Efficient Storage and Temporal Query Evaluation of Hierarchical Data Archiving Systems

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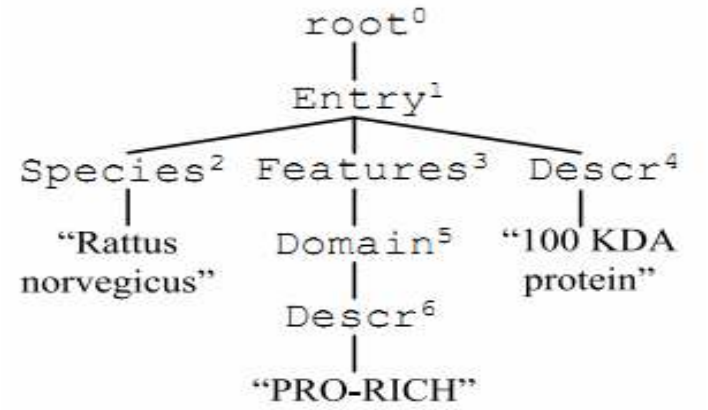
Scientific Data in XML

- eXtensible Markup Language (XML): A mark-up language
- XML for scientific data
  - Describe data structure and give simple processing instructions (e.g., XSIL and XDMF)
  - Provide common data format that is an open, universal standard (e.g, CML, MathML, GML)

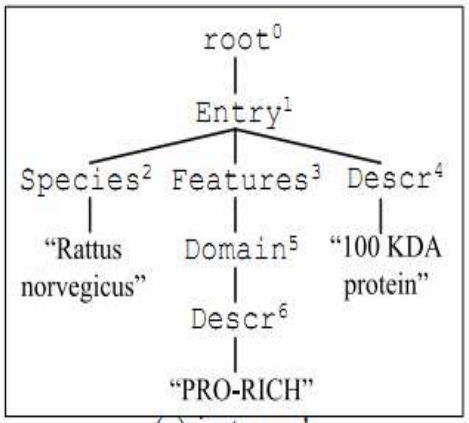


Swiss-Prot Dataset

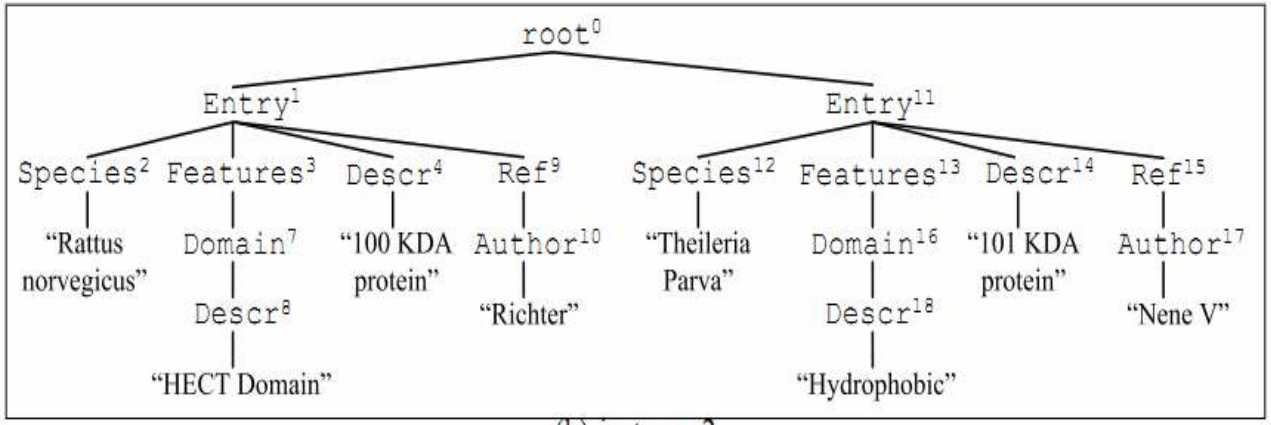
Updates on Scientific Data in XML

- Scientific databases are continuously updated
- Necessity of maintaining all versions in the archive
- **Problem:** as increasing volumes of these data being accumulated, the archives can reach a critical mass.

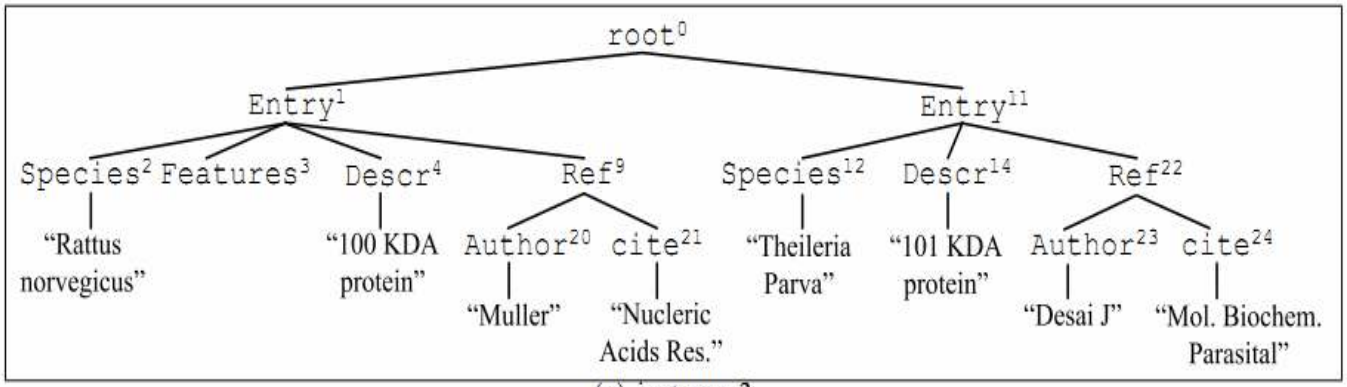
An Example of Multiple XML Dataset Versions



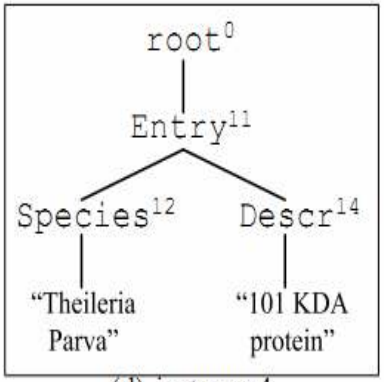
(a) instance 1



(b) instance 2



(c) instance 3



(d) instance 4

Four consecutive instances of an extract of the Swiss-Prot Dataset

Challenges

(1) how to store successive versions of XML databases in an archiving database in a cost-effective way.

(2) how to evaluate queries efficiently on the archiving database.

Our Contributions

- A novel **compact and updateable storage** scheme for XML archiving databases.
- A simple yet expressive **query language** for XML archiving databases.
- **Optimization of query evaluation** over the compact storage.

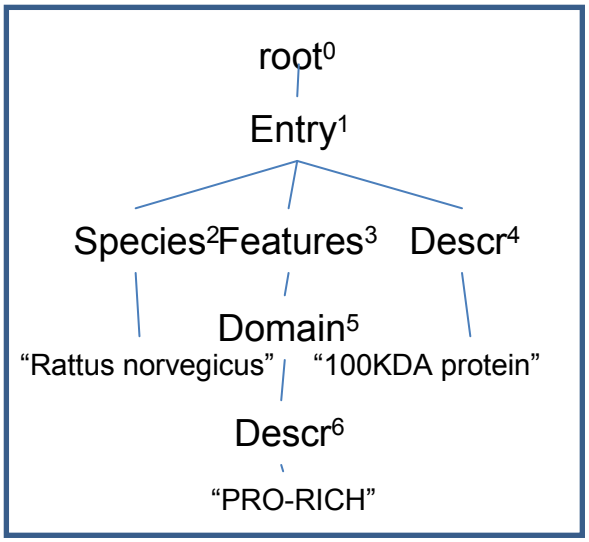
Outline

- Preliminaries
- **Compact storage**
- Temporal query language
- Query optimization
- Experiments
- Conclusion

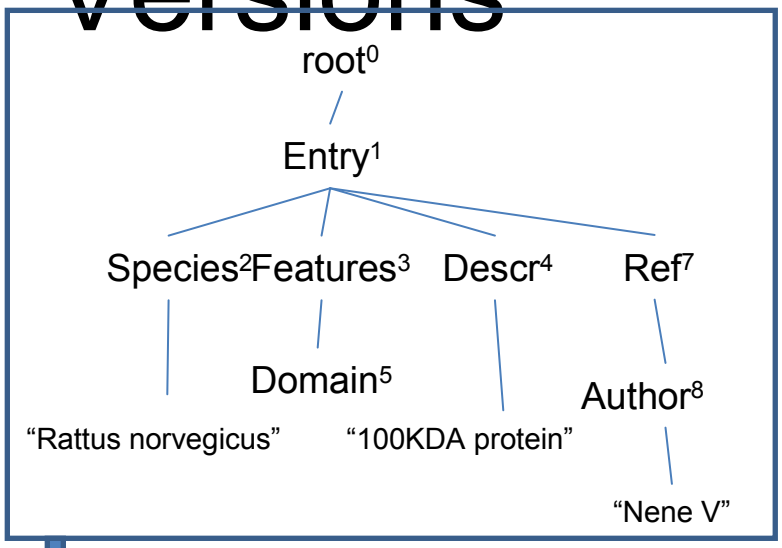
Compact Storage Scheme (I)

- Merge versions
  - Store multiple occurrences of the same node only once in the archiving database *A*.
  - Each node *p* in *A* is associated with a *timestamp set* which contains the timestamps of the instances of *p*.

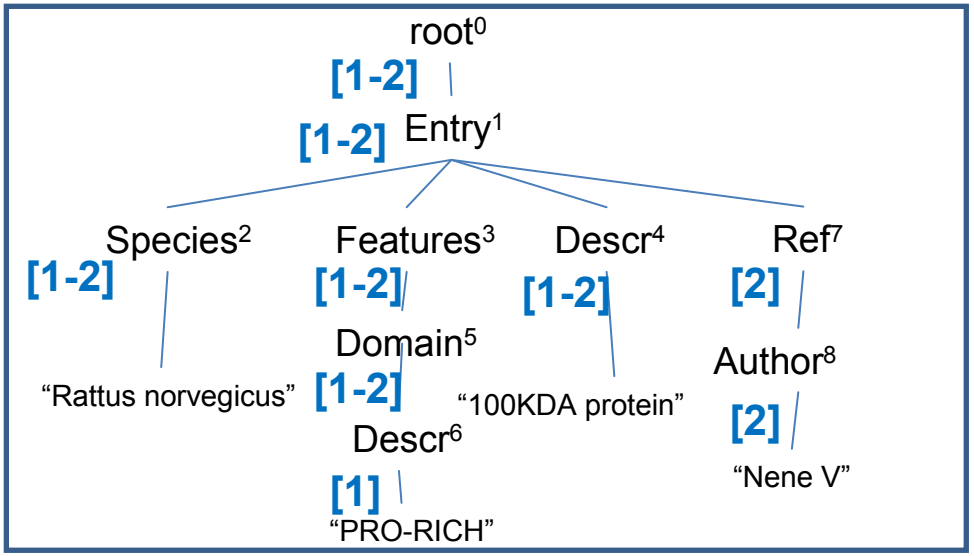
An Example of Merging Versions



Version 1



Version 2



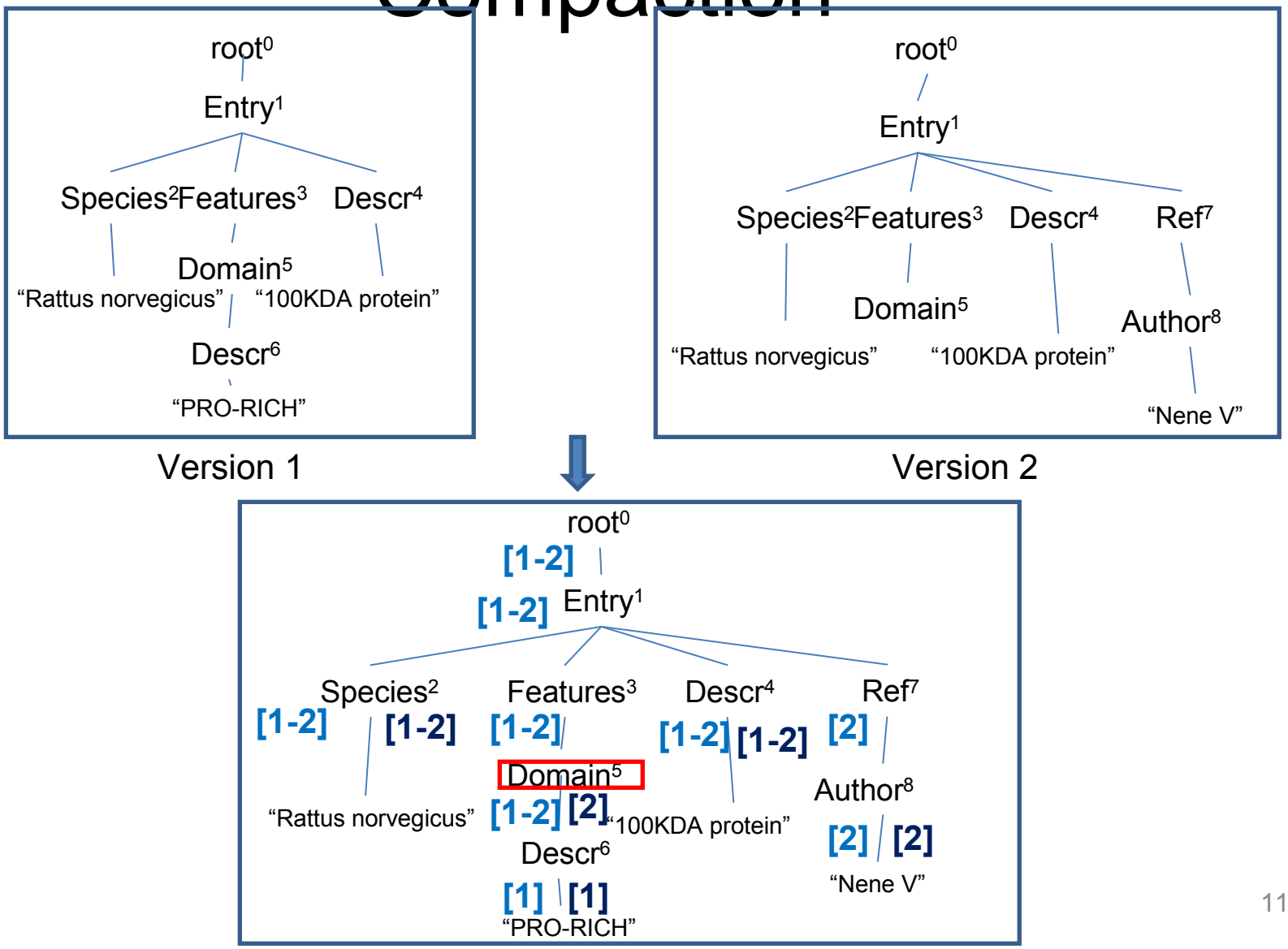
Monotone property on timestamps of the nodes on the same path

Compact Storage Scheme (II)

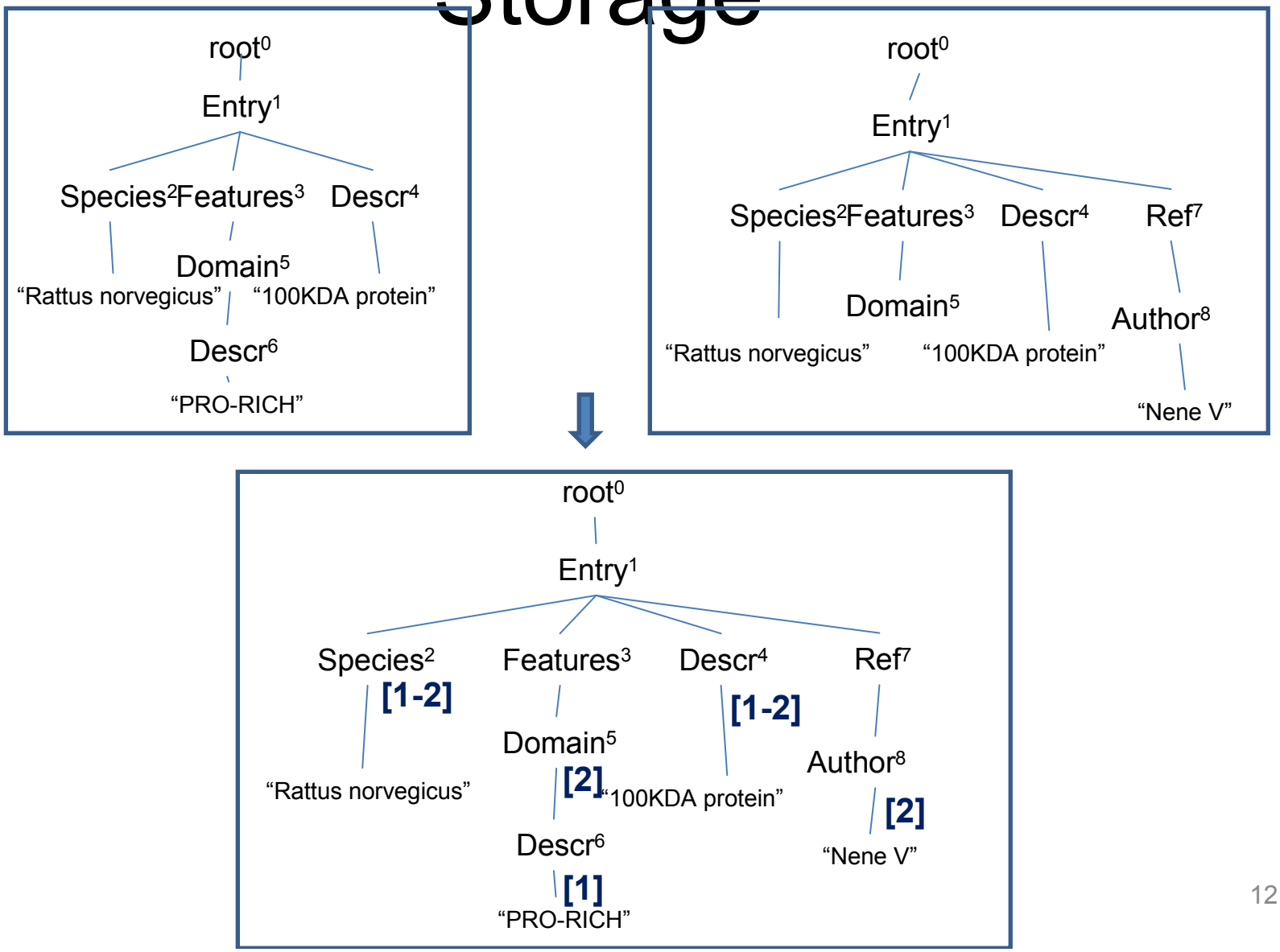
- Timestamp set compaction
  - The timestamp label of the parent node only preserves the timestamps that do not appear on any of its children.

$$Lp = ts(p) - \cup_{c \in child(p)} ts(c)$$

An Example of Timestamp Set Compaction

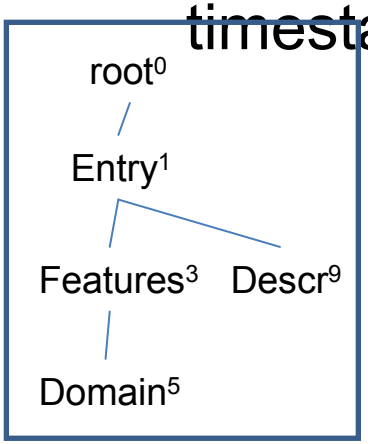


An Example of Compact Storage

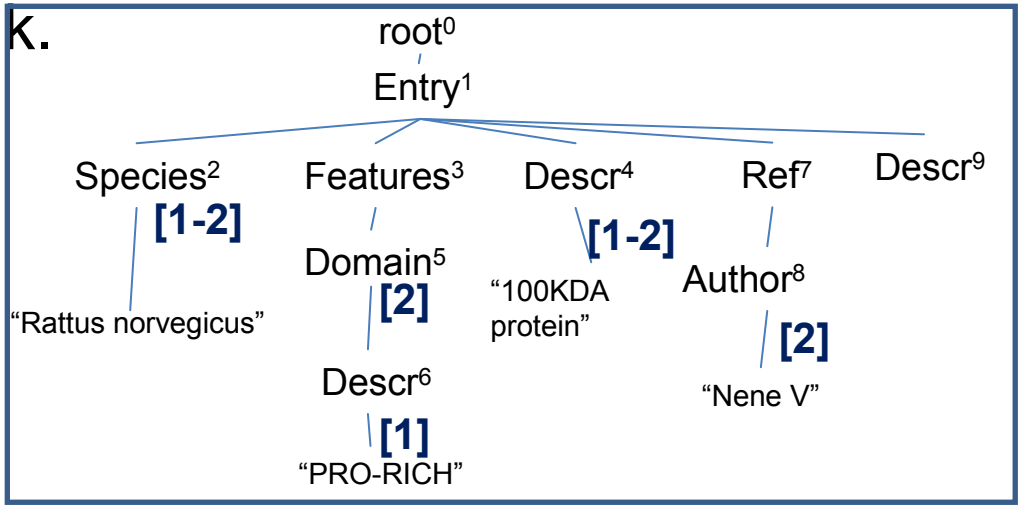


Efficient Updates

- Incremental timestamp label computation
  - When insert a new instance D_k at timestamp k,
    - add the newly inserted trees $T_1, \ldots, T_m$ in D_k to the archive,
    - For **leaf** nodes in D_k , update the timestamp labels of their corresponding archive nodes by adding timestamp k.



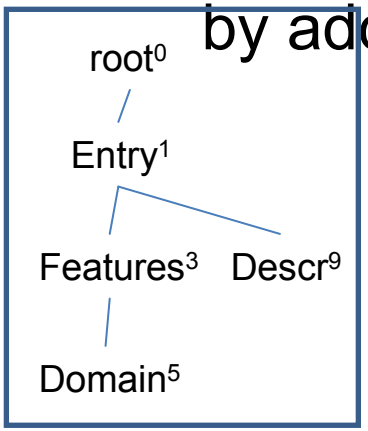
Version 3



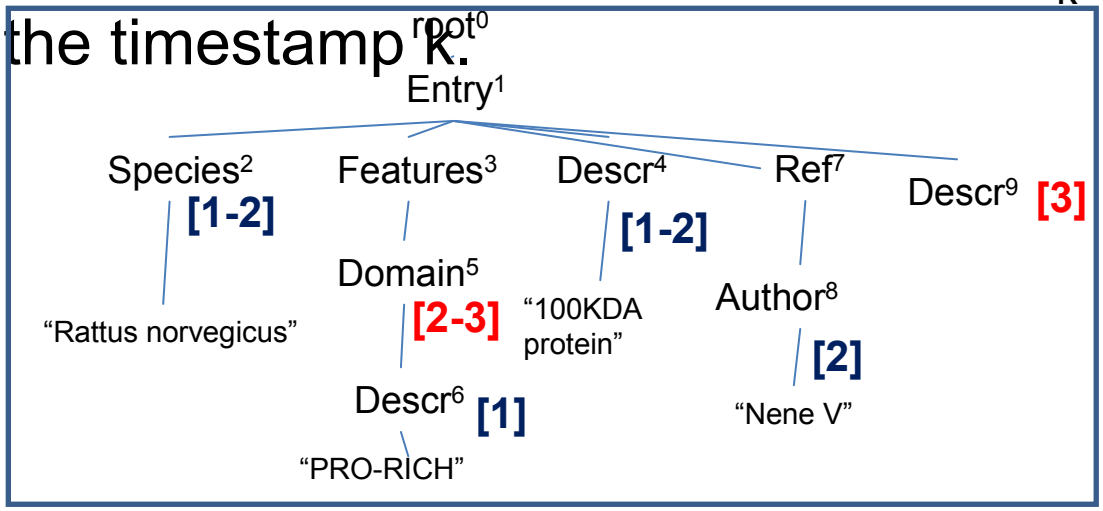
Archiving Dataset before Update

Efficient Updates

- Incremental timestamp label computation
  - When insert a new instance D_k at timestamp k,
    - add the newly inserted trees $T_1, \ldots, T_m$ in D_k to the archive,
    - update the archive nodes of the **leaf** nodes in D_k by adding the timestamp k.



Version 3

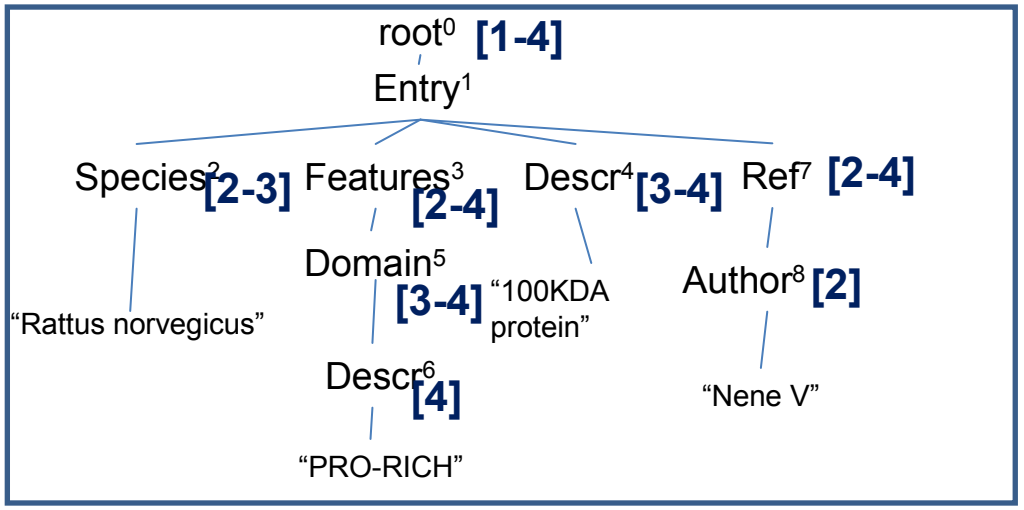


Archiving Dataset after Update

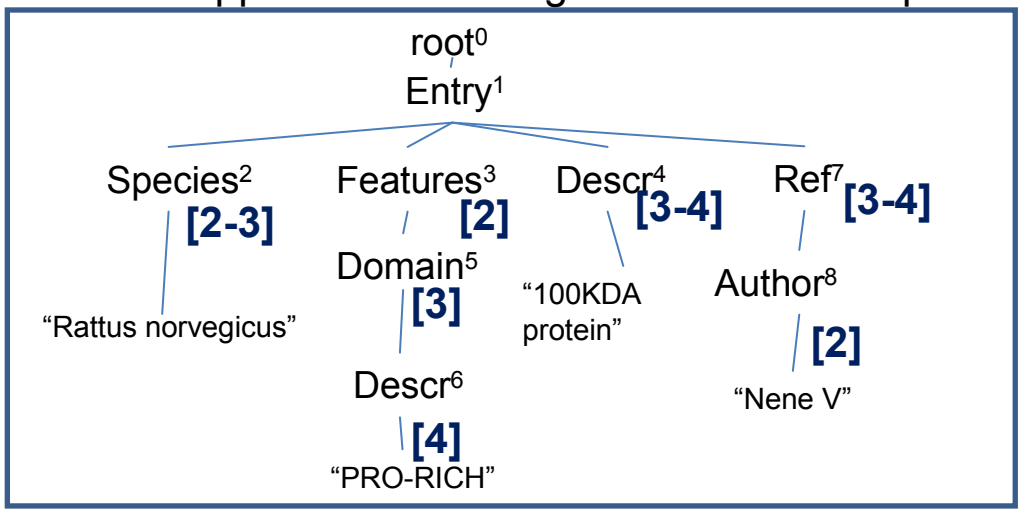
Comparison with Related Work

- Compact storage [1] (Top-down approach)
  - Remove timestamps at children if they are the same as those of the parent node
- Compared with our solution (bottom-up approach) w.r.t. # of updated timestamp labels when inserting a new instance D_k into the archiving database *A*
  - TD: # of nodes in D_k whose corresponding nodes in A have timestamp labels + new nodes in D_k
  - BU: # of leaf nodes in D_k

An Example of TD V.S. BU

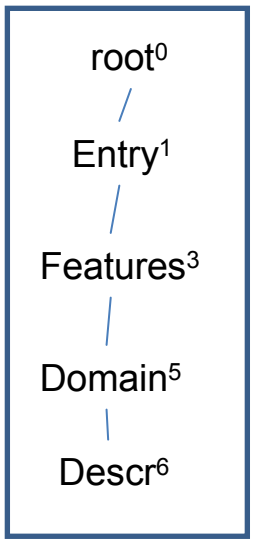


TD approach: Archiving Dataset before Update

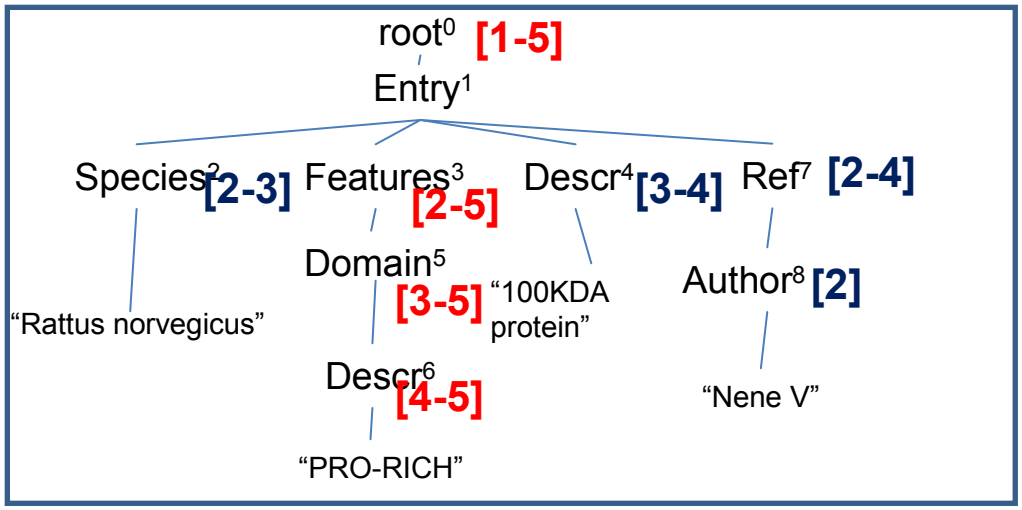


BU approach: Archiving Dataset before Update

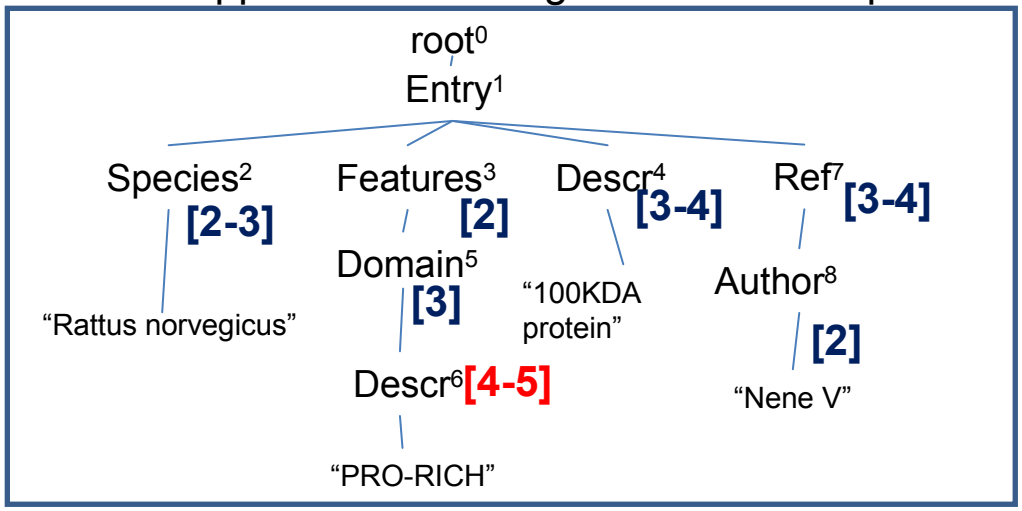
An Example of TD V.S. BU



Version 5



TD approach: Archiving Dataset after Update



BU approach: Archiving Dataset after Update

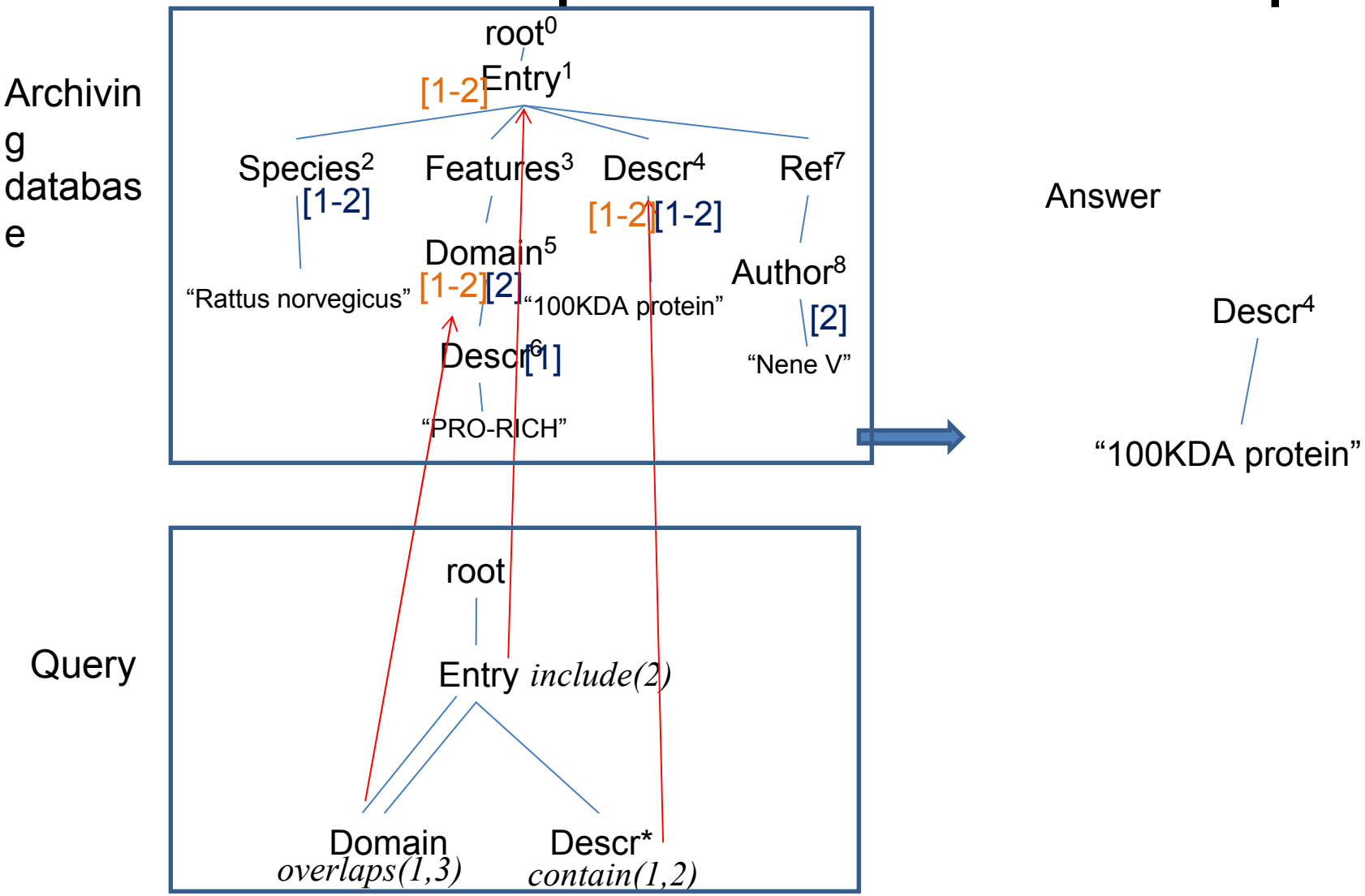
Outline

- Compact storage
- **Temporal query language**
- Query optimization
- Experiments
- Conclusion

Temporal Query Language

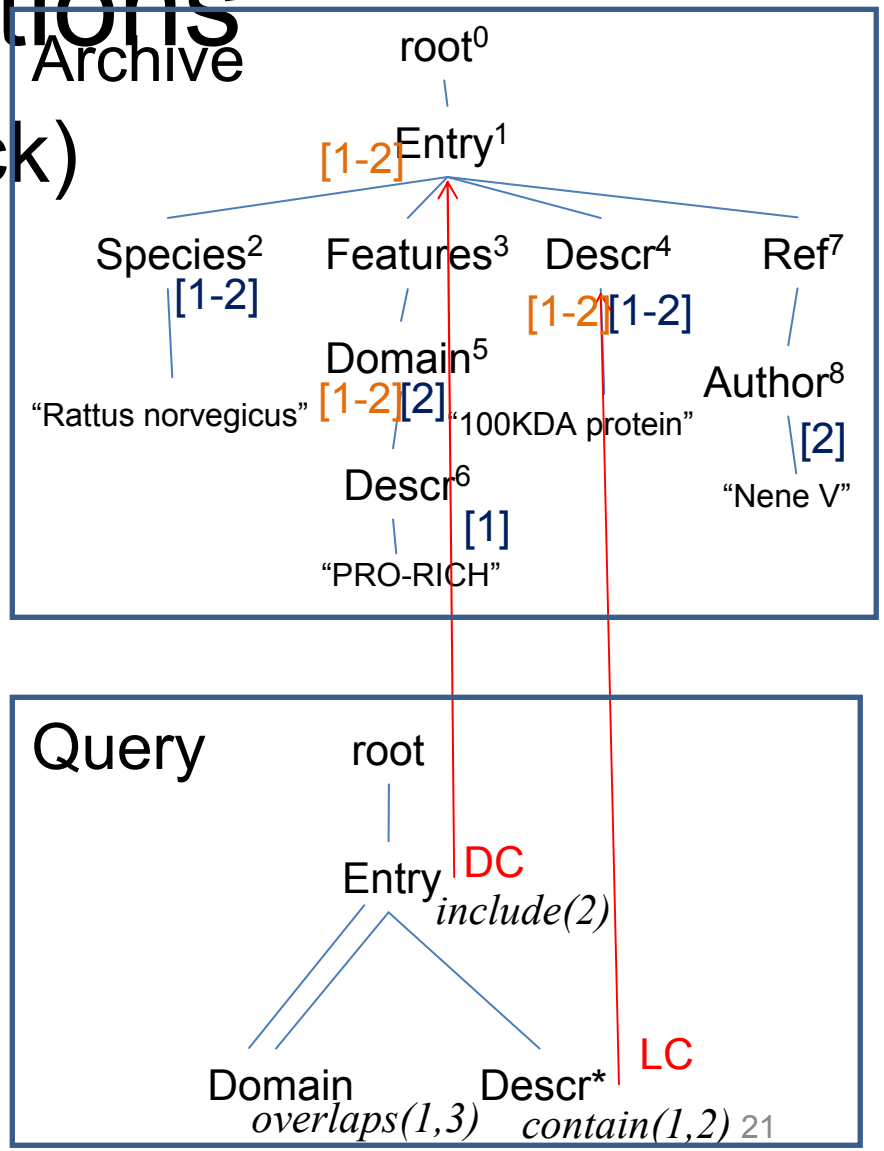
- Types:
  - Snapshot
  - history trace
- Temporal constraints:
  - $includes(t)$, $overlaps(t_a, t_b)$, $before(t)/after(t)$, $contains(t_a, t_b)/is\_contained(t_a, t_b)$, $meets(t_a, t_b)$
- Temporal queries: XML structural queries + temporal constraints on query nodes

Evaluation of Temporal Constraints over Compressed Timestamps



Temporal Evaluation Annotations

- *DC* (Descendant Check)
- *LC* (Local Check)
- *NC* (No Check)

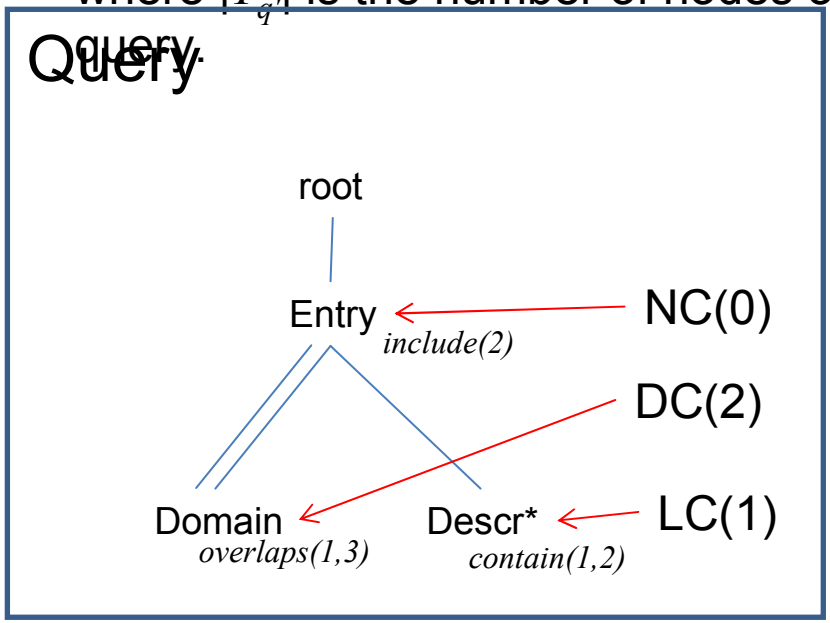


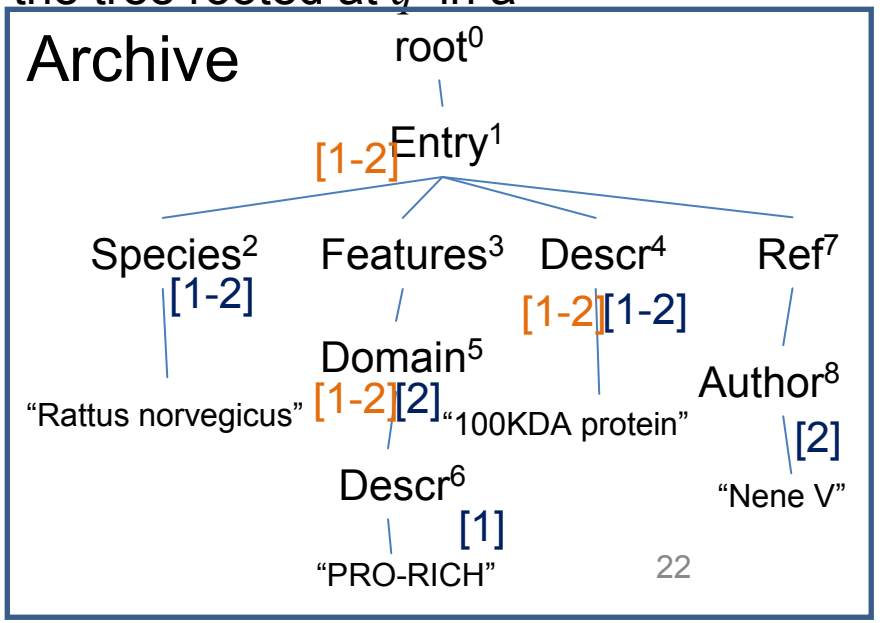
Cost Model

Cost model of temporal evaluation annotations

$$C_\ell(q) = \begin{cases} \max_{q'} |T_{q'}| & \ell = \mathrm{DC}; \\ 1 & \ell = \mathrm{LC}; \\ 0 & \ell = \mathrm{NC}. \end{cases}$$

where $|T_{q'}|$ is the number of nodes of the tree rooted at q' in a query.





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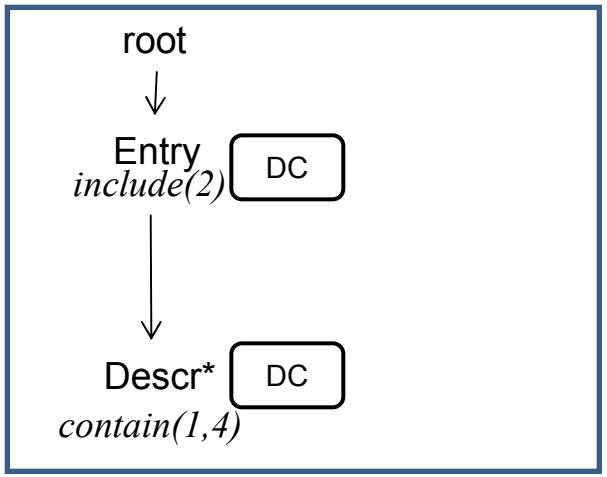
Optimization Problem

- DC is expensive (recursive check)
- DC can be replaced by LC/NC in some cases

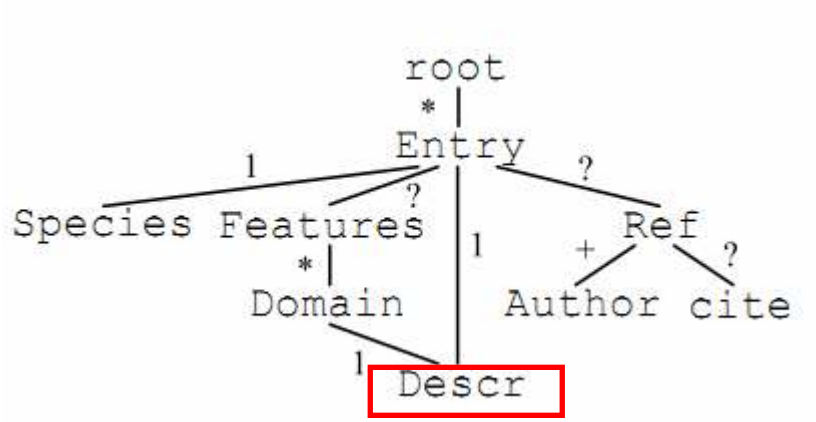
Goal:

- Replace as many DCs as possible with LCs/NCs

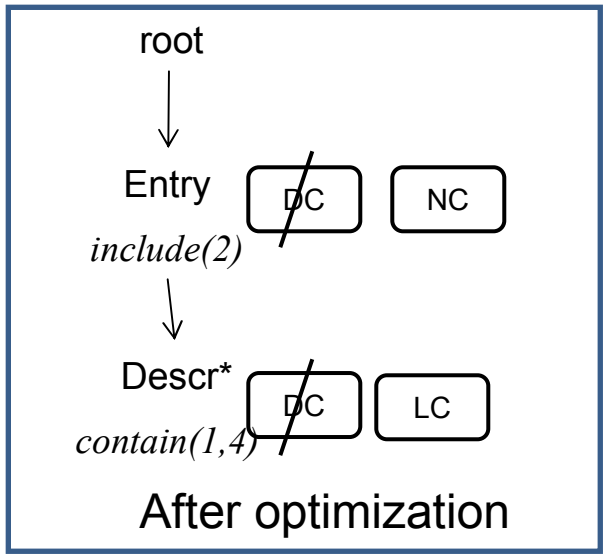
An Example of Optimization



Query Q



Database Schema



After optimization

Inference Rules

- We use inference rules to find redundant temporal annotations
- *Inference rules:* $P_1, \ldots, P_k \rightarrow R$
  - if the premises $P_1, \ldots, P_k$ are true, then the conclusion R is also true.
- Types of inference rules
  - Without database schema
  - With presence of database schema

Inference Rules: No Database Schema

- AD(ancestor-descendant) Rule:

$$Q \models p//q \rightarrow q \sqsupset_t p$$

- TR(transitivity) Rule:

$$p \sqsupset_t \mathrm{q} \text{ and } q \sqsupset_t r \rightarrow p \sqsupset_t r$$

Inference Rules: with Database Schema

- SP(SinglePath) Rule:

$$Q \models p//q, SinglePath(p\Delta, q\Delta) \rightarrow p =_t q$$

- DC(descendant) Rule:

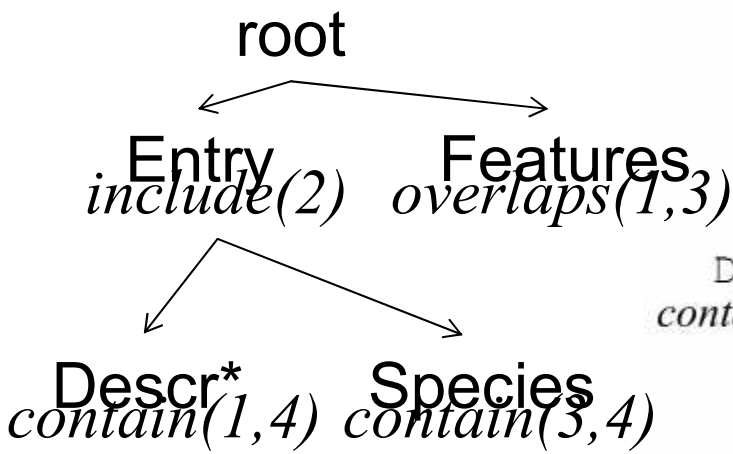
$$Q \models p//q, Q \models p//r, SinglePath(p\Delta, r\Delta) \rightarrow q \ \square_t \ r$$

- DE(derived) Rule:

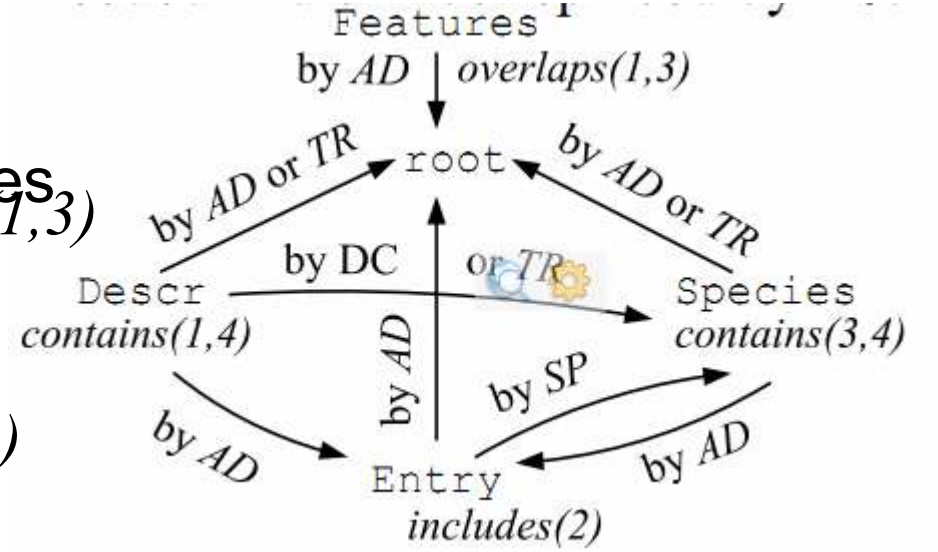
$$Q \models p//q, Q \models p//r, SinglePath(p\Delta, r\Delta), SinglePath(q\Delta, r\Delta) \rightarrow r \ \square_t \ q$$

Temporal Constraint Graph

Query



Temporal constraint graph



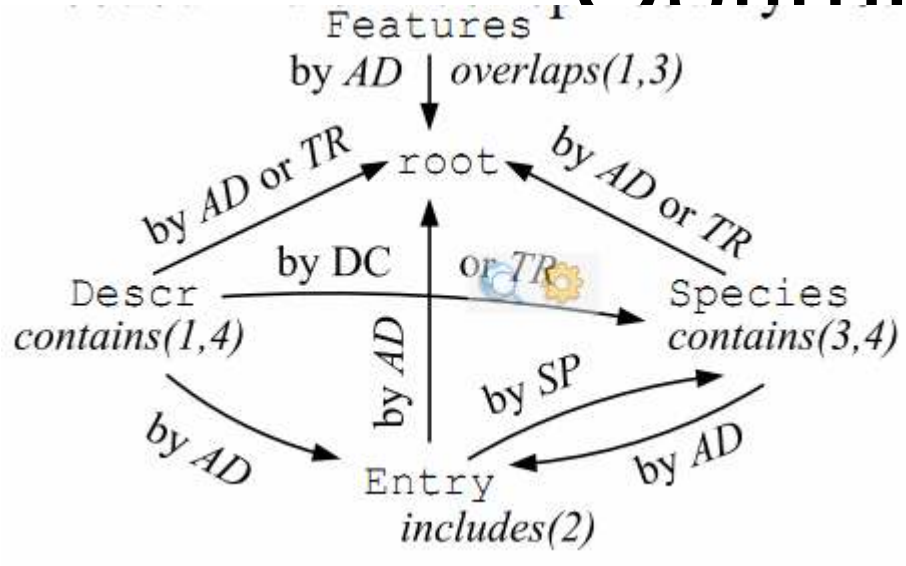
An edge from p to q indicates an inferred $p \square_t q$ relationship

Temporal Constraint Consumption

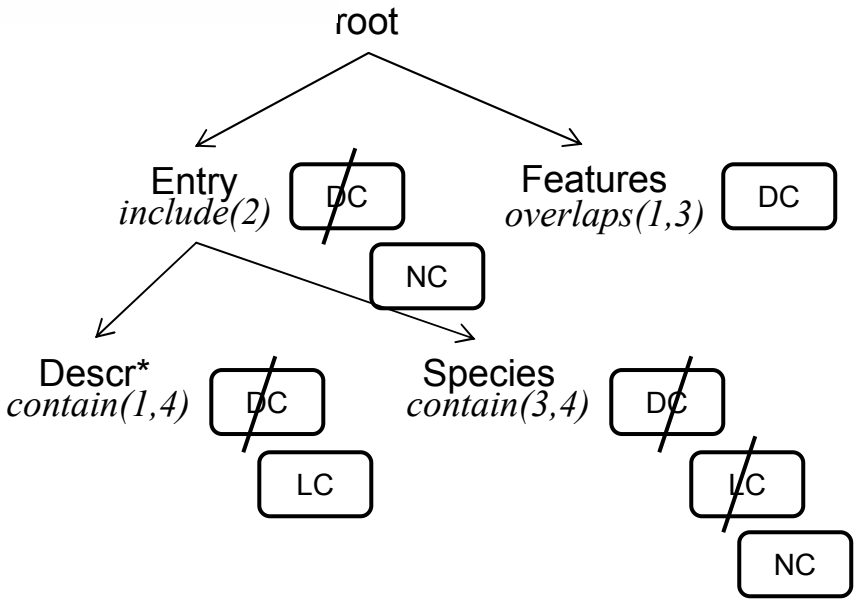
- We check temporal constraint consumption on the temporal constraint graph

Consuming temporal constraint on p	Consumed temporal constraint on q
$p \square_t q$	
$include(t)$	$includes(t)$ $overlaps(t_1, t_2), t \square [t_1, t_2]$
$contains(t_1, t_2)$	$includes(t_3), t_3 \square [t_1, t_2]$ $contains(t_3, t_4), t_3 \geq t_1, t_4 \leq t_2$ $overlaps(t_3, t_4), t_1 < t_3 < t_2$ or $t_1 < t_4 < t_2$
$q \square_t p$	
$is\_contained(t_1, t_2)$	$is\_contained(t_3, t_4), t_3 \leq t_1, t_4 \geq t_2$
$before(t)$	$before(t_1), t_1 \geq t$
$after(t)$	$after(t_1), t_1 \leq t$
$q =_t p$	
$meets(t_1, t_2)$	$meets(t_1, t_2)$

An Example of Query Optimization



Consuming temporal constraint on *p* *(Descr)*	Consumed temporal constraint on *q* *(Entry)*
Descr $\square_t$ *Entry*	
contains(*1*, *4*)	*includes*(*2*)



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- **Experiments**
- Conclusion

Experiment Setup

- Hardware
  - Intel Core 2 CPU 2.40 GHz processor, 4.00 GB of RAM
- Software
  - OS: Windows 7
  - The algorithms were implemented in Java
  - JDOM engine: parse the XML databases
  - Wutka DTD parser: parse the XML DTD
  - Oracle Berkeley DB XML engine: query evaluation

Datasets

- Synthetic dataset
  - using the IBM XML generator on the DTD of the XMark benchmark
- Real dataset
  - Treebank dataset

Dataset	Size	# of elements	Max. depth	Avg. depth
Treebank	22.3MB	491108	36	8.5
Xmark	14.6MB	160929	21	20.068

Versions

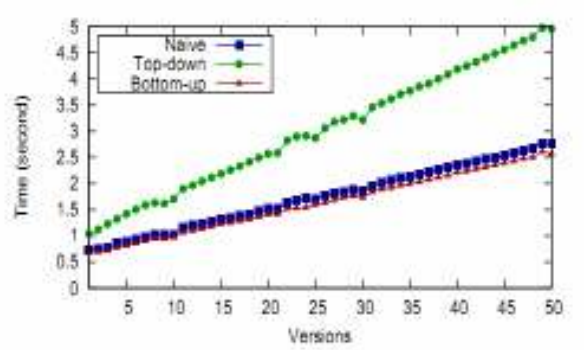
- For Xmark and Treebank datasets, we created 50 and 20 consecutive database instances respectively.
- Each instance was generated from the previous one by first deleting and then inserting (sub)trees.
- The (inserted and deleted) trees take 10% of the nodes of the database instance.

Experiment

- Three storage approaches:
  - The naive approach (NA): keeps the timestamp sets as un-compacted
  - The top-down (TD) approach ([1]): eliminates the timestamps of the ***children*** nodes that are identical to the parent.
  - Our bottom-up (BU) approach: eliminates the timestamps from the ***parent*** nodes that are repeated on children.

Experiment: Archiving Overhead

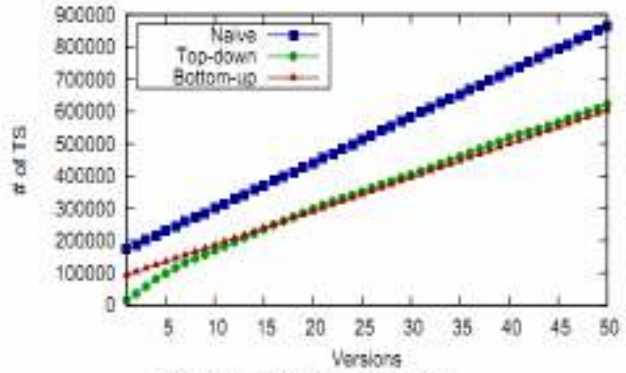
Archiving Time



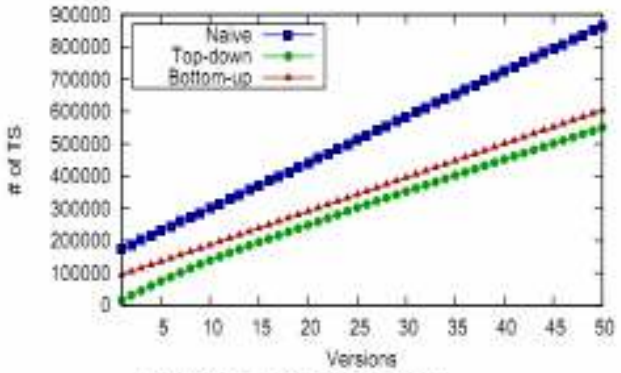
Compaction ratio

Dataset	Top-down	Bottom-up
XMark (shallow&fat)	2.15%	2.72%
XMark (deep&thin)	3.09%	2.75%

Total number of timestamps (space overhead)

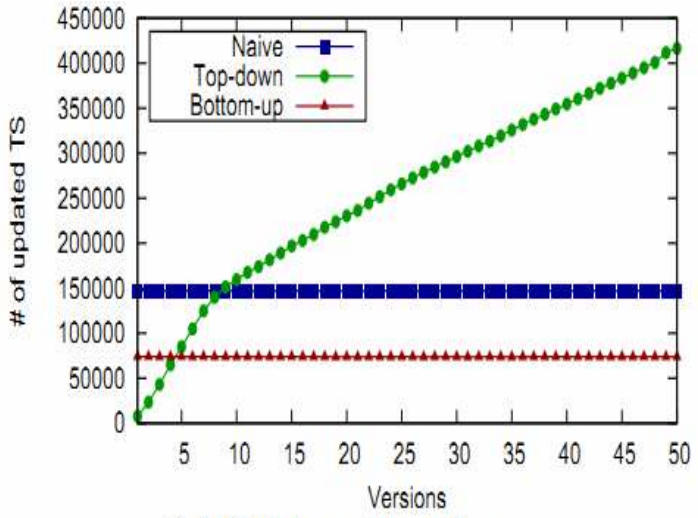


(a) DT tree insertion

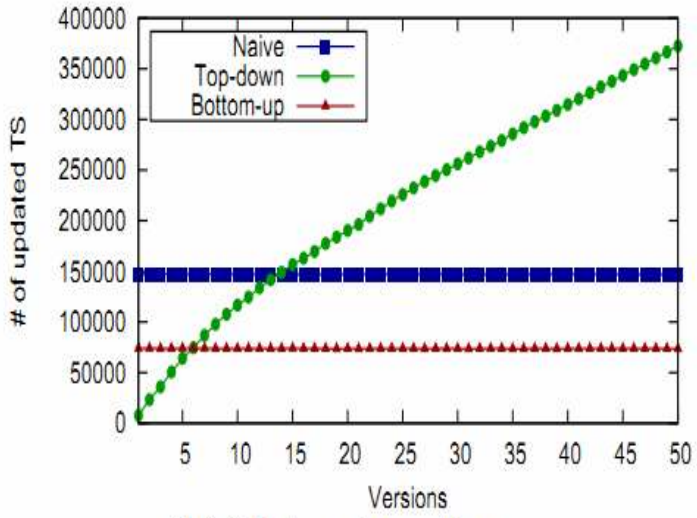


(b) SF tree insertion

Experiment: Update Cost



(a) DT tree insertion



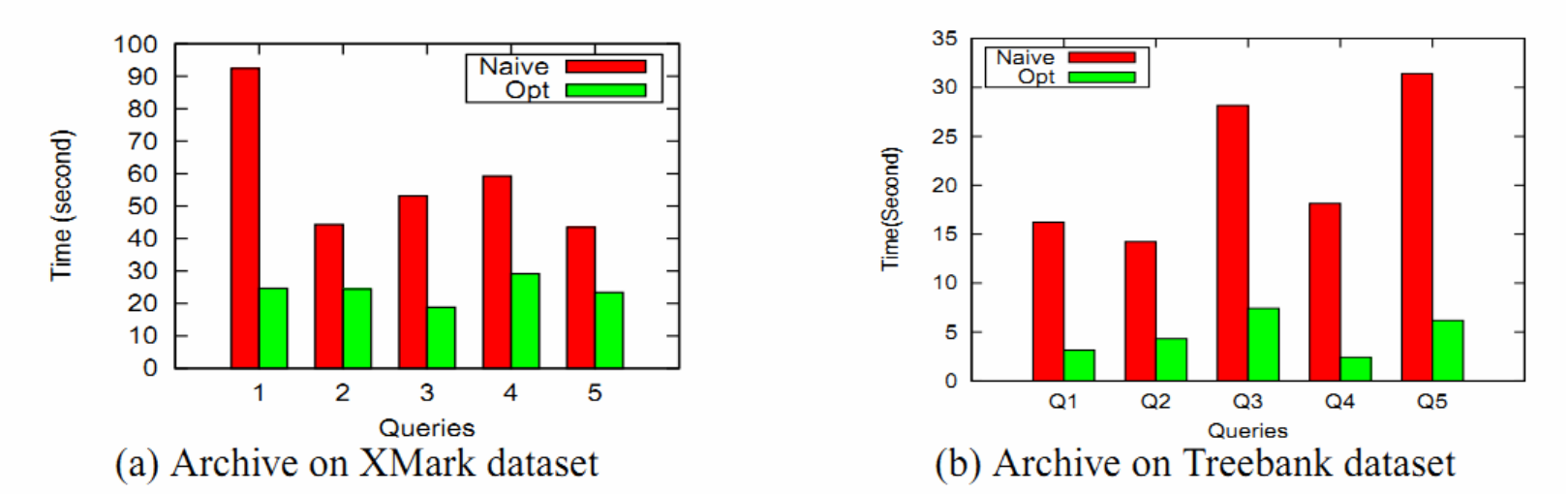
(b) SF tree insertion

Summary of archiving overhead

- Both TD and BU can reduce the number of timestamps in the archive.
- The difference between TD and BU regarding the number of timetstamps is not significant.
- BU always has much better update cost than TD.

Experiment: Query Optimization

Temporal Constraint Evaluation Optimization



(a) Archive on XMark dataset

(b) Archive on Treebank dataset

Our optimization can bring significant performance improvement with negligible overhead

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Conclusion

- We proposed an efficient XML archiving database system that consists of
  - A novel compact and updateable storage scheme
  - A simple yet expressive query language for XML archiving databases
  - Optimization of query evaluation over the compact storage

Future Work

- Consider additional temporal constraints
- Consider unrestricted database schemas that may contain cycles
- Design efficient optimization algorithms that can work in this broader framework

Thank you!

Reference

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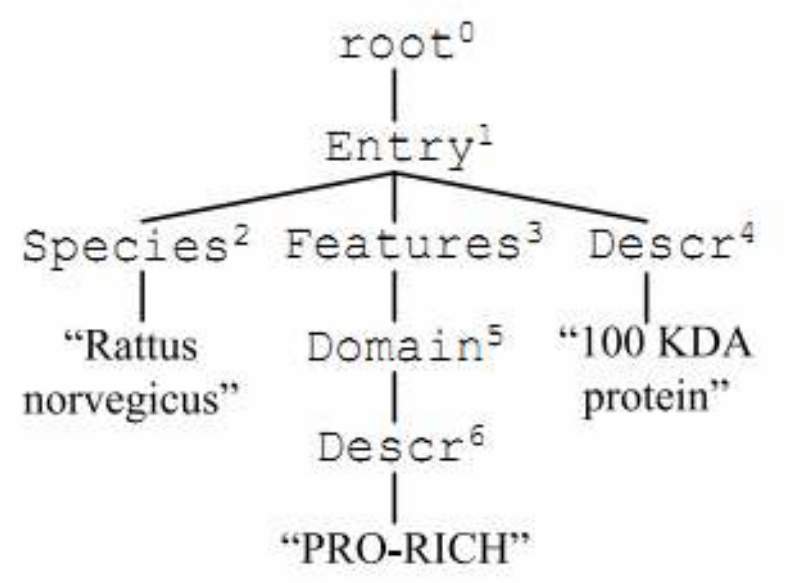
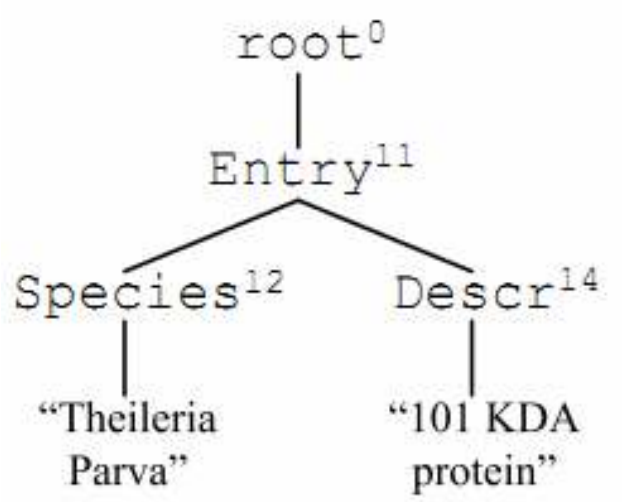
XML database

- XML database: tree-structured, ID-based.



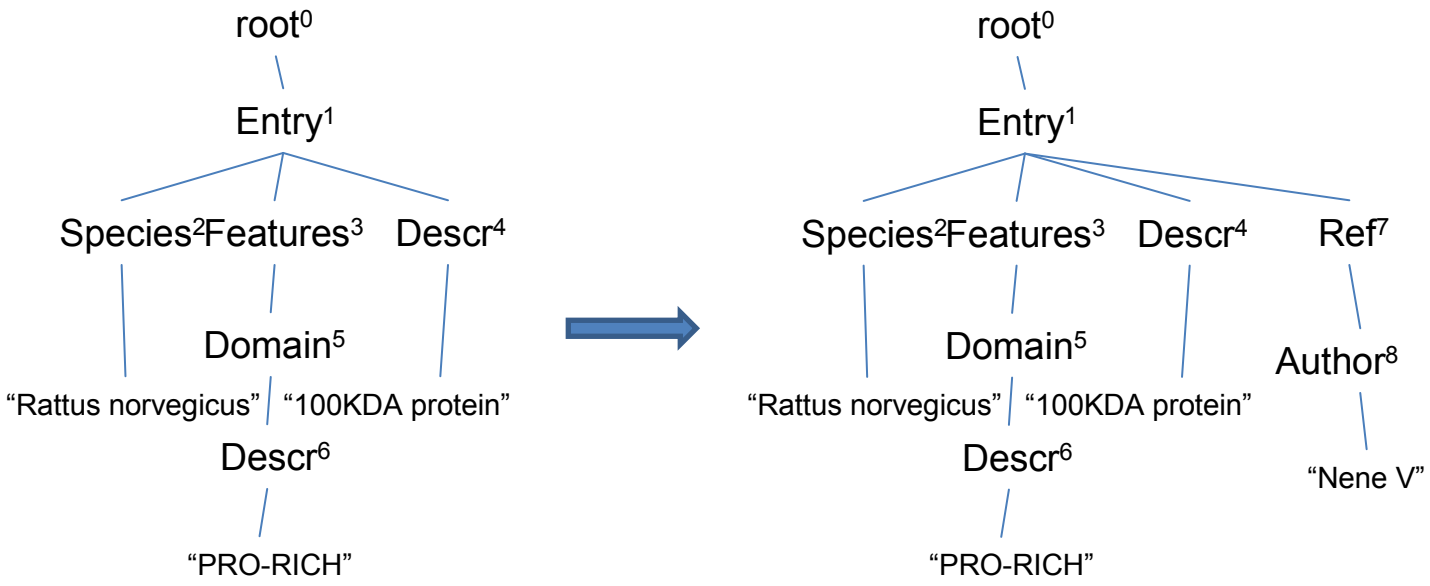


Archiving XML database

- XML instances: XML database at certain time point
  - Each instance is associate with a timestamp (version number)
- Archiving Database: multiple instances are merged into one database

Updating XML database

- Update operations:
  - ***insertion***
  - ***deletion***
- A sequence of update operations can be modeled as a set of deletions followed by a set of insertions.



A Piece of Related Work

P. Buneman, et al. *Archiving scientific data.* TODS, 2004.

- Solution:
  - Merge instances
  - Remove timestamps if same as parent node (Top-down)
- Weakness:
  - Inefficient updates
  - Inefficient query

Witness Graph

- Definition

  Given a query Q , a witness graph for Q is a graph WQ such that

  a)the nodes of W_Q correspond to the nodes of Q

  b)there is an edge from node p to node q in W_Q , iff p is a witness node of q in Q.

- Example
  - Construct the witness graph from the temporal constraint graph after temporal annotation consumption (next page)