# Gossip-based networking

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## Gossip (Wikipedia)

- **Gossip** consists of casual or idle talk of any sort, sometimes (but not always) slanderous and/or devoted to discussing others.

  While gossip forms one of the oldest and (still) the mo... and sharing ... reputation fo... other variati... transmitted...

**Reliable way of spreading information**



## Epidemic (Wikipedia)

- In epidemiology, an **epidemic** is a disease that appears as new cases in a given human population, during a given period, at a rate that substantially exceeds what is "expected".
- Non-biologic...

  The term is ... refer to wide...

**Efficient way of spreading something**

## Gossip/epidemic in distributed computing

Replace people by computers (nodes or peers), words with data

We retain from

- Gossip: peerwise exchange of information
- Epidemic: wide and exponential spread

Refer to gossip in the reminder of the talk

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## The gossip revival

- Dramatic shift in scale (size, data, spread)
- Dynamic nature (mobility, versatility, …) leads to near continuous changes

Lead to a fair amount of uncertainty

**Gossip-based networking**

- Peer to peer communication paradigm
- Probabilistic nature
- Eventual convergence

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## Gossip-based protocols

- Some form of randomization
- Periodic exchange of information
- Bounded messages
- Strengths
  - Simplicity
  - Emergent structure
  - Convergence
  - Robustness
- Weaknesses
  - Overhead
  - Hard to cope with malicious behavior

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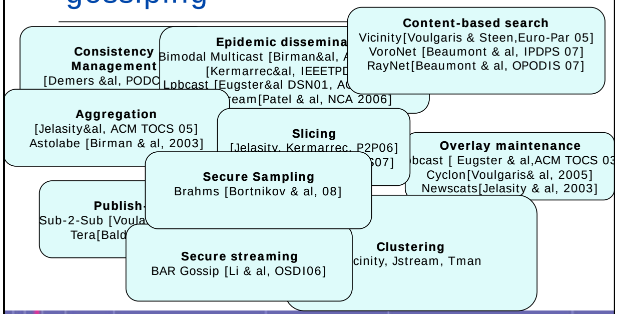
## 1001 ways of leveraging gossiping





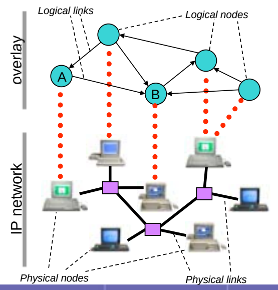

## Agenda

1. Overlay maintenance: Unstructured networks
   Random Peer Sampling
2. Loose structuring: clustering
   Biased Peer Sampling
3. Enabling efficient routing
   Kleinberg-like Peer Sampling
4. Gossip-based structured networks: for which applications?
   1. Distributed Slicing
   2. Content-based pub-sub systems (Sub-2-sub)
   3. Range queries in multidimentional spaces (Voronet/Raynet)



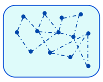
## P2P overlay: which structure?

## Peer to peer overlay networks






## Peer to peer overlay networks



Routing capabilities

Flexibility

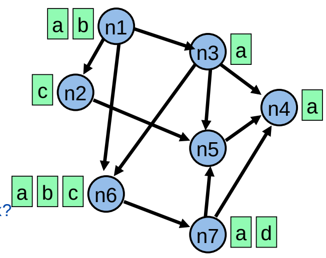
Unstructured networks — Fully structured networks

- Provide various functionalities/performance: search, dissemination, etc
- Common characteristics
  - Self-organizing
  - Local knowledge
  - Resource aggregation
- Resulting properties
  - Scalability
  - Resilience to churn



## Example: Search in peer to peer overlays

- Data distributed (and potentially replicated) between nodes
- Each node knows only the IP @ of its neighbours and potentially some data attributes
- How to find a data without a central index?



## Impact of the structure on search

- Several ways of organizing a P2P overlay network
  - Search techniques: flooding versus routing
  - Expressiveness
  - Completeness
- Structured P2P overlay: DHT functionality
  - Support for exact search
- Unstructured gossip-based P2P overlays
  - Support for keyword-based search or range queries
- Weakly structured gossip-based overlays
  - Improve search efficiency upon fully unstructured overlays

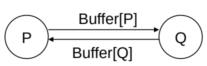


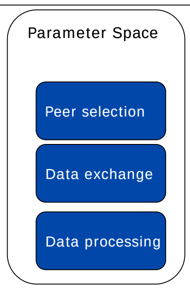
## A generic gossip-based substrate



## Gossip-based generic substrate

- Each node maintains a set of neighbours (c entries)
- Periodic peerwise exchange of information
- Each process runs an active and passive threads



## A generic gossip-based substrate

| Active thread (peer P) | Passive thread (peer Q) |
|---|---|
| (1) selectPeer (&Q); | (1) |
| (2) selectToSend(&bufs); | (2) |
| (3) sendTo(Q,bufs); → | (3) receiveFrom(&P,&bufr); |
| (4) - | (4) selectToSend(&bufs); |
| (5) receiveFrom(Q,&bufr); ← | (5) sendTo(P,bufs); |
| (6) selectToKeep(cache,bufr); | (6) selectToKeep(cache,bufr); |
| (7) processData(cache) | (7) processData(cache) |



## Dissemination

| | | |
|---|---|---|
| Peer selection | K random | Broadcast protocol (Lpbcast) |
| Data exchange | Message | |
| Data processing | | |



## Overlay maintenance

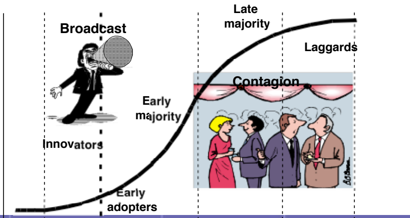
| | | | |
|---|---|---|---|
| Peer selection | Random | Oldest | Closest |
| Data exchange | List of neighbours | ½ List of neighbours | List of neighbours |
| Data processing | Random merging | Age-based merging | Proximity Based merging |
| | LpbCast | Cyclon | T-man |

# Decentralized computations

| | Aggregation | System size estimation | Slicing |
|---|---|---|---|
| Peer selection | Random | Random | Random |
| Data exchange | value | value | Attribute value<br>Random value |
| Data processing | Aggregation<br>Average | Aggregation | Attribute/random matching |



# Why are we interested in building random graphs?
## Illustration through dissemination






# Epidemic-based dissemination

- **Goal**:
  - Broadcast reliably a msg to a large number of peers in a decentralized way
  - Proactive technique to tolerate failures
- **System model**
  - *n* processes
  - Each process forwards the message once to *f* (fanout) neighbors, picked up uniformly at random.
  - Alternatively f times to 1 neighbour.
- **Metrics of the success of an epidemic process**
  - Proportion of infected processes

    $Y_r = Z_r / n$

    $Z_r$ is the number of infected processes prior to round $r$
  - Probability of atomic "infection"

    $P(Z_r = n)$

## Proportion of infected processes

Large system of size n

Probability that the epidemic catches (1-$p_{ext}$)

Proportion of processes eventually contaminated

$\pi = 1 - e^{-\pi f}$ where $f$ is the fanout

Independent of $n$, a fixed average of descendants will lead to the same proportion of infected processes



## Probability of atomic infection

Erdos/Renyi examine final system state, the system is represented as a graph where each node is a process, there is an edge from $n_1$ to $n_2$ if $n_1$ is infected and chooses $n_2$ .

An epidemic starting at $n_0$ is successful if there is a path from $n_0$ to all members. If the fanout is log$(n) + c$, the probability that a random graph is connected is

$$p(connect) = e^{-e^{-c}}$$



## Other measures

- Latency of infection

*[Bollobas, Random Graphs, Cambridge University Press, 2001]*

Logarithmic number of rounds

$$R = \frac{\log(n)}{\log(\log(n))} + O(1)$$

- Resilience to failure

[KMG, IEEE Tpds 14(3), Probabilistic reliable dissemination in Large-scale systems, 2003]

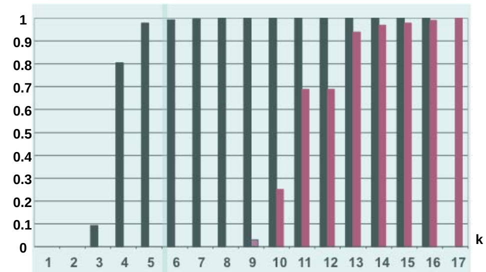
$$k = (n/n')[\log(n') + c + O(1)]$$

## The log(n) magic

- Simple dissemination algorithm
- Probabilistic guarantees of delivery
- Each node forwards the message to *f* nodes chosen uniformly at random
  - If *f=O(log(n))*, “atomic” broadcast whp
  - Result is valid if the fanout for each peer is on average *log(N)* + *c*, whatever the degree distribution.
- Relate probability of reliable dissemination and proportion of failure
  - Set parameters



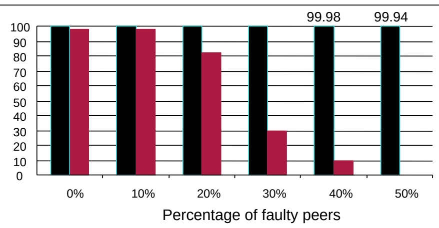
## Performance (100,000 peers)




**Proportion of “atomic”broadcast**
**Proportion of connected peers in non “atomic” broadcast**



## Failure resilience (100,000 peers)




**Proportion of “atomic” broadcast**
**Proportion of connected peers in non “atomic” broadcast**

## The relevance of gossip

- Introduces implicit redundancy
- Flexible and simple protocols
- Overhead
  - Small messages
  - Application to maintenance, monitoring, etc…

Differ in the choice of gossip targets and information exchanged



## Gossip-based dissemination

Peer selection — K random

Data exchanged — Message

Data processing

Dissemination
Data = msg to broadcast

Each process gossips one message once

How can we achieve Random sampling?



## Achieving random topologies through gossiping

- Epidemic dissemination
- Distributed computations (average)
- System size estimation

## The peer sampling service

- How to create a graph upon which applying gossip-based dissemination?... **By gossiping around**
- **Goal:**
  - Create an overlay network
  - Provide each peer with a **random** sample of the network in a decentralized way
- **Means:** gossip-based protocols
  - What data should be gossiped?
  - To whom?
  - How to process the exchanged data?
- Resulting "who knows who" graphs: overlay
  - Properties (degree, clustering, diameter, etc.)
  - Resilience to network dynamics
  - Closeness to random graphs



## The peer sampling service

- Creates unstructured overlay network topologies
- Interface
  - *Init()*: service initialization
  - *GetPeer()*: returns a peer address, ideally drawn uniformly at random



## Properties

- View: local knowledge of the system
  - Continuously updated to reflect the dynamics of the system
  - Provides a sample of the network
- Generic framework [GJKvSV, ACM TOCS 2007]
  - Covers existing gossip-based membership protocols: Lpbcast [EGKK01], Newscast[JKvS03], Cyclon[VDvS03]
  - Explore the design space
    - Evaluation of the "randomness" of the sampling
  - Interestingly enough: generic enough for many other protocols

## System model

- System of n peers
- Peers join and leave (and fail) the system dynamically and are identified uniquely (IP @)
- Epidemic interaction model:
  - Peers exchange some membership information periodically to update their own membership information
  - Reflect the dynamics of the system
  - Ensures connectivity
- Each peer maintains a view (membership table) of c entries
  - Network @ (IP@)
  - Age (freshness of the descriptor)
  - Each entry is unique
  - Ordered list
- Active and passive threads on each node



## Protocol

**Active thread**

```
Wait (T time units)
P <- selectPeer()
if push then
     myDescriptor <- (my@,0)
     buffer <- merge (view,
     {myDescriptor})
     send buffer to p
else send{} to p //triggers response
if pull then
     receive view from p
     buffer <- merge(view_p, view)
     view <- selectView(buffer)
view_p<-increaseage(view_p)
```

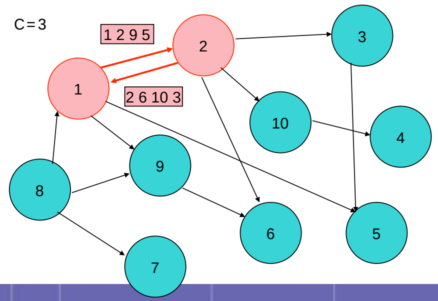
**Passive Thread**

```
(p,view_p) <- waitMessage()

if pull then
     myDescriptor <-(my@,0)
     buffer <-merge(view,
     {myDescriptor})
     send buffer to p

View_p <-increaseage(view_p

buffer <- merge(view_p, view)
View <-selectView(buffer)
```



## Example: Gossip-based generic protocol

C=3



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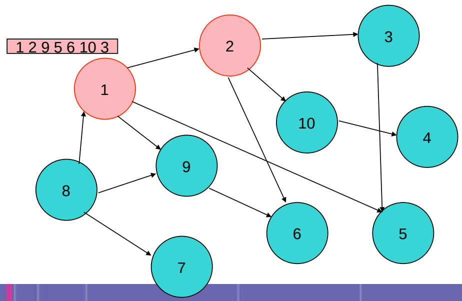
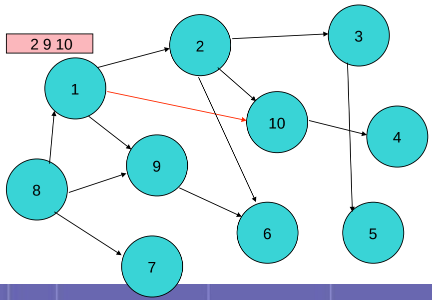





## Example: Gossip-based generic protocol






## Design space

- Periodically each peer initiates communication with another peer
- **Peer selection**
- **Data exchange (View propagation)**
  - How peers exchange their membership information?
  - What do they exchange?
- **Data processing (View selection)**: Select (c, buffer)
  - c: size of the resulting view
  - Buffer: information exchanged

## Design space: data exchange

- **Buffer (h)**
  - initialized with the descriptor of the gossiper
  - contains c/2 elements
  - ignore h “oldest”
- **Communication model**
  - Push:buffer sent
  - Push/Pull: buffers sent both ways
  - (Pull: left out, the gossiper cannot inject information about itself, harms connectivity)



## Design space: peer selection

- Selection
  - Rand: pick a peer uniformly at random
  - Head: pick the “youngest” peer
  - Tail: pick the “oldest” peer

Note that head leads to correlated views.



## Design space: Data processing

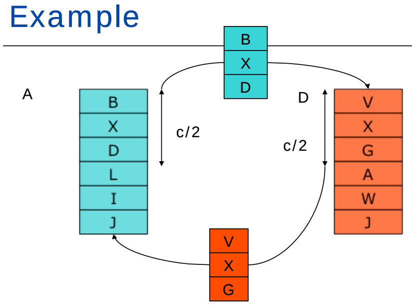
c: size of the resulting view
H: self-healing parameter

- Select(c,h,s,buffer)

1. Buffer appended to view
2. Keep the freshest entry for each node
3. h oldest items removed
4. s first items removed (the one sent over)
5. Random nodes removed

- Merge strategies
  - Blind (h=0,s=0): select a random subset
  - Healer (h=c/2): select the “freshest” entries
  - Shuffler (h=0, s=c/2): minimize loss

## Example



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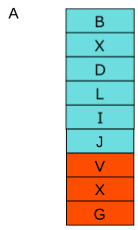



1. Buffer appended to view
2. Keep the freshest entry for each node
3. h (=1) oldest items removed
4. s (=1) first items removed (the one sent over)
5. Random nodes removed



## Resulting graphs properties

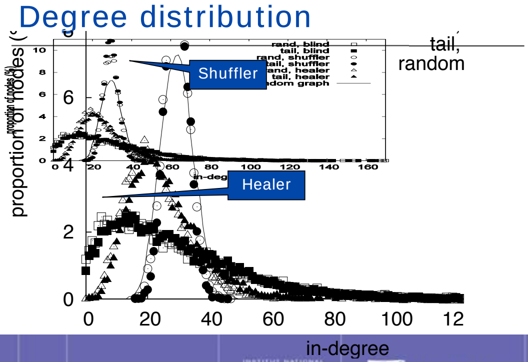
- Relationship « who knows who »
  - Highly dynamic
  - Capture quickly changes in the overlay networks
- Experimental study= lattice, random, growing networks
- Metrics
  - Degree distribution
  - Average path length
  - Clustering coefficient
- Healer (h=c/2, s=0)
- Shuffler (h=0, s=c/2)

## Degree distribution

- Out degree = c (30) in 10.000 node system
- Distribution of in-degree
  - Detect hotspot and bottleneck
  - Load balancing properties
- Convergence
  - Self-organization ability irrespective of the initial topology



## Degree distribution






## Degree distribution

- Convergence, even in growing scenario
- View selection parameter matters
- Shuffler and healer result in lower standard deviation for opposite reasons
  - Shuffler
    - Controlled degree distribution
    - New links to a node are created only when the node itself injects its own fresh node descriptor during communication.
  - Healer
    - Short life time of links
    - When a node injects a new descriptor about itself, this descriptor is copied to other nodes for a few cycles.
    - Later all copies are removed because they are pushed out by new links injected in the meantime

## Average path length

- Shortest path length between a and b
  - minimal number of edges required to traverse in the graph to reach b from a
- Defines a lower bound on the time and costs of reaching a peer.
- Small average path length essential for scalability



## Average path length

- Results
  - all protocols result in a very low path length.
  - large S values are the closest to the random graph.



## Clustering coefficient

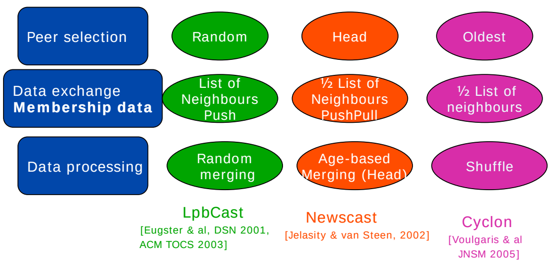
- Results
  - clustering coefficient also converges
  - controlled mainly by H.
    - Large value of H result in significant clustering, where the deviation from the random graph is large.
      large part of the views of any two communicating nodes overlap right after communication (freshest entries).
    - Large values of S, clustering is close to random

## Peer sampling service: Summary

- Experimental study
  - How random are the resulting graphs?
  - What properties may affect the applications
- Global randomness
  - Best configuration is the shuffler irrespective of the peer selection
- Load balancing
  - Blind performs poorly
  - Best configuration is shuffler while healer performs well
- Fault-tolerance
  - More important parameter is H: the higher the better
  - Shuffler is slow to remove dead links



## Overlay maintenance






## Imposing more structure: biasing the peer sampling

## Structuring the network

- T-Man[Jelasity&Babaoglu, 2004]
- Peers optimize their view using the view of their close neighbours
- Ranking function
  $R(x, \{y_1, \ldots, y_m\})$ ranks $y_j$ strictly lower than $y_i$ if $y_i$ precedes strictly $y_j$ in all possible rankings
- Peer selection
  - Rank nodes in the view according to *R*
  - Returns a random sample from the first half
- Data exchange
  - Rank the elements in the (view+buffer) according to *R*
  - Returns the first *c* elements
- Data processing
  - Keep the c closest

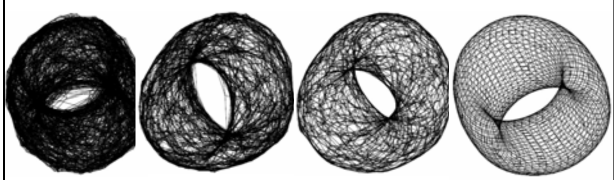


## Gossip-based topology management

- Line: d(a,b) =|a-b|
- Ring: interval[0,N], d(a,b)=min(N-|a-b|,|a-b|)
- Mesh and torus: d=Manhattan distance
- Sorting problems: any other application dependent metric



## T-man: torus



Cycle 3 Cycle 5 Cycle 8 Cycle 15

## T-man wrap up

- Generate a large number of structured topologies
- Exponential convergence (logarithmic in the number of nodes)
- Irrespective of the initial topology
- Exact structure



## Clustering similar peers

- Vicinity: Introducing application-dependent proximity metric [VvS, EuroPar 2005]
- Two-layered approach
  1. Biased gossip reflecting some application semantic
  2. Unbiased peer sampling service



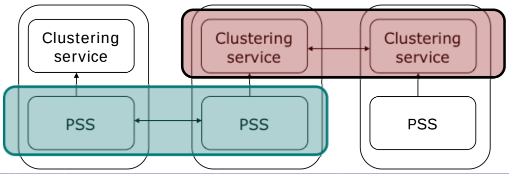
## System model

- Semantic view of *l* semantic neighbours
- Semantic proximity function *S(P,Q)*.
  - The higher the value of *S(P,Q)*, the “closer” the nodes.
  - The objective is to fill P’s semantic view to optimize

$$\sum_{i=1}^{l} S(P,Q_i)$$

## Gossiping framework

- Target selection
  - Close peers
  - All nodes are examined: create a "small-world" like structure so that new nodes are discovered.






## Gossip parameter setting

- Clustering protocol

  Peer selection
  - tail "oldest timestamp"

  Data exchange
  - aggressively biased,
  - select the g items the closest from semantic and random views

  Data processing
  - select the l closest peers (buffer, semantic and random views)
- Peer sampling service



## Improving routing: Kleinberg-like peer sampling

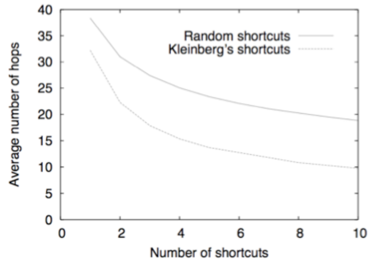
## Motivation

- Small-world overlay networks
  - Neighbour set: Close + shortcuts
  - Theoretical analysis: Asymptotic bounds on routing performance (random versus Kleinberg's shortcuts)
- Epidemic-based overlay networks
  - Decentralized overlay building and maintenance using gossip-based protocols
  - Practical systems: efficient routing

**Epidemic-based small-world networks**
Clustering protocols: close neighbours
Peer sampling service: shortcuts



## Motivation





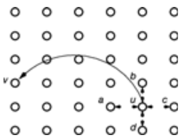

## Objective

Leveraging theory: how to apply Kleinberg's results to improve upon current epidemic protocols?

**Epidemic-based small world networks**

## Small world overlay network

- Neighbour set
  - Local contacts
  - Shortcuts
- Shortcut selection
  - Random [Watts &Strogatz1998]
    Greedy routing $O(n^{1/3})$
  - Harmonic distribution [Kleinberg 2000]
    Greedy routing $O(\log^2(n))$
- Results
  - Asymptotic bounds : Magnitude order of routing performance

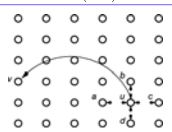




## Shortcut selection and routing performance

- **Random selection**
  - Shortcuts picked uniformly at random
  - Greedy routing performance

  $O(n^{1/3})$



- **Kleinberg selection**

  Selection with probability proportional to distance

  $$\delta(B) = \frac{1}{d(A,B)^2}$$

  B chosen by A with

  $$P = \frac{\delta(B)}{\sum_{B \in S} \delta(B)}$$

  S = Set of peers not neighbour of A
- Greedy routing performance

  $O(\log^2(n))$



## Small-world gossip-based networks

Assume each node has some coordinates in a d-dimensional space

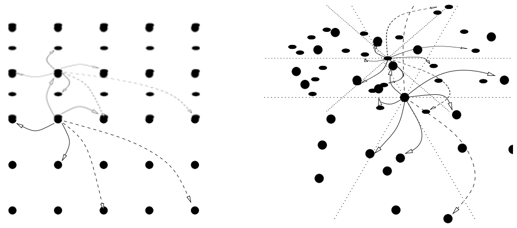
**Clustering service**
Peer selection: "closest"
Data exchange: c entries
Data Processing: "closest" kept

Close links

**Peer sampling service**
Peer selection: random
Data exchange: c/2 entries
Data Processing: random

Shortcuts
[Watts &Strogatz1998]

## Topologies






## Gossip-based small-world networks

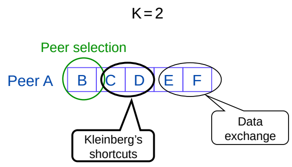
- Leverage theory
- Decentralized selection of neighbours
  - Clustering protocol: local neighbours
  - Peer sampling: shortcuts
- Shortcut selection: peer sampling service
  - Random selection: random peer sampling
  - Kleinberg selection: tune the view so that it matches the Kleinberg's distribution
- What are we interested in?
  - Impact on the routing efficiency
  - Impact on the graph properties



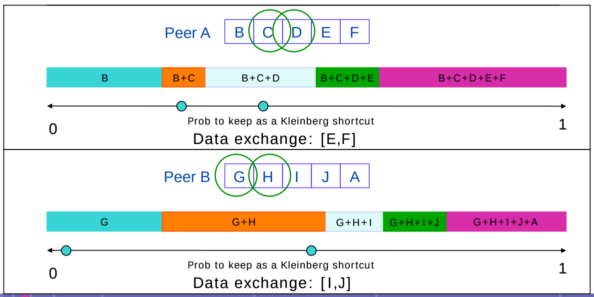
## Kleinberg's peer sampling

- Use standard clustering protocol for local neighbours
- Shortcuts: bias Cyclon protocol to approximate Kleinberg's distribution (probability of being kept is $1/d^2$

**Peer sampling service**
Peer selection: random
Data exchange: k entries, c-k kept bias by Kleinberg's distribution
Data Processing: c-k entries exchanged



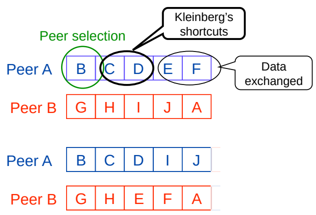
# Implementation





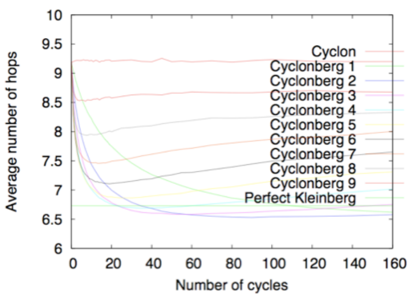

# Kleinberg's peer sampling

- Example

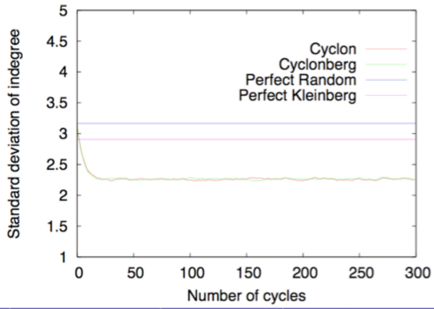





# Routing performance

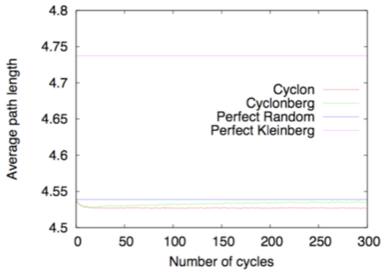


## Impact on the degree



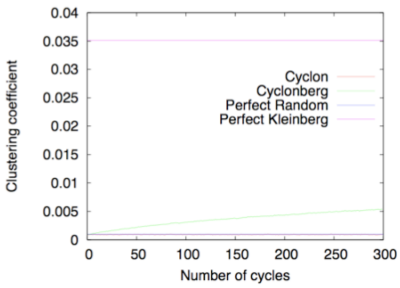



## Path length






## Clustering coefficient



## Outcomes

- Possible to tune the peer sampling to achieve a routing similar to the one obtained with a Kleinberg's shortcut selection
  - Driven by the shuffle length
- Resulting graph properties
  - Degree distribution and average path length similar to a random peer sampling
  - Clustering coefficient: slightly higher
  - Harmless to most distributed applications
- Improves the clustering algorithm

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## Structuring the network: ordering nodes

Gossip-based distributed slicing
[JK,P2P 2006] [FGJKR,ICDCS 2007]

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## Why slicing a P2P network?

- Slices: sets of size proportional to the size of the network
- Heterogeneous environment: Identify sets of specific nodes
  - Live streaming applications (upload)
  - Load balancers in datacenters (CPU,availability)
  - File sharing systems (number of files, storage)

**Basic structure: slice**

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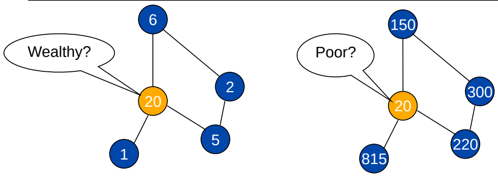
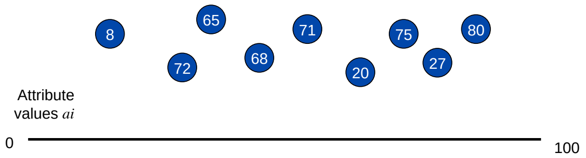
## Why slicing is not trivial?




- Presence of churn
- Dynamic heterogeneity
- No global information

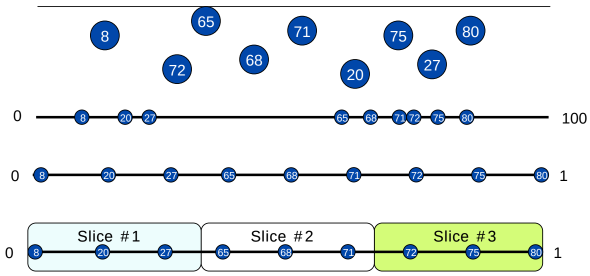


## Classifying nodes






## Slicing the network



## Objective

**Create and maintain equally balanced slices of the network in a fully decentralized manner**

Upon termination: each node knows the slice it belongs to



## Gossip-based approach

Use a gossip-based approach to estimate to which partition a node belongs

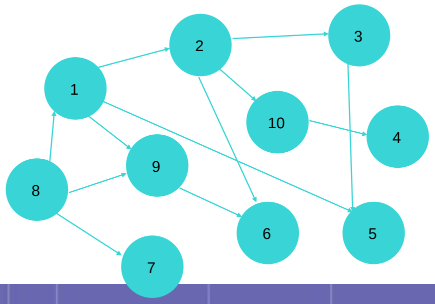
- Scalable
- Robust
- Based on local knowledge
- Fast convergence



## System model

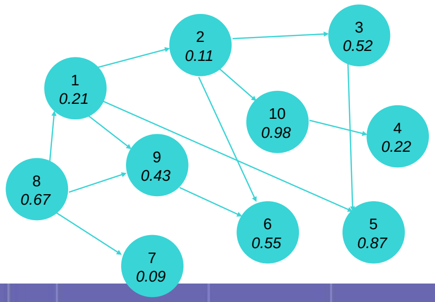
- Dynamic system of peers uniquely identified
- Each node belongs to one slice and has
  - an attribute: capacity in the metric of interest
  - a random number
  - a view of *c* entries (peer sampling)
  - a time stamp

## Random slices



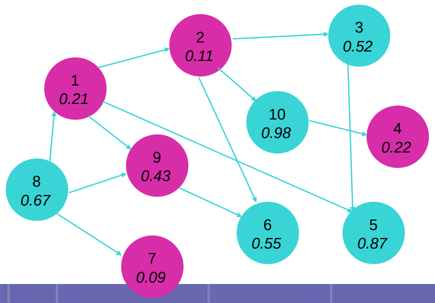



## Random slices

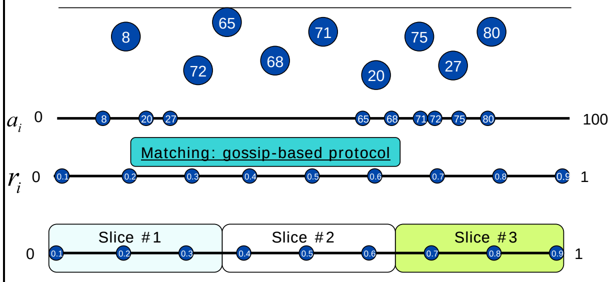





## Random slices



## Gossip-based approach






## Ordered slicing algorithm: basic operation

Node a — Node b

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $a_i$ | 72 | 71 | 20 | 65 | 68 | 75 | 27 | 8 | 80 |
| $r_i$ | 0.6 | 0.5 | 0.3 | 0.7 | 0.1 | 0.4 | 0.2 | 0.9 | 0.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $a_i$ | 72 | 71 | 20 | 65 | 68 | 75 | 27 | 8 | 80 |
| $r_i$ | 0.6 | 0.5 | 0.9 | 0.7 | 0.1 | 0.4 | 0.2 | 0.3 | 0.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $a_i$ | 8 | 20 | 27 | 65 | 68 | 71 | 72 | 75 | 80 |
| $r_i$ | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |



## The ordered slicing algorithm

On each node *q*

- Pick a node *p* at random in its view
- Initiate a gossip with p
  - Send its own $a_q, r_q$
  - Receive the *freshest c* entries from *p*
- Select *i* such that $(a_i - a_q)(r_i - r_q) < 0$
  - Swap random values

## Ordered slicing algorithm: maintenance

- New nodes discovery: peer sampling (age-biased)
- Random values: uniform spread
- Once the order stabilizes: each node knows which slice it belongs to

A peer with a number <0.5 knows in the first 50% of the nodes according to the metric



## Analogy with average

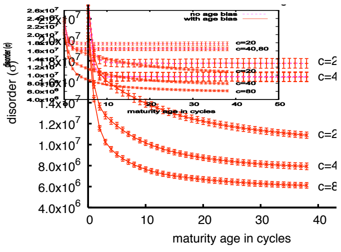
- Weight conserving property

$$1/N\sum_{j=1}^{N} j - i_j(t) = 1/N\sum_{j=1}^{N} j - 1/N\sum_{j=1}^{N} i_j(t) = 0$$

- The swapping does not influence this value (=0) but always reduces the disorder value



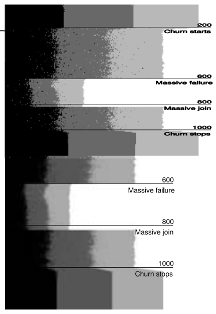
## Age-based technique




Young nodes disordered
Old nodes protected

## Main results

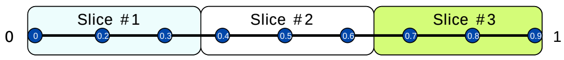
- Exponential decrease of the disorder
- Quick stabilization
- Relatively well-defined slices
- Stabilizes as soon as churn stops






## Ordered slicing: optimizations & issues

- Further optimization: Local measure of the disorder [Fernandez & al, ICDCS 2007]
- Issues
  - Uniformity requirement

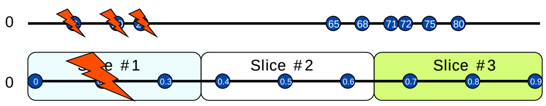





## Ordered slicing: issues

- Uniformity requirement
- Failures are correlated to the attribute values

**Provides an ordering not an accurate ranking**



## Ordered slicing

- Issue when failures are correlated to the attribute values
- Fix the uniformity requirement
- [Fernandez & al, ICDCS 2007]
  - Infer slice from a sample of attributes
  - Gossip-based propagation



## Why would we want to route efficiently in something else than a DHT? Why is gossip relevant here?

- Range queries in a P2P overlay: VoroNet-RayNet [Beaumont & al, IPDPS 2006, OPODIS 2007]
- Content-based publish-subscribe systems: Sub-2-Sub [Voulgaris&al, IPTPS 2006]

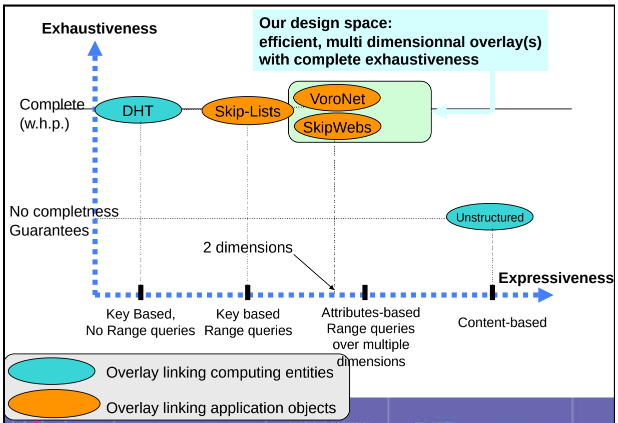


## VoroNet A scalable object network based on Voronoï tessellations

## Design rationale

- Efficient data location service
  - **Efficiency = expressiveness + completeness**
- Expressiveness versus completeness
  - Unstructured overlay/Structured overlays (DHT)
- Overlay structure should reflect the application one
  - Linking objects in an efficient routing overlay
  - Use of Voronoï tesselation of the object space
  - Efficient routing: Kleinberg small world model

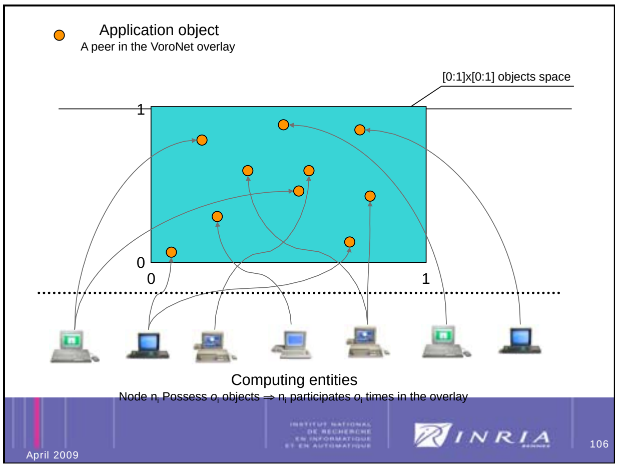







## Model

- An object is described by a set of attributes
  - Objects with "near" attributes are neighbours in the overlay
  - Multidimensional naming space
  - ***For ease of explanation***
    - we limit to the case where dimension is 2
- Native and efficient support for efficient query mechanisms
  - Scalable, polylogarithmic routing
  - No hash mechanisms ⇒ Ordering preserved
  - Generalizes Kleinberg Small-World model
- State per object is O(1)
  - Independently of the object set size and distribution
  - The basic overlay is based on the Voronoï tessellation of the objects set in the Euclidean naming space



Application object
A peer in the VoroNet overlay
[0:1]x[0:1] objects space
1
0
0
1
Computing entities
Node $n_i$ Possess $o_i$ objects ⇒ $n_i$ participates $o_i$ times in the overlay
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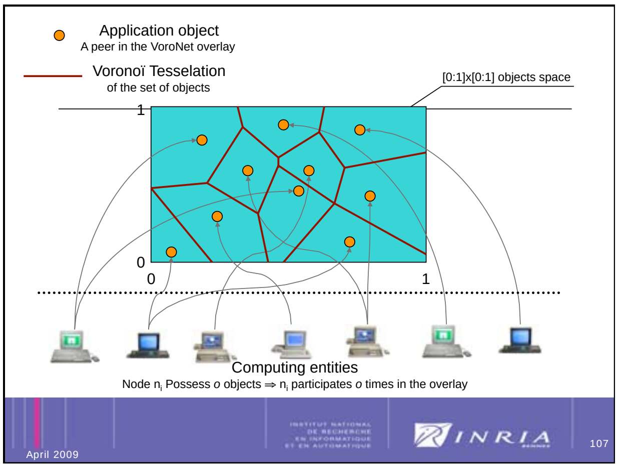

Application object
A peer in the VoroNet overlay
Voronoï Tesselation
of the set of objects
[0:1]x[0:1] objects space
1
0
0
1
Computing entities
Node $n_i$ Possess *o* objects ⇒ $n_i$ participates *o* times in the overlay
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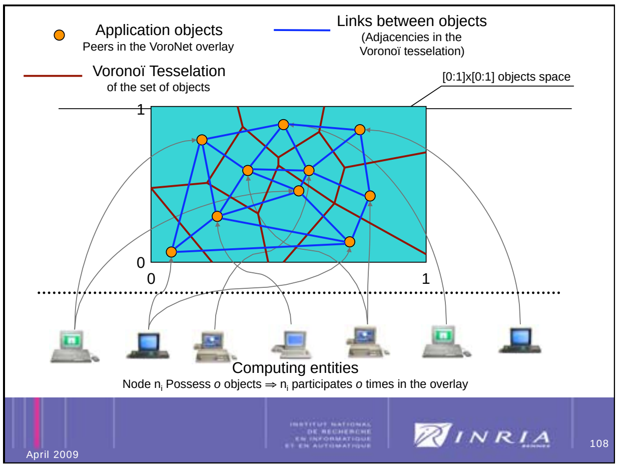

Application objects
Peers in the VoroNet overlay
Links between objects
(Adjacencies in the
Voronoï tesselation)
Voronoï Tesselation
of the set of objects
[0:1]x[0:1] objects space
1
0
0
1
Computing entities
Node $n_i$ Possess *o* objects ⇒ $n_i$ participates *o* times in the overlay
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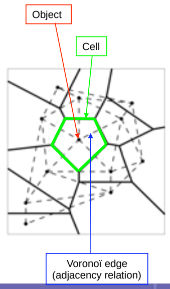
## Voronoï tesselation

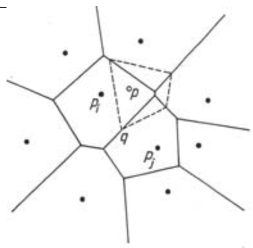
- Definition
  - For each point p among a set
  - p's cell contains all points nearest to p than to any other point
- The dual of the Voronoï diagram is the Delaunay triangulation
  - Mean(#neighbors) ≤ 6
  - Navigability: greedy Euclidean routing always succeeds (in linear number of steps)
- **Overlay primary links** between objects are adjacency links of objects (virtual) cells






## Object insertion

- Each object knows
  - Neighbors coordinates and zones
- A joining peer p routes a message to its coordinate
  - Peer $p_i$ is responsible for p insertion
  - $p_i$ computes p's new zone and modifications to its neighbors's (e.g. $p_j$) zones
  - $p_i$ disseminates changes to its neighbors and notify p of its new neighborhood






## Efficient routing

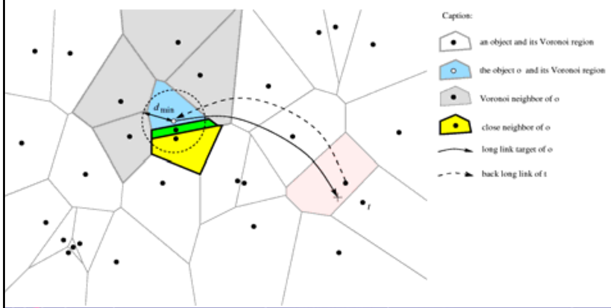
- Greedy routing
  - Each routing step gets closer to the destination A
  - Delaunay triangulation properties ensure that this succeeds deterministically
  - But…..may be O(N) steps
- Small world routing
  - Additional shortcuts
  - Extension of the Kleinberg's model
  - Polylogarithmic routing in N : $O(\log^x(N))$

## Extending the Kleinberg model

- Each object chooses a shortcut destination point according to a harmonic distribution, and uniform direction
- The topology is not a grid !
  - The destination point is not necessarily an object …
  - But the destination stands in an object cell
- The object chosen as shortcut neighbour is always the object which has the shortcut destination in its zone
- Greedy routing ensures paths of polylogarithmic size



## Management of long links



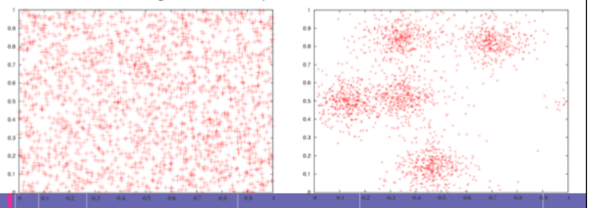



## How many neighbours?

- Close neighbors: Voronoï neighbours (Mean ≤ 6)
- Shortcuts
  - Simulations have shown that around 6 shortcuts is a good tradeoff between maintenance cost and performance
- Back long link neighbours
  - Dependent on the distribution of objects,
  - Balanced even with sparse distributions due to long link properties (random versus harmonic)
- Overall neighbour set size is O(1)
  - Independent of the number of objects
  - Independent of objects distribution

## Experimental settings

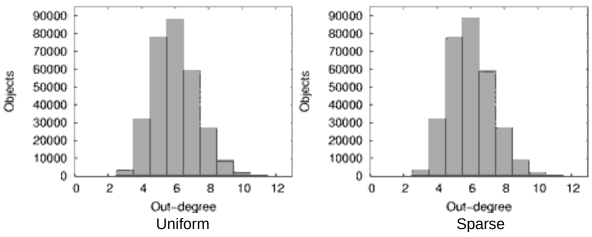
- 300.000 objects (no object leaving)
- 2 object distributions in [0:1]x[0:1]
  - Uniform
  - Sparse: 5 equally popular regions. Popularity of objects around a region follows a power law with $\alpha = 5$





## Simulation: object degree

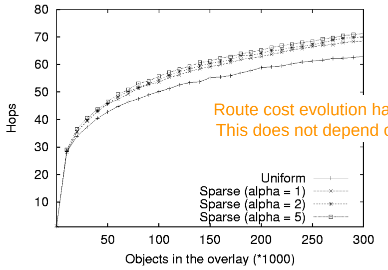
number of Voronoï neighbours




Object out-degree does not depend of the objects distribution in space

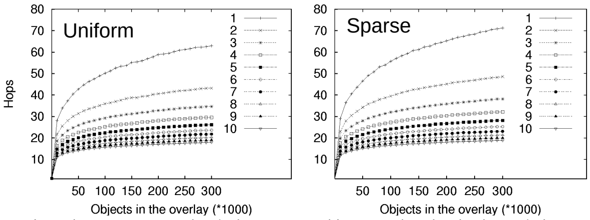


## Polylogarithmic routes (1)




Route cost evolution has a logarithmic shape.
This does not depend on objects distribution.

## Using several long links improves routing performance




- Linear improvement: Using *k* shortcuts provides a routing that is almost *k* times more efficient
  - At each step, the probability of using a long link that divide the path by log(N) is k/log(N)
  - A reasonable amount of long links is ~6 for a 300.000 objects overlay



## Voronoï cell computations are an overkill

RayNet: gossip-based approximation of complex structures

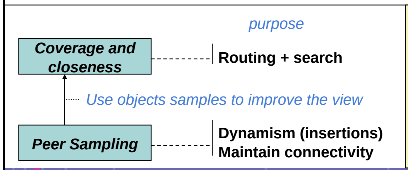


## Voronoï diagrams, RayNet rationale

- VoroNet
  - Complex structure to compute, to maintain in face of churn, potential unlimited number of neighbours
- **What really matters?**
  - Neighbours: to ensure correct routing
- **Using an approximation of the structure is enough** to compute such neighborhoods
- Gossip-based protocols for Voronoï neighbours and shortcuts

## Gossip-based construction of RayNet

- Local links: Coverage and closeness
  - Gossip-based construction of approximate Voronoï links
  - Close objects (in the semantic space) in all directions
- Shortcuts: Kleinberg peer sampling

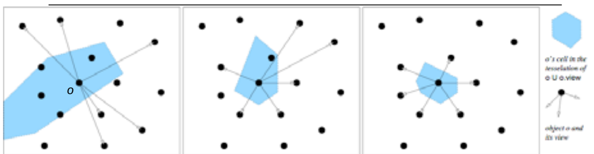



Challenge:

Evolution of local views towards a global routing structure



## Coverage and closeness




An object o's view == Voronoï neighbours

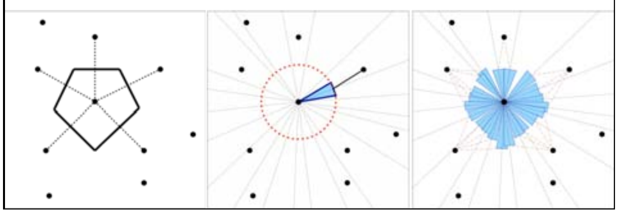
**Idea:**

- Exchange views & converge towards an approximation of Voronoï neighbours
- No need to compute the Voronoï cells: use the **volume** as an indication of convergence (the smaller, the better)



## Monte Carlo cell size estimation

- **Idea**: sample the boundaries of the zone using "rays"
- Gossip-based protocol: evaluate the view as a whole (configuration)



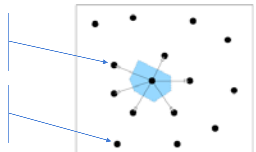
## View update operation: naïve approach

- View size is c=3d+1 peers
- Exchange entire views : o.view + $o_{partner}$.view
- For each set S of objects of size c, in o.view + $o_{partner}$.view
  - Estimate the volume of o's cell in the diagram of S
  - Keep the set with minimal volume as the new view
- Effective, but there are O(c!) configurations to examine…



## View update operation: efficient approach

- Determine the potential contribution of each object to the coverage and closeness (ie to the volume of o's cell)
- For each object o' in o.view + $o_{partner}$.view
  - Compute the volume of o's cell in o.view + $o_{partner}$.view <u>without</u> o'

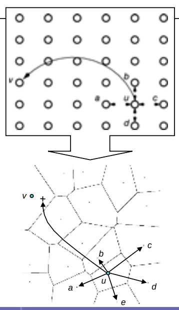



- Keep the c objects with the greatest contribution



## Efficient routing

- Routing in the approximate Voronoï diagram requires O(N) hops
- Small-Worlds models:
  - Small paths + navigability
- Using biased peer sampling
- $O(\log^d N)$ routing with 1 shortcut

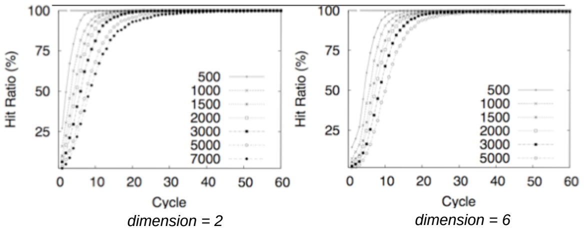


## Simulations

- Settings
  - 1.000 to 7.000 objects
  - Emergence from a chaotic state
    - No RayNet links
    - Random graph for the Kleinberg-biased peer sampling service
- Metrics
  - Self-organization speed
    - Cycles needed before full routing success
  - Routing efficiency
    - Mean hops



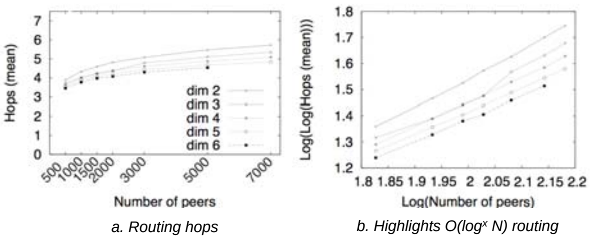
## Self-organization speed




Less than 35 cycles of exchanges are needed
for reaching a structure where **all routes succeed** onto the correct object



## Routing efficiency




Routing efficiency is achieved by the biased peer sampling layer

## RayNet wrap-up

- RayNet, overlay for exhaustive and expressive queries
  - Self-organizing
  - Routing efficiency
- Approximation of a complex & 'ideal' structure while still benefiting from its capacities
  - Expressiveness of the query model preserved
  - Efficient up to 10 dimensions



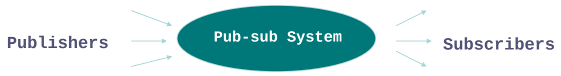
## Gossiping for content-based publish-subscribe systems

Sub-2-sub [VRKvS, IPTPS 2006]



## Pub-sub systems

- Asynchronous event notification system
- A set of Subscribers register their interest (subscriptions)
- A set of Publishers issue some events (events)




- Publish-subscribe system
  - Mapping between events and matching subscriptions
  - An event is delivered to all interested subscribers, and no others
  - Loosely coupled events sources and targets
- Flexible and seamless messaging substrate for applications

## Pub-sub systems: expressiveness

- Differences in subscription expressiveness
- System classification
  - Topic-based = *(peer to peer )* **Group Multicast** *Scribe (Pastry), CAN-Multicast, Bayeux (Tapestry), …*
    topic=h
  - Attribute-based
    s1=(city=Rennes) (capacity=2_Bedrooms)
  - Content-based
    s1=(city=Rennes || Saint Malo) && (capacity=3_Bedrooms || price < 300,000 EUR)



## Content-based: (semi-)centralized solutions

- Current systems: One or more centralized servers (brokers)
  - e.g., Tibco (*Web Services Eventing*)
- Servers become a bottleneck/single point of failure
  - Reverse Path Forwarding
    - Notifications follow reverse paths of subscriptions
  - Brokers deliver events to interested subscribers
    - Brokers end up maintaining the whole set of subscriptions
  - network size increases
  - node churn increases
  - more events are published
- Triggered interest in decentralized P2P solutions



## Sub-2-Sub

[Voulgaris & al, IPTPS 2006]

- Peers are subscriptions
  - Rather than physical nodes
  - Each peer manages its own subscription(s)
  - The more it subscribes, the more it contributes
- Self-organizing overlay
  - Eventually cluster similar subscriptions
  - Efficient event dissemination structure
  - Adapted to dynamism

**Gossip-based algorithm to cluster peers according to their interests**

## Sub-2-Sub: definitions

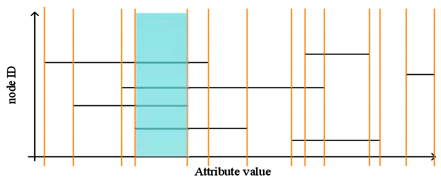
- Assume N attributes (real numbers)
  - $A_1$, $A_2$, …, $A_N$
  - The N-hyperspace
- Subscriptions are range (trivially exact) predicates on one or more attributes
  - E.g. $A_2 == 3.07$ && ($2.5 < A_4 < 4.7$)
  - A N-hypercube
- Events define exact values for all attributes
  - E.g. $\{A_1, A_2, A_3, A_4\} = \{3, 0, 7, 10.5\}$
  - A point
- The set of all possible events define the event space, It's an continuous space of dimension N



## Sub-2-Sub: Key Concept

**"Partition event space in homogeneous subspaces"**

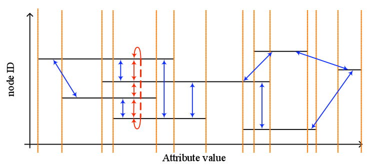
(homogeneous subspace: all its events have the same subscribers)






## Sub-2-Sub: Operation

1. Let subscribers of "near" subspaces discover each other
2. Organize subscribers of each subspace in a ring
3. To publish an event, navigate to the right subspace, and hand the event to any one subscriber
   - Event reaches all and only interested subscribers, autonomously!



## Sub-2-Sub overlay creation

| | |
|---|---|
| • Maintain connectivity | • Peer sampling service |
| • Create clusters of "related" subcribers | • Clustering service |
| • Organize subscribers within a subspace in a ring ? | • Ranking service |

**Gossip around**



## Maintaining connectivity

- Connectivity = no overlay-network partition
- Peer sampling service: Cyclon

[S. Voulgaris, D. Gavidia, M. van Steen. *Journal of Network and Systems Management*, Vol. 13, No. 2, June 2005]



## Forming clusters: gossip-based clustering

- Keep a small fixed-sized set of neighbors with similar interests
- Similarity is based on a notion of distance
  - the minimum Euclidean distance between two subscriptions

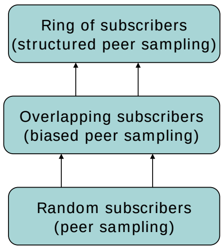
  (Note: Distance 0 means some overlapping interests)
- peerSelect()
  - Choose a neighbor in the random view provided by peer sampling
- select()
  - Keep neighbors of smallest distance

## Organizing clusters in rings: gossip-based structuring

- Each subscription is given a fully random ID upon creation
  - Total order on IDs
  - Defined only to permit ring creation
- peerSelect()
  - Choose a neighbor in the similar interest view
- update()
  - Keep neighbors of smallest distance
- Distance definition :
  - 0 (ZERO), if overlapping and ID is the nearest for part of the supscriptions overlap
  - INFINITE, otherwise
- update() keeps neighbors whose ID is nearer from the subscription ID for any portion of subscription hypercube
  - Size of the neighbor set depends on subscription width



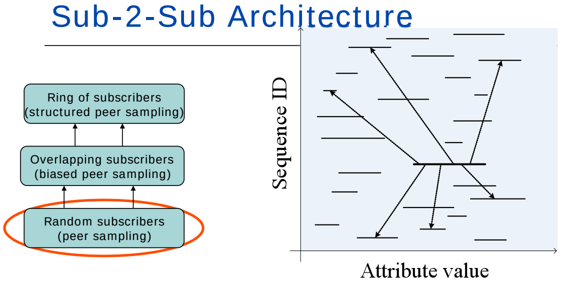
## Sub-2-Sub Architecture




- Three-layer architecture
- Each layer gossips to a neighbor's respective layer

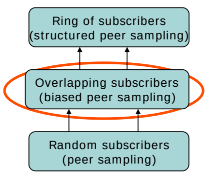


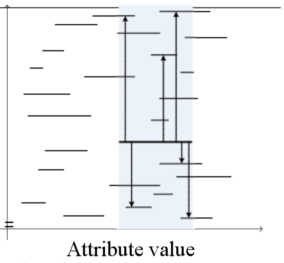
## Sub-2-Sub Architecture




- RPS finds random links (needed for BPS)
- and keeps the overlay connected

## Sub-2-Sub Architecture



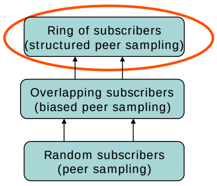



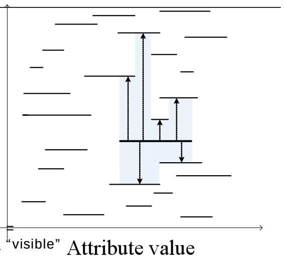

Proximity between 2 subscribers =

- 0 (ZERO), if overlapping
- the Euclidean distance between the 2 hypercubes, otherwise



## Sub-2-Sub Architecture

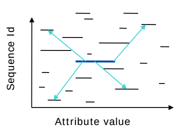


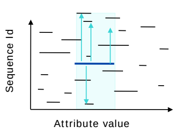



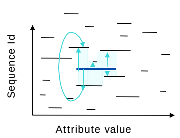

- Proximity between 2 subscribers =
  - 0 (ZERO), if overlapping and "visible"
  - INFINITE, otherwise
- Variable length view



## Sub-2-Sub in a nutshell




Random links

-Traditional random-based epidemic algorithms

Interest links

- Peer selection and links kept based on proximity in the attribute space

*d(i,j) = 0 if no overlap*

$S_i = [l_1^i, r_1^i] \times [l_n^i, r_n^i]$

$d(i,j) = \sqrt{\sum_{k=1}^{n} (\min(r_k^i, r_k^j) - \max(l_k^i, l_k^j))^2}$

Structured links

•Peer selection: in the ring
•Links kept, sorted according to growing id
•Subscription cover

## Dissemination of events

- The event is sent to any of the subscription peer
  - Greedy routing using Euclidean distance along random neighbors and interest proximity links
  - It eventually reach one of the interested subscriber ⇒ dissemination begins
- A node receiving an event for the first time, forwards it:
  - Along its two ring links
  - To one random subscriber interested in the event (if exists)
- Load balancing
  - Subscribers forward each event up to 3 times.



## Sub-2-Sub summary

- Showed that a dedicated P2P present soundness for complex applications such as content/based
- Sub-2-Sub
  - Accurate → All and only interested nodes receive event
  - Autonomous → No need for extra device
  - Collaborative
  - Self-organized
  - Very scalable (nodes and attributes)
    - Experiments for 10 attributes present the same results
- Current work
  - Limiting the number if neighbours by articially manipulating the size of subscriptions



## The take-away slide

Gossip-based protocols are a powerful tool in large-scale distributed computing
- Overlay maintenance
- Dissemination
- Search
- Distributed computations

You've seen a small subset only☺

An exciting research agenda
1. Coping with selfish behaviors
2. Coping with malicious nodes
3. Adapting protocols to node capacities
4. Leveraging multiple overlays
5. Increasing the target applications

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