Gossipping in Bologna

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Background

- 2003: Márk Jelasity brings the gossipping gospel to Bologna from Amsterdam
- 2003-2006: We get good milage from gossipping in the context of Project BISON
- 2005-present: Continue to get milage in the context of Project DELIS

What have we done?

- We have used gossipping to obtain fast, robust, decentralized solutions for
  - Aggregation
  - Overlay topology management
  - Heartbeat synchronization
  - Cooperation in selfish environments

Collaborators

- Márk Jelasity
- Alberto Montresor
- Gianpaolo Jesi
- Toni Binci
- David Hales
- Stefano Arteconi

Proactive gossip framework

```
// active thread
do forever
    wait(T time units)
    q = SelectPeer()
    push S to q
    pull Sq from q
    S = Update(S,Sq)

// passive thread
do forever
    (p,Sp) = pull * from *
    push S to p
    S = Update(S,Sp)
```


Proactive gossip framework

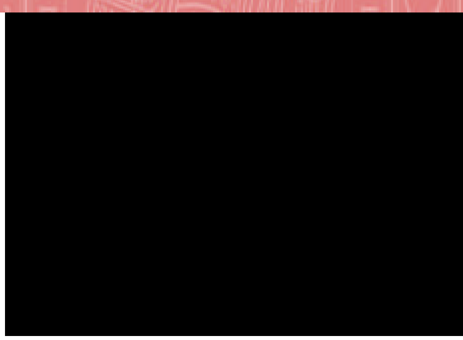
- To instantiate the framework, need to define
  - Local state ***S***
  - Method **SelectPeer()**
  - Style of interaction
    - ? **push-pull**
    - ? **push**
    - ? **pull**
  - Method **Update()**

#1
Aggregation

Gossip framework instantiation

- Style of interaction: push-pull
- Local state ***S***: Current estimate of global aggregate
- Method **SelectPeer()**: Single random neighbor
- Method **Update()**: Numerical function defined according to desired global aggregate (arithmetic/geometric mean, min, max, etc.)

Exponential convergence of averaging

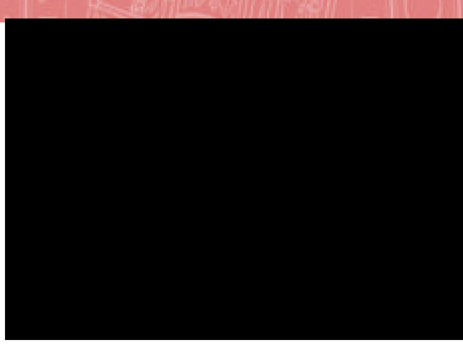


Properties of gossip-based aggregation

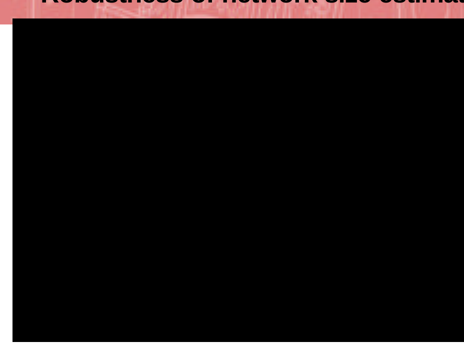
- In gossip-based averaging, if the selected peer is a globally random sample, then the variance of the set of estimates decreases exponentially
- Convergence factor:

$$r = \frac{E(s^2_{i+1})}{E(s^2_i)} \approx \frac{1}{2\sqrt{e}} \approx 0.303$$

Robustness of network size estimation



Robustness of network size estimation

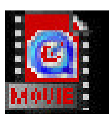


#2
Topology Management

Gossip framework instantiation

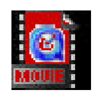
- Style of interaction: push-pull
- Local state ***S***: Current neighbor set
- Method **SelectPeer()**: Single random neighbor
- Method **Update()**: Ranking function defined according to desired topology (ring, mesh, torus, DHT, etc.)

Mesh Example



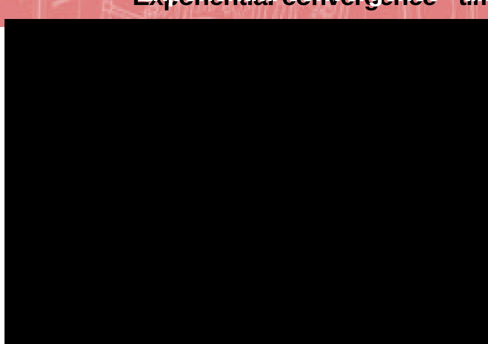
Mesh.mov

Sorting example



Sort-3.mov

Exponential convergence - time



Exponential convergence - network size

#3
Heartbeat Synchronization

Synchrony in nature

- Nature displays astonishing cases of synchrony among independent actors
  - Heart pacemaker cells
  - Chirping crickets
  - Menstrual cycle of women living together
  - Flashing of fireflies
- Actors may belong to the same organism or they may be parts of different organisms

Coupled oscillators

- The "Coupled oscillator" model can be used to explain the phenomenon of "self-synchronization"
- Each actor is an independent "oscillator", like a pendulum
- Oscillators coupled through their environment
  - Mechanical vibrations
  - Air pressure
  - Visual clues
  - Olfactory signals
- They influence each other, causing minor local adjustments that result in global synchrony

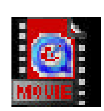
Fireflies

- Certain species of (male) fireflies (e.g., *luciola pupilla*) are known to synchronize their flashes despite:
  - Small connectivity (each firefly has a small number of "neighbors")
  - Communication not instantaneous
  - Independent local "clocks" with random initial periods

Gossip framework instantiation

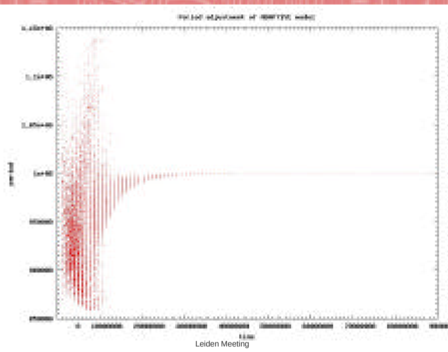
- Style of interaction: push
- Local state ***S***: Current phase of local oscillator
- Method **SelectPeer()**: (small) set of random neighbors
- Method **Update()**: Function to reset the local oscillator based on the phase of arriving flash

Experimental results



fireflies.mov

Exponential convergence



#4
Cooperation in Selfish Environments

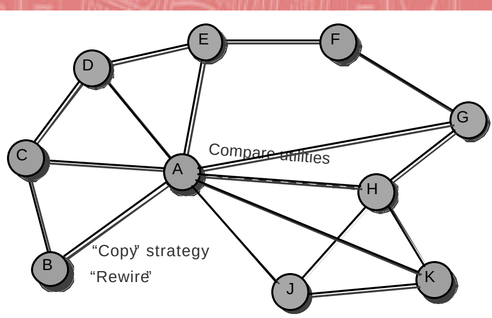
Outline

- P2P networks are usually open systems
  - Possibility to free-ride
  - High levels of free-riding can seriously degrade global performance
- A gossip-based algorithm can be used to sustain high levels of cooperation despite selfish nodes
- Based on simple “copy” and “rewire” operations

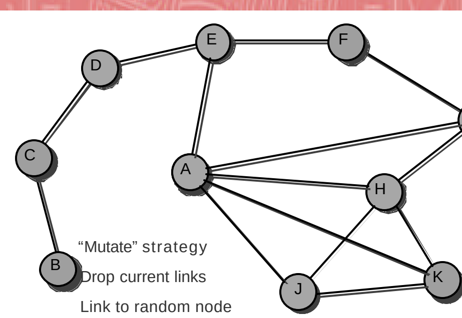
Gossip framework instantiation

- Style of interaction: pull
- Local state ***S***: Current *utility*, *strategy* and *neighborhood* within an *interaction* network
- Method **SelectPeer()**: Single random sample
- Method **Update()**: Copy strategy and neighborhood if the peer is achieving better utility

SLAC Algorithm: “Copy and Rewire”



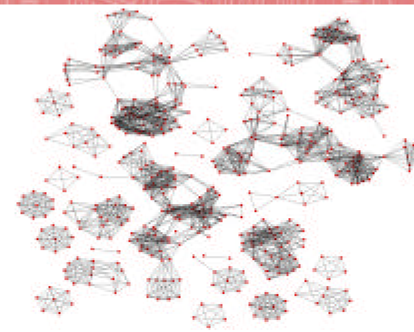
SLAC Algorithm: “Mutate”



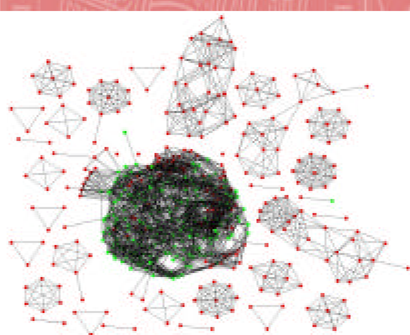
Prisoner's Dilemma

- Prisoner's Dilemma in SLAC
  - Nodes play PD with neighbors chosen randomly in the interaction network
  - Only pure strategies (always C or always D)
  - Strategy mutation: flip current strategy
  - Utility: average payoff achieved

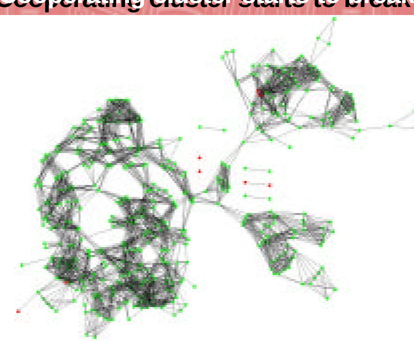
Cycle 180: Small defective clusters



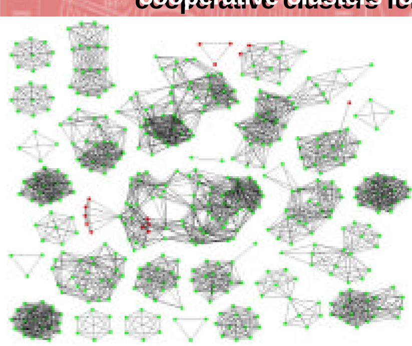
Cycle 220: Cooperation emerges



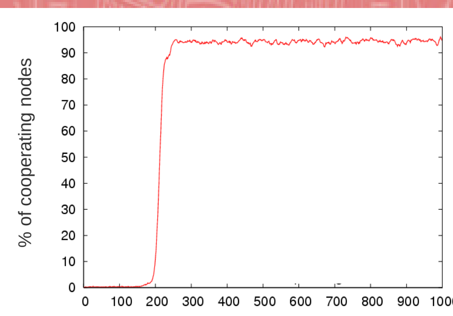
Cycle 230: Cooperating cluster starts to break apart



Cycle 300: Defective nodes isolated, small cooperative clusters formed



Phase transition of cooperation



Broadcast Application

- How to communicate a piece of information from a single node to all other nodes
- While:
  - Minimizing the number of messages sent (*MC*)
  - Maximizing the percentage of nodes that receive the message (*NR*)
  - Minimizing the elapsed time (*TR*)

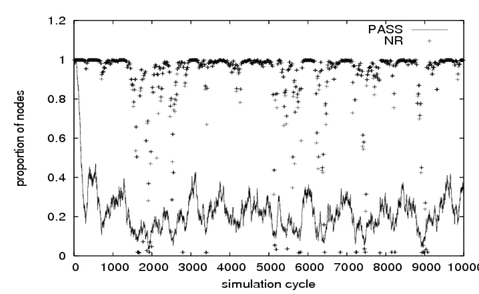
Broadcast Application

- Given a network with N nodes and L links
  - A spanning tree has $MC = N$
  - A flood-fill algorithm has $MC = L$
- For fixed networks containing reliable nodes, it is possible to use an initial flood-fill to build a spanning tree from any node
- Practical if broadcasting initiated by a few nodes only
- In P2P applications this is not practical due to network dynamicity and the fact that all nodes may need to broadcast

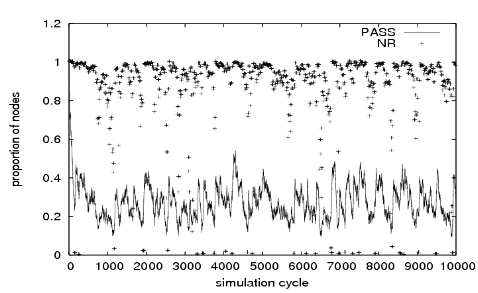
The broadcast game

- Node initiates a broadcast by sending a message to each neighbor
- Two different node behaviors determine what happens when they receive a message for the first time:
  - Pass: Forward the message to all neighbors
  - Drop: Do nothing
- Utilities are updated as follows:
  - Nodes that receive the message gain a benefit ß
  - Nodes that pass the message incur a cost ?
  - Assume ß > ? > 0, indicating nodes have an incentive to receive messages but also an incentive to not forward them

1000-node static random network

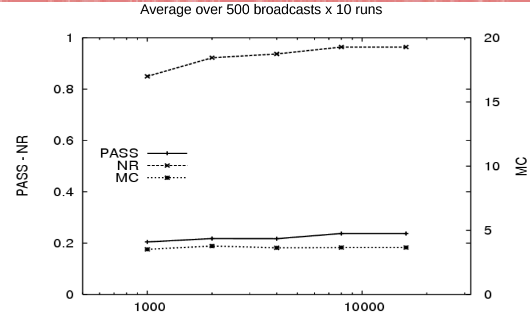


1000-node high churn network



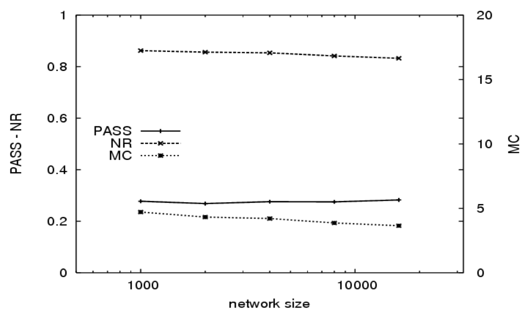
Fixed random network

Average over 500 broadcasts x 10 runs



High churn network

Average over 500 broadcasts x 10 runs



Some food for thought

- What is it that makes a protocol “gossip based”?
  - Cyclic execution structure (whether proactive or reactive)
  - Bounded information exchange per peer, per cycle
  - Bounded number of peers per cycle
  - Random selection of peer(s)

Some food for thought

- Bounded information exchange per peer, per round implies
  - Information condensation — aggregation
- Is aggregation the mother of all gossip protocols?

Some food for thought

- Is exponential convergence a universal characterization of all gossip protocols?
- No, depends on the properties of the peer selection step
- What are the minimum properties for peer selection that are necessary to guarantee exponential convergence?

Gossip versus evolutionary computing

- What is the relationship between gossip and evolutionary computing?
- Is one more powerful than the other? Are they equal?