Performance Evaluation in Database Research: Principles and Experiences

Stefan Manegold

Stefan.Manegold@cwi.nl
CWI (Centrum Wiskunde & Informatica)
Amsterdam, The Netherlands
http://www.cwi.nl/~manegold/
Performance evaluation

Disclaimer

- There is **no single way** how to do it right.
- There are **many ways** how to do it wrong.
- This is not a “mandatory” script.
- This is more a collection of **anecdotes or fairy tales** — not always to be taken literally, only, but all provide some **general rules or guidelines** what (not) to do.
1. Planning & conducting experiments
2. Presentation
3. Repeatability
4. Summary
1. Planning & conducting experiments
   - From micro-benchmarks to real-life applications
   - Choosing the hardware
   - Choosing the software
   - What and how to measure
   - How to run
   - Comparison with others
   - CSI

2. Presentation

3. Repeatability

4. Summary
Planning & conducting experiments

What do you plan to do / analyze / test / prove / show?

- Which data / data sets should be used?
- Which workload / queries should be run?
- Which hardware & software should be used?
- Metrics:
  - What to measure?
  - How to measure?
- How to compare?
- CSI: How to find out what is going on?
Data sets & workloads

- Micro-benchmarks
- Standard benchmarks
- Real-life applications

- No general simple rules, which to use when
- But some guidelines for the choice...
## Micro-benchmarks

### Definition

- Specialized, stand-alone piece of software
- Isolating one particular piece of a larger system
- E.g., single DB operator (select, join, aggregation, etc.)
## Micro-benchmarks

### Pros

- Focused on problem at hand
- Controllable workload and data characteristics
  - Data sets (synthetic & real)
  - Data size / volume (scalability)
  - Value ranges and distribution
  - Correlation
  - Queries
  - Workload size (scalability)
- Allow broad parameter range(s)
- Useful for detailed, in-depth analysis
- Low setup threshold; easy to run
Micro-benchmarks

Cons

- Neglect larger picture
- Neglect contribution of local costs to global/total costs
- Neglect impact of micro-benchmark on real-life applications
- Neglect embedding in context/system at large
- Generalization of result difficult
- Application of insights in full systems / real-life applications not obvious
- Metrics not standardized
- Comparison?
Standard benchmarks

Examples

- RDBMS, OODBMS, ORDMBS:
  TPC-\{A,B,C,H,R,DS\}, OO7, ...
- XML, XPath, XQuery, XUF, SQL/XML:
  MBench, XBench, XMach-1, XMark, X007, TPoX, ...
- Stream Processing:
  Linear Road, ...
- General Computing:
  SPEC, ...
- ...
Standard benchmarks

**Pros**

- Mimic real-life scenarios
- Publicly available
- Well defined (in theory ...)
- Scalable data sets and workloads (if well designed ...)
- Metrics well defined (if well designed ...)
- Easily comparable (?)
Standard benchmarks

Cons

- Often “outdated” (standardization takes (too?) long)
- Often compromises
- Often very large and complicated to run
- Limited dataset variation
- Limited workload variation
- Systems are often optimized for the benchmark(s), only!
Real-life applications

Pros

- There are so many of them
- Existing problems and challenges
Real-life applications

**Cons**

- There are so many of them
- Proprietary datasets and workloads
Two types of experiments

Analysis: “CSI”
- Investigate (all?) details
- Analyze and understand behavior and characteristics
- Find out where the time goes and why!

Publication
- “Sell your story”
- Describe picture at large
- Highlight (some) important / interesting details
- Compare to others
Choosing the hardware

Choice mainly depends on your problem, knowledge, background, taste, etc.

What ever is required by / adequate for your problem

A laptop might not be the most suitable / representative database server...
Choosing the software

Which DBMS to use?

**Commercial**

- Require license
- “Free” versions with limited functionality and/or optimization capabilities?
- Limitations on publishing results
- No access to code
- Optimizers
- Analysis & Tuning Tools

**Open source**

- Freely available
- No limitations on publishing results
- Access to source code
Choosing the software

Other choices depend on your problem, knowledge, background, taste, etc.

- Operating system
- Programming language
- Compiler
- Scripting languages
- System tools
- Visualization tools
Metrics: What to measure?

- **Basic**
  - Throughput: queries per time
  - Evaluation time
    - wall-clock ("real")
    - CPU ("user")
    - I/O ("system")
    - Server-side vs. client-side
  - Memory and/or storage usage / requirements

- **Comparison**
  - Scale-up
  - Speed-up

- **Analysis**
  - System events & interrupts
  - Hardware events
Laptop: 1.5 GHz Pentium M (Dothan), 2 MB L2 cache, 2 GB RAM, 5400 RPM disk

TPC-H ($sf = 1$)

MonetDB/SQL v5.5.0/2.23.0

measured 3rd ($& 4th$) of four consecutive runs

<table>
<thead>
<tr>
<th>Q</th>
<th>server 3rd user</th>
<th>real user</th>
<th>real server</th>
<th>client 3rd real</th>
<th>real client</th>
<th>4th real</th>
<th>run ... time (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2830</td>
<td>3533</td>
<td>3534</td>
<td>3575</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>550</td>
<td>618</td>
<td>707</td>
<td>1468</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
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measured 3rd & 4th of four consecutive runs

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<tr>
<th>Q</th>
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<th>real</th>
<th>client 3rd</th>
<th>4th real</th>
<th>run ... time (milliseconds)</th>
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</thead>
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**Metrics: What to measure?**

- Laptop: 1.5 GHz Pentium M (Dothan), 2 MB L2 cache, 2 GB RAM, 5400 RPM disk
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- measured 3\textsuperscript{rd} (\& 4\textsuperscript{th}) of four consecutive runs

<table>
<thead>
<tr>
<th>Q</th>
<th>server 3\textsuperscript{rd}</th>
<th>client 4\textsuperscript{th}</th>
<th>run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>user file</td>
<td>real file</td>
<td>result size</td>
</tr>
<tr>
<td>1</td>
<td>2830</td>
<td>3533</td>
<td>1.3 KB</td>
</tr>
<tr>
<td>16</td>
<td>550</td>
<td>618</td>
<td>1.2 MB</td>
</tr>
</tbody>
</table>
Metrics: What to measure?

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- measured 3rd (& 4th) of four consecutive runs

<table>
<thead>
<tr>
<th>Q</th>
<th>server 3rd user file</th>
<th>server 3rd real file</th>
<th>client 4th real terminal</th>
<th>result size</th>
<th>run ... time (millisseconds) output went to ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2830</td>
<td>3533</td>
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Be aware what you measure!
Tools, functions and/or system calls to measure time: **Unix**

- `/usr/bin/time`, shell built-in time
  - Command line tool ⇒ works with any executable
  - Reports “real”, “user” & “sys” time (*milliseconds*)
  - Measures entire process incl. start-up
  - **Note: output format varies!**

- `gettimeofday()`
  - System function ⇒ requires source code
  - Reports timestamp (*microseconds*)
Metrics: How to measure?

Tools, functions and/or system calls to measure time: Windows

- **TimeGetTime()**, **GetTickCount()**
  - System function ⇒ requires source code
  - Reports timestamp (milliseconds)
  - Resolution can be as coarse as 10 milliseconds

- **QueryPerformanceCounter()** / **QueryPerformanceFrequency()**
  - System function ⇒ requires source code
  - Reports timestamp (ticks per seconds)
  - Resolution can be as fine as 1 microsecond

- cf., [http://support.microsoft.com/kb/172338](http://support.microsoft.com/kb/172338)
Metrics: How to measure?

Use timings provided by the tested software (DBMS)

- IBM DB2
  - db2batch
- Microsoft SQLserver
  - GUI and system variables
- PostgreSQL
  
  ```
  postgresql.conf
  log_statement_stats = on
  log_min_duration_statement = 0
  log_duration = on
  ```

- MonetDB/XQuery & MonetDB/SQL
  - mclient -lxquery -t
  - mclient -lsql -t
  - (PROFILE|TRACE) select ...
### Metrics: How to measure?

**mclient -lxquery -t -s’1+2’**

3
- **Trans**: 11.626 msec
- **Shred**: 0.000 msec
- **Query**: 6.462 msec
- **Print**: 1.934 msec
- **Timer**: 21.201 msec

---

**mclient -lsql -t PROFILE_select_1.sql**

- `% . # table_name`
- `% single_value # name`
- `% tinyint # type`
- `% 1 # length`
- `[ 1 ]`

#times real 62, user 0, system 0, 100
- **Timer**: 0.273 msec
“We run all experiments in warm memory.”
"We run all experiments in warm memory."
“hot” vs. “cold”

- Depends on what you want to show / measure / analyze
- No formal definition, but “common sense”

**Cold run**

A cold run is a run of the query right after a DBMS is started and no (benchmark-relevant) data is preloaded into the system’s main memory, neither by the DBMS, nor in filesystem caches. Such a clean state can be achieved via a system reboot or by running an application that accesses sufficient (benchmark-irrelevant) data to flush filesystem caches, main memory, and CPU caches.

**Hot run**

A hot run is a run of a query such that as much (query-relevant) data is available as close to the CPU as possible when the measured run starts. This can (e.g.) be achieved by running the query (at least) once before the actual measured run starts.

- Be aware and document what you do / choose
“hot” vs. “cold”

- Laptop: 1.5 GHz Pentium M (Dothan), 2 MB L2 cache, 2 GB RAM, 5400 RPM disk
- TPC-H \( (sf = 1) \)
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<table>
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<tr>
<th>Q</th>
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<th>hot</th>
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“hot” vs. “cold”

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“hot” vs. “cold” & user vs. real time

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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2930</td>
<td>13243</td>
<td>2830</td>
<td>3534</td>
<td></td>
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Be aware *what* you measure!
Once upon a time at CWI ...

- Two colleagues A & B each implemented one version of an algorithm, A the “old” version and B the improved “new” version.
- They ran identical experiments on identical machines, each for his code.
- Though both agreed that B’s new code should be significantly better, results were consistently worse.
Of apples and oranges

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- They tested, profiled, analyzed, argued, wondered, fought for several days ...
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- Though both agreed that B’s new code should be significantly better, results were consistently worse.
- They tested, profiled, analyzed, argued, wondered, fought for several days ...
- ... and eventually found out that A had compiled with optimization enabled, while B had not ...
Of apples and oranges

**DBG**

```bash
configure --enable-debug --disable-optimize --enable-assert
CFLAGS = "-g [-00]"
```

**OPT**

```bash
configure --disable-debug --enable-optimize --disable-assert
CFLAGS = 
-O6 -fomit-frame-pointer -finline-functions
-malign-loops=4 -malign-jumps=4 -malign-functions=4
-fexpensive-optimizations -funroll-all-loops -funroll-loops
-frerun-cse-after-loop -frerun-loop-opt -DNDEBUG"
```
Of apples and oranges

relative execution time: DBG/OPT
TPC-H queries

Manegold (CWI)
Performance Evaluation: Principles & Experiences
Of apples and oranges

- Compiler optimization ⇒ up to factor 2 performance difference
- DBMS configuration and tuning ⇒ factor $x$ performance difference ($2 \leq x \leq 10?$)
  - “Self-*” still research
  - Default settings often too “conservative”
  - Do you know all systems you use/compare equally well?

“Absolutely fair” comparisons virtually impossible
But:
Be at least aware of the crucial factors and their impact,
and document accurately and completely what you do.
Of apples and oranges

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Of apples and oranges

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Of apples and oranges

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- “Absolutely fair” comparisons virtually impossible
- But:
  Be at least aware of the the crucial factors and their impact, and document accurately and completely what you do.
Do you know what happens?

Simple In-Memory Scan: SELECT MAX(column) FROM table

<table>
<thead>
<tr>
<th>Year</th>
<th>System</th>
<th>CPU Type</th>
<th>CPU Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>Sun LX</td>
<td>Sparc</td>
<td>50 MHz</td>
</tr>
<tr>
<td>1996</td>
<td>Sun Ultra</td>
<td>UltraSparc</td>
<td>200 MHz</td>
</tr>
<tr>
<td>1997</td>
<td>SunUltra</td>
<td>UltraSparcII</td>
<td>296 MHz</td>
</tr>
<tr>
<td>1998</td>
<td>DEC Alpha</td>
<td>Alpha</td>
<td>500 MHz</td>
</tr>
<tr>
<td>2000</td>
<td>Origin2000</td>
<td>R12000</td>
<td>300 MHz</td>
</tr>
</tbody>
</table>
Do you know what happens?

Simple In-Memory Scan: SELECT MAX(column) FROM table

- No disk-I/O involved
- Up to 10x improvement in CPU clock-speed

⇒ Yet hardly any performance improvement!??
Do you know what happens?

Simple In-Memory Scan: `SELECT MAX(column) FROM table`

- No disk-I/O involved
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- Research: Always question what you see!
Do you know what happens?

Simple In-Memory Scan: SELECT MAX(column) FROM table

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- Research: Always question what you see!
- Standard profiling (e.g., ‘gcc -gp‘ + ‘gprof‘) does not reveal more (in this case)
Do you know what happens?

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Research: Always question what you see!

- Standard profiling (e.g., ‘gcc -gp’ + ‘gprof’) does not reveal more (in this case)

- Need to dissect CPU & memory access costs
- Use hardware performance counters to analyze cache-hits, -misses & memory accesses
- VTune, oprofile, perfctr, perfmon2, PAPI, PCL, etc.
Simple In-Memory Scan: SELECT MAX(column) FROM table

Find out what happens!
Find out what happens!

Use info provided by the tested software (DBMS)

- IBM DB2
  - `db2expln`
- Microsoft SQLserver
  - GUI and system variables
- MySQL, PostgreSQL
  - `EXPLAIN select ...`
- MonetDB/SQL
  - `(PLAN|EXPLAIN|TRACE) select ...`
Find out what happens!

Use profiling and monitoring tools

- `gcc -gp` + `gprof`
  - Reports call tree, time per function and time per line
  - Requires re-compilation and static linking
- `valgrind --tool=callgrind` + `kcachegrind`
  - Reports call tree, times, instructions executed and cache misses
  - Thread-aware
  - Does not require (re-)compilation
  - Simulation-based ⇒ slows down execution up to a factor 100

- Hardware performance counters
  - to analyze cache-hits, -misses & memory accesses
  - VTune, oprofile, perfctr, perfmon2, PAPI, PCL, etc.

- System monitors
  - `ps`, `top`, `iostat`, ...
TPC-H Q1 ($sf = 1$) (AMD AthlonMP @ 1533 GHz, 1 GB RAM)

MySQL gprof trace

MonetDB/MIL trace
1. Planning & conducting experiments

2. Presentation
   - Guidelines
   - Mistakes

3. Repeatability

4. Summary
Graphical presentation of results

We all know

A picture is worth a thousand words
Graphical presentation of results

We all know

A picture is worth a thousand words

Er, maybe not all pictures...
Graphical presentation of results

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A picture is worth a thousand words
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(Borrowed from T. Grust’s slides at VLDB 2007 panel)
Guidelines for preparing good graphic charts

Require minimum effort from the reader
Guidelines for preparing good graphic charts

Require minimum effort from the reader

- Not the minimum effort from you
Guidelines for preparing good graphic charts

- Require minimum effort from the reader
- Not the minimum effort \textit{from you}
- Try to be honest: how would you like to see it?
Guidelines for preparing good graphic charts

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**Guidelines for preparing good graphic charts**

**Maximize information**: try to make the graph self-sufficient

- Use keywords in place of symbols to avoid a join in the reader’s brain
- Use informative axis labels: prefer “Average I/Os per query” to “Average I/Os” to “I/Os”
- Include units in the labels: prefer “CPU time (ms)” to “CPU time”
Guidelines for preparing good graphic charts

Maximize information: try to make the graph self-sufficient

- Use keywords in place of symbols to avoid a join in the reader’s brain
- Use informative axis labels: prefer “Average I/Os per query” to “Average I/Os” to “I/Os”
- Include units in the labels: prefer “CPU time (ms)” to “CPU time”

Use commonly accepted practice: present what people expect

- *Usually* axes begin at 0, the factor is plotted on x, the result on y
- *Usually* scales are linear, increase from left to right, divisions are equal
- Use exceptions as necessary
Guidelines for preparing good graphic charts

Minimize ink: present as much information as possible with as little ink as possible
Guidelines for preparing good graphic charts

**Minimize ink:** present as much information as possible with as little ink as possible
Prefer the chart that gives the most information out of the same data
Guidelines for preparing good graphic charts

**Minimize ink:** present as much information as possible with as little ink as possible. Prefer the chart that gives the most information out of the same data.

![Graph](image1)

**Availability**

<table>
<thead>
<tr>
<th>Day of the week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph](image2)

**Unavailability**

<table>
<thead>
<tr>
<th>Day of the week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unavailability</td>
<td>0.1</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reading material


http://www.edwardtufte.com/tufte/books_vdqi
Common presentation mistakes

Presenting too many alternatives on a single chart

Rules of thumb, to override with good reason:

- A line chart should be limited to 6 curves
- A column chart or bar should be limited to 10 bars
- A pie chart should be limited to 8 components
- Each cell in a histogram should have at least five data points
Common presentation mistakes

Presenting many result variables on a single chart
Commonly done to fit into available page count :-(

![Graph showing response time, utilization, and throughput vs number of users.](image-url)
Common presentation mistakes

Presenting many result variables on a single chart
Commonly done to fit into available page count :-(

Huh?
Common presentation mistakes

Using symbols in place of text
Common presentation mistakes

Using symbols in place of text

Response time

Arrival rate

\[ \lambda \]

\[ \mu = 1 \]

\[ \mu = 2 \]

\[ \mu = 3 \]

1 job/sec

2 jobs/sec

3 jobs/sec

Human brain is a poor join processor

Manegold (CWI)

Performance Evaluation: Principles & Experiences
Common presentation mistakes

Using symbols in place of text

Human brain is a poor join processor
Common presentation mistakes

Using symbols in place of text

Human brain is a poor join processor
Humans get frustrated by computing joins
Common presentation mistakes

Change the graphical layout of a given curve from one figure to another
Common presentation mistakes

Change the graphical layout of a given curve from one figure to another

![Graphs showing time (different machines)](image)
Common presentation mistakes

Change the graphical layout of a given curve from one figure to another

What do you mean “my graphs are not legible”? 
Pictorial games

MINE is better than YOURS!
MINE is better than YOURS!
Pictorial games

MINE is better than YOURS!

A-ha
Pictorial games

Recommended layout: let the useful height of the graph be $3/4$th of its useful width
Plot random quantities without confidence intervals
Pictorial games

Plot random quantities without confidence intervals

Overlapping confidence intervals sometimes mean the two quantities are statistically indifferent.
Pictorial games

Manipulating cell size in histograms

- Rule of thumb: each cell should have at least five points.
- Not sufficient to uniquely determine what one should do.
Pictorial games

Manipulating cell size in histograms

Rule of thumb: each cell should have at least five points.
Not sufficient to uniquely determine what one should do.
Pictorial games: gnuplot & \LaTeX

Rule of thumb for papers:
width of plot = \frac{x}{textwidth} \Rightarrow \text{set size ratio 0 } x * 1.5, y

Manegold (CWI)
Performance Evaluation: Principles & Experiences
86/144
Pictorial games: gnuplot & \LaTeX

**default:**
\begin{verbatim}
set size ratio 0 1,1
\end{verbatim}

**better:**
\begin{verbatim}
set size ratio 0 0.5,0.5
\end{verbatim}
Pictorial games: gnuplot & \LaTeX

**Rule of thumb for papers:**

width of plot = $x\textwidth$

$\Rightarrow$ set size ratio 0 $x\times1.5,y$
Specifying hardware environments

“We use a machine with 3.4 GHz.”
Specifying hardware environments

“We use a machine with 3.4 GHz.”

3400x
Specifying hardware environments

“We use a machine with 3.4 GHz.”

⇒ Under-specified!
### Specifying hardware environments

```
cat /proc/cpuinfo
```

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>processor</td>
<td>0</td>
</tr>
<tr>
<td>vendor_id</td>
<td>GenuineIntel</td>
</tr>
<tr>
<td>cpu family</td>
<td>6</td>
</tr>
<tr>
<td>model</td>
<td>13</td>
</tr>
<tr>
<td>model name</td>
<td>Intel(R) Pentium(R) M processor 1.50GHz</td>
</tr>
<tr>
<td>stepping</td>
<td>6</td>
</tr>
<tr>
<td>cpu MHz</td>
<td>600.000</td>
</tr>
<tr>
<td>cache size</td>
<td>2048 KB</td>
</tr>
<tr>
<td>fdiv_bug</td>
<td>no</td>
</tr>
<tr>
<td>hlt_bug</td>
<td>no</td>
</tr>
<tr>
<td>f00f_bug</td>
<td>no</td>
</tr>
<tr>
<td>coma_bug</td>
<td>no</td>
</tr>
<tr>
<td>fpu</td>
<td>yes</td>
</tr>
<tr>
<td>fpu_exception</td>
<td>yes</td>
</tr>
<tr>
<td>cpuid level</td>
<td>2</td>
</tr>
<tr>
<td>wp</td>
<td>yes</td>
</tr>
<tr>
<td>flags</td>
<td>fpu vme de pse tsc msr mce cx8 mtrr pge mca cmov pat clflush dts acpi mmx fxsr sse sse2 ss tm pbe up bts est tm2</td>
</tr>
<tr>
<td>bogomips</td>
<td>1196.56</td>
</tr>
<tr>
<td>clflush size</td>
<td>64</td>
</tr>
</tbody>
</table>
### Specifying hardware environments

```bash
cat /proc/cpuinfo
```

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<td>600.000 ← throttle down by speed stepping!</td>
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Specifying hardware environments

/sbin/lspci -v

00:00.0 Host bridge: Intel Corporation 82852/82855 GM/GME/PM/GMV Processor to I/O Controller (rev 02)
  Flags: bus master, fast devsel, latency 0
  Memory at <unassigned> (32-bit, prefetchable)
  Capabilities: <access denied>
  Kernel driver in use: agpgart-intel

...

01:08.0 Ethernet controller: Intel Corporation 82801DB PRO/100 VE (MOB) Ethernet Controller (rev 83)
  Subsystem: Benq Corporation Unknown device 5002
  Flags: bus master, medium devsel, latency 64, IRQ 10
  Memory at e0000000 (32-bit, non-prefetchable) [size=4K]
  I/O ports at c000 [size=64]
  Capabilities: <access denied>
  Kernel driver in use: e100
  Kernel modules: e100

/sbin/lspci -v | wc

  151 lines
  861 words
  6663 characters
Specifying hardware environments

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  Kernel modules: e100
```

```
/sbin/lspci -v | wc

  151 lines
  861 words
  6663 characters

⇒ Over-specified!
```
Specifying hardware environments

- **CPU**: Vendor, model, generation, clockspeed, cache size(s)
  - 1.5 GHz Pentium M (Dothan), 32 KB L1 cache, 2 MB L2 cache

- **Main memory**: size
  - 2 GB RAM

- **Disk (system)**: size & speed
  - 120 GB Laptop ATA disk @ 5400 RPM
  - 1 TB striped RAID-0 system (5x 200 GB S-ATA disk @ 7200 RPM)

- **Network (interconnection)**: type, speed & topology
  - 1 GB shared Ethernet
Specifying software environments

- Product names, **exact version numbers**, and/or sources where obtained from
1. Planning & conducting experiments

2. Presentation

3. Repeatability
   - Portable parameterizable experiments
   - Test suite
   - Documenting your experiment suite

4. Summary
Making experiments repeatable

Purpose: another human equipped with the appropriate software and hardware can repeat your experiments.
Making experiments repeatable

Purpose: another human equipped with the appropriate software and hardware can repeat your experiments.

- Your supervisor / your students
- Your colleagues
- Yourself, 3 months later when you have a new idea
- Yourself, 3 years later when writing the thesis or answering requests for that journal version of your conference paper
- Future researchers (you get cited!)
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- Yourself, 3 months later when you have a new idea
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- Future researchers (you get cited!)

Making experiments repeatable means:

1. Making experiments **portable and parameterizable**
2. Building a **test suite** and scripts
3. Writing **instructions**
Making experiments portable

Try to use not-so-exotic hardware
Try to use free or commonly available tools (databases, compilers, plotters...)

Clearly, scientific needs go first (joins on graphic cards; smart card research; energy consumption study...)

You may omit using Matlab as the driving platform for the experiments
20-years old software that only works on an old SUN and is now unavailable

If you really love your code, you may even maintain it
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Manegold (CWI)
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4-years old library that is no longer distributed and you do no longer have (idem)
/usr/bin/time to time execution, parse the output with perl, divide by zero
Which abstract do you prefer?

Abstract (Take 1)

We provide a new algorithm that consistently outperforms the state of the art.
Which abstract do you prefer?

Abstract (Take 1)
We provide a new algorithm that consistently outperforms the state of the art.

Abstract (Take 2)
We provide a new algorithm that on a Debian Linux machine with 4 GHz CPU, 60 GB disk, DMA, 2 GB main memory and our own brand of system libraries consistently outperforms the state of the art.
Which abstract do you prefer?

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We provide a new algorithm that consistently outperforms the state of the art.

Abstract (Take 2)
We provide a new algorithm that on a Debian Linux machine with 4 GHz CPU, 60 GB disk, DMA, 2 GB main memory and our own brand of system libraries consistently outperforms the state of the art.

There are obvious, undisputed exceptions.
Making experiments parameterizable

This is huge
This is **huge**

Parameters your code may depend on:
- credentials (OS, database, other)
- values of important environment variables (usually one or two)
- various paths and directories (see: environment variables)
- where the input comes from
- switches (pre-process, optimize, prune, materialize, plot . . .)
- where the output goes
Making experiments parameterizable

Purpose: have a very simple mean to obtain a test for the values

\[ f_1 = v_1, f_2 = v_2, \ldots, f_k = v_k \]
Making experiments parameterizable

Purpose: have a very simple mean to obtain a test for the values

\[ f_1 = v_1, f_2 = v_2, \ldots, f_k = v_k \]

Many tricks. Very simple ones:

- argc / argv: specific to each class' main
- Configuration files
- Java Properties pattern
- + command-line arguments
Making experiments parameterizable

Configuration files

Omnipresent in large-scale software

- Crucial if you hope for serious installations: see gnu software install procedure
- Decide on a specific relative directory, fix the syntax
- Report meaningful error if the configuration file is not found

Pro: human-readable even without running code
Con: the values are read when the process is created
Making experiments parameterizable

Java util.Properties

Flexible management of parameters for Java projects
Defaults + overriding

How does it go:

- Properties extends Hashtable
- Properties is a map of (key, value) string pairs
  
  ```
  {“dataDir”, “./data”} {“doStore”, “true”}
  ```

- Methods:
  
  ```
  getProperty(String s)
  setProperty(String s1, String s2)
  load(InputStream is)
  store(OutputStream os, String comments)
  loadFromXML(...), storeToXML(...)
  ```
class Parameters {
    Properties prop;
    String[][] defaults = {{{"dataDir", ".\data"}},
                           {{"doStore", "true"}}};

    void init() {
        prop = new Properties();
        for (int i = 0; i < defaults.length; i++)
            prop.put(defaults[i][0], defaults[i][1]);
    }

    void set(String s, String v) {
        prop.put(s, v);
    }

    String get(String s) {
        // error if prop is null!
        return prop.get(s);
    }
}
Using `java.util.Properties`

When the code starts, it calls `Parameters.init()`, loading the defaults. The defaults may be overridden later from the code by calling `set()`. The properties are accessible to all the code. The properties are stored in one place. Simple serialization/deserialization mechanisms may be used instead of constant defaults.
Better init method

class Parameters{
    Properties prop;
    ...
    void init(){
        prop = new Properties();
        for (int i = 0; i < defaults.length; i ++)
            prop.put(defaults[i][0], defaults[i][1]);
        Properties sysProps = System.getProperties();
        // copy sysProps into (over) prop! } 
}

Call with:

    java -DdataDir=./test -DdoStore=false pack.AnyClass
Making your code parameterizable

The bottom line: you will want to run it in different settings

- With your or the competitor’s algorithm or special optimization
- On your desktop or your laptop
- With a local or remote MySQL server
- Make it easy to produce a point
- If it is very difficult to produce a new point, ask questions
Making your code parameterizable

The bottom line: you \textbf{will} want to run it in different settings

- With your or the competitor’s algorithm or special optimization
- On your desktop or your laptop
- With a local or remote MySQL server
- Make it easy to produce a point
- If it is very difficult to produce a new point, ask questions

You may omit coding like this:

The input data set files should be specified in source file `util.GlobalProperty.java`. 
Building a test suite

You already have:

- Designs
- Easy way to get any measure point

You need:

- Suited directory structure (e.g.: source, bin, data, res, graphs)
- Control loops to generate the points needed for each graph, under res/, and possibly to produce graphs under graphs
  - Even Java can be used for the control loops, but...
  - It does pay off to know how to write a loop in shell/perl etc.
Building a test suite

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- Control loops to generate the points needed for each graph, under res/, and possibly to produce graphs under graphs
  - Even Java can be used for the control loops, but...
  - It does pay off to know how to write a loop in shell/perl etc.

You may omit coding like this:

Change the value of the 'delta' variable in distribution.DistFreeNode.java into 1,5,15,20 and so on.
Automatically generated graphs

You have:

- files containing numbers characterizing the parameter values and the results
- basic shell skills

Most frequently used solutions:
- Based on Gnuplot
- Based on Excel or OpenOffice clone
- Other solutions: R; Matlab (remember portability)

Manegold (CWI)

Performance Evaluation: Principles & Experiences
Automatically generated graphs

You have:
- files containing numbers characterizing the parameter values and the results
- basic shell skills

You need: graphs

Most frequently used solutions:
- Based on Gnuplot
- Based on Excel or OpenOffice clone

Other solutions: R; Matlab (remember portability)
Automatically generating graphs with Gnuplot

Data file `results-m1-n5.csv`:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1234</td>
</tr>
<tr>
<td>2</td>
<td>2467</td>
</tr>
<tr>
<td>3</td>
<td>4623</td>
</tr>
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</table>
Automatically generating graphs with Gnuplot

1. Data file `results-m1-n5.csv`:

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</tbody>
</table>

2. Gnuplot command file `plot-m1-n5.gnu` for plotting this graph:

   ```
   set data style linespoints
   set terminal postscript eps color
   set output "results-m1-n5.eps"
   set title "Execution time for various scale factors"
   set xlabel "Scale factor"
   set ylabel "Execution time (ms)"
   plot "results-m1-n5.csv"
   ```

   Call `gnuplot plot-m1-n5.gnu`
Automatically generating graphs with Gnuplot

1. Data file results-m1-n5.csv:

<p>| | |</p>
<table>
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```plaintext
set data style linespoints
set terminal postscript eps color
set output "results-m1-n5.eps"
set title "Execution time for various scale factors"
set xlabel "Scale factor"
set ylabel "Execution time (ms)"
plot "results-m1-n5.csv"
```
Automatically generating graphs with Gnuplot

1. Data file results-m1-n5.csv:

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plot "results-m1-n5.csv"
```

3. Call gnuplot plot-m1-n5.gnu
Automatically producing graphs with Excel

1. Create an Excel file `results-m1-n5.xls` with the column labels:

<table>
<thead>
<tr>
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<th>B</th>
<th>C</th>
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</thead>
<tbody>
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</table>

2. Insert in the area B2-C3 a link to the file `results-m1-n5.csv`.

3. Create in the .xls file a graph out of the cells A1:B3, chose the layout, colors etc.

4. When the .csv file will be created, the graph is automatically filled in.
Automatically producing graphs with Excel

1. Create an Excel file `results-m1-n5.xls` with the column labels:

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3. Create in the `.xls` file a graph out of the cells A1:B3, chose the layout, colors etc.

4. When the `.csv` file will be created, the graph is automatically filled in.
Graph generation

You may omit working like this:

In `avgs.out`, the first 15 lines correspond to `xyzT`, the next 15 lines correspond to `xYZT`, the next 15 lines correspond to `XyzT`, the next 15 lines correspond to `xyZT`, the next 15 lines correspond to `XYZT`, and the next 15 lines correspond to `XyZT`. In each of these sets of 15, the numbers correspond to queries 1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3, 2.4, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, and 4.3.
You may omit working like this:

In avgs.out, the first 15 lines correspond to $xyzT$, the next 15 lines correspond to $xYZT$, the next 15 lines correspond to $Xyzt$, the next 15 lines correspond to $xyZT$, the next 15 lines correspond to $XyzT$, the next 15 lines correspond to $XYZT$, and the next 15 lines correspond to $XyZT$. In each of these sets of 15, the numbers correspond to queries 1.1,1.2,1.3,1.4,2.1,2.2,2.3,2.4,3.1,3.2,3.3,3.4,4.1,4.2,and 4.3.

... either because you want to do clean work, or because you don’t want this to happen:
Why you should take care to generate your own graphs

File `avgs.out` contains average times over three runs:

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.666</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
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<tr>
<td>3</td>
<td>12.3333</td>
</tr>
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<td>4</td>
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The graph doesn't look good :-(

Hard to figure out when you have to produce by hand 20 such graphs and most of them look OK
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Copy-paste into OpenOffice 2.3.0-6.11-fc8:

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The graph doesn’t look good :-(
Why you should take care to generate your own graphs

File `avgs.out` contains average times over three runs: (’.’ decimals)

<p>| | |</p>
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Copy-paste into OpenOffice 2.3.0-6.11-fc8: (expecting ’,’ decimals)

<p>| | |</p>
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The graph doesn’t look good :-(

Hard to figure out when you have to produce by hand 20 such graphs and most of them look OK
Documenting your experiment suite

Very easy if experiments are already portable, parameterizable, and if graphs are automatically generated.

Specify:

1. What the installation requires; how to install
2. For each experiment
   1. Extra installation if any
   2. Script to run
   3. Where to look for the graph
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Specify:

1. What the installation requires; how to install
2. For each experiment
   1. Extra installation if any
   2. Script to run
   3. Where to look for the graph
   4. How long it takes
Good and repeatable performance evaluation and experimental assessment require no fancy magic but rather solid craftsmanship.

Proper planning helps to keep you from “getting lost” and ensure repeatability.

Repeatable experiments simplify your own work (and help others to understand it better).

There is no single way how to do it right.

There are many ways how to do it wrong.

We provided some simple rules and guidelines what (not) to do.