Performance Analysis

http://d3s.mff.cuni.cz

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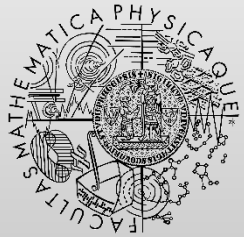

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Performance analysis

- Find where the program spends most time
  - Identify code that you should optimize for speed
- Call graph: function names and spent time
- Important performance characteristics
  - throughput, latency, maximal load, average request processing time, ...

- Main approaches
  - **profiling**, benchmarking, load testing

Profiling

- Tools measuring frequency and duration of procedure calls during program execution
  - **GProf**, `perf`, OProfile, Valgrind, Intel VTune

- Basic principles (how it works)
  - Sampling: results not precise for short time periods
  - Recording program counter (PC) at regular intervals
  - Program instrumented with profiling-related code
  - Getting information from HW performance counters

GProf

- GNU Profiler
  - Distributed as a part of `binutils`

- Documentation
  - https://sourceware.org/binutils/docs/gprof/

How to use GProf

1) Build program with enabled profiling

```
gcc -g -pg -o program program.c
```

- Instrumentation: code that collects raw timing data added to the entry and exit points of each function

2) Execute the program normally

- Raw profile data written to the file `gmon.out`

3) Generate statistics (tables with results)

```
gprof <options> program [gmon.out]
```

- Output: flat profile, call graph

Flat profile

- How to get it
  - `gprof -p program [gmon.out]`
  - Excluding specific function
    - `gprof -p -P<function_name> program`

% time	cumulative seconds	self seconds	calls	self ms/call	total ms/call	name
35.29	0.06	0.06	3	20.00	43.33	compute
32.35	0.12	0.06	14000896	0.00	0.00	S_n
17.65	0.14	0.03	3	10.00	53.33	get_msg
5.88	0.15	0.01	5000320	0.00	0.00	F
5.88	0.17	0.01				main

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Example

- Basic features of GProf
  - Generating the flat profile
  - Excluding some functions
- Subject program
  - http://d3s.mff.cuni.cz/files/teaching/nswi154/sha.tgz
- Program has to run for a long time (at least few seconds) to get useful results
  - Measurement results are invalid otherwise

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Flat profile: source code lines

- How to get it
  - `gprof -p -l program`

```
Each sample counts as 0.01 seconds.
 %   cumulative   self
time   seconds   seconds          name
17.65      0.03     0.03         S_n (sha.c:18 @ 80485f9)
11.76      0.05     0.02  ....   S_n (sha.c:17 @ 80485f0)
11.76      0.07     0.02         compute (sha.c:152 @ 804895b)
11.76      0.09     0.02         get_msg (sha.c:192 @ 8048baa)
```

Call graph

- How to get it
  - `gprof -q program`

```
index % time    self  children    called     name
-----------------------------------------------
                0.03    0.13       3/3          main [1]
[2]     94.1    0.03    0.13       3         get_message_digest [2]
                0.06    0.07       3/3          compute_digest [3]
                0.00    0.00       3/3          get_padded_length [10]
                0.00    0.00       3/3          padd_message [11]
-----------------------------------------------
                0.06    0.07       3/3          get_message_digest [2]
[3]     76.5    0.06    0.07       3         compute_digest [3]
                0.06    0.00 14000896/14000896  S_n [4]
                0.01    0.01 5000320/5000320    F [5]
-----------------------------------------------
```

The perf utility

- Collects and presents various performance data (metrics)
  - executed instructions, branches, page faults, ...
  - Linux (user space and kernel)

- Resources
  - https://perfwiki.github.io/main/
  - https://perfwiki.github.io/main/top-down-analysis/
  - https://perfwiki.github.io/main/tutorial/

Performance analysis

- It is hard and tricky
  - Profiling results not 100% precise
  - Statistical approximation is used
  - Many things influence performance
    - Resource sharing (caches), garbage collection
  - Even harder for programs in JVM / .NET CLR

- Recommended practice
  - Use profilers only to identify parts of your program that are much slower than others

VisualVM

- GUI profiler for Java (heap, CPU)
- Documentation
  - https://visualvm.github.io/
- Important features
  - Heap dump
  - CPU sampling

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Visual Studio profiling

- Available tools
  - CPU usage, memory usage, and many others
- Web (documentation, tutorials)
  - https://learn.microsoft.com/en-us/visualstudio/profiling/?view=vs-2022

Other profiling tools

- YourKit
  - Powerful profiler for Java and .NET
  - http://yourkit.com/home/index.jsp
  - Many advanced features (see web)
  - Handles also very large applications
- dotTrace
  - Target platform: C#, .NET applications
  - https://www.jetbrains.com/profiler/
- PerfView
  - https://github.com/microsoft/perfview

Other profiling tools

- Valgrind
  - Supported tools: Cachegrind, Callgrind, Massif, DHAT, …
  - Running: `--tool=<cachegrind | callgrind | massif>`
  - Inspecting results: `cg_annotate`, `callgrind_annotate`, `ms_print`
  - Demo: using tools on some program

- Intel VTune
  - https://www.intel.com/content/www/us/en/developer/tools/oneapi/vtune-profiler.html

Performance measurements – literature

- John Ousterhout. Always Measure One Level Deeper. Communications of the ACM, July 2018, Vol. 61 No. 7
  - https://cacm.acm.org/magazines/2018/7/229031-always-measure-one-level-deeper/fulltext
  - Describes common mistakes and suggestions how engineers should do measurements of software performance (methodology, infrastructure, hints)

Load testing

- Generating specific (heavy) load for server applications (WWW, email, database)
  - Target URL and payload
  - Number of threads (clients)
  - Frequency of requests
- JMeter (http://jmeter.apache.org/)
  - supports: GUI, command-line, distributed mode
- Netling (https://github.com/hallatore/Netling)

Coverage

- Metrics
  - Statement coverage
  - Branch coverage
  - Control-flow paths
- Tools
  - GCov (https://gcc.gnu.org/onlinedocs/gcc/Gcov.html)
  - JCov (https://wiki.openjdk.java.net/display/CodeTools/jcov)
  - JaCoCo (http://www.jacoco.org/jacoco/)

Measuring coverage with GCov

- Build program with special options
  - `gcc -fprofile-arcs -ftest-coverage -o program program.c`
- Execute the program normally
- Run the gcov tool on source code files
  - `gcov program.c`
- Open the file `program.c.gcov`

- With branch and block statistics
  - `gcov -b program.c`

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Related tools

- Compiler Explorer
  - https://godbolt.org/

Related courses

- NSWI131: Vyhodnocování výkonnosti počítačových systémů
  - Topics: benchmarking, experimental evaluation, statistical analysis, modeling, simulation

- NSWI126: Pokročilé nástroje pro vývoj a monitorování software
  - Topics: other profilers and performance analyzers
  - ZS 2025/2026

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Homework

- Assignment
  - ReCodEx: group associated with this course
  - Web: http://d3s.mff.cuni.cz/files/teaching/nswi154/ukoly/
- Deadline
  - 7.5.2025

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