Performance measurements of computer systems: tools and analysis

Master 2R SL module MD

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Outline

1. Introduction, Definitions, Classifications
   - Performance Metric
   - Monitors & Measurements

2. Monitoring Examples
   - Measuring Time: Practical Considerations
   - Sequential Program Execution Monitoring: Profiling
   - “API-based” Monitoring Examples
   - Indirect Metrics

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Performance Metric

Metrics are criteria to compare the performances of a system.
In general, the metrics are related to speed, accuracy, reliability and availability of services.
The basic characteristis of a computer system that we typically need to measure are:

- a count of how many times an event occurs,
- the duration of some time interval, and
- the size of some parameter.

From these types of measured values, we can derive the actual value that we wish to use to describe the system: the performance metric.

Performance Metric Characterization

Reliability A system A always outperforms a system $B \Leftrightarrow$ the performance metric indicates that A always outperforms B.

Repeatability The same value of the metric is measured each tme the same experiments is performed.

Consistency Units of the metrics and its precise definition are the same across different systems and different configurations of the same system.

Linearity The value of the metric should be linearly proportional to the actual performance of the machine.

Easiness of measurement If a metric is hard to measure, it is unlikely anyone will actually use it. Moreover it is more likely to be incorrectly determined.

Independence Metrics should not be defined to favor particular systems.

Many metrics do not fulfill these requirements.

Performance as Time

- Time between the start and the end of an operation
  - Also called running time, elapsed time, wall-clock time, response time, latency, execution time, ...
  - Most straightforward measure: "my program takes 12.5s on a Pentium 3.5GHz"
  - Can be normalized to some reference time
- Must be measured on a "dedicated" machine

Performance as Rate

Used often so that performance can be independent on the "size" of the application (e.g., compressing a 1MB file takes 1 minute. compressing a 2MB file takes 2 minutes $\leadsto$ the performance is the same).

MIPS Millions of instructions / sec $= \frac{\text{instruction count}}{\text{execution time} \times 10^6} = \frac{\text{clock rate}}{\text{CPI} \times 10^6}$.

But Instructions Set Architectures are not equivalent

- 1 CISC instruction = many RISC instructions
- Programs use different instruction mixes
- May be ok for same program on same architectures

MFlops Millions of floating point operations /sec

- Very popular, but often misleading
- e.g., A high MFlops rate in a stupid algorithm could have poor application performance

Application-specific

- Millions of frames rendered per second
- Millions of amino-acid compared per second
- Millions of HTTP requests served per seconds

Application-specific metrics are often preferable and others may be misleading

“Peak” Performance?

Resource vendors always talk about peak performance rate

- computed based on specifications of the machine
- For instance:
  - I build a machine with 2 floating point units
  - Each unit can do an operation in 2 cycles
  - My CPU is at 1GHz
  - Therefore I have a 1*2/2 =1GFlops Machine
- Problem:
  - In real code you will never be able to use the two floating point units constantly
  - Data needs to come from memory and cause the floating point units to be idle

Typically, real code achieves only an (often small) fraction of the peak performance

Benchmarks

- Since many performance metrics turn out to be misleading, people have designed benchmarks
- Example: SPEC Benchmark
  - Integer benchmark
  - Floating point benchmark
- These benchmarks are typically a collection of several codes that come from "real-world software"
- The question "what is a good benchmark" is difficult
  - A benchmark is representative of a given workload.
  - If the benchmarks do not correspond to what you'll do with the computer, then the benchmark results are not relevant to you
- Other typical benchmarks
  - Livermore loops, NAS kernels, LINPACK, . . .
  - SPEC SFS, SPECWeb, . . .

How About GHz?

- This is often the way in which people say that a computer is better than another
  - More instruction per seconds for higher clock rate
- Faces the same problems as MIPS

Processor	Clock Rate	SPEC FP2000 Benchmark
IBM Power3	450 MHz	434
Intel PIII	1.4 GHz	456
Intel P4	2.4GHz	833
Itanium-2	1.0GHz	1356

- But usable within a specific architecture

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Monitor

A Monitor is a tool to observe the activities on a system. In general, a monitor:

1. makes measurements on the system (Observation)
2. collects performance statistics (Collection),
3. analyzes the data (Analysis),
4. displays results (Presentation).

Why do we want a monitor ?

- A programmer wants to find frequently used segments of a program to optimize them.
- A system administrator wants to measure resource utilizations to find performance bottlenecks.
- A system administrator wants to tune the system and measure the impact of system parameters modifications on the system performance.
- An analyst wants to characterize the workload. Results may be used for capacity planning and for creating test workloads.
- An analyst wants to find model parameters, to validate models or to develop inputs for models.

Monitor Terminology

Event A change in the system state (context switch, seek on a disk, packet arrival, . . .).

Trace Log of events usually including the time of the events, their type and other important parameters.

Overhead Measurement generally induce slight perturbations and consume system resources (CPU, storage,. . .).

Domain The set of activites observable by the monitor (CPU time, number of bytes sent on a network card,. . .).

Input Rate The maximum frequency of events that a monitor can correctly observe. One generally distinguish between burst rate and sustained rate.

Resolution Coarseness of the information observed.

Input Width The number of bits of information recorded on an event.

Portability Amount of system modificitions required to implement the monitor.

Events and metrics

The different types of metrics that an analyst may wish to measure can be classified into the following categories:

Event-count metrics Simply count the number of times a specific event occurs (e.g., number of page faults, number of disk I/O made by a program).

Secondary-event metrics These types of metrics record the values of some secondary parameters whenever a given event occurs (e.g., the average message size).

Profiles A profile is an aggregate metric used to charactrize the overall behavior of an application program or of an entire system.

Observation mechanisms

Observation is commonly performed with three mechanisms:

Implicit spying it is sometimes possible to spy the system without really interfering with it (listening on a local ethernet bus or in wireless environments). Thus, there is almost no impact on the performance of the system being monitored. Implicit-spying is generally used with filters because many observed data are not interesting.

Explicit Instrumenting By incorporating trace points, probe points, hooks or counters, additional informations to implicit-spying can be obtained. Some systems offer an API to incorporate such hooks or exports the values of internal counters.

Probing Making “feeler” requests on the system to sense its current performance.

Some activities can be observed by only one of the three mechanisms.

Activation Mechanisms

Event-driven Record the information whenever a given event occurs. Generally done with counters. The overhead is thus proportionnal to the frequency of events.

Tracing Similar to event-driven strategies, except that parts of the system state are also recorded. This is thus even more time-consuming and also also requires much more storage.

Sampling Recording of informations occurs periodically. The overhead and the resolution of the sampling can thus be adjusted. This strategies produces a statistical summary of the overall behavior of the system. Events that occurs infrequently may be completly missed. Results may also be different from one run to the other.

Indirect An indirect measurement must be used ben the metric that is to be determined is not directly accessible (e.g., for portability reasons or for practical reasons). In this case, one must find anoter metric that can be measured directly, from which one can deduce or derive the desired performance metric.

Generally, a model of the system is underlying the deduced metric and the quality of this model is fundamental.

Collection

The collection mechanism higly depends on whether we are working on a online monitor (system state is displayed during monitoring) or on a batch monitor (system state is stored for later analysis).

Most data need to be recorded in buffers, hence buffer management issues:

- buffer size is a function of input rate, input width and emptying rate,
- larger number of buffers allows to cope with variations in filling and emptying rates,
- buffer overflow management and tracking,
- data compression, on-line analysis,

Abnormal events should also be monitored and even handled at higher priority (low probability $\rightsquigarrow$ low overhead, possibility to take preventive action before the system becomes unavailable).

Distributed Monitoring Issues

- The problem of communication between m collectors and n observers often arises.
- We generally resort to hierarchy of collectors/observers for a better scalability. This intensifies all previous buffer management issues.
- When collecting data from several observers, clock synchronization often becomes an important issue. The tolerence or maximum allowed clock skew is often related to the round-trip delay. The larger the system, the more problematic clock skews.

Presentation

This layer is closely tied to the applications for which the monitor is used (performance monitoring, configuration monitoring, fault monitoring,. . .).

- Presentation frequency (for online monitors).
- Hierarchical representation/aggregation (space/time/states/values).
- Alarm mode (thresholds, abnormal events).

Measurement Induces Perturbations

- The system resources consumed by the measurement tool itself as it collects dat will strongly affect how much perturbation the tool will cause in the system.
- Tracing produces the highest level of perturbation (both CPU and disk are used), in particular on time measurements, spatial and temporal memory access (cache flush, different paging,...), or on system response time (and thus on workload characterization).
- The largest the overhead, the more likely the system behavior will be modified.

Measuring a system alters it

Remain alert to how these perturbations may bias your measurements and, ultimately, the conclusions you are able to draw from your experiments.

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Exercise

Try to find the main characteristics, advantages and drawbacks of the following monitors.

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Measuring time by hand?

- One possibility would be to do this by just “looking” at a clock, launching the program, “looking” at the clock again when the program terminates
- This of course has some drawbacks
  - Poor resolution
  - Requires the user’s attention
- Therefore operating systems provide ways to time programs automatically
- UNIX provide the `time` command

The UNIX time Command

- You can put `time` in front of any UNIX command you invoke
- When the invoked command completes, time prints out timing (and other) information

```
surf:~$ /usr/bin/X11/time ls -la -R ~/ > /dev/null
4.17user 4.34system 2:55.83elapsed 4%CPU
(0avgtext+0avgdata 0maxresident)k
0inputs+0outputs (0major+1344minor)pagefaults 0swaps
```

- 4.17 seconds of user time
- 4.34 seconds of system time
- 2 minutes and 55.85 seconds of wall-clock time
- 4% of CPU was used
- 0+0k memory used (text + data)
- 0 input, 0 output output (file system I/O)
- 1344 minor pagefaults and 0 swaps

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  - because the process can be suspended by the O/S due to contention for the CPU by other processes

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- Wall-Clock $\geq$ User + System. Why?
  - because the process can be suspended by the O/S due to contention for the CPU by other processes
  - because the process can be blocked waiting for I/O

Using time

- It's interesting to know what the user time and the system time are
  - for instance, if the system time is really high, it may be that the code does to many calls to malloc(), for instance
  - But one would really need more information to fix the code (not always clear which system calls may be responsible for the high system time)
- Wall-clock - system - user $\simeq$ I/O $+$ suspended
  - If the system is dedicated, suspended $\simeq 0$
  - Therefore one can estimate the ecost of I/O
  - If I/O is really high, one may want to look at reducing I/O or doing I/O better
- Therefore, time can give us insight into bottlenecks and gives us wall-clock time
- Measurements should be done on dedicated systems
- `time` relies on `times(2)`, `getrusage(2)` and `clock(3)`.

Dedicated Systems

- Measuring the performance of a code must be done on a "quiescent", "unloaded" machine (the machine only runs the standard O/S processes)
- The machine must be dedicated
  - No other user can start a process
  - The user measuring the performance only runs the minimum amount of processes (basically, a shell)
- Nevertheless, one should always present measurement results as averages over several experiments (because the (small) load imposed by the O/S is not deterministic)

Drawbacks of UNIX `time`

- The `time` command has poor resolution
  - "Only" milliseconds
  - Sometimes we want a higher precision, especially if our performance improvements are in the 1-2% range
- `time` times the whole code
  - Sometimes we're only interested in timing some part of the code, for instance the one that we are trying to optimize
  - Sometimes we want to compare the execution time of different sections of the code

Timing with gettimeofday

- gettimeofday from the standard C library
- Measures the number of microseconds since midnight, Jan 1st 1970, expressed in seconds and microseconds

```
struct timeval start;
...
gettimeofday(&tv,NULL);
printf("%ld,%ld\n",start.tv_sec, start.tv_usec);
```

- Can be used to time sections of code
  - Call gettimeofday at beginning of section
  - Call gettimeofday at end of section
  - Compute the time elapsed in microseconds: `(end.tv_sec*1000000.0 + end.tv_usec - start.tv_sec*1000000.0 - start.tv_usec) / 1000000.0`)

Other Ways to Time Code

- `ntp_gettime()` (Internet RFC 1589)
  - Sort of like `gettimeofday`, but reports estimated error on time measurement
  - Not available for all systems
  - Part of the GNU C Library
- Java: `System.currentTimeMillis()`
  - Known to have resolution problems, with resolution higher than 1 millisecond!
  - Solution: use a native interface to a better timer
- Java: `System.nanoTime()`
  - Added in J2SE 5.0
  - Probably not accurate at the nanosecond level
- Tons of "high precision timing in Java" on the Web

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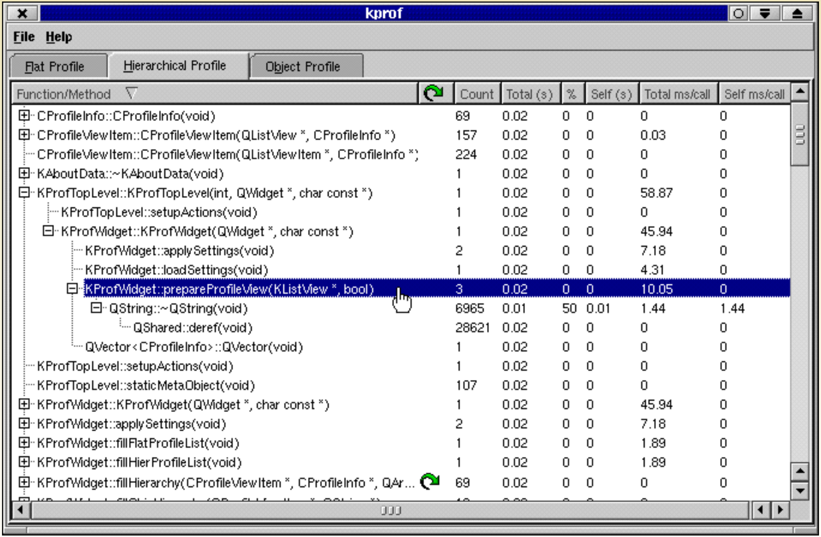
Profiling

- A profiler is a tool that monitors the execution of a program and that reports the amount of time spent in different functions
- Useful to identify the expensive functions
- Profiling cycle
  - Compile the code with the profiler
  - Run the code
  - Identify the most expensive function
  - Optimize that function (i.e. call it less often if possible or make it faster)
  - Repeat until you can't think of any ways to further optimize the most expensive function

Using gprof

- Compile your code using gcc with the -pg option
- Run your code until completion
- Then run gprof with your program's name as single command-line argument
- Example: `gcc -pg prog.c -o prog; ./prog gprof prog > profile_file`
- The output file contains all profiling information (amount and fraction of time spent in which function)

Using gprof



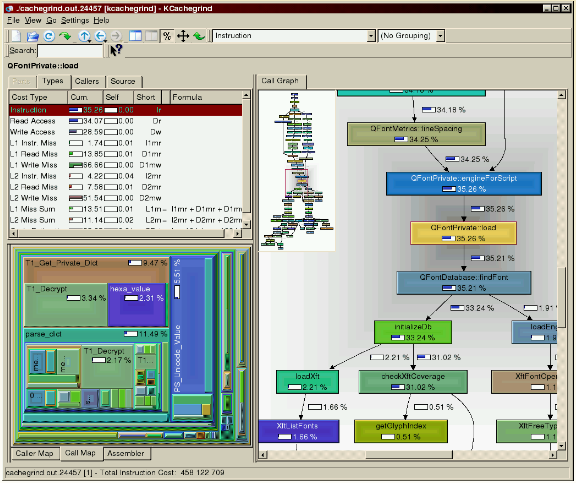
Function/Method	Count	Total (s)	%	Self (s)	Total ms/call	Self ms/call
⊞ CProfileInfo::CProfileInfo(void)	69	0.02	0	0	0	0
⊞ CProfileViewItem::CProfileViewItem(QListView *, CProfileInfo *)	157	0.02	0	0	0.03	0
CProfileViewItem::CProfileViewItem(QListViewItem *, CProfileInfo *)	224	0.02	0	0	0	0
⊞ KAboutData::~KAboutData(void)	1	0.02	0	0	0	0
⊟ KProfTopLevel::KProfTopLevel(int, QWidget *, char const *)	1	0.02	0	0	58.87	0
KProfTopLevel::setupActions(void)	1	0.02	0	0	0	0
⊟ KProfWidget::KProfWidget(QWidget *, char const *)	1	0.02	0	0	45.94	0
KProfWidget::applySettings(void)	2	0.02	0	0	7.18	0
KProfWidget::loadSettings(void)	1	0.02	0	0	4.31	0
⊟ KProfWidget::prepareProfileView(KListView *, bool)	3	0.02	0	0	10.05	0
⊟ QString::~QString(void)	6965	0.01	50	0.01	1.44	1.44
QShared::deref(void)	28621	0.02	0	0	0	0
QVector<CProfileInfo>::QVector(void)	1	0.02	0	0	0	0
KProfTopLevel::setupActions(void)	1	0.02	0	0	0	0
KProfTopLevel::staticMetaObject(void)	107	0.02	0	0	0	0
⊞ KProfWidget::KProfWidget(QWidget *, char const *)	1	0.02	0	0	45.94	0
⊞ KProfWidget::applySettings(void)	2	0.02	0	0	7.18	0
⊞ KProfWidget::fillFlatProfileList(void)	1	0.02	0	0	1.89	0
⊞ KProfWidget::fillHierProfileList(void)	1	0.02	0	0	1.89	0
⊞ KProfWidget::fillHierarchy(CProfileViewItem *, CProfileInfo *, QAr...	69	0.02	0	0	0	0

Callgrind

- Callgrind is a tool that uses runtime code instrumentation framework of Valgrind for call-graph generation
- Valgrind is a kind of emulator or virtual machine.
  - It uses JIT (just-in-time) compilation techniques to translate x86 instructions to simpler form called ucode on which various tools can be executed.
  - The ucode processed by the tools is then translated back to the x86 instructions and executed on the host CPU.
- This way even shared libraries and dynamically loaded plugins can be analyzed but this kind of approach results with huge slow down (about 50 times for callgrind tool) of analyzed application and big memory consumption.

Callgrind/Kcachegrind

Data produced by callgrind can be loaded into KCacheGrind tool for browsing the performance results.



QFontPrivate::load

Cost Type	Cum.	Self	Short		Formula
Instruction	35.26	0.00	Ir		
Read Access	34.07	0.00	Dr		
Write Access	28.59	0.00	Dw		
L1 Instr. Miss	1.74	0.01	I1mr		
L1 Read Miss	13.85	0.01	D1mr		
L1 Write Miss	66.66	0.00	D1mw		
L2 Instr. Miss	4.22	0.04	I2mr		
L2 Read Miss	7.58	0.01	D2mr		
L2 Write Miss	51.54	0.00	D2mw		
L1 Miss Sum	13.51	0.01	L1m=		I1mr + D1mr + D1m
L2 Miss Sum	11.14	0.02	L2m=		I2mr + D2mr + D2m

cachegrind.out.24457 [1] - Total Instruction Cost: 458 122 709

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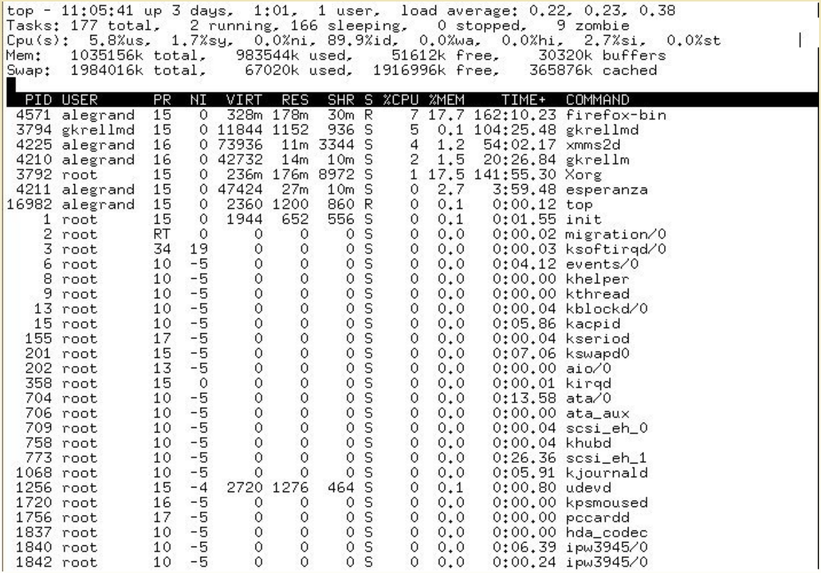
top



```
top - 11:05:41 up 3 days,  1:01,  1 user,  load average: 0.22, 0.23, 0.38
Tasks: 177 total,   2 running, 166 sleeping,   0 stopped,   9 zombie
Cpu(s):  5.8%us,  1.7%sy,  0.0%ni, 89.9%id,  0.0%wa,  0.0%hi,  2.7%si,  0.0%st
Mem:   1035156k total,   983544k used,    51612k free,    30320k buffers
Swap:  1984016k total,    67020k used,  1916996k free,   365876k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 4571 alegrand  15   0  328m 178m  30m R    7 17.7 162:10.23 firefox-bin
 3794 gkrellmd  15   0 11844 1152  936 S    5  0.1 104:25.48 gkrellmd
 4225 alegrand  16   0 73936  11m 3344 S    4  1.2  54:02.17 xmms2d
 4210 alegrand  16   0 42732  14m  10m S    2  1.5  20:26.84 gkrellm
 3792 root      15   0  236m 176m 8972 S    1 17.5 141:55.30 Xorg
 4211 alegrand  15   0 47424  27m  10m S    0  2.7   3:59.48 esperanza
16982 alegrand  15   0  2360 1200  860 R    0  0.1   0:00.12 top
    1 root      15   0  1944  652  556 S    0  0.1   0:01.55 init
    2 root      RT   0     0    0    0 S    0  0.0   0:00.02 migration/0
    3 root      34  19     0    0    0 S    0  0.0   0:00.03 ksoftirqd/0
    6 root      10  -5     0    0    0 S    0  0.0   0:04.12 events/0
    8 root      10  -5     0    0    0 S    0  0.0   0:00.00 khelper
    9 root      10  -5     0    0    0 S    0  0.0   0:00.00 kthread
   13 root      10  -5     0    0    0 S    0  0.0   0:00.04 kblockd/0
   15 root      10  -5     0    0    0 S    0  0.0   0:05.86 kacpid
  155 root      17  -5     0    0    0 S    0  0.0   0:00.04 kseriod
  201 root      15  -5     0    0    0 S    0  0.0   0:07.06 kswapd0
  202 root      13  -5     0    0    0 S    0  0.0   0:00.00 aio/0
  358 root      15   0     0    0    0 S    0  0.0   0:00.01 kirqd
  704 root      10  -5     0    0    0 S    0  0.0   0:13.58 ata/0
  706 root      10  -5     0    0    0 S    0  0.0   0:00.00 ata_aux
  709 root      10  -5     0    0    0 S    0  0.0   0:00.04 scsi_eh_0
  758 root      10  -5     0    0    0 S    0  0.0   0:00.04 khubd
  773 root      10  -5     0    0    0 S    0  0.0   0:26.36 scsi_eh_1
 1068 root      10  -5     0    0    0 S    0  0.0   0:05.91 kjournald
 1256 root      15  -4  2720 1276  464 S    0  0.1   0:00.80 udevd
 1720 root      16  -5     0    0    0 S    0  0.0   0:00.00 kpsmoused
 1756 root      17  -5     0    0    0 S    0  0.0   0:00.00 pccardd
 1837 root      10  -5     0    0    0 S    0  0.0   0:00.00 hda_codec
 1840 root      10  -5     0    0    0 S    0  0.0   0:06.39 ipw3945/0
 1842 root      10  -5     0    0    0 S    0  0.0   0:00.24 ipw3945/0
```

How does top get all these informations?

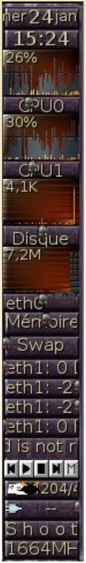
It uses /proc!

```
kanza:  $ ldd ‘which top‘
  linux-gate.so.1 libproc-3.2.7.so.5
  libncurses.so libc.so.6
  libdl.so.2 /lib/ld-linux.so.2
```

`/proc` is a way for the kernel to provice information about the status of entries in its process table.

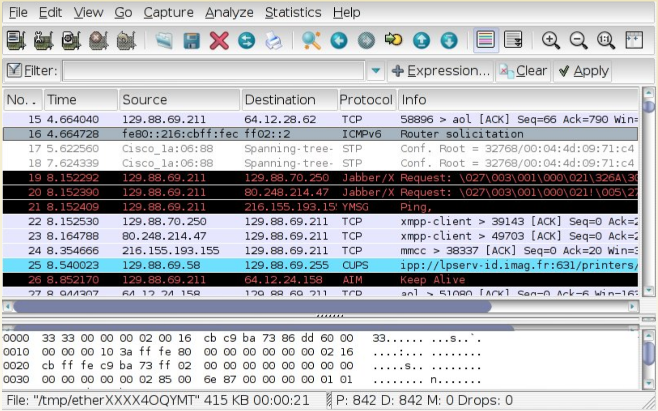
On systems where `/proc` is available, there is no need to instrument the kernel or the application to get these informations. Measures are always but it doesn't mean that `top` does not induce perturbations. . . .

Other tools (e.g., `gkrellm`) rely on the same API.



Getting finer informations

TCPdump is based on libpcap and enables to dump the traffic on a network card.



```
No. . Time      Source              Destination       Protocol  Info
   15 4.664040  129.88.69.211       64.12.28.62       TCP       58896 > aol [ACK] Seq=66 Ack=790 Win=
   16 4.664728  fe80::216:cbff:fec  ff02::2           ICMPv6    Router solicitation
   17 5.622560  Cisco_1a:06:88      Spanning-tree-    STP       Conf. Root = 32768/00:04:4d:09:71:c4
   18 7.624339  Cisco_1a:06:88      Spanning-tree-    STP       Conf. Root = 32768/00:04:4d:09:71:c4
   19 8.152292  129.88.69.211       129.88.70.250     Jabber/X  Request: \027\003\001\000\021\326A\30
   20 8.152390  129.88.69.211       80.248.214.47     Jabber/X  Request: \027\003\001\000\021!\005\27
   21 8.152409  129.88.69.211       216.155.193.15!   YMSG      Ping,
   22 8.152530  129.88.70.250       129.88.69.211     TCP       xmpp-client > 39143 [ACK] Seq=0 Ack=2
   23 8.164788  80.248.214.47       129.88.69.211     TCP       xmpp-client > 49703 [ACK] Seq=0 Ack=2
   24 8.354666  216.155.193.155     129.88.69.211     TCP       mmcc > 38337 [ACK] Seq=0 Ack=20 Win=3
   25 8.540023  129.88.69.58        129.88.69.255     CUPS      ipp://lpserv-id.imag.fr:631/printers/
   26 8.852170  129.88.69.211       64.12.24.158      AIM       Keep Alive
   27 8.944307  64.12.24.158        129.88.69.211     TCP       aol > 51080 [ACK] Seq=0 Ack=6 Win=16:
```

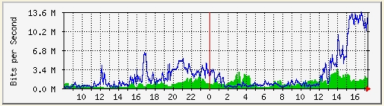
```
0000  33 33 00 00 00 02 00 16  cb c9 ba 73 86 dd 60 00   33...... ...s..`.
0010  00 00 00 10 3a ff fe 80  00 00 00 00 00 00 02 16   ....:... ........
0020  cb ff fe c9 ba 73 ff 02  00 00 00 00 00 00 00 00   .....s.. ........
0030  00 00 00 00 00 02 85 00  6e 87 00 00 00 00 01 01   ........ n.......
```

File: "/tmp/etherXXXX4OQYMT" 415 KB 00:00:21 P: 842 D: 842 M: 0 Drops: 0

/proc is rather common but accessing such informations requires specific access permissions. Such library does not work on high performance cards such as MyriNet, InfiniBand, ...

SNMP-based tools

- The Simple Network Management Protocol (SNMP) is an application layer protocol that facilitates the exchange of management information between network devices. It is part of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. SNMP enables network administrators to manage network performance, find and solve network problems, and plan for network growth.
- Many tools build upon SNMP to gather informations on routers



- SNMP can even be used to build maps of the network. However, SNMP requires specific access permissions and is often closed for network security reasons.

Hard things

- An API to access monitoring informations is often available but not always. . .
- Even when these monitors are "built-in", they are generally low-level and building a usable high-level monitoring tool requires a lots of work on:
  - Sampling
  - Collection
  - Analysis and Presentation
- When such an API is not available you can:
  - either design a low-level monitor if possible,
  - ot try to evaluate the metric you are interested in an other way.

Outline

1 Introduction, Definitions, Classifications
- Performance Metric
- Monitors & Measurements

2 Monitoring Examples
- Measuring Time: Practical Considerations
- Sequential Program Execution Monitoring: Profiling
- "API-based" Monitoring Examples
- Indirect Metrics

Atlas

- ATLAS (Automatically Tuned Linear Algebra Software) is an approach for the automatic generation and optimization of numerical software (BLAS and a subset of the linear algebra routines in the LAPACK library).
- To produce such kernels, ATLAS needs to know the number of cache levels, their respective sizes, whether the processor has the ability to perform additions and multiplications at the same time, whether it can make use of vector registers or specific instruction sets (e.g., 3dnow, SSE1, or SSE2 extensions). . .
- There is no portable API providing such informations, therefore ATLAS runs some probes to guess these values.

NWS

- The Network Weather Service is the de facto standard of the emerging Grid community to monitor the system availability. It provides high-level metrics to help applications and schedulers. It also provides trends thanks to a set of statistical forecasters.
- Available cpu share for a new process ((system+user)/(total)): due to the process priorities and other scheduling tricks, this value is hard to guess from the `/proc` values without actually probing. As probes are intrusive, NWS uses `/proc` values and uses a correcting factor based on regular probes.
- Available bandwidth between two hosts: how much bandwidth would get an application using a single standard socket ? Active probes are performed.
- What about the capacity of network links between two hosts? Pathchar infers the characteristics of links along an Internet path by sending series of probes with varying values of TTL and of size and using statistical analysis.

A last example

Peer-to-peer systems:

- Having good evaluations of the current number of peers is a crucial problem and an active research domain.
- "Probabilistic games" give good results.

Main Issue

All the previous approach rely on a model of the system and on parameters estimation based on the expected model prediction. When the model is incorrect, the estimation is likely to be incorrect as well.

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