# Dynamic Data Dissemination (Publish/Subscribe)



# Dynamic Data

Traffic data

- packets thru switches / vehicles on highways

Stock prices, Sport Scores

- rapid and unpredictable changes
- time critical, value critical
- used in on-line monitoring, decision making

More and more of data gathered from the web/internet is dynamic



# Coherency of Dynamic Data

Source *S(t)* → Repository *R(t)* → Client *U(t)*

- **Strong coherency**
  - The client and source always in sync (*U(t)* = *S(t)*)
  - Strong coherency is expensive!
- **Relax strong coherency**: $\Delta$ - coherency
  - Time domain: $\mathbf{\Delta t}$ - coherency
  - Value domain: $\mathbf{\Delta v}$ - coherency
    - The difference in the data values at the client and the source bounded by $\mathbf{\Delta v}$ at all times
    - E.g.: temperature changes greater than 1 degree

$$\forall t, |U(t) - S(t)| < \Delta_v$$



# Modes of Data Dissemination

- Pull:

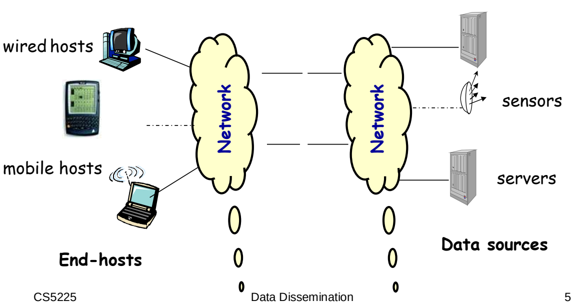
  Client pulls data from the source.

- Push:

  Source pushes data of interest to the client.

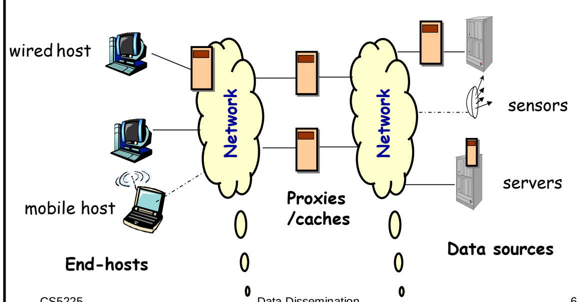


# Generic Architecture






# Generic Architecture



## Where should the queries execute ?

- At clients
  - can't optimize across clients, links
- At source (where changes take place)
  - Advantages
    - Minimum number of refresh messages, high fidelity
  - Main challenge
    - Scalability
    - Multiple sources hard to handle
- At Data Aggregators -- DAs/proxies -- placed at *edge* of network
  - Advantages
    - Allows scalability through consolidation, Multiple data sources
  - Main challenge
    - Need mechanisms for maintaining data consistency at DAs



## The Basic Problem…

- To create a scalable content dissemination network (CDN) for streaming/dynamic data.

**Metric:**

*Fidelity*:

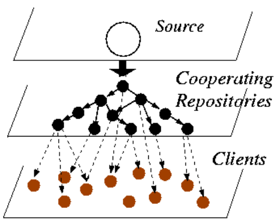
% of time coherency requirement is met

Goal: To achieve high fidelity and resiliency



## Cooperative Repository Architecture

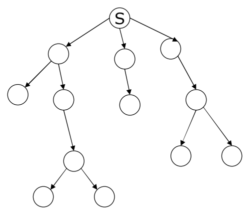
- Clients request for different data items by specifying coherence requirements for each item
- Repositories derive their requirements from the client requirements
- Source *pushes* the changes of interest to repositories
- Repositories cooperate with each other and the source to serve clients






## Dissemination Tree/Graph

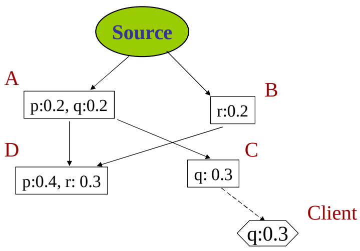
- Solution: Nodes are organized into dissemination trees






## Dissemination Graph: Example

Data Set: p,q,r    Max # push connections : 2



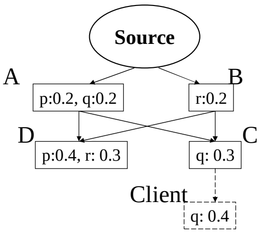



## Challenges

- Given the data and coherency needs of repositories, how should repositories cooperate to satisfy these needs?
- How should repositories refresh the data such that coherency requirements of dependents are satisfied?
- How to make repository network resilient to failures?
- Given the data and the coherency available at repositories, how to assign clients to the repositories?

## Data Dissemination (Supp reading 1)

- Different users have different coherency req for the same data item.
- Coherency requirement at a repository should be *at least as stringent as* that of the dependents.
- Repositories disseminate only changes of interest.






## Data Dissemination

A repository *P* sends changes of interest to the dependent *Q* if

$$\left| x^P - x^Q \right| \geq c^Q$$

$x^p$: value of x at P
$c^Q$: coherency req of x at Q



## Data dissemination -- must be done with care

$c^P = 0.3$ $c^Q = 0.5$

Source → Repository P → Repository Q

| Source | Repository P | Repository Q |
|---|---|---|
| 1 → | 1 → | 1 |
| 1.2 | 1 | 1 |
| 1.4 → | 1.4 | 1 |
| 1.5 | 1.4 | 1 |
| 1.7 → | 1.7 → | 1.7 |

should prevent missed updates!



## Dissemination Algorithms

- Source Based (Centralized)
- Repository Based (Distributed)



## Source Based Dissemination Algorithm

- For each data item, source maintains
  - unique coherency requirements of repositories
  - the last update sent for that coherency
- For every change,
  - source finds the maximum coherency for which it must be disseminated
  - tags the change with that coherency
  - disseminates *(changed data, tag)*



## Source Based Dissemination Algorithm

$c^P = 0.3$ $c^Q = 0.5$

Source → Repository P → Repository Q

| Source | Repository P | Repository Q |
|---|---|---|
| 1 → | 1 → | 1 |
| 1.2 | 1 | 1 |
| 1.4 → | 1.4 | 1 |
| 1.5 → | 1.5 → | 1.5 |
| 1.7 | 1.5 | 1.5 |

## Repository Based Dissemination Algorithm

A repository $P$ sends changes of interest to the dependent $Q$ if

$$\left|x^P - x^Q\right| \geq c^Q - c^P$$



## Repository Based Dissemination Algorithm

| Source | Repository P ($c^P = 0.3$) | Repository Q ($c^Q = 0.5$) |
|---|---|---|
| 1 → | 1 → | 1 |
| 1.2 | 1 | 1 |
| 1.4 → | 1.4 → | 1.4 |
| 1.5 | 1.4 | 1.4 |
| 1.7 → | 1.7 → | 1.7 |



## Dissemination Algorithms

- Repository based algorithm requires *fewer* checks at source
- Source based algorithm requires *less* messages

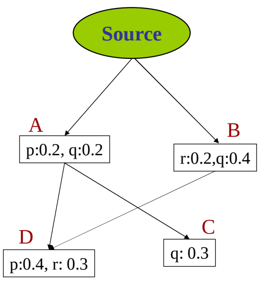


## Logical Structure of the CDN

- Repositories want many data items,

  each with different coherency requirements.
- Issues:

  *Which* repository should serve *what* to *whom*?






## Constructing the Layout Network

Algorithm LeLA (Level by Level Algorithm): Insert repositories one by one

- Check level by level starting from the source
  - Each level has a load controller.
  - The load controller tries to find data providers for the new repository(Q).



## Selecting Data Providers

- Repositories with low *preference factor* are considered as potential data providers.
- *The most preferred repository with a needed data item* is made the provider of that data item.
- The most preferred repository is made to provide the remaining data items (some of these may not be currently disseminated via the node)

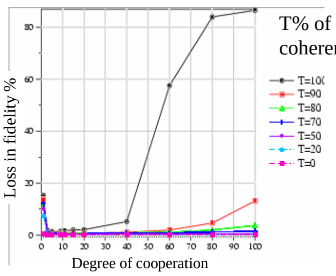
## Preference Factor

- Resource Availability factor:
  Can repository (P) be the provider for one more dependent?
- Data Availability Factor:
  #data items that P can provide for the new repository Q.
- Computational delay factor:
  #dependents P provides for.
- Communication delay factor:
  network delay between the 2 repositories.

$$\frac{\textit{Comm delay (P, Q) X number dependents(P)}}{\textit{Number of data items P can serve Q}}$$



## Loss of fidelity for different coherency requirements




T% of the data items have stringent coherency requirements

The less stringent the coherency requirement, the better the fidelity.

For little/no cooperation, loss in fidely is high.

Too much cooperation?



## Controlled cooperation

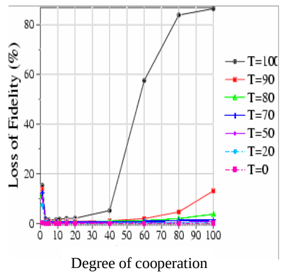
*Actual degree of cooperation*

$$= \frac{\textit{average network delay}}{\textit{average comp delay} \times \#\textit{interested dependents}}$$

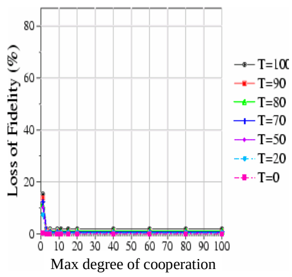
Subject to offered degree of cooperation



## Controlled cooperation is essential




Without controlled cooperation




With controlled cooperation



## But …

Loss in fidelity increases for large # data items.

Repositories with stringent coherence requirements should be closer to the source.



## If parents are not chosen judiciously

It may result in

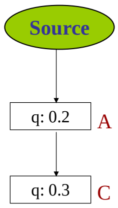
- Uneven distribution of load on repositories.
- Increase in the number of messages in the system.

⇩

Increase in loss in fidelity!

## Data item at a Time Algorithm

- A dissemination tree for *each* data item.
- Source serving the data item is the root.
- Repositories with more stringent coherency requirements are placed closer to the root.




Dynamic Data Dissemination Tree - for *q*



## *DiTA*

- Repository *N* needs data item *x*
- If the source has available push connections, or the source is the only node in the dissemination tree for *x*
  - *N* is made the child of the source
- Else
  - repository is inserted in most suitable subtree where
    - *N*'s ancestors have more stringent coherency requirements
    - *N* is closest to the root



## Most Suitable Subtree?

- *l*: smallest level in the subtree with coherency requirement less stringent than *N*'s.
- *d*: communication delay from the root of the subtree to *N*.
- smallest (*l* x *d* ): most suitable subtree.

**Essentially, minimize communication delays!**



## Example

Initially the network consists of the source.

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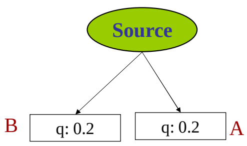
*A* and *B* request service of *q* with coherency requirement *0.2*

*What if C requests service of q with coherency requirement of 0.1?*





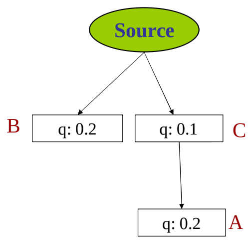

## Example

Initially the network consists of the source.

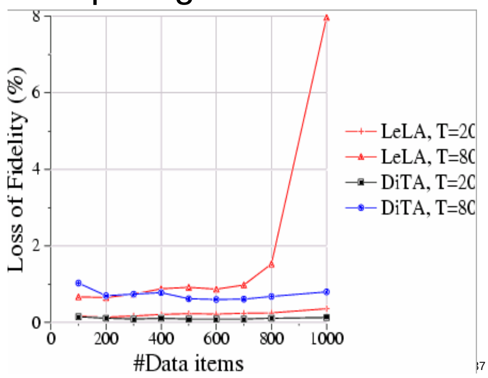
*A* and *B* request service of *q* with coherency requirement *0.2*

*What if C requests service of q with coherency requirement of 0.1?*

*C* requests service of *q* with coherency requirement *0.1*



## Comparing LeLA & DiTA






## Handling Failures in the Network

- Need to detect permanent/transient failures in the network and to recover from them
- Resiliency is obtained by adding redundancy
- Without redundancy,
  failures ➡ loss in fidelity
- Adding redundancy can increase cost
  ➡ possible loss of fidelity!
- Handle failures such that
  cost of adding resiliency is low!



## Passive/Active Failure Handling

- Passive failure detection:
  - Parent sends I'm alive messages at the end of every time interval.
    - what should the time interval be?
- Active failure handling:
  - Always be prepared for failures.
  - For example: 2 repositories can serve the same data item at the same coherency to a child.
    - *This means lots of work*
      ➡ *greater loss in fidelity*.

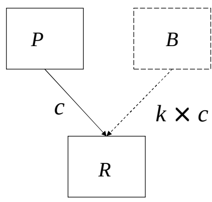
Need to be clever!



## Middle Path

Let repository $R$ want data item $x$ with coherency $c$.

A backup parent $B$ is found for each data item that the repository needs



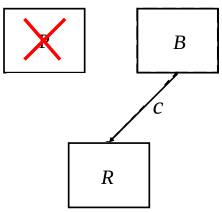

*At what coherency should B serve R?*

$B$ serves $R$ with coherency $k \times c$



## If a parent fails

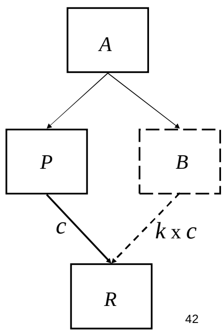
- *Detection*: Child gets two consecutive updates from the backup parent with no updates from the parent
- *Recovery*: Backup parent is asked to serve at coherency *c* till we get an update from the parent






## Adding Resiliency to *DiTA*

- A sibling of *P* is chosen as the backup parent of *R*.
- If *P* fails,
  *A* serves *B* with coherency *c*
  ➡ change is local.
- If *P* has no siblings, a sibling of nearest ancestor is chosen.
  Else the source is made the backup parent.



## Cost-Based Approach (Supp reading 2)

- Exiting heuristics (e.g., DiTA):
  - The parent node should have a more stringent coherency requirement than its children;
  - Impose an apriori fanout constraint on each node;
- Potential problems:
  - A slow node with a very stringent requirement is put at the top of the tree
  - Multiple rounds of trial and error to obtain a good fanout constraint
  - Cannot adapt to changes of the system
    - Eg. coherency requirements, workload in the nodes, transfer delays etc.



## Cost-based Solution

- A cost-based approach:
  - Can explore a larger solution space
  - No trial and error is needed
- Assumptions?
- Adapting the dissemination tree at run time



## Cost model

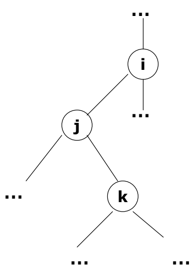
- $LF_i = r_i \bullet D_i$
  - $r_i$ : the avg update arrival rate for the *i*th node
  - $D_i$ : the avg delay of each update message for the *i*th node
- $D_i$ includes the aggregated
  - comm delay
  - queueing time (estimated using M/M/1 queueing model)
  - processing time

in the path from source S to the *i*th node;



## Local Transformation Rules

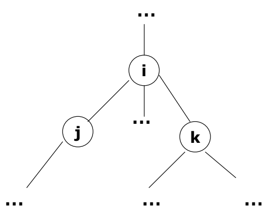
- Node Promotion






## Local Transformation Rules

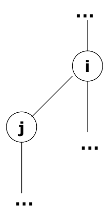
- Node Demotion





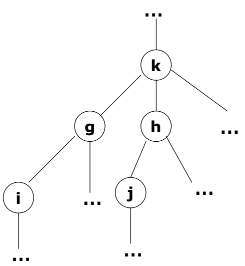

## Local Transformation Rules

- Parent-Child Swap



## Local Transformation Rules

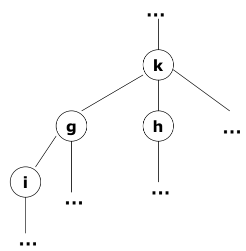
- Cousin Swap






## Local Transformation Rules

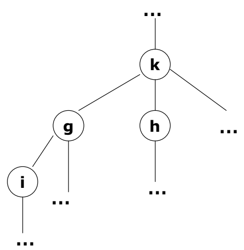
- Nephew Adoption






## Local Transformation Rules

- Uncle-Nephew Swap






## Benefit Estimation

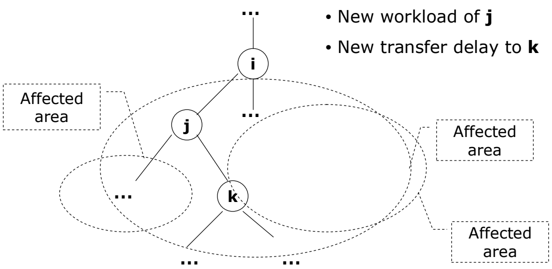
- Re-computing the new cost from scratch incurs large overhead
- Fortunately, each transformation affects only part of the tree
  - We can compute the $\Delta$ cost in *constant time* using only local information.



## Benefit Estimation - Example

- Node Promotion

- New workload of **i**
- New workload of **j**
- New transfer delay to **k**






## Making adaptation decisions

- Centralized approach
  - Less scalable and reliable
- Fully distributed approach
  - Conflicts
    - Two nodes make contradicting decisions
  - Resource wastage
    - Two nodes arrive in the same decision

# Making adaptation decisions

- A token-based distributed approach:
  - Each node only consider the transformations involving its children and grandchildren;
  - A node can make decisions only when it holds a token;
  - At the start of each round, a token is generated by the root;
  - The token is passed to the children once the adaptation is done;
  - Each node chooses the transformation that has the highest benefit.

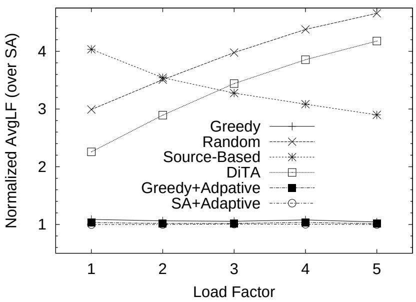


# Static Construction Algorithms

- For static environment or initial tree construction
- Heuristic Algorithm
  - Sort the nodes in ascending order of comm. delays and processing times;
  - For each node in the list:
    - Select a position in the tree so that the average LF of the whole tree is minimized;
- Simulated Annealing
  - Use the above local transformation rules;

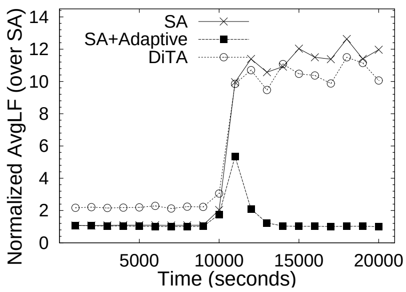


# Sensitivity to processing time






# Dynamic Environment






# Conclusion

- Dynamic data has to be disseminated to maximize fidelity
- Basic approach is to design a dissemination tree/graph
- Both heuristics and cost-based approach have been presented
- Cost-based approach is shown to be superior