Trust Networks: Interpersonal, Social, and Sensor

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Broad Outline

- Real-life Motivational Examples (Why?)
- Trust : Characteristics and Related Concepts (What?)
- Trust Ontology (What?)
  - Type, Value, Process, Scope
- Gleaning Trustworthiness (How?)
  - Practical Examples of Trust Metrics
- Research Challenges (Why-What-How?)
  - Sensor Networks
  - Social Networks
  - Interpersonal

Real-life Motivational Examples

(Why track trust?)

Interpersonal

- With which neighbor should we leave our children over the weekend when we are required to be at the hospital?
- Who should be named as a guardian for our children in the Will?

Social

- In Email:
  - SUBJECT: [TitanPad] Amit Sheth invited you to an EtherPad document.
  - CONTENT: View it here:
    http://knoesis.titanpad.com/200

- *Issue*: Is the request genuine or a trap?

Social

- To click or not to click a http://bit.ly-URL

- To rely or not to rely on a product review (when only a few reviews are present)?

Sensors

- Weather sensor network-based prediction of a potential tornado in the vicinity of a city.
- *Issue*: Should we mobilize emergency response teams ahead of time?
- Van's TCS (Traction Control System) indicator light came on intermittently, while driving.
- *Issue*: Which was faulty: the indicator light or the traction control system?
- Van's Check Engine light came on, while driving.
- *Issue*: Which was faulty: the indicator light or the transmission control system?

Common Issues and Context

- Uncertainty
  - About the validity of a claim or assumption
- Need for action
- Critical decision with potential for loss
  - Past Experience : Vulnerability Examples
    - Irresponsible / selfish guardian => Marred future.
    - Illegal invitation / attachment => Loss of private data.
    - Malfunctioning sensor => Loss of funds.

Commonality among Trust Definitions*

- a Trustor
  - someone who must choose whether, and how much, to trust
- a Trustee
  - someone or something that is to be trusted
- an Action
  - by which the trustor is choosing to be vulnerable to the trustee based on an assessment of trustee's nature
- a Context
  - in which the potential negative consequences of betrayal outweigh any perceived positive results.

*http://www.iarpa.gov/rfi_trust.html

Why Track Trust?

- To predict future behavior.
- To incentivize “good” behavior and discourage “bad” behavior.
- To detect malicious entities.

Trust and Related Concepts

(What is trust?)

Trust Definition : Psychology slant

Trust is the psychological state comprising a willingness to be vulnerable in expectation of a valued result.

Ontology of Trust, Huang and Fox, 2006
Josang et al's Decision Trust

Trust Definition : Psychology slant

Trust in a person is a *commitment to an action* based on a *belief* that the future actions of that person will lead to good outcome.

Golbeck and Hendler, 2006

Trust Definition : Probability slant

Trust (or, symmetrically, distrust) is a level of subjective probability with which an agent assesses that another agent will perform a particular action, both before and independently of such an action being monitored …

Can we Trust Trust?, Diego Gambetta, 2000
Josang et al's Reliability Trust

Trustworthiness Definition : Psychology Slant

Trustworthiness is a collection of qualities of an agent that leads them to be considered as deserving of trust from others (in one or more environments, under different conditions, and to different degrees).

http://www.iarpa.gov/rfi_trust.html

Trustworthiness Definition : Probability slant

Trustworthiness is the objective probability that the trustee performs a particular action on which the interests of the trustor depend.

Solhaug et al, 2007

Trust vs Trustworthiness : My View

Trust Disposition

Depends on

Potentially Quantified Trustworthiness Qualities

+

Context-based Trust Threshold

E.g.*, In the context of trusting strangers, people in the West will trust for lower levels of trustworthiness than people in the Gulf.

*Bohnet et al, 5/2010

(Community-based) Reputation

- Reputation* is the community or public estimation of standing for merit, achievement, reliability, etc. *dictionary.com
- Reputation** is the opinion (or a social evaluation) of a community toward a person, a group of people, or an organization on a certain criterion. **Wikipedia
    - Cf. Brand-value, PageRank, eBay profile, etc.

Trust vs. (Community-based) Reputation

Reputation can be a basis for trust. However, they are different notions*.

- I trust you because of your good reputation.
- I trust you despite your bad reputation.
- Do you still trust Toyota brand?

*Josang et al, 2007

Trust vs. (Community-based) Reputation

Trust :: Reputation

::::

Local :: Global

::::

Subjective :: Objective

(Cf. *Security* refers to resistance to attacks.)

Reputation is Overloaded

Community-based Reputation

vs.

Temporal Reputation-based Process

(Cf. Sustained good behavior over time elicits *temporal reputation-based trust*.)

Trust vs. Belief

- Trust is a relationship among agents.
- Belief is a relationship between an agent and a statement.

Trust Ontology

(What is trust?)

Illustration of Knowledge Representation and Reasoning:
Relating Semantics to Data Structures and Algorithms

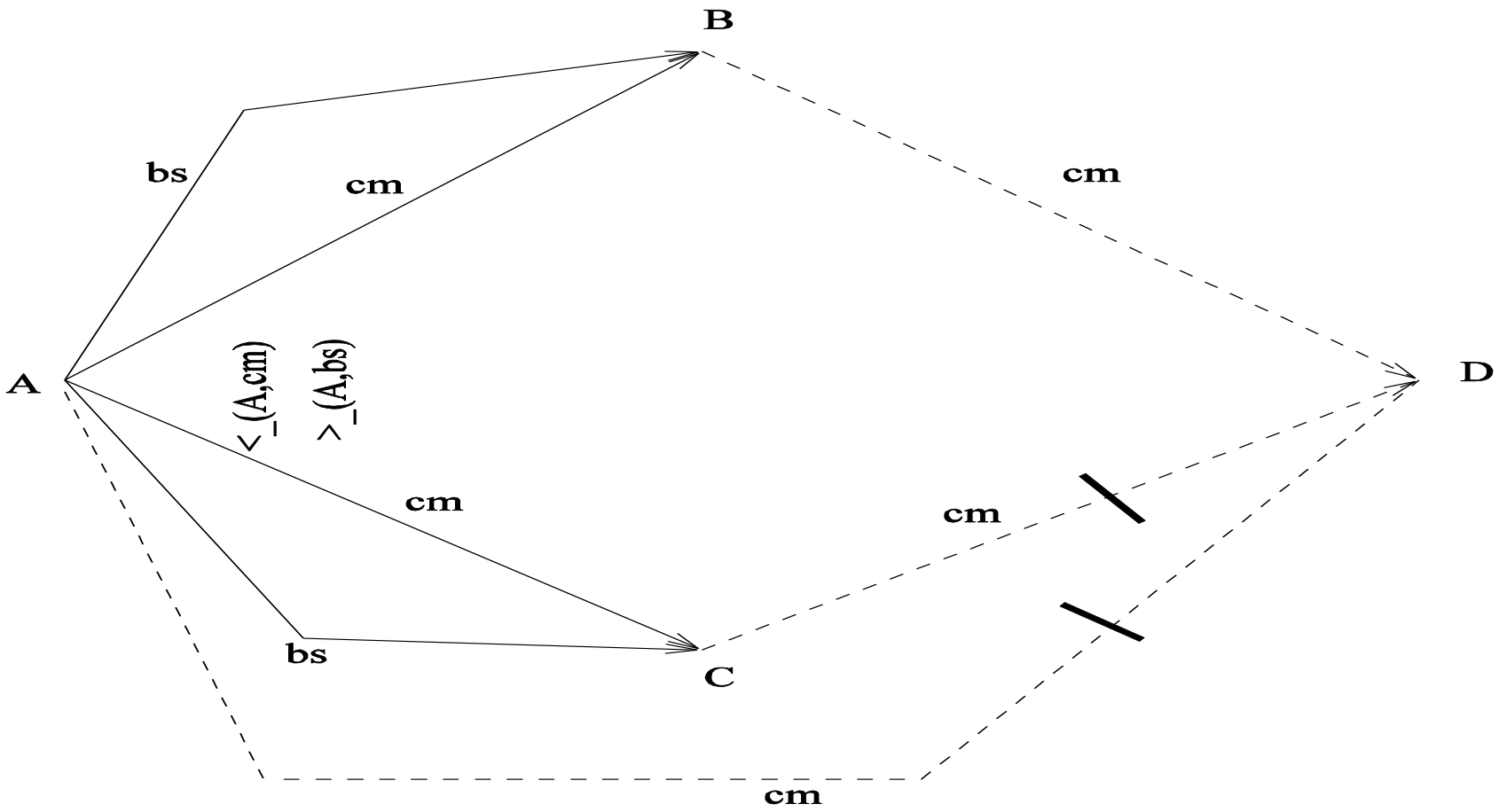
Example Trust Network - Different Trust Links with Local Order on out-links

- Alice trusts Bob *for recommending* good car mechanic.
- Bob trusts Dick *to be* a good car mechanic.
- Charlie *does not* trust Dick to be a good car mechanic.
- Alice trusts Bob *more than* Charlie, *for recommending* good car mechanic.
- Alice trusts Charlie *more than* Bob, *for recommending* good baby sitter.

*Thirunarayan et al, IICAI 2009

Digression: Illustration of Knowledge Representation and Reasoning

- Abstract and encode clearly delineated "subarea" of knowledge in a formal language.
  - Trust Networks => node-labeled, edge-labeled directed graph (DATA STRUCTURES)
- Specify the meaning in terms of how "network elements" relate to or compose with each other.
  - Semantics of Trust, Trust Metrics => using logic or probabilistic basis, constraints, etc. (SEMANTICS)
- Develop efficient graph-based procedures
  - Trust value determination/querying (INFERENCE ALGORITHMS)



Referral trust link (In recommendations)

Functional trust link (For capacity to act)

Nonfunctional trust link (For lack of capacity to act)

Trust Ontology*

6-tuple representing a trust relationship:

Type – Represents the nature of trust relationship.

Value – Quantifies trustworthiness for comparison.

Scope – Represents applicable context for trust.

Process – Represents the method by which the *value* is created and maintained.

*Anantharam et al, NAECON 2010

Trust Ontology:
Trust Type, Trust Value, and Trust Scope

- Trust Type*
  - *Referral Trust* – Agent a1 trusts agent a2's ability to recommend another agent.
  - (Non-)*Functional Trust* – Agent a1 (dis)trusts agent a2's ability to perform an action.
    - Cf. ** trust in belief vs. trust in performance
- Trust Value
  - E.g., Star rating, numeric rating, or partial ordering.
- Trust Scope*
  - E.g., Car Mechanic context.

*Thirunarayan et al, IICAI 2009
** Huang and Fox, 2006

Organizing Trust Scopes

- Provision trust describes the relying party's trust in a service or resource provider.
- Access trust describes trust in principals for the purpose of accessing resources owned by or under the responsibility of the relying party.
- Delegation trust describes trust in an agent (the delegate) that acts and makes decision on behalf of the relying party.
- Identity trust describes the belief that an agent identity is as claimed.
- Context trust describes the extent to which the relying party believes that the necessary systems and institutions are in place in order to support the transaction and provide a safety net in case something should go wrong.

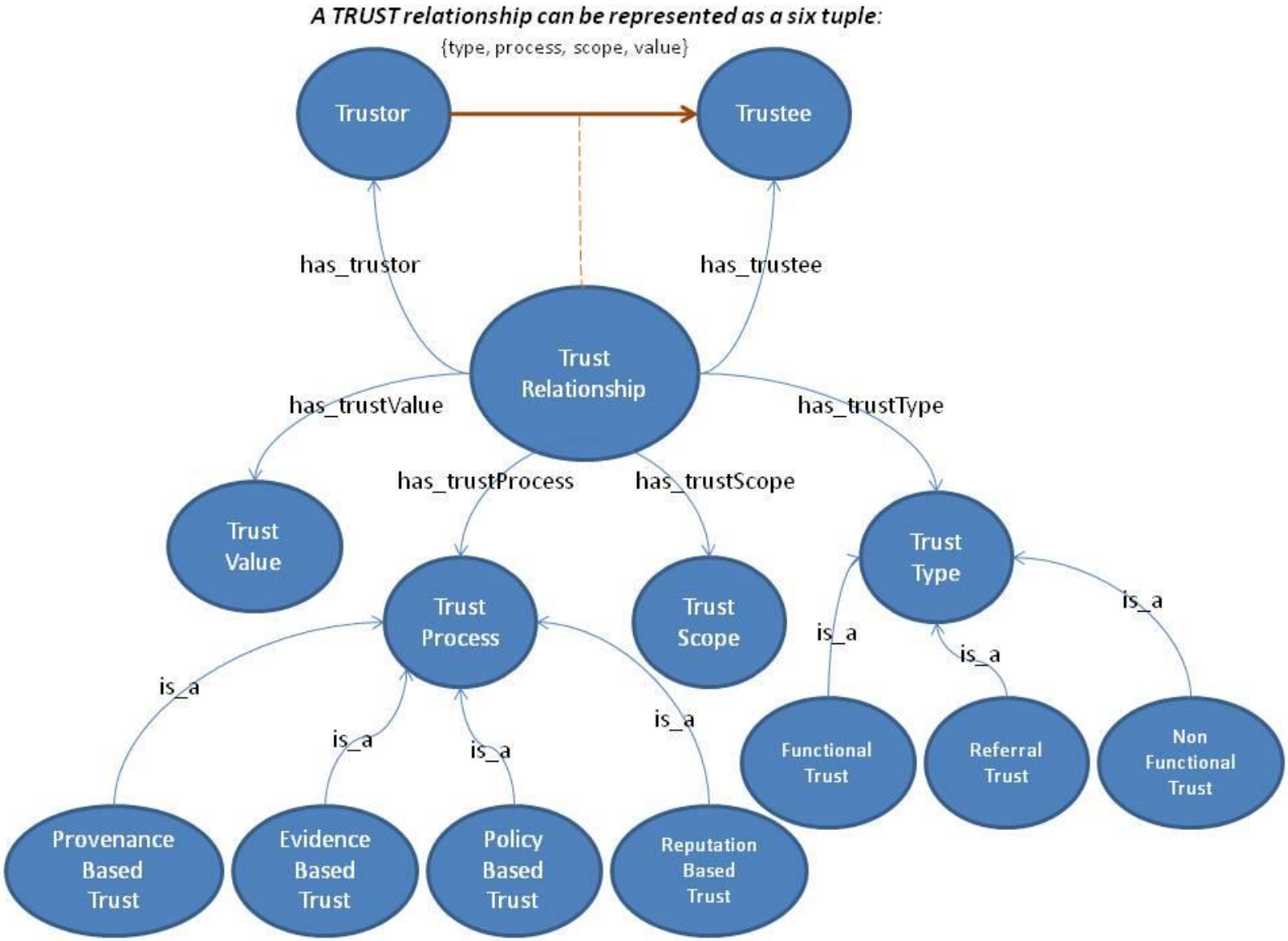
*Josang et al, 2007

Trust Ontology:
Trust Process

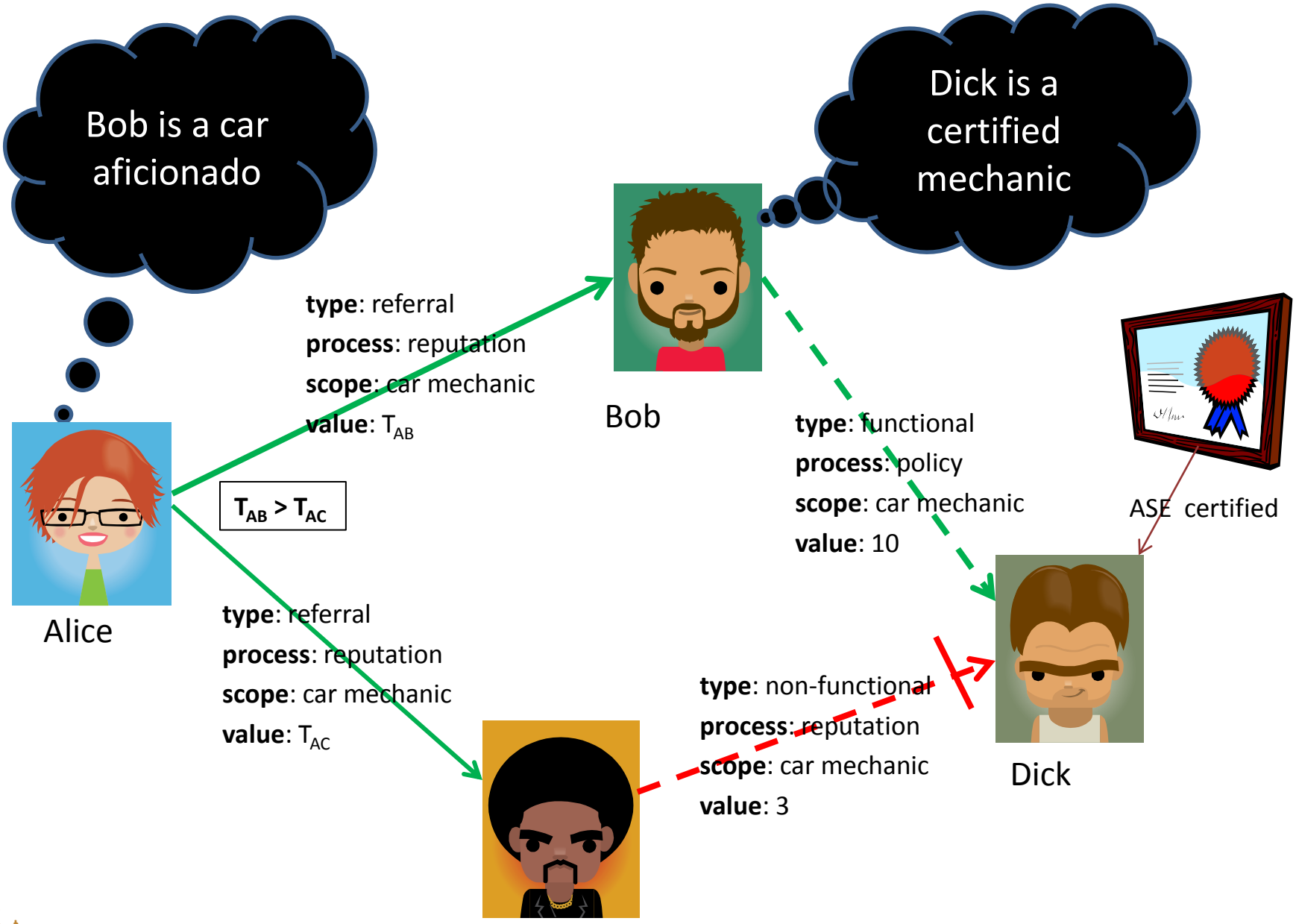
- Represents the method by which the value is computed and maintained.
  - **Primitive (for functional and referral links)***
    - (Temporal) Reputation – based on past behavior.
    - Policy – based on explicitly stated constraints.
    - Evidence – based on seeking/verifying evidence.
    - Provenance – based on lineage information.
  - **Composite (for admissible paths)****
    - Propagation (Chaining and Aggregation)

*Anantharam et al, NAECON 2010
**Thirunarayan et al, IICAI 2009

Trust Ontology



Example Trust Network illustrating Ontology Concepts



Unified Illustration of Trust Processes

Scenario : Hiring Web Search Engineer - An R&D Position

Various Trust Processes :

- (Temporal) Reputation-based: Past job experience
- Policy-based: Scores on screening test
- Provenance-based: Department/University of graduation
- Evidence-based: Multiple interviews (phone, on-site, R&D team)

Gleaning Trustworthiness : Practical Examples

(How to determine trustworthiness?)

Direct Trust : Functional
Reputation-based Process

(Using large number of observations)

Using Large Number of Observations

- Over time (<= Referral + Functional) :
  Temporal Reputation-based Process
  - Mobile Ad-Hoc Networks
  - Sensor Networks
    - Quantitative information
      (Numeric data)
- Over agents (<= Referral + Functional) :
  Community Reputation-based Process
  - Product Rating Systems
    - Quantitative + Qualitative information
      (Numeric + text data)

Desiderata for Trustworthiness Computation Function

- Initialization Problem : How do we get *initial* value?
- Update Problem : How do we reflect the *observed behavior* in the current value *dynamically*?
- Trusting Trust* Issue: How do we mirror *uncertainty* in our estimates as a function of observations?
  - Law of Large Numbers: The *average* of the results obtained from a large number of trials should be close to the *expected value*.
- Efficiency Problem : How do we *store* and *update* values *efficiently*?

*Ken Thompson's Turing Award Lecture: "**Reflections on Trusting Trust**"

Beta Probability Density Function(PDF)

$$f(x;\alpha,\beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\,du}$$

$$= \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\,x^{\alpha-1}(1-x)^{\beta-1}$$

$$= \frac{1}{\mathrm{B}(\alpha,\beta)}\,x^{\alpha-1}(1-x)^{\beta-1}$$

$$\mathrm{E}(X) = \frac{\alpha}{\alpha+\beta}$$

$$\mathrm{E}(X^2) = \frac{\alpha(\alpha+1)}{(\alpha+\beta)(\alpha+\beta+1)}$$

$$\mathrm{Var}(X) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$$

x is a probability, so it ranges from 0-1

If the prior distribution of p is uniform, then the beta distribution gives posterior distribution of p after observing $\alpha-1$ occurrences of event with probability p and $\beta-1$ occurrences of the complementary event with probability (1-p).

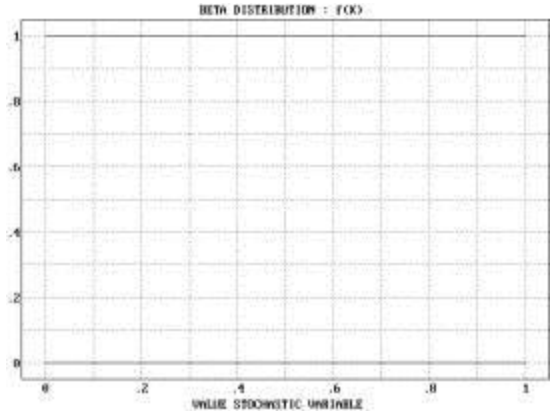
Beta-distribution : More Gently

- Consider a (potentially unfair) coin that comes up with HEADS with probability p and TAILS with probability $(1 - p)$.
- Suppose we perform ($r + s$) coin tosses and the coin turns up with HEADS r times and with TAILS s times. What is the best estimate of the distribution of the probability p given these observations?

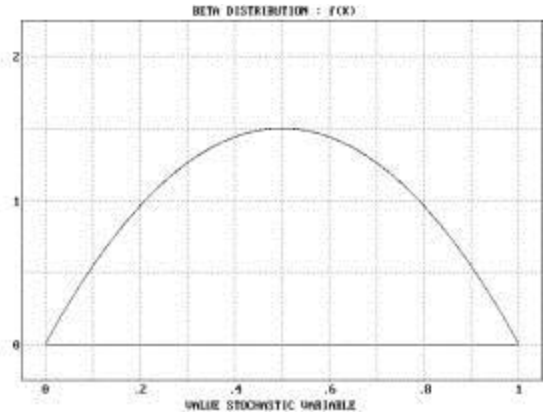
  => Beta-distribution with parameters (r+1, s+1)

$$f(p; r+1, s+1)$$

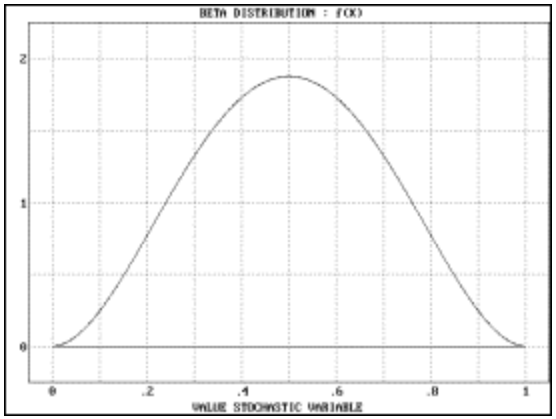
$\alpha = \beta$, so the pdf's are symmetric w.r.t 0.5.
Note that the graphs get narrower as $(\alpha+\beta)$ increases.



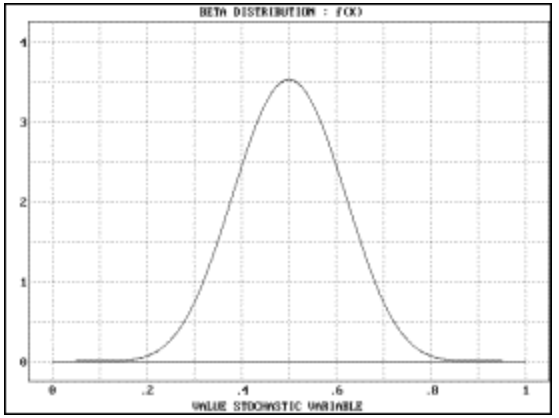
$\alpha = 1$
$\beta = 1$



$\alpha = 2$
$\beta = 2$



$\alpha = 5$
$\beta = 5$



$\alpha = 10$
$\beta = 10$

Beta-distribution - Applicability

- Dynamic trustworthiness can be characterized using beta probability distribution function gleaned from total number of correct (supportive) r = $(\alpha - 1)$ and total number of erroneous (opposing) s = $(\beta - 1)$ observations so far.
- Overall trustworthiness (reputation) is its mean: $\alpha/\alpha + \beta$

Why Beta-distribution?

- Intuitively satisfactory, Mathematically precise, and Computationally tractable
  - Initialization Problem : Assumes that all probability values are equally likely.
  - Update Problem : Updates (α, β) by incrementing α for every correct (supportive) observation and β for every erroneous (opposing) observation.
  - Trusting Trust Issue: The graph peaks around the mean, and the variance diminishes as the number of observations increase, if the agent is well-behaved.
  - Efficiency Problem: Only two numbers stored/updated.

Information Theoretic Interpretation of Trustworthiness Probability

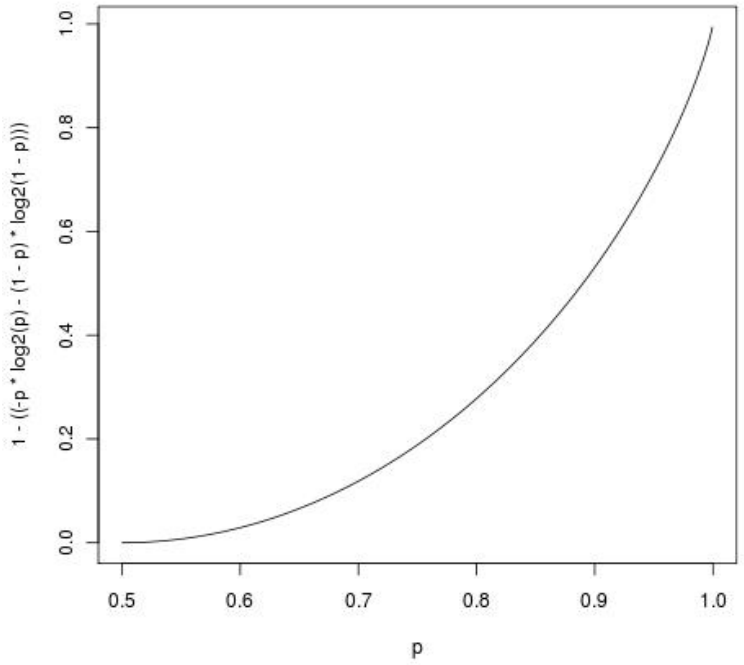
- Intuitively, probability values of 0 and 1 imply certainty, while probability value of 0.5 implies a lot of uncertainty.

- This can be formalized by mapping probability in [0,1] to trust value in [–1,1], using information theoretic approach.

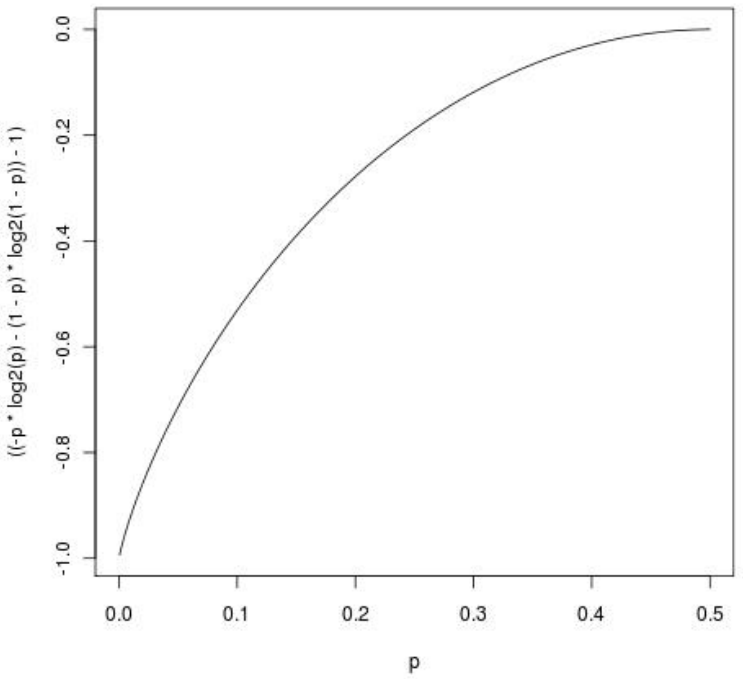
Y. L. Sun, et al, 2/2008

Plot of T(trustee : trustor, action) vs. p

Trust portion (p in [0.5,1])



Distrust portion (p in [0,0.5])



Direct Trust : Functional
Policy-based Process

(Using Trustworthiness Qualities)

General Approach to Trust Assessment

- Domain dependent qualities for determining trustworthiness
  - Based on Content / Data
  - Based on External Cues / Metadata
- Domain independent mapping to trust values or levels
  - Quantification through aggregation and classification

Example: Wikipedia Articles

- Quality (content-based)
  - Appraisal of information provenance
    - References to peer-reviewed publication
    - Proportion of paragraphs with citation
  - Article size
- Credibility (metadata-based)
  - Author connectivity
  - Edit pattern and development history
    - Revision count
    - Proportion of reverted edits - (i) normal (ii) due to vandalism
    - Mean time between edits
    - Mean edit length.

Sai Moturu, 8/2009

(cont'd)

- Quantification of Trustworthiness
  - Based on Dispersion Degree Score

    (Extent of deviation from mean)

- Evaluation Metric
  - Ranking based on trust level (determined from trustworthiness scores), and compared to gold standard classification using Normalized Discounted Cumulative Gain (NDCG)

Example: Websites

- Trustworthiness estimated based on criticality of data exchanged.
  - Email address / Username / password
  - Phone number / Home address
  - Date of birth
  - Social Security Number / Bank Account Number
- *Intuition*: A piece of data is critical if and only if it is exchanged with a small number of highly trusted sites.

Indirect Trust : Referral + Functional
Variety of Trust Metrics

(Using Propagation – Chaining and Fusing over Paths)

Collaborative Filtering

- Collaborative Filtering: Item-rating by a user predicted on the basis of user's similarity to other users.

- Similarity Measures:
  - Profile-based
  - Item-ratings-based
  - Item-category-based

Collaborative Filtering

- Pros:
  - Items-agnostic
  - Scales well over time with large number of items
- Cons:
  - Data Sparsity Problem: Small number of common items between users.
  - Cold Start Users: Small number of items rated by a user.
  - Prone to Copy-Profile Attack: An attacker can create a targeted-user-like profile to manipulate recommendations.

Massa-Avesani, 2007

Trust-aware Recommender System

- TaRS uses explicit/direct trust between users to predict implicit/indirect trust between users through chaining.
- Collaborative Filtering Limitations Overcome:
  - Mitigates Data Sparsity: Trust propagation is more general and improves coverage.
  - Bootstraps Cold Start Users: A single trust link from a new user can enable the user to inherit several "parental" recommendations.
  - Robust w.r.t Copy-Profile Attack: Fake identities are not trusted by an active user.

Massa-Avesani, 2007

Trust Propagation Frameworks

- **Chaining, Aggregation, and Overriding**

Golbeck – Hendler, 2006

Massa-Avesani, 2005
Bintzios et al, 2006

Sun et al, 2006
Thirunarayan et al, 2010

- Trust Management
  - Abstract properties of operators

Richardson et al, 2003

- Reasoning with trust
  - Matrix-based trust propagation

Guha et al., 2004

- The Beta-Reputation System
  - Algebra on opinion = (belief, disbelief, uncertainty)

Josang and Ismail, 2002

Trust Propagation Algorithms

- Top-down
  - 1: Extract trust DAG (eliminate cycles)
  - 2:Predict trust score for a source in a target by aggregating trust scores in target inherited from source's "trusted" parents weighted with trust value in the corresponding parent.
    - Computation is level-by-level
    - Alternatively, computation can be based on paths.

Golbeck – Hendler, 2006

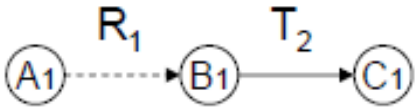
Trust Propagation Algorithms

- Bottom-up
  - 1: Extract trust DAG (eliminate cycles)
  - 2:Predict trust score for a source in a target by aggregating trust scores in target inherited from target's "trusted" neighbors weighted with trust value in the corresponding neighbor.
    - Computation is level-by-level
    - Alternatively, computation can be based on paths.

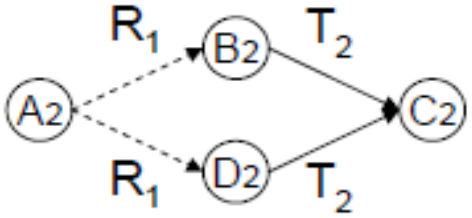
Massa-Avesani, 2005
Bintzios et al, 2006

Trust Propagation Rules : Axioms for Trust Models

Rule 1: Concatenation propagation does not increase trust.



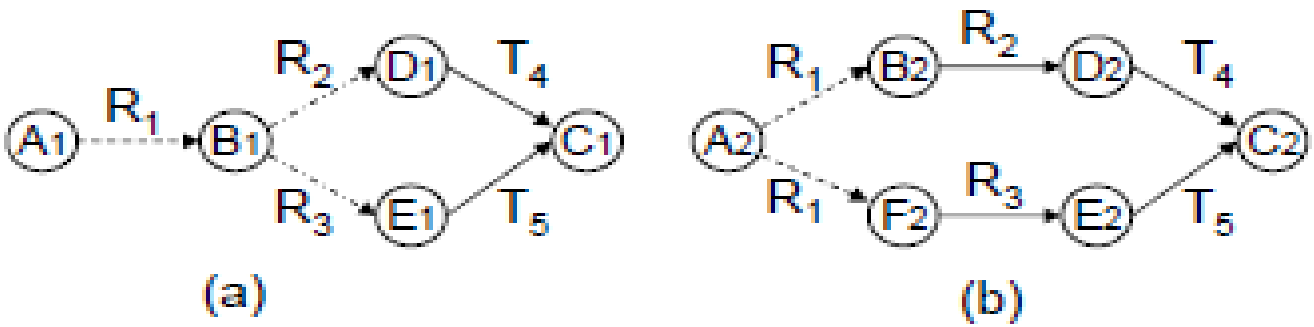
Rule 2: Multipath propagation does not reduce trust.



Sun et al, 2006

(cont'd)

Rule 3: Trust based on multiple referrals from a single source should not be higher than that from independent sources.

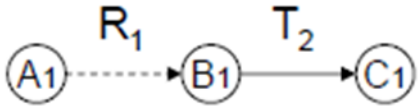


Sun et al, 2006

Trust Propagation Rules : Implementation

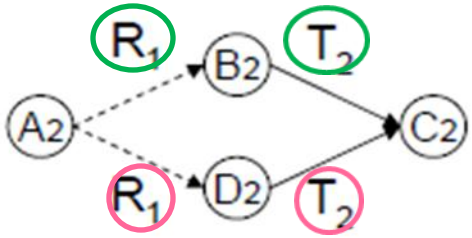
Rule 1: Concatenation propagation (reputation discounting)

$$T(A_1,C_1) = R_1 * T_2$$



Rule 2: Multipath propagation (combining feedback)

$$T(A_2,C_2) = \frac{R_1(R_1*T_2)+R_1(R_1*T_2)}{R_1 + R_1}$$



Sun et al, 2006

Trust Propagation Rules : Beta Reputation System

opinion = (belief **b**, disbelief **d**, uncertainty **u**)

in terms of (# correct values **r**, # errors **s**)

$$b = \frac{r}{r+s+2} \qquad d = \frac{s}{r+s+2} \qquad u = \frac{2}{r+s+2}$$

chaining of opinions

$$b = b1 * b2 \qquad d = b1 * d2$$

$$u = d1 + u1 + b1 * u2$$

Josang and Ismail, 2002

Trust Propagation Rules : Beta Reputation System

Rule 1: Concatenation propagation (reputation discounting)

$$r = 2*r1 * r2 \;/\; (s1+2)(r2+s2+2)+2*r1$$

$$s = 2*r1 * s2 \;/\; (s1+2)(r2+s2+2)+2*r1$$

Rule 2: Multipath propagation (combining feedback)

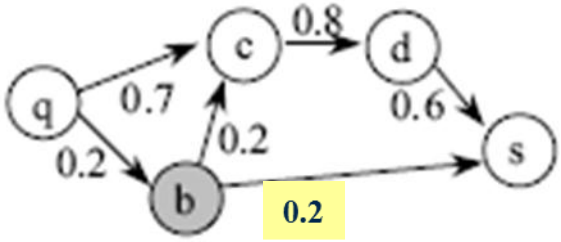
$$r = r1 + r2 \qquad s = s1 + s2$$

*Rule *:* Temporal Decay (Forgetting)

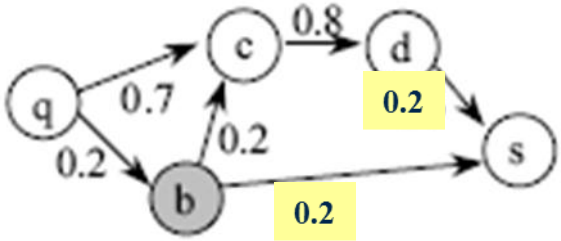
Josang and Ismail, 2002

Example: Comparative Analysis

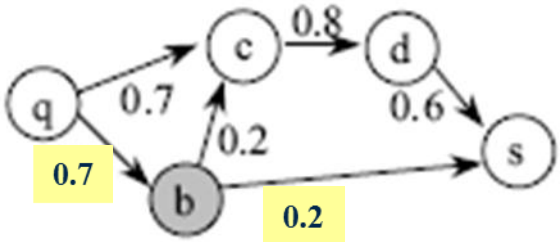
Same Interpretation:
q trusts s



Same Interpretation:
q distrusts s

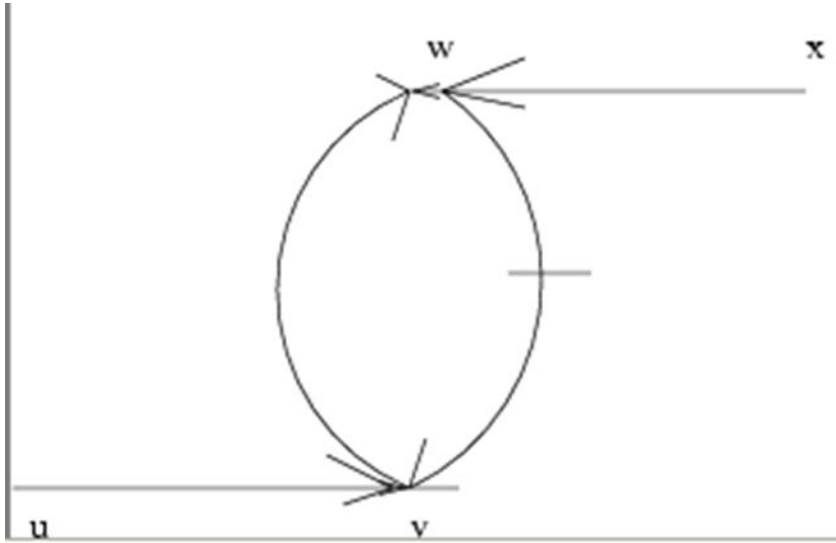


Different Interpretation:
q distrusts s (*Bintzios et al's*)
vs
q has no information about the trustworthiness of s (*our's, Golbeck rounding algorithm*)



Thirunarayan and Verma, 2007

Example: Well-founded Cyclic Trust Network



$T(u,v) = true$
$T(u,w) = true$
$T(v,w) = true$
$T(w,v) = false$
$T(x,w) = true$
$T(x,v) = false$
$T(\_,\_) = \bot$ Otherwise

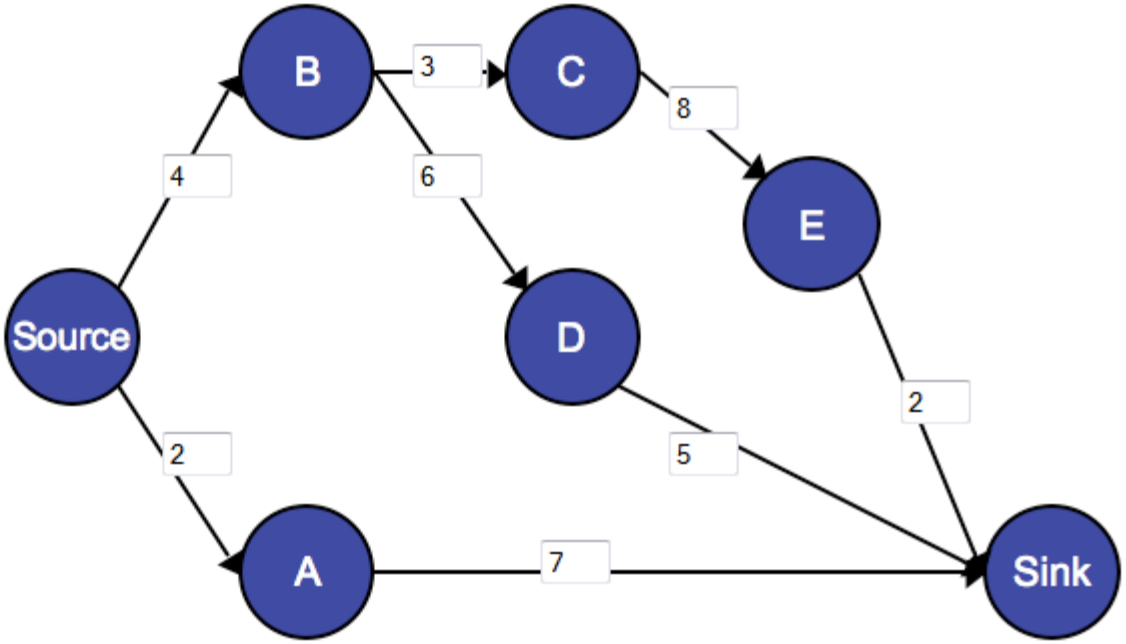
Thirunarayan and Verma, 2007

Example: Using TidalTrust Algorithm

Maximum Depth of Search: 4

Minimum Trust Value 1

Compute Inferred Trust Value 5



Research Challenges

(What-Why-How of trust?)

HARD PROBLEMS

Generic Directions

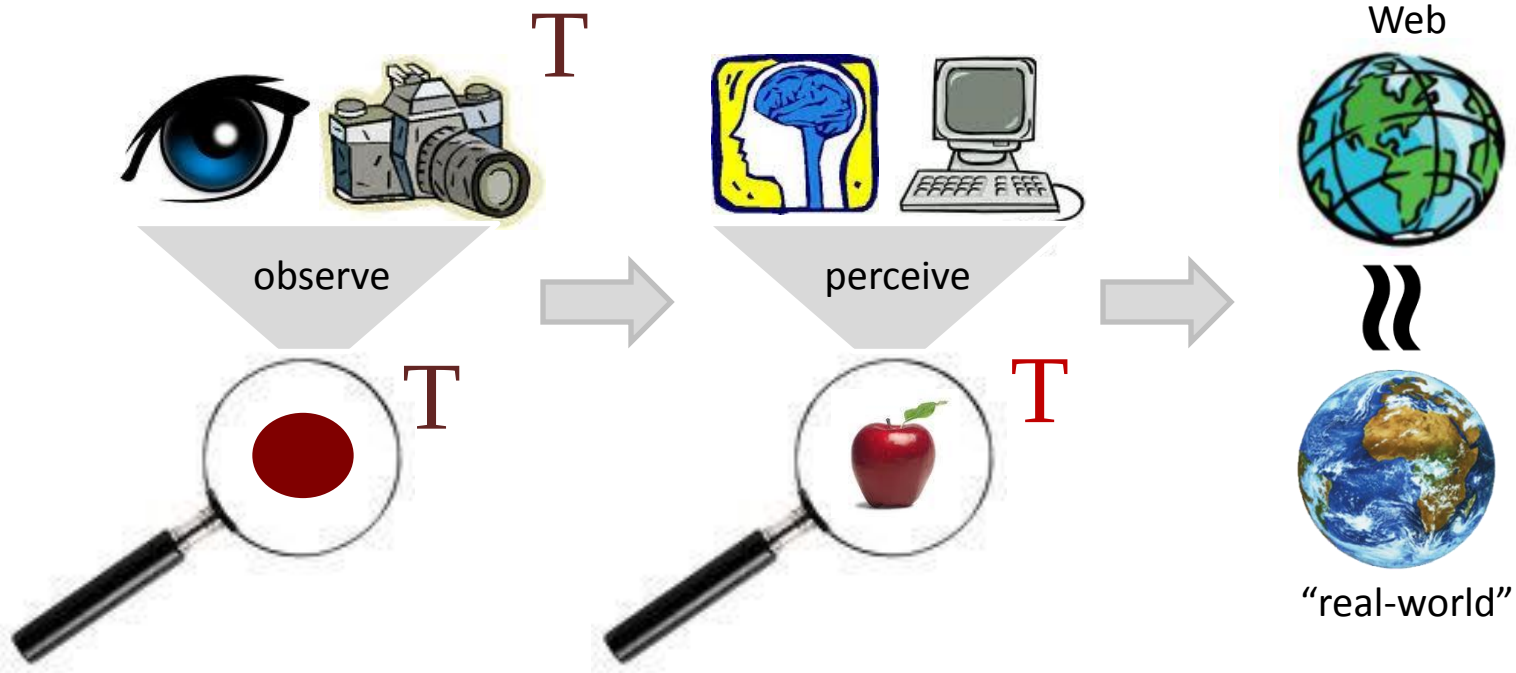
- Finding **online substitutes** for traditional cues to **derive measures of trust**.
- Creating **efficient** and **secure** systems for managing and deriving trust, in order to **support decision making**.

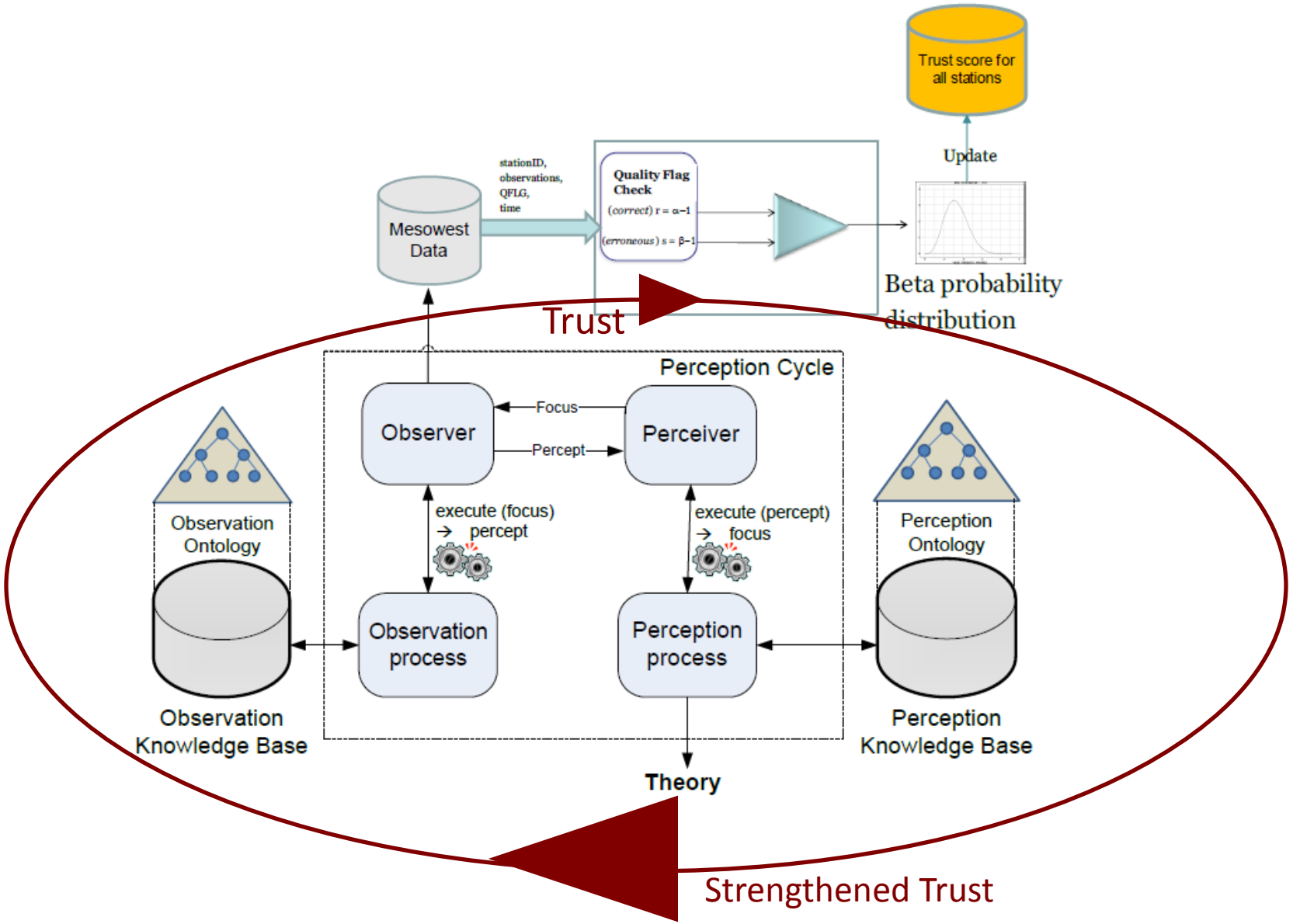
Josang et al, 2007

Sensor Networks

Our Research

Abstract trustworthiness of sensors and observations to perceptions to obtain actionable situation awareness!



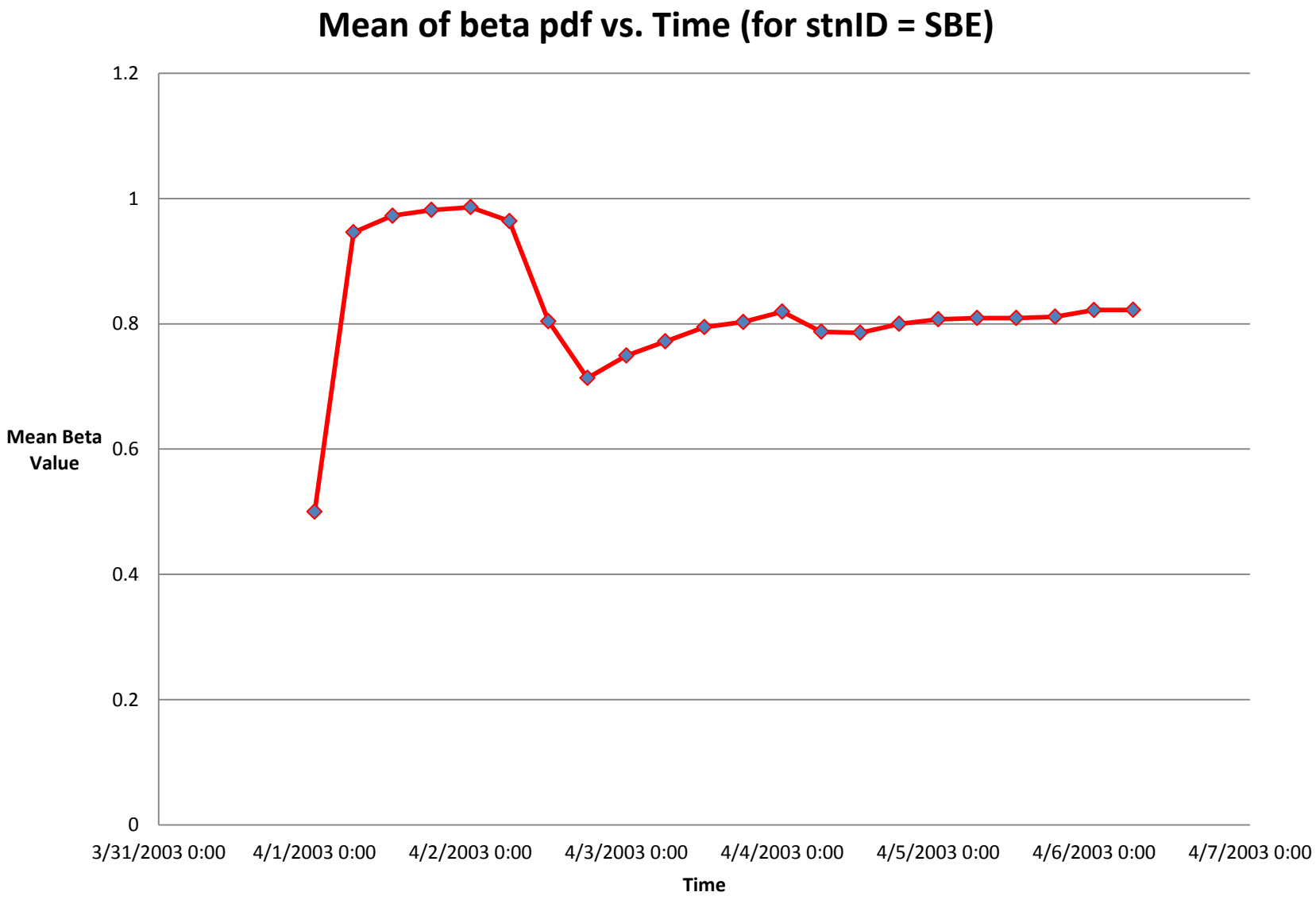

Trust score for all stations
Update
stationID, observations, QFLG, time
Mesowest Data
Quality Flag Check
(correct) r = α−1
(erroneous) s = β−1
Beta probability distribution
Trust
Perception Cycle
Observer
Focus
Percept
Perceiver
execute (focus) → percept
execute (percept) → focus
Observation Ontology
Perception Ontology
Observation process
Perception process
Observation Knowledge Base
Perception Knowledge Base
Theory
Strengthened Trust

Concrete Application

- Applied Beta-pdf to Mesowest Weather Data
  - Used quality flags (OK, CAUTION, SUSPECT) associated with observations from a sensor station over time to derive reputation of a sensor and trustworthiness of a perceptual theory that explains the observation.
  - Perception cycle used data from ~800 stations, collected for a blizzard during 4/1-6/03.

Concrete Application

- Perception Cycle
  - http://harp.cs.wright.edu/perception/
- Trusted Perception Cycle
  - http://www.youtube.com/watch?v=lTxzghCjGgU


Mean of beta pdf vs. Time (for stnID = SBE)
1.2
1
0.8
0.6
0.4
0.2
0
Mean Beta Value
3/31/2003 0:00
4/1/2003 0:00
4/2/2003 0:00
4/3/2003 0:00
4/4/2003 0:00
4/5/2003 0:00
4/6/2003 0:00
4/7/2003 0:00
Time

Research Issues

- Outlier Detection
  - Homogeneous Networks
    - Statistical Techniques
  - Heterogeneous Networks (sensor + social)
    - Domain Models
- Distinguishing between abnormal phenomenon (observation), malfunction (of a sensor), and compromised behavior (of a sensor)
  - Abnormal situations
  - Faulty behaviors
  - Malicious attacks

Ganeriwal et al, 2008

Social Networks

Our Research

- Study semantic issues relevant to trust
- Proposed model of trust/trust metrics to formalize *indirect* trust

Quote

- Guha et al:

  While continuous-valued trusts are mathematically clean, from the standpoint of usability, most real-world systems will in fact use discrete values at which one user can rate another.

- E.g., Epinions, Ebay, Amazon, Facebook, etc all use small sets for (dis)trust/rating values.

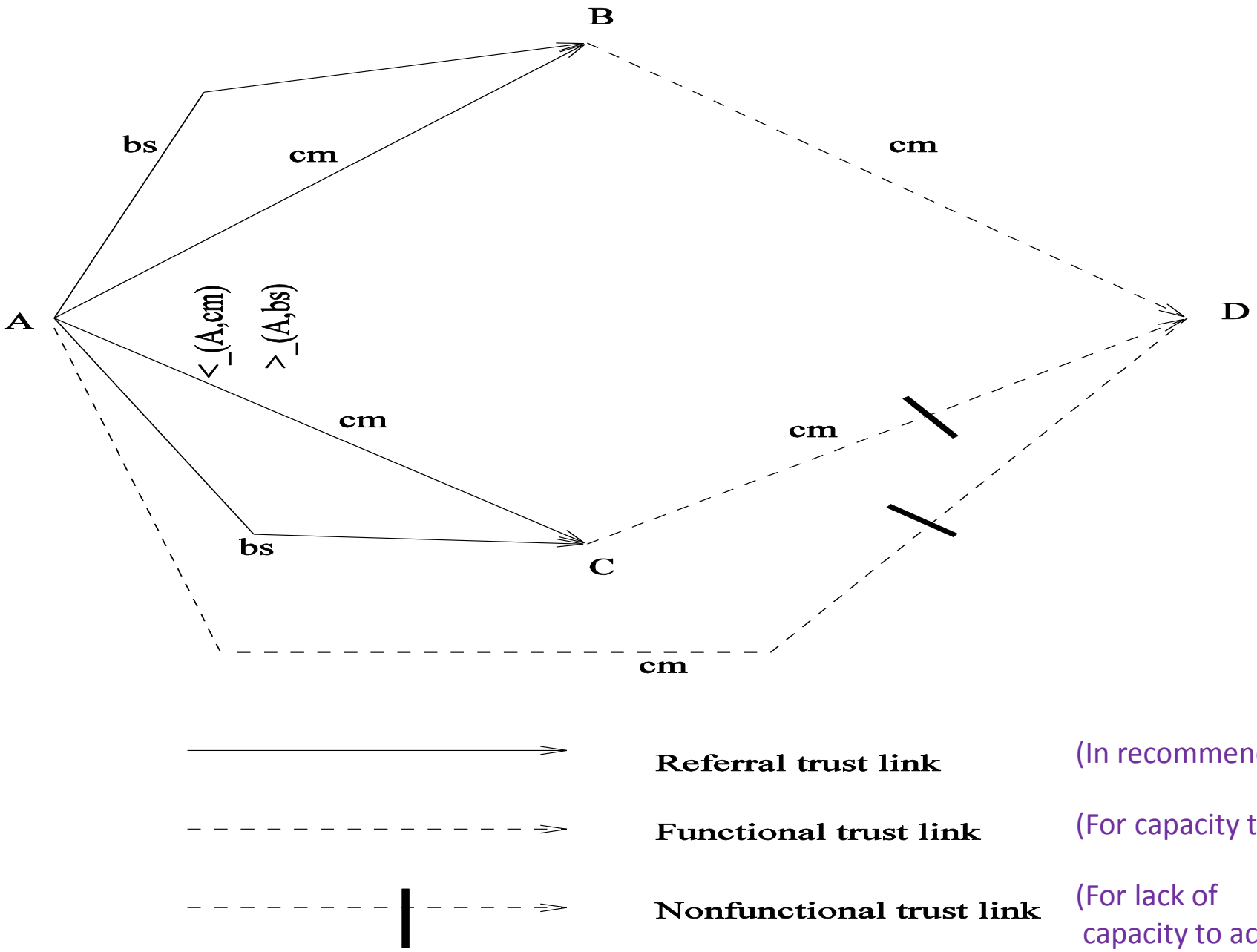
Our Approach

- Trust formalized in terms of partial orders (with emphasis on *relative* magnitude)
- *Local* but realistic semantics
  - Distinguishes *functional* and *referral* trust
  - Distinguishes *direct* and *inferred* trust
    - Direct trust *overrides* conflicting inferred trust
  - Represents *ambiguity* explicitly

Thirunarayan et al , 2010

Formalizing the Framework

- Given a trust network (Nodes AN, Edges RL U PFL U NFL with Trust Scopes TSF, Local Orderings $\preceq_{ANxAN}$), specify when a source can trust, distrust, or be ambiguous about a target, reflecting local semantics of:
  - *Functional* and *referral* trust links
  - *Direct* and *inferred* trust
  - *Locality*



Referral trust link (In recommendations)

Functional trust link (For capacity to act)

Nonfunctional trust link (For lack of capacity to act)

Evidence in support of Referral Trust: a_i can referral trust a_j in trust scope ts if there is an explicit trust link from a_i to a_j, or there is a successor a_k of a_i that referral trusts a_j in trust scope ts.

$$\forall a_i, a_j \in AN : a_i \textbf{ can referral trust } a_j \textbf{ in trust scope } ts \text{ if}$$

$$[\,(a_i, a_j) \in \text{RL} \;\wedge\; ts \;\in\; TSF(a_i, a_j)\,] \;\vee$$

$$[\exists a_k \in \text{AN} : \;\; (a_i, a_k) \in \text{RL} \;\wedge\; ts \;\in\; TSF(a_i, a_k) \;\wedge\; ts \;\in\; \mathcal{R}(a_k, a_j)\,]$$

$$\| \text{ Undefeated functional trust of } a_i \textbf{ in } a_j \textbf{ for } ts \| \ =$$

$$\| \{(a_i, a_k) \in \text{RL} \ \mid \ ts \in TSF(a_i, a_k) \ \wedge \ (ts, true) \ \in \ \mathcal{F}(a_k, a_j)$$

$$\wedge \ \neg \exists a_l \in \text{AN} : \ (a_k \prec_{(a_i, ts)} a_l)$$

$$\wedge (a_i, a_l) \in \text{RL} \ \wedge \ ts \in TSF(a_i, a_k) \ \wedge \ (ts, bf) \ \in \ \mathcal{F}(a_l, a_j)\} \wedge bf \geq false \ \|$$

and

$$\| \text{ Undefeated nonfunctional trust of } a_i \textbf{ in } a_j \textbf{ for } ts \| \ =$$

$$\| \{(a_i, a_k) \in \text{RL} \ \mid \ ts \in TSF(a_i, a_k) \ \wedge \ (ts, false) \ \in \ \mathcal{F}(a_k, a_j)$$

$$\wedge \ \neg \exists a_l \in \text{AN} : \ (a_k \prec_{(a_i, ts)} a_l)$$

$$\wedge (a_i, a_l) \in \text{RL} \ \wedge \ ts \in TSF(a_i, a_k) \ \wedge \ (ts, bt) \ \in \ \mathcal{F}(a_l, a_j)\} \wedge bt \geq true \ \|$$

Evidence in support of Positive Functional Trust: a_i can functional trust a_j in trust scope ts if there is an explicit positive functional trust link from a_i to a_j, or there is majority of most referral trusted successors a_k of a_i that functional trust a_j rather than distrust a_j. In other words, for the purposes of a_j in trust scope ts, there are more endorsements than disapprovals via a_i's successors. We introduce a factor Kp to quantify the strength of majority for positive functional trust. Normally, its value is at least 1, and for simple majority, Kp is equal to 1.

$$\forall a_i, a_j \in AN : a_i \textbf{ can functional trust } a_j \textbf{ in trust scope } ts \text{ if}$$

$$(a_i, a_j) \in \text{PFL} \quad \wedge \quad ts \in TSF(a_i, a_j) \quad \vee$$

$$\frac{\| \text{ Undefeated functional trust of } a_i \textbf{ in } a_j \textbf{ for } ts \ \|}{\| \text{ Undefeated nonfunctional trust of } a_i \textbf{ in } a_j \textbf{ for } ts \ \|} \quad > \quad Kp$$

Similarly for Evidence in support of Negative Functional Trust.

Practical Issues

- Refinement of numeric ratings using reviews in product rating networks
  - Relevance : Separate ratings of vendor or about extraneous features from ratings of product
    - E.g., Issues about Amazon's policies
    - E.g., Publishing under multiple titles (Paul Davies' "The Goldilock's Enigma" vs. "Cosmic Jackpot")
  - Polarity/Degree of support: Check consistency between rating and review using sentiment analysis; amplify hidden sentiments
    - E.g., rate a phone as 1-star because it is the best ☹

Research Issues

- Determination of trust / influence from social networks
  - Text analytics on communication
  - Analysis of network topology
    - E.g., follower relationship, friend relationship, etc.
- Determination of untrustworthy and anti-social elements in social networks
- HOLY GRAIL: Direct Semantics in favor of Indirect Translations

Research Issues

- Evolving trust ontology
  - Introducing trust threshold
    - For binary decision to act in spite of vulnerability/risk
  - Structuring trust scope
    - Class hierarchy
  - Structuring trust value
    - Or does *relative* trust suffice?
  - Refining trust types
    - Or does trust scope suffice?
  - Restrictions on trust propagation
    - Limited horizon

Research Issues

- Improving Security : Robustness to Attack
  - How to exploit different trust processes to detect and recover from attacks?
    - Bad mouthing attack
    - Ballot stuffing attack
    - Sleeper attack
      - Temporal trust discounting proportional to trust value
      - Using *policy-based process* to ward-off attack using *reputation-based process*
    - Sybil attack
    - Newcomer attack

Research Issues

- Intelligent integration of mobile sensor and social data for situational awareness
  - To exploit complementary and corroborative evidence provided by them
  - To obtain qualitative and quantitative context
  - To improve robustness and completeness
  - To incorporate socio-cultural, linguistic and behavioral knowledge as part of ontologies to improve semantic processing and analysis of data

Interpersonal Networks

Research Issues

- Linguistic clues that betray trustworthiness
- Experiments for gauging interpersonal trust in real world situations
  - *Techniques and tools to detect and amplify useful signals in Self to more accurately predict trust and trustworthiness in Others

*IARPA-TRUST program

Research Issues

- Study of cross-cultural differences in trustworthiness qualities and trust thresholds to better understand
  - Influence
    - What aspects improve influence?
  - Manipulation
    - What aspects flag manipulation?

Conclusion

- Provided simple examples of trust (Why?)
- Explained salient features of trust (What?)
- Showed examples of gleaning trustworthiness (How?)
- Touched upon research challenges for gleaning trustworthiness in
  - Sensor Networks
  - Social Networks
  - Interpersonal Networks

Thank You!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