DIFS: A Distributed Index for Features in Sensor Networks

B. Greenstein, D. Estrin, R. Govindan,
S. Ratnasamy, S. Shenker

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'Naive' use of a Sensor Network

Sensor Network$\equiv$ Pure Data Collection Device

- individual nodes gather low-level data and send it to central instance for storage, processing, interpretation
- huge amounts of data induce communication bottlenecks
- energy required to transfer data enormous, even if no ongoing queries

'Less Naive' use of a Sensor Network

Sensor Network$\equiv$ Data Collection *and Storage* Device

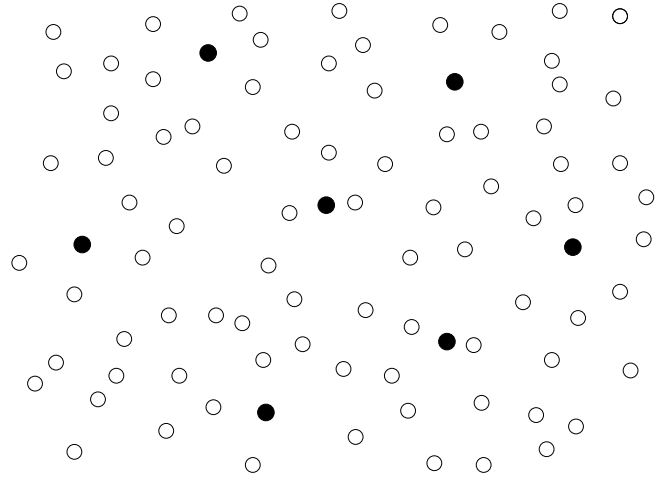
- each sensor stores its collected data locally
- a query is flooded to all nodes of the network, nodes with matching information answer
- no effort when no queries
- bad if a lot of queries arrive
- Possible: data aggregation/pruning while answering query
- . . . still bad for many queries

Data Centric Storage (1)

- define a map f : Event Type $\rightarrow$ Network Location
- store all occurrences of an event at location defined by f
- e.g. all 'elephant sightings' are stored at node $f(\text{elephant sighting})$
- well chosen *hash function* $f \Rightarrow$ load is well distributed for many different event types
- query for 'elephant sightings' only needs to inquire at location $f(\text{elephant sightings})$
- examples: GHT + extensions

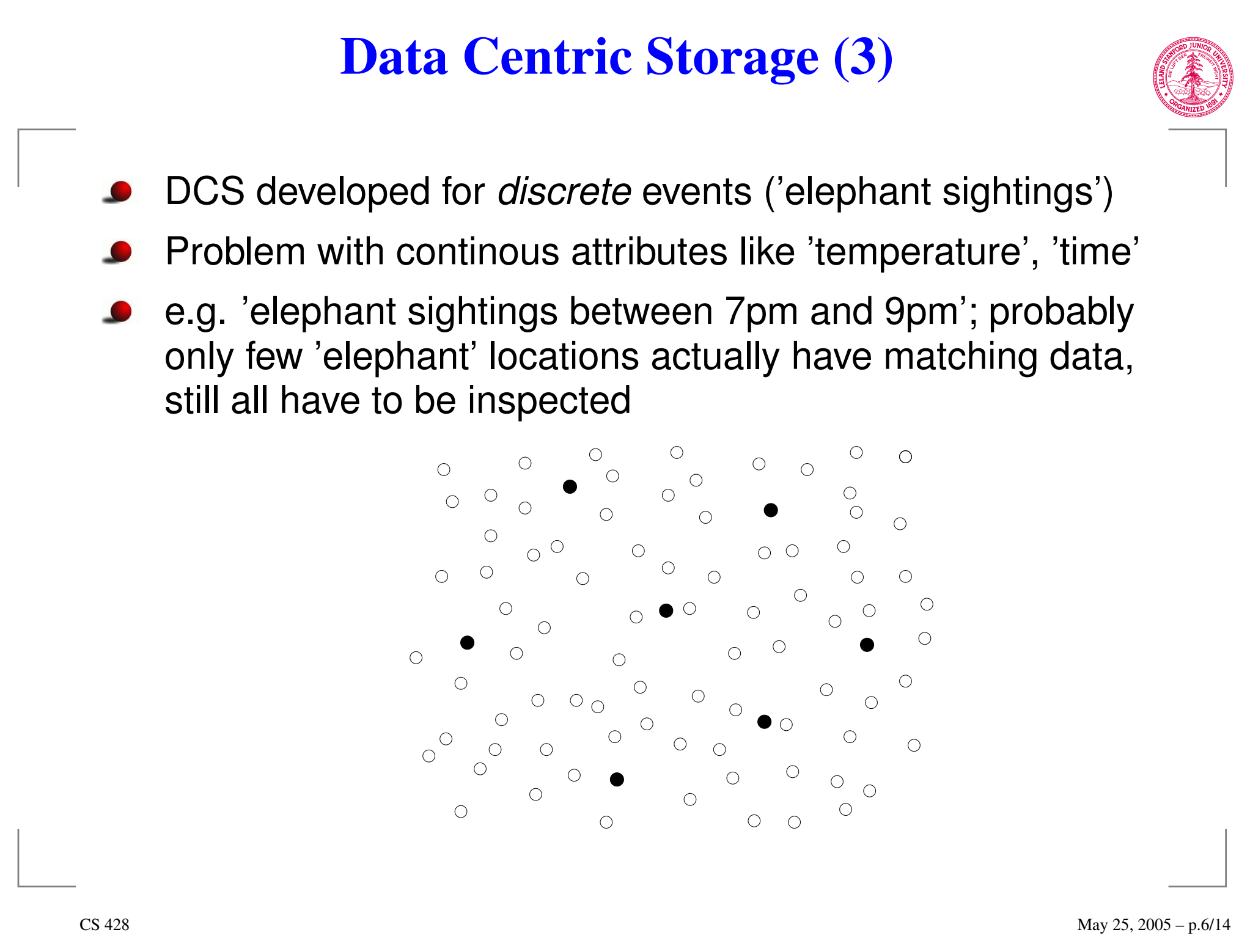
Data Centric Storage (2)

- load problem when many events of same type are occuring
- $\Rightarrow$ create 'well-spread' set of locations responsible for one data type
- event is always stored at *closest* of these locations



- Upon query: check *all* responsible locations

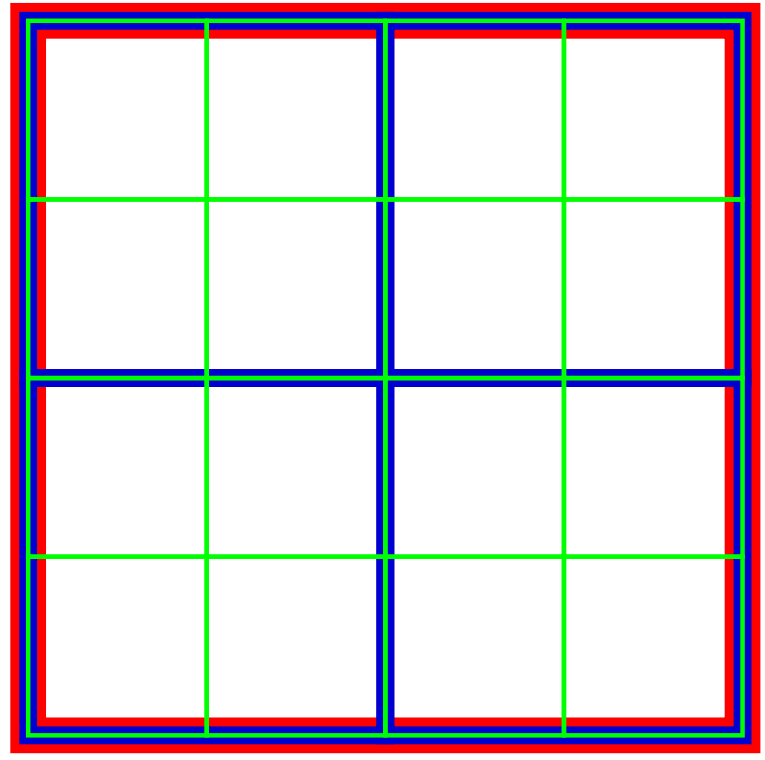
Data Centric Storage (3)



- DCS developed for *discrete* events ('elephant sightings')
- Problem with continous attributes like 'temperature', 'time'
- e.g. 'elephant sightings between 7pm and 9pm'; probably only few 'elephant' locations actually have matching data, still all have to be inspected

A quadtree-based approach

- use hierarchical decomp., e.g. Quadtree
- define for each event type and square a unique responsible location
- responsible location knows histogram of event times of resp. locs. of its children
- query starts at root and only descends into subtrees where histogram indicates matches
- Problem: high load on responsible root node



DIFS: Relieving the Root node

- 1st Idea: hash not only by event type and square but also by time range to a particular node, i.e.
  f : Square $\times$ Type $\times$ Time Range $\rightarrow$ Location
- if time is $[0,255]$, we could hash $f(s, \text{eleph}, 0)$, $f(s, \text{eleph}, 1)$, ...
- in the lowest level of the Quadtree where there are a lot of squares, we'd get 255 as many resp. locations!
- 2nd Idea: while the relevant region for a resp. location shrinks when going down the tree, we want the range to *increase*
- at level 0 hash only with $(ES, [0,255])$,
- at level 1 hash for $(ES, [0,63])$, $(ES, [64,127])$, $(ES, [128,191])$, $(ES, [192,255])$
- ...

DIFS: Event registration / Queries

Registration:

- $(ES, 155)$ is stored at $f(\text{cell}, ES, (0, 255))$
- $f(\text{cell}, ES, (0, 255))$ updates its histogram and sends the changed part $(128, 191)$ to $f(\text{par(cell)}, ES, (128, 191))$

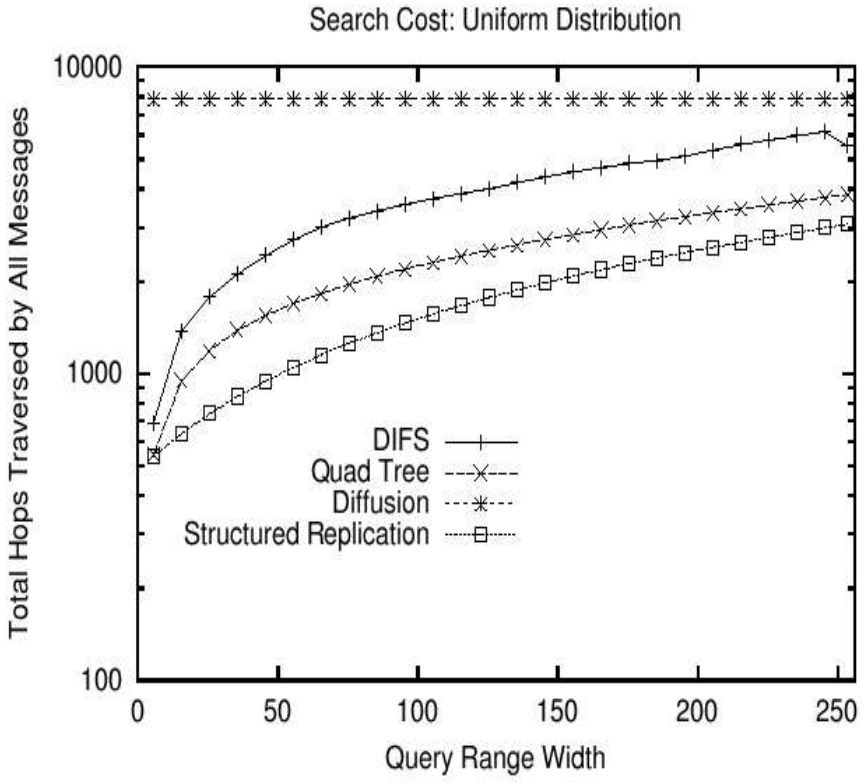
Query: all ES in $(47, 68)$

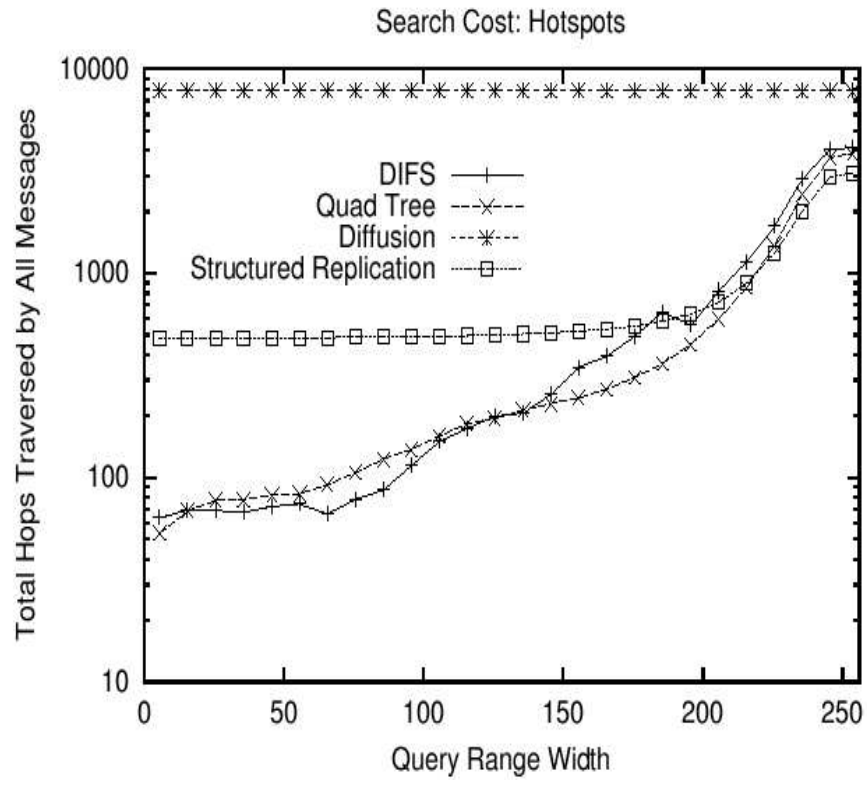
- decompose into $(47, 47), (48, 63), (64, 67), (68, 68)$ (essentially $\log|\text{range}|$ pieces)
- inspect all responsible locations determined by ES and decomposed ranges
- Queries do not always start at a root node !

Experimental Evaluation

- 1024m $\times$ 1024m area
- 2048 nodes with comm. radius of 25m (sparse)
- generated 2048 events at random locations
- Uniform: scalar value random
- HotSpot: inversely proportional to distance to closest of 5 'hot spots'
- For comparison: simple DCS, QuadTree, Directed Diffusion
- Not clear: Quadtree/DIFS refined to bottom ?

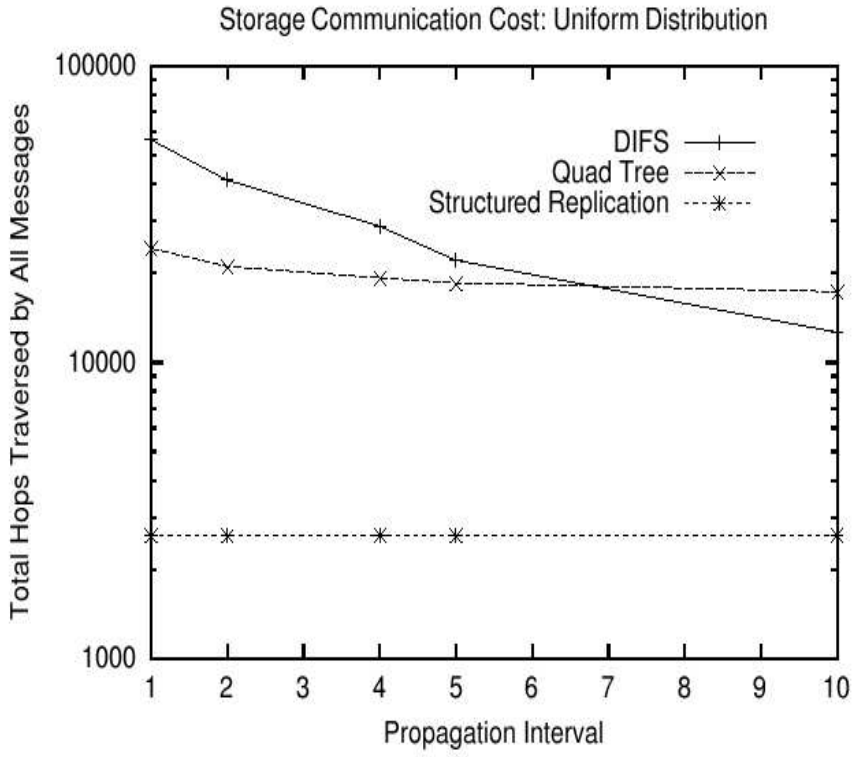
Query Costs

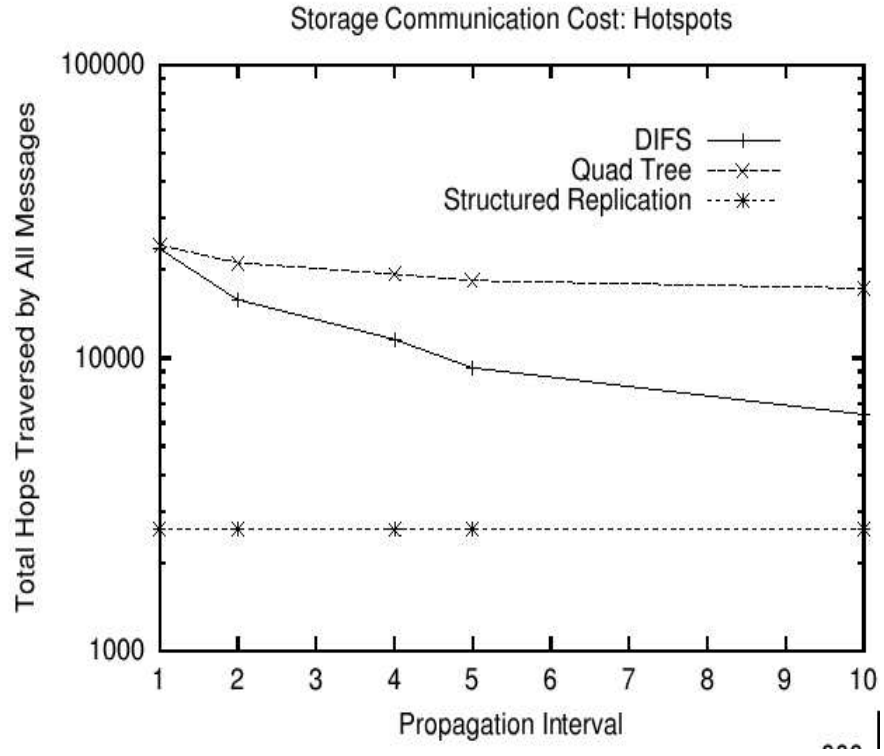




- Pruning not very effective for uniform case
- for small ranges and non-uniform case QT and DIFS good

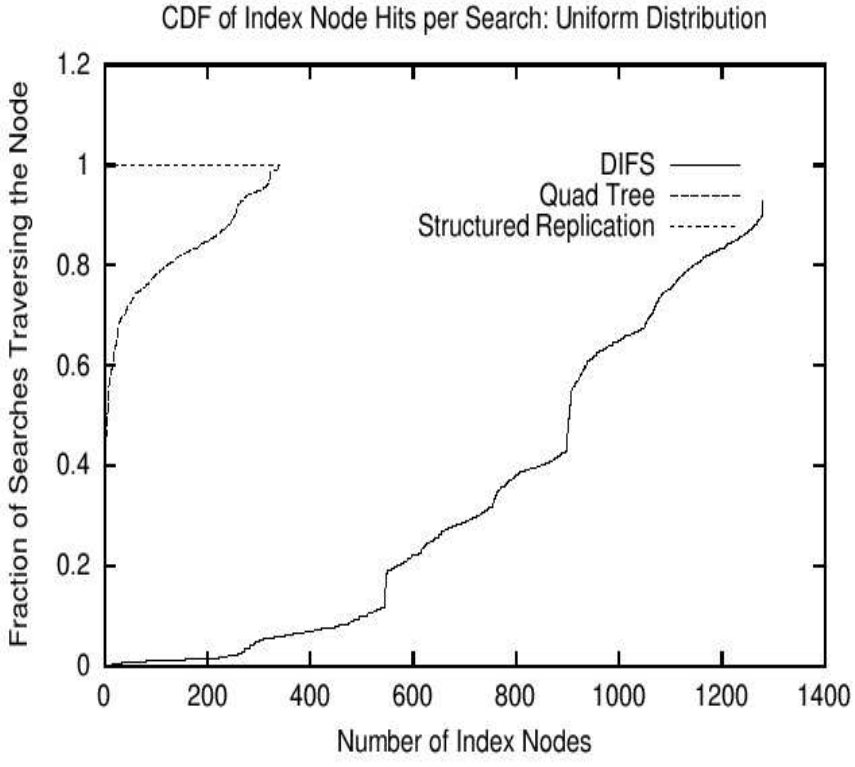
Storage Communication Costs

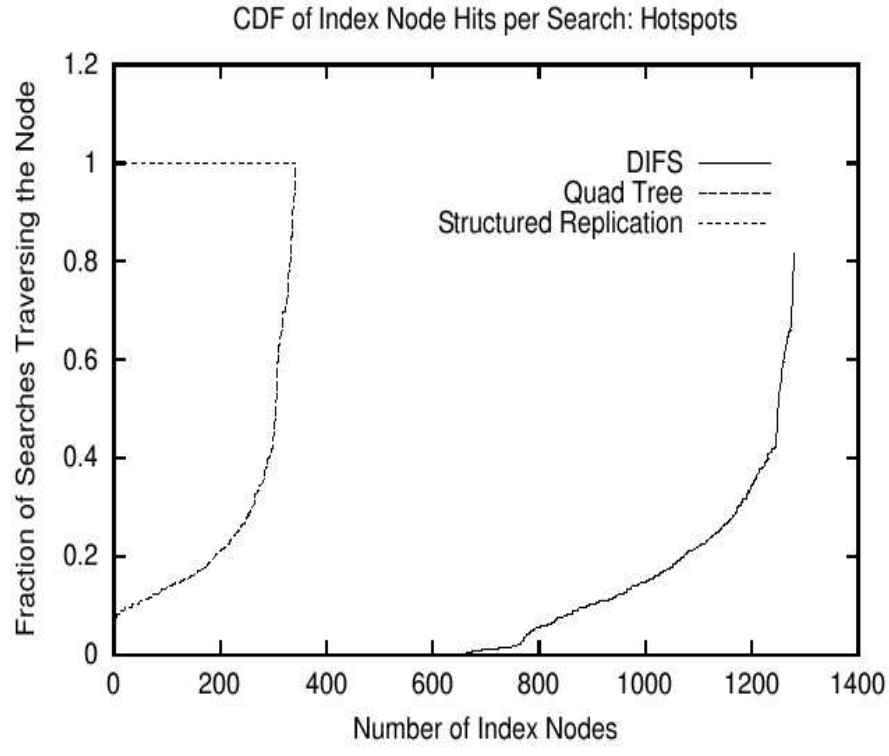




- Registration order of magnitude worse than for DCS
- No update intervals for QT ??

Bottleneck nodes during queries





- load on individual nodes much lower for DIFS

Summary

- #queries $\leq$ # events, uncorrelated events, or storage limitations $\Rightarrow$ standard DCS
- # queries $\gg$ # events and correlated events make additional in-network organization worthwhile $\Rightarrow$ QT/DIFS
- if balancing load over network nodes is important $\Rightarrow$ DIFS