Optimizing the Secure Evaluation of Twig Queries

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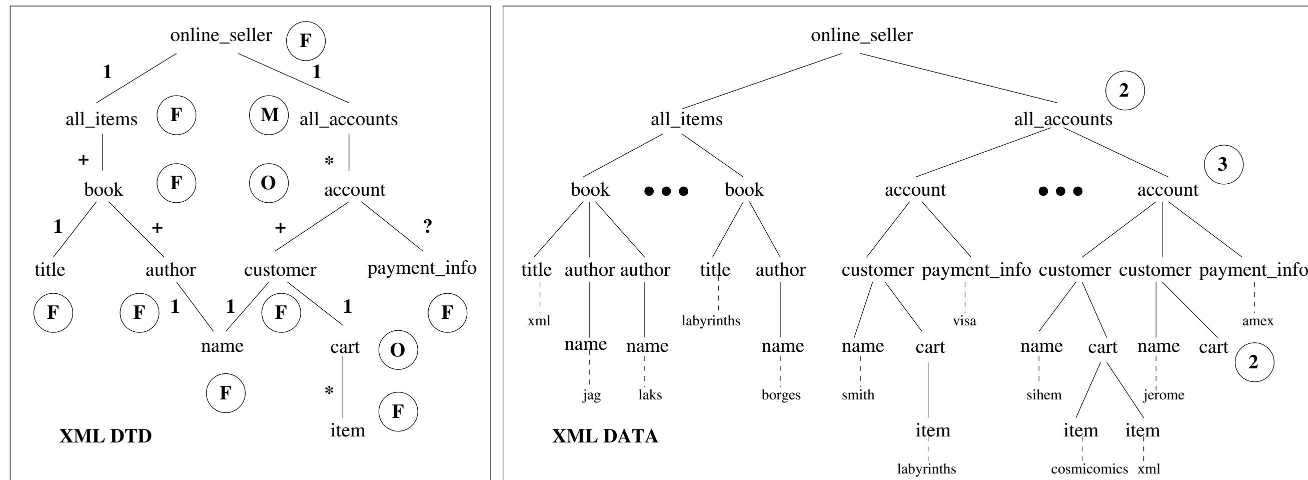
Outline of Talk

- XML security model
- Secure query evaluation
- Optimizing for security
- Experimental results

Motivation: Why XML Security?

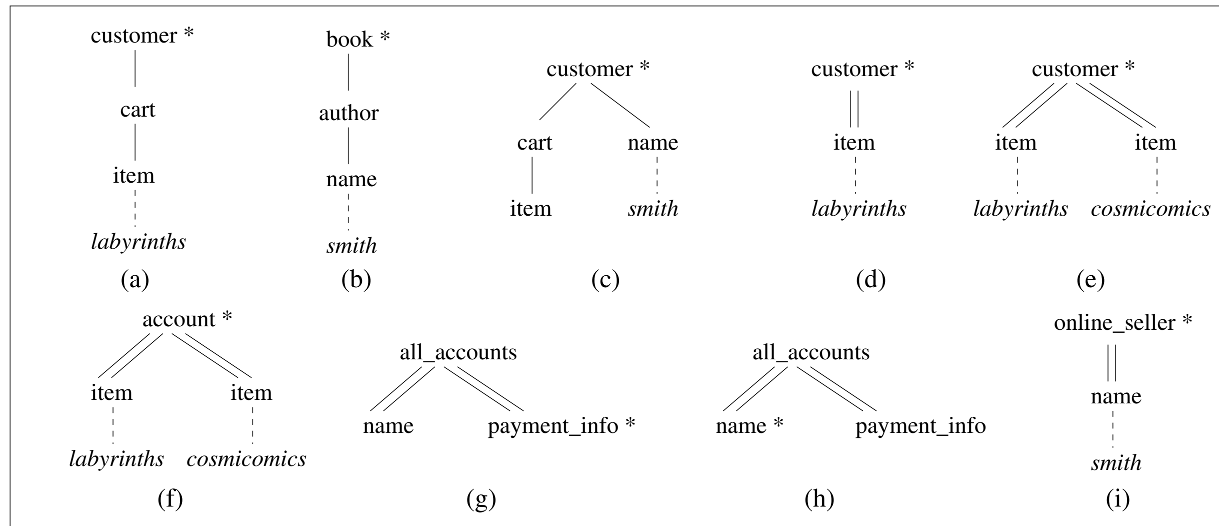
- XML: standard for data publication/exchange over the Web
  - query access is important
- Different data elements may have different security levels
  - low security: catalogs
  - medium security: customer accounts
  - high security: special customers

XML Security Model: Multi-Level Security



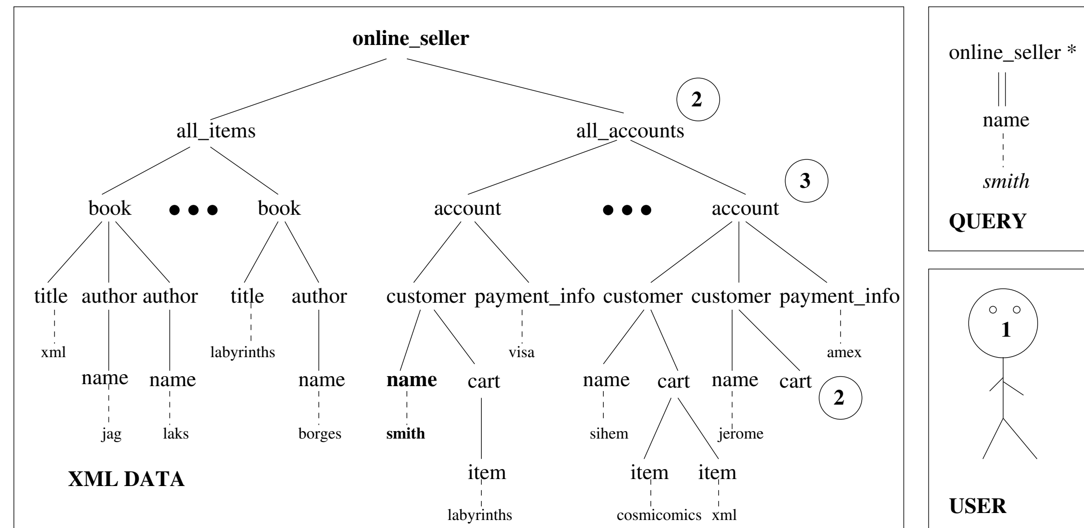
- Data: define security level ($\in [1..n]$) at elements
  - inherited if not defined, non-monotonicity allowed
  - schema/DTD: mandatory (M), optional (O), forbidden (F) at elements
- User: define security level ($\in [1..n]$)
  - accessibility: user.SecurityLevel $\geq$ element.SecurityLevel

Twig Queries



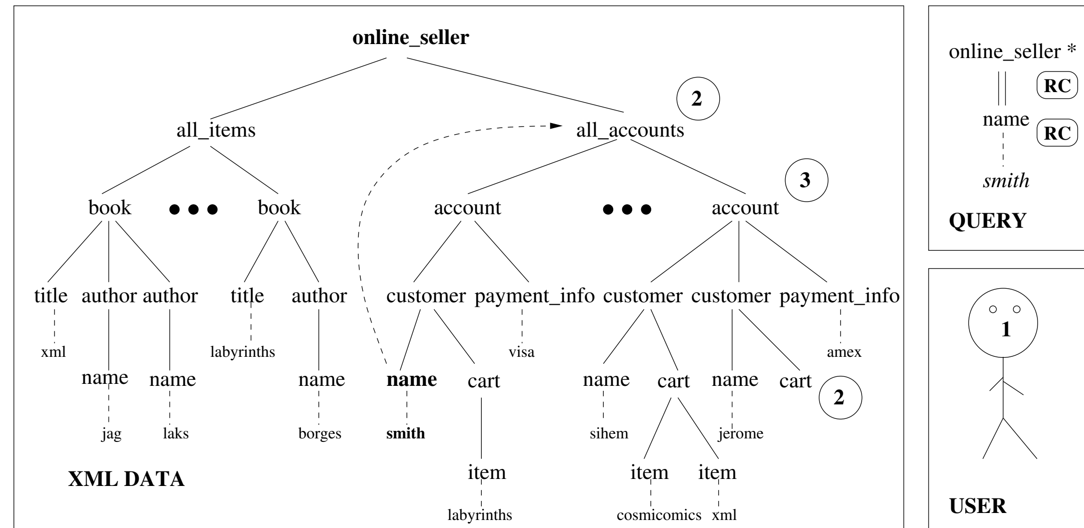
- Core component of XQuery, XML-QL
  - child and descendant axes of XPath, one distinguished ($*$) node
- Semantics: existential matching of non-distinguished nodes
  - crucial to take security into account

Secure Query Evaluation: Incorrect Strategies



- Postprocessing: evaluate query, check results for accessibility
  - problem: witness elements may be inaccessible
- Local checks: test **LC** predicate at each query node
  - problem: element's security level may be inherited

Secure Query Evaluation: An Inefficient Strategy

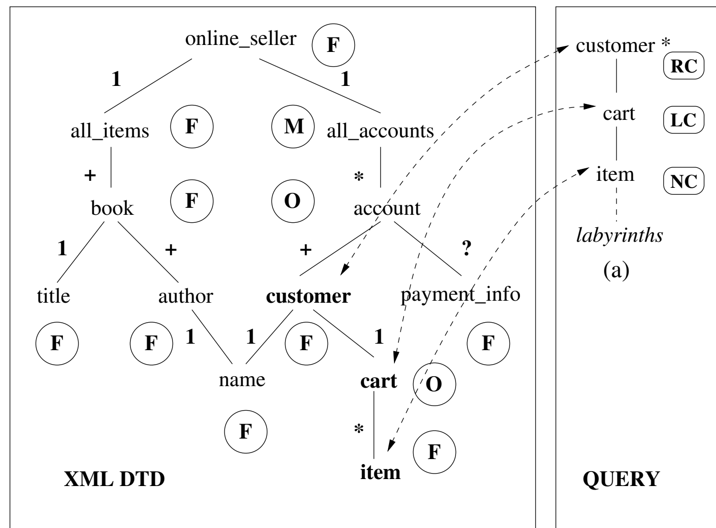


- Recursive checks: test **RC** predicate at each query node
  - computes element's (possibly inherited) security level
- Correct, but inefficient (experimental results later)
  - scope for optimization of secure evaluation!

Secure Query Evaluation: Optimizations

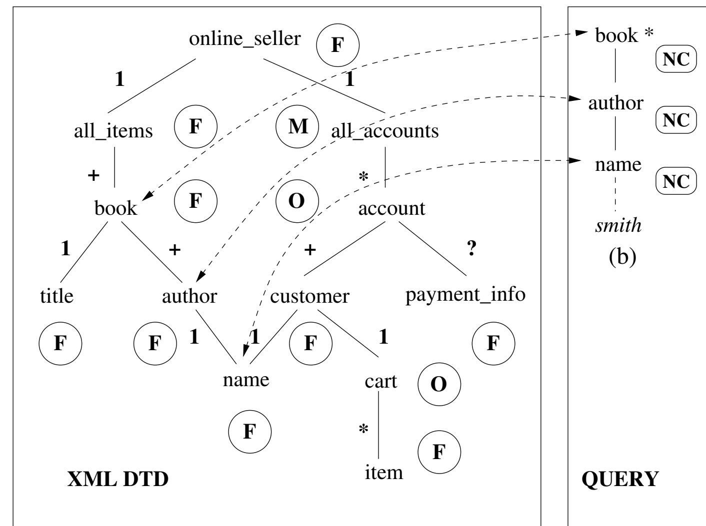
- Annotate query nodes by security check annotation labels
  - **NC** (no check): a no-op
  - **LC** (local check): checks security level attribute only at the element
  - **RC** (recursive check): identifies closest ancestor with security level defined
- Find an optimal cost, correct security check annotation
  - **NC** < **LC** < **RC**
  - optimal = non-dominated annotation
  - examine only query and DTD, not the database

Example: Optimizing Parent-Child Edges



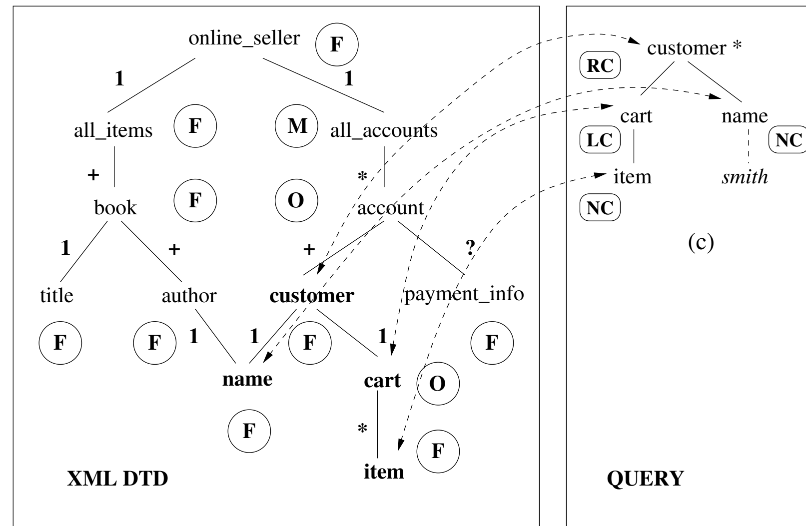
- Examine query nodes in a top-down fashion
  - natural, since security levels are inherited top-down
- Identify paths in DTD along which security levels are inherited
  - parent-child edges: children get **LC** or **NC**

Example: Optimizing Parent-Child Edges



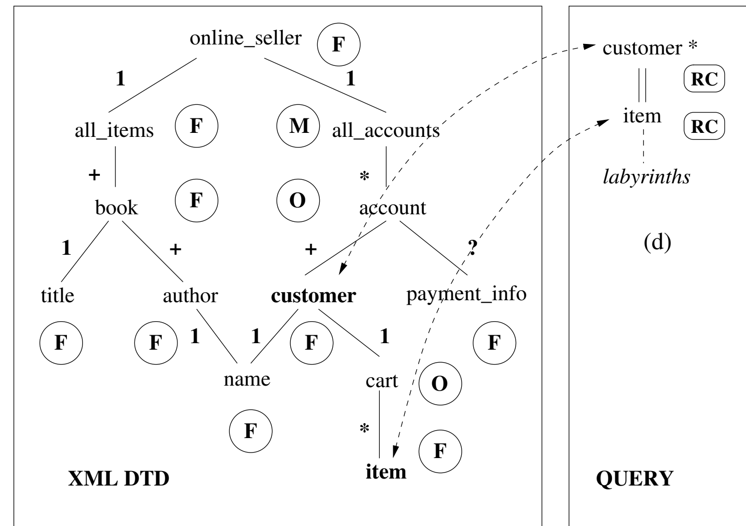
- Query root node has an **NC** label
  - no path from DTD root has mandatory or optional security level
- Other query nodes also have an **NC** label
  - parent-child edges, DTD nodes have forbidden security levels

Example: Optimizing Parent-Child Edges



- Label of query root node depends on path from DTD root node
  - any node with mandatory or optional security level?
- Label of other query nodes depends on corresponding DTD nodes
  - mandatory/optional $\Rightarrow$ **LC**, else **NC**

Example: Optimizing Ancestor-Descendant Edges

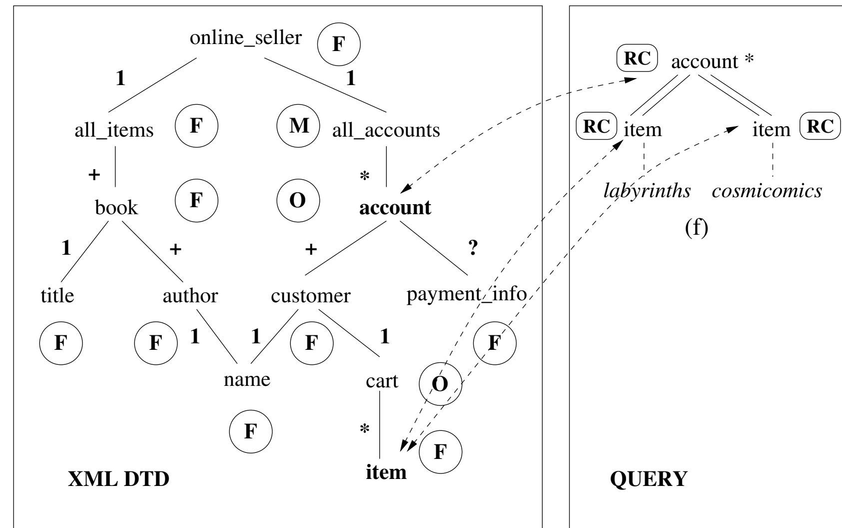


- Examine query nodes in a top-down fashion
  - natural, since security levels are inherited top-down
- Identify paths in DTD along which security levels are inherited
  - possibility of non-query nodes with mandatory/optional security levels

Example: Insufficiency of Top-Down Analysis

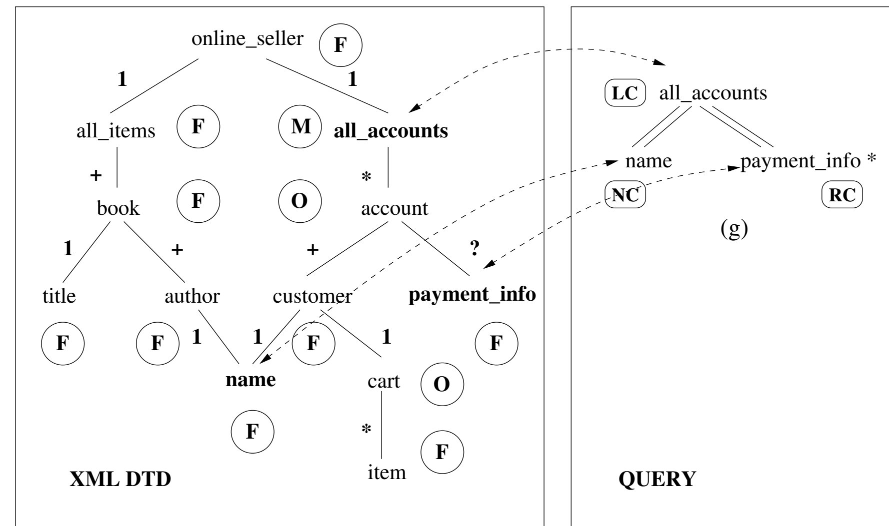
- Sibling `item` elements with same security level
  - guaranteed to inherit same security level from common ancestor
- Need for a forward pass, in topological order of query nodes
  - state information maintained about visited query nodes

Example: Utility of a Forward Pass



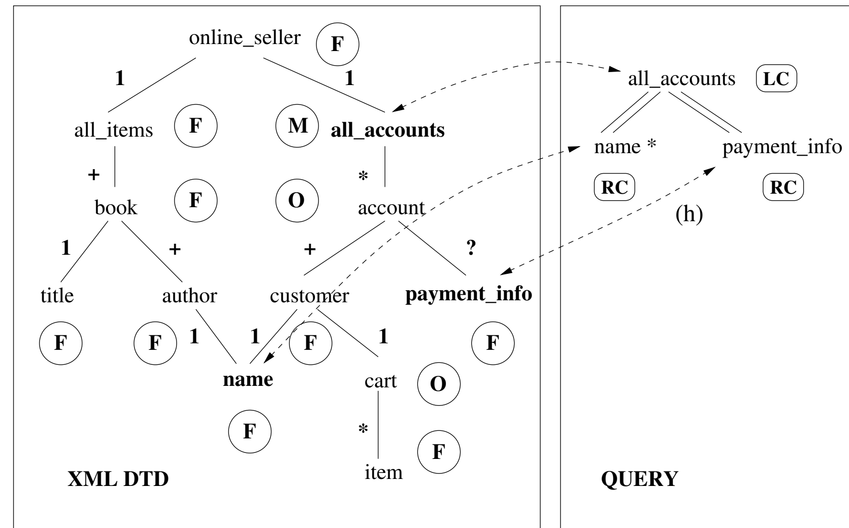
- Sibling `item` elements with different security levels
  - possible to inherit different security levels from different ancestors
- A forward pass, in topological order of query nodes, suffices
  - track DTD node from which security level is inherited

Example: Dealing with Existential Checks



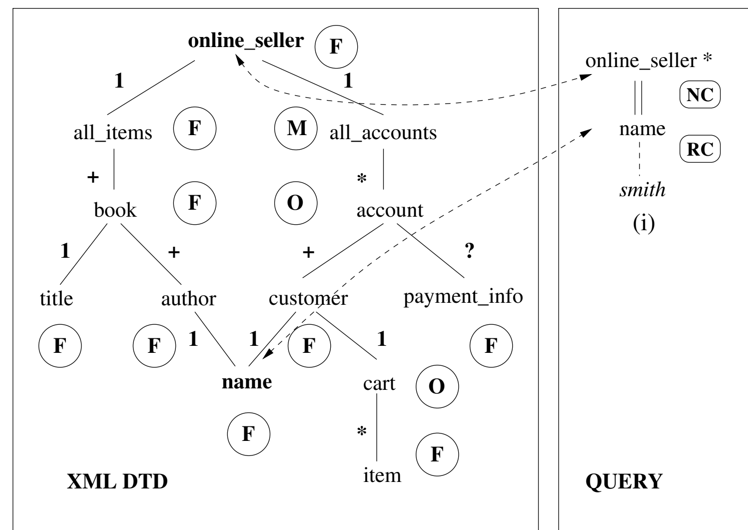
- Guaranteed accessible sibling element
  - `payment_info` always has a `name` sibling, with same security level
- A forward pass, in topological order of query nodes, suffices
  - track DTD nodes and edge labels along which security levels are inherited

Example: Dealing with Existential Checks



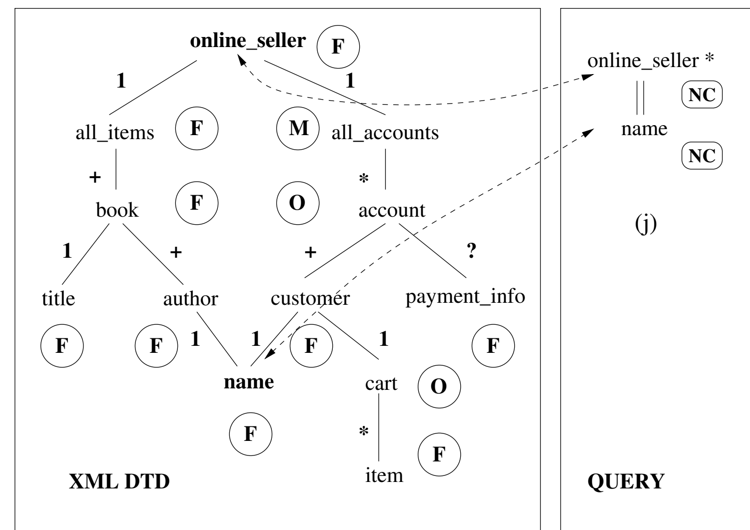
- No guarantee of accessible sibling element
  - `name` doesn't always have a `payment_info` sibling
- A forward pass, in topological order of query nodes, suffices
  - track DTD nodes and edge labels along which security levels are inherited

Example: Dealing with a DAG DTD



- Desired `name` may be of a `customer`, not an `author`
  - such a name element may be inaccessible
- Need to check multiple paths between DTD nodes

Example: Dealing with a DAG DTD



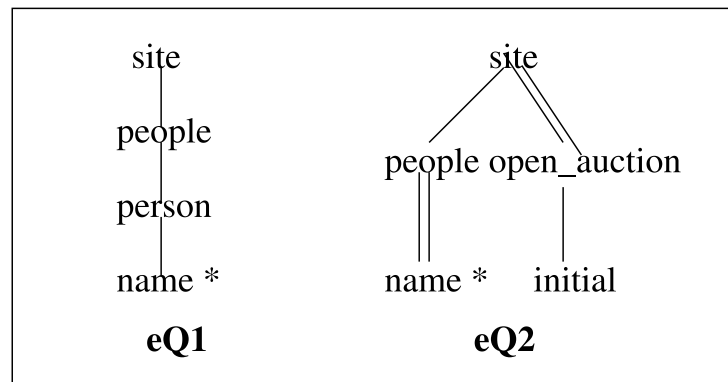
- Existential check for a `name` descendant of `online_seller`
  - guaranteed accessible `author` of `book`
- Need to check **some** path between DTD nodes

Correctness and Optimality

Theorem 5.1 (Optimality of `ForwardPassTree`) Let Q be an arbitrary XML twig query, and D be any tree-structured DTD graph. Algorithm `ForwardPassTree` correctly optimizes the SC annotations of Q on D. Further, it is *optimal* in that if Q_a is the SC annotation of Q computed by Algorithm `ForwardPassTree`, then $\nexists$ SC annotation $Q_b (\neq Q_a)$ of Q such that $Q_b \leq Q_a$.

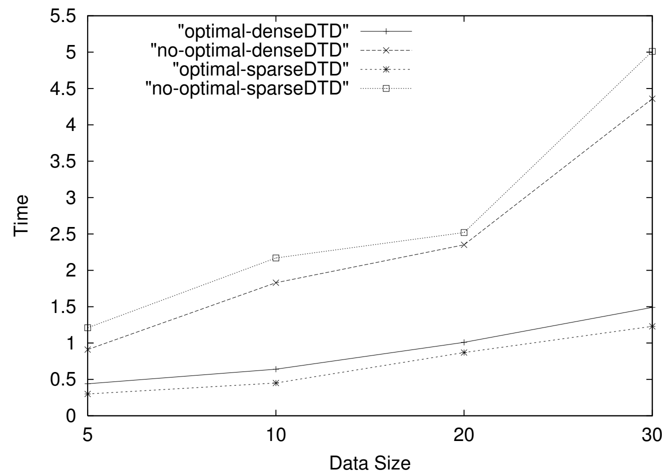
Experimental Evaluation: Setup

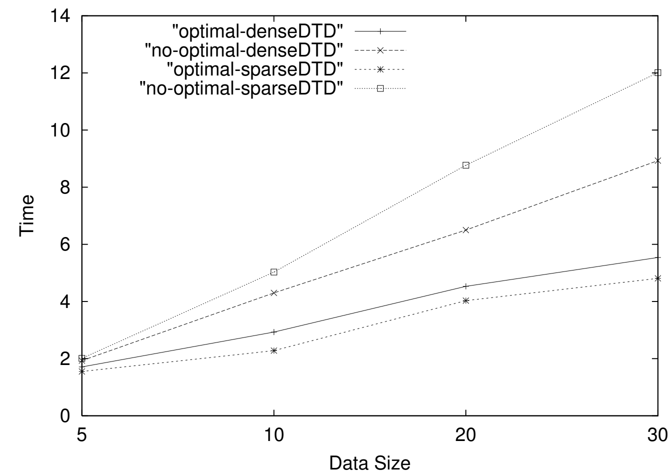
- XMark benchmark dataset: 5MB to 30MB
  - DTDs with sparse (3) and dense (half) optional security levels
  - all elements with optional security level assigned values
- Twig queries provided by XMark



- Optimizer implemented on top of XALAN

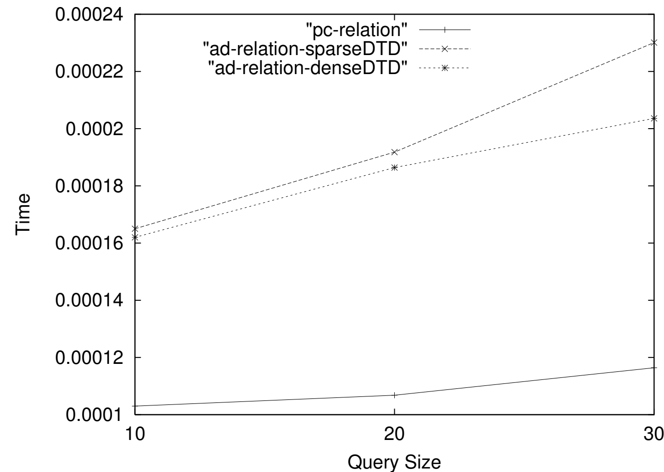
Evaluation Time Comparisons





- Optimized evaluation is much better than unoptimized evaluation
  - optimized secure evaluation did not add much overhead
- Benefits of optimization more for sparse DTDs
  - unoptimized: sparse $>$ dense, optimized: dense $>$ sparse

Optimization Overhead



- Optimization time for query with *pc* edges independent of DTD
- With *ad* edges, optimization time higher for sparse DTDs
  - more edges needed to be traversed in DTD
- Optimization is very fast (with 20-30 nodes, < 0.25ms)

Related Work

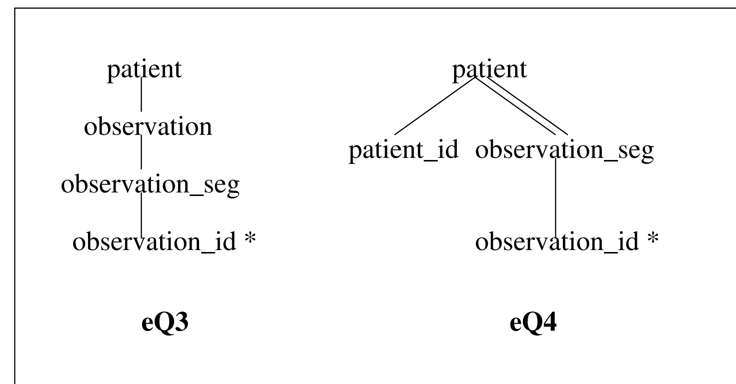
- Sophisticated access control models for XML
  - [B+00,D+00,B+01]: positive/negative authorizations, authorization propagation flexibility, accessible view per user
  - [KH00]: XML access control language, with authorization, non-repudiation, confidentiality, audit trail
- XML query rewritings using DTD [PV99,W99]
  - containment mappings, chase, unification
  - not applicable for optimizing secure evaluation

Conclusions

- Secure evaluation of XML twig queries
  - efficient algorithm for determining optimal annotations
  - experimental validation
- Open problems
  - dealing with DTDs with cycles, alternation
  - utilizing default values for security levels, monotonicity
  - ...

Experimental Evaluation: Setup

- HL7 clinical dataset: 5MB to 30MB
  - 25% `patient`s with SL=2, all `observation`s with SL=2
  - 75% `patient`s with SL=1, 50% `observation`s with SL=2
- Synthetic twig queries



- Optimizer implemented on top of XALAN