Characterizing a Java Implementation of TPC-W

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Outline

• What is TPC-W?
• Our implementation of TPC-W
  ◦ Why Java?
• Full system simulation
• Results
• Future work and summary
What is TPC-W?

- TPC-W is the TPC’s newest benchmark
  - **Version D5.5** (11/19/99), final version due 1Q 2000
  - Our implementation is based on vD5.5
  - www.tpc.org

- Measures systems for transactional web environments

- Transactional web environment
  - **Web serving** of static and dynamic content
  - On-line transaction processing (**OLTP**)
  - Some decision support (**DSS**)
What does TPC-W model?

- Models an online bookstore
  - Searching
  - Browsing
  - Shopping carts and secure purchasing
  - Best sellers and new products
  - Customer registration
  - Administrative updates
Observations about TPC-W

- **Dynamic web pages**, static images
- **Durable shopping cart**
- **Lazy consistency**
  - Allows 30 seconds for some pages to be updated
  - Enables various caching optimizations
  - We did not exploit this opportunity
- **Scaling**
  - ~5MB in DB tables per concurrent user (like TPC-C)
  - ~1KB per item in DB tables (like TPC-D)
  - ~25KB per item in static images
Our TPC-W implementation

- **All 14 web interactions** implemented
- Components
  - Jigsaw [Java web server](http://www.w3.org/Jigsaw)
  - Server side Java ‘[servlets’](http://www.w3.org/Jigsaw)
  - Java Database Connectivity ([JDBC](http://www.w3.org/Jigsaw))
  - IBM’s [DB2](http://www.w3.org/Jigsaw) Universal Database 6.1
  - Images stored in filesystem
- **Did not implement**
  - Secure sockets layer ([SSL](http://www.w3.org/Jigsaw))
  - Payment gateway emulator ([PGE](http://www.w3.org/Jigsaw))
Our TPC-W Implementation

Images Used in Web Content

Merchant Tables Session Information (i.e., shopping cart)

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Why Java?

- **Portability**
  - Studied workload on PowerPC and Sparc ISAs
  - Workload ran on **both architectures with no changes**

- **JDBC interface**
  - Connecting server side applications to a database
  - **Simple and elegant**

- **Server side Java**
  - Java servlet behavior not well understood
  - Opportunity to study new environment
Why full-system simulation?

- TPC-W has
  - Multiple users, threads, and components
  - Significant inter-process communication
  - TCP/IP networking
  - File caching of static content

- Performance counters are not enough

- Full-system simulation is necessary for an accurate and complete characterization of TPC-W

- Simulated two architectures
SimOS-PowerPC

- **AIX 4.3.1** (slightly modified)
- 64-bit **PowerPC ISA**
- **Simulates device interfaces** → modified device drivers
- **Checkpointing support**
- Fast simulation through **runtime code-generation**
  - Runs only on AIX PowerPC machines
- **Emitter interface** for trace-based studies
- **Source code available**
- SimOS-PPC publicly available
SimICS

- **Solaris 7** (unmodified)
- 64-bit **Sparc v9 ISA**
- **Simulates hardware devices** → unmodified drivers
- Fast simulation through threaded code and **simulator translation cache** (STC)
- Source code not generally available
  - Runs only on Solaris/SPARC machines
  - **Add code through loadable modules**
- **www.simics.com** (Virtutech)
Full-system simulation challenges

- Significant work in getting the **right disk image**
- External ethernet & TCP/IP **networking simulation tricky**
  - Machine-room simulation?
- **Checkpointing simulated multi-tier implementation**
  - External interactions add complexity
- **Simulation speed/detail tradeoff**
- Large workload requires simulating large systems
  - Multiple processors
  - Large memories
  - Long warmups
Simulation parameters

- **Single-tier** configuration
  - All servers & browser emulators **on single system**
  - One web server
  - Eight emulated browsers with no think time
- Dual processor (SimICS), Uniprocessor (SimOS)
- **1 GB main memory, Single-level cache**
- ~**250 MB of database** tables
  - 144000 customers, 10,000 items
- Images not served
- Database warm-up by full table scans on all tables
- JVM 1.1.x (No JIT)
Workload CPU breakdown

**SimICS** (from Unix utility: *top*)

<table>
<thead>
<tr>
<th>Process</th>
<th>System Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>rbe</td>
<td>2 - 5 %</td>
</tr>
<tr>
<td>jigsaw</td>
<td>15 - 25 %</td>
</tr>
<tr>
<td>db2</td>
<td>70 - 83 %</td>
</tr>
</tbody>
</table>

In kernel mode: 5 - 15 %

**SimOS-PPC** (from emitter interface)

<table>
<thead>
<tr>
<th>Process</th>
<th>Instructions</th>
<th>Loads</th>
<th>Stores</th>
</tr>
</thead>
<tbody>
<tr>
<td>kernel (1 thread)</td>
<td>33 %</td>
<td>23 %</td>
<td>23 %</td>
</tr>
<tr>
<td>rbe (10 threads)</td>
<td>5 %</td>
<td>2 %</td>
<td>5 %</td>
</tr>
<tr>
<td>jigsaw (14 threads)</td>
<td>23 %</td>
<td>16 %</td>
<td>22 %</td>
</tr>
<tr>
<td>db2 (17 threads)</td>
<td>38 %</td>
<td>59 %</td>
<td>49 %</td>
</tr>
</tbody>
</table>
Response time (from a real system)

Searches and ‘best sellers’ requests dominate database server utilization

Response Time

% Interactions vs Time (s)
## Instruction supply (SimICS/SimOS)

### SimICS:

#### I-Cache Hit Rate (150M inst.)
64-byte block, 4-way

<table>
<thead>
<tr>
<th>Size</th>
<th>Proc #1</th>
<th>Proc #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4KB</td>
<td>91.9 %</td>
<td>92.6 %</td>
</tr>
<tr>
<td>16KB</td>
<td>94.4 %</td>
<td>95.0 %</td>
</tr>
<tr>
<td>64KB</td>
<td>97.5 %</td>
<td>97.7 %</td>
</tr>
<tr>
<td>256KB</td>
<td>99.0 %</td>
<td>99.1 %</td>
</tr>
<tr>
<td>1MB</td>
<td>99.7 %</td>
<td>99.7 %</td>
</tr>
</tbody>
</table>

#### Overall Branch Predictor Accuracy

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Proc #1</th>
<th>Proc #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>small 2-bit (128B table)</td>
<td>84.1 %</td>
<td>85.1 %</td>
</tr>
<tr>
<td>medium 2-bit (1KB table)</td>
<td>93.4 %</td>
<td>92.8 %</td>
</tr>
<tr>
<td>large 2-bit (16KB table)</td>
<td>96.6 %</td>
<td>95.5 %</td>
</tr>
<tr>
<td>small gshare (10b history, 256B table)</td>
<td>89.5 %</td>
<td>89.2 %</td>
</tr>
<tr>
<td>large gshare (16b history, 16KB table)</td>
<td>96.7 %</td>
<td>95.4 %</td>
</tr>
</tbody>
</table>

### SimOS-PPC:

#### I-Cache Hit Rate (2.5B inst.)
64-byte block, 2-way

<table>
<thead>
<tr>
<th>Size</th>
<th>Proc #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4KB</td>
<td>95.6 %</td>
</tr>
<tr>
<td>16KB</td>
<td>97.7 %</td>
</tr>
<tr>
<td>64KB</td>
<td>99.1 %</td>
</tr>
<tr>
<td>256KB</td>
<td>99.7 %</td>
</tr>
<tr>
<td>1MB</td>
<td>99.9 %</td>
</tr>
</tbody>
</table>

#### Per Thread Branch Predictor Accuracy
large gshare (16b history, 16KB table)

<table>
<thead>
<tr>
<th>Thread</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>kernel</td>
<td>96.7 %</td>
</tr>
<tr>
<td>rbe</td>
<td>96.4 %</td>
</tr>
<tr>
<td>jigsaw</td>
<td>93.6 %</td>
</tr>
<tr>
<td>db2</td>
<td>93.0 %</td>
</tr>
</tbody>
</table>
Data supply (SimOS/ SimICS)

SimOS: **Data Cache Miss Rate** (2.5 B inst.), per memory access, 128-byte block, 4-way

<table>
<thead>
<tr>
<th>Size</th>
<th>Load</th>
<th>Store</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>512 KB</td>
<td>0.25 %</td>
<td>0.22 %</td>
<td>0.24 %</td>
</tr>
<tr>
<td>1 MB</td>
<td>0.19 %</td>
<td>0.19 %</td>
<td>0.19 %</td>
</tr>
<tr>
<td>2 MB</td>
<td>0.14 %</td>
<td>0.17 %</td>
<td>0.15 %</td>
</tr>
<tr>
<td>4 MB</td>
<td>0.11 %</td>
<td>0.15 %</td>
<td>0.13 %</td>
</tr>
<tr>
<td>16 MB</td>
<td>0.08 %</td>
<td>0.13 %</td>
<td>0.1 %</td>
</tr>
</tbody>
</table>

SimICS: **Data Cache Miss Rate** (300-450 M inst.), per instruction, 64-byte block, 4-way

<table>
<thead>
<tr>
<th>Size</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MB</td>
<td>0.64 %</td>
</tr>
<tr>
<td>4 MB</td>
<td>0.43 %</td>
</tr>
</tbody>
</table>
Future work

- More **workload tuning**
  - We found proper indexing important
  - Exploit **lazy consistency**
  - **Database tuning**
    - More efficient Java servlet/JDBC code
    - Better JVM/JIT
- SSL Implementation
- Larger database size
- **Multi-tier measurements**
- **Detailed architectural characterization**
Summary

• A difficult and complex task
  • Most of the TPC-W specification implemented
  • Setup of TPC-W on two different full-system simulators
• Using Java enables study of two ISAs and OSs with no changes to the application
• Performance tuning and optimization to be completed
• Preliminary characterization of this workload
• Most complex workload setup under full-system simulation?
• Look for updates and a future source code release at http://www.ece.wisc.edu/~mikko/tpcw.html
Remote browser emulator (RBE)

- **Emulates web users** interacting through browsers
  - RBE manages a collection of Emulated Browsers (EBs)
  - Each EB represents a single user
- **Non-deterministic walk** over web pages
  - Send HTTP request
  - Parse HTTP response for images and other URLs
  - Wait for think time
  - Repeat
- Collects statistics required by TPC-W (**Matlab file**)
  - Throughput over time (**WIPS**)
  - Web interaction response times (**WIRT**)
  - Transaction mix
### DB2 table sizes

13 indexes were added to speed up the queries

<table>
<thead>
<tr>
<th>Table Name</th>
<th>Number of Rows</th>
<th>Maximum Bytes</th>
<th>Maximum Total Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>address</td>
<td>288,000</td>
<td>146</td>
<td>42,048,000</td>
</tr>
<tr>
<td>author</td>
<td>2,500</td>
<td>568</td>
<td>1,420,000</td>
</tr>
<tr>
<td>cc_xacts</td>
<td>129,600</td>
<td>89</td>
<td>11,534,400</td>
</tr>
<tr>
<td>item</td>
<td>10,000</td>
<td>869</td>
<td>8,690,000</td>
</tr>
<tr>
<td>country</td>
<td>92</td>
<td>70</td>
<td>6,440</td>
</tr>
<tr>
<td>customer</td>
<td>144,000</td>
<td>695</td>
<td>100,080,000</td>
</tr>
<tr>
<td>orderline</td>
<td>388,800</td>
<td>116</td>
<td>45,100,800</td>
</tr>
<tr>
<td>orders</td>
<td>129,600</td>
<td>81</td>
<td>10,497,600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,092,592</td>
<td><strong>N/A</strong></td>
<td>219,377,240</td>
</tr>
</tbody>
</table>