Prioritized Evaluation of Continuous Moving Queries over Streaming Locations

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Managing Streaming Locations

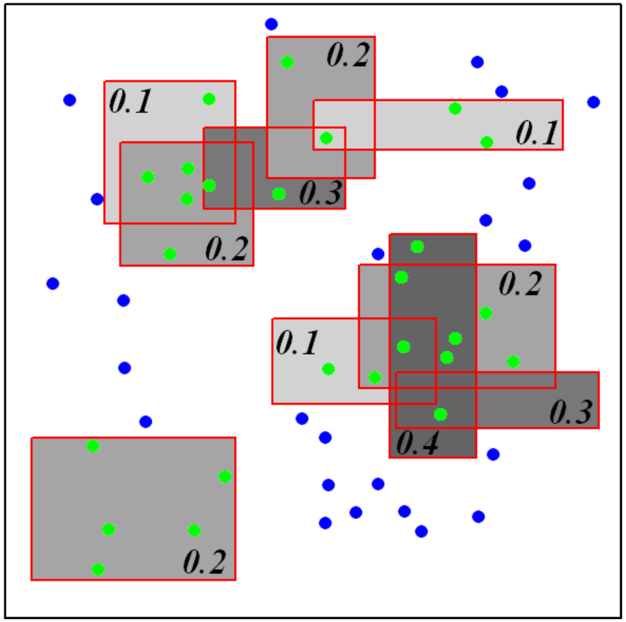
- Proliferation of location-enabled mobile devices
  - mobile phones, PDA's, GPS, …

  for tracking *moving objects*: people, vehicles, animals …
- Continuous user requests require real-time results
  - e.g., range or *k*-nearest neighbor search, skyline computation
  - against *data streams* of massive positional updates
  - Typically, all queries are considered of equal importance

➢ IDEA: introduce *priorities* to moving continuous queries
  - Model users' interest to receive response promptly or frequently
    - Message classification according to criticality
    - call for ambulance vs. search for restaurants or cinemas
  - Priorities may be also assigned by the central processor
    - Schedule execution of queries so as to better utilize system resources

Problem Specs

- Assuming a centralized processor that:
  - Receives timestamped locations from *N* moving objects
    - streaming tuples like $\langle oid, x_i, y_i, \tau \rangle$
  - Evaluates *M prioritized* moving range queries
    - also updated as tuples $\langle q_j, a_j, \rho_j, \tau \rangle$
    - specifying rectangles of interest a_j
    - with time-varying rank values $\rho_j \in [0..1]$
  - Runs periodically in *execution cycles*
    - Each cycle lasts for *T* time units
    - Refreshes location and query updates
    - Evaluates registered user requests against concurrent locations
    - *Synchronized data*: No out-of-order items for object or query streams



Our Approach

- Investigate priority-based evaluation strategies
  - for *range* queries with user-specified and time-varying ranks
- ➢ Distinguishing features
  - *Timeliness*
    - always provide fresh, but perhaps *approximate* responses
  - *Fairness*
    - treat queries according to their rankings
  - *Robustness*
    - handle scalable number of moving objects & queries
- ➢ Search for solutions that
  - share computation among queries
  - exploit common spatial predicates in query specifications

Related Work

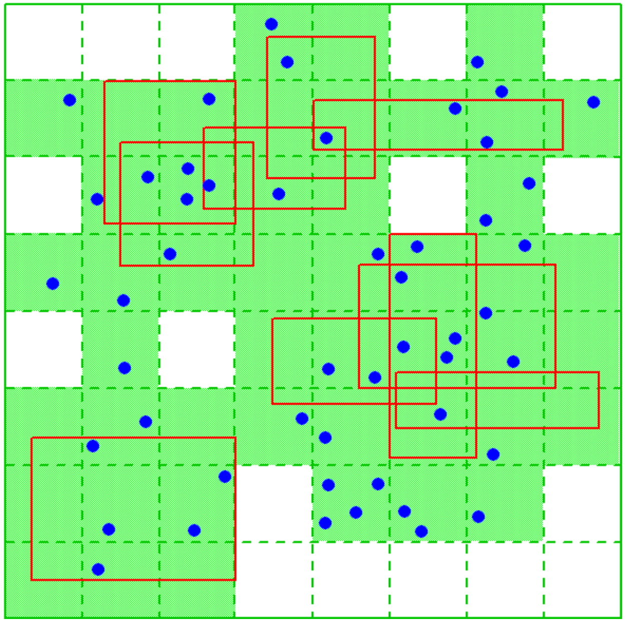
- Personalized queries (Koutrika & Ioannidis)
  - Query answering with respect to user profiles [ICDE'04]
  - Ranking model for selecting preferences [ICDE'05]
- Quality contracts (Qu & Labrinidis [ICDE'07])
  - Resource allocation between queries and data updates in websites
    - Model combining user preferences for both QoS and QoD
    - Specify time deadlines and freshness constraints
- Distributed processing on data streams
  - Prioritized transmission of local query results (Zhang *et al*. [ICDE'07])
  - LIRA: effective *region-aware* load shedding (Gedik *et al*. [ICDE'07])
- Continuous monitoring of moving objects
  - Range (Gedik & Liu [EDBT'04]) or *k*-NN (Mouratidis *et al.* [SIGMOD'05])
  - …*but* without ranking of requests or prioritized delivery of results

Outline

- Flexible spatial indexing
  - handle massive updates for moving objects and queries
- Ranking model
  - Rank aggregation schemes for multiple queries
  - Assignment of ranking scores to cells
  - Balance query rankings vs. object distribution
- Prioritized query evaluation
  - Execution in presence of changing ranking scores
  - Alternative examination strategies for cells
- Experimental Study
- Concluding Remarks

Spatial indexing

- Typical spatial access methods seem inadequate
  - Cannot easily cope with streaming positional updates at high rates
- Apply a regular *grid partitioning* of 2-*d* plane
  - Subdivide area of interest into $c \times c$ *square cells*
  - Common for locations and query ranges
- At each execution cycle
  - Hash current locations and rectangles against the grid
  - For each grid cell, update:
    - List of objects within cell
    - List of queries overlapping with cell
  - No history maintained for cells
    - *Queries always refer to current time*

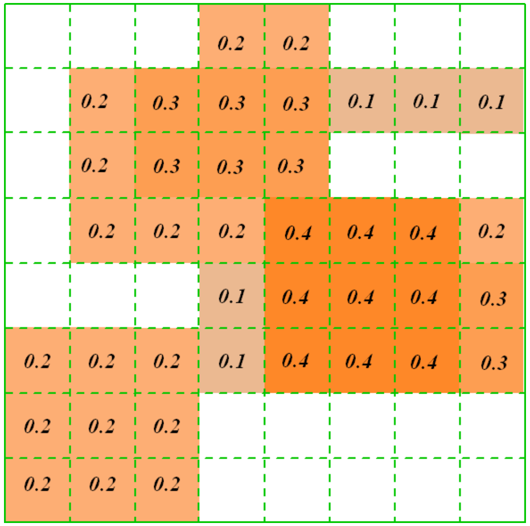


Ranking model

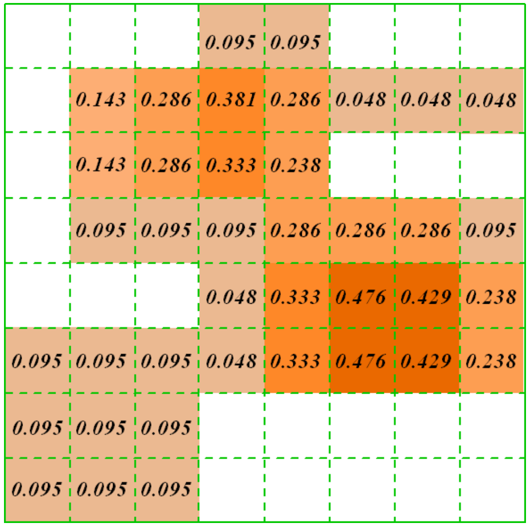
- Attempt to estimate *collective ranking* of multiple queries
  - Organize examination of queries in groups, not in isolation
    - Do not excessively penalize low-ranked queries
    - *… to the benefit of a few top-ranked ones!*
- Working *at cell level*
  - Each cell is assigned a *score* according to its query rankings
    - A mixture of query rankings is expected in each cell
    - Also take into account current distribution of object locations
  - Determine a visiting order for cells
  - Provide responses to queries affecting the cell under examination
- Introduce a family of representative *scoring functions*
  - to determine current collective rank *σ per cell*
    - queries are moving and their ranks may be fluctuating at each cycle
    - consider range extents that cover *or* partially overlap a given cell

Scoring Functions

- *Dominant* $\sigma(c_k) = \max_{q_i \in c_k}(\rho_i)$
  - Cell rank : the *highest* priority observed among its overlapping queries
  - Biased policy:
    - Give precedence to (a few) urgent requests against (many) non-critical ones

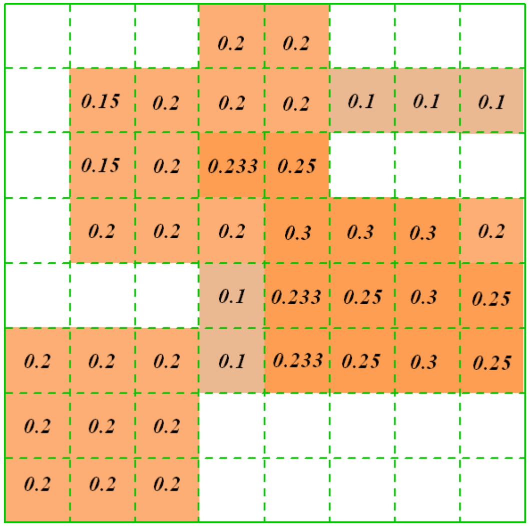


- *Normalized* $\sigma(c_k) = \frac{\sum_{q_i \in c_k} \rho_i}{\sum_{q_j \in Q} \rho_j}$
  - Cell rank : the relative importance of this cell over the cumulative ranking of all queries
  - Proportional scheme:
    - based on distribution of priorities across cells
    - attempts to examine cells with impartiality

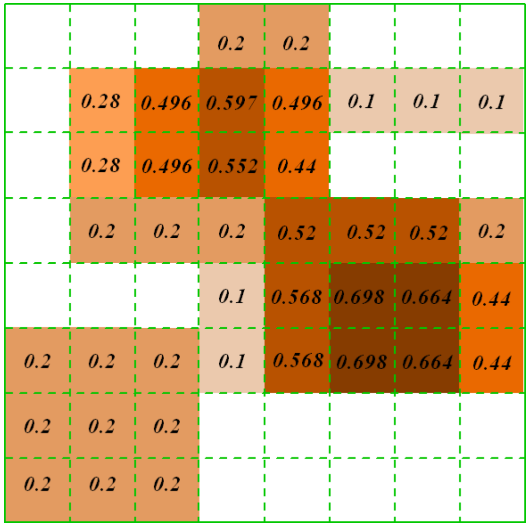


Scoring Functions (*cont'd*)

- ***Average*** $\sigma(c_k) = \frac{1}{m_k} \cdot \sum_{q_i \in c_k} \rho_i$
  - Cell rank : average priority of *local* queries
  - Egalitarian approach:
    - Smooth down the effect of extreme ranks
    - Presence of many low-ranked queries may cause delays to urgent requests



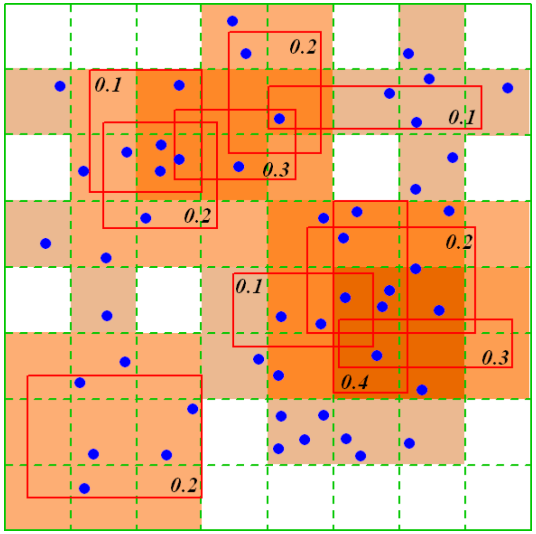
- ***Inflationary*** $\sigma(c_k) = 1 - \prod_{q_i \in c_k} (1 - \rho_i)$
  - Cell rank : extremely increasing when many high-ranked queries are found in this cell
  - Biased approach:
    - Queries of higher priority are given superior influence on cell scores
    - Favor query "clusters" of greater interest



Cell ranking scores

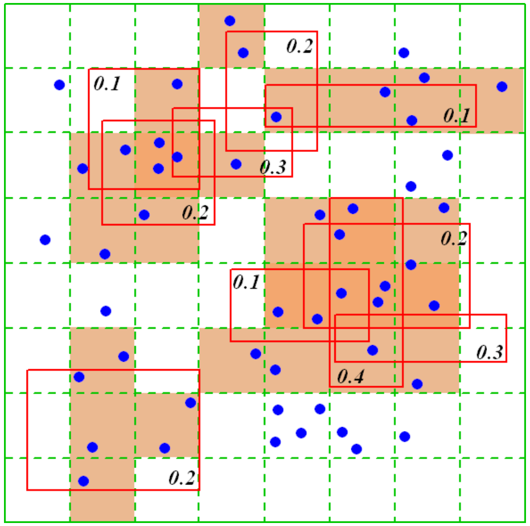
- Determine an *overall ranking score* β_k per cell c_k :
  - Collective query rank $\sigma(c_k)$
  - Present *object density* P_k in each cell
  - System-wide *regulation parameter* λ
    - to leverage between actual query rankings and object distribution
  - Propose alternative ranking schemes
    - *balanced, harmonic, combined*

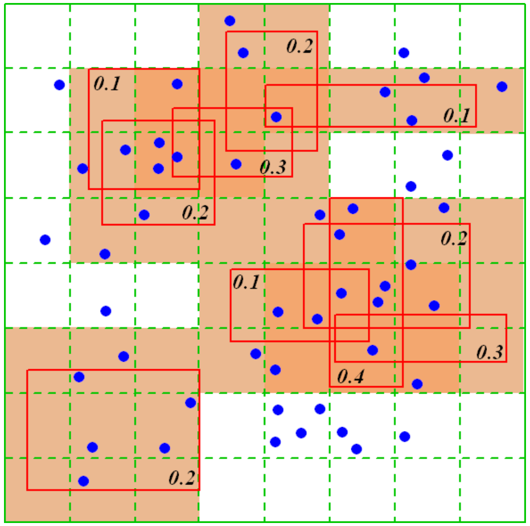
- *Balanced score* $\beta_k = \lambda \cdot \sigma(c_k) + (1 - \lambda) \cdot P_k$
  - Weigh importance of queries vs. objects
  - Possible settings for $\lambda \in [0..1]$:
    - $\lambda = 0.5$: equal weight
    - $\lambda = 1$: ignore object distribution
    - $\lambda = 0$: ignore query rankings



Cell ranking scores (*cont'd*)

- *Harmonic score* $\beta_k = \frac{(1+\lambda)\cdot\sigma(c_k)\cdot P_k}{\lambda\cdot\sigma(c_k)+P_k}$
  - Weighted harmonic mean per cell c_k
    - collective query rankings $\sigma(c_k)$
    - object distribution P_k
  - Possible settings for $\lambda \geq 0$:
    - $\lambda = 1$: equal importance
    - $\lambda < 1$: accentuate importance of queries
    - $\lambda > 1$: emphasize on object densities
- *Combined score* $\beta_k = \frac{m_k+n_k}{M+N} \cdot \sigma(c_k)$
  - Regularize collective ranking score by mixed density of m_k queries and n_k objects in cell
  - Take into account cell "*popularity*"
    - with pending queries and observed locations





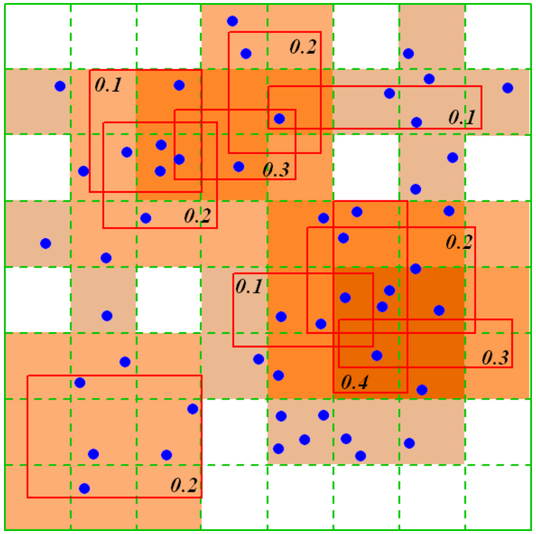
Prioritized Query Evaluation

- Evaluation in execution cycles
  - During each period *T* :
    1. Update data structures linked to grid cells
    2. Compute new cell rankings
    3. For the remaining interval, visit cells and generate query results
  - When deadline is reached, *start a new cycle*
    - Current state is dropped altogether
    - Some queries may receive *incomplete* or even *no response* at all !
  - Estimate *QoS* after each cycle:
    - *Global success ratio* $$\gamma(\tau) = \frac{\sum_{c_k} \sum_{q_i \in R} \rho_i}{\sum_{c_k} \sum_{q_j \in Q} \rho_j}$$
    - for all grid cells
    - *R*: queries that received some response during this cycle
    - *Q*: current query workload
    - If $\gamma(\tau) = 1$, then all queries received complete response.

Cell Examination Strategies

- Trivially, when visiting a cell:
  - queries should be probed in descending rank order
- Issues arising:
  - Examine all queries in a given cell, before going to next one ?
  - Respond first to all high-ranked queries in each cell ?
  - How to handle potential starvation of low-priority queries ?
- Three *alternative evaluation strategies*:
  - Exhaustive
  - Stratified
  - Threshold-guided
- Exhaustive Evaluation
  - Start from the cell with highest score and *probe all its queries*
  - Continue will other cells *in descending score order*
    - as long as deadline *T* is not reached

Stratified Evaluation

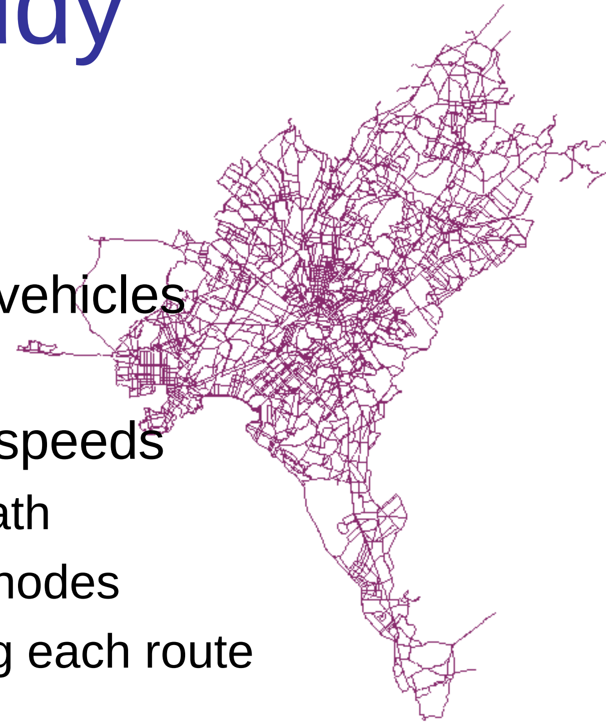


- Classify cells into *l strata*:
  - Like an *equi-sum histogram* or *quantile*
    - based on ranking scores
- *Rotating scheme* to prioritize queries:
  - Top-stratum cells examined at *each* cycle
  - Second-stratum cells get precedence every *two* cycles
  - Third-stratum cells every *four* cycles, etc.
  - Prevent possible *starvation or queries*…
- At each cycle, it favors a different stratum
  - Examine all other strata and their cells in descending score order
  - Cells with lower scores sometimes get prioritized, even not so often
  - Out-of-order prioritization depends on number *l* of strata

Threshold-guided Evaluation

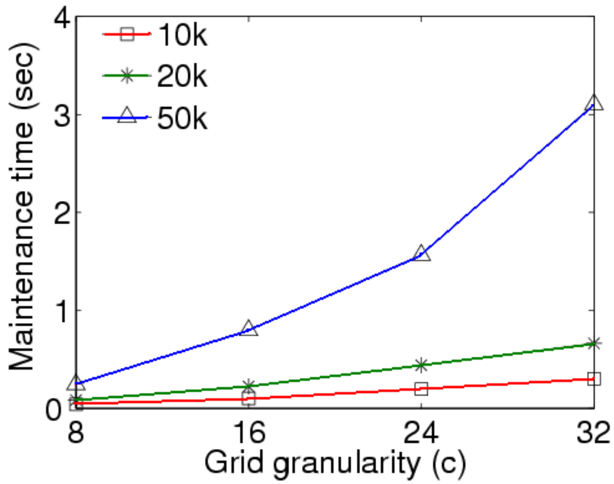
- IDEA: In each cell, examine high-ranked queries only
  - If all cells were visited within the deadline, and there is time left:
    - Start a new round, with adjusted cell scores
    - Provide response to more queries of lower ranks within current cycle
  - *BUT*, difficult to choose a suitable *threshold*
    - to discriminate such *élites* of high-ranked requests …
- Opt for a *dynamically adjusted threshold*:
  - Set global success ratio $\gamma(\tau - 1)$ of previous cycle as *target*
  - For currently examined cell c_k :
    - Compute a *local success ratio* $\gamma_k(\tau)$
    - Continue examination of this cell for as long as $\gamma_k(\tau) < \gamma(\tau - 1)$
  - To avoid degradation of system performance :
    - *Optimistically* raise the expected target by a small percentage
    - ➢ Attempt to improve global success ratio in successive cycles

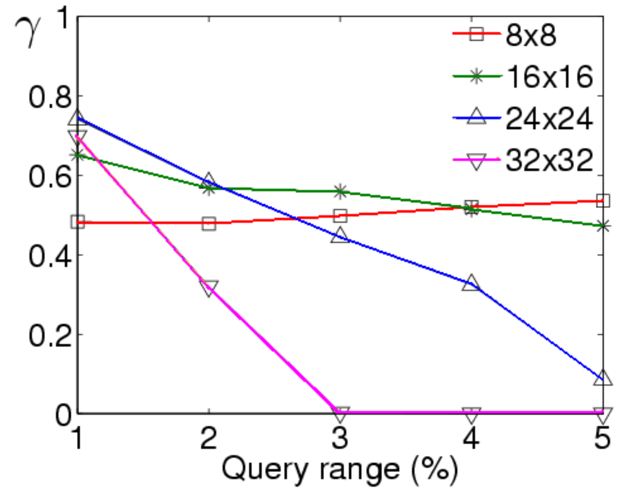
Experimental Study



- Experimental setting
  - Synthetic datasets emulating movement of vehicles
    - Along the road network of greater Athens
  - Objects/Query centroids moving at diverse speeds
    - Trajectories produced by running shortest path between pairs of randomly chosen network nodes
    - Samples of 200 timestamped locations along each route
  - Simulations
    - Number of objects *N* = 100 000
    - Query workload *M* = 10 000 , 20 000 , 50 000 of various ranges
    - Concurrent positional updates, *agility* = 100%
    - Query rankings assigned with a *Zipfian* distribution (*s*=1)
    - 10 rank values varying between 0.1 (low) and 1 (high preference)

Choosing grid granularity

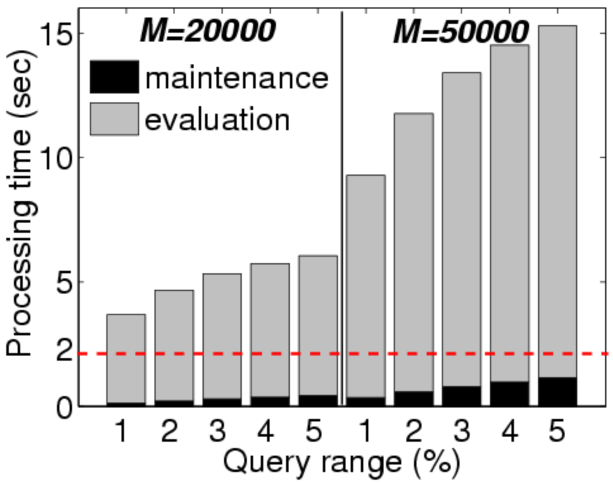


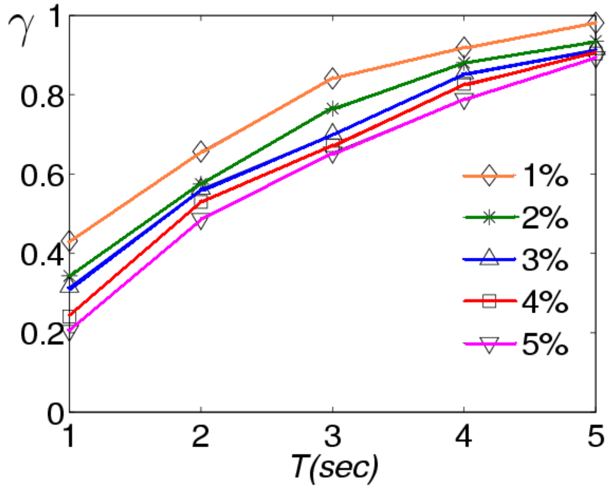


- Per cycle cost for hashing locations and queries
  - Maintenance time deteriorates with larger workloads
    - The finer the granularity, the more cells must be updated with scores
- Global success ratio γ under diverse grid granularities
  - Coarser subdivisions seem more stable for most query ranges

➢ Finally, *c*=16 was chosen for subsequent experiments

Impact of cycle duration

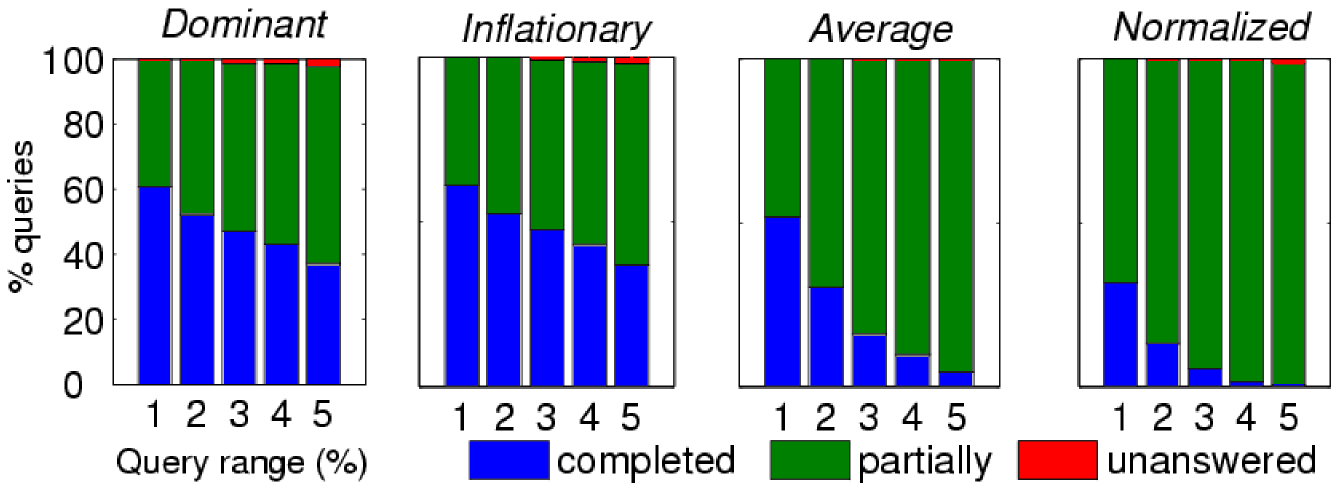




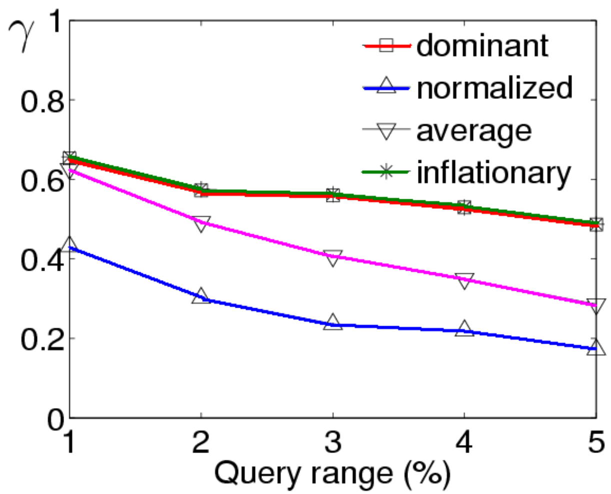
- Processing cost for *complete response* to all queries
  - Index maintenance and rank aggregation is minimal
  - Most time is spent on actual evaluation of queries
- Success ratio for *M* = 20000 queries with various deadlines
  - A strict deadline leads to drop in QoS => many unanswered queries
  - Best *T* is a trade-off between *M* and varying range extents

➢ Set *T=2 sec* for subsequent experiments, to compare performance

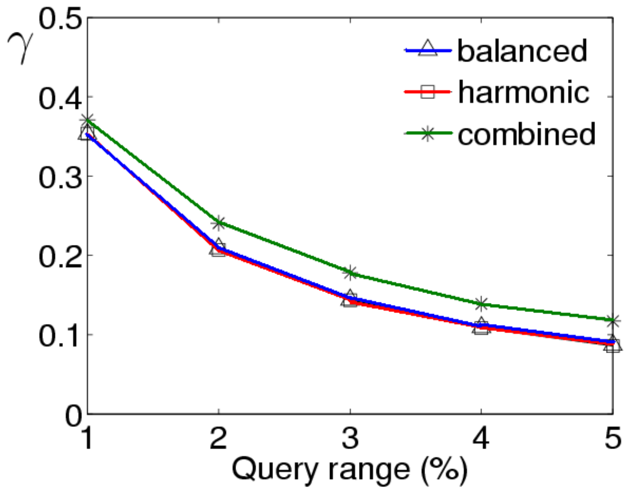
Comparing scoring functions

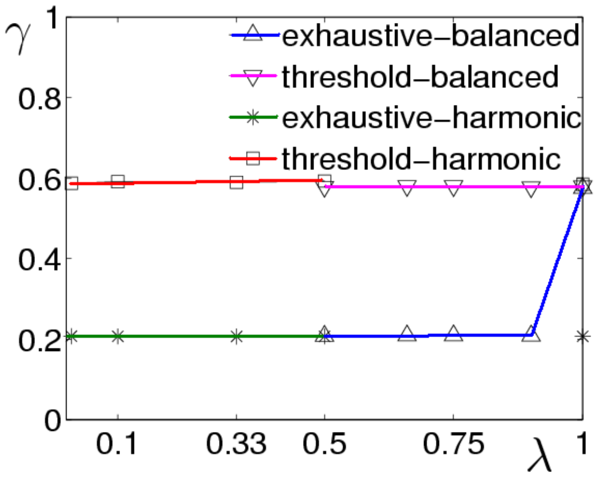


- Tests with $\lambda = 0$ (*i.e. ignoring objects*)
  - Better quality with biased schemes
    - Urgent requests boost rankings of certain cells, favoring affected queries
    - Queries left unanswered only rarely
  - *Inflationary* scheme prevails
    - with diverse ranges & query workloads



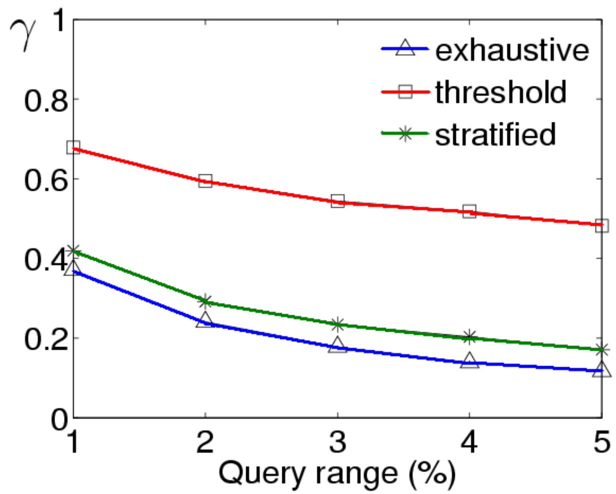
Alternative cell scoring schemes

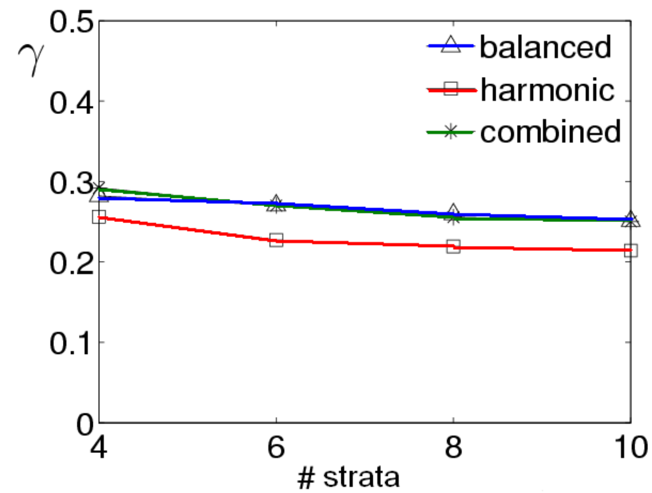




- Assessment of best method for assigning cell scores
  - Exhaustive test with significance of queries = 2 X significance of objects
- *Combined score* is superior
  - "Intensifies" aggregated ranks in proportion to current cell densities
- Results not accidentally biased from regulation effect
  - Balanced and harmonic schemes are practically immune to moderate λ

Alternative examination strategies





- *Threshold-guided execution* prevails
  - Self-regulating strategy which tends to examine more queries
  - At each cycle, this "best-effort" policy tries to gain an even better QoS
  - Stratified execution is slightly better than exhaustive
- Stratified evaluation
  - Under all scoring schemes, quality deteriorates with number of strata
  - More strata => less often each stratum gets prioritized

Conclusions

- Novel processing framework for moving range queries
  - Take into account user-specified priorities for query evaluation
  - Develop a ranking model to organize greater groups of queries
    - enable shared computation against scalable datasets
  - Propose adaptive policies with varying degrees of answering quality
    - most user requests receive in time at least partial results
- Possible future extensions:
  - Estimate accuracy in responses & confidence margins for queries
  - Adjust ranking model with estimated cost & query selectivity
  - Dynamic data-driven specification of regulation parameter
  - Develop an *aging-aware prioritization* mechanism
    - Artificially favor long-penalized queries to avoid starvation
  - Apply similar ranking schemes to other query types, like *k*-NN

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Thank you!