Performance Profiling with EndoScope, an Acquisitional Software Monitoring Framework

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Collecting System Runtime Data

- Many uses
  - Real-time system monitoring
  - Detect security breaches
  - Dynamic recompilation

- However, collecting such information is often difficult

Example: Software Profiling

- Sampling / statistical profilers
  - Gprof, oprofile
  - Might not be accurate
  - Can only be used to collect certain types of statistics
- Augment source code / Binary instrumentation
  - ATOM, valgrind, dtrace
  - Tedious work
  - Create substantial overhead
- Want: a unifying infrastructure that can be used to collect and reason about program's runtime data that is easy to use and introduces low overhead

Our Contributions

- Easy to use interface
  - Use declarative queries
- Uniform data model that represents all sorts of runtime data
  - Model them using the streaming data model
- Small footprint / overhead
  - Be acquisitional: queries drive what data is collected
    - **you only pay to collect data you asked for**
  - Decouple program running site and monitoring site
  - Use both sampling and instrumentation techniques
  - Query evaluation tricks

Outline

- Data Model
- Query Evaluation Techniques
- Experiments
- Conclusions

Program Runtime Data as Streams

- EndoScope provides a number of basic streams that represent data coming from the runtime environment
  - function start (function name, time)
  - variable value (name, value, time)
  - cpu usage (% busy, % idle, time)
  - ...
- Users can define additional streams on top of basic streams
- Streams are defined into two categories
  - Enumerable streams are those that have discrete values in time (e.g., function start stream)
  - Non-enumerable streams are those that have infinite values in time (e.g., CPU usage stream)
  - Non-enumerable streams need to be *quantified* before they can be used (e.g., in an iterator)

Operations on Streams

- Quantify
  - Sample non-enumerable streams at points in time
- Select
- Project
- Aggregate
- Window-based join

Conditions / Triggers

- Specify actions to be performed when certain event occurs

- Action examples:
  - Start monitor CPU / heap usages
  - Generate report to user
  - Update machine learning models

Query Examples

- ```
  when
  select  avg(f1.duration) > 5 sec and
          avg(f2.duration) > 5 sec
  from    function_duration f1, f2
  where   f1.function_name = “foo” and
          f2.function_name = “bar”
  then
     sample cpu_load every 1 min
  ```

- ```
  select *
  from   function_start fs, cpu_load cl
  where  fs.function_name = “foo” and
         cl.busy > 70%
  ```

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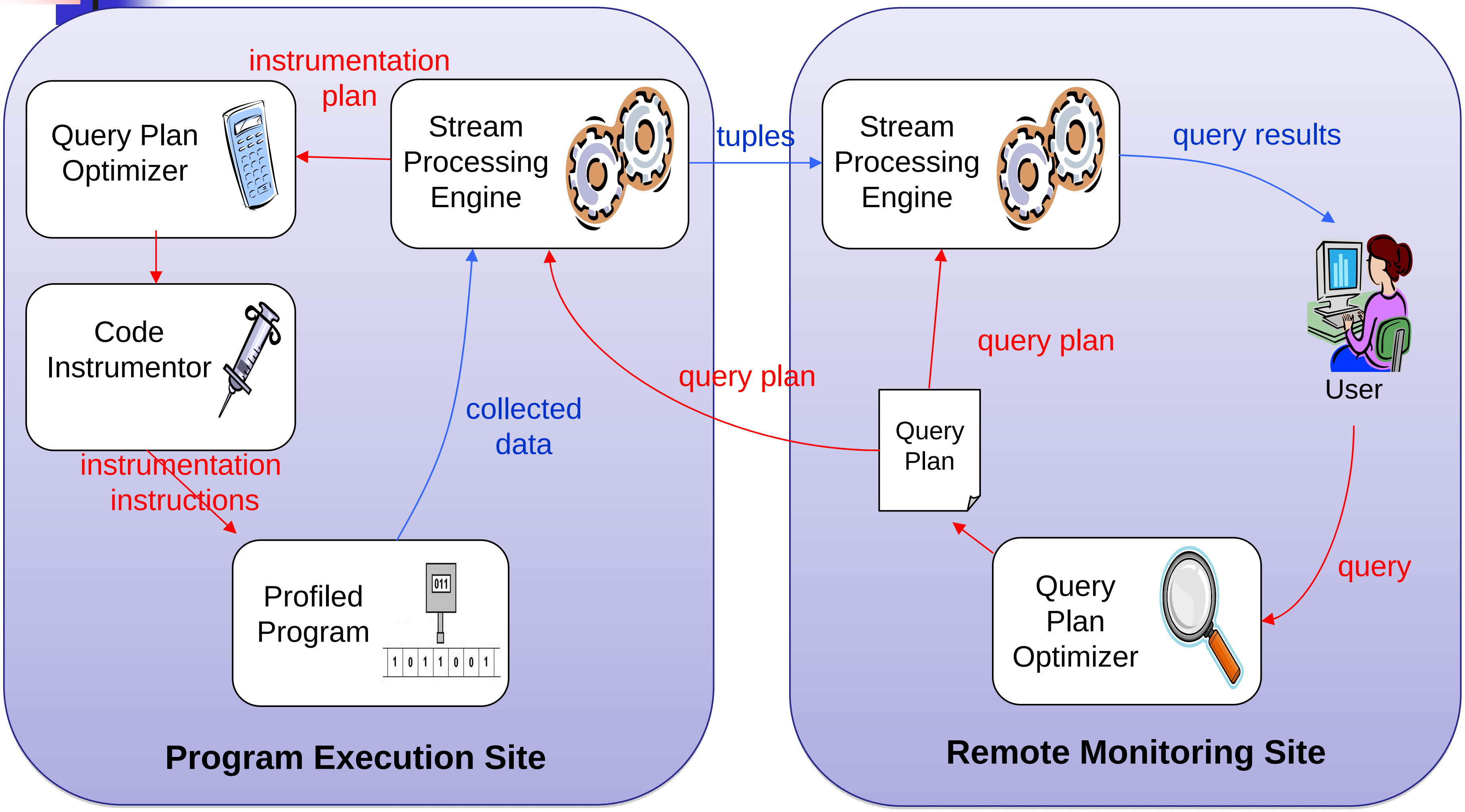
Architecture



Optimizing Query Execution

- Goal: introduce as little runtime overhead as possible while providing reasonable query execution performance

- Three levels of optimization
  - Execution site
  - Query plan
  - Stream implementation

Execution Site Selection

- Query plan can be executed on program running site or remote monitoring site
  - Aspects to consider
    - cpu bound vs. network bound
    - Amount of data needed to be sent
    - Number of monitoring sites
  - System conditions change over time!

    → Change query plans adaptively (future work)

Query Plan Optimization

- ```
  select *
  from   function_start fs, cpu_load cl
  where  fs.function_name = “foo” and
          cl.busy > 70%
  ```

- Join evaluation strategy 1:
  - Monitor all “foo” call sites and cpu usage at all times
- Join evaluation strategy 2:
  - Instrument all “foo” call sites
  - Every time when “foo” is called, sample cpu usage, check if > 70%
- Join evaluation strategy 3:
  - Do not instrument “foo”
  - Continuously sample cpu usage
  - If sampled usage is > 70%, then instrument “foo” call sites
  ```

Query Plan Optimization (2)

- Need cost model
- Simple cost model:

$$\left(\begin{array}{c}\text{Extra instructions}\\ \text{from data collecting}\\ \text{operations}\end{array}\right) \times \left(\begin{array}{c}\text{Frequency}\\ \text{of such operations}\end{array}\right)$$

- Challenge
  - Frequency estimates changes over program lifetime!

    → Change query plans adaptively (future work)

Optimizing Stream Implementation

- Implementing function start stream
  - Exact
    - Instrument all call sites
    - Use code analysis to reduce # functions to instrument
  - Approximate
    - Sample stack trace and check if function is called
- Need cost model, and understand how much approximation user can tolerate

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Experiments Setup

- Implemented a simple profiler for Java programs on top of EndoScope
- Monitored performance of 3 apps
  - SimpleApp included with Apache Derby
  - TPC-C implementation using Derby
  - Petstore app hosted on Tomcat that uses Derby
- Measured runtime overhead

Runtime Overhead Experiment

- Rank all functions by their call frequencies over program run

- Issue query to system
  - Progressively increase the % of functions monitored, with the least frequently called function chosen first
  - Compare time overhead with other profilers

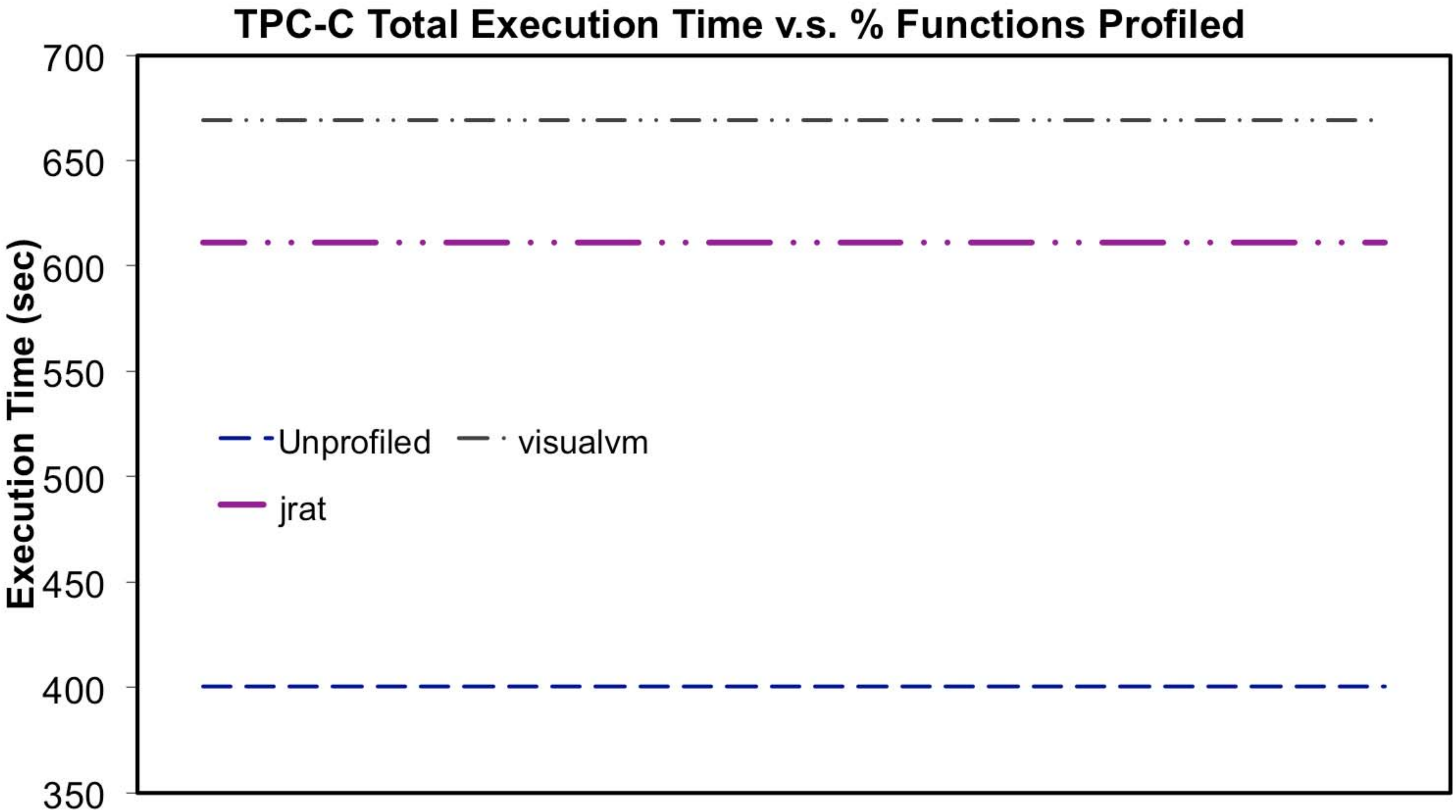
TPC-C Total Execution Time v.s. % Functions Profiled
Execution Time (sec)
700
650
600
550
500
450
400
350
Unprofiled
visualvm
jrat

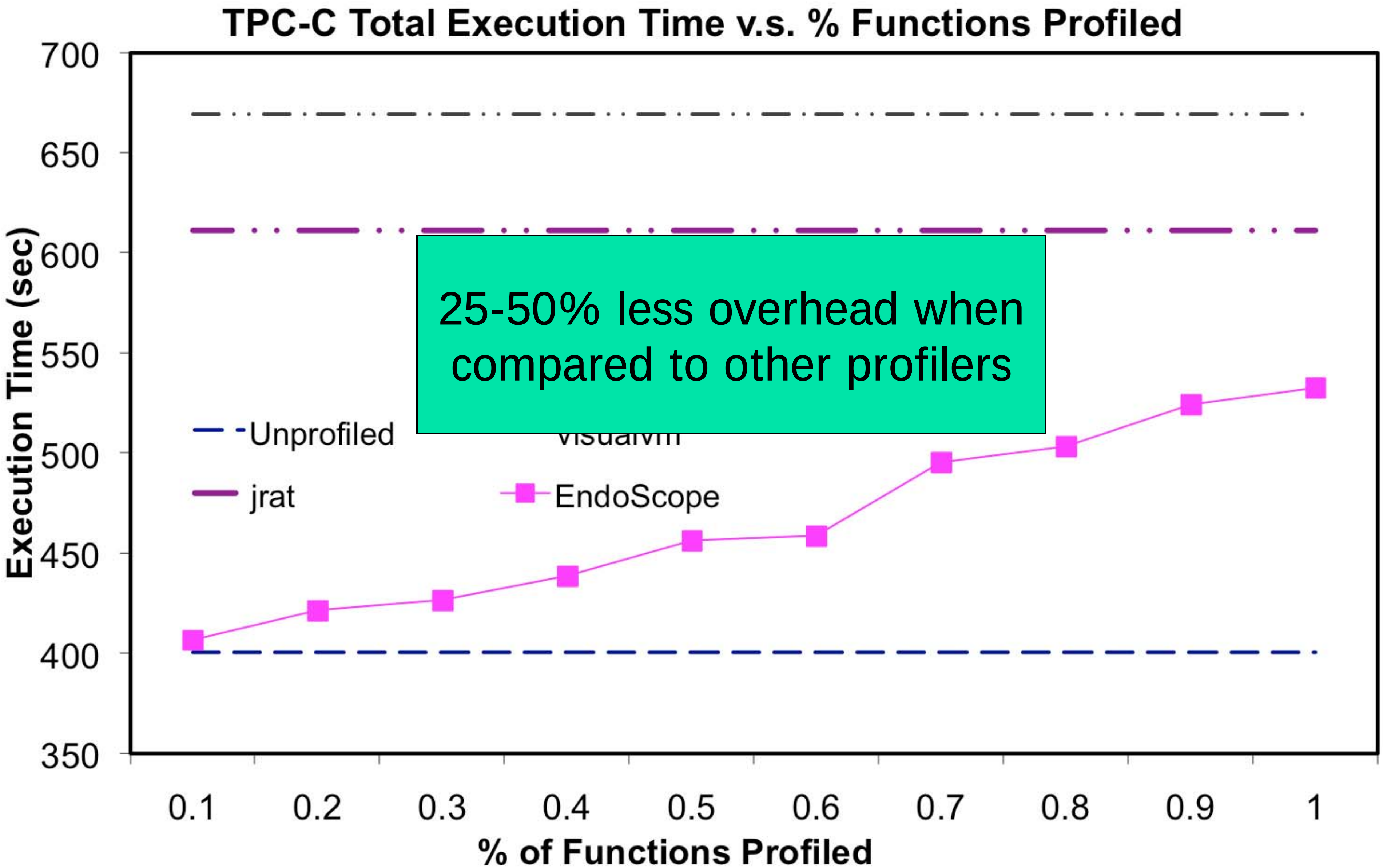

TPC-C Total Execution Time v.s. % Functions Profiled
Execution Time (sec)
700
650
600
550
500
450
400
350
Unprofiled
jrat
EndoScope
25-50% less overhead when compared to other profilers
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
% of Functions Profiled

Join Operator Ordering Expt

- Query on top of TPC-C implementation
  - ```
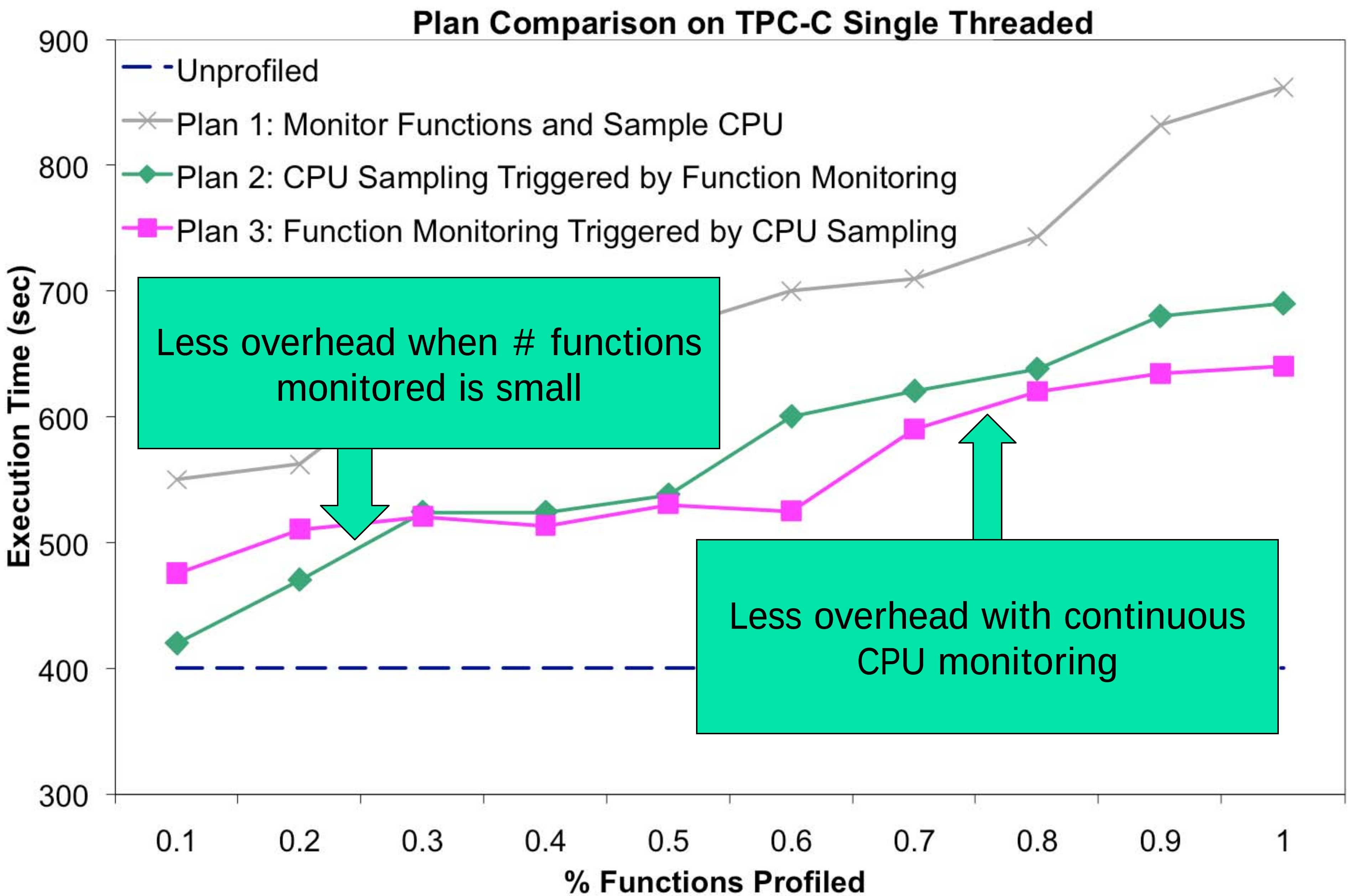
    SELECT *
    FROM   function_start fs, cpu_load cl
    WHERE  fs.function_name in (f1,f2..)
           AND cl.busy > 70%
    ```

- Quantify the effects of operators ordering by measuring the time overhead of 3 different query plans
    ```


Plan Comparison on TPC-C Single Threaded
Unprofiled
Plan 1: Monitor Functions and Sample CPU
Plan 2: CPU Sampling Triggered by Function Monitoring
Plan 3: Function Monitoring Triggered by CPU Sampling
Less overhead when # functions monitored is small
Less overhead with continuous CPU monitoring
Execution Time (sec)
900
800
700
600
500
400
300
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
% Functions Profiled

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Contributions

- Introduced a low overhead, query driven, acquisitional software monitoring framework
- Proposed data model, a declarative query language, and query evaluation techniques
- Implemented a simple profiler for Java programs and validated on real-world systems