Partiqle: Relational Queries Over Program Traces

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Does `doTransaction` call `sleep`?

```
public class DB {
  void doTransaction() {
    (new B()).y();
} }
public class B {
  void y() { sleep(); }
  void sleep() {}
}
```

- Obviously yes for this example
- How might one find out?

Manual Instrumentation?

```
public class DB {
  public static boolean active = false;
  void doTransaction() {
    active = true;
    (new B()).y();
    active = false;
} }
public class B {
  void y() { sleep(); }
  void sleep() {
    if (DB.active) {
      println("call to sleep()!");
    }
} }
```

Failings of Manual Instrumentation

- Easy to get wrong
  - recursion, exceptions, threads
- Managing lots of data
- Non-local
  - hard to maintain

More Generally...

- How does one answer questions about program behavior?
- For example
  - Does `doTransaction` call `sleep`?
  - Does my program leak resources?
  - Does it use the API correctly?
  - Does it pass a `null` pointer to method `foo`?

Solution

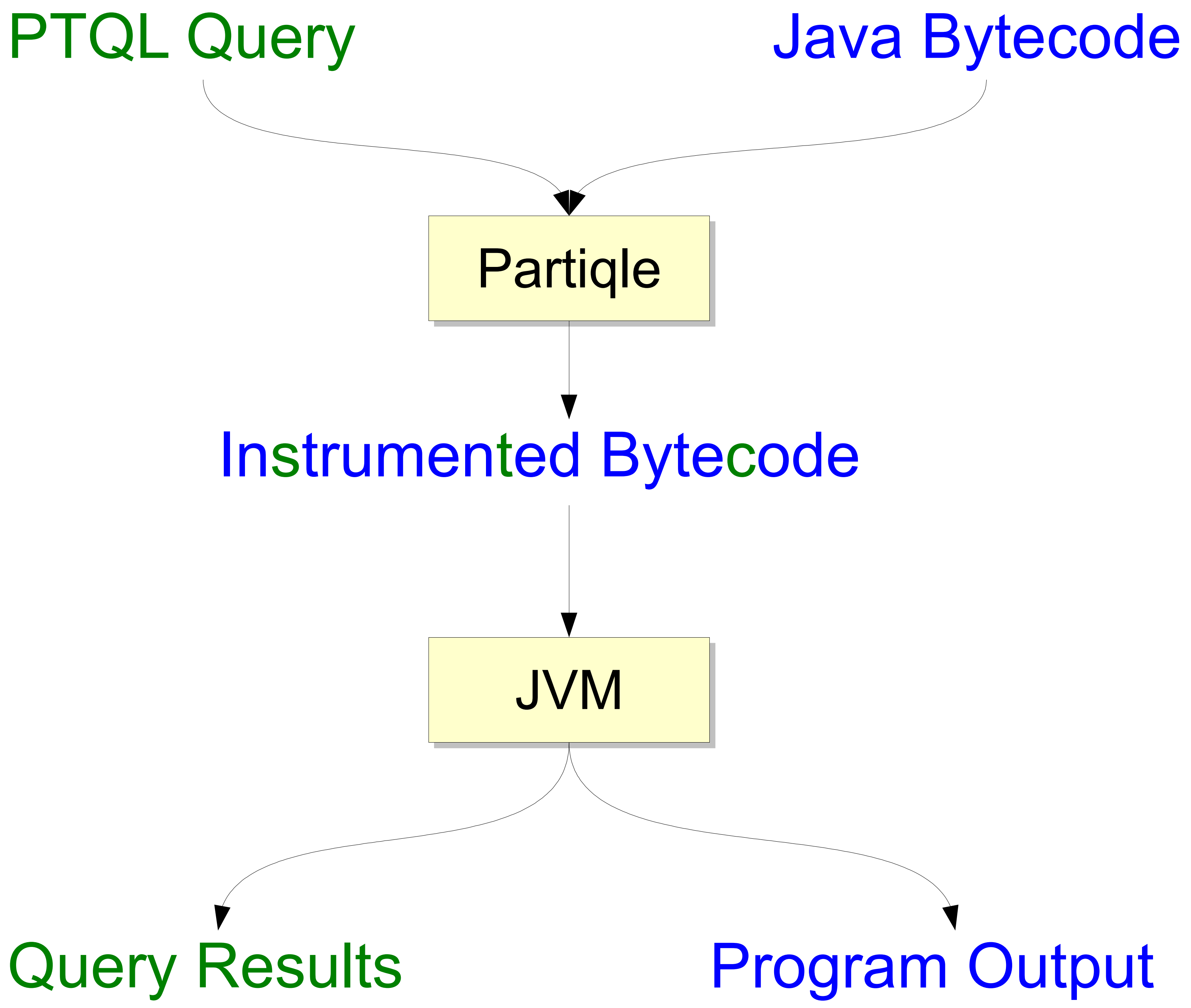
a query language over *program traces*

Terminology

- An **event** is a method call, object allocation, etc.
- A **program trace** is a sequence of time-stamped *events* that happen during a given program's execution.
- A **query** is an SQL query against the *program trace* regarded as a table of *events*.

Artifacts

- Program Trace Query Language (PTQL)
  - a query language over program traces
  - subset of SQL => familiar, declarative
- Partiqle compiler
  - compiles PTQL query to optimized instrumentation of Java bytecode
  - instrumentation outputs query results as they become available


PTQL Query
Java Bytecode
Partiqle
Instrumented Bytecode
JVM
Query Results
Program Output

Does `doTransaction` call `sleep`?

```
SELECT sleep.backTrace
FROM MethodInvoc('DB.doTransaction') trans
JOIN MethodInvoc('B.sleep') sleep
  ON trans.thread = sleep.thread
 AND trans.startTime < sleep.startTime
 AND sleep.startTime < trans.endTime
```

Advantages

- Partiqle manages the data
- Partiqle instrumentation is general
  - it works in the presence of threads, exceptions, recursion
- You write a declarative PTQL query
  - not a new dynamic analysis tool
  - not manual instrumentation

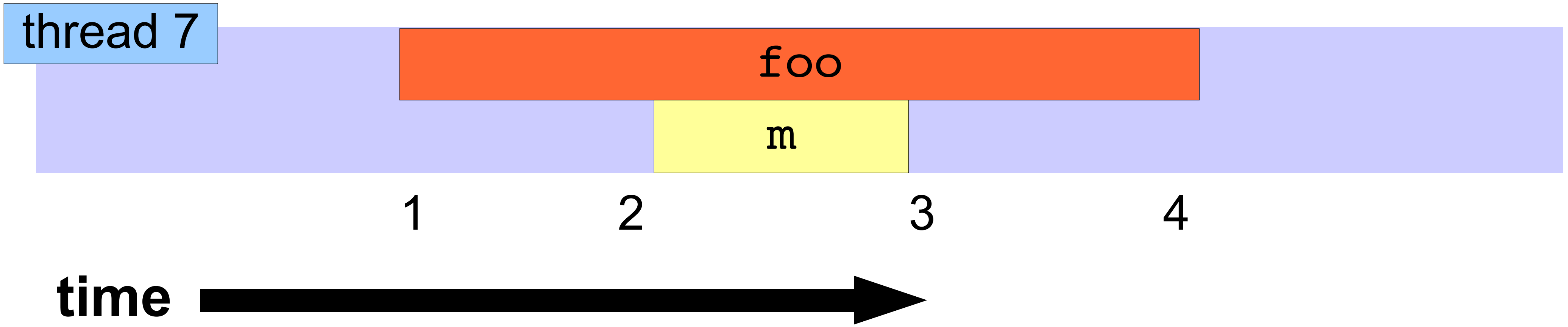
Program Trace Query Language (PTQL)

- Regard program trace as tables:
  - `MethodInvoc`
  - `ObjectAlloc`
- Event happens => record in table
  - A call to `foo()` adds a record to `MethodInvoc`
- PTQL = SQL query over this schema

Example PTQL Query I

- What methods does method `foo` call?

```
SELECT m.*
  FROM MethodInvoc('foo') foo
  JOIN MethodInvoc m
    ON m.thread = foo.thread
   AND foo.startTime < m.startTime
   AND m.endTime < foo.endTime
```



Example PTQL Query II

- Show streams `close`d >1s after the last `read`/`write`

```
SELECT close.*
  FROM MethodInvoc('read'|'write') rw
  JOIN MethodInvoc('close') close
    ON rw.receiver = close.receiver
   AND close.endTime > rw.endTime + 1000
ANTIJOIN MethodInvoc nrw('read'|'write')
      ON nrw.receiver = rw.receiver
     AND rw.endTime < nrw.endTime
     AND nrw.endTime < close.endTime
```

Example PTQL Query III*

- Look for SQL injection attacks

```
SELECT tainted.result
FROM MethodInvoc('HttpServletRequest.getParameter') tainted
JOIN MethodInvoc('Connection.execute') exec
  ON tainted.result = exec.param1
```

Example PTQL Query III*

- Ok if you check input before calling `execute`

```
SELECT tainted.result
FROM MethodInvoc('HttpServletRequest.getParameter') tainted
JOIN MethodInvoc('Connection.execute') exec
  ON tainted.result = exec.param1
 ANTIJOIN MethodInvoc('Util.inputOk') check
       ON check.param1 = tainted.result
      AND check.result = true
     AND check.endTime < exec.startTime
```

Partiqle: Overview

- Compiles PTQL query to instrumentation
  - Record “interesting” events in runtime tables
    - Those that might contribute to query results
  - Search tables for query results
    - Sets of events that match the query

Does `doTransaction` call `sleep`?

```
SELECT sleep.backTrace
FROM MethodInvoc('DB.doTransaction') trans
JOIN MethodInvoc('B.sleep') sleep
  ON trans.thread = sleep.thread
 AND trans.startTime < sleep.startTime
 AND sleep.startTime < trans.endTime
```

- Query result = 2 events
  - a call to `doTransaction`
  - and a call to `sleep`

Recording Events

- Instrument code that may generate events

Query

```
                    ...
FROM MethodInvoc('DB.doTransaction') trans
                    ...
```

Code

```
void doTransaction() {
    b.y();
}
```

Recording Events

- Instrument code that may generate events
  - to add events records to the runtime tables

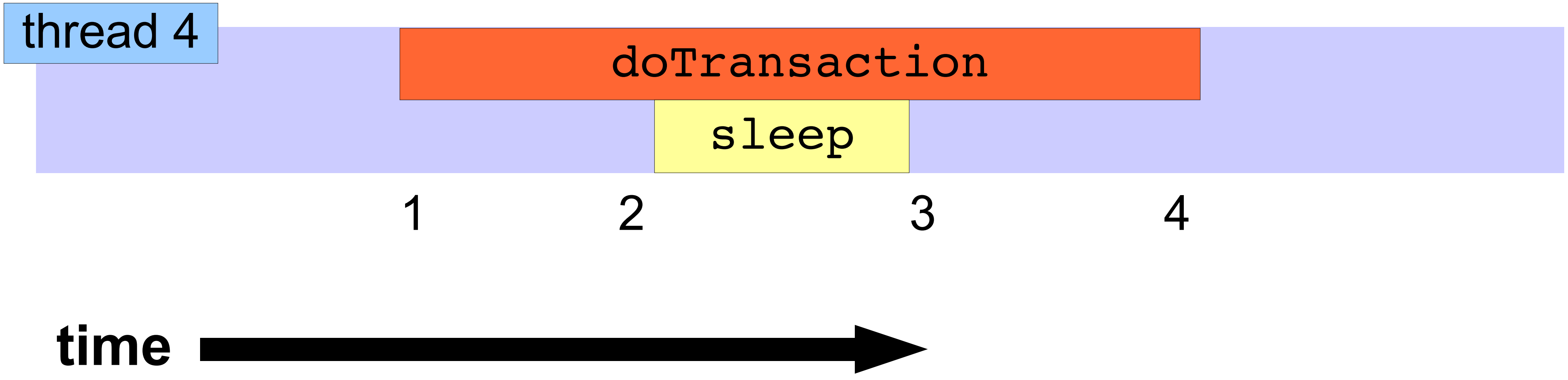
```
void doTransaction() {
  trans_Record r;
  synchronized(partiqleLock) {
    r = trans_Table.add(getTime(), getThread());
  } try {
    b.y();  // method body
  } finally { synchronized(partiqleLock) {
    r.setEndTime(getTime());
  } }
}
```

Timing

- In what order must the events happen?

Query

```
        ...
    trans.startTime < sleep.startTime
AND sleep.startTime < trans.endTime
```



Query Evaluation

- Any event that may be last triggers query evaluation

```
void sleep() {
  // method body
}
```

➡

```
void sleep() {
  queryEval( getThread(),
             getTime() );
  // method body
}
```

Query Evaluation

- Query evaluation searches runtime tables for matching events

```
void queryEval(int threadId, long now) {
  synchronized(partiqleLock) {
    foreach r in trans_Table {
      if ( threadId == r.threadId
           && r.startTime < now
           && r.endTime > now ) {
        print getBackTrace();
} } } }
```

Optimization

- Finished calls to `doTransaction` cannot contribute to query results

```
void doTransaction() {
  trans_Record r;
  synchronized(partiqleLock) {
    r = trans_Table.add(~~getTime(),~~ getThread());
  } try {
    b.y();  // method body
  } finally { synchronized(partiqleLock) {
    ~~r.setEndTime(getTime());~~
    trans_Table.delete(r);
  } }
}
```

Optimization

- Finished calls to `doTransaction` cannot contribute to query results

```
void doTransaction() {
  trans_Record r;
  synchronized(partiqleLock) {
    r = trans_Table.add(getThread());
  } try {
    b.y();  // method body
  } finally { synchronized(partiqleLock) {
    trans_Table.delete(r);
  } }
}
```

Optimization

- Finished calls to `doTransaction` cannot contribute to query results

```
void queryEval(int threadId~~, long now~~) {
  synchronized(partiqleLock) {
    foreach r in trans_Table {
      if ( threadId == r.threadId
           ~~&& r.startTime < now~~
           ~~&& r.endTime > now~~ ) {
        print getBackTrace();
} } } }
```

Optimization

- Finished calls to `doTransaction` cannot contribute to query results

```
void queryEval(int threadId) {
  synchronized(partiqleLock) {
    foreach r in trans_Table {
      if ( threadId == r.threadId {
        print getBackTrace();
} } } }
```

Runtime Table for `trans_Table`

- Store only essential fields
  - just `thread`
- Support only necessary operations
  - add(`thread`), delete(`thread`), iterate(`thread`)
- Pick reasonable data structure
  - map from `thread` to an integer counter
    - add => increment
    - delete => decrement

Partiqle: Compilation Summary

- Generate specialized data structures to store event records
- Instrumentation to create and store event records
- Generate query evaluation code

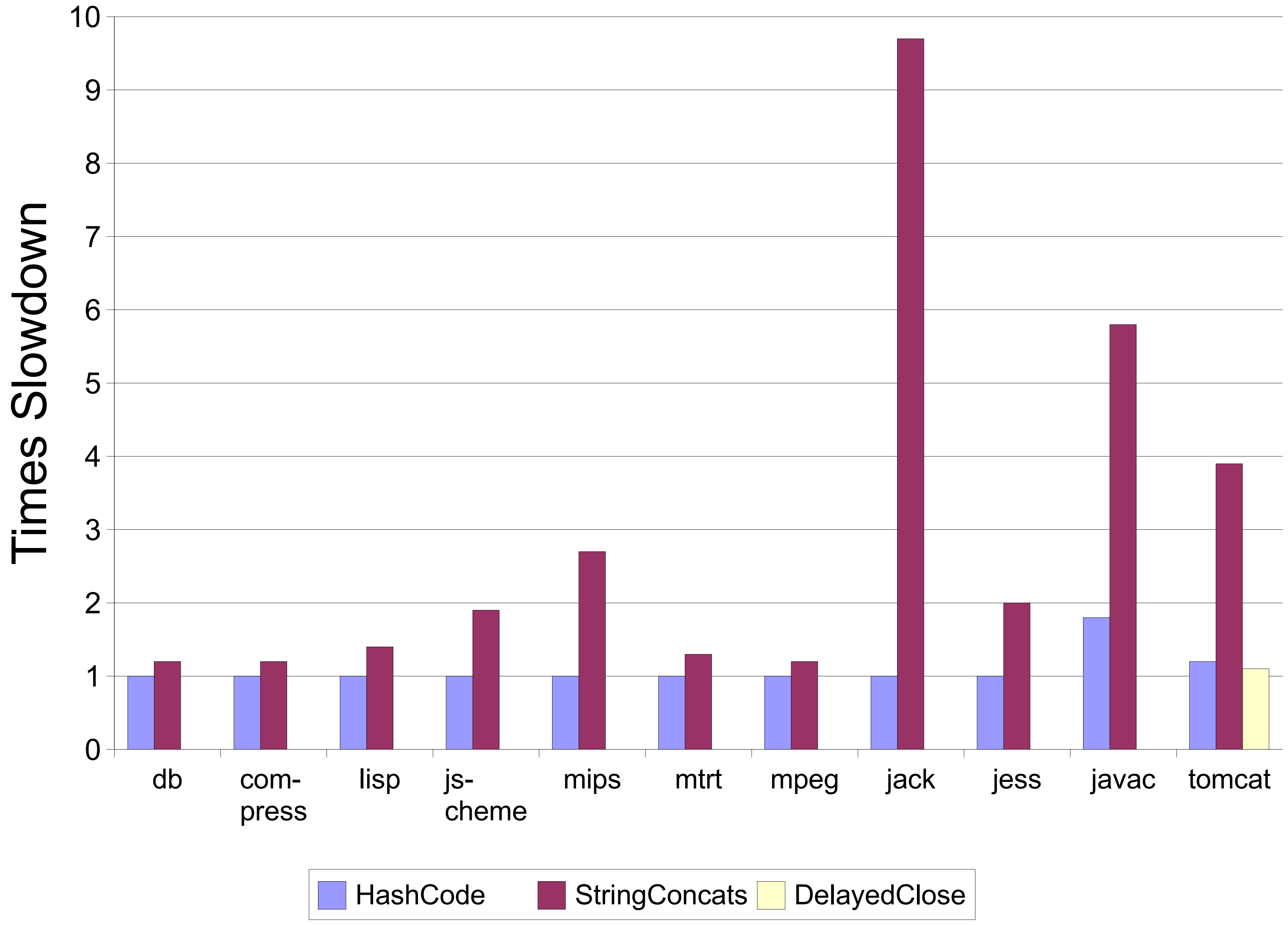
Experiments: Queries

- DelayedClose
  - Show streams `close`d >1s after the last `read`/`write`
  - looked at Tomcat-specific stream class
- StringConcats
  - No `s=s+“stuff”` many times in a row
- HashCode
  - An object's `hashCode` does not change
  - Important if it is in a `Hashtable`

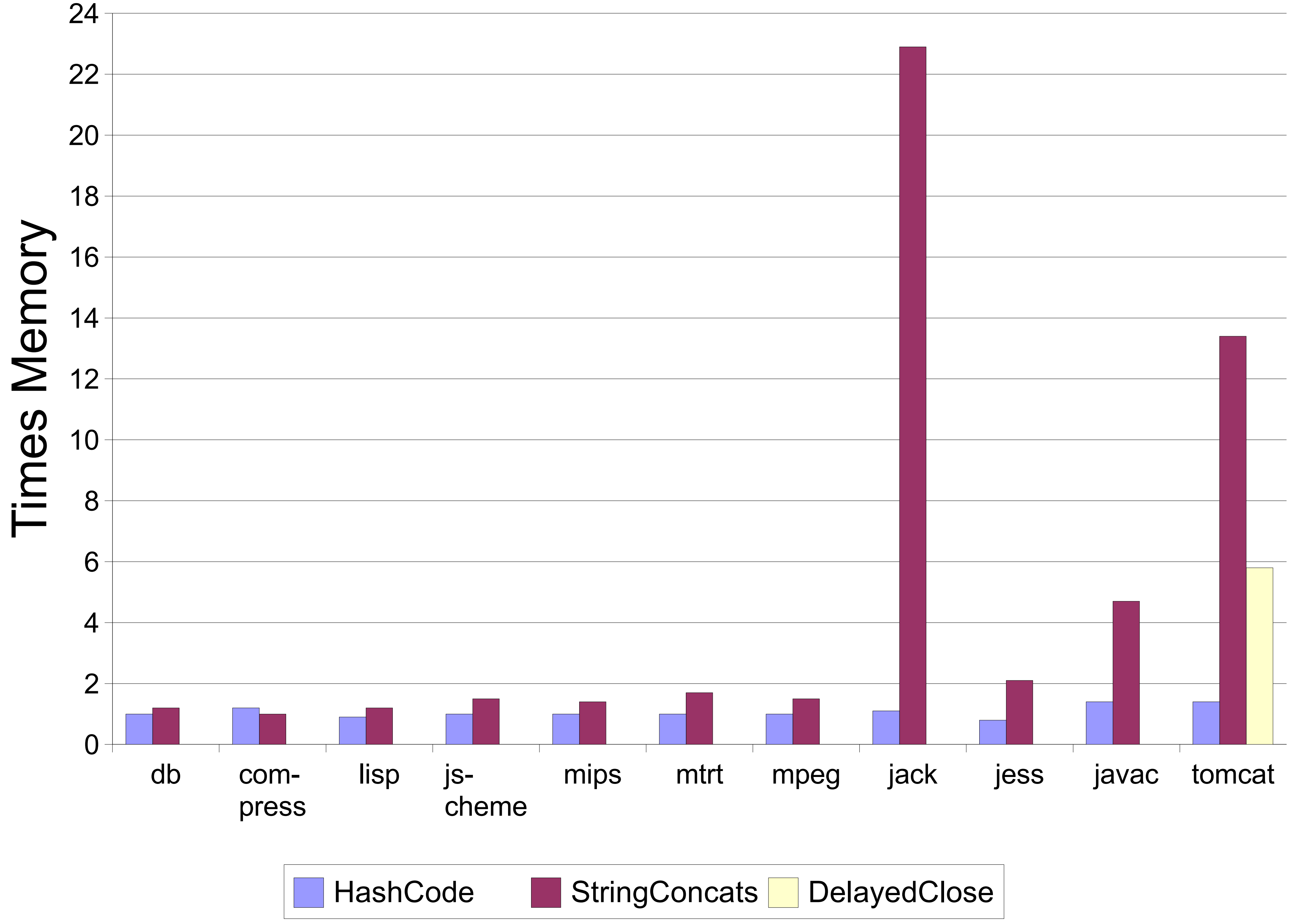
Experiments: Programs

- Ran queries on
  - Apache Tomcat (web server / Java servlets) (17k methods)
  - SpecJVM98 benchmarks
  - Some microbenchmarks
- Measured slowdown and memory footprint

Time Overhead



Memory Overhead



Bugs Found

- Found several performance bugs (string concats)
  - Jack (SpecJVM98 benchmark)
  - Apache Tomcat's XML parser
  - IBM JDK
- Found correct, but subtle code
  - Hash code consistency in Xerces XML parser

Related Work

- Aspect Oriented Programming Languages
  - Tracematches (talk before previous talk)
- Other trace-based query engines
  - PMMS (Liao & Cohen, 1992)
  - PQL (previous talk)
- Program Monitors
  - Eagle (Barringer et al., RV 2004)
- DIDUCE / Daikon / Statistical Debugging

Conclusion

PTQL: declarative query language over program traces

Partiqle: compiles PTQL to Java bytecode instrumentation

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answers to questions about program behavior

Thanks!

- Thanks to
  - Michael Martin et al. (PQL) and
  - Oege de Moor et al. (Tracematches)

for sharing early drafts of their papers