Statistical Learning Techniques for Costing XML Queries

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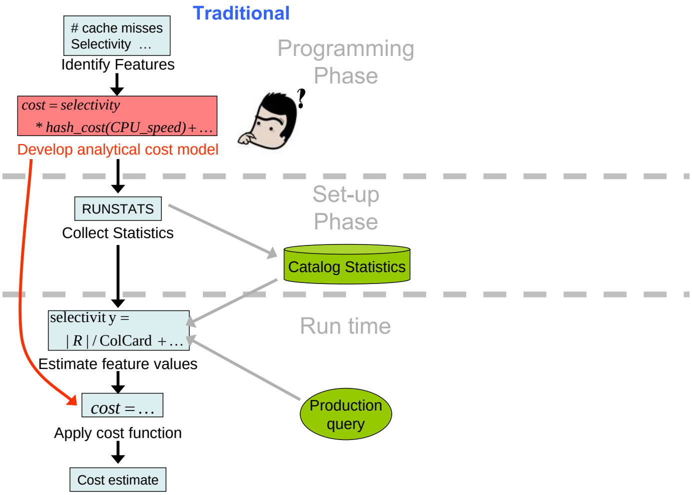
COMET: A New Cost-Modeling Approach



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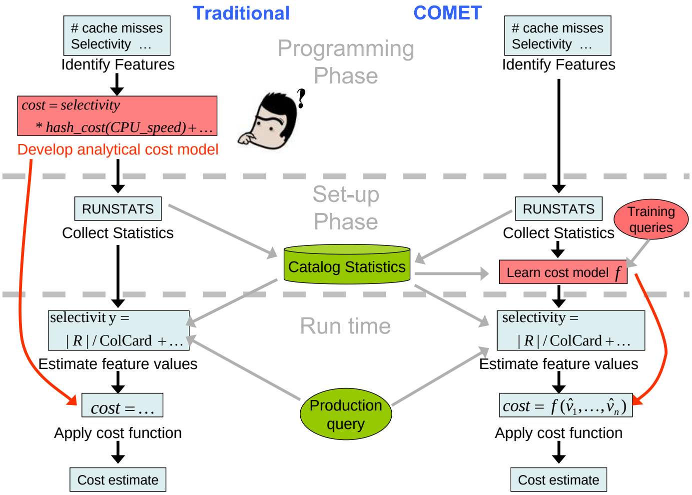

Advantages of COMET Approach

Can handle complex operators using statistical learning

- Operators not decomposable into simple scans, joins, etc.
- Operators with highly non-sequential data access patterns
- Used successfully to cost UDFs, remote DB systems (Lee et al. 2004, He et al. 2004, Rahal et al. 2004)

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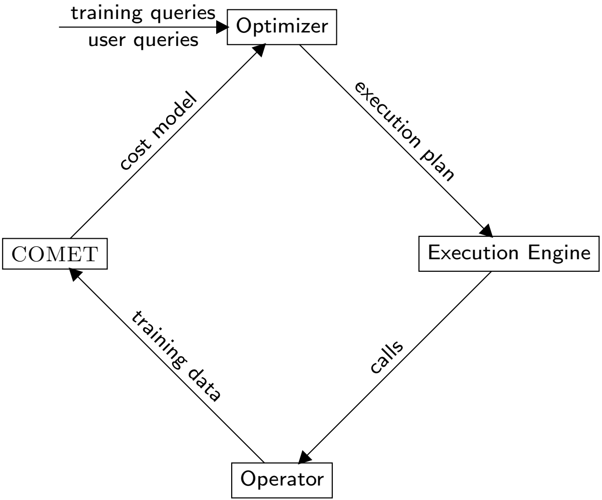
Simplifies cost-model development

- Reduces need for painstaking code analysis used in analytical modeling
- Easier to incorporate new operators into optimizer
- Helps avoid brittle simplifying assumptions
- Avoids need to explicitly incorporate HW parameters

COMET Permits Optimizer to be Self Tuning



Our Motivation: XML Query Optimization

Query q_1:

```
<bib>
{
  for $b in
    doc("bib.xml")/bib/book
  where
   $b/authors//last = "Stevens"
   and $b/@year > 1991
  return
    <book>
      { $b/title }
    </book>
}
</bib>
```

Need to cost candidate execution plans:

1. Navigational plan:
   - navigate the `bib.xml` tree
   - check pred's for each **book**
2. Value-based index plan:
   - find elements with "Stevens" or "1991" using value-based index
   - navigate up to **book** and check remaining conditions
3. Structure-based index plan:
   - look up matching tree structures using a path/twig index
   - check pred's for each **book**

Today's Talk: Application of COMET Approach to an XML Operator

XML operator to be modeled:

- XNAV operator (complex and dynamic, so hard to model)
- Adaptation of TurboXPath (Josifovski et al. 2005)
- Will model CPU costs (nontrivial component of overall cost)
  - prior work has focused primarily on cardinality estimation

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Nontrivial steps in applying COMET methodology:

Step 1: Identify XNAV features

Step 2: Determine statistics for estimating feature values

Step 3: Determine formulas for feature-value estimation

Step 4: Identify appropriate statistical learning algorithm for fitting cost model

XNAV: A Complex XML Navigational Operator

What is XNAV?

- $XNAV_{XPath}(XMLTrees) \longrightarrow$ list of matching XML nodes
- XNAV is complex:
  - equivalent to non-decomposable N-way join
  - data stored as paged tree

High-level description of XNAV algorithm:

- XNAV traverses the XML tree in a single pass, with possible skipping of nodes
- XNAV maintains internal states and buffers for matching the query tree during the traversal

Step 1: Identifying XNAV Features

Basis for feature identification

- Knowledge of XNAV algorithm (involves human interaction)
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Some features for XNAV:

- **#visits** : # of XML nodes actually traversed
- **#p_requests** : # of pages read
- ... more features given in the paper

Step 2: Novel Statistics for Estimating Features

How to choose statistics ?

- "As simple as possible, but not simpler"
  - Easy to collect and maintain, less error-prone
- Need to balance space and time requirements
  - Storing redundant stats can speed up feature-value estimation

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Example — Simple Path (SP) Statistics

- **cardinality**: $|p|$, where p is a "simple" path (no branching, no wildcards, etc.)
- **children and descendant cardinality**: $|p/*|$ and $|p//*|$
- **page cardinality**: $\|p\|$
- ... more in the paper

Step 3: Feature-Value Estimation Using Stats

Can estimate all needed feature values using SP stats

- Analysis required, but much easier than analyzing entire XNAV operator
- See paper for detailed formulas (algorithms)
- Formulas tend to overestimate feature values, but COMET automatically compensates for bias (see below)

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Example

- **#visits** $= \sum_{p \in S} |p/*| + \sum_{q \in C} |q//*|$

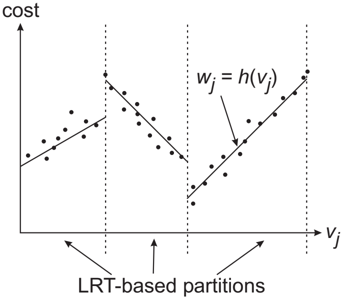
  where S is a set of root-to-non-leaf simple path in the query tree whose next step is connected by a /-axis;
  C is a set of root-to-non-leaf simple path in the query tree whose next step is connected by a //-axis

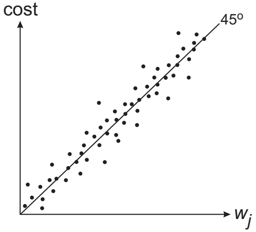
Step 4: Fitting The Cost Model

Use Transform Regression (Pednault 2004)

- "Linear regression on steroids"
- Handles discontinuities and nonlinearities in cost function
- Fully automated (no statistician needed) and highly efficient
- Seamlessly handles both numerical and categorical features

Uses 1-level linear regression tree to "linearize" each feature





Step 4: Transform Regression—Continued

Uses multivariate linear regression on linearized features

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Model learned from estimated feature values

- So COMET is robust to systematic bias in feature-value estimation

Experimental Study

Training data and queries:

- Synthetic and real-world data sets
  (Including TPC-H, XMark, NASA, and XBench)
- Randomly generated queries:
  - Simple linear paths (e.g., `/a/b/c`)
  - Branching paths (e.g., `/a[b][c]/d`)
  - Complex paths (e.g., `/a[.//b][c//d]//e`)

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Model evaluation:

- Use 5-fold cross-validation
- Plot predicted vs. actual costs
- Calculate accuracy measurements

Evaluating COMET's Accuracy

Error metrics:

- **NRMSE (Normalized Root-Mean-Squared Error)**: measures the average (relative) prediction error

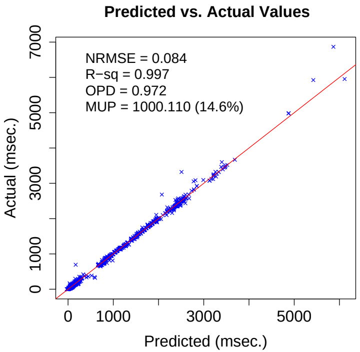
$$\text{NRMSE} = \frac{1}{\bar{c}}\left(\frac{1}{n}\sum_{i=1}^{n}\left(c_i - \hat{c}_i\right)^2\right)^{1/2}$$

  where c_i and $\hat{c}_i$ are the actual and estimated costs for ith query, and $\bar{c} = \text{average}(c_1, c_2, \ldots, c_n)$

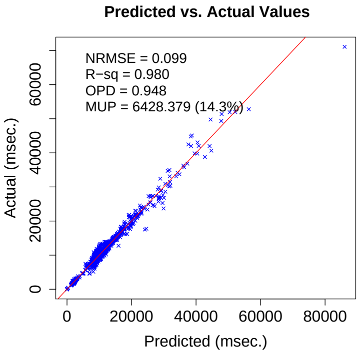
- Other metrics discussed in paper: $\mathbf{R^2}$, **OPD**, **MUP**

Accuracy of COMET

COMET does decent-to-excellent job in most cases:



(a) XMark (Mixed Queries)

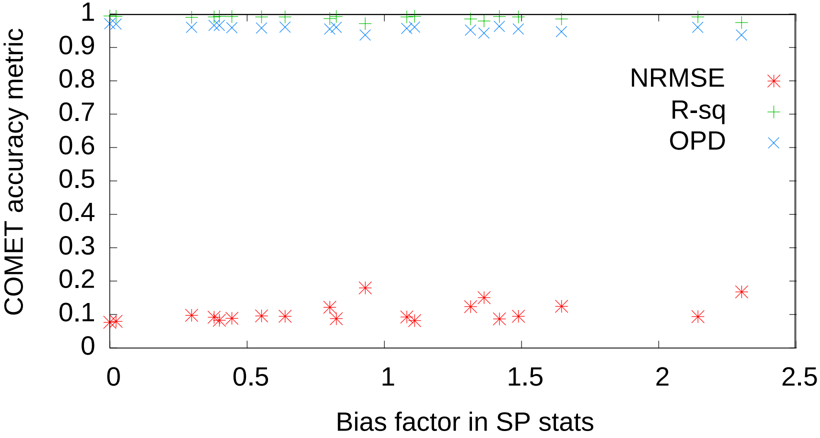


(b) TPC-H (Mixed Queries)

Add query type (simple, branching, complex) as feature?

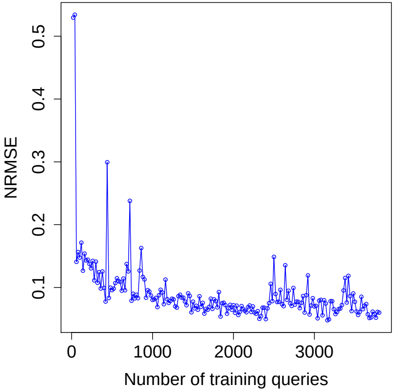
Effect of Errors in SP Statistics

COMET is not sensitive to systematic errors in SP stats:



Effect of Training-set Size

Training-set is of reasonable size for reasonable accuracy:



Model build time for
1000 training queries:
$<$ 1 second

Conclusion

Summary

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- COMET can accurately model XNAV cost
- COMET cost model is fast to construct and adaptable to changing environment
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Future Work

- Automatic identification of features
- Smarter generation of training queries
- Extensions to handle I/O costs, multi-user environments (will identify appropriate features)
- Incorporation of selectivity-estimation technology
- Improve dynamic model maintenance (incremental model building)
- Apply to other operators (XML, relational, text)