KLEE: A Framework for Distributed Top-k Query Algorithms

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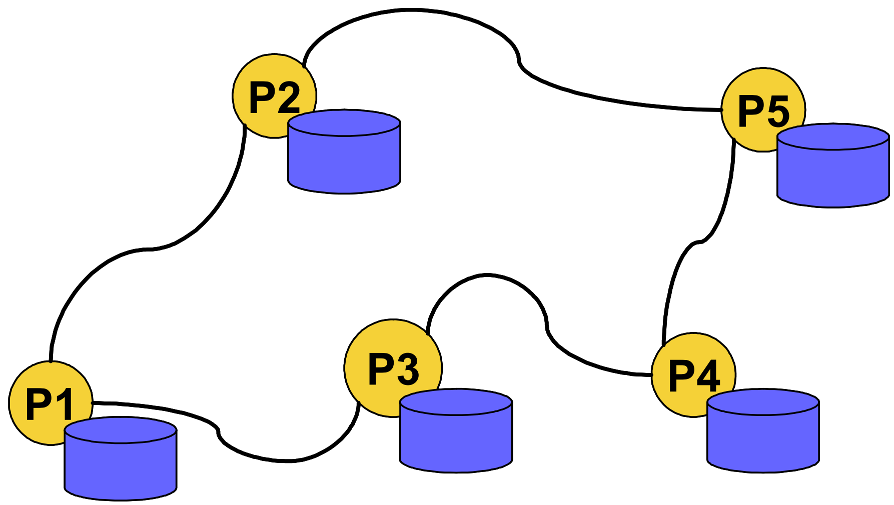
Overview

- Problem Statement
- Related Work
- KLEE
- The Histogram Bloom Structure
- Candidate Filtering
- Evaluation
- Conclusion / Future Work

Computational Model

- **Distributed aggregation queries:**
  Query with m terms with index lists spread across m peers P1 ... Pm

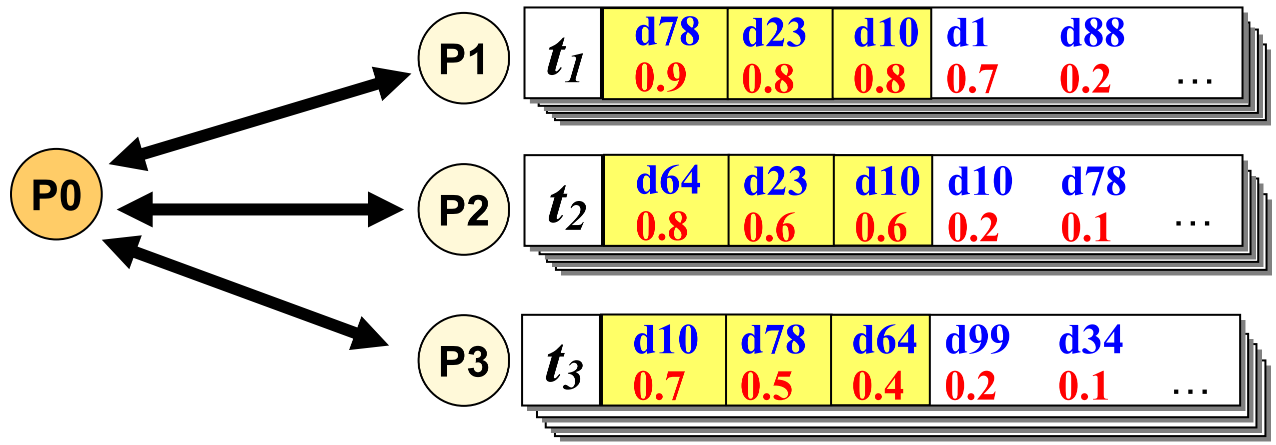


Applications:

- **Internet traffic monitoring**
- **Sensor networks**
- **P2P Web search**

Problem Statement

Query initiator P0 serves as per-query coordinator



- Consider
  - network consumption
  - per peer load
  - latency (query response time)
    - network
    - I/O
    - processing

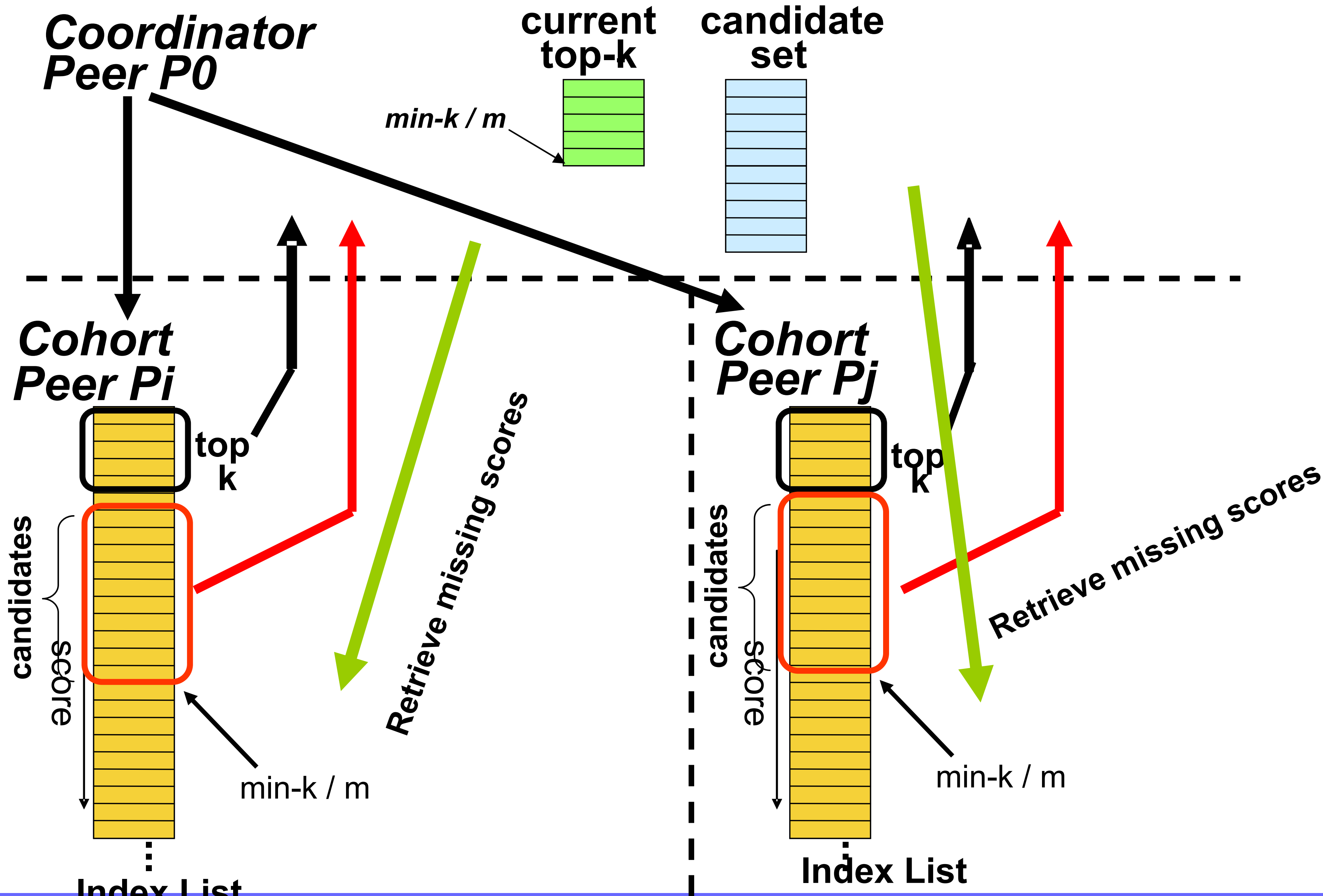
Related Work

Existing Methods:

- **Distributed NRA/TA:** Extend NRA/TA (Fagin et al. `99/'03, Güntzer et al. `01, Nepal et al. `99) with batched access
- **TPUT (Cao/Wang 2004):**
  1) fetch k best entries (d, s_j) from each of P1 ... Pm and aggregate ($\sum_{j=1..m} s_j(d)$) at P0
  2) ask each of P1 ... Pm for all entries with $s_j >$ min-k / m and aggregate results at P0
  3) fetch missing scores for all candidates by random lookups at P1 ... Pm

+ DNRA aims to minimize per-peer work
- DTA/DNRA incur many messages
+ TPUT guarantees fixed number of message rounds
- TPUT incurs high per-peer load and net BW

TPUT



Coordinator Peer P0
current top-k
candidate set
min-k / m
Cohort Peer Pi
top k
candidates
score
Retrieve missing scores
min-k / m
Index List
Cohort Peer Pj
top k
candidates
score
Retrieve missing scores
min-k / m
Index List

KLEE: Key Ideas

- if `mink / m` is small TPUT retrieves a lot of data in Phase 2

    ➔ high network traffic

- random accesses

    ➔ high per-peer load

KLEE:

- Different philosophy: approximate answers!
- Efficiency:
    - Reduces (docId, score)-pair transfers
    - no random accesses at each peer
- Two pillars:
    - The HistogramBlooms structure
    - The Candidate List Filter structure

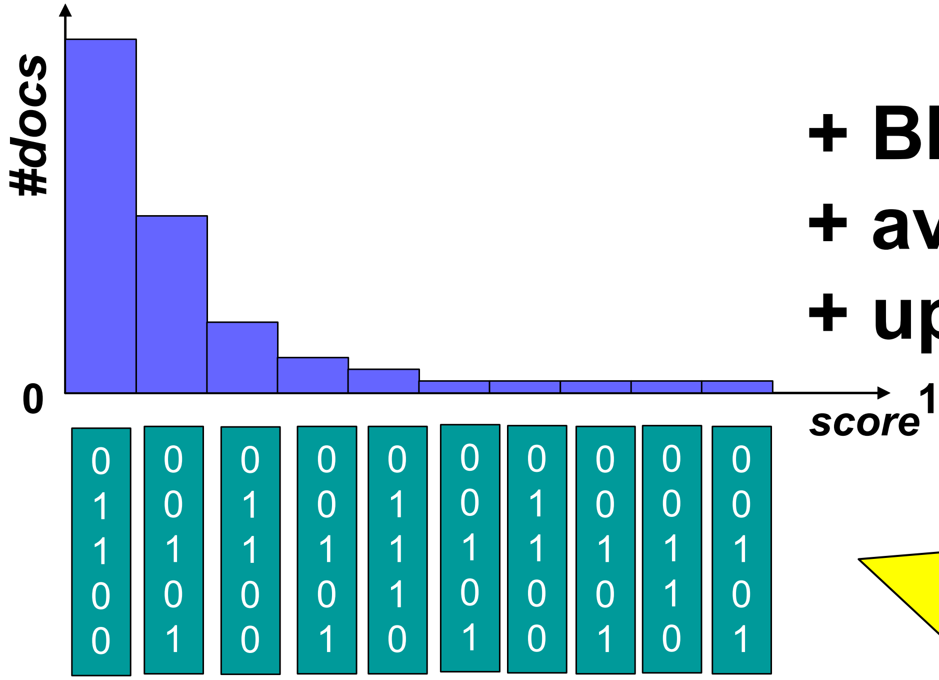
The KLEE Algorithms

- **KLEE 3 or 4 steps:**
  1. **Exploration Step:** … to get a better approximation of min-k score threshold
  2. **Optimization Step:**
     - decide**:** 3 or 4 steps ?
  3. **Candidate Filtering: …** a docID is a good candidate if high-scored in many peers.
  4. **Candidate Retrieval:** get all good docID candidates.

Histogram Bloom Structure

- Each peer pre-computes for each index list:

an equi-width histogram



+ Bloom filter for each cell
+ average score per cell
+ upper/lower score

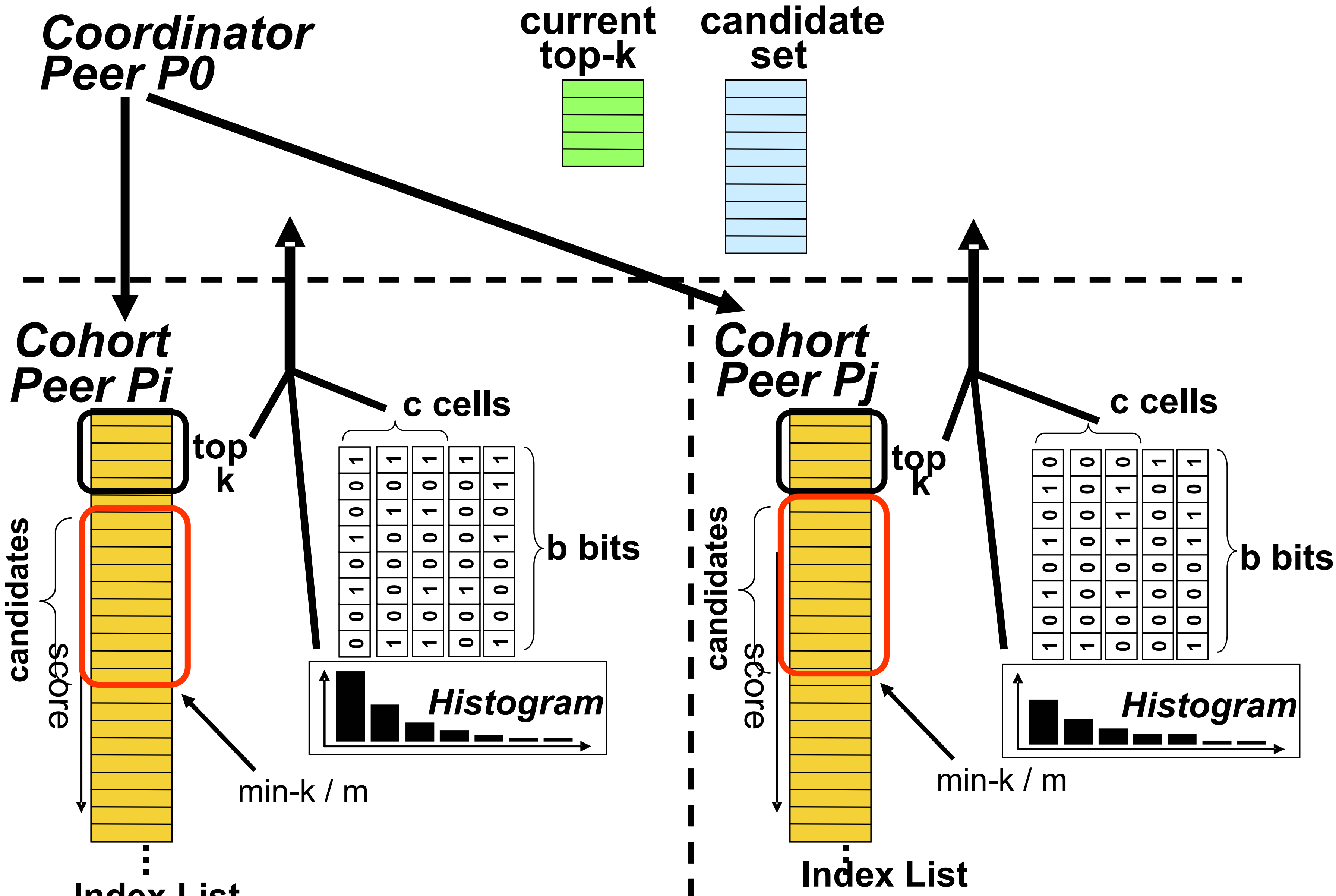
“increase” the mink / m threshold

Bloom Filter

- **bit array of size *m***
- ***k* hash functions**

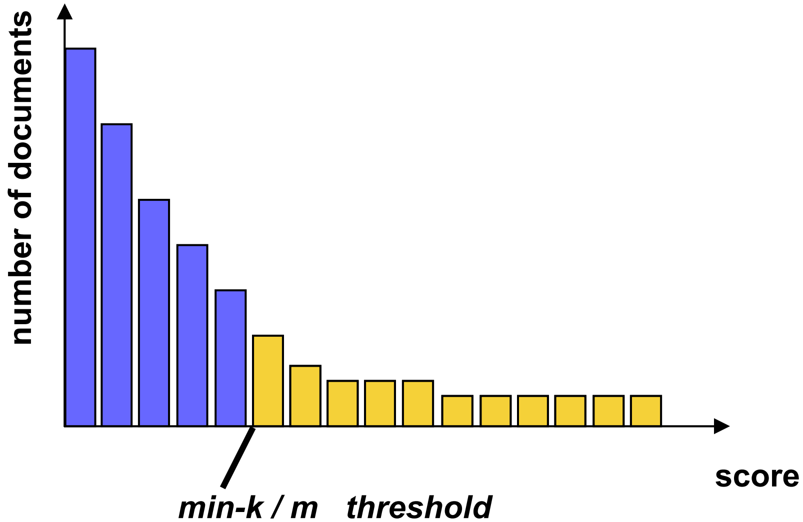
  h_i: *docId_space → {1,..,m}*
- **insert *n* docs by hashing the ids and settings the corresponding bits**
- **Membership Queries:**
  - **document is in the Bloom Filter if the corresponding bits are set**
- **probability of false positives (*pfp*)** $pfp = (1 - e^{-kn/m})^k$
- **tradeoff accuracy vs. efficiency**

Exploration and Candidate Retrieval



Candidate List Filter Matrix

- **Goal: filter out unpromising candidate documents in step 2**
- **estimate the max number of docs that are above the `mink / m` threshold**



- **send this number and the threshold to the cohort peers**

Candidate List Filter Matrix (2)

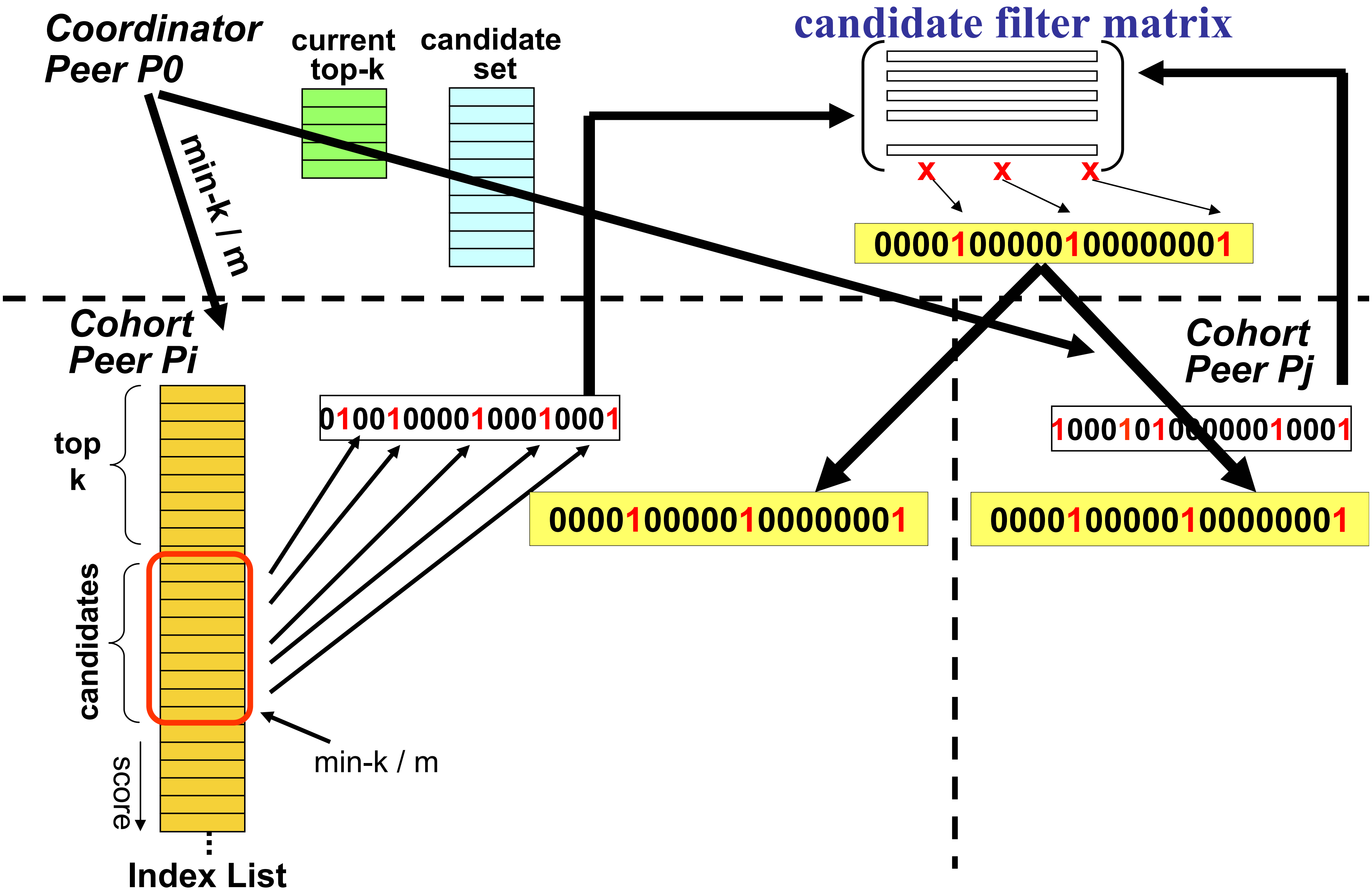
- **Each cohort returns a Bloom Filter that "contains" all docs above the `mink / m` threshold**

➔Candidate List Filter Matrix (*CLFM*)

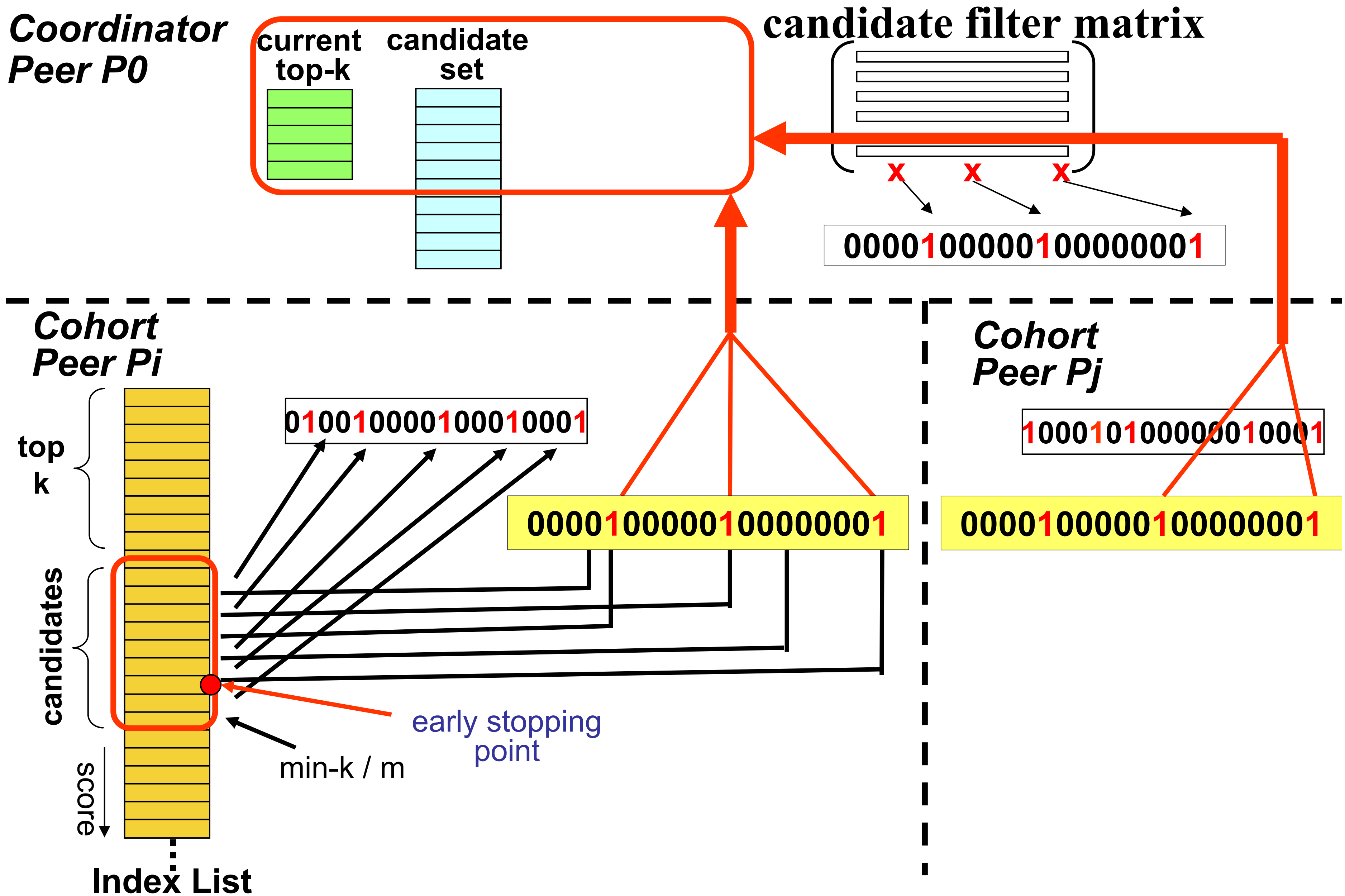
0101010010111110101001001010101001
0100100110010111111001001010111110
1010101010101001100100100111110000
00000000100000001000000000000100000

Select all columns with at least R bits set

KLEE– Candidate Set Reduction



KLEE – Candidate Retrieval



Enhanced Filtering

- BF represenation can be improved …

(d1, 0.9)
(d2, 0.6)
(d5, 0.5)
(d3, 0.3)
(d4, 0.25)
(d17, 0.08)
(d9, 0.07)

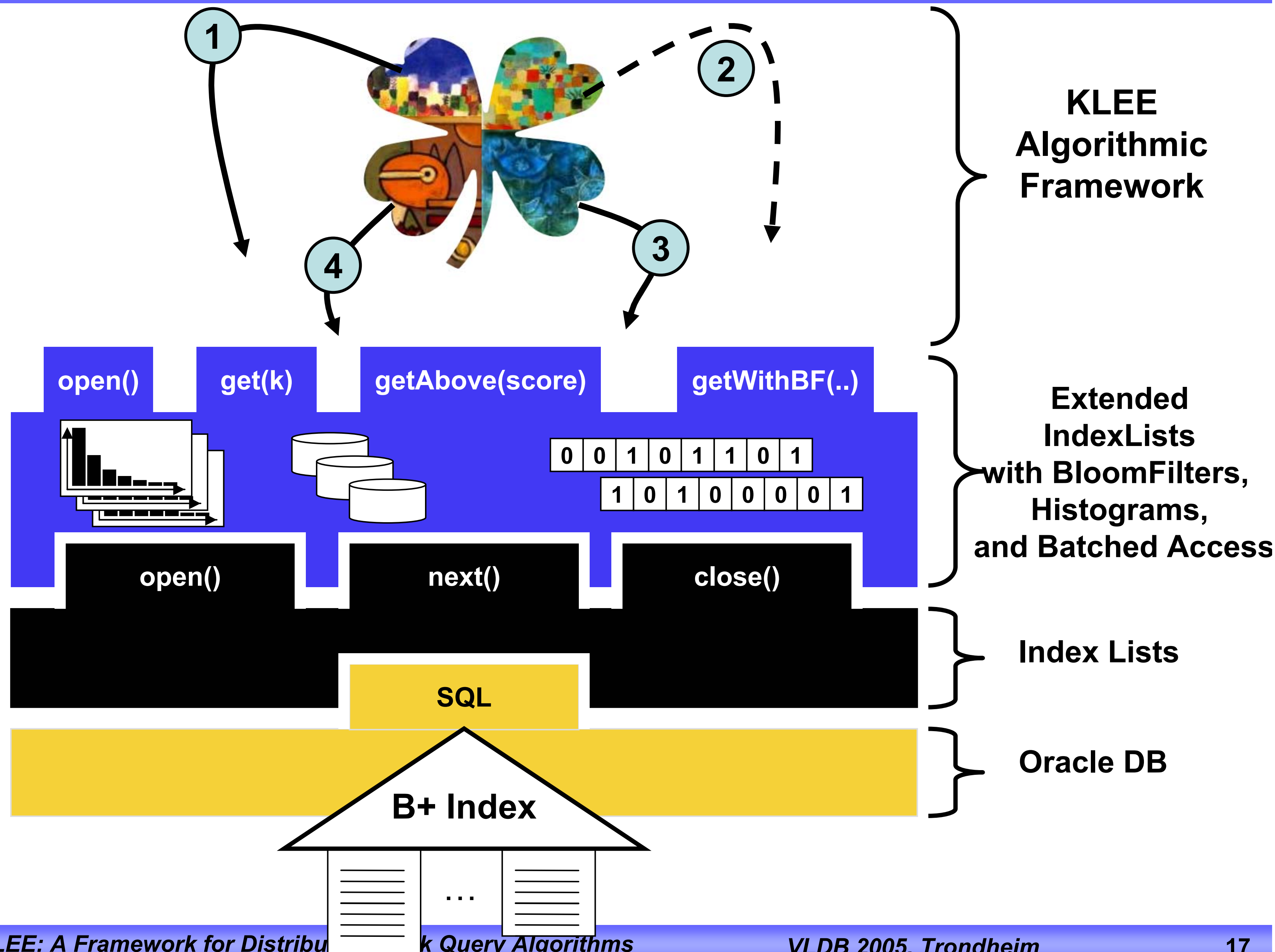
28,23,14,85,34,23,11,24,54,33,60,34
43,13,15,25,54,21,71,44,64,71,72,31
31,43,21,75,21,71,64,34,74,63,50,62

d1, d2, and d5 are promising documents but e.g. s1-s5 = 0.4 !

- Send byte-array with cell-numbers instead of bits
- Select „columns“ with

Sum over upper-bounds > min-k

Architecture/Testbed



Evaluation: 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*
- **IMDB**: Movie Database, queries like
  - actor = John Wayne; genre =western
- **Synthetic Distribution** (Zipf, different skewness): GOV collection but with synthetic scores
- **Synthetic Distribution + Synthetic Correlation**: 10 index lists

Evaluation: Metrics

- Relative recall w.r.t. to the actual results
- Score error
- Bandwidth consumption
- Rank distance
- Number of RA and number of SA
- Query response time

  - network cost (150ms RTT,
    800Kb/s data transfer rate)
  - local I/O cost (8ms rotation latency
    + 8MB/s transfer delay)
  - processing cost

Evaluated Algorithms

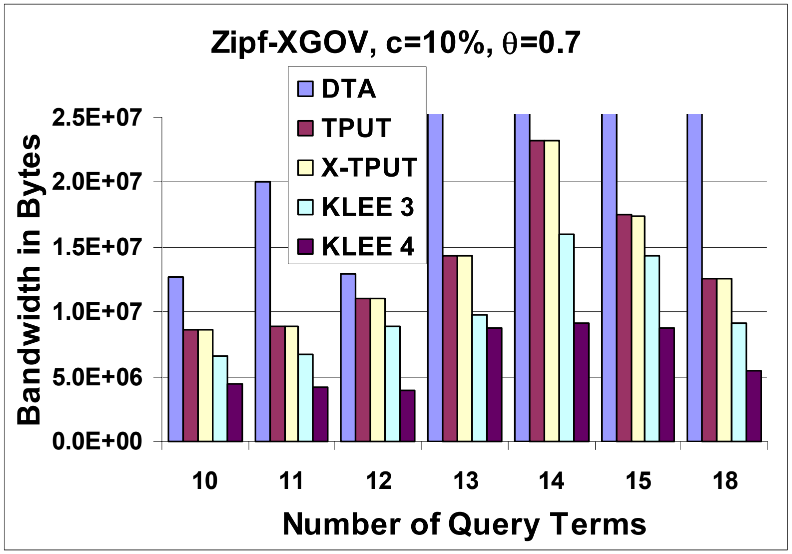
- DTA:
  - batched distributed threshold algorithm, batch size k.
- TPUT
- X-TPUT:
  - approximate TPUT. No random accesses.
- KLEE-3
- KLEE-4

C = 10% of the score mass

Synthetic Score Benchmarks

Zipf-GOV c=10%	Total # of Bytes	Total Time in ms	Average Recall
DTA	17,752,769	3,532,180	1
TPUT	53,494,903	576,713	1
X-TPUT	53,011,252	404,991	0.99
KLEE 3	49,861,342	367,931	0.97
KLEE 4	25,057,920	160,585	0.94

Zipf-XGOV c=10%	Total # of Bytes	Total Time in ms	Average Recall
DTA	617,009,260	39,582,682	1
TPUT	377,928,880	1,599,581	1
X-TPUT	377,097,644	1,521,220	0.98
KLEE 3	287,294,812	1,189,891	0.91
KLEE 4	165,077,807	375,077	0.92

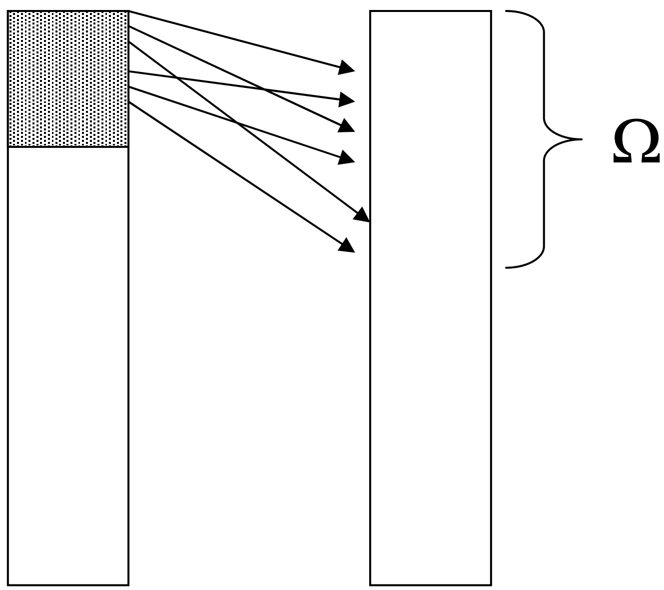


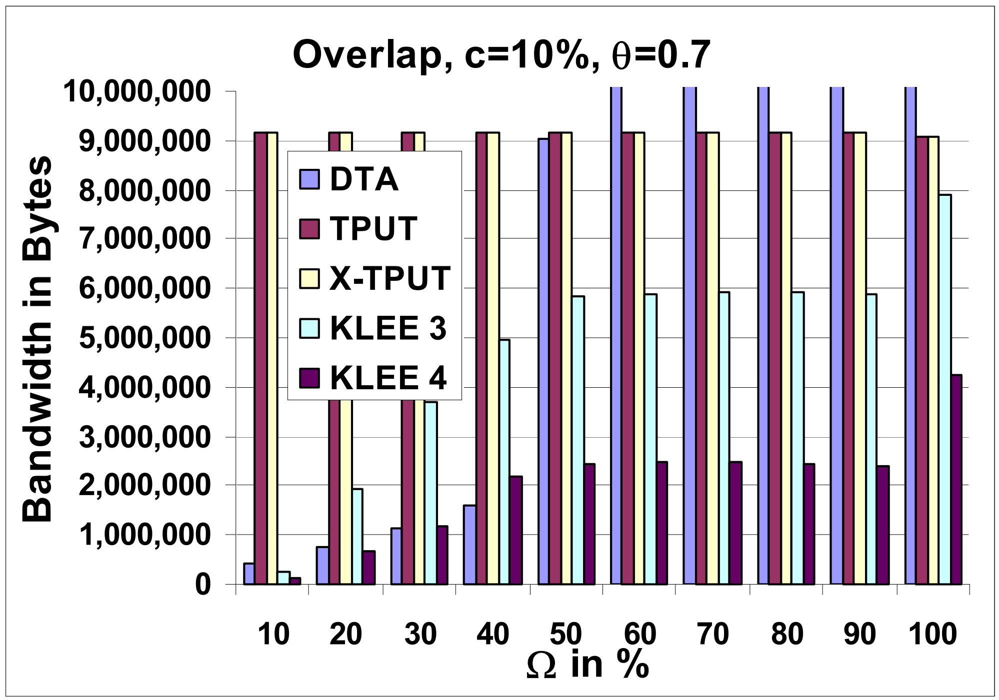
θ = 0.7

Synthetic Correlation Benchmark

Overlap+Zipf c=10% Ω = 30%	Total # of Bytes	Total Time in ms	Average Recall
DTA	1,146.32	157,420	1
TPUT	9,150,904	29,270	1
X-TPUT	9,150,904	28,335	1
KLEE 3	3,678,780	12,971	0.92
KLEE 4	1,192,704	6,546	0.91

randomly insert top k documents from list i in the top Ω documents of list j

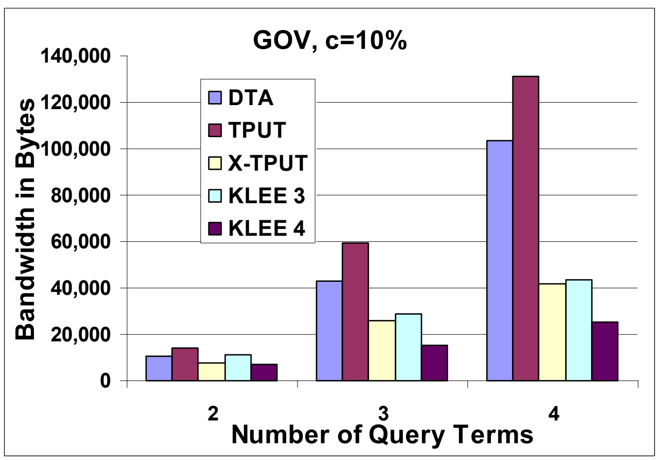


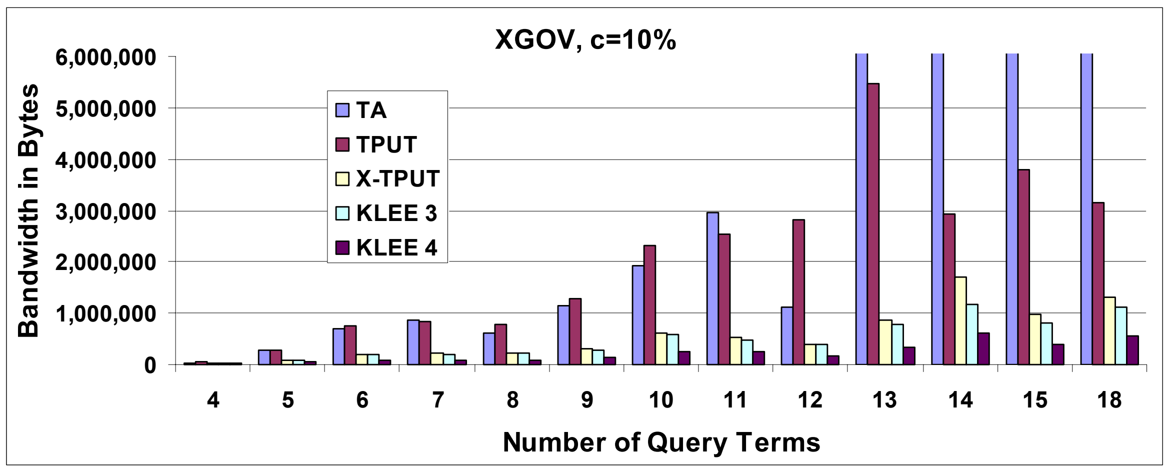


GOV / XGOV

GOV c=10%	Total # of Bytes	Total Time in ms	Average Recall
DTA	1,172,446	190,259	1
TPUT	1,505,290	185,049	1
X-TPUT	597,991	31,432	0.89
KLEE 3	722,664	28,319	0.9
KLEE 4	440,868	39,564	0.9

XGOV c=10%	Total # of Bytes	Total Time in ms	Average Recall
DTA	92,587,264	3,740,677	1
TPUT	70,044,884	2,346,882	1
X-TPUT	19,236,084	96,153	0.91
KLEE 3	16,690,912	88,271	0.83
KLEE 4	7,920,774	56,609	0.79





Conclusion / Future Work

- Conclusion
  - KLEE: approximate top-k algorithms for wide-area networks
  - significant performance benefits can be enjoyed, at only small penalties in result quality
  - flexible framework for top-k algorithms, allowing for trading-off
    - efficiency versus result quality and
    - bandwidth savings versus the number of communication phases.
  - various fine-tuning parameters
- Future Work
  - Reasoning about parameter values
  - Consider "moving" coordinator

Thanks for your attention!

Questions?

Comments?