Engineering Emergence through Gossip

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Abstract Components of Gossip (I)

- Communication network
  - The nodes of the network are people
  - The connections (edges) in the network are defined by relations such as neighbours, friends, relatives, etc. Communication takes place among connected people in this network
  - Network is restricted: e.g. in social networks often small diameter, high clustering, Zipf degree distribution
  - It can change, perhaps as a result of gossip
Communication Algorithm
- People exchange information with their neighbours in the social network more or less regularly.
- They might have a bias towards interacting with some people (famous, rich, understanding, close-by, funny, etc).

Computation
- People also process information: they reason about it, alter or combine it. They also perceive or forget information.
Overlay Networks

- **Communication Network**
  - Nodes are computing devices connected to a computer network
  - Neighbours are defined by the “knows-about” relation (NOT physical neighbors in the network). Eg WWW, file-sharing networks, Skype.

- **Communication Algorithm**
  - Each node regularly selects a neighbour to exchange state information with

- **Computation**
  - Can be arbitrary. It is a very powerful framework that covers information spreading but also other processes like diffusion, reaction-diffusion, random walks, etc.
System Abstraction: basic concepts

Overlay network

View of B:
- Descriptor of A
- Descriptor of C
- Descriptor of E
Gossip protocols for topology management
Gossip protocols for topology management

SelectPeer
Gossip protocols for topology management

A

Exchange of views

E
Gossip protocols for topology management

Both sides apply update thereby redefining topology
Gossip protocols for topology management

- Fully symmetric and decentralized model
- Components of the framework
  - node descriptors: in the view we store not only the address but additional information as well about the nodes
  - selectPeer: uses the actual view to select a peer to contact
  - update(view₁, view₂): based on information available on the peer nodes in the views (node descriptors) constructs the next view
Newscast: a gossip protocol for random topologies

- **Goal:** generate and maintain a
  - connected random topology
  - in the face of extreme dynamism
- **Node descriptors:** contain `timestamp` of creating the descriptor
- **selectPeer:** randomly selects a neighbor from the view
- **update:** fills the view with the **freshest descriptors**. New information gradually replaces old information
Newscast: Summary

- extremely robust to node and link failure and node dynamism (churn)
- maintains a connected approximately random topology
- scalable
- useful as a source of a continuous stream of random samples from the set of nodes: peer sampling service
**Goal:** quickly generate and maintain a
- A very wide range of pre-specified or even dynamically specified topologies
- In the face of dynamism (churn, failures, etc)

**node descriptors:** contain the **profile** of the node (real number, vector, etc)

**selectPeer:** Ranks view using a **ranking function** that defines the target topology and selects the **lowest rank** neighbor

**update:** fills the view with the **lowest rank descriptors**
Example 1 (ring and line): Let the nodes be real numbers. Let the ranking function be defined by the distance $d(a,b)=|a-b|$. For the ring, apply periodic boundary conditions, assuming nodes are from $[0,N]$.

Example 2 (mesh and torus): Let the nodes be two dimensional real vectors. Similarly to the ring, let the Manhattan distance define the topology.
Biological inspiration

- Result of collaboration with TU Dresden (Andreas Deutsch)
- Biological pattern formation and regeneration: an interesting theory is based on **cell adhesion**
  - different cell types "like" or "dislike" each other
  - any cell configuration has an energy
  - the cells try to improve their neighborhood through a stochastic process
Layered structure

- T-Man views are initialized at random (join)
- T-Man sends random nodes too during information exchange, not only the structured (T-Man) view
  - this helps joining nodes
  - this makes it possible to adapt to changing ranking functions
Distance based ranking functions

- Example 3 (binary tree):
  Let the nodes be binary strings of length $m$. Let the ranking function be defined by the distance given by the hop count in the binary undirected rooted tree as illustrated.
Convergence factor

(c) binary tree

(a) ring

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Time to reach perfect topology

(d) $N=2^{74}$

(e) $N=2^{20}$

number of missing target links

cycles

binary tree, $c=20$
binary tree, $c=40$
binary tree, $c=80$
ring, $c=20$
ring, $c=40$
ring, $c=80$
torus, $c=20$
torus, $c=40$
torus, $c=80$
Similarly to newscast, we add the creation timestamp to node descriptors.

Before exchanging views, the nodes remove the H oldest descriptors (H: self-healing parameter).

Experiments with artificial, extremely high churn rates.
Self-healing

All nodes

Nodes younger than 10 cycles

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Applications of T-Man

- Sorting
- Clustering

- (geographical, semantic, etc) proximity overlays
- Distributed Hashtables
Direction dependent ranking functions

- **Example 4 (sorting):** Let $\leq$ be a total ordering over the nodes. Let the ranking function apply a distance function consistent with $\leq$ separately to those $<$ and $>$ than the base node, and merge the ranked two subsets.
  
  For example R(10,\{1,2,4,100, 300\}) could return (4,100,2,300,1). No distance function over the set of nodes generates this ranking function!

- **Example 5 (2d proximity):** Similar to sorting, classifying nodes into four subsets, ordering them according to distance and merging them.
Illustration of clustering and sorting
T-Man Summary

- capable of generating a wide range of topologies (small and large diameter, clustered, sorted, etc)
- experimental results show that T-Man is scalable: converges with high accuracy in approximately logarithmic time
- many interesting open questions of both theoretical and experimental nature
We assume that we have an overlay network (WWW, file-sharing, or even mobile phones, etc)

The network is assumed to be large-scale and highly dynamic

The task is to collect global information about the system (average, maximum, etc of some parameters, network size, data model fitting)
Implementation of Aggregation

- **State**: current approximation of aggregate
- **selectPeer**: uses newscast as a service to select a peer to contact
- **updateState(s1,s2)**: elementary aggregation step, examples include
  - \((s1+s2)/2\) for average
  - \((s1s2)^{1/2}\) for geometric mean
  - \(\text{max}(s1,s2)\) for maximum
- combining elementary aggregations more complex functions can be computed such as sum, network size, variance, etc.
Illustration of Averaging
Illustration of Averaging

\[
\frac{10+2}{2}=6
\]
Illustration of Averaging
Illustration of Averaging

\[
\frac{16 + 4}{2} = 10
\]
Illustration of average calculation

<table>
<thead>
<tr>
<th>Initial state</th>
<th>Cycle 1</th>
<th>Cycle 2</th>
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<table>
<thead>
<tr>
<th>Cycle 3</th>
<th>Cycle 4</th>
<th>Cycle 5</th>
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The base theorem

\[ E(\sigma_{i+1}^2) \approx E(2^{-\varphi})E(\sigma_i^2) \]

Where \( \varphi \) is the random variable that defines the number of times a random node participates in an information exchange during a cycle.
Convergence factor

It follows that if the underlying overlay network is random then

\[ P(\varphi = j) = \frac{1}{(j-1)!} e^{-1} \rightarrow E(2^{-\varphi}) = \frac{1}{2\sqrt{e}} \]
Aggregation: Summary

- In case of averaging, the variance of the set of approximations decreases exponentially.
- Extreme robustness to node and link failure and node dynamism (churn).