MINERVA Infinity: A Scalable Efficient Peer-to-Peer Search Engine

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Grenoble, France

Vision

- Today: Web Search is dominated by centralized engines ("to google")
  - censorship?
  - single point of attack/abuse
  - coverage of the web?

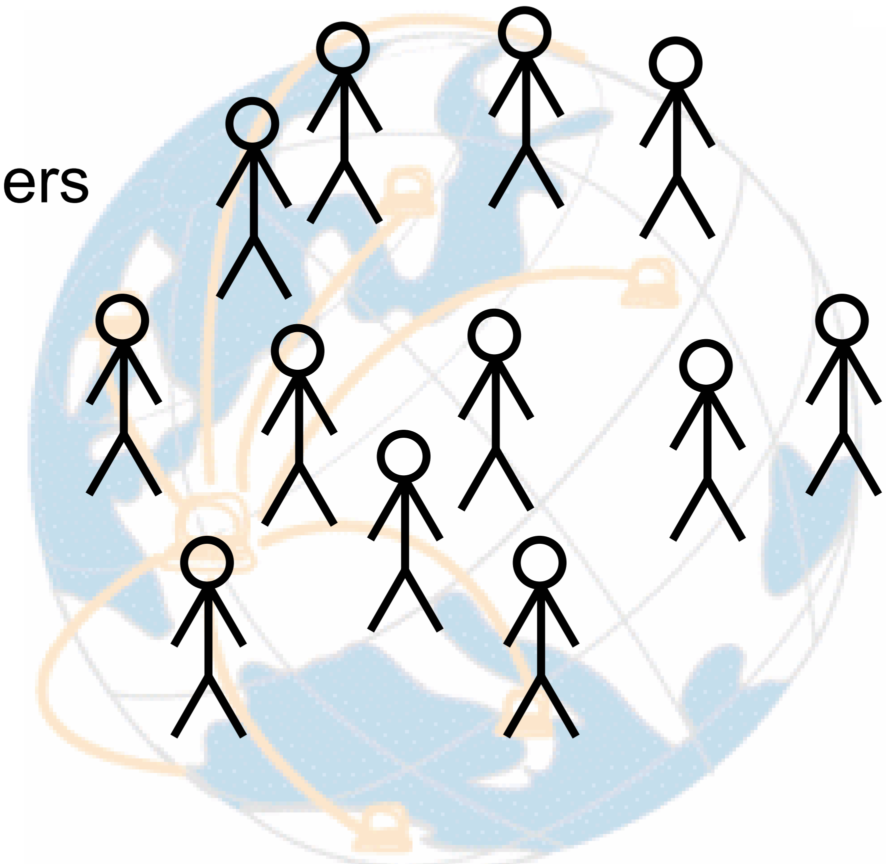
- Ultimate goal: "Distributed Google" to break information monopolies

Google
YAHOO!
msn

- P2P approach best suitable
  - large number of peers
  - exploit mostly idle resources
  - intellectual input of user community

Challenges

- **large scale networks**
  – 100,000 to 10,000,000 users
- **large collections**
  > 10^10 documents
  – 1,000,000 terms
- **high dynamics**



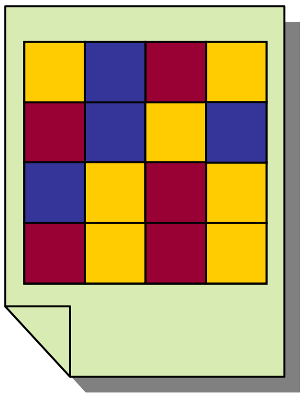
Questions

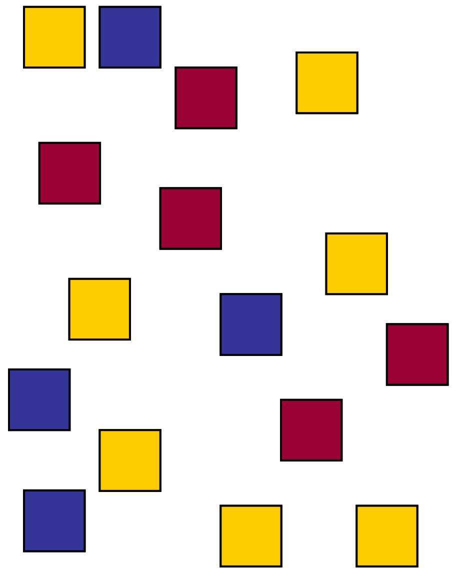
- **Network Organization**
  - structured?
  - hierarchical?
  - unstructured?
- **Data Placement**
  - move data around?
  - data remains at the owner?
- **Scalability?**
- **Query Routing/Execution**
  - Routing indexes?
  - Message flooding?

Overview

- Motivation (Vision/Challenges/Questions)
- **Introduction to IR and P2P Systems**
- **P2P- IR**
- **Minerva Infinity**
- **Network Organization**
- **Data Placement**
- **Query Processing**
- **Data Replication**
- **Experiments**
- **Conclusion**

Information Retrieval Basics





5 x

7 x

4 x

Document

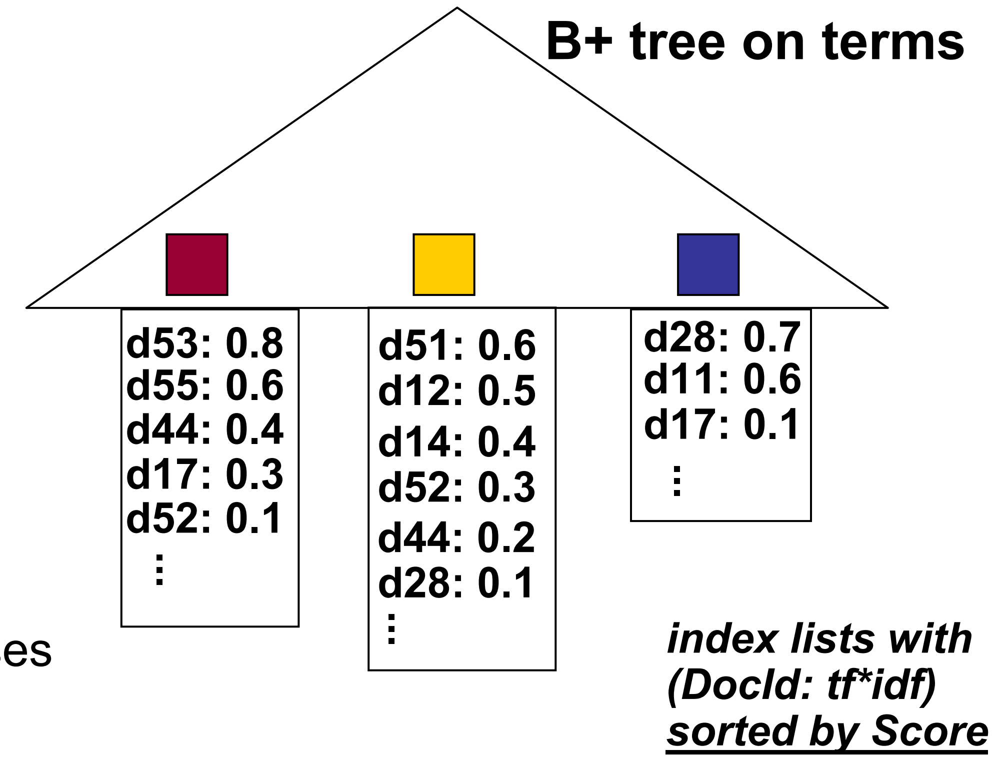
Terms

# of terms (term frequency)

Information Retrieval Basics (2)

Top-k Query Processing: find *k* documents with the highest total score

Query Execution: Usually using some kind of threshold algorithm*:
- sequential scans over the index lists (round-robin)
- (random accesses to fetch missing scores)
- aggregate scores
- stop when the threshold is reached



e.g. Fagin's algorithm
TA or a variant without random accesses

P2P Systems

- Peer:
  - **“one that is of equal standing with another”** *(source: Merriam-Webster Online Dictionary)*
- Benefits:
  - no single point of failure
  - resource/data sharing
- Problems/Challenges:
  - authority/trust/incentives
  - high dynamics
  - …
- Applications:
  - File Sharing
  - IP Telephony
  - Web Search
  - Digital Libraries

Structured P2P Systems based on Distributed Hash Tables (DHTs)

- “structured” P2P networks
- provide one simple method:

`lookup:key->peer`

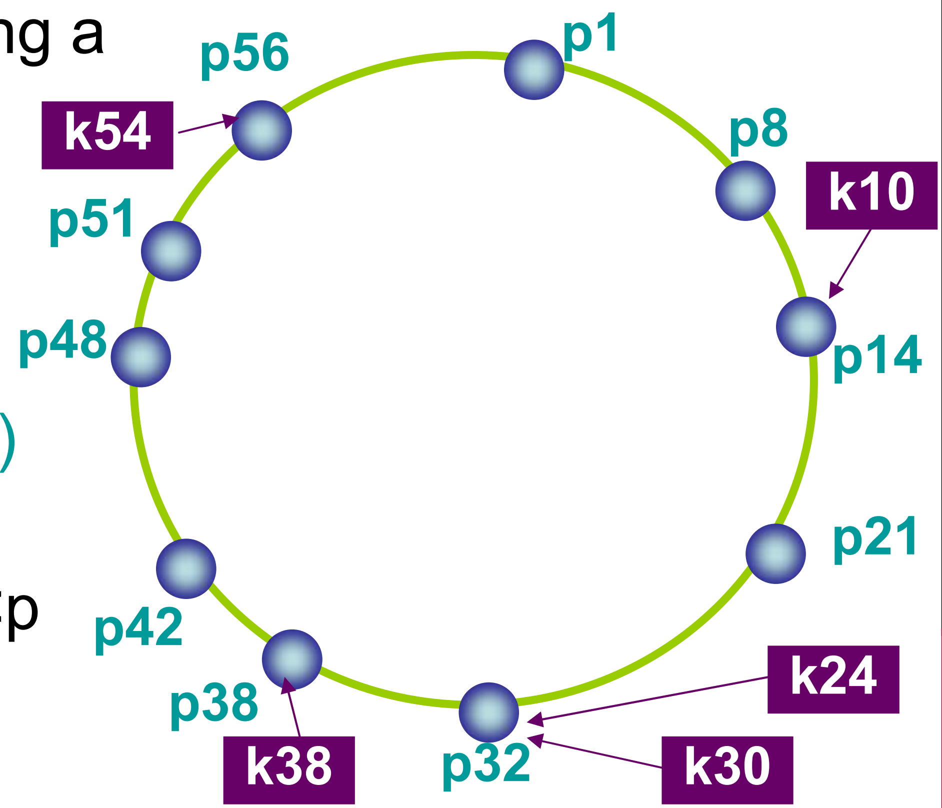
- CAN [SIGCOMM 2001]
- CHORD [SIGCOMM 2001]
- Pastry [Middleware 2001]
- P-Grid [CoopIS 2001]

robustness to load skew, failures, dynamics

Chord

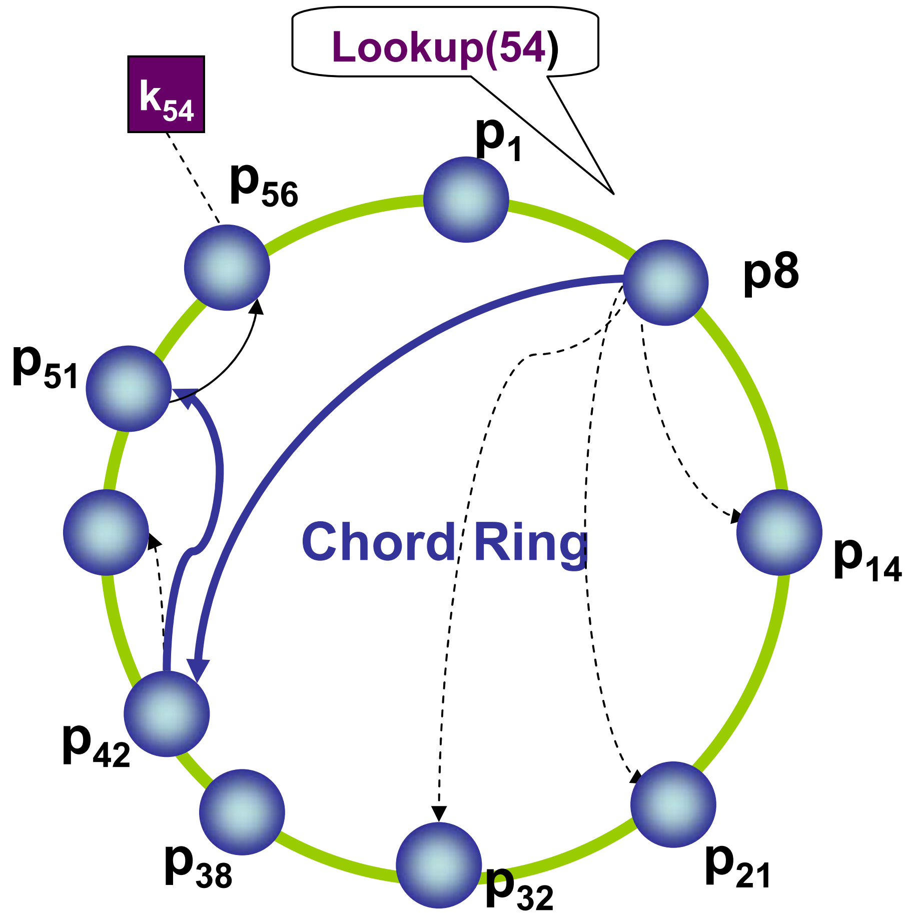
- Peers and keys are mapped to the same cyclic ID space using a hash function

- Key k (e.g., hash(file name)) is assigned to the node with key p (e.g., hash(IP address)) such that k ≤ p and there is no node p‘ with k ≤ p‘ and p‘<p



Chord (2)

- Using **finger tables** to speed up lookup process
- Store pointers to few distant peers
- Lookup in O(log *n*) steps



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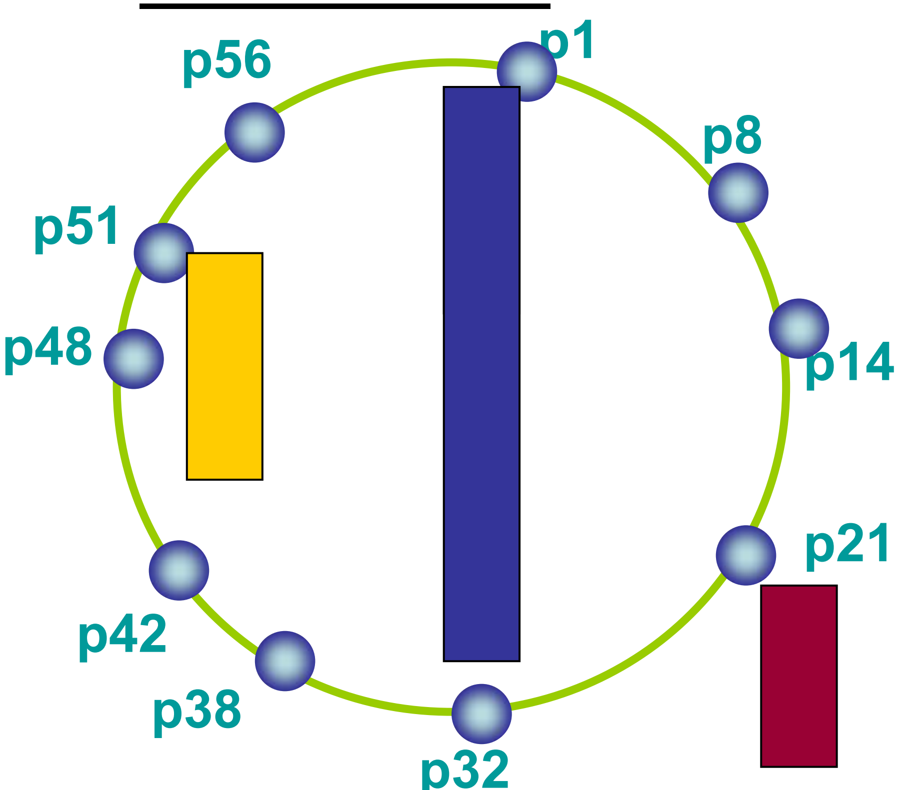
P2P - IR

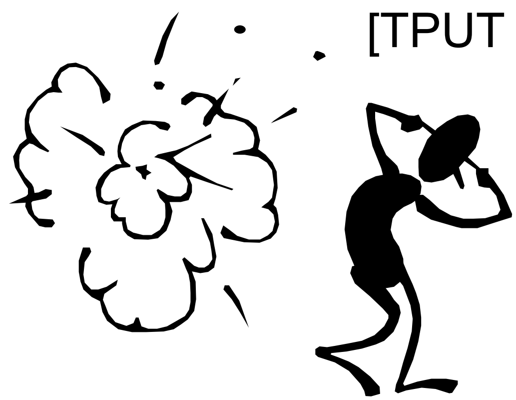
- Share documents (e.g. Web pages) in an efficient and scalable way
- Ranked retrieval
  - simple DHT is insufficient

Possible Approaches

- Each peer is responsible for storing the <u>COMPLETE</u> index list for a subset of terms.



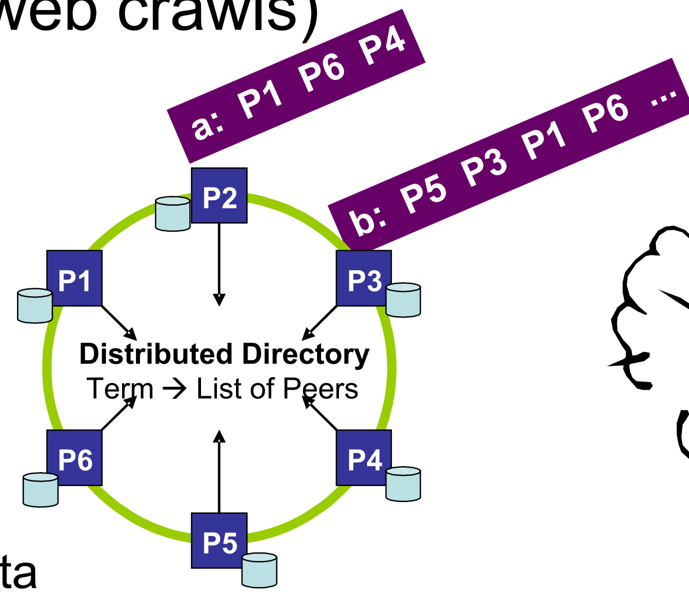
Query Routing: DHT lookups
Query Execution: Distributed Top-k [TPUT '04, KLEE '05]



capacity overload of peers with highly frequent / popular terms (data load <u>AND</u> query load)

Possible Approaches (2)

- Each peer has its own local index (e.g., created by web crawls)



Query Routing:

1. DHT lookups
2. Retrieve Metadata
3. Find most promising peers

Query Execution:

- Send the complete Query and merge the incoming results

capacity overload of peers with
- highly frequent terms
- high-quality collections

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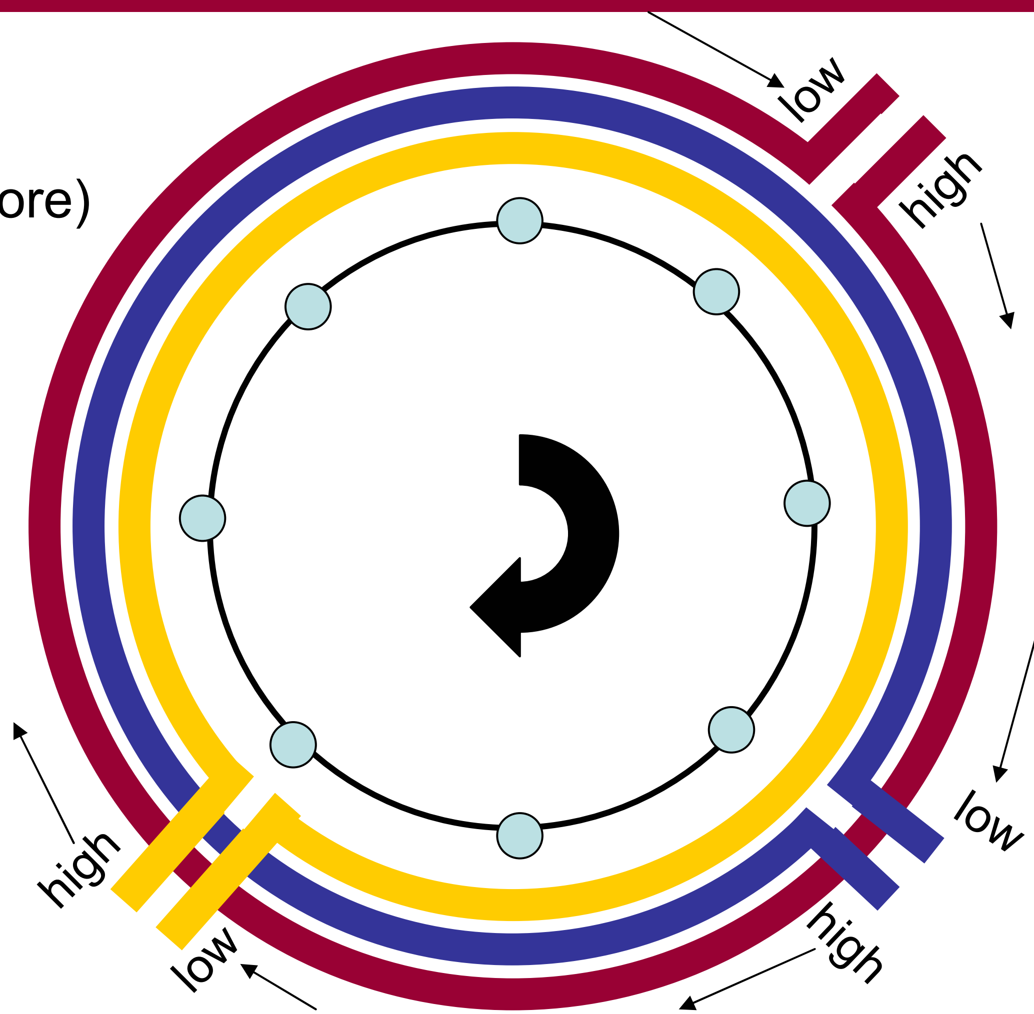
Minerva Infinity

- Idea:
  - assign (term, docId, score) triplets to the peers
    - order preserving
    - load balancing
  - hash(score)+ hash(term) as offset
  - guarantee 100% recall



Hash Function

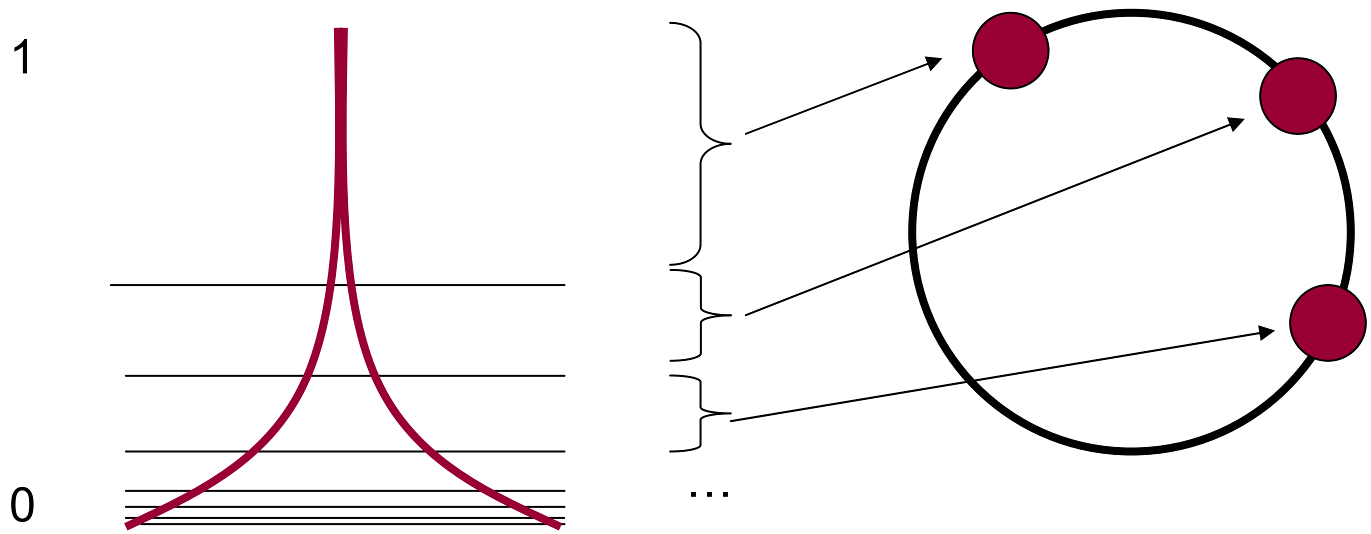
- Requirements:
  - Load balancing (to avoid overloading peers)
  - Order preserving (to make the QP work)
- One without the other is trivial ...
  - Load balancing: apply a pseudo random hash function
  - Order preserving:

$$\frac{S - S_{min}}{S_{max} - S_{min}} * N$$

- Both together is challenging …

Hash Function (2)

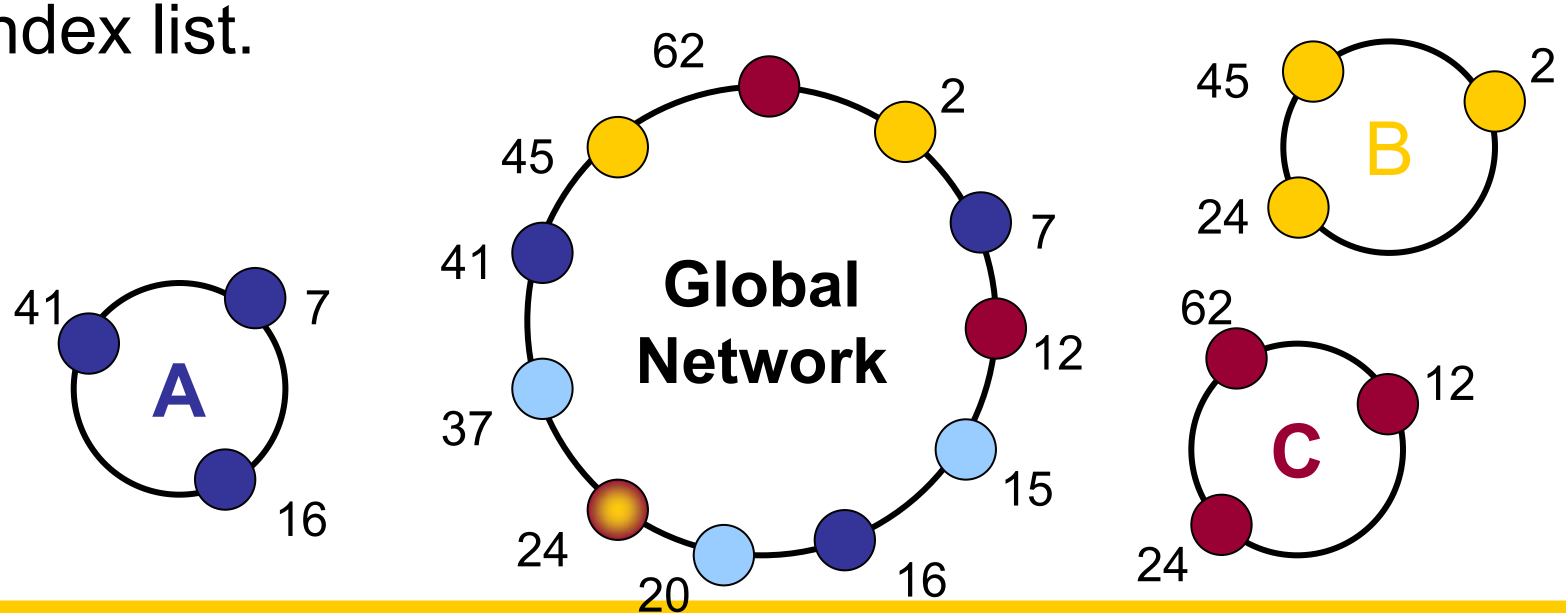
- Assume an exponential score distribution
- Place the first half of the data to the first peer
- The next quarter to the next peer
- and so on …



Term Index Networks (TINs)

- Reduce # of hops during QP by reducing the number of peers that maintain the index list for a particular term

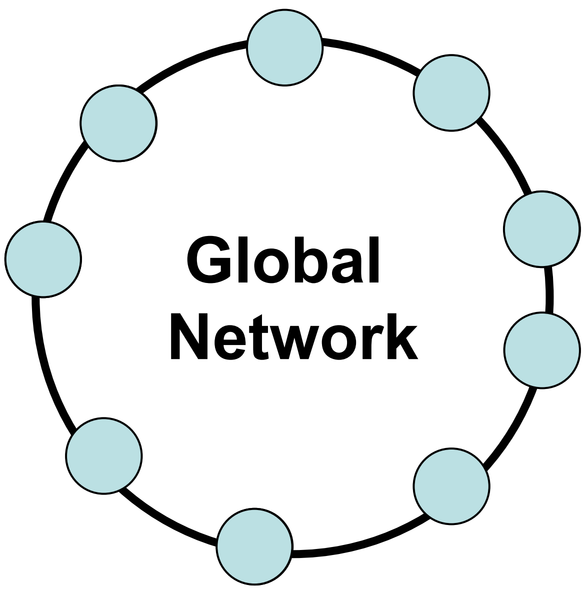
→ Only a <u>small</u> subset of peers is used to store an index list.

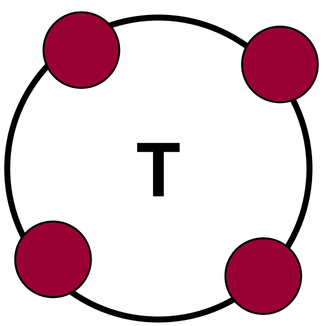


How to Create/Find a TIN

- Use ***u*** Beacon-Peers to bootstrap the TIN for term T

```
p = 1/u
For i=0 to i<n' do
        id = hash(t, i*p)
        if (i>0) use hash(t,(i-1)*p)
                  as a gateway to the TIN
        else node with id creates the TIN
End for
```



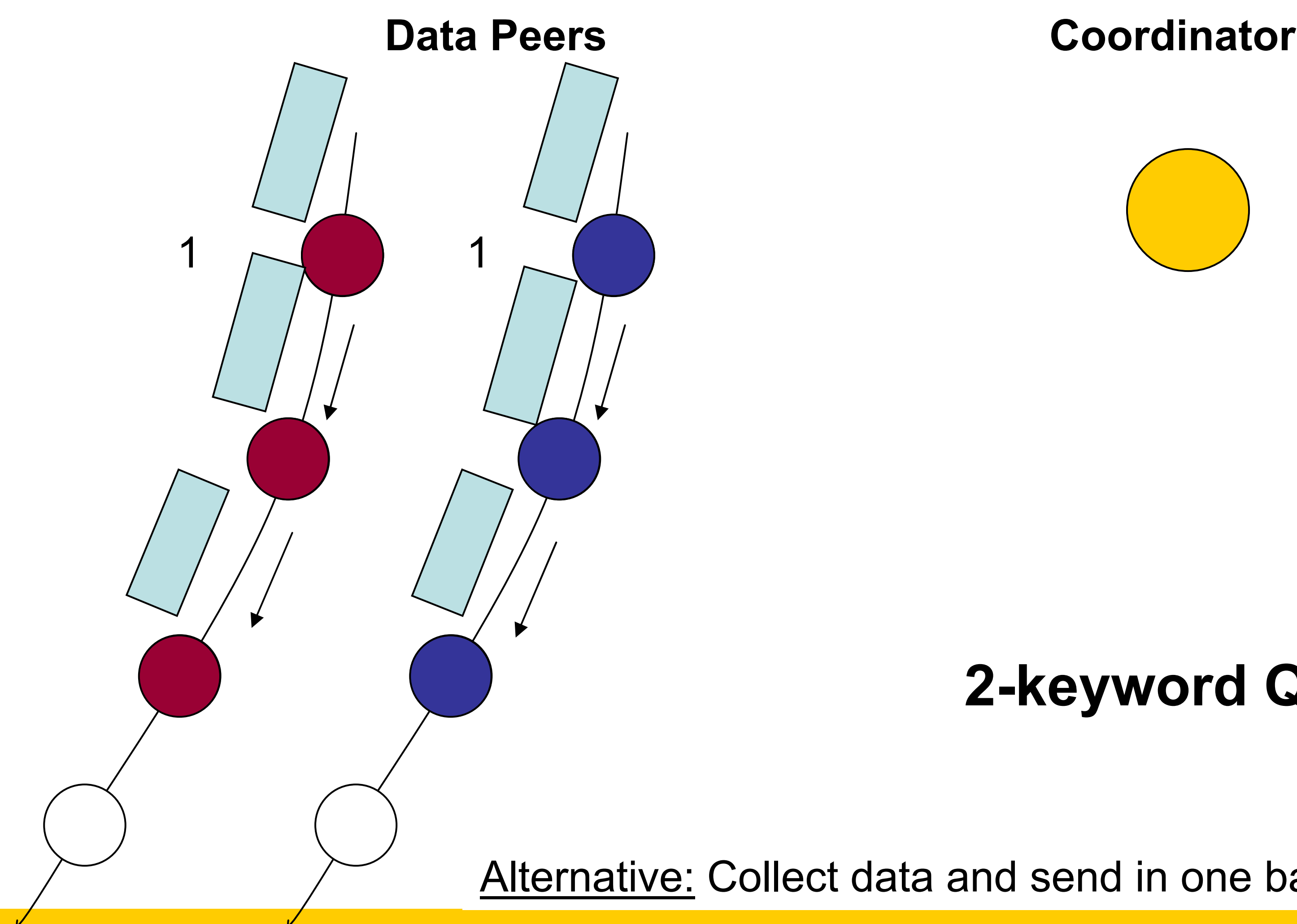


Beacon nodes act as gateways to the TIN

Publish Data / Join a TIN

- Peer with id = hash(t, score) not in the TIN for term t
- Randomly select a **beacon** node
  (Beacon nodes act as gateways to the TIN)
- Call the join method
- Store the item (docId, t, score)

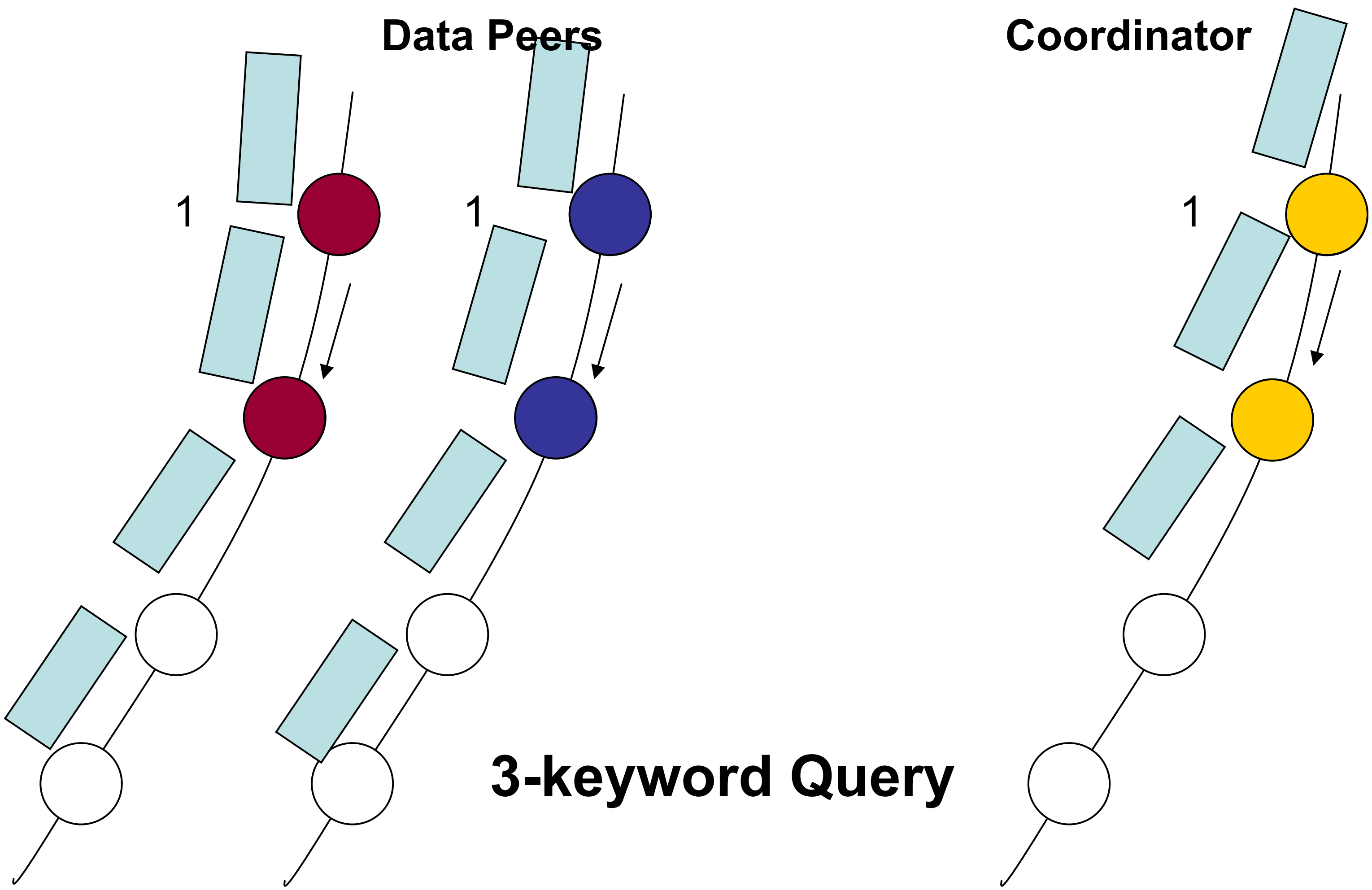
Query Processing



2-keyword Query

Alternative: Collect data and send in one batch.

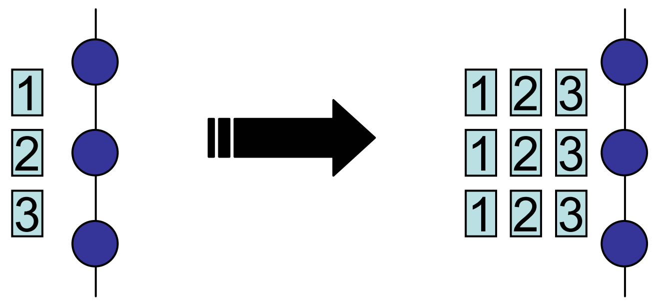
QP with Moving Coordinator



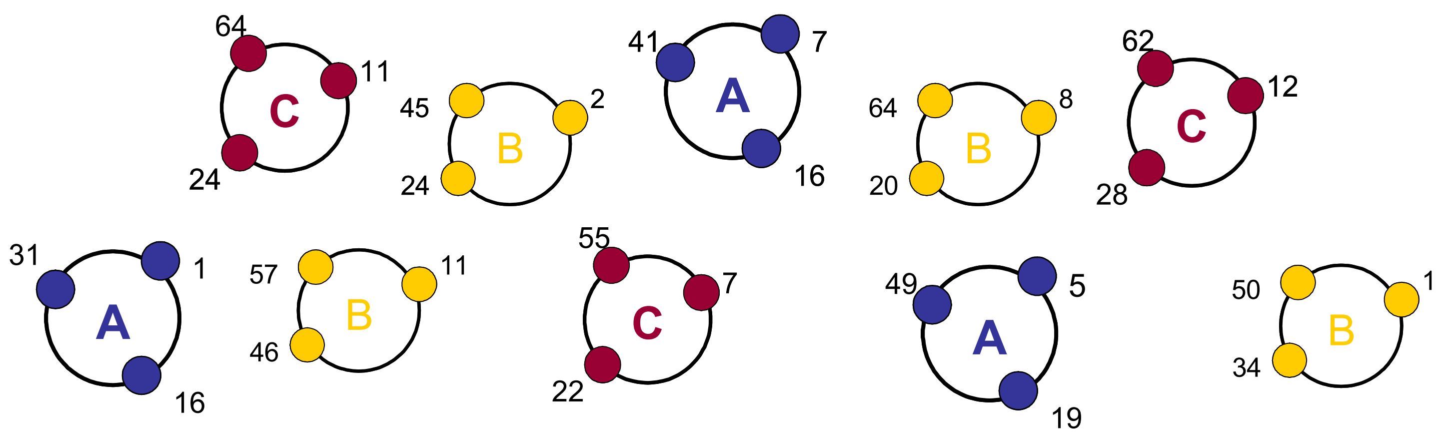
3-keyword Query

Data Replication

- *Vertical*: Replicate data inside a TIN via a 'reverse' communication.



- *Horizontal*: Replicate complete TINs



Experiments

Test bed:

10,000 peers

Benchmarks:

- GOV: TREC .GOV collection + 50 TREC-2003 Web queries, e.g. *juvenile delinquency*
- XGOV: TREC .GOV collection + 50 manually expanded queries, e.g. *juvenile delinquency youth minor crime law jurisdiction offense prevention*
- SCALABILITY: One query executed multiple times

……….

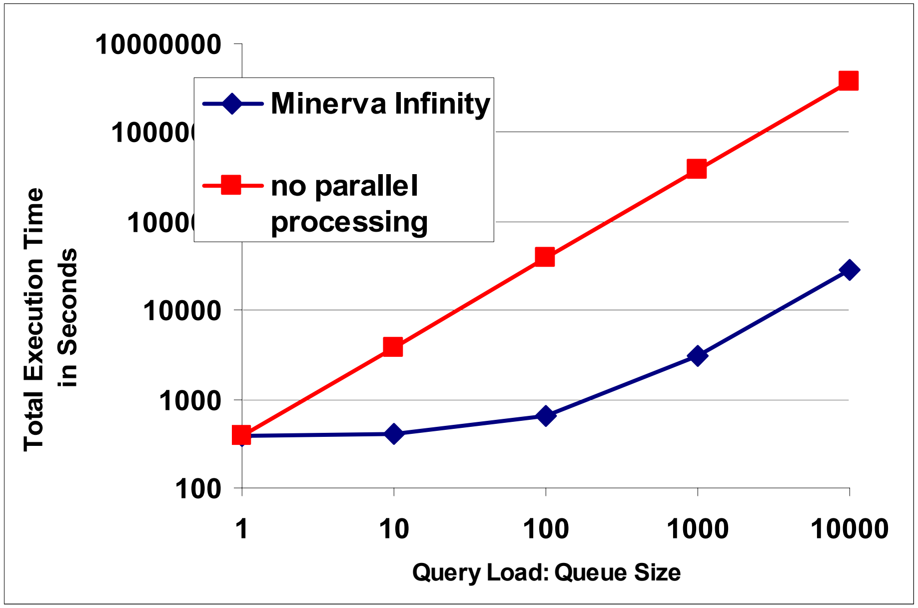
Experiments: Metrics

Metrics

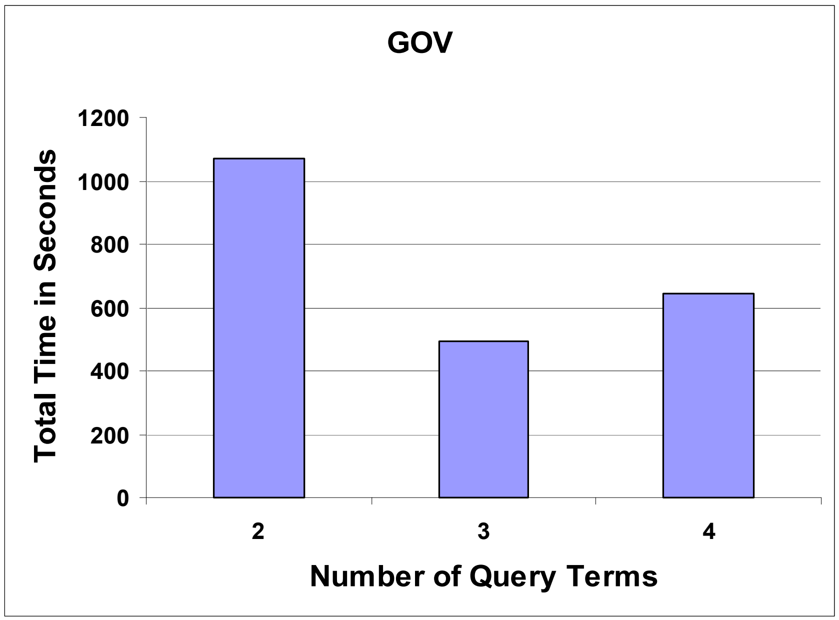
- Network traffic (in KB)
- Query response time (in s)
  - network cost (150ms RTT,
    800Kb/s data transfer rate)
  - local I/O cost (8ms rotation latency
    + 8MB/s transfer delay)
  - processing cost
- Number of Hops

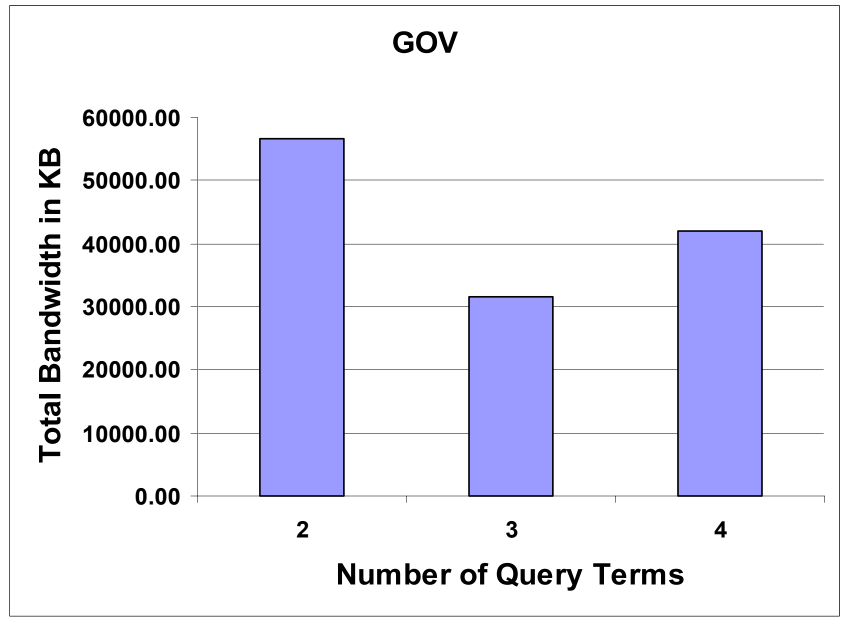
Scalability Experiment

- Measure time for a different query loads.
  – identical queries
  – inserted into a queue



Experiments: Results





Conclusion

- Novel architecture for P2P web search.
- High level of distribution both in data and processing.
- Novel algorithms to create the networks, place data, and execute queries.
- Support of two different data replication strategies.

Future Work

- Support of different score distributions
- Adapt TIN sizes to the actual load
- Different top-k query processing algorithms

Thank you for your attention