Trust in the Internet of Things
From Personal Experience to Global Reputation

Nguyen Truong

PhD student, Liverpool John Moores University

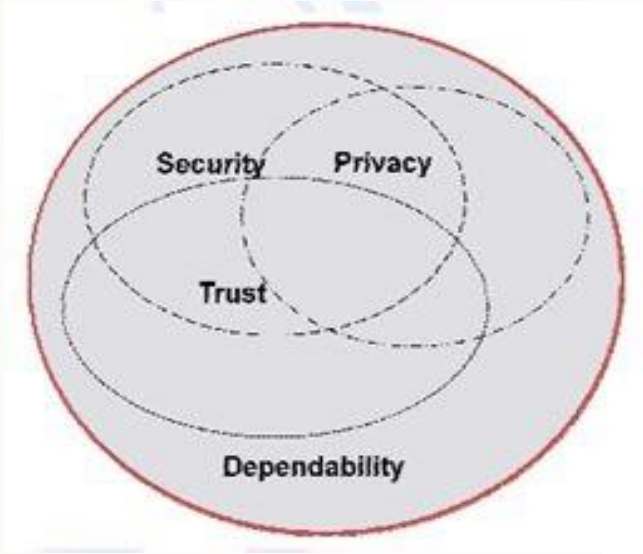
Outline

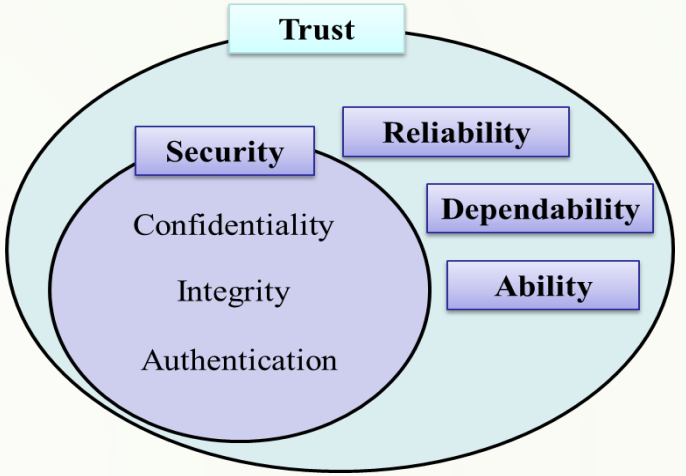
I. Background on Trust in Computer Science
II. Overview of Trust Evaluation Mechanisms
III. Experience and Reputation and REK Trust Evaluation Model

I. BACKGROUND ON TRUST IN COMPUTER SCIENCE

Understanding of Trust in Computer Science

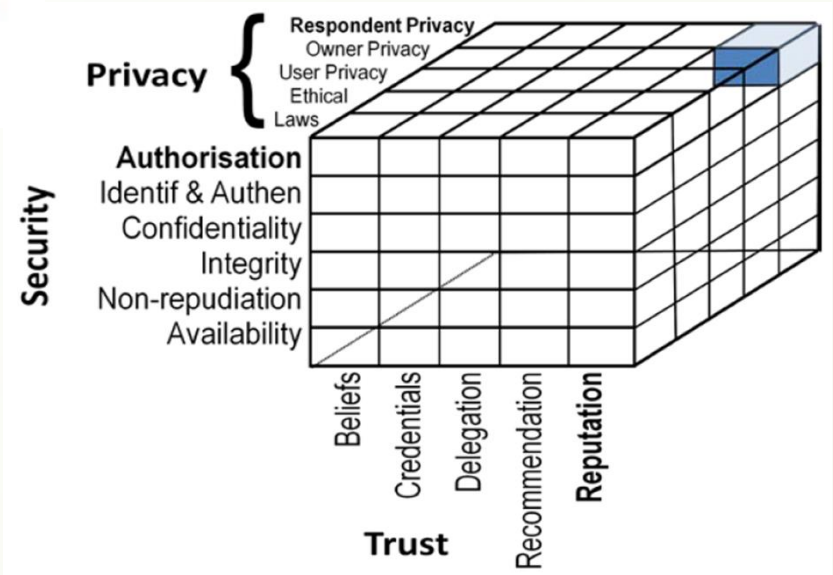
- Definitions?
- Metrics?
- Attributes?





Different views on Trust

- IoPTS
  - Internet of People, Things and Services (**Privacy, Trust, Security**)



(Source) JHP Eloff, et al., "Internet of People, Things and Services - The Convergence of Security, Trust and Privacy"

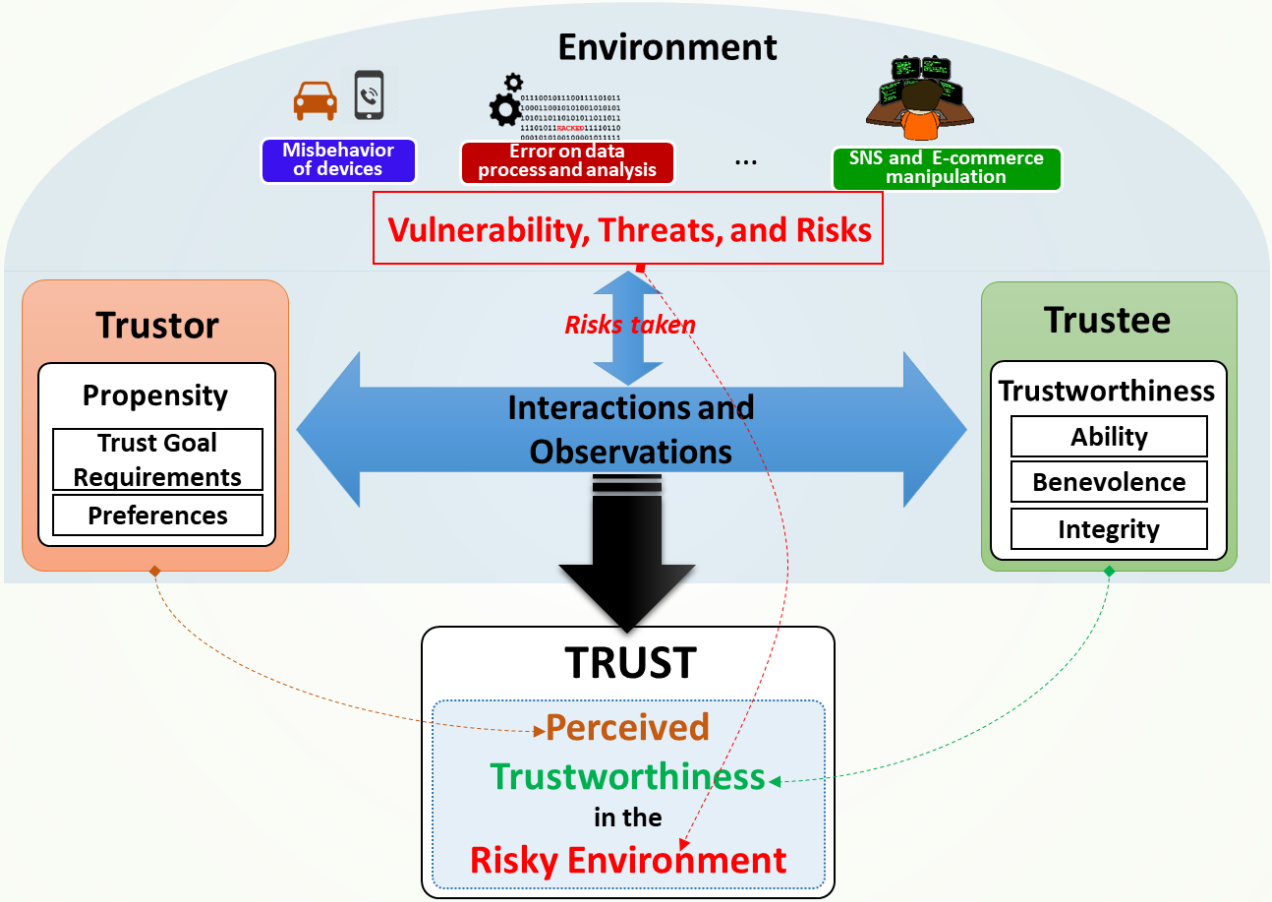
A General Definition of Trust (1)

- *"Belief" or "assurance" of trustor on trustee that the trustee will act in a way not causing harms and as expected*

- Trust is the *perception of a trustor* on *trustee's trustworthiness* under a *particular environment* (within a *period of time*)
  - Trustors and Trustees are computing institutions

(Source) Nguyen B. Truong, et al., "Toward a Trust Evaluation Mechanism in the Social Internet of Things" , SENSORS, 2017

A General Definition of Trust (2)



Trust is the *perception of a trustor* on *trustee's trustworthiness* under a *particular environment*

Importance of Trust in ICT

- Trust helps both humans and machines to overcome the perception of uncertainty and risk before making decision

- Trust is expected to:
  - Become a key property to establish reliable and seamless connectivity and transactions
  - Offer securer and more privacy for services

"Despite the presence of effective base technologies, there remains a need for further innovation before **trust** can be **managed efficiently** at the service level".

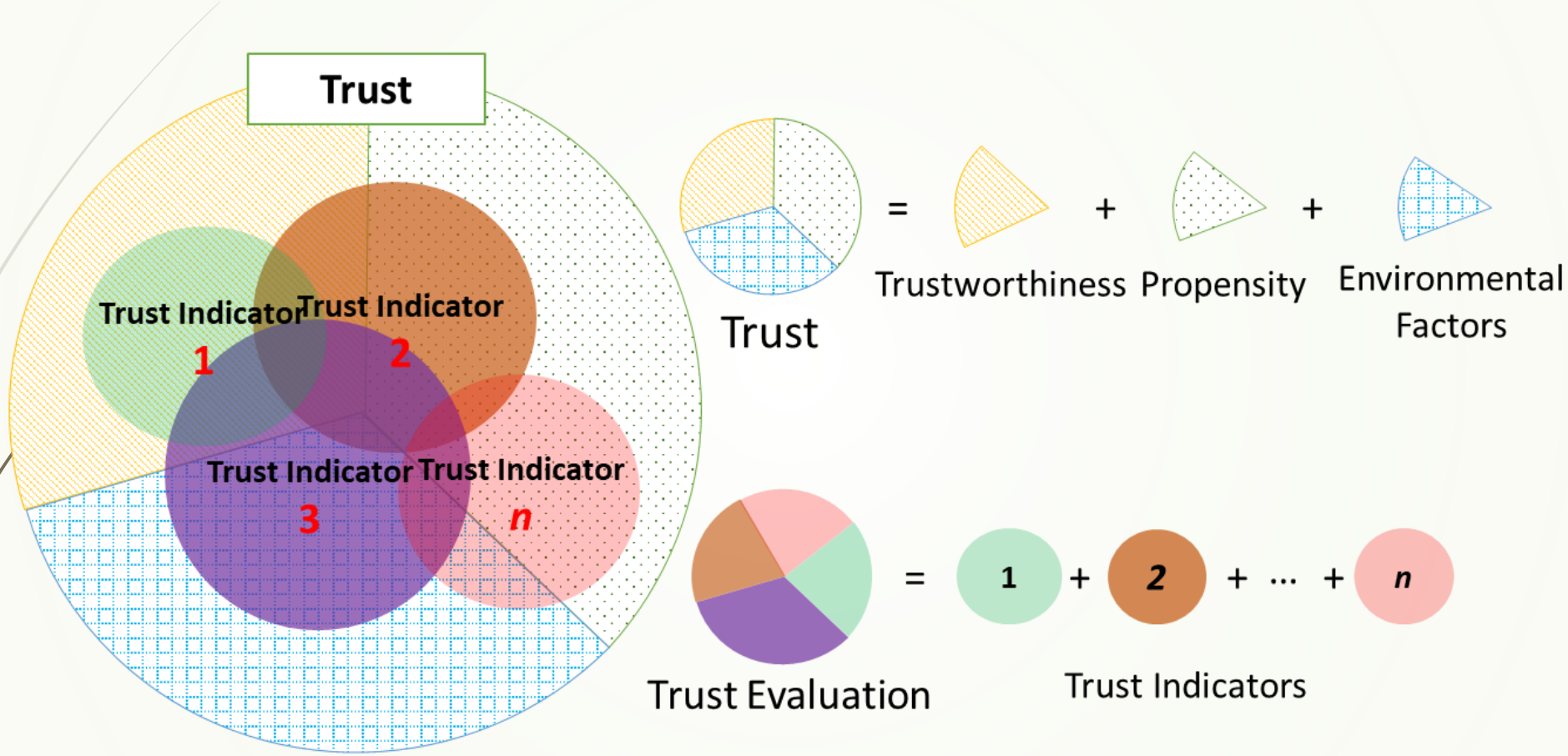
Patricia Hewitt - UK former minister for e-commerce

Research Topics on Trust

- How to build & improve Trust?
  - Security mechanisms
  - Privacy mechanisms
  - Transparency and Accountability
- **How to manage & evaluate Trust?**
  - System Dependability
  - Evidence-based Evaluation mechanisms
  - Feedback & Reputation mechanisms

II. OVERVIEW OF TRUST EVALUATION MECHANISMS

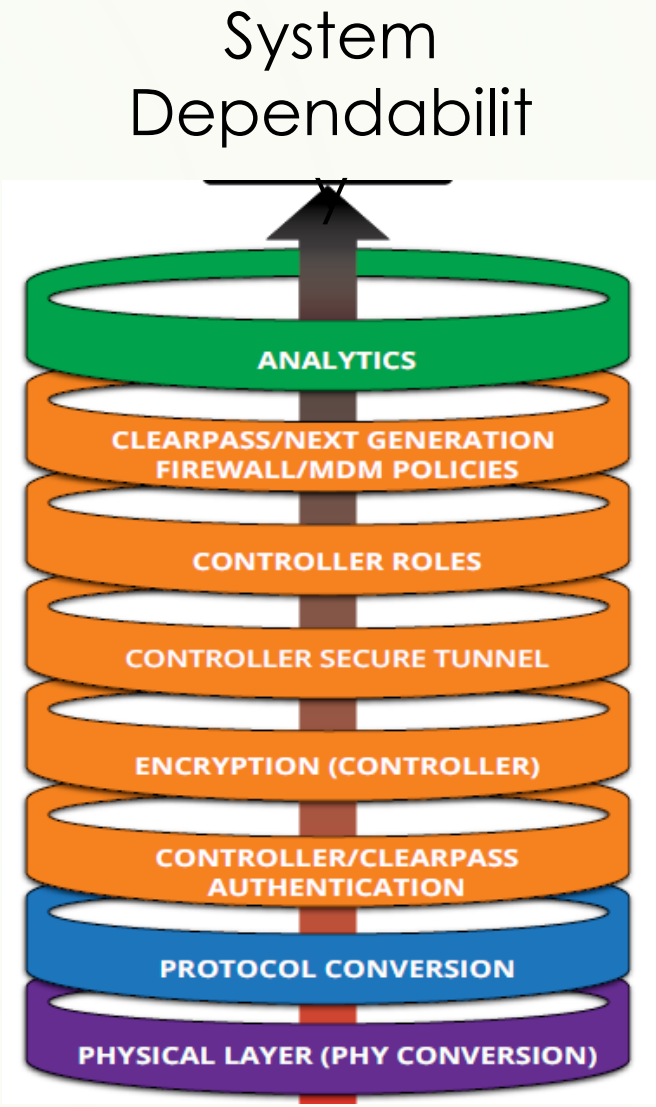
Trust Evaluation Models



(Source) Nguyen B. Truong, et al., "Toward a Trust Evaluation Mechanism in the Social Internet of Things", SENSORS, 2017

Some Trust Evaluation Mechanisms (1)

1. **Observation-based Trust Evaluation (System Dependability):** To show how a institution is going to operate
   - Attributes: Availability, Integrity, Safety, Confidentiality, Serviceability, Reliability
   - Method:
     - Dependability model for evaluating these Attributes



"CONNECT-AND-PROTECT: Building a Trust-Based Internet of Things for Business-Critical Applications" @Aruba Networks, HP

Some Trust Evaluation Mechanisms (2)

2. **Reputation-based approaches**
   - Gathering feedback (E-commerce) (1)
   - PageRank-like algorithms: EigenTrust (2), Web Ranking (4)
3. **Graph theory-based approaches** (Malicious peers detection in Social networks) (3)

(1) S. Kraounakis and e. al., "A Robust Reputation-Based Computational Model for Trust Establishment in Pervasive Systems," IEEE Systems Journal, pp. 878-891, 2015

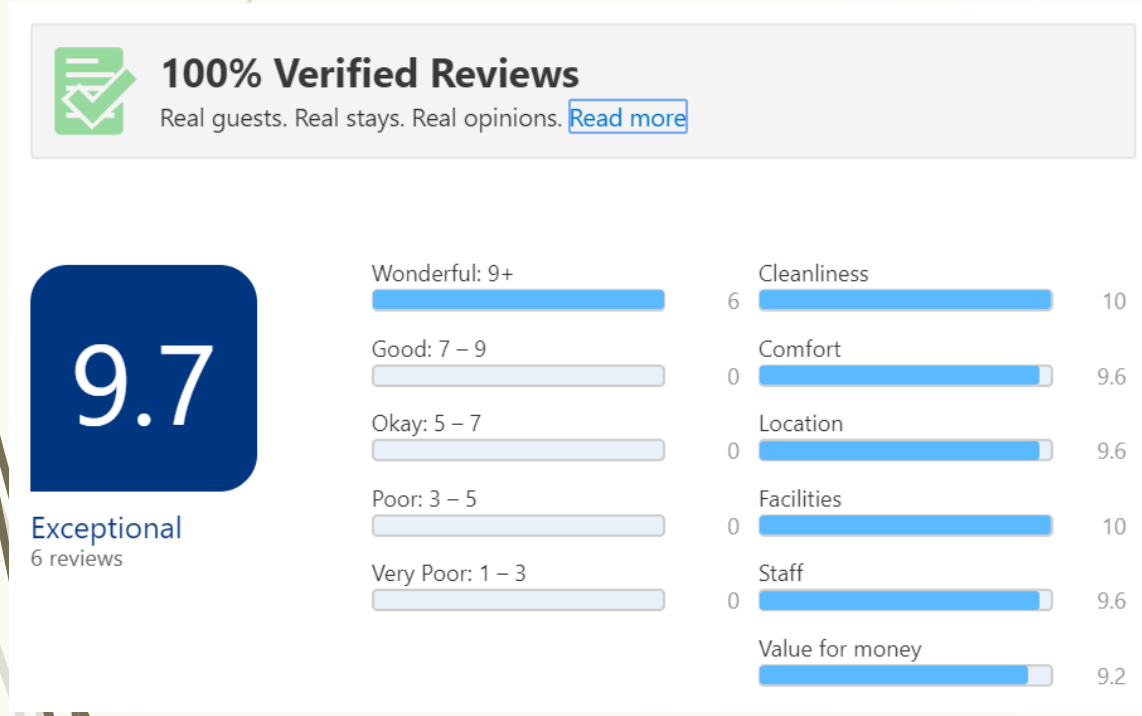
(2) S.D Kamvar, M.T Schlosser, and H. Garcia-Molina, The eigentrust algorithm for reputation management in p2p networks. World Wide Web (WWW) Conference 2003(pp. 640-651).

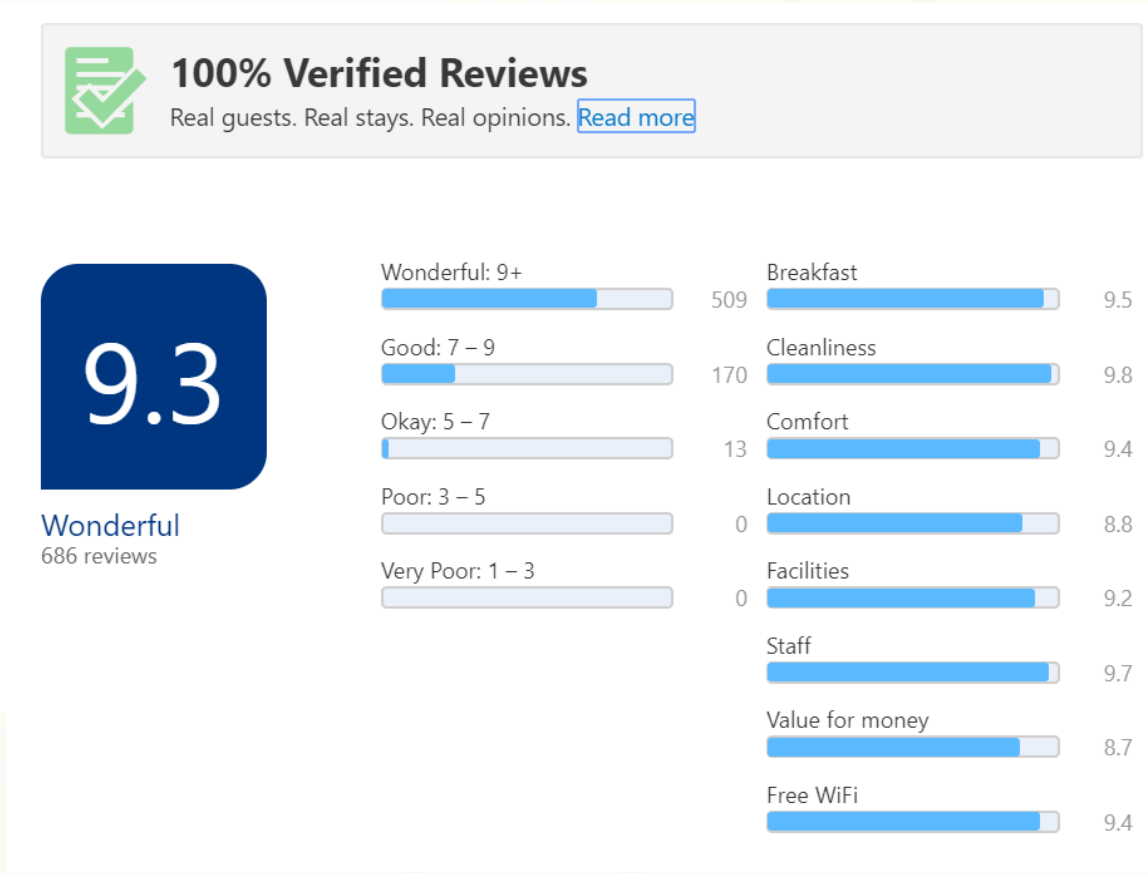
(3) Golbeck, Jennifer Ann. "Computing and applying trust in web-based social networks." (2005)

(4) S. Brin and L. Page, "Reprint of: The anatomy of a large-scale hypertextual web search engine," Computer Networks, vol. 56, no. 18, p. 3825–3833, 2012

Reputation-based Trust Evaluation: Gathering feedbacks

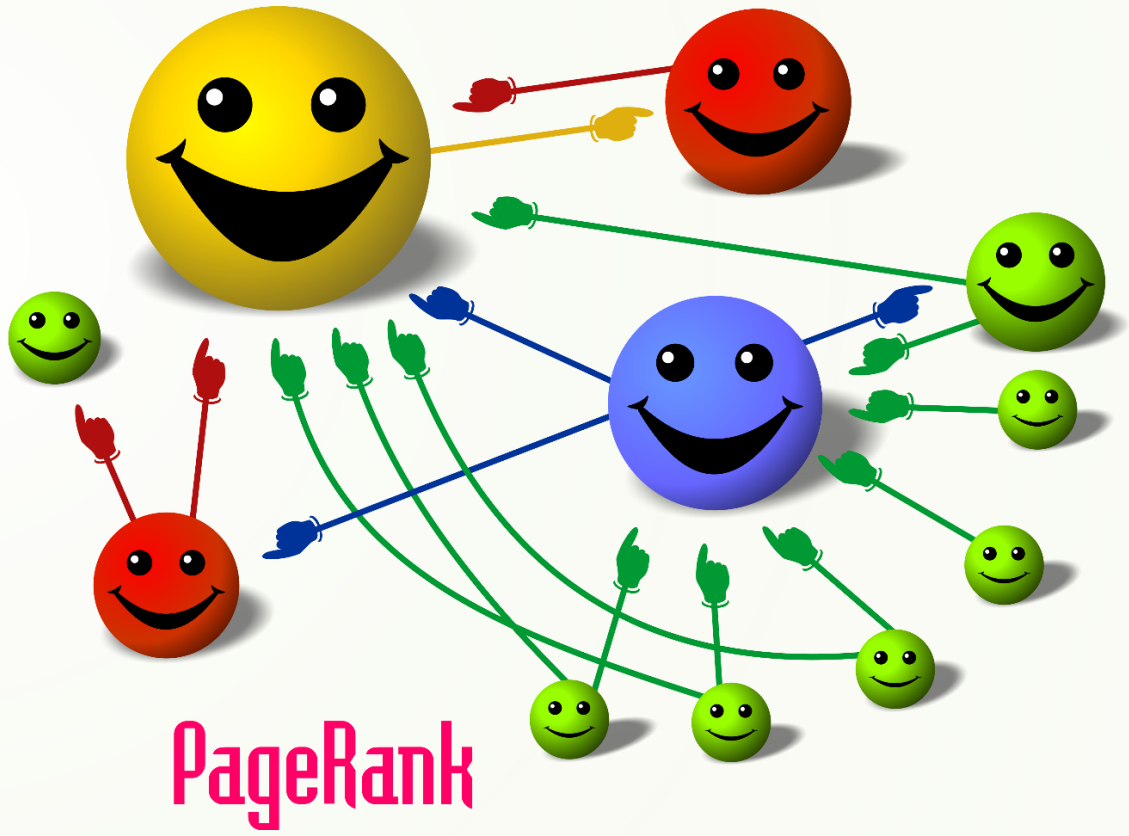
Which hotel is more trusted?

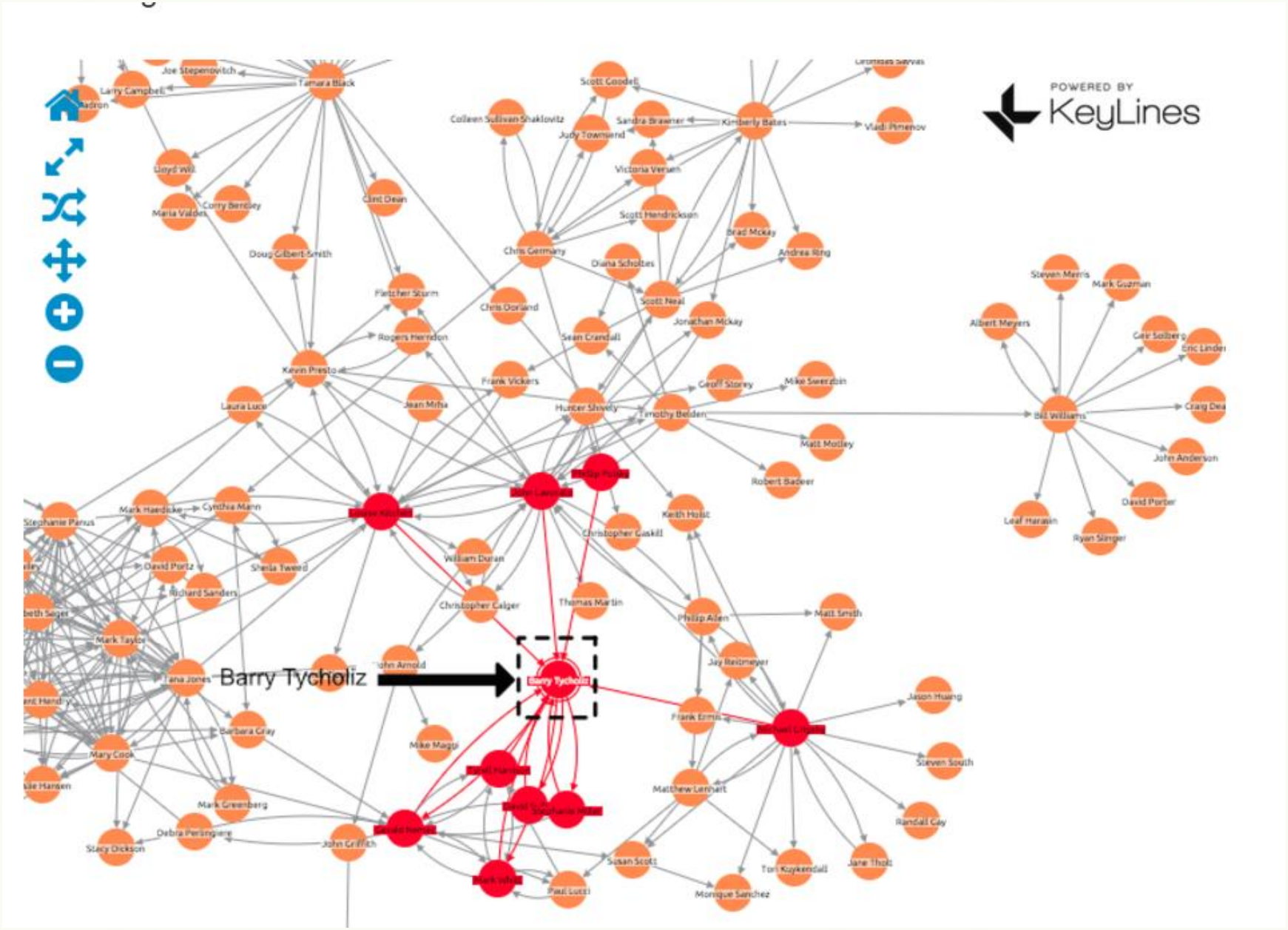




Reputation-based Trust Evaluation: PageRank and EigenTrust

- The size of each face is proportional to the total size of the other faces which are pointing to it.
- Any issue with this approach for trust evaluation?




POWERED BY
KeyLines
Barry Tycholiz
Tamara Black
Kimberly Bates
Chris Germany
Kevin Presto
Hunter Shively
Timothy Belden
Bill Williams
Barry Tycholiz
Tana Jones
Mark Taylor
Barbara Gray
Mary Cook
Mark Greenberg
Debra Perlingiere
Stacy Dickson
John Griffith
Susan Scott
Matthew Lenhart
Jay Reitmeyer
Philip Allen
Frank Ermis
Matt Smith
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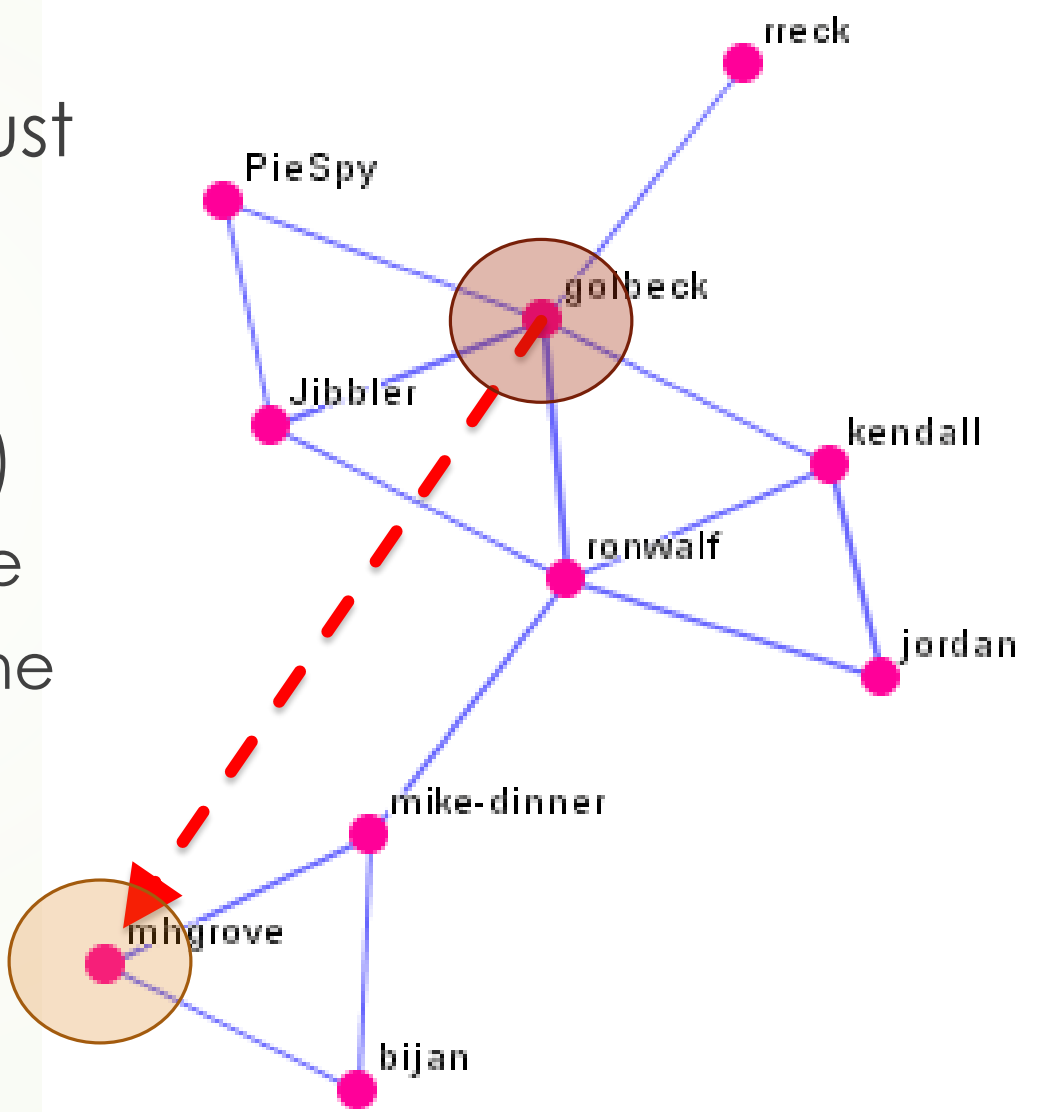
Andrea Ring
Albert Meyers
Steven Morris
Mark Guzman
Geir Solberg
Eric Linder
Craig Dean
John Anderson
David Porter
Ryan Slinger
Leaf Harasin

Graph Theory-based Trust Evaluation

- Based on transitivity property of trust
  - Recommendation-based trust
- Mechanism:
  - Compose trust values (edge weights)
  - Find a route from a trustor to a trustee
  - Calculate the trust value based on the route (path length).

→Trust is transferred over the network

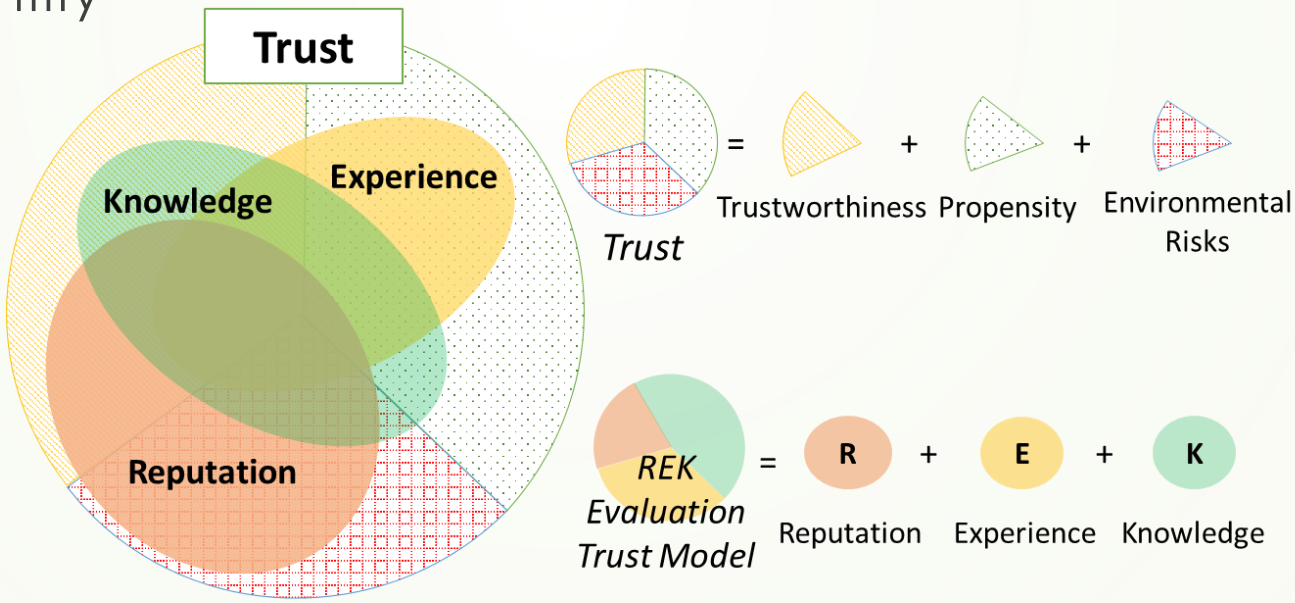


III. REK TRUST EVALUATION MODEL

FROM PERSONAL EXPERIENCE TO GLOBAL REPUTATION

REK Trust Evaluation Model

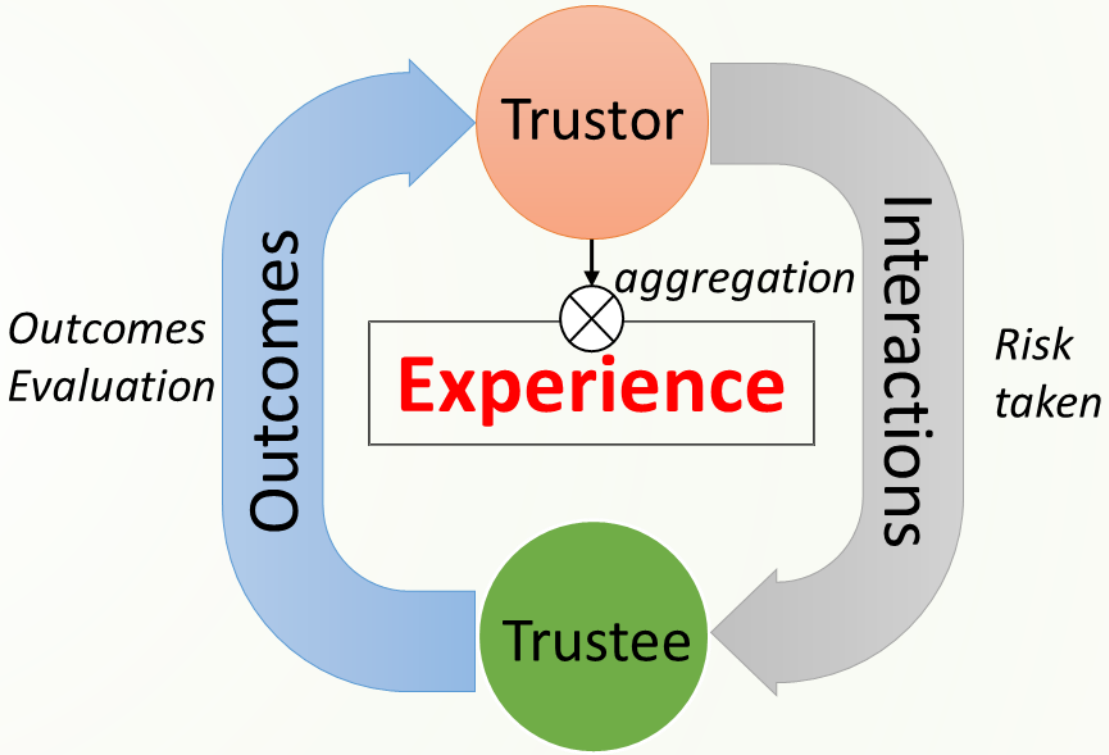
- **Knowledge**: direct observation based on properties of the three factors of trust
- **Experience**: personal trust between two entities quantified by aggregating previous interactions between the two.
- **Reputation**: a properties of an entity quantified by considering all Experience pointed to that entity



(Source) Nguyen B. Truong, et al., "From Personal Experience to Global Reputation in the Internet of Things", IEEE Globecom 2017

Experience (1)

- A asymmetric relationship between a trustor and a trustee
- Experience tends to follow the assumptions from many trust-related sociological literature
  - **Develops** due to cooperative interactions
  - **Decreases** due to uncooperative interactions
  - **Decays** when it is not maintained



The Experience Model

Experience (2)

- Development

$$Exp_{t+1} = Exp_t + \Delta Exp_{t+1}$$

$$\Delta Exp_{t+1} = \alpha - \alpha \times \frac{Exp_t}{max_{Exp}}$$

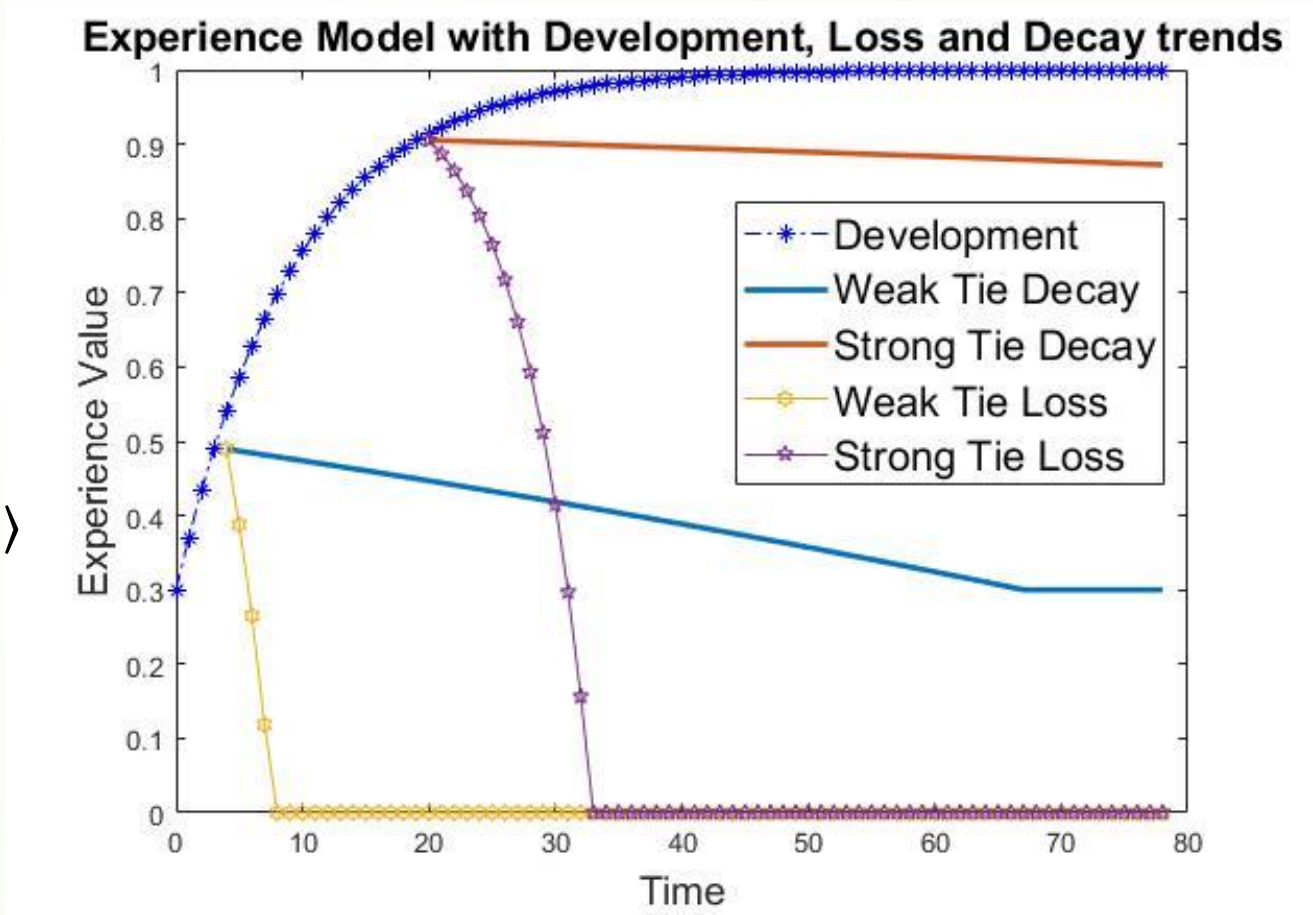
- Loss

$$Exp_{t+1} = Max\langle min_{Exp}, Exp_t - \beta \times \Delta Exp_{t+1}\rangle$$

- Decay

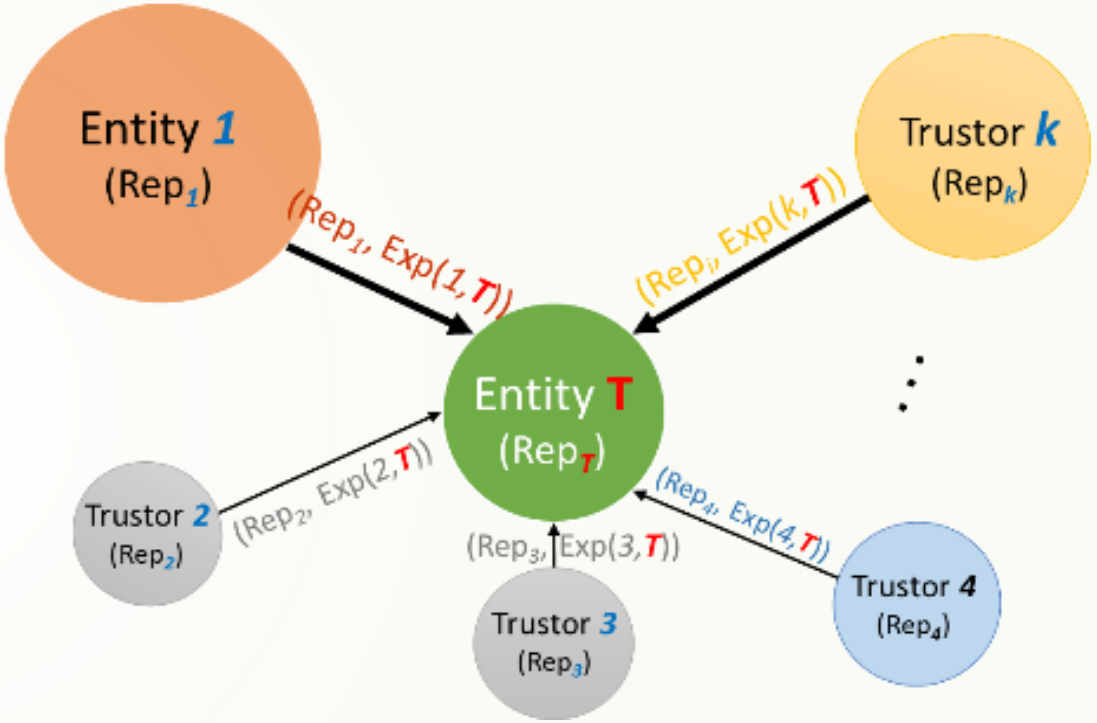
$$Exp_{t+1} = Max\langle init_{Exp}, Exp_t - \Delta decay_{t+1}\rangle$$

$$\Delta decay_{t+1} = \delta \times \left(1 + \gamma - \frac{Exp_{t-1}}{max_{Exp}}\right)$$



Reputation (1)

- Reputation is originally from social science concept corresponding to a general (global) understanding about an entity.
- Consider a directed graph in which:
  - Edges are Experiences from a trustor node to a trustee node
  - Reputation of a node is calculated based on all edges pointed to it



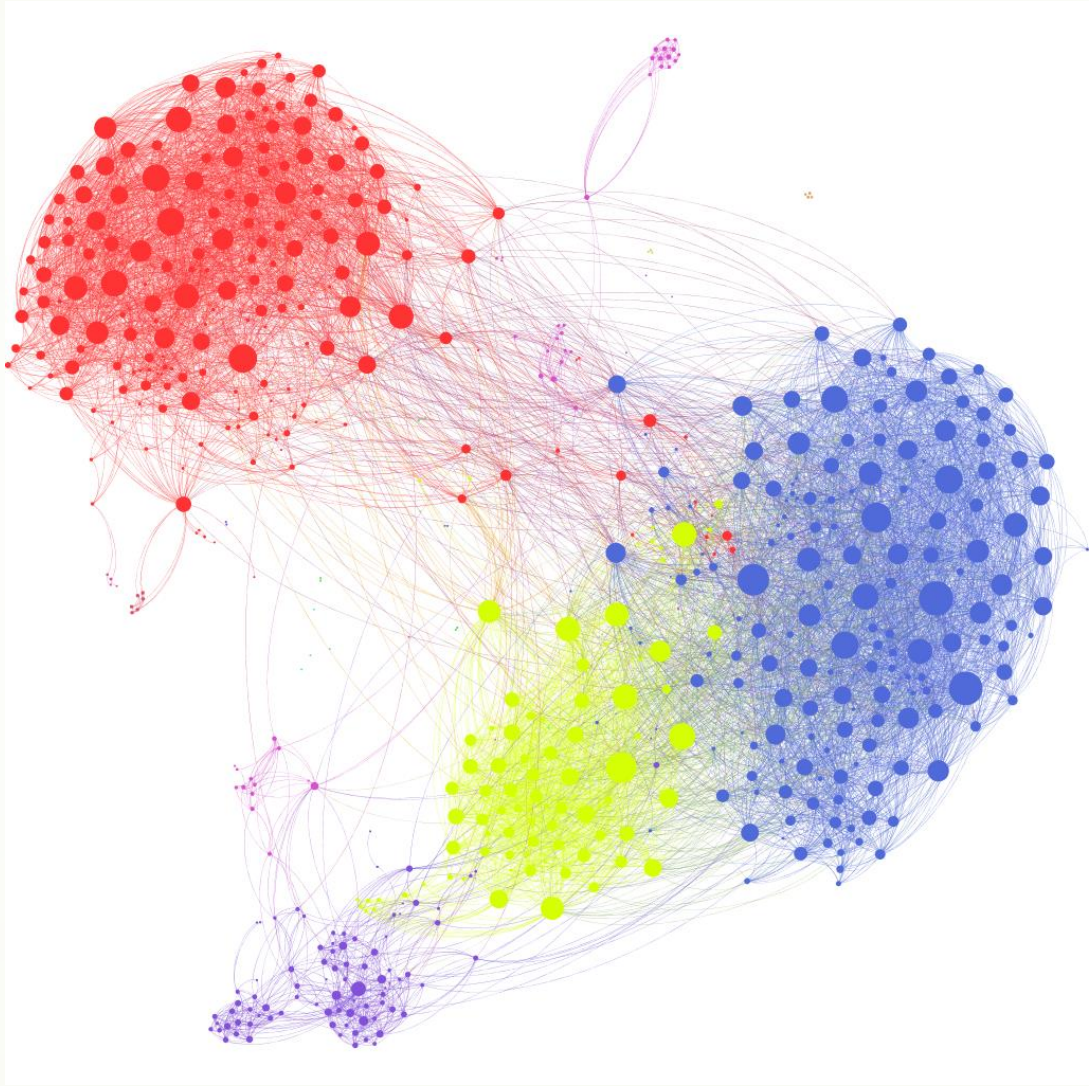
Reputation (2)

→ PageRank-like mechanism

- Differences:
  - Have each edge has its weight
  - Contain both supportive edge and unsupportive edge

→ Solution: weighted PageRank

→ Solution: Separate supportive edges ($Exp(i, X) \geq \theta$ threshold) and unsupportive edges ($Exp(j, X) < \theta$ threshold)



Graph of a social network indicating reputation

Reputation (3)

- Mathematical Equations:

$$Rep_{Pos}(X) = \frac{(1-\boldsymbol{d})}{N} + \mathrm{d} \times \left(\sum_{\forall i} Rep_{Pos}(i) \times \frac{Exp(i,X)}{C_{Pos}(i)} \right)$$

$$Rep_{Neg}(X) = \frac{(1-d)}{N} + \mathrm{d} \times \left(\sum_{\forall i} Rep_{Neg}(i) \times \frac{1-Exp(i,X)}{C_{Neg}(i)} \right)$$

$$Rep(X) = \max\left(min_{Rep}, Rep_{Pos}(X) - Rep_{Neg}(X)\right)$$

Reputation (4)

- Where:

- $\boldsymbol{Rep(i)}$ is the reputation of the entity *i* that we are interested. Equation (10) guarantees that Reputation TI values are not below min_{Rep} (i.e., 0).
- $\boldsymbol{N}$ is total numbers of entities in the networks for calculating Reputation
- $\boldsymbol{d}$ is the damping factor. Various studies on web ranking have tested different damping factors and come up at *0.85*.
- $\boldsymbol{Exp(i,X)}$ is Experience TI from the entity *i* toward the entity *X* described in Section III.
- $\boldsymbol{Rep_{Pos}(i)}$is positive reputation of the entity *i* which considers only supportive recommendations.
- $\boldsymbol{C_{Pos}(i)}= \sum_{\boldsymbol{Exp(i,j)>\theta}} \boldsymbol{Exp(i,j)}$is the total values of all experiences in supportive recommendations that the entity *i* is currently sharing.
- $\boldsymbol{Rep_{Neg}(i)}$ is negative reputation of the entity *i* which considers only unsupportive recommendations.
- $\boldsymbol{C_{Neg}(i)} = \sum_{\boldsymbol{Exp(i,j)<\theta}}(\boldsymbol{1} - \boldsymbol{Exp(i,j)})$ is total compliments of experiences in all negative recommendations that the entity *i* is currently sharing.

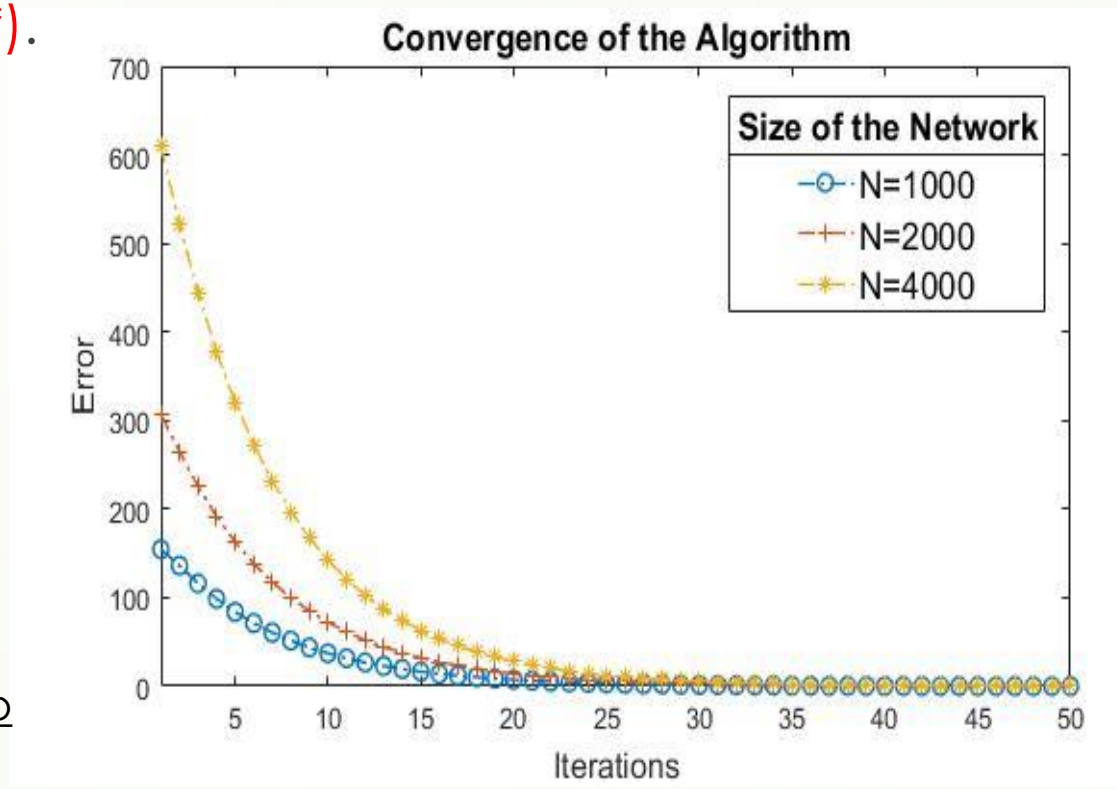
Reputation (5)

Considering Reputation for supportive Experiences:

- Let Rep_{Pos} is the vector of the positive reputation $Rep_{Pos}(i)$ $\forall i = \overline{1, N}$.
- Similar to PageRank, it is existed and unique (*).
- Rep_{Pos} can be calculated using either

Algebraically (not suitable with large N)

or iteratively (as Google is doing).



Details of the (*) proof can be found in our paper Nguyen B. Truong, et al., "From Personal Experience to Global Reputation in the Internet of Things", IEEE Globecom 2017

Overall Trust Value

$$Trust(A,B) = \alpha Rep(B) + \beta Exp(A,B) + \gamma Knowledge(A,B)$$

Thank you for your listening