Impact of Trust on the Performance of a Recommendation System in a Social Network

Frank E. Walter, Stefano Battiston, and Frank Schweitzer

{fewalter,sbattiston,fschweitzer}@ethz.ch

ECCS 06, Oxford, UK

Agenda

Motivation

- Greater and greater importance of the Internet in everyone's life
- People have to cope with an *information overload*
- Many *social mechanisms* that people rely on in the real world do not have an appropriate *digital mapping*
- Emergence of Internet services based on *social networking*

Both from a theoretical and a practical perspective, formal and quantitative approaches are necessary

Recommendation Systems

Recommendation systems: means to cope with information overload through filtering

- *majority rules*: based on frequency of recommendations, thus not personalised for agents
- *similarity-based*: low effort, but passive and no active tuning

A social network can be leveraged for reduced effort *and* tuning of the recommendation system at the same time!

- *use an agent's social network* to reach distributed knowledge
- *incorporate trust* to filter reachable knowledge

"Trust": appropriateness and reliability of former recommendations
$\longrightarrow$ *trust-based*: high effort, not passive but active tuning

Trust-Based Networks

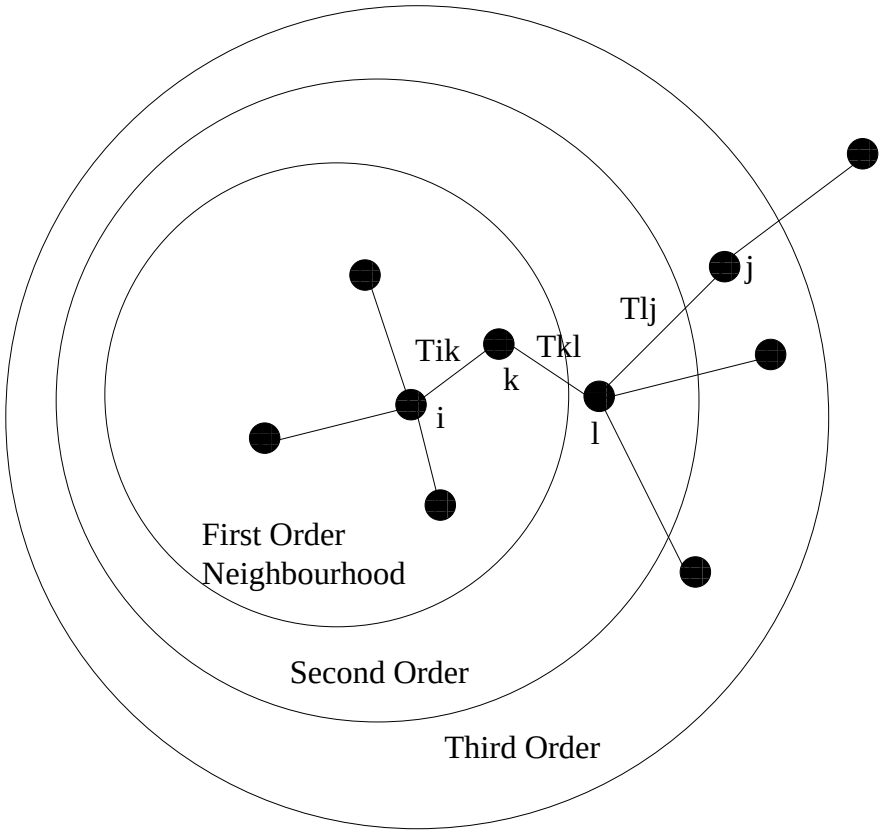
Recommendation systems in trust-based networks outperform majority-based recommendation systems within a range of:

- *network density*:
  - if the network is not dense enough, agents receive replies with recommendations on only a fraction of the items they query about
- *preference heterogeneity*:
  - if agents are very homogeneous, there is no need for filtering, almost any recommendation will be appropriate
  - if agents are too heterogenous, they cannot find other agents that act as suitable filters

Model Outline

- Scenario: agents select products based on recommendations
  - N_a agents connected in a social network
  - N_p products classified in N_c categories
- Agents:
  - Rational and self-interested agents
  - Agent preference values for products: $f_{a,p} \in [-1, 1]$
  - Each agent knows its own preference values for m of categories
  - Product selection based on trusted recommendations
  - Trust T_{a_i,a_j} from a_i to a_j is updated over time
  - Utility of the agents: $U_{a,p} = F(f_{a,p}, cost)$
- Performance of the system: $\Phi = \left\langle \frac{1}{N_a} \sum_{a_i} U_{a_i} \right\rangle_{time}$

Illustration



Temporal Structure

At each time step t:

- Each agent a purchases one item from a randomly chosen category l of products
- Agent a sends a query to the network to inquire about the preferences of other agents on that category
- Based on the responses, a makes its choice, and realizes a value of utility
- Based on the utility, a updates the value of trust towards the neighbour who transmitted the recommendation chosen

Queries, Search, and Responses (1)

A query consists of:

- id of querying agent a_q
- id of category c requested

Search on the network (essentially a non-exhaustive *BFS*):

- a_q sends query to all its first neighbours
- a_k receives query and either replies or passes it on
- eventually, agent a_q receives a set of responses

Queries, Search, and Responses (2)

A response consists of:

- id of recommended product p
- preference from recommender $f_{a_r,p}$
- product of trust values along the path involved:

$$\tau_{a_q,a_r} = \prod_{(a_k,a_l) \in \mathrm{path}(a_q,a_r)} T_{a_k,a_l}$$

- id of neighbour a_n who transmitted the recommendation

Decision Making

- The querying agent a_q chooses from a set of k responses obtained from the network: $\{f_{a_r,p}, \tau_{a_q,a_r}\}$, $r = 1, ..., k$
- The probability of selecting recommendation r is given by a *logit function* of the products of value and trust:

$$P_{a_q,p_r} = \frac{\exp(\beta \tau_{a_q,a_r} f_{a_r,p_r})}{\sum_r \exp(\beta \tau_{a_q,a_r} f_{a_r,p_r})}$$

  where β measures the *risk aversion* of agents
- Note that agents only know the identity of a_n, i.e. the neighbour that the recommendation came through

Dynamics of Trust

- Range: $T_{a_i,a_j}(t) \in [0,1]$; thus $\tau_{a_q,a_r} \in [0,1]$
- Initialisation: $T_{a_i,a_j}(t=0) = 0.5$
- Update: only towards neighbours a_j of agent a_i and only in the following two cases:
  1. a_i has chosen an item directly recommended by a_j
  2. a_i chooses a recommendation which came through a_j

$$
\begin{aligned}
r_{a_i,a_j,p} &= (1 - |f_{a_i,p} - f_{a_j,p}|) \\
\tilde{T}_{a_i,a_j} &= \gamma \tilde{T}_{a_i,a_j} + r_{a_i,a_j,p} \\
T_{a_i,a_j} &= \frac{1}{2}(1 + \tanh(\beta \tilde{T}_{a_i,a_j})) \in [0,1]
\end{aligned}
$$

where $\gamma \in [0,1]$ is a parameter controlling the memory size

Special Case

- Discrete preferences from the set $\{-1, +1\}$
- Each agent has one profile from a set of k distinct profiles
- The sum of preferences over a profile is equal to 0
- The social network is a random graph with a certain density
- There are N_p products in N_c categories

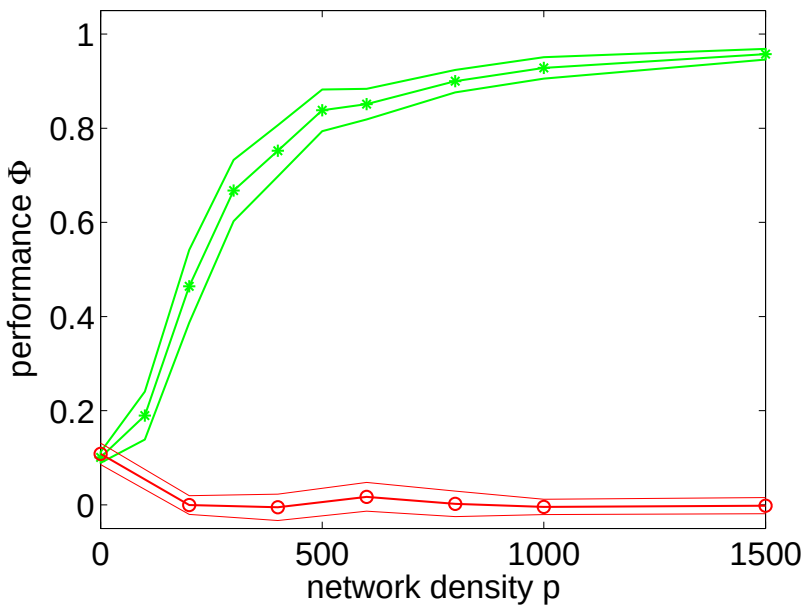
Analytical Approximation

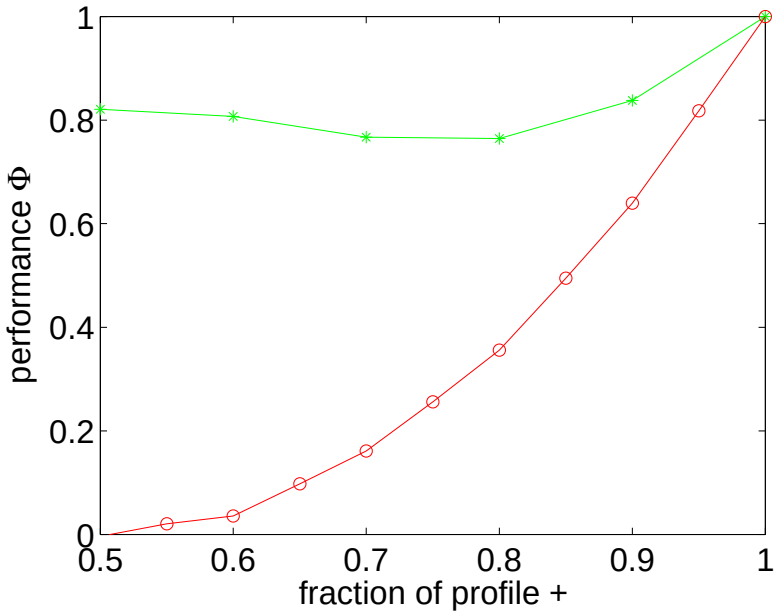
Outline: the expected preference from a choice is

$$E(f_{a_q,p_r}) = \sum_{p_r} f_{a_q,p_r} P_{a_q,p_r} = \frac{\sum_{p_r} f_{a_q,p_r} \exp(\beta \tau_{a_q,a_r})}{\sum_{p_r} \exp(\beta \tau_{a_q,a_r})}$$

- Probabilistic Term = (probability of choosing recommendation from an agent with a given similarity) multiplied by (probability that the similarity value occurs among a_q and a_r)
- The expected utility of the system can be predicted as function of the density of the network and the distribution of the profiles of preferences among the agents!

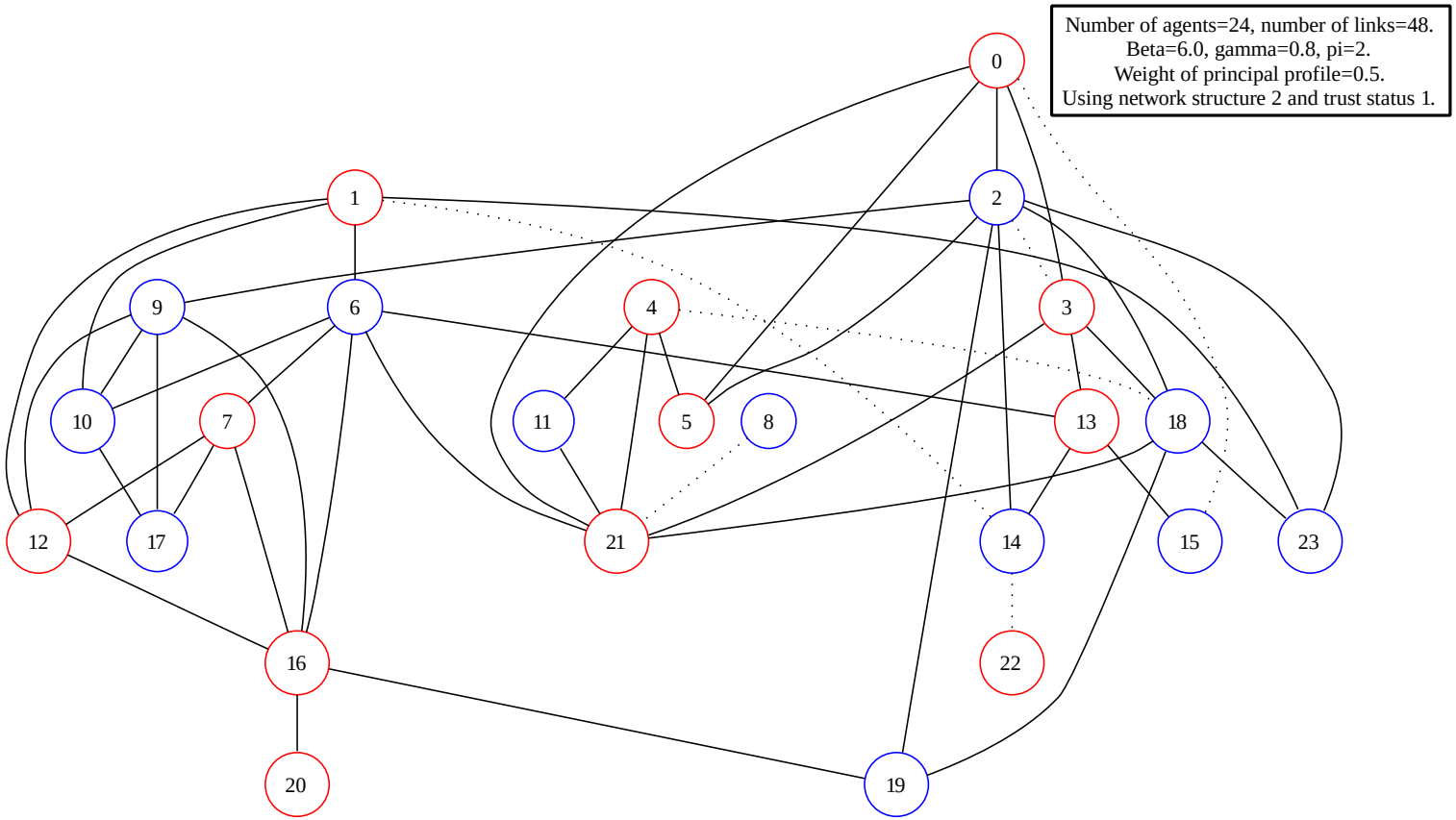
Results





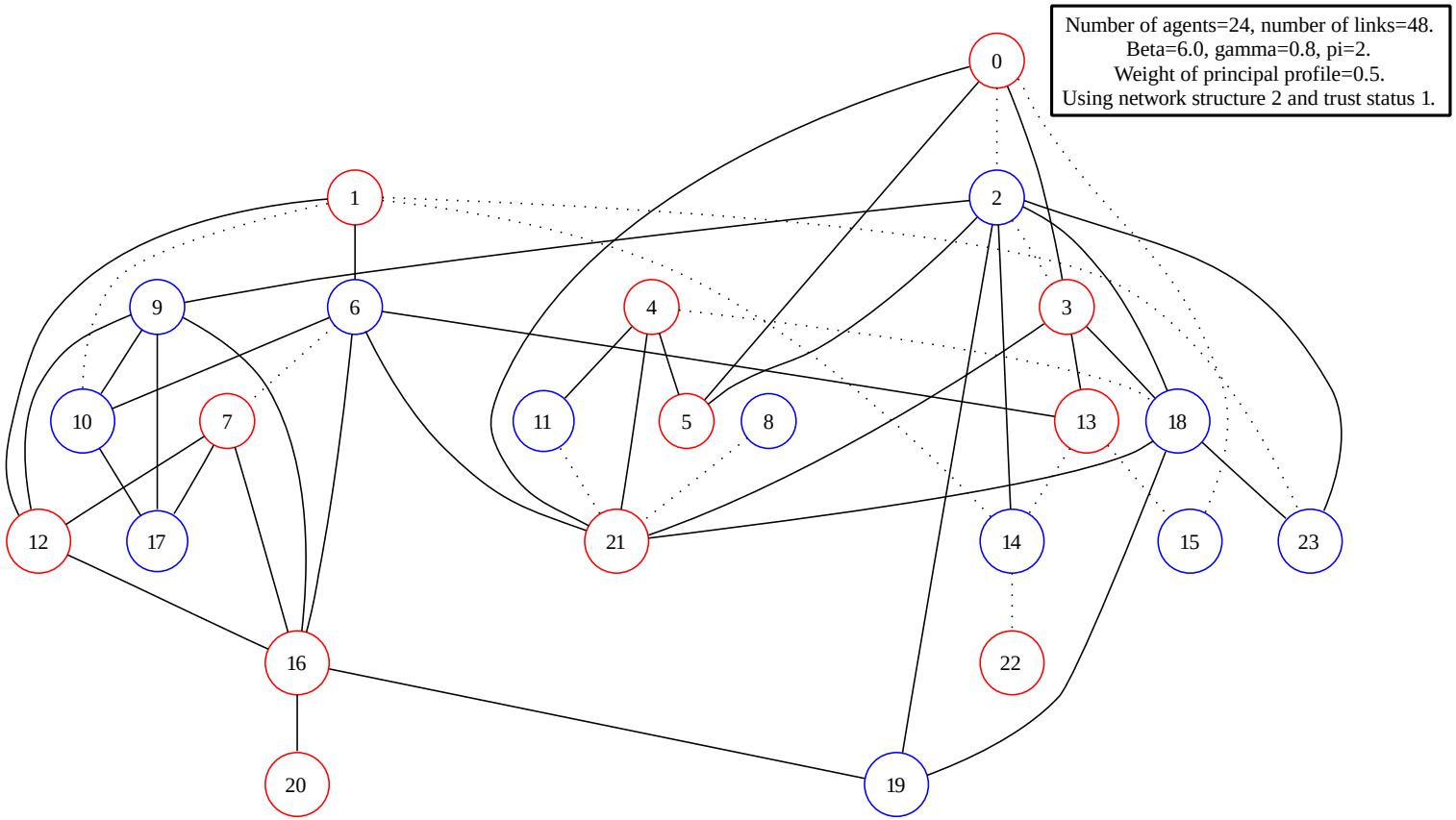
- Trust causes a performance gain above a critical density
- Performance gain decreases with increasing homogeneity

Evolving Network of Trust (1)



Initial stage: random network of agents, each having one of two possible profiles

Evolving Network of Trust (2)



Some time steps have passed: links between agents of different profiles become weaker, between agents of the same profiles stronger

Conclusions

- Recommendation systems in trust-based networks
  - *outperform* majority-based recommendation systems within a range of *network density* and *preference heterogeneity*
  - provide active *tuning* as opposed to passive other approaches
- In a special case, the expected performance can be *approximated analytically* by a mean-field approach
- Possible extensions:
  - different underlying *network structures* and *evolving network*
  - analysis of robustness against *selfish* and *malicious* agents
  - different *trust adjustment mechanisms* from the literature

Additional Resources

Exystence Topical Workshop
Trust-Based Networks and Robustness in Organisations
ETH Zurich, 13-17 March 2006
Frank Schweitzer, Stefano Battiston, Nigel Gilbert

Workshop programme and presentations available from:
`http://intern.sg.ethz.ch/events/TW_Trust/`