Peer-to-Peer Web Archival and Time-Travel Search

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Motivation

- Web is constantly changing and evolving. “Only 20% of the existing web-pages will exist after a year”
- Web today contains information from all walks of life and capturing these changes is essential
- Web archiving is the process of collecting portions from the web and ensuring the collection is preserved in an archive for future analysis

Motivation

- Searching on the archives makes historical analysis possible. E.g "John McCain @ 9/11/2001"
- Current attempts like Internet Archive (IA) have limited search capability and their scalability is also questionable
- We propose a scalable, decentralized and peer-to-peer(p2p) approach to web archiving which supports time-travel search

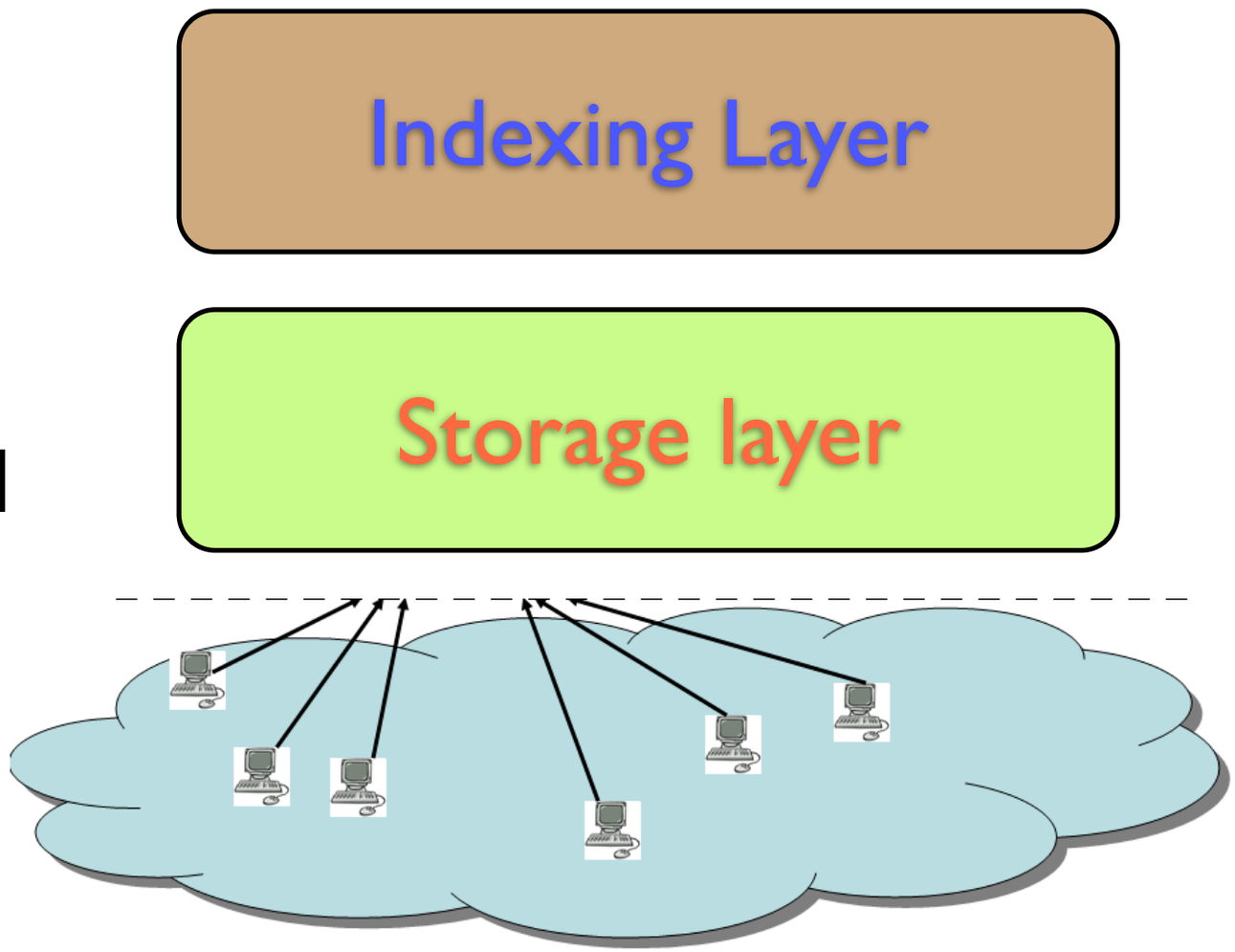
Outline

- P2P Framework for Web Archival
- Index organization for time-travel queries
- Partitioning Strategies for Index lists
- Results
- Conclusion

System Architecture

P2P Architecture for archival and search

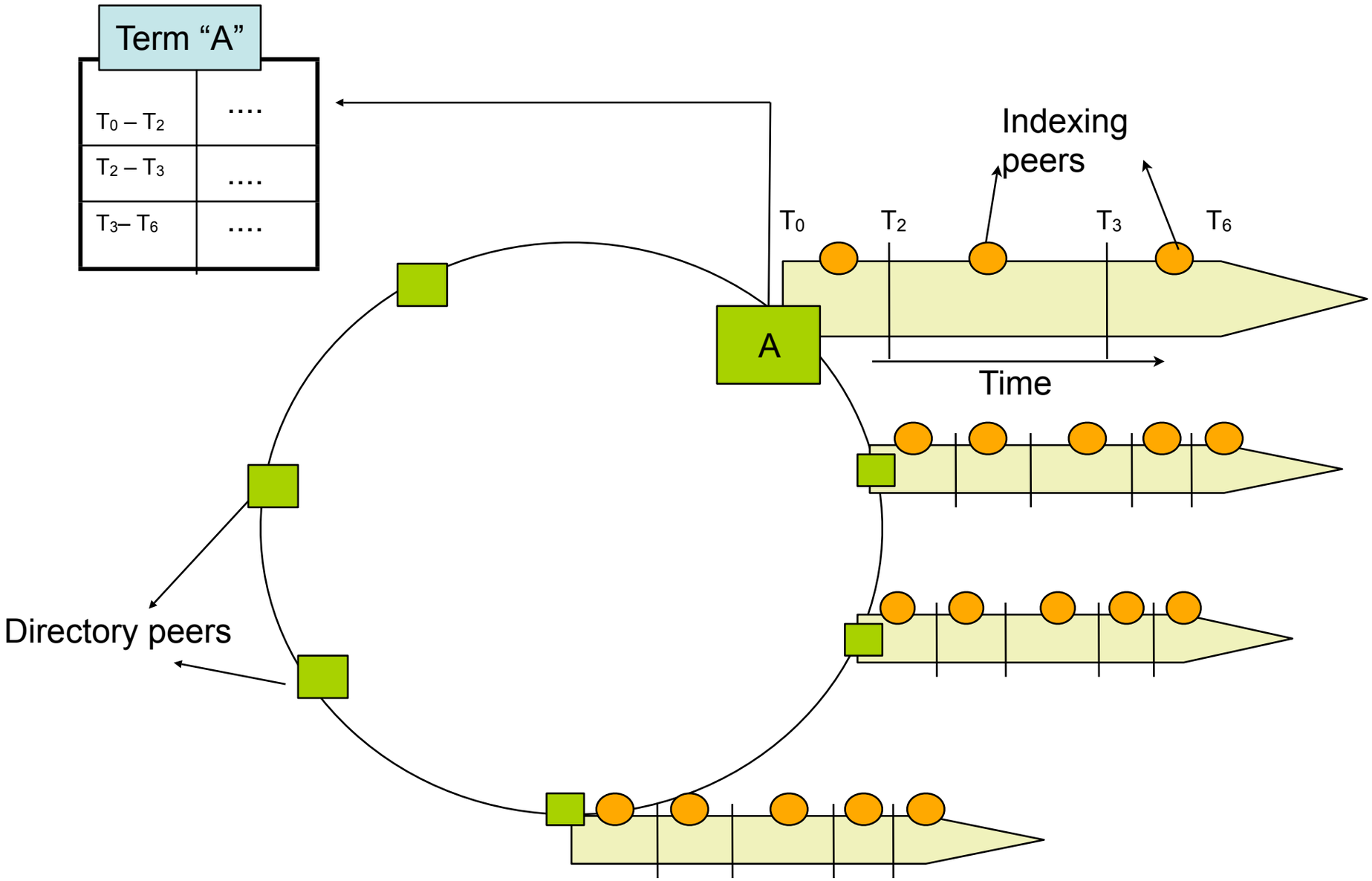
- Crawling peers push content periodically to storage layer
- Storage peers organized to store data in a durable and persistent way
- Indexing peers organized to process queries efficiently



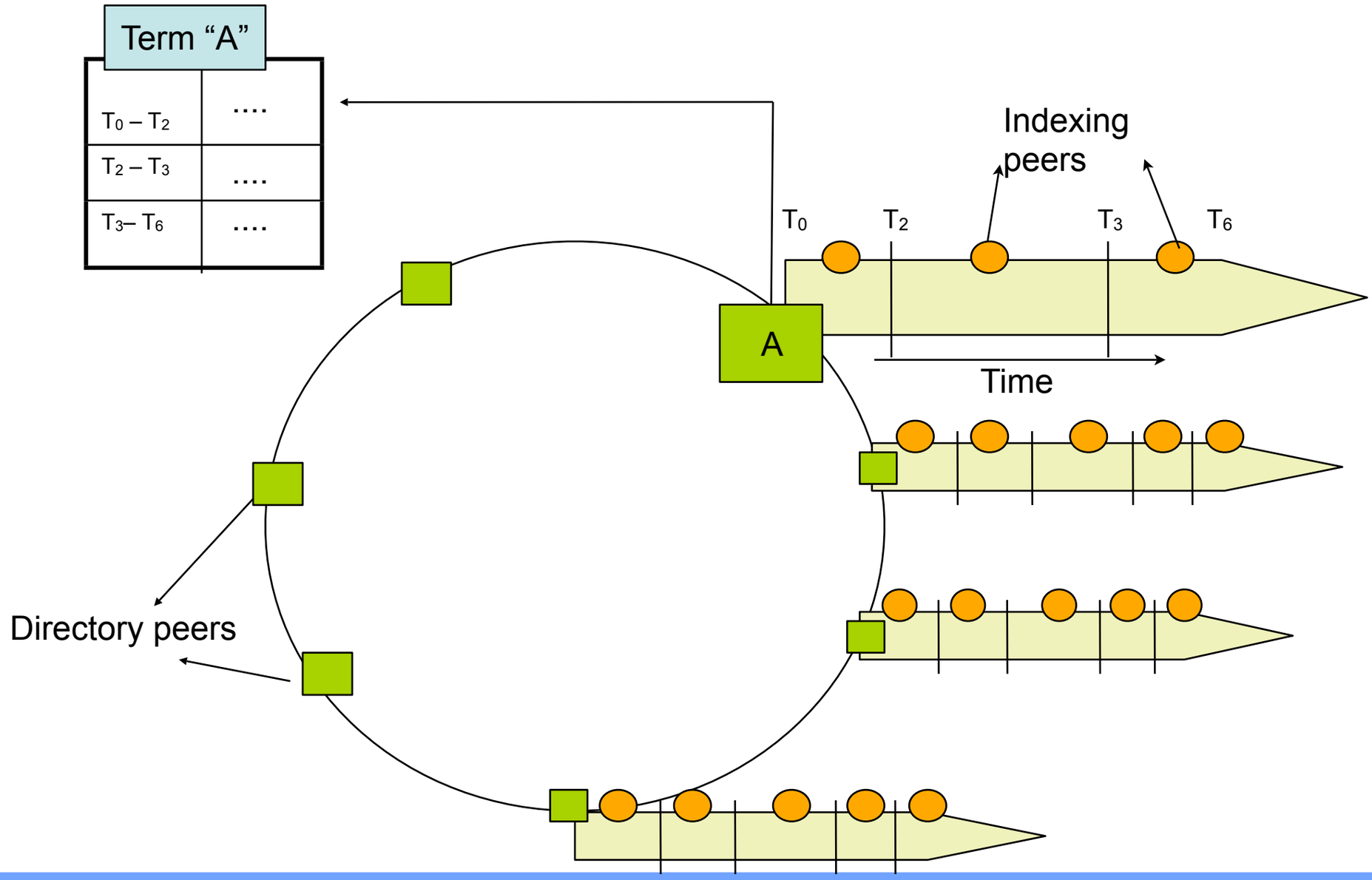
Index Partitioning

- Indexing layer is organized such that peers holds part of an index-list.
- Index are partitioned both along the time-axis and in term-space.
- Term Partitioning based on the hashing used by structured p2p overlays (Chord, Pastry etc.).
- Time Partitioning is partitioning the index list per term in the time axis

Term-Time Partitioning

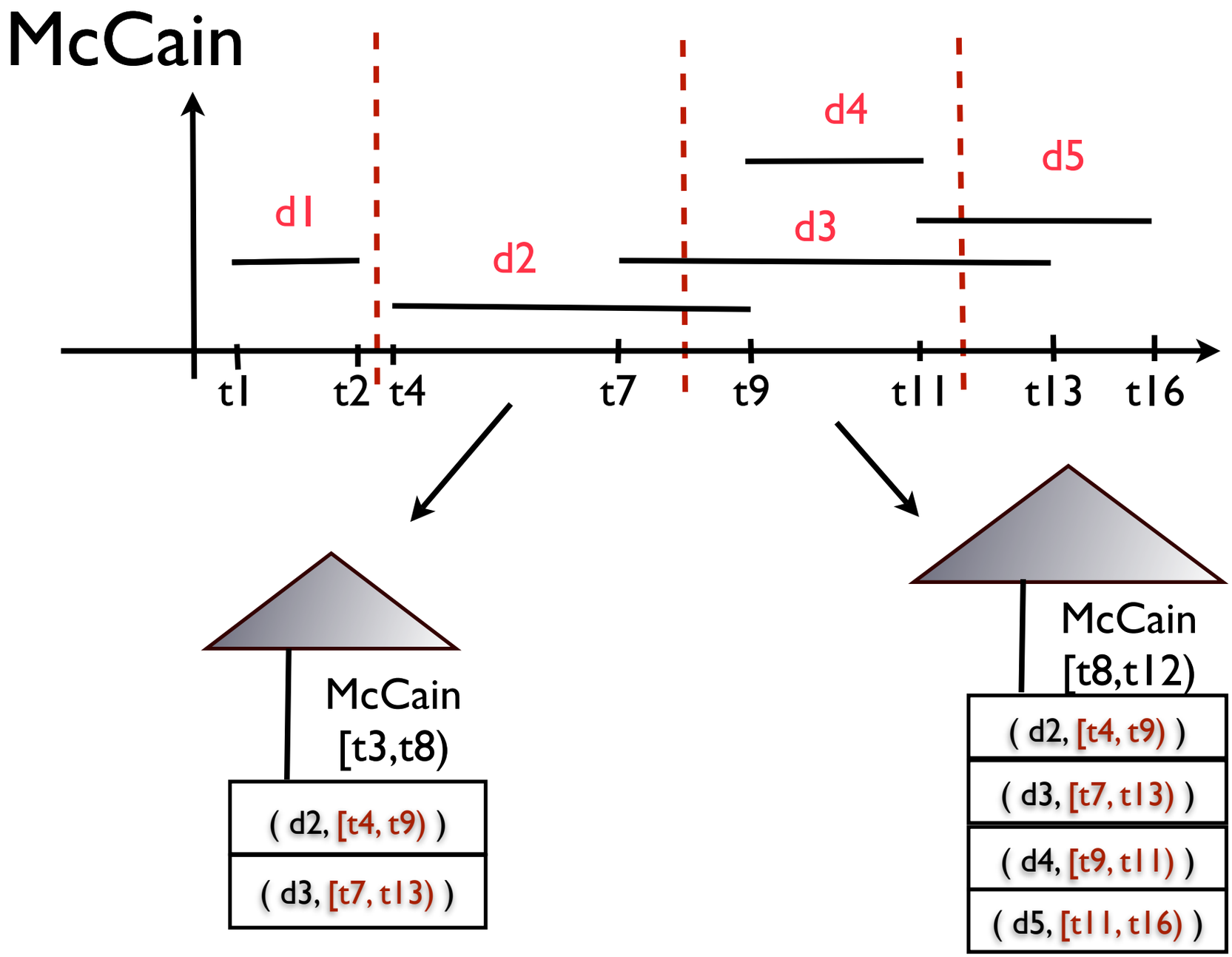


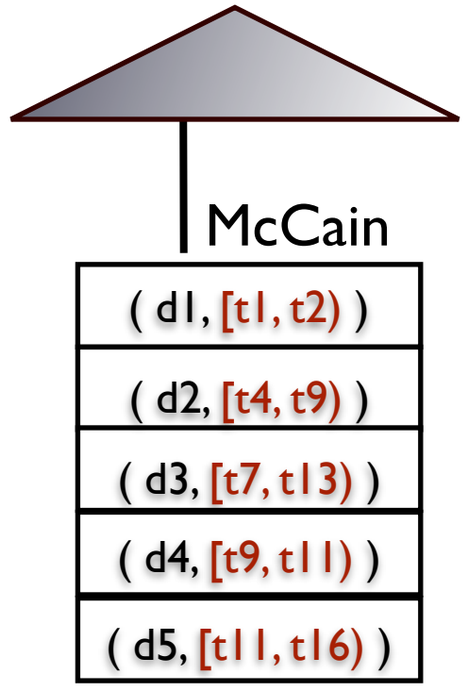
Term-Time Partitioning



A time-travel query “A @ t” routed to the directory peer responsible for “A” and then the indexing peer responsible for “t”

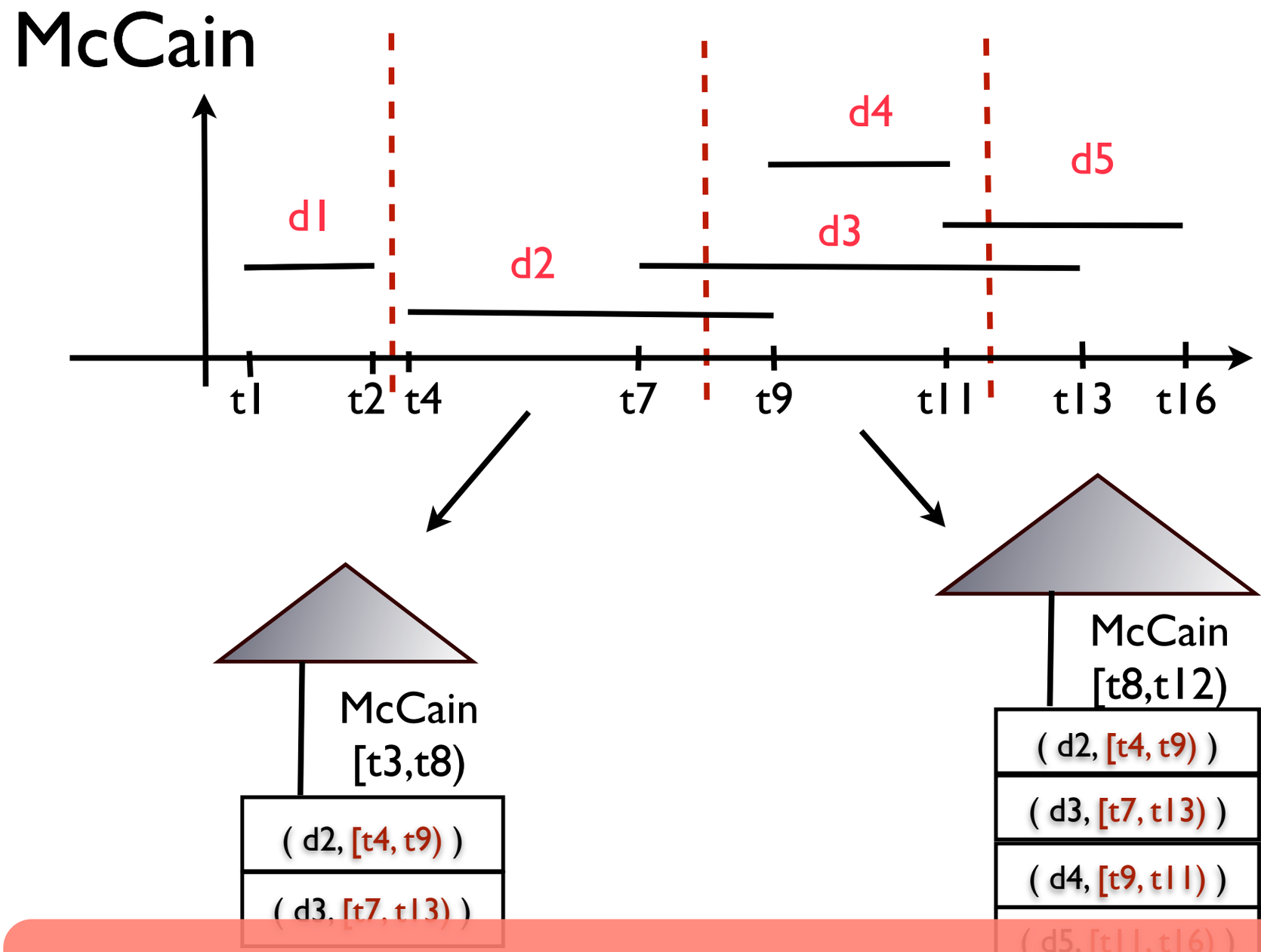
Index Partitioning

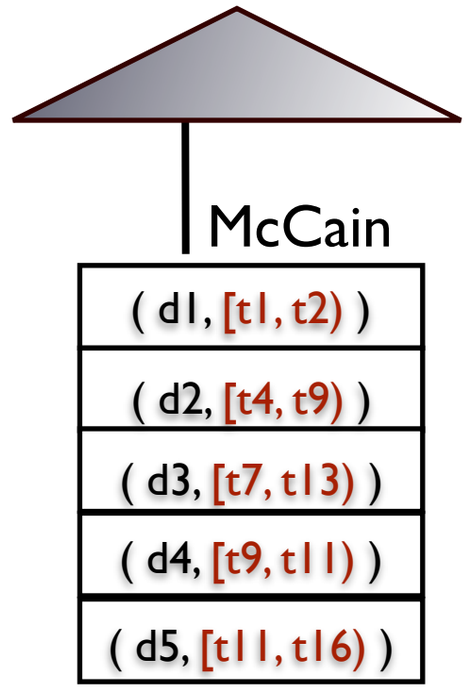




Each version is a new entry, hence long list:
need partitioning

Index Partitioning





Each version is a new entry, hence long list:
need partitioning

Overall size increases due to duplicate entries

Partitioning Strategies

- Centralized Setting : Key issue is to provide performance while partitioning index [Berberich et. al, SIGIR '07]

- Distributed Setting :
  - Loss of data due to churn (leaving of peers)
  - Reconstruction from underlying storage is expensive
  - We leverage the replication due to partitioning to support index reconstruction

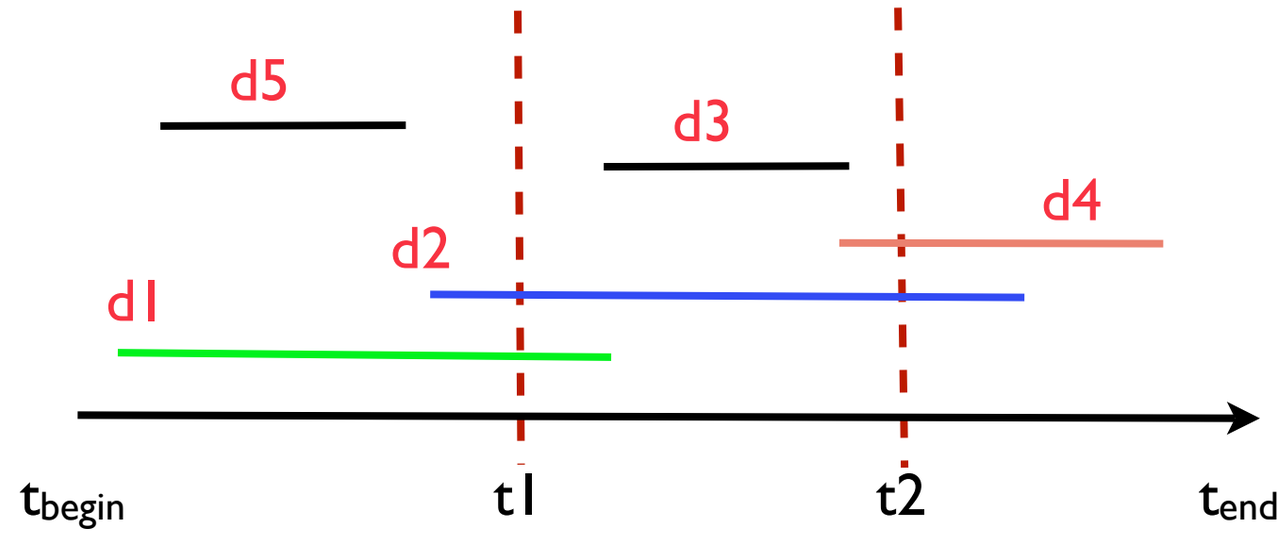
Partitioning Strategies

Live Entries in a Partition

- Live entries in a partition L_v: $[t_i , t_j)$:

$$L_v : [t_i, t_j) = \{(d, p, [t_b, t_e)) \in L_v \mid t_b <= t_j \wedge t_e > t_i\}$$

- Live entries in a partition could be classified into left, right, strikethrough and subsumed.



L_v: [t1, t2) = {d1, d2, d3, d4} L_v: t1 = {d1, d2}

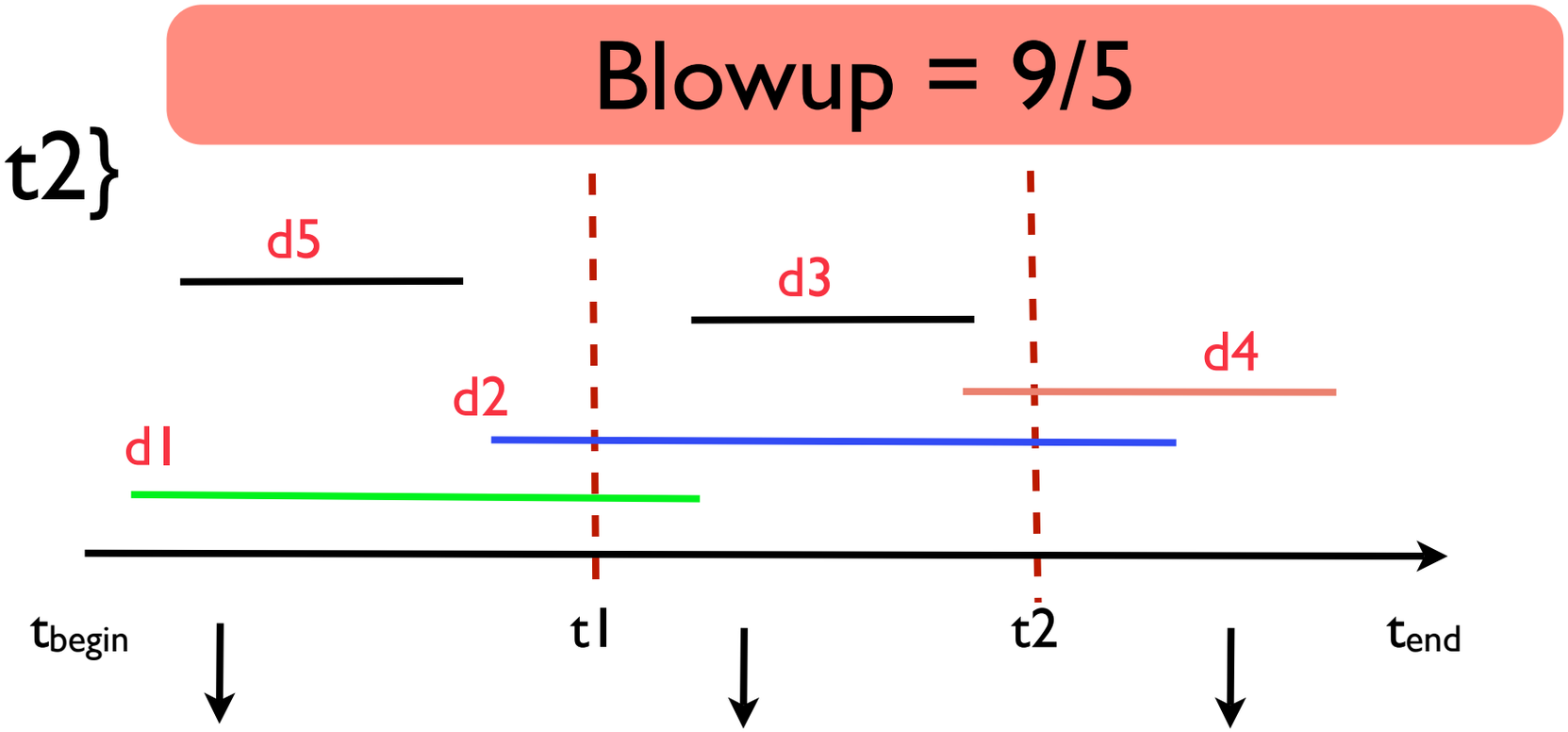
(d, $[t_b , t_e)$) is the posting for the document **d** which begins at **t_b** and ends at **t_e**.

L_v set of all the documents in the collection having term v

Blowup

- Blowup (ϒ): Ratio of sum of live entries in each partition to the total number of entries

P (M) = {t1, t2}



Live entries : 3 4 2

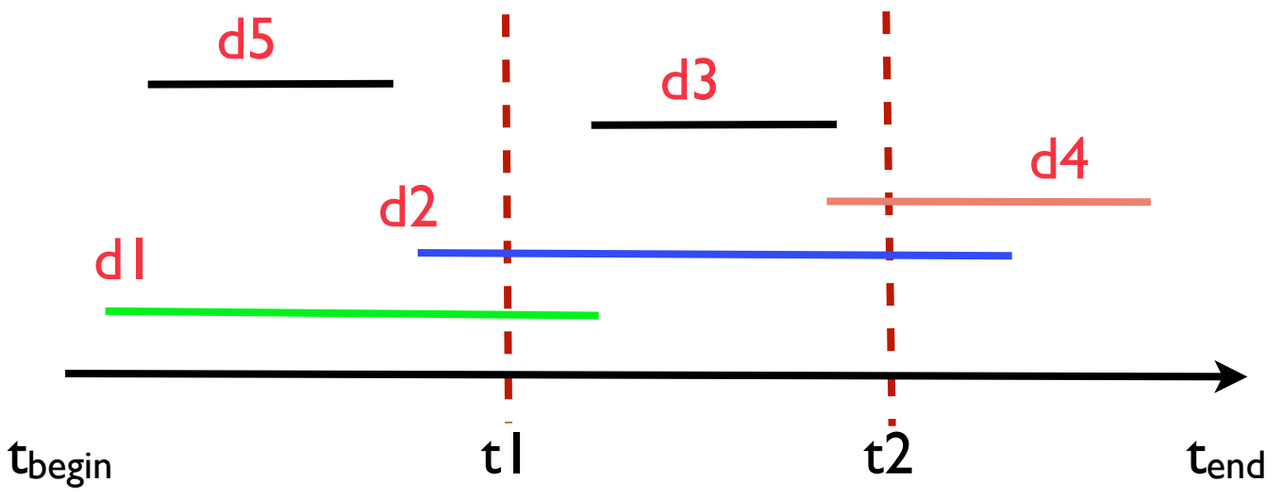
Replication

- Replication(R) measures the fraction of index entries that are ever replicated or replicated at least once.

$$\mathcal{R}(\mathcal{M}) = \frac{|\bigcup_{\mathbf{t_i} \in \mathbf{P}(\mathcal{M})} L_v : t_i|}{|L_v|}.$$

P(M) is the set of time-points where the partitions exists

Replication R(M) = 3/5

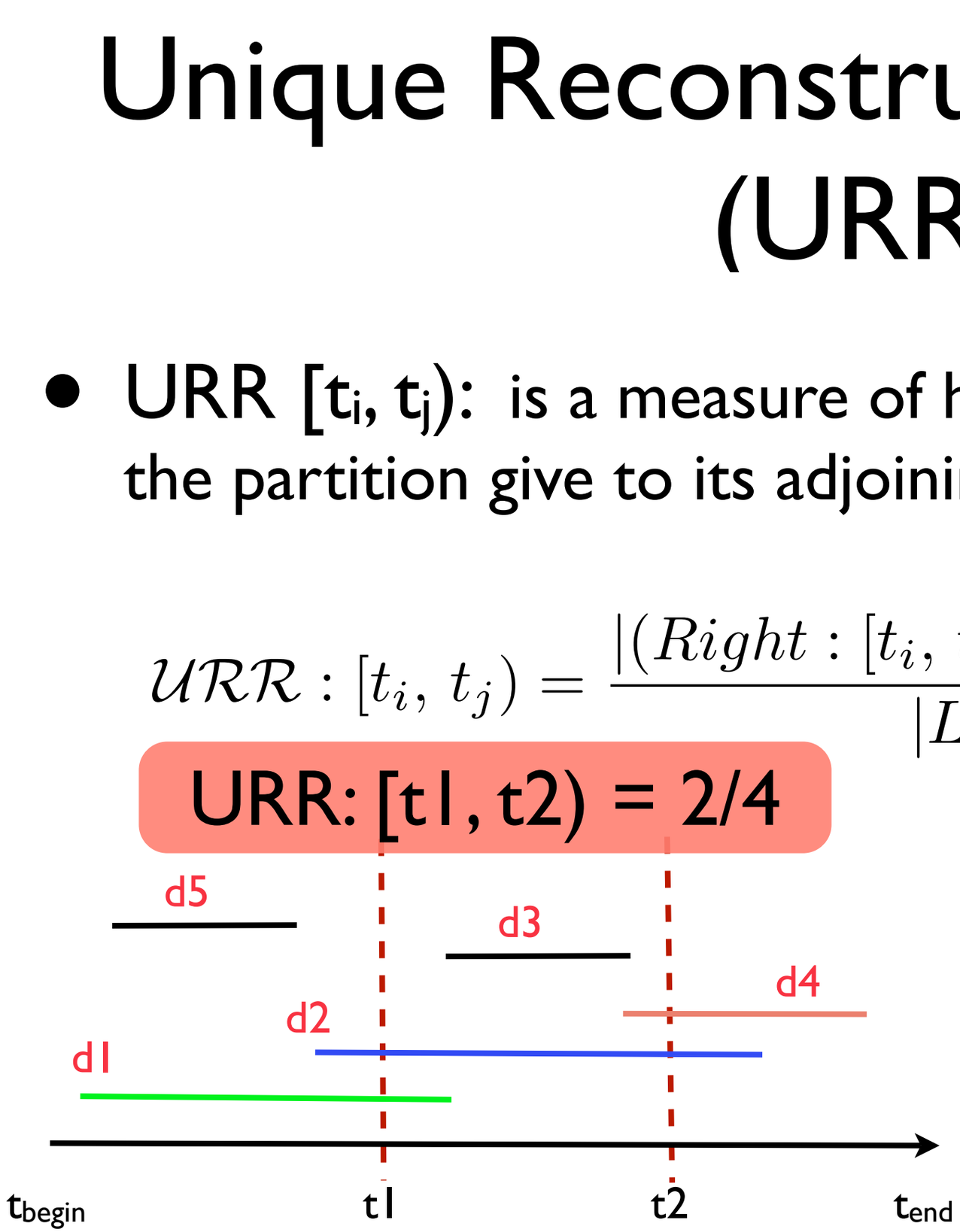


P (M) = {t1, t2}

Unique Reconstructibility Ratio (URR)

- URR $[t_i, t_j)$: is a measure of how much benefit does the partition give to its adjoining partitions

$$\mathcal{URR} : [t_i, t_j) = \frac{|(Right : [t_i, t_j)) \cup (Left : [t_i, t_j))|}{|L_v : [t_i, t_j)|}$$



Right: [t1, t2) = {d4}

Left: [t1, t2) = {d1}

L_v: [t1, t2) = {d1,d2,d3,d4}

Maximum Replication

- **Maximum Replication (Max-Rep):** Find a partitioning to Maximize replication keeping the blowup in check.

- Max-Rep is NP-Hard : Reduction from subset-sum problem
- Optimal implementation (Branch-and-Bound) for a limited time-range

$$\arg\max_{\mathcal{M}} \mathcal{R}(\mathcal{M}) \quad \text{s.t.}$$

$$\sum_{m \in \mathcal{M}} |L_v : m| \leq \gamma |L_v| \, .$$

Maximum Minimum Reconstructibility

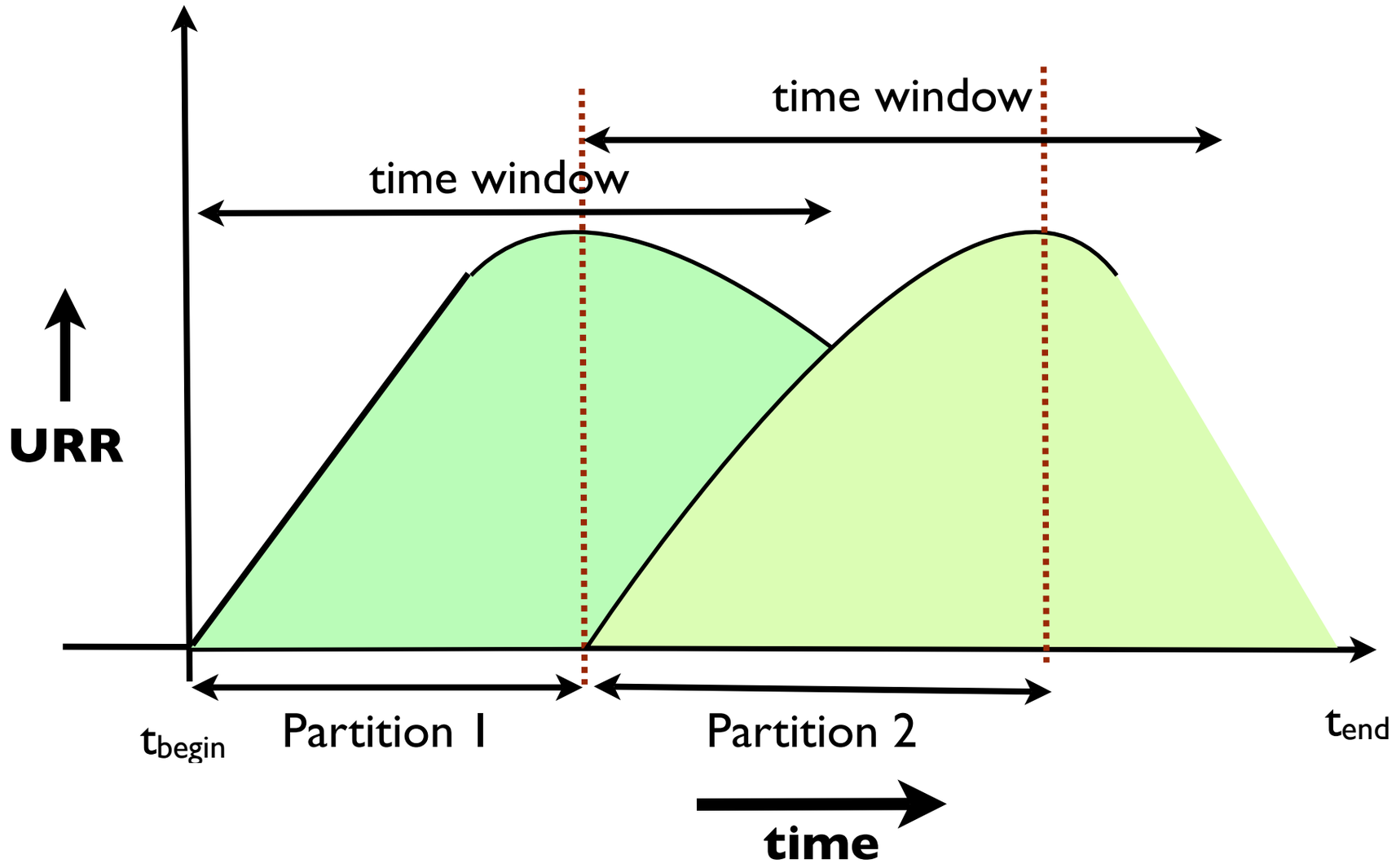
- **Max-Min Reconstructibility:** Find a partitioning to Maximize the minimum URR keeping the blowup in check.

- Complexity yet to be established
- Heuristic approaches like Greedy considered
- Importance of approaches which do not change the past

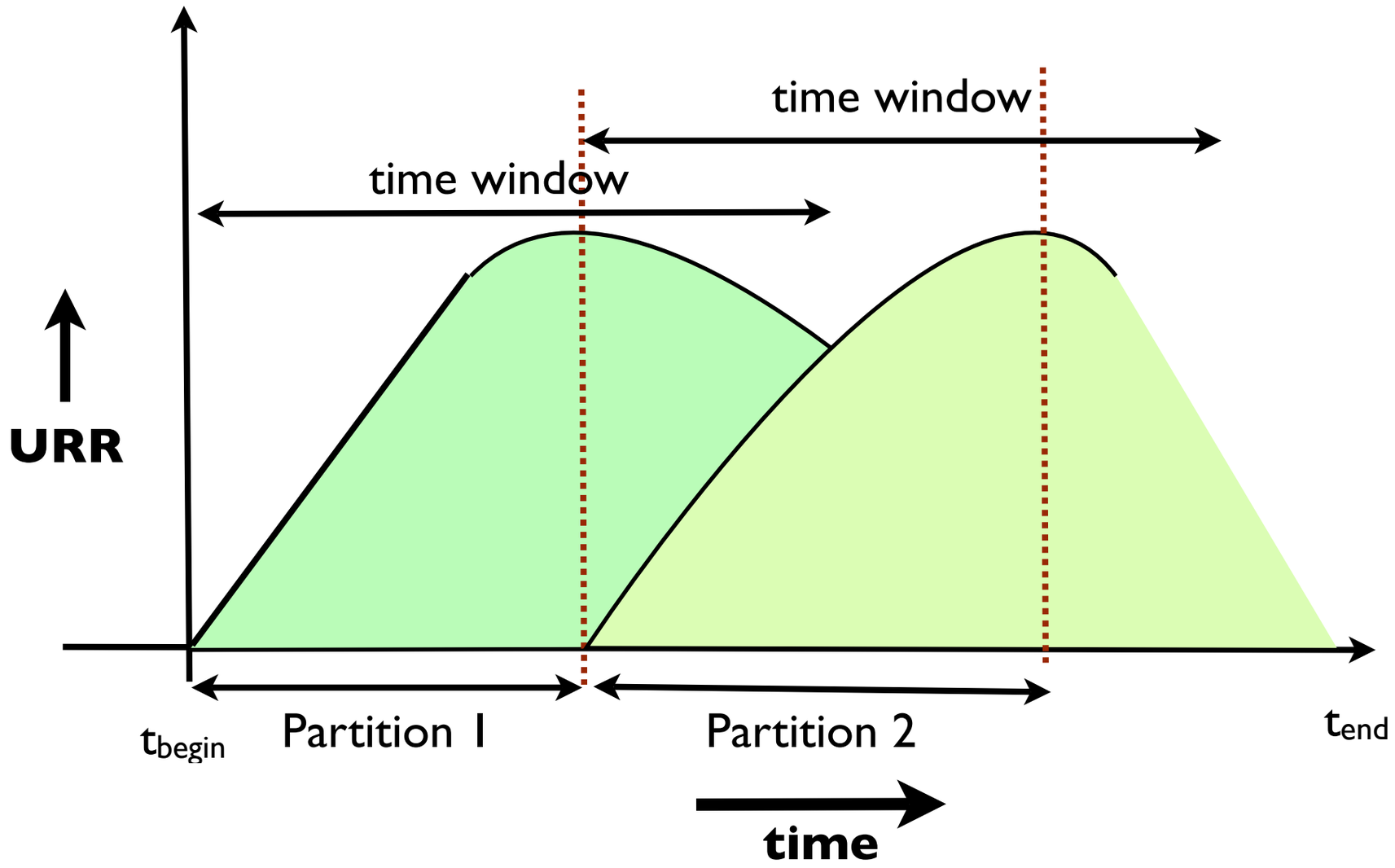
$$\arg\max_{\mathcal{M}} \min_{\mathbf{m}\in\mathcal{M}} \mathcal{URR}(\mathbf{m}) \quad \text{s.t.}$$

$$\sum_{m\in\mathcal{M}} |L_v : m| \leq \gamma\,|L_v| \ .$$

Greedy Approach



Greedy Approach



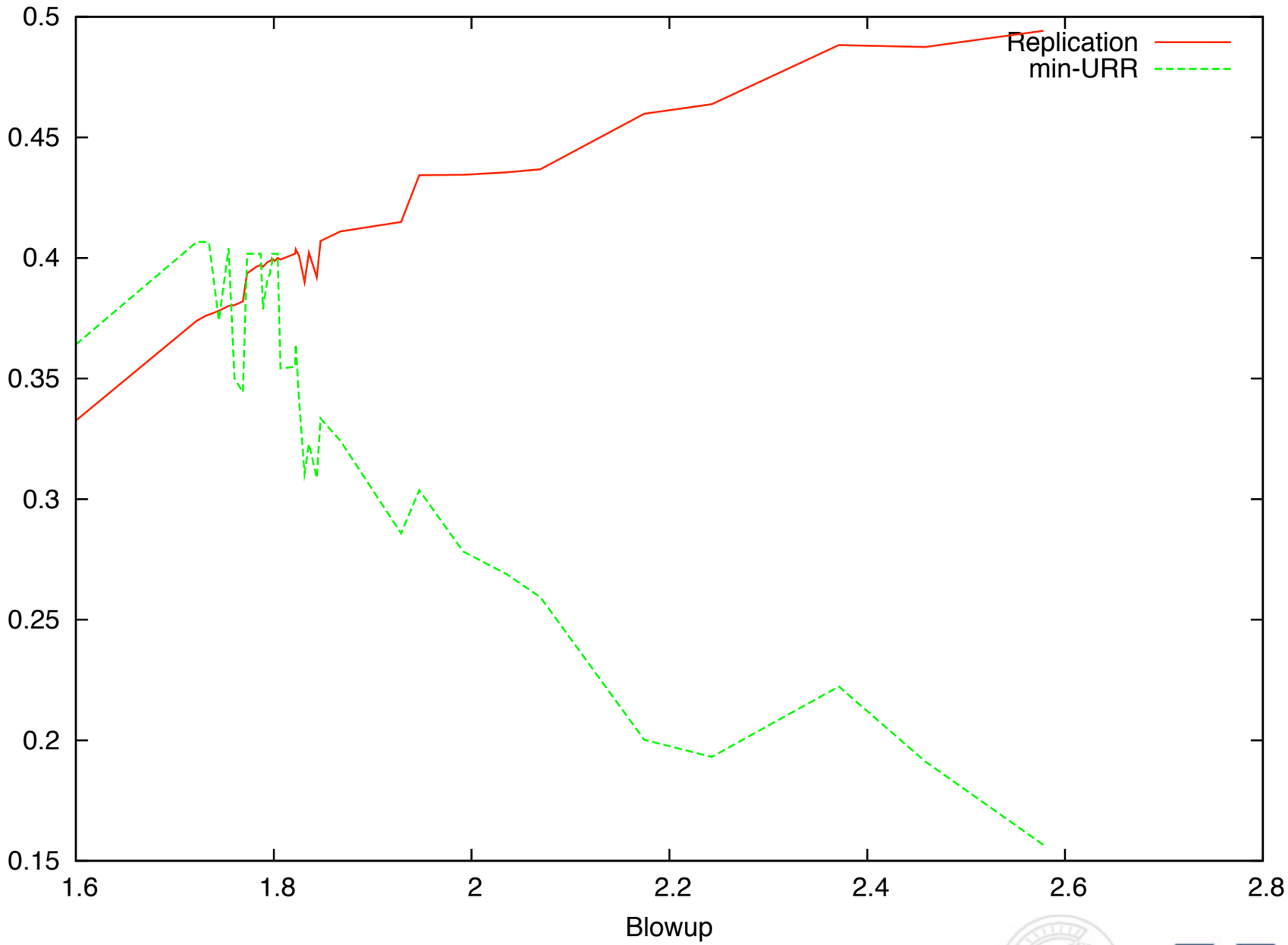
Time-points with the highest values of URR in a given time-window are chosen as partitions

Experimental Setup

- We use the version lifetimes from **Wikipedia**
- Each version considered as a separate document
- We consider lifetimes in day-level granularity
- Plot response of min-URR, Replication (R) with varying blowup values

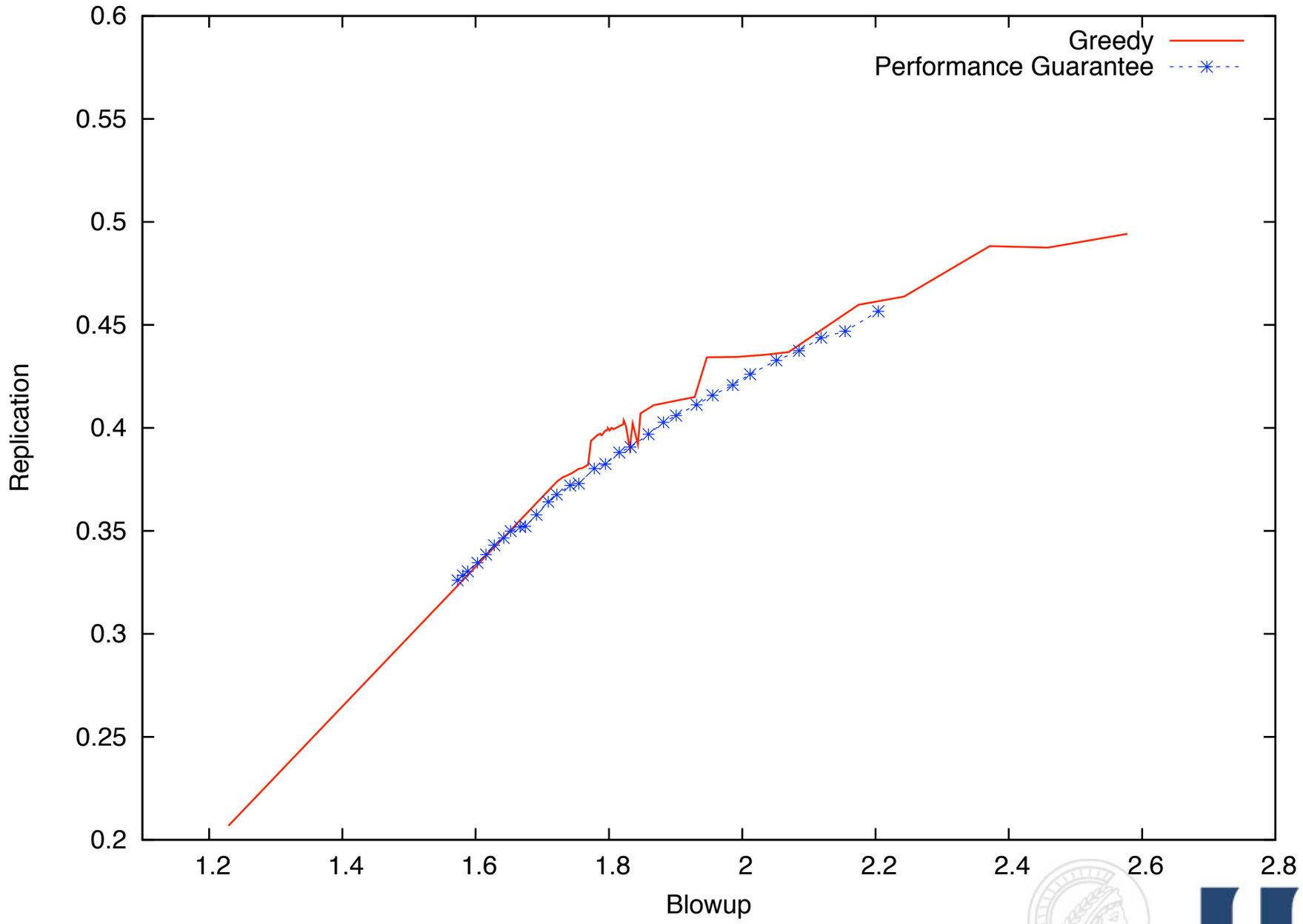
Results

Analysis of min-URR, blowup and R using Greedy approach



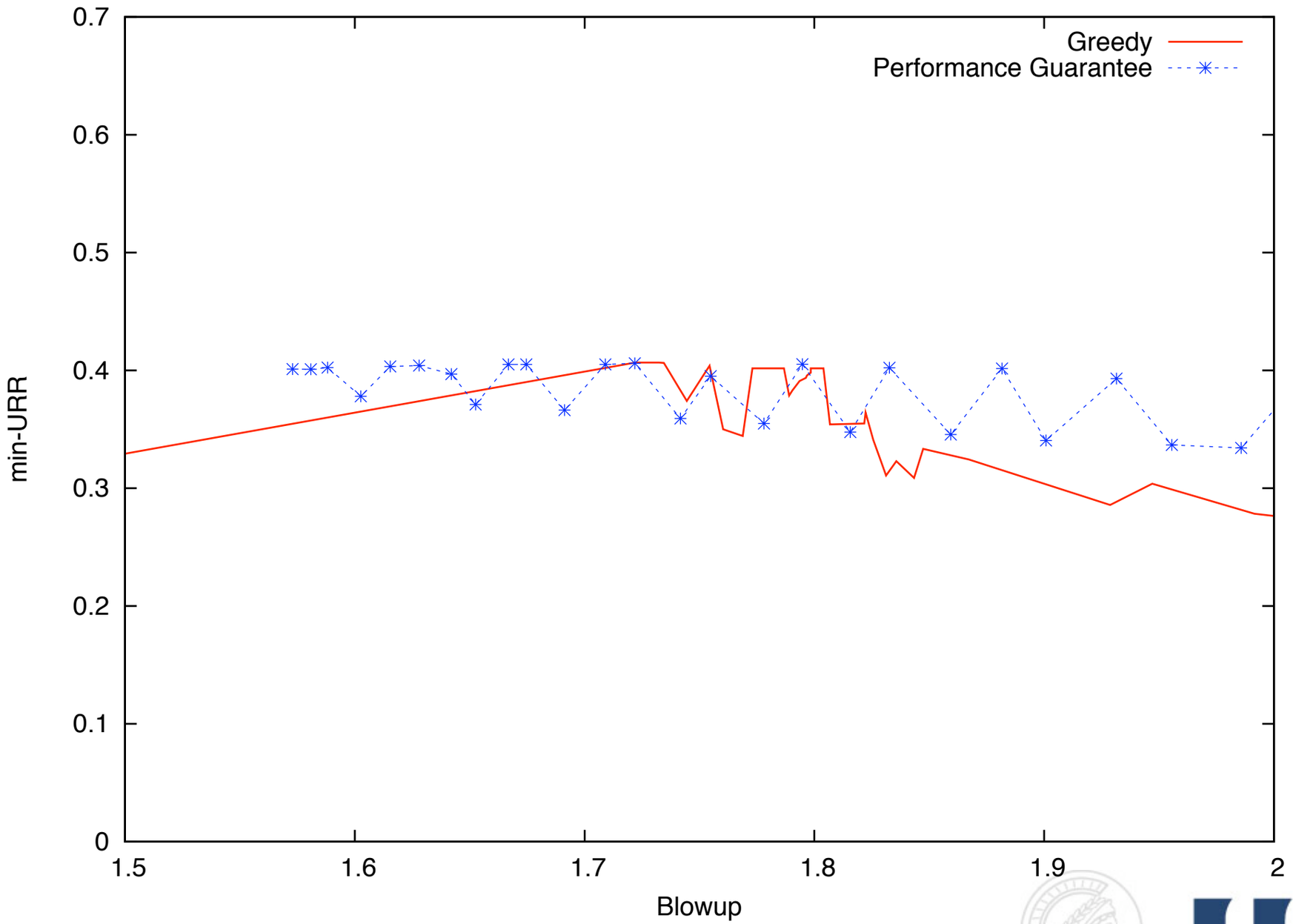
Results

Analysis of Performance-Guarantee vs Greedy for Replication



Results

Analysis of Performance-Guarantee vs Greedy for min-URR



Future Work

- To determine complexity of MMR and come up with centralized solutions
- To look at combination of both Min-URR and Replication as an optimization problem
- Explore possible applications of partitioning strategies to other areas involving continuous attributes

Thank You

References

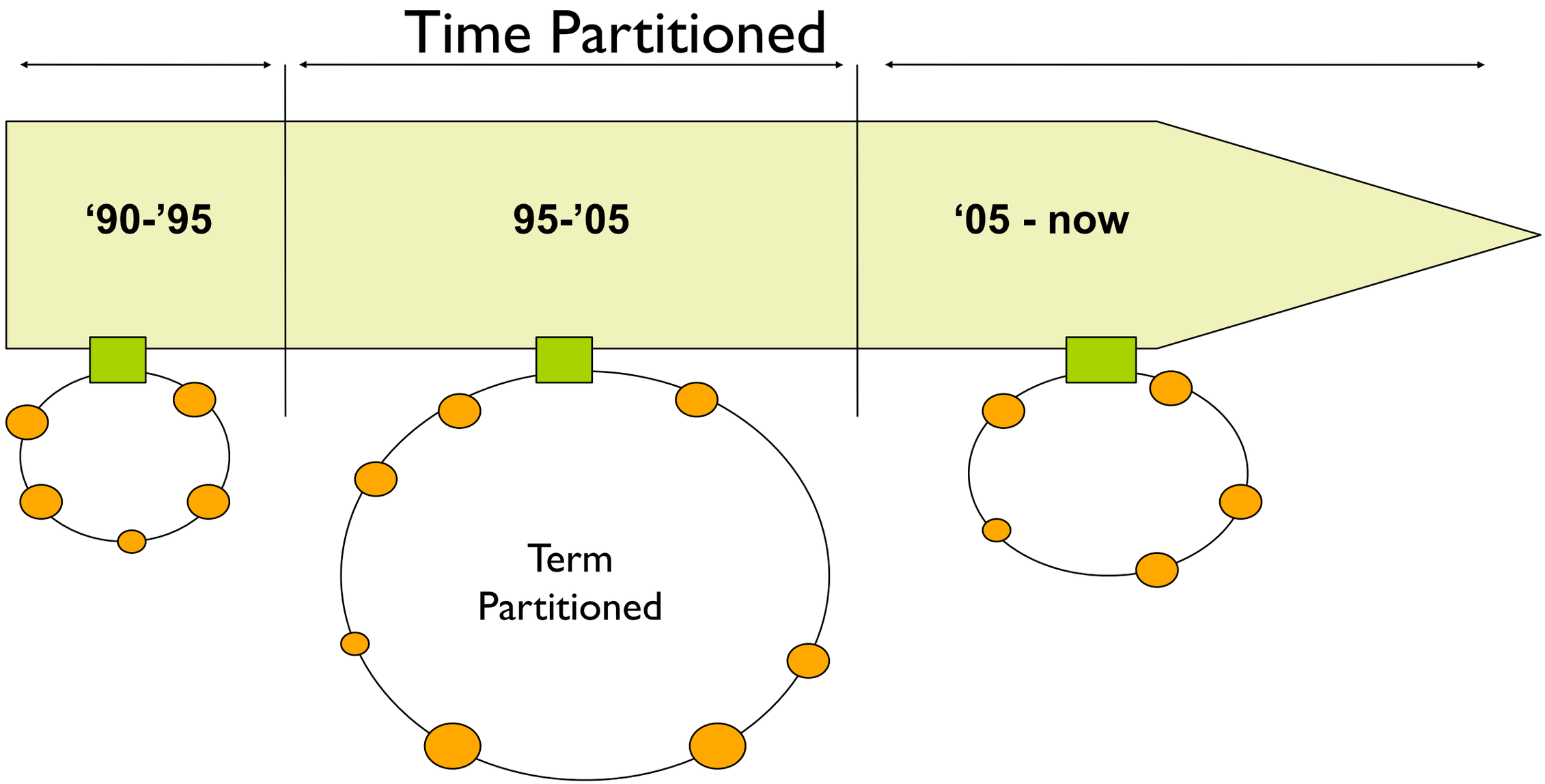
- [1] Klaus Berberich, Srikanta Bedathur, Thomas Neumann, Gerhard Weikum: *A Time Machine for Text Search* SIGIR 2007, July 2007

- [2] Srikanta Bedathur, Avishek Anand, Klaus Berberich, Ralf Schenkel, Christos Tryfonopoulos: Realizing an Everlasting Web, under submission CIDR 2009.

- [3] Klaus Berberich, Srikanta Bedathur, Thomas Neumann, Gerhard Weikum: *A Time Machine for Text Search* MPII Technical Report MPI-I-2007-5-002, July 2007

- [4] http://www.wikipedia.org/

Time-Term Partitioning



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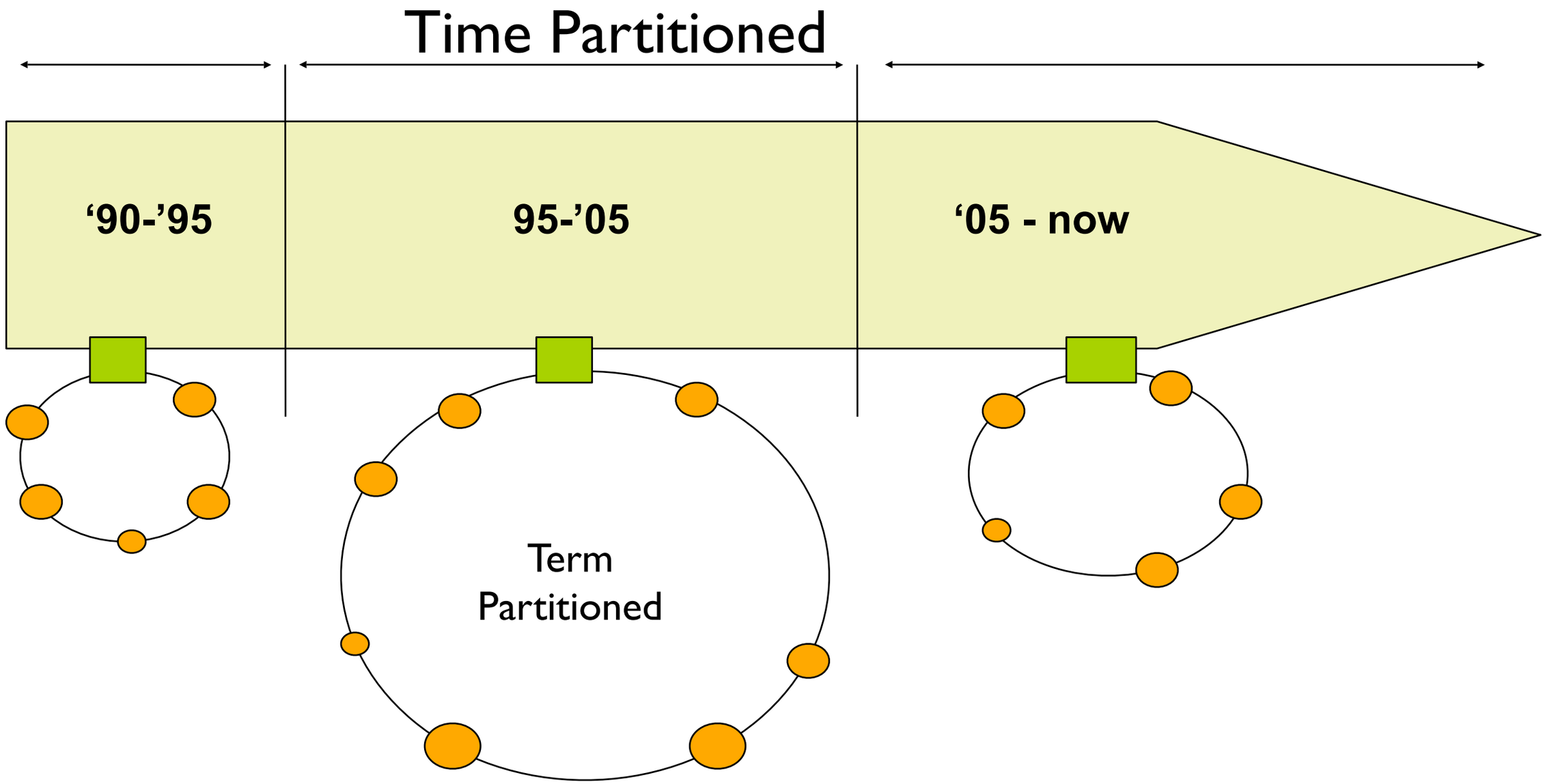
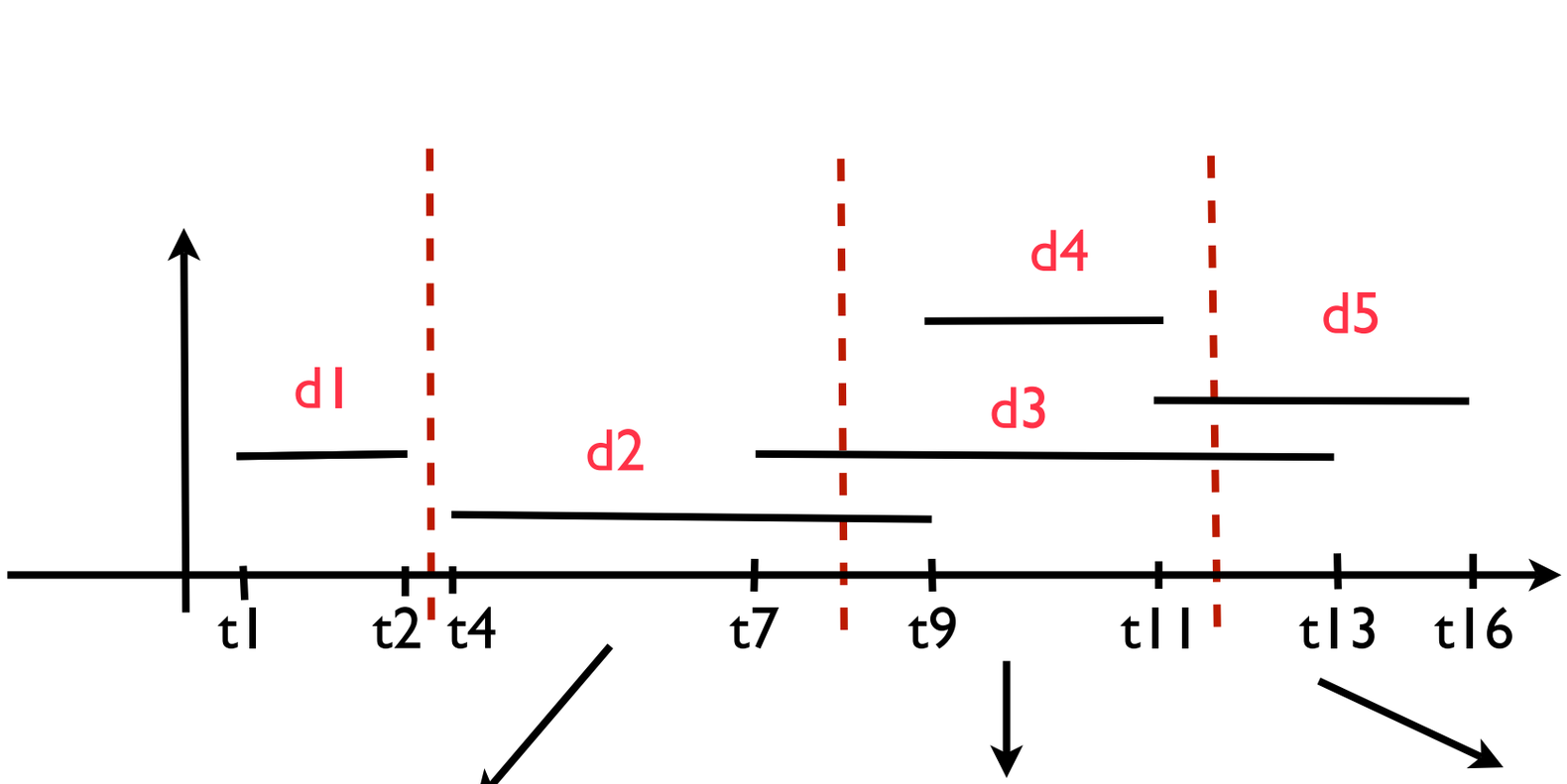
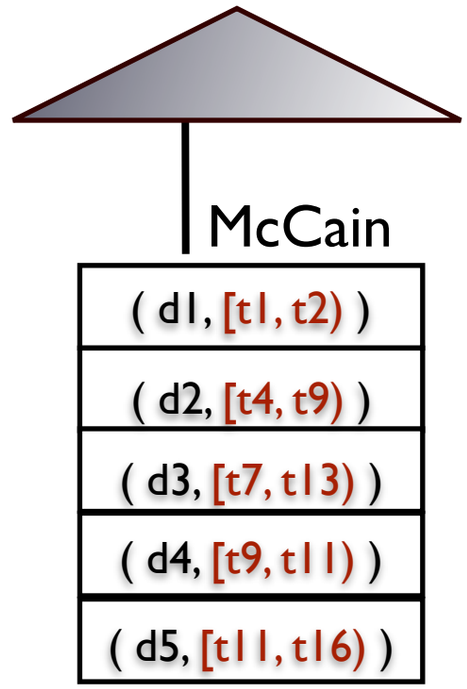
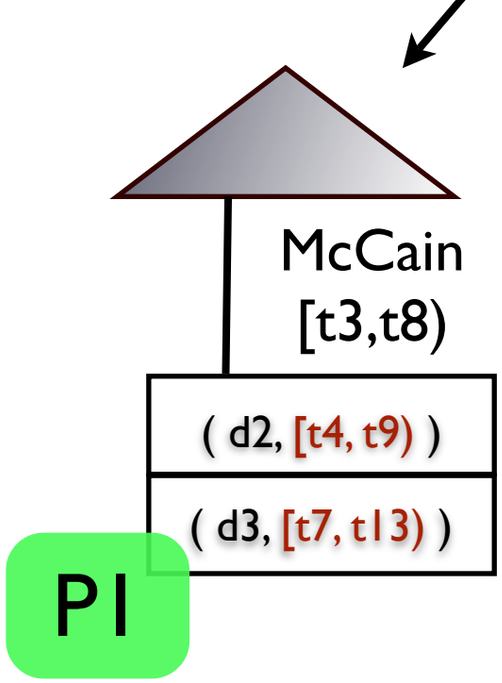


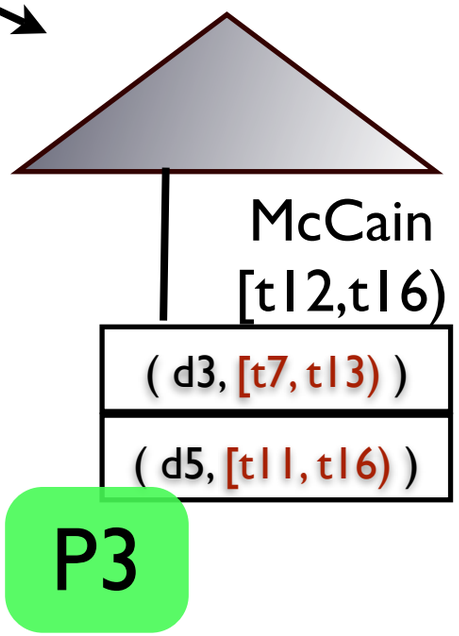
A query "q @ t" routed to gateway peer responsible for "t" and then the peer responsible for "q"

Index Partitioning









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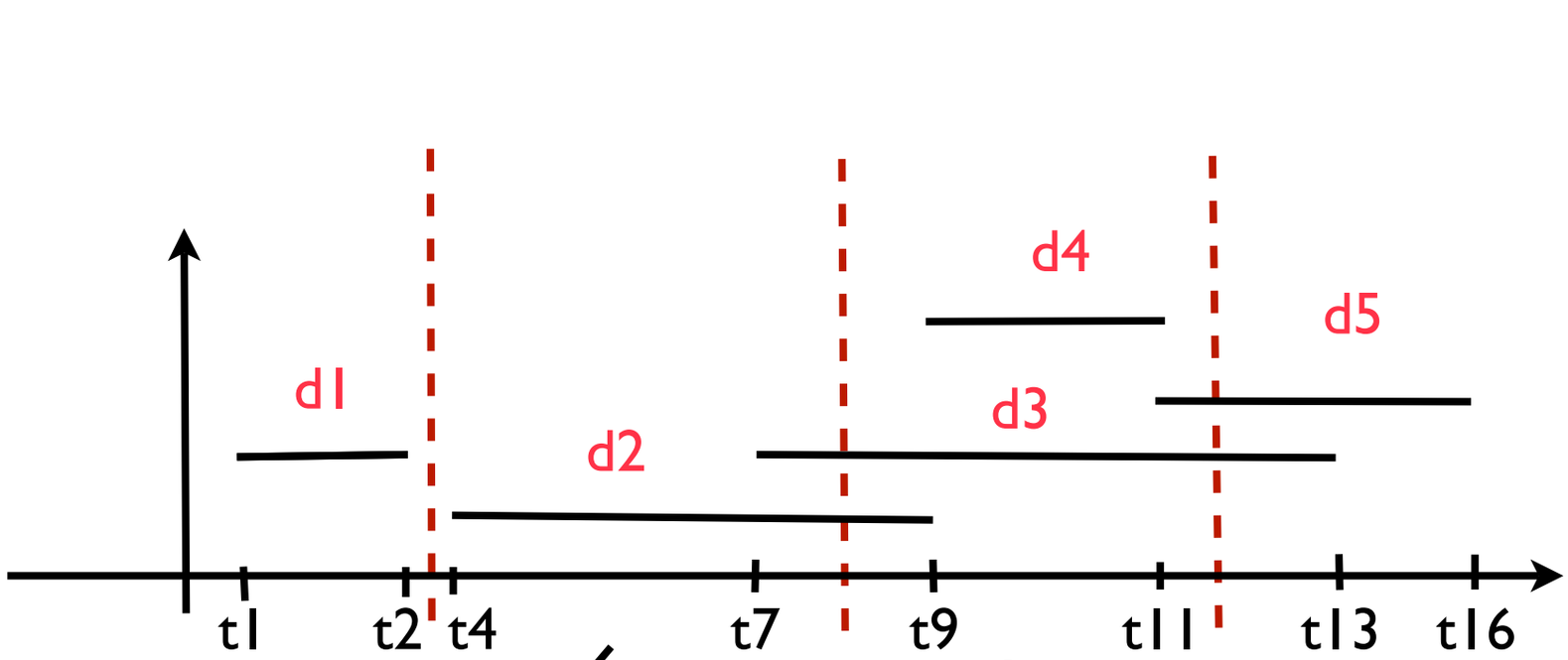

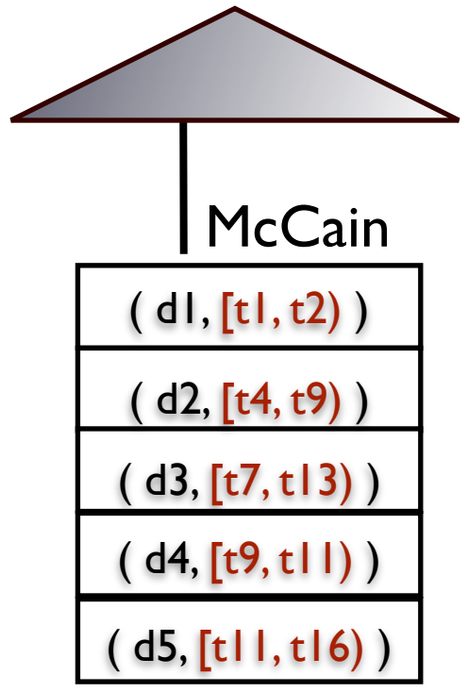

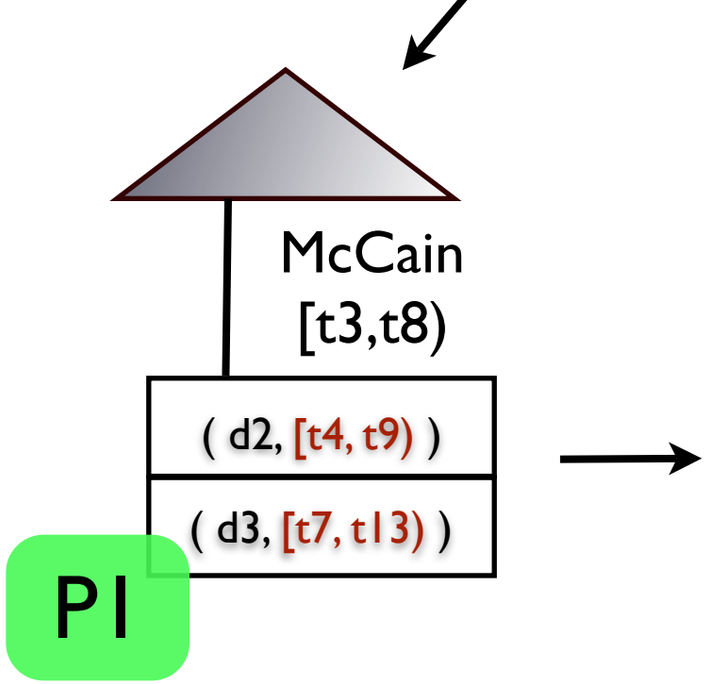

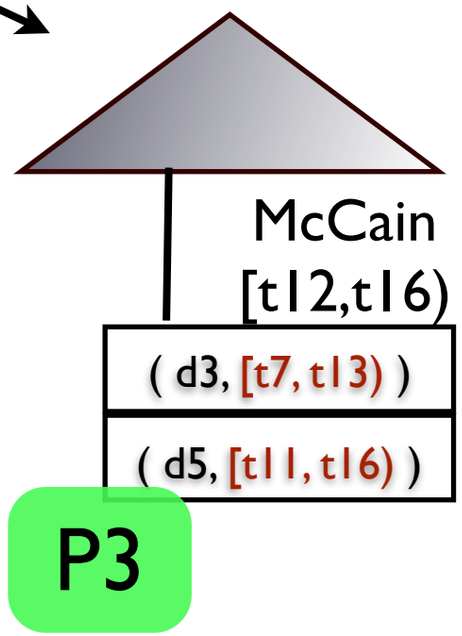

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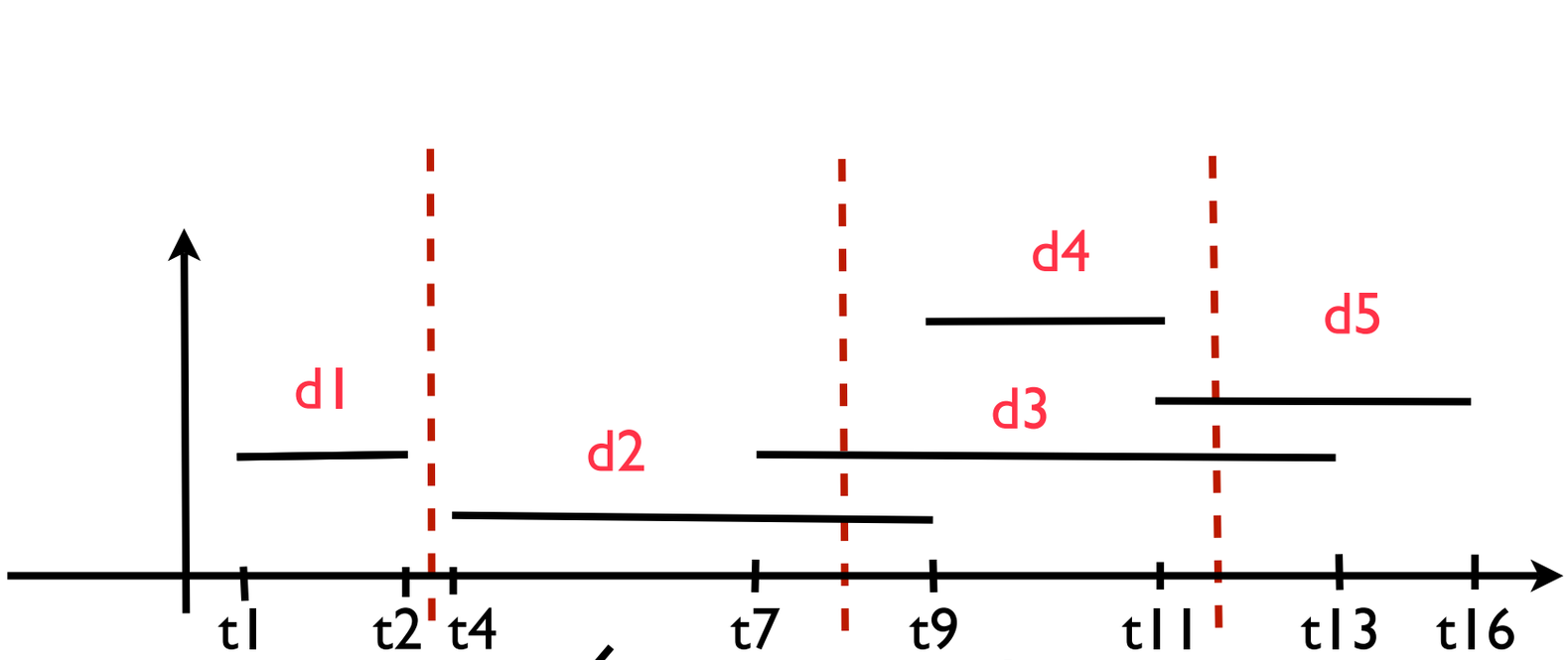

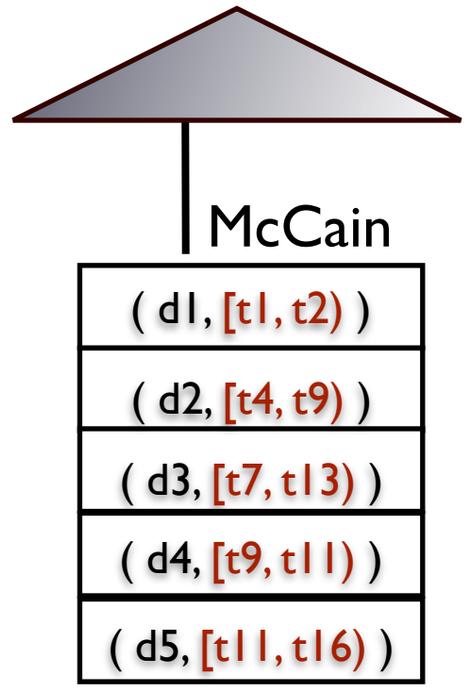

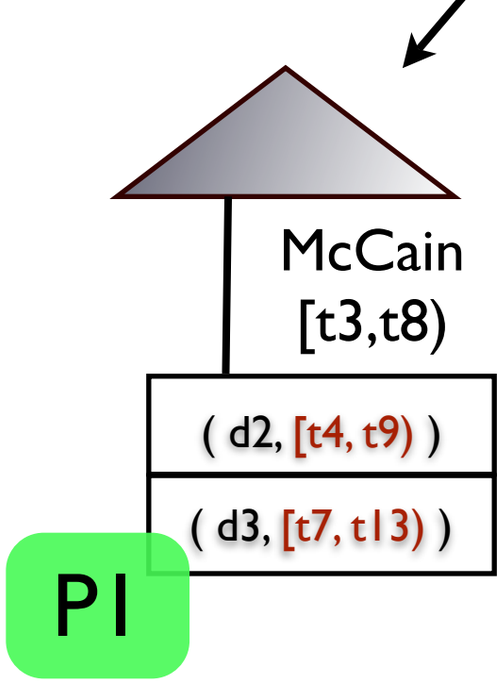

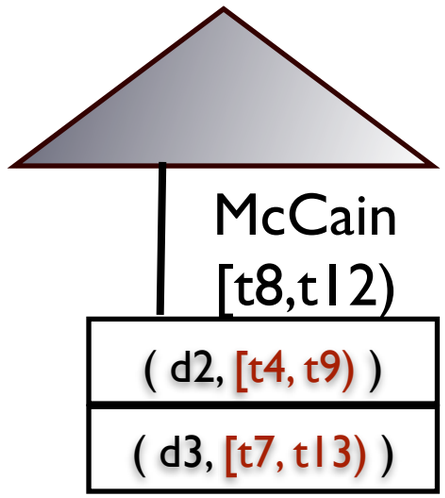

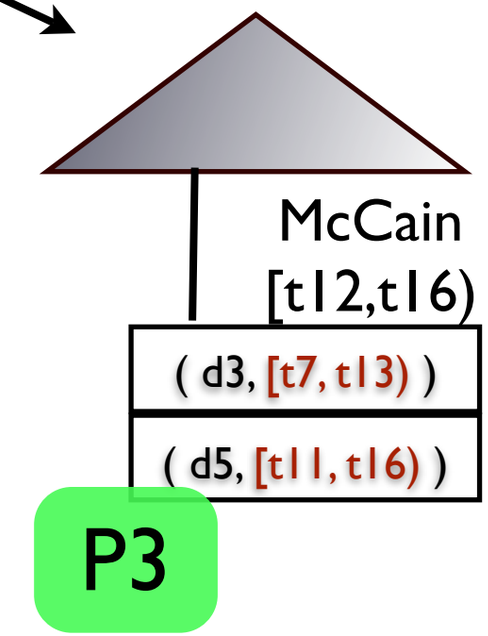

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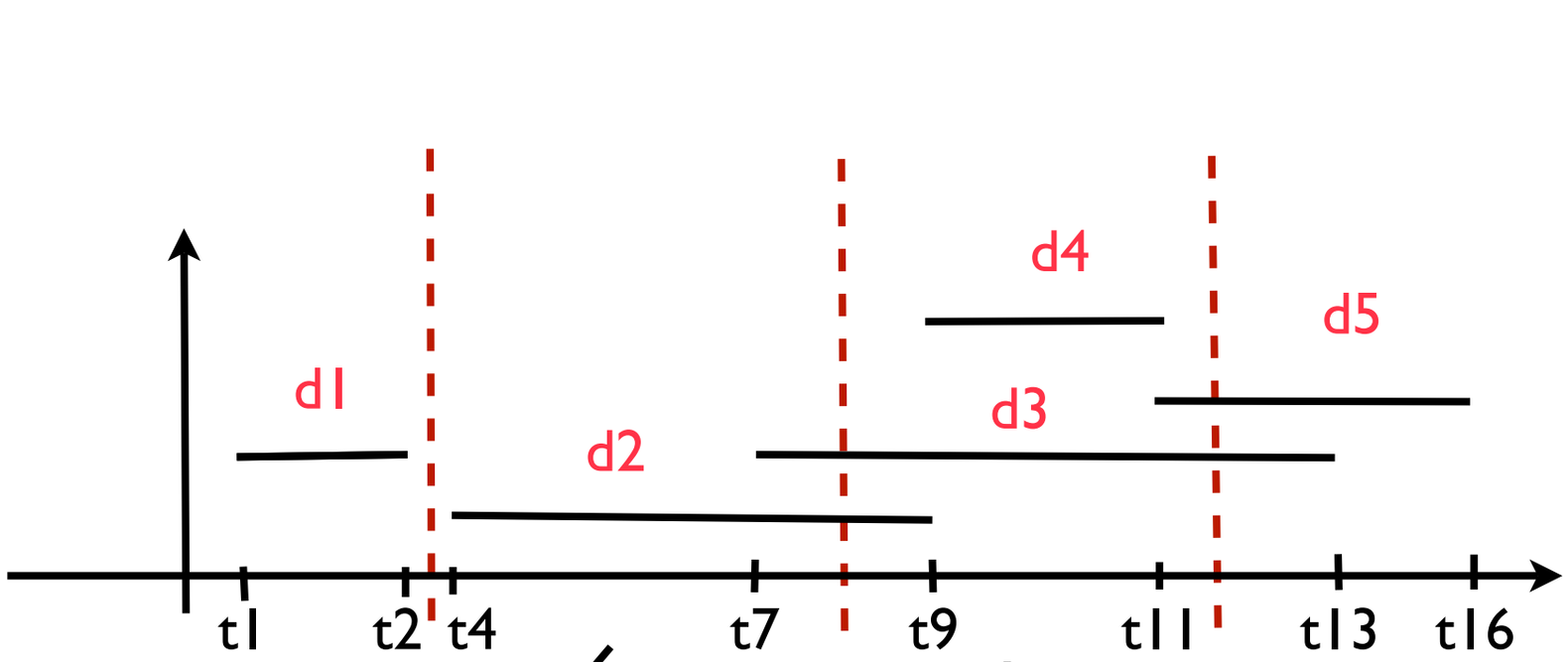

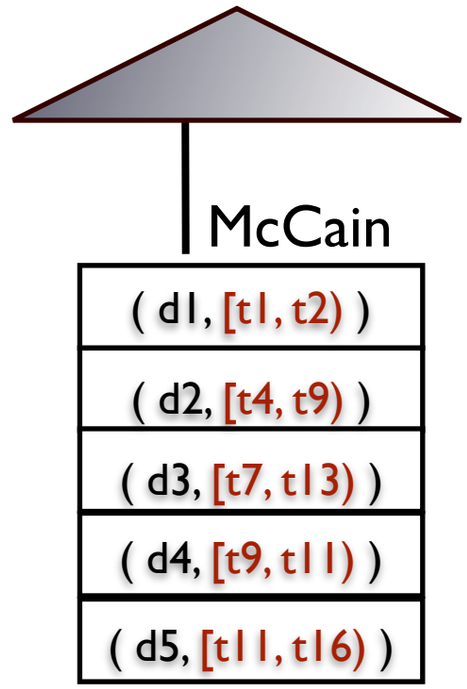

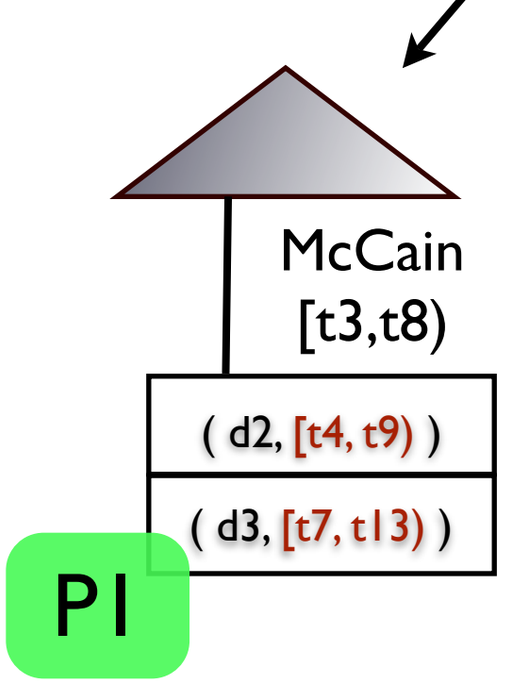

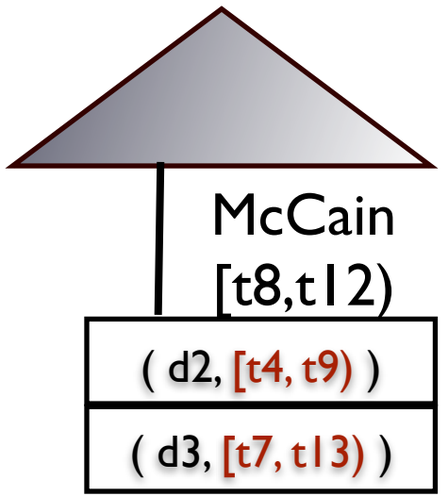

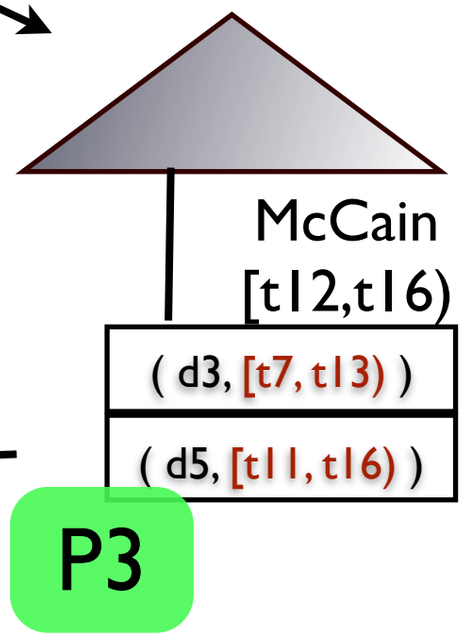

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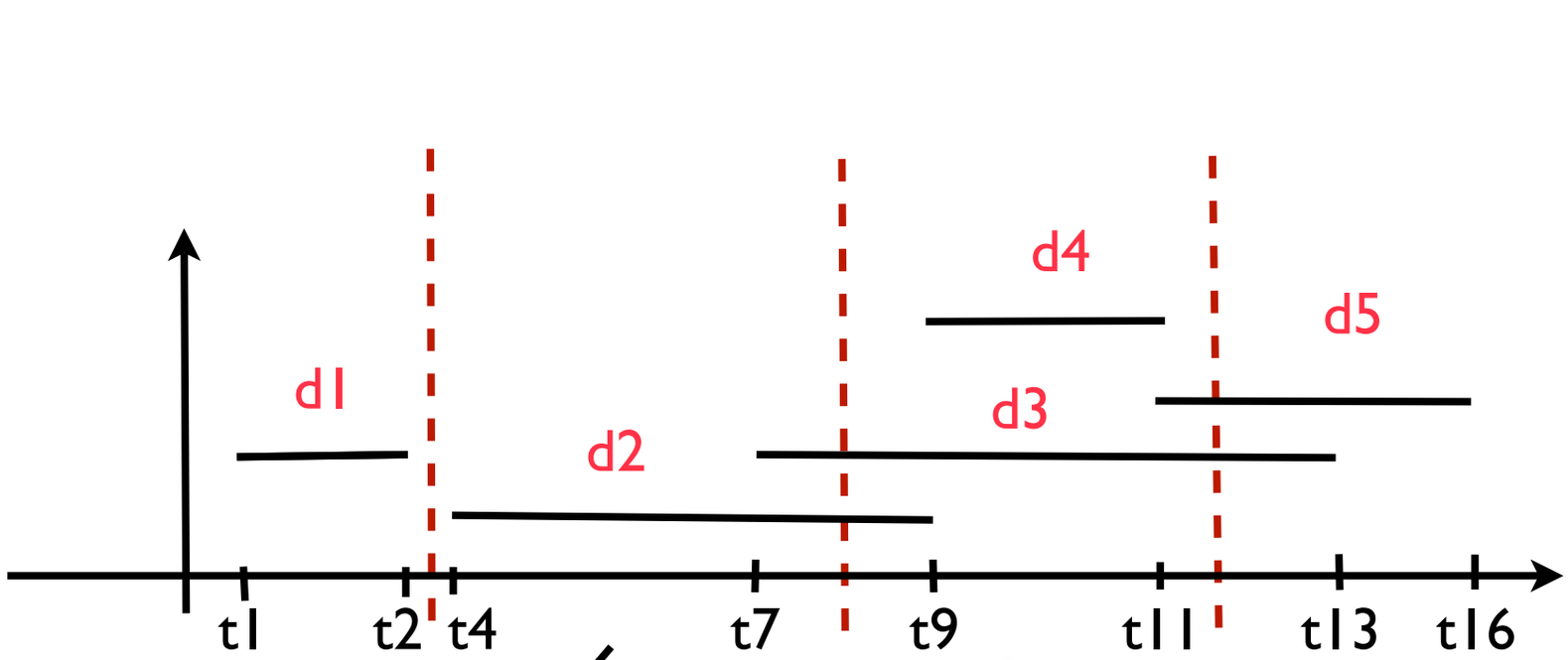

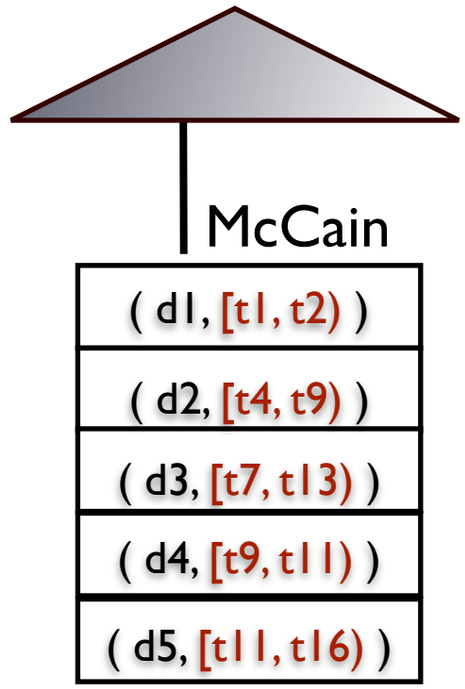

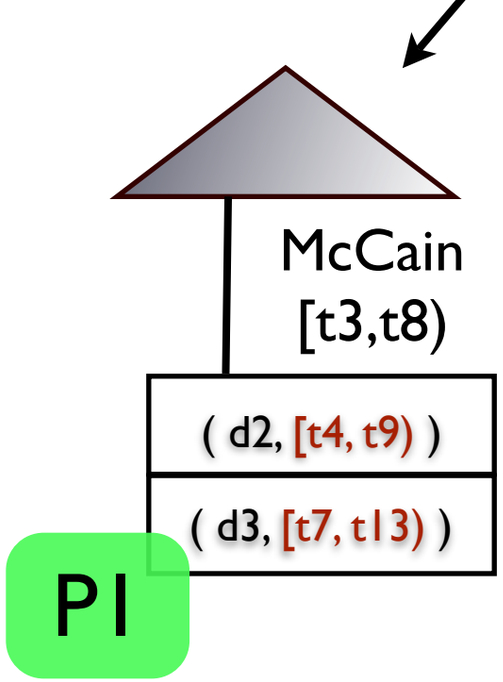

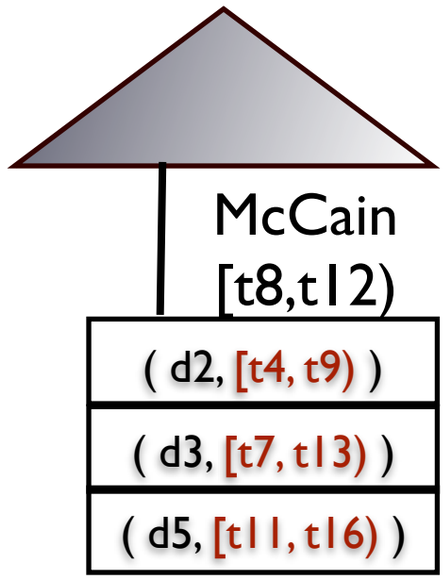

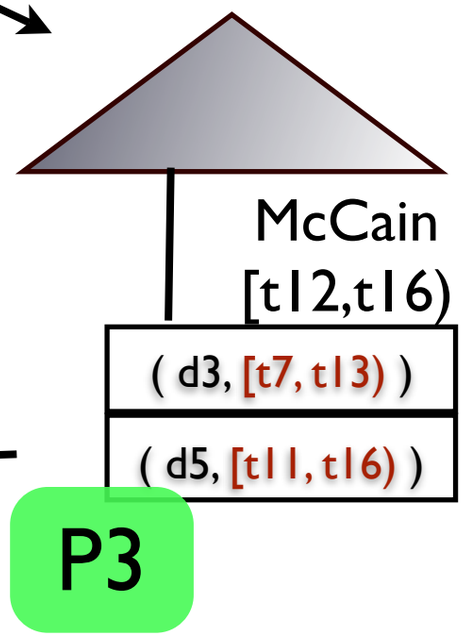

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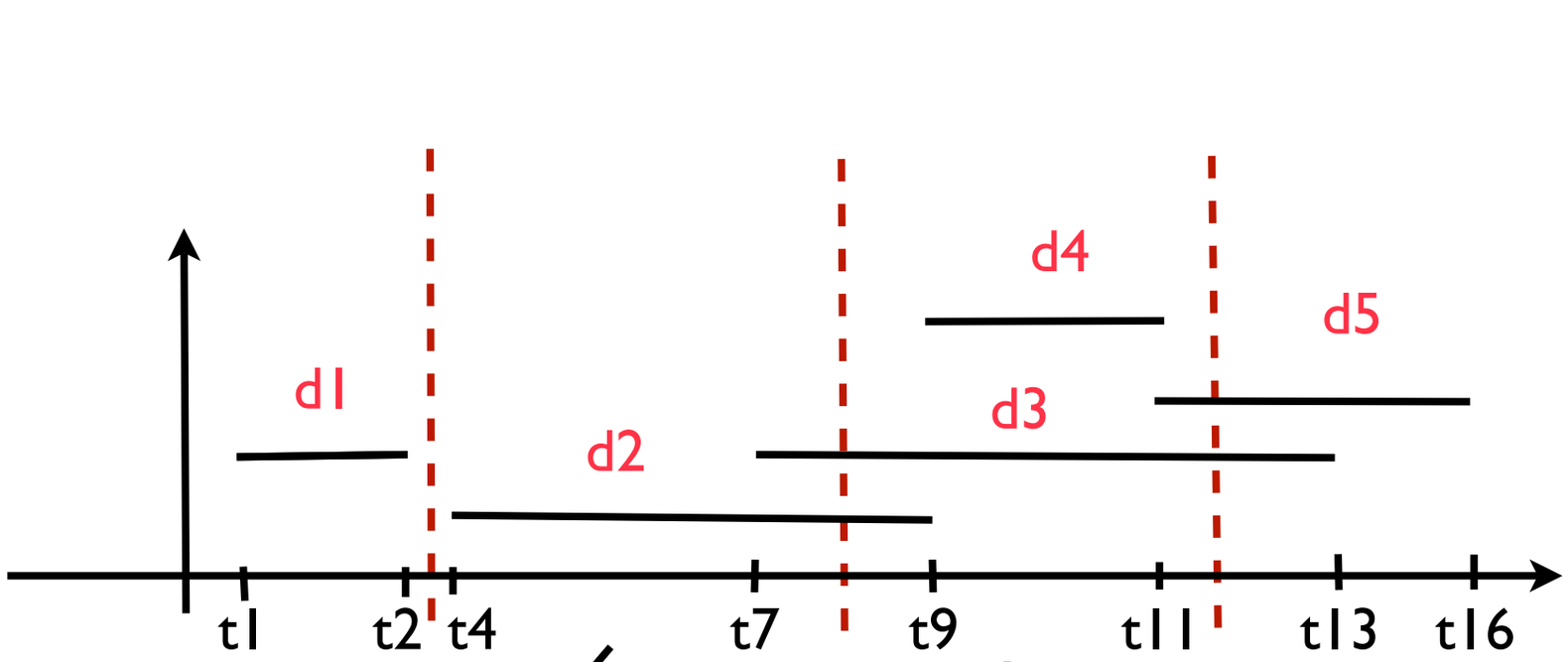
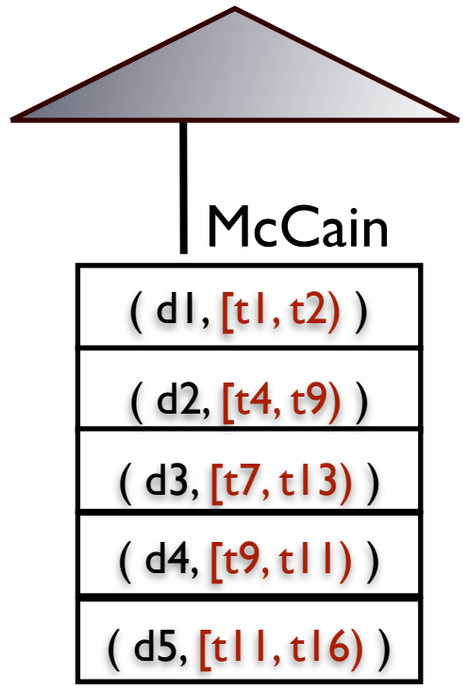
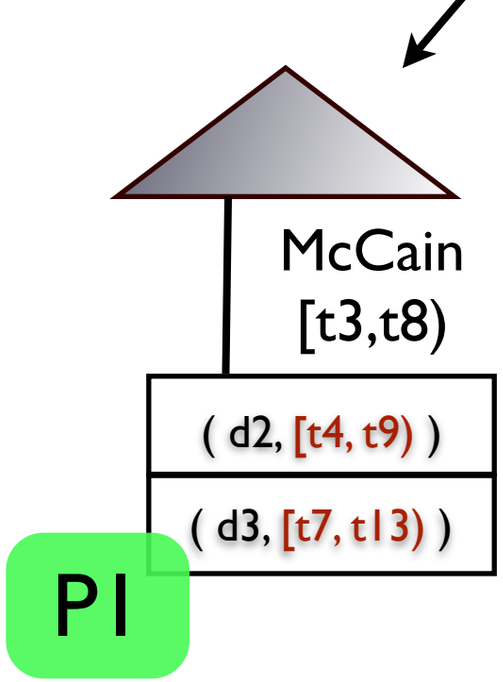
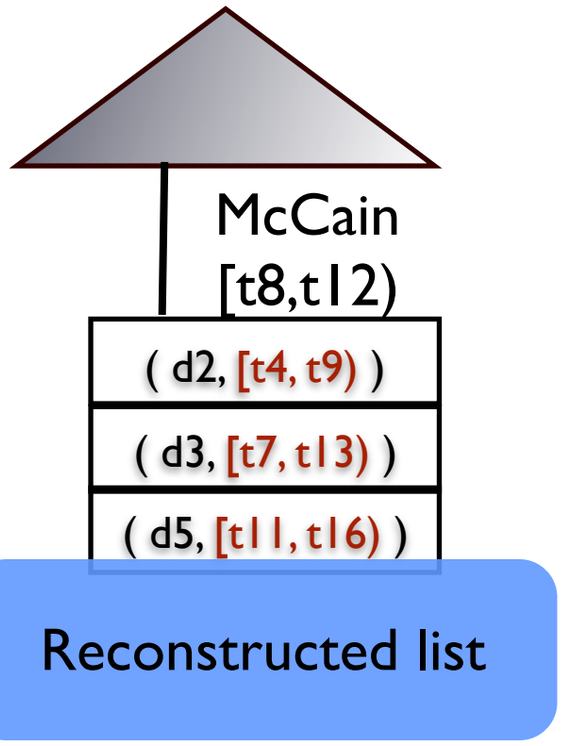
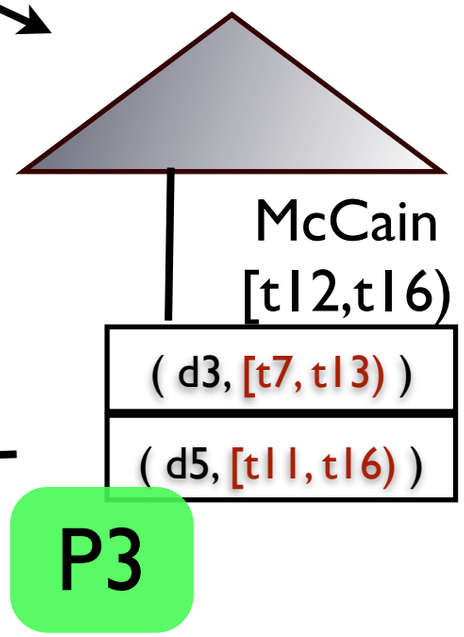




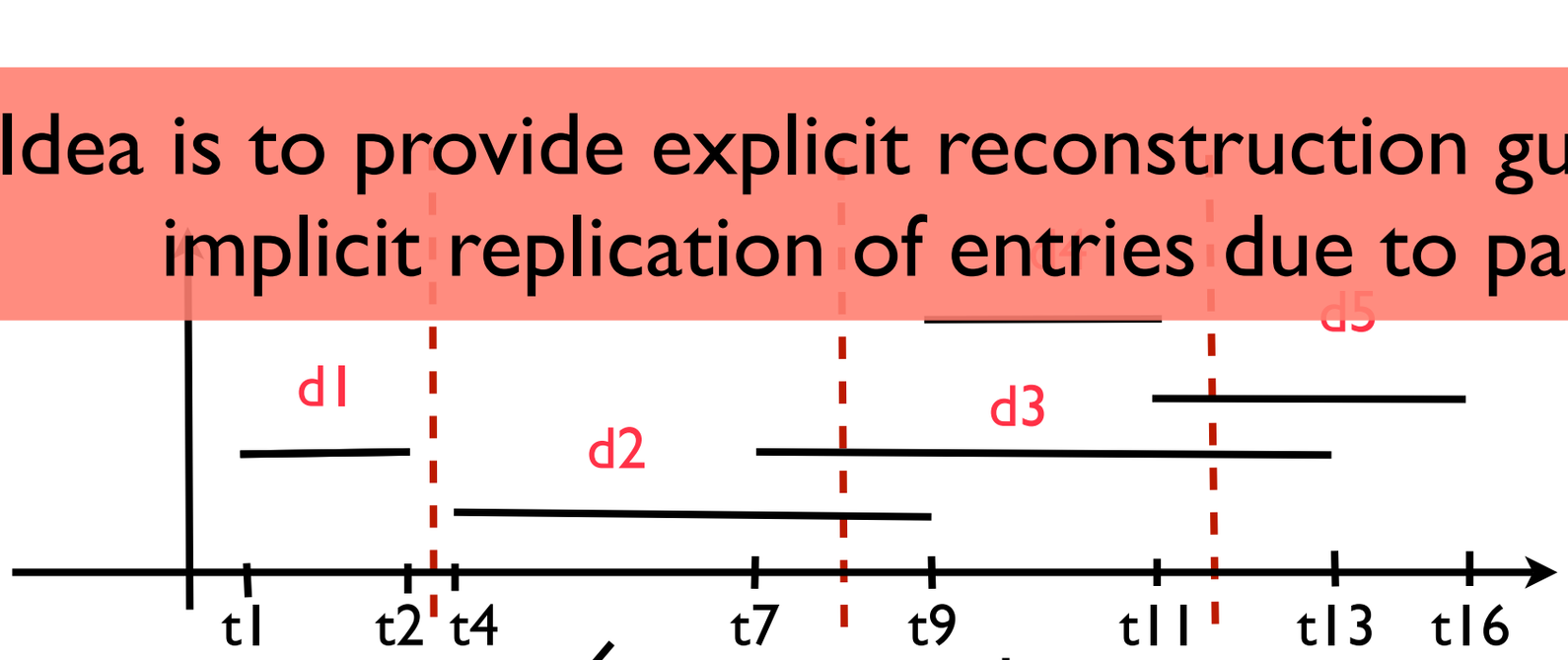


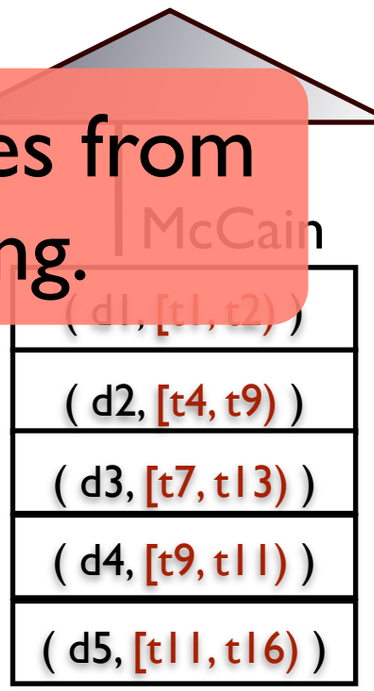


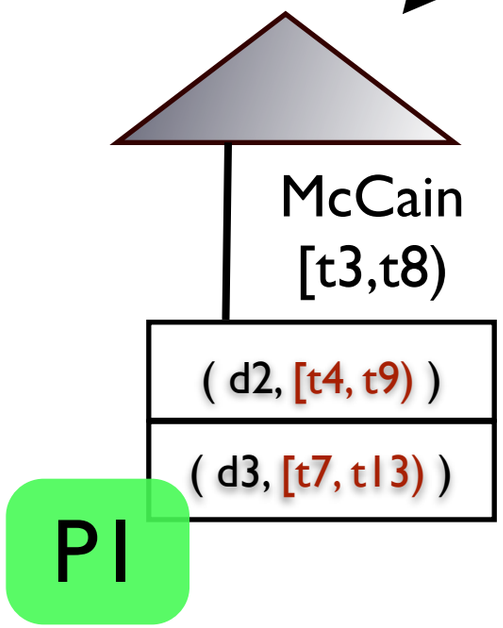


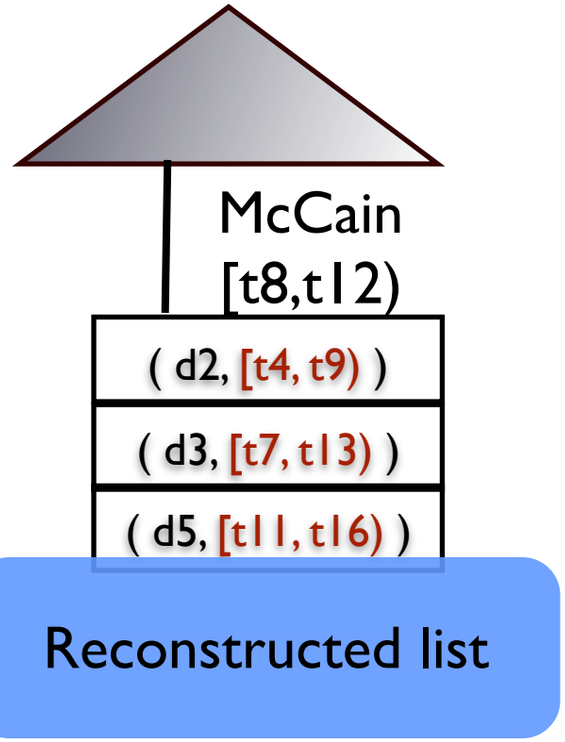
Index Partitioning

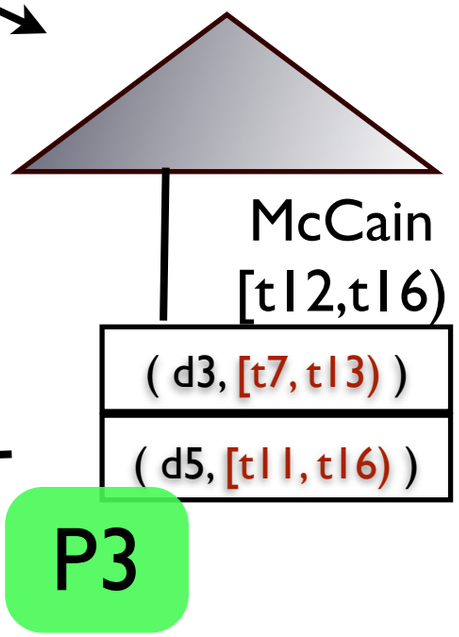
Idea is to provide explicit reconstruction guarantees from implicit replication of entries due to partitioning.





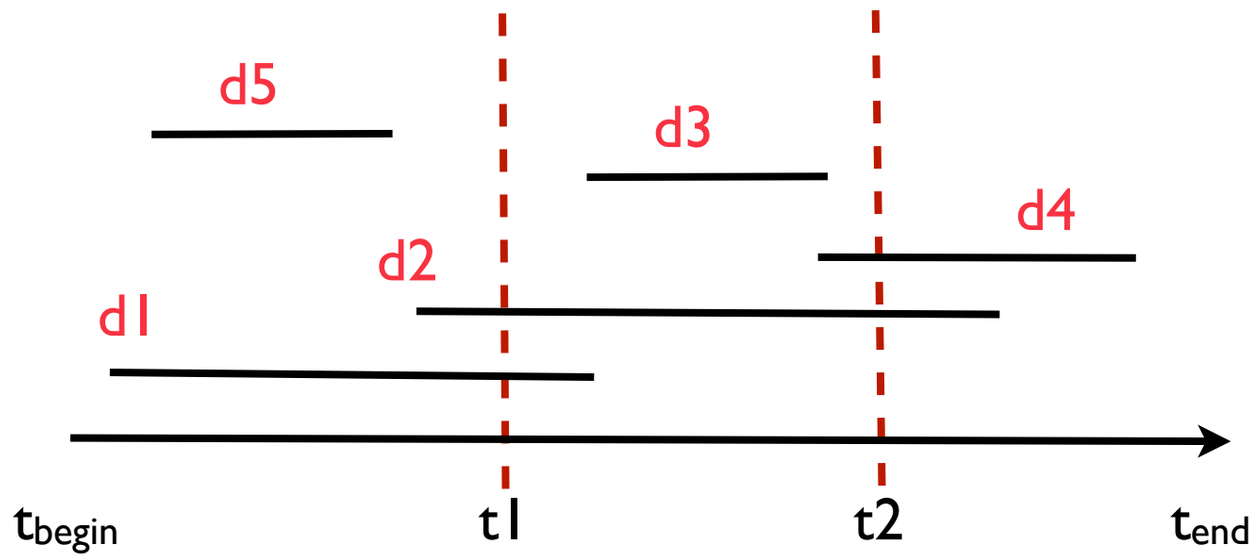






Live Entries

- Live entries in a partition could be classified into left, right, strikethrough and subsumed.



left:[t1, t2] = {d1}

right:[t1, t2] = {d4}

str:[t1, t2] = {d2}

sub:[t1, t2] = {d3}

N_{t1}= {d1, d2} N_{t2} = {d2, d4}

L_v: [t1, t2) = {d1, d2, d3, d4}

L_v = {d1, d2, d3, d4, d5}

Live Entries in a Partition

- Live entries at a time-point t_i is a set of all entries which exist at t_i.

$$N_{t_i} = \{(d, p, [t_j, t_k)) \in L_v \mid t_j \leq t_i \wedge t_k > t_i\} .$$

- Live entries in a partition L_v: $[t_i , t_j)$:

$$L_v : [t_i, t_j) = \{(d, p, [t_b, t_e)) \in L_v \mid t_b < t_j \wedge t_e > t_i\} .$$

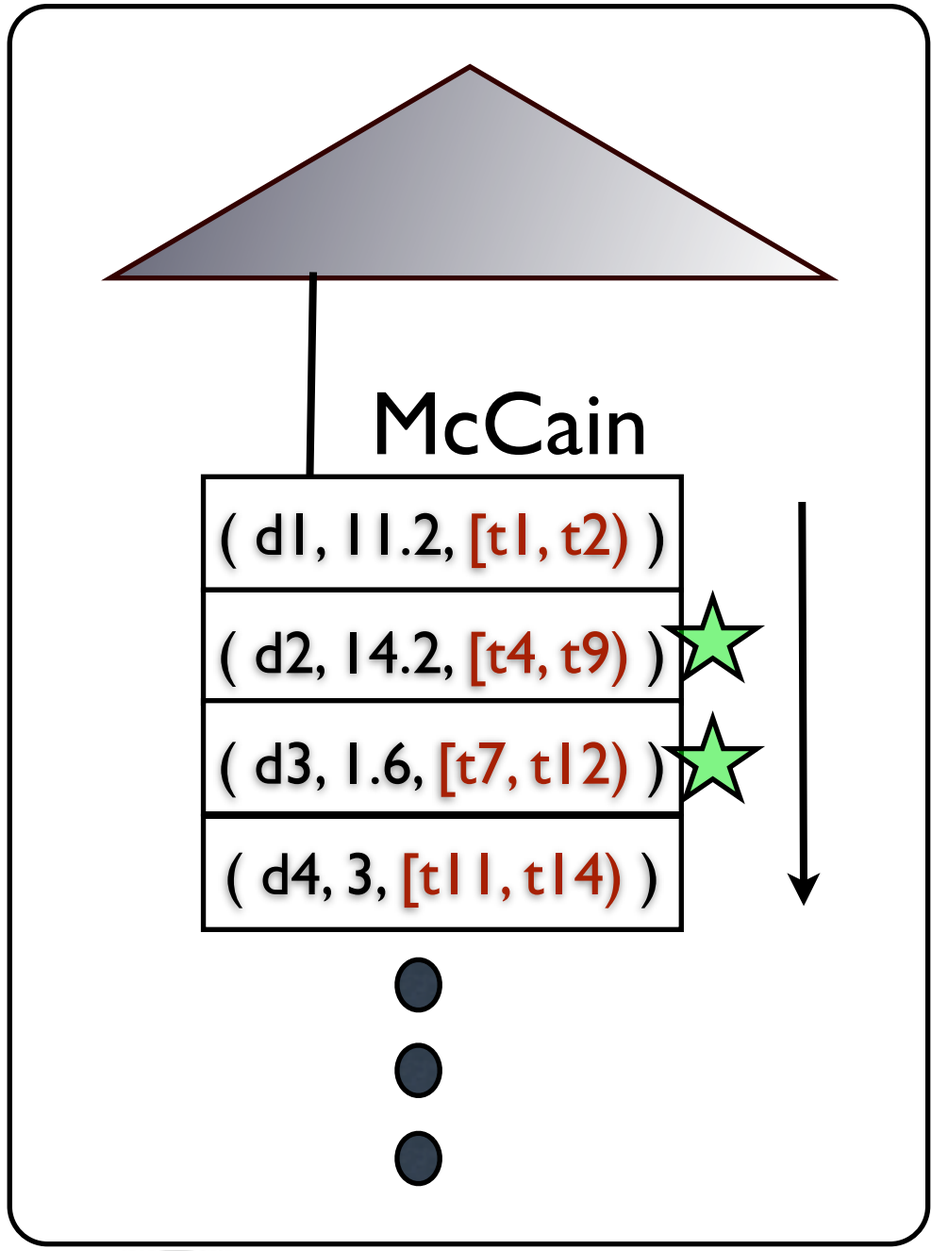
(d, p, [t_b , t_e)) is the posting for the document **d** which begins at **t_b** and ends at **t_e**.
L_v denotes all the documents in the collection.

Backup Slides

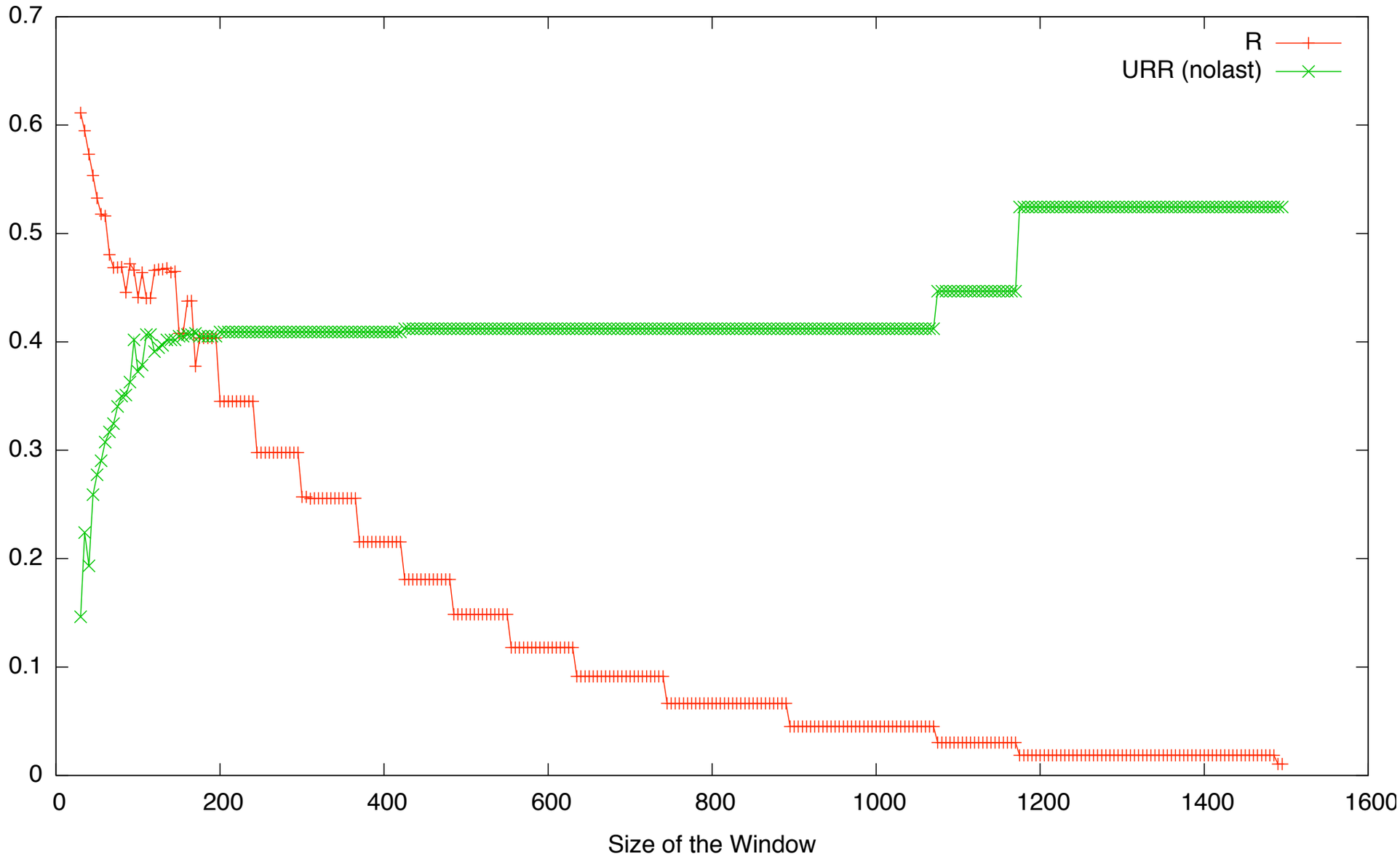
- Everlast as Web Archival system
- Other lifetime analysis results about Wikipedia

Time-travel queries

- Time-travel queries are keyword queries with a temporal context. E.g "McCain @ t5"
- The conventional inverted index structures are extended by addition of validity time-interval
- "McCain @ t8" => d2 , d3
- Every version is considered as a new entry resulting in long lists.



Results



Values of R and Min URR for different window values on wikipedia data