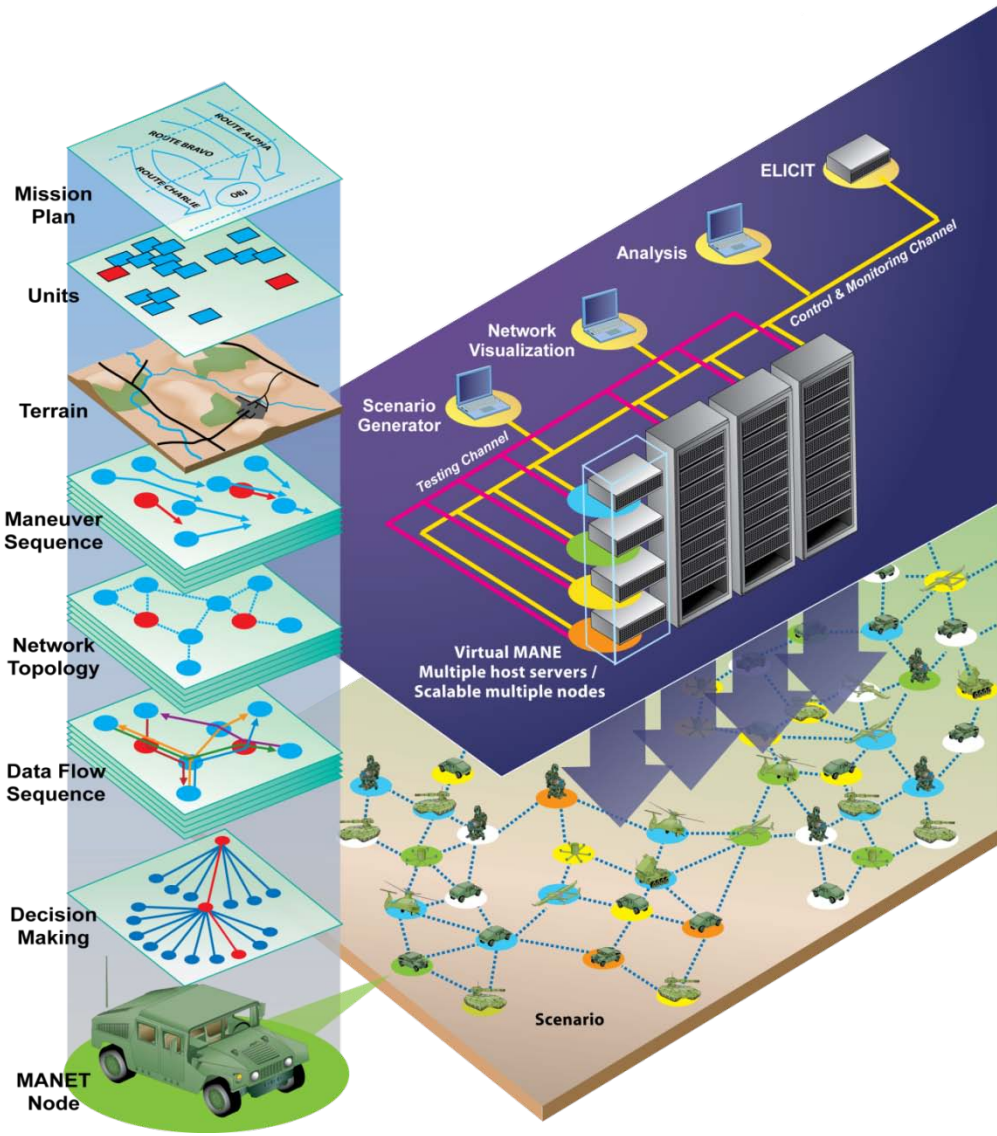
Limitations

- Current information sharing models do not consider the increased complexity of tactical networking environments
- Existing experiment platforms do not readily test protocols that consider multiple elements of composite networks

Update

- Development of composite trust model for information sharing scenario
- Proposed installation of trust model into agent-based ELICIT

- WEL: a controlled, repeatable emulation environment for tactical wireless Mobile Ad hoc Networks (MANETs) and Information Assurance (IA) experiments
  - EMANE
    - up to 600 virtual nodes
    - runs actual communication radio code, routing protocols, medium access control protocols
    - transmission medium is emulated
  - Topodef: specifies topology and mobility over duration of experiment



ELICIT/EMANE integration roadmap

- **Integration**: Adding the EMANE communication network models into ELICIT

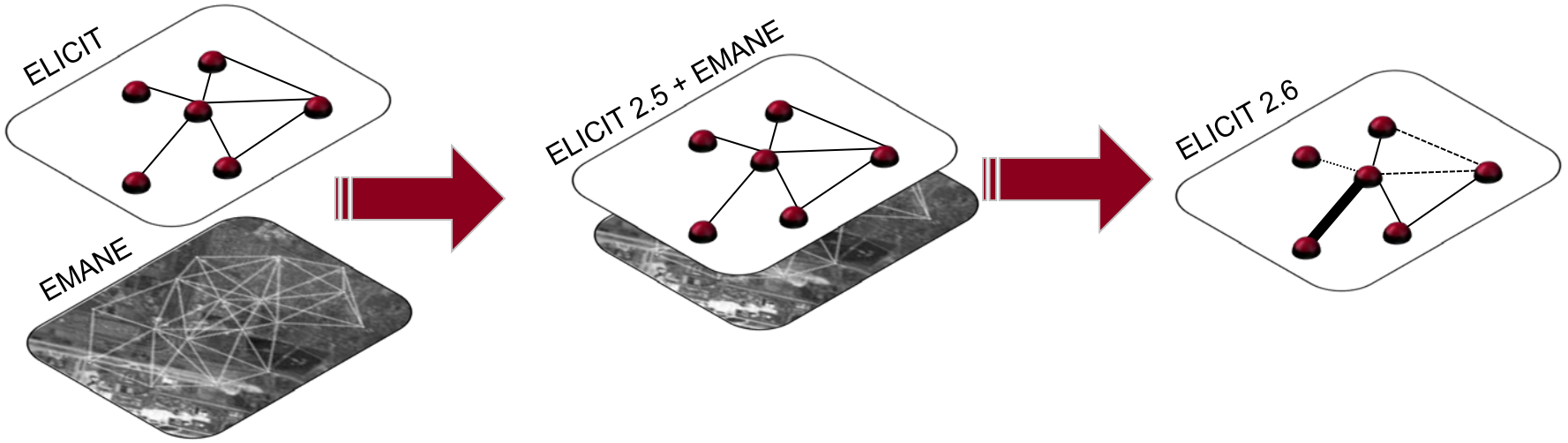
ELICIT

- C2/Organizational theory
- Decision-making scenario
- Sensemaking agents
- Communication network models

ELICIT 2.5

Trust

ELICIT 2.6



Trust in decision making has to balance two competing factors

Competence (t_c): the ability of a team member to send pertinent or useful information

- 'human capital' – capability of node

Willingness (t_w): the amount of effort a team member is willing to spend on the given node

- 'Social bandwidth'
- Reciprocation

A very competent member may not be willing to spend time sharing information: ex. team leader

Very willing members may not be the most competent: ex. close friends.

Bayesian Update of trust distribution

$$p(trust|evidence) \sim p(evidence|trust)p(trust)$$

Updated trust given prior beliefs and evidence

Model of how new evidence is evaluated based on prior trust beliefs

Prior trust beliefs

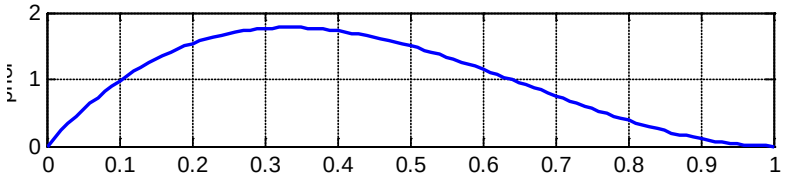
Trust = Prior + Evidence

- Conjugate distributions
  - o Use evidence as likelihood
  - o Prior distribution is initialized distribution of trust
  - o Posterior distribution is the initialized distribution with evidence considered
  - o Conveniently, for some conjugate distributions, the prior and posterior are the same distribution

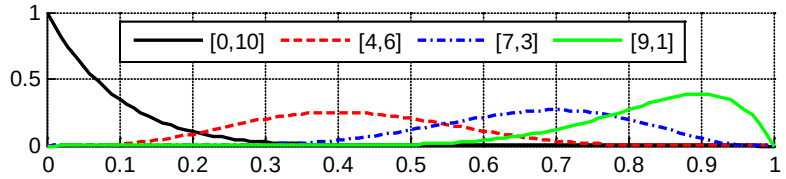
Computational Model of Trust/Evidence: Competence

- **Competence:** $t_c(i,j)$
  - Modeled with the beta-binomial conjugate prior
  - Initialized a, b parameters of beta distribution
  - r: number of new messages received (positive evidence)
  - s: number of duplicate messages received

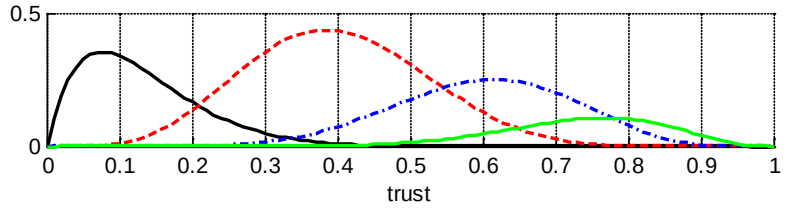
Prior Distribution



Evidence (Likelihood)



Posterior Distribution



Computational Model of Trust/Evidence

- **Competence:** $t_c(i,j)$
  - Prior Distribution

$$p_c(\text{trust}) = \frac{t^{\alpha-1}(1-t)^{\beta-1}}{B(\alpha,\beta)}$$

  - Evidence (received messages)

$$p_c(\text{evidence} \mid \text{trust}) = \binom{r+s}{r} t^r (1-t)^s$$

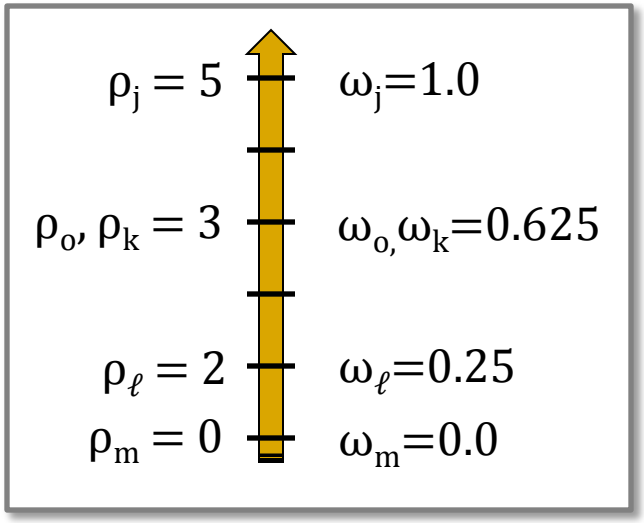
  - Posterior Distribution Parameters

$$E(t) = \frac{\alpha + r}{\beta + s}$$

$$\sigma^2(t) = \frac{(\alpha + r)(\beta + s)}{(\alpha + r + \beta + s)^2 (\alpha + r + \beta + s + 1)}$$

Computational Model of Trust/Evidence: Willingness

- **Willingness:** $t_w(i,j)$
  - Modeled with Gaussian-Gaussian distribution
  - Initialized μ, σ^2 parameters of Gaussian distribution
  - $\omega_j(t) = (0,1)$: based on total number of received messages, $\rho_j(t)$



Computational Model of Trust/Evidence

Willingness: $t_w(i,j)$

- Prior Distribution

$$p_w(\text{trust}) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(t-\mu_0)^2}{2\sigma^2}}$$

- Evidence (received messages)

$$p_w(\text{evidence} \mid \text{trust}) = \frac{1}{\sqrt{2\pi\sigma_U^{\ 2}}} e^{-\frac{(\omega-t)^2}{2\sigma_U^2}}$$

- Posterior Distribution Parameters

$$E(t) = \left(\frac{u_0}{\sigma_0^2} + \frac{u}{\sigma_U^2}\right) \Big/ \left(\frac{\sigma_0^2 + \sigma_U^2}{\sigma_0^2 \sigma_U^2}\right)$$

$$\sigma^2(t) = \left(\frac{\sigma_0^2 \sigma_U^2}{\sigma_0^2 + \sigma_U^2}\right)$$

Trust Evolution in an Information Sharing Scenario

Evolution of Trust

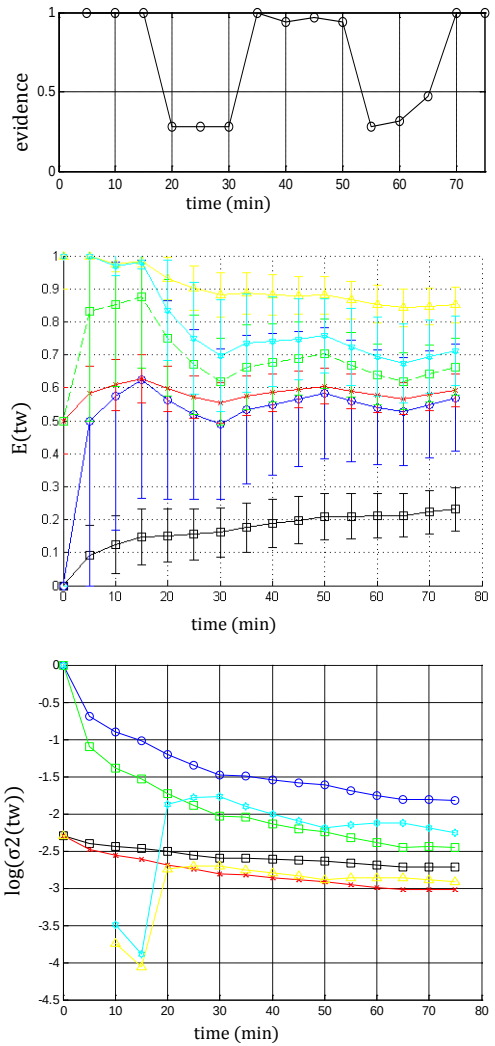
- Willingness and competence evidence of an ELICIT run for one link
- Variation of expected trust and uncertainty based on evidence and prior trust
- Priors:

(α, β)
(100,10)
(10,1)
(1,1)
(1,10)
(10,100)

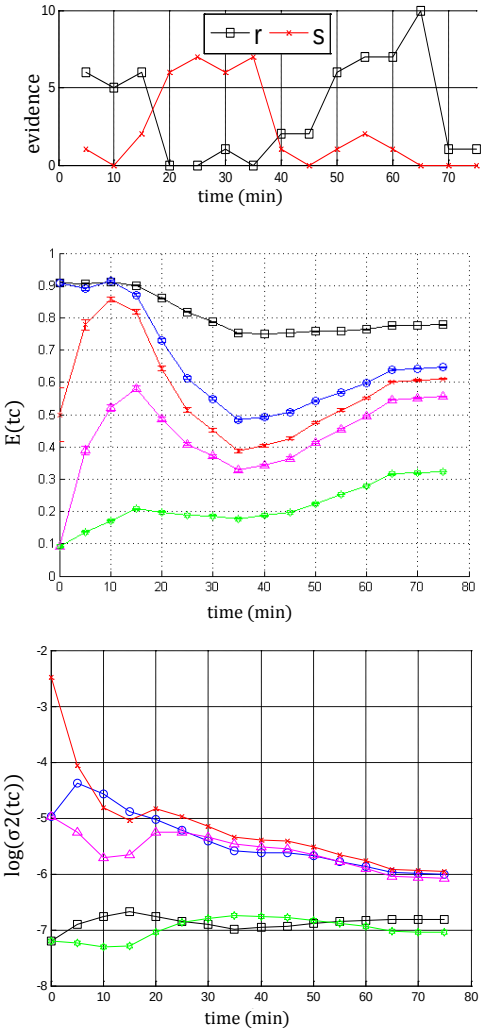
$(\mu 0, \sigma 0^2)$
(0.1, 0.1)
(0.1, 1)
(0.5, 0.1)
(0.5, 1)
(0.9, 0.1)
(0.9, 1)

- Beta for t_c, Gaussian for t_w
- Posterior trust weighs evidence according to prior uncertainty
- Uncertainty tends to decrease as more evidence is collected

Willingness Trust



Competence Trust



Estimated trust can impact sharing and processing

- **Trust Categories:** Assign each neighbor one of the following categories
  - Trusted Discriminating (TD)
  - Trusted Non-discriminating (TNd)
  - Trusted Unknown (TU)
  - Untrusted / Distrusted (DT)
  - No Opinion (Nop)
- Adapt its sharing and processing strategies according to its trust with its neighbors

$(t_c, \sigma^2(t_c))$ \ $(t_\omega, \sigma^2(t_\omega))$

	hh	hℓ	ℓℓ	ℓh
hh	NOp	TU	NOp	NOp
hℓ	NOp	TD	NOp	NOp
ℓℓ	NOp	TNd	DT	NOp
ℓh	NOp	TU	NOp	NOp

Trust in ELICIT agents

- Proposed trust model implemented into ELICIT agent code with the following parameters

  - `willingness|Willingness trust level|0.5`
  - `uncertaintyWillingness|Uncertainty of willingness trust|0.5`
  - `competence|Competence trust level|0.5`
  - `uncertaintyCompetence|Uncertainty of competence trust|0.05`
  - `willingnessThreshold|Willingness trust level threshold|0.5`
  - `uncertaintyWillingnessThreshold|Uncertainty of willingness trust threshold|0.03`
  - `competenceThreshold|Competence trust level threshold|0.5`
  - `uncertaintyCompetenceThreshold|Uncertainty of competence trust threshold|0.03`
  - `recalculateTrustLevelDelay|Time interval to recalculate trust|300000`

Thanks!

Questions?

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- **ELICIT COI: June 21, 2012, 1:00 to 5:00 PM**