Understanding load averages and stretch factors

STRETCH!

What is the real meaning of those little "load average" values in the output of shell commands like procinfo and uptime, and what can you do with these numbers?

BY NEIL J. GUNTHER

Most Linux system administrators are familiar with those three little numbers that appear in shell commands like *procinfo*, *uptime*, *top*, and remote host *ruptime*. Uptime, for example, emits:

```
9:40am up 9 days, ➘
load average: 0.02, 0.01, 0.00
```

The load average metrics are always included within the output of commands like *uptime*. While the load average is well known to Linux system administrators, its meaning is often poorly understood. The man page for *uptime* states that these values represent

```
a one line display of ... ➘
the system load averages for ➘
the past 1, 5, and 15 minutes.
```

which explains why there are three numbers, but it does not explain what the word *load* means or how to use these figures to forecast and troubleshoot system performance. This article takes a close look at the load average metrics and how to use them.

Controlled Experiments

I'll start with a small experiment to demonstrate how the load average values respond to changes in system load. Experimental load averages were sampled over a one-hour period (3600 seconds) on an otherwise quiescent single-CPU Linux box. These tests consisted of two phases. Two CPU-intensive jobs were initiated as background processes and allowed to execute for 2100 seconds. At that point, these two processes were stopped simultaneously, but load average measurements were continued for another 1500 seconds after the jobs stopped.

Listing 1 is a Perl script that was used to sample the load average every 5 seconds using the *uptime* command

A C program called *burncpu.c* was designed to waste CPU cycles. Output from *top* shows the two instances of *burncpu* ranked as the highest CPU consumers during the measurement period when *getload* was running (Table 1).

Figure 1 shows that the 1-minute load average reaches a value of 2.0 after 300 seconds into the test; the 5-minute load average reaches 2.0 at around 1200 seconds; the 15-minute load average would reach 2.0 at approximately 4500 seconds; but the processes were killed at 2100 seconds.

Readers with a background in electrical engineering will immediately spot the striking resemblance between the data in Figure 1 and the voltage curves produced by charging and discharging an RC circuit. Notice that the maximum load during the test is equivalent to the number of CPU-intensive processes running at the time of the measurements.

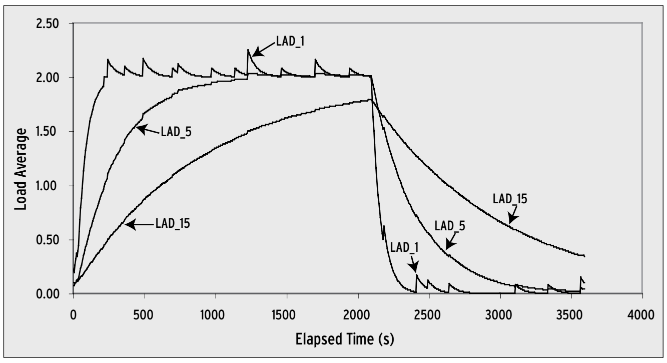
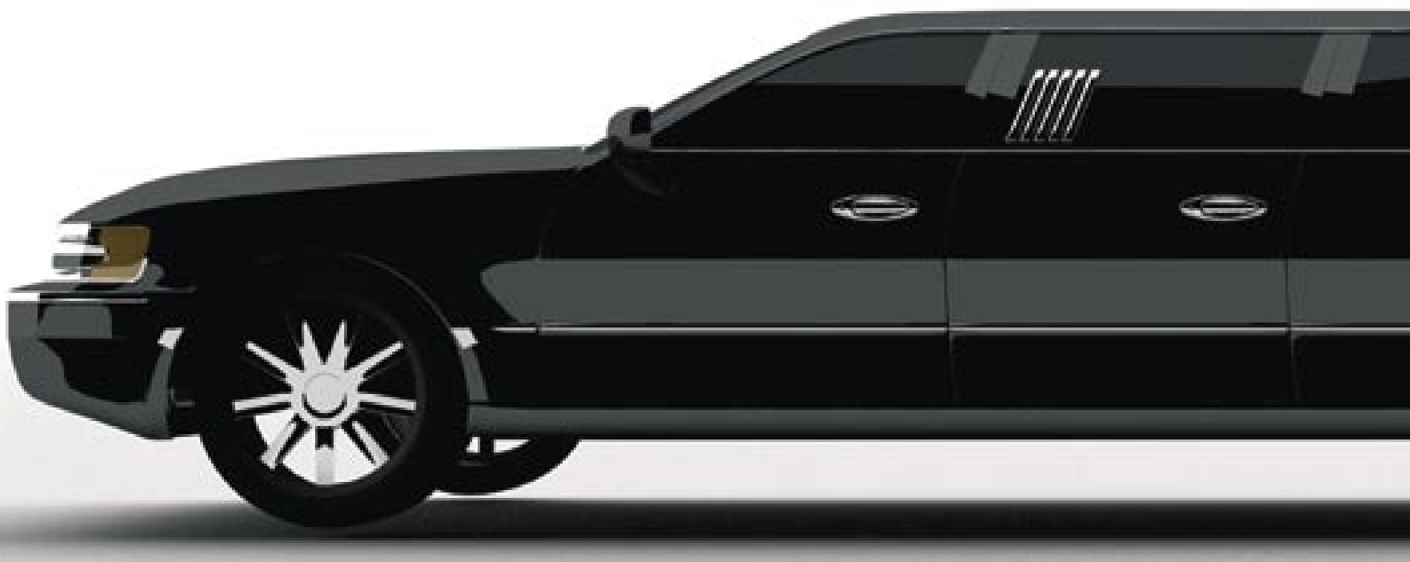


Figure 1: Load average data (LAD) collected on a controlled Linux platform during a one-hour period. LAD 1, LAD 5, and LAD 15 signify the 1-, 5-, and 15-minute metrics.



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Listing 1: Sampling the load average

```
#! /usr/bin/perl -w
$sample_interval = 5; # seconds

# Fire up background cpu-intensive tasks ...
system("./burncpu &");
system("./burncpu &");

# Perpetually monitor the load average via uptime
# and emit it as tab-separated fields for possible
# use in a spreadsheet program.
while (1) {

@uptime = split (/ /, 'uptime');
foreach $up (@uptime) {
# collect the timestamp
if ($up =~ m/(\d\d:\d\d:\d\d)/) {
print "$1\t";
}
# collect the three load metrics
if ($up =~ m/(\d{1,}\.\d\d)/) {
print "$1\t";
}
}
print "\n";
sleep ($sample_interval); }
```

The "fins" in the top curve are a result of various daemons waking up temporarily and then going back to sleep.

My next objective was to explain why the load average data from these experiments exhibits the characteristics seen in Figure 1. For that, I needed to explore the Linux kernel code that calculates the load average. I chose to use the Linux 2.6.20.1 source code [1], complete with cross-referencing hyperlinks for easier navigation and enhanced readability.

Kernel Code

Looking at the source code for the CPU scheduler [2], we find the C function function shown in Listing 2. This is the primary routine that calculates the load average metrics. Essentially, the routine checks to see whether the sample period has expired, resets the sampling counter, and calls the subroutine *CALC_LOAD* to calculate each of the 1-minute, 5-minute, and 15-minute metrics. The sampling interval used for *LOAD_FREQ* is 5*HZ. How long is that interval?

Every Linux platform has a clock implemented in hardware. This hardware clock has a constant ticking rate by which the system is synchronized. To make this ticking rate known, the clock sends an interrupt to the kernel on every clock tick. The actual interval between ticks differs. Most Linux systems have the CPU tick interval set to 10ms of wall-clock time.

The specific definition of the tick rate is contained in a constant labeled HZ that is maintained in a system-specific header file called *param.h*. For the online Linux source code we are using here, you can see the value is 100 for an Intel platform in *lxr.linux.no/source/include/asm-i386/ param.h*, and for a SPARC-based system in *lxr.linux.no/source/include/asm-sparc/param.h*.

calc_load is called at a frequency defined by the tick rate – once every 5 seconds (not 5 times per second, as some people think). This sampling period of 5 seconds is independent of the 1-, 5-, and 15-minute reporting periods.

Load Average Revealed

The *calc_load* function in Listing 2 refers to the C macro *CALC_LOAD*, which does the real work of calculating the load average (Listing 3). *CALC_LOAD* is defined in *http://lxr.linux.no/source/include/linux/sched.h*.

Mathematically, *CALC_LOAD* is equivalent to taking the current value of the variable *load* and multiplying it by a factor called *exp*. This value of *load* is then added to a term comprising the number of active processes *n* multiplied by another variable called *FIXED_1-exp*. The last line of the macro decimalizes the value of load.

We also know that the macro variable *exp* is equivalent to $e^{-\sigma/r}$ (see the box on "Fixed-Point Arithmetic"), and *FIXED_1-exp* is equivalent to $1 - e^{-\sigma/r}$. Writing the *CALC_LOAD* macro in more conventional mathematical notation produces:

$$L(t) = L(t-1)\, e^{-\sigma/r} + n(t)\, (1 - e^{-\sigma/r}) \quad (1)$$

where *L(t)* is the current value of the load variable, *L(t – 1)* is its value from

the previous sample, and *n(t)* is the number of currently active processes.

A Linux process can be in one of about half a dozen states (depending on how you count), of which running, runnable (*R* in the *ps* command), and sleeping (*S* in *ps* command) are the three primary states. Each load-average metric is based on the total number of processes that are:

- runnable and waiting in the scheduler run queue
- currently running or executing on a processor.

In queueing theory terminology, the total active processes is called a queue. It literally means not just those processes that are in the waiting line (the so-called run queue), but also those that are currently being serviced (i.e., running). So, *CALC_LOAD* is the fixed-point arithmetic version of equation (1). (See the box titled "Fixed-Point Arithmetic.")

Listing 2: calc_load

```
1136 unsigned long avenrun[3];
1137
1138 EXPORT_SYMBOL(avenrun);
1139
1140 /*
1141 * calc_load -given tick count, update the avenrun load
     estimates.
1142 * This is called while holding a write_lock on xtime_lock.
1143 */
1144 static inline void calc_load(unsigned long ticks)
1145 {
1146 unsigned long active_tasks; /* fixed-point */
1147 static int count = LOAD_FREQ;
1148
1149 count -= ticks;
1150 if (unlikely(count < 0)) {
1151 active_tasks = count_active_tasks();
1152 do {
1153 CALC_LOAD(avenrun[0], EXP_1, active_tasks);
1154 CALC_LOAD(avenrun[1], EXP_5, active_tasks);
1155 CALC_LOAD(avenrun[2], EXP_15, active_tasks);
1156 count += LOAD_FREQ;
1157 } while (count < 0);
1158 }
1159 }
```

Smoothing

It turns out that there is nothing particularly novel about the way the load average is calculated. In fact, a common technique for processing highly variable raw data for subsequent analysis is to apply some kind of smoothing function to that data. The general relationship between the raw input data and the smoothed output data is given by:

$$\underbrace{Y(t)}_{\text{smooth}} = Y(t-1) + \underbrace{\alpha}_{\text{const.}}\left[\underbrace{X(t)}_{\text{raw}} - Y(t-1)\right] \quad (2)$$

The smoothing function in equation (2) is an exponential filter or exponentially smoothed moving average of the type used in financial forecasting [3] and signal processing. The parameter α in equation (2) is commonly called the smoothing constant, while $(1 - \alpha)$ is called the damping factor. Both these factors can be directly related to the corresponding factors in equation (1). The magnitude of the smoothing coefficient $(0 <= \alpha <= 1)$ determines how much the current forecast must be corrected for error in the previous iteration of the forecast.

Notice that the exponential damping factor for r_1 in Table 4 agrees with the value calculated in the "Fixed-Point Arithmetic" sidebar to four decimal places. The 1-minute load average metric has the least damping, or about 8% correction, because it is the most responsive to instantaneous changes in the length of the run queue. Conversely, the 15-minute load average has the most damping, or only 1% correction, because it is the least responsive metric.

Stretch Factors

Inevitably, the question arises: What is a good load average? Since we now know that the load average is an exponentially damped moving average of activity in the process run queue, we could convert the question to, "How long should my queue be?"

Long queues correspond to long response times, so it's really the response time metric that should get your attention. One consequence is that a long queue can cause "poor response times," but that depends on what *poor* means. In most performance management tools, there is a disconnect between the measured run-queue length and the user-perceived response times. Another problem is that queue length is an absolute measure, whereas what is really needed is a relative performance measure. Even the

Table 1: Top Output

PID	USER	PRI	NI	SIZE	RSS	SHARE	STAT	%CPU	%MEM	TIME	CPU	COMMAND
20048	neil	25	0	256	256	212	R	30.6	0.0	0:32	0	burncpu
20046	neil	25	0	256	256	212	R	29.3	0.0	0:32	0	burncpu
15709	mir	24	0	9656	9656	4168	R	25.6	1.8	45:32	0	kscience.kss
1248	root	15	0	66092	10M	1024	S	9.5	2.1	368:25	0	X
20057	neil	16	0	1068	1068	808	R	2.3	0.2	0:01	0	top
1567	mir	15	0	39228	38M	14260	S	1.3	7.6	40:10	0	mozilla-bin

words *poor* and *good* are relative terms. Such a relative metric is called the stretch factor, and it measures the mean queue length relative to the mean number of requests already in service. It is expressed in multiples of service units. A stretch factor of 1 means no waiting time is involved.

What makes the stretch factor really useful is that it can easily be compared with service level targets. Service targets are usually expressed in certain types of business units (e.g., quotes per hour is a common business unit of work for an insurance industry). The expected service level is called the service level objective or SLO, and it is expressed as multiples of the relevant service unit. An SLO might be documented as, "The average user response time is not to exceed 15 service units between the peak operating hours of 10am and 2pm."

This is the same as saying the SLO shall not exceed a stretch factor of 15.

Using the symbols defined in Table 5, the stretch factor *f* can be calculated as the ratio:

$$f = \frac{Q}{mp} \quad (3)$$

From the experiments described earlier, we know that $m = 1$ because it was a single-process box, $Q = 2$ for the 1-minute load average, and $p = 1$ because the workload was CPU-bound. Substituting these values into equation (3) gives a stretch factor of $f = 2$. This result tells us that the expected time for any process to complete is two service periods. Notice that we don't have to know what the actual service period is. The stretch factor and the load average happen to be identical in this case, because the processes are running on a single processor and they are CPU-intensive. I'll describe a couple scenarios for using this stretch factor in real situations.

Anti-Spam Farm

All major email hosting services run spam analyzers. A typical configuration might consist of a set of specialized servers, each raking over email text using a filtering tool like SpamAssassin [4]. One such well-known, and therefore heavily trafficked, web portal has a battery of some 100 servers, each comprising two dual-cores, all performing 24/7 email scanning. Typical daily spam-filtering statistics are shown in Table 6.

A load balancer was used to distribute work into the server farm. The effectiveness of the load balancer was monitored using 1-minute load averages. The sample of these load averages from 50 of the servers (as shown in Figure 2) reveals an imbalance of work in the farm.

Listing 3: CALC_LOAD()

```
/*
 * These are the constant used to fake the fixed-point load-average
 * counting. Some notes:
 * - 11 bit fractions expand to 22 bits by the multiplies: this
   gives
 *   a load-average precision of 10 bits integer + 11 bits fractional
 * - if you want to count load-averages more often, you need more
 *   precision, or rounding will get you. With 2-second counting
   freq,
 *   the EXP_n values would be 1981, 2034 and 2043 if still using
   only
 *   11 bit fractions.
 */
extern unsigned long avenrun[];     /* Load averages */

#define FSHIFT      11            /* nr of bits of precision */
#define FIXED_1     (1<<FSHIFT)     /* 1.0 as fixed-point */
#define LOAD_FREQ   (5*HZ)         /* 5 sec intervals */
#define EXP_1       1884          /* 1/exp(5sec/1min) as
   fixed-point */
#define EXP_5       2014          /* 1/exp(5sec/5min) */
#define EXP_15      2037          /* 1/exp(5sec/15min) */

#define CALC_LOAD(load,exp,n) \
        load *= exp; \
        load += n*(FIXED_1-exp); \
        load >>= FSHIFT;
```

Table 2: Bit positions in 10.11 fixed-point format

<- 10 Bits ->					<--11 Bits -->						
0000000001	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
Bit Position:	10	9	8	7	6	5	4	3	2	1	0

Table 3: Magic Numbers for 5-second Sampling

Base	Sec.	1.exp(-5/r)	Rounded	Binary
r_1	60	1884.25	1884_{10}	11101011100_2
r_5	300	2014.15	2014_{10}	11111011110_2
r_{15}	900	2036.65	2037_{10}	11111110101_2

Table 4: Damping Factors for CALC_LOAD()

Timebase Parameter	Damping Factor	Smoothing Constant
r_1	0.9200	0.0800 (+/- 8%)
r_5	0.9835	0.0165 (+/- 2%)
r_{15}	0.9945	0.0055 (+/- 1%)

Table 5: Stretch Factor Definitions

m	number of processors or cores
Q	measured load average
p	measured processor utilization

A system administrator might ask:

- Why is there a load imbalance?
- Are most servers overdriven as a consequence of the load imbalance?
- Is a load average of Q = *97.36* emails desirable?
- What should be the actual server performance?
- How many additional servers will be needed in the next fiscal year to maintain current scanning performance at higher loads?

Let's substitute the load average into equation (3) to calculate the stretch factor:

$$f = \frac{97,36}{4 \bullet 0,99} = 24.59 \tag{4}$$

From Table 6, the average time to scan an email message (S) is 6 seconds.

So, a stretch factor of f = 25 service periods implies that it takes about 25 x 6 = 150 seconds or 2.5 minutes from the time an email message reaches the portal until it lands in the intended user's email box.

An absolute value of Q = 97.36 for the load average tells us very little. The relative stretch factor, however, tells you how many service periods the spam filtering is costing.

As for the question about whether a load average of 97.36 is desirable, that depends on the agreed upon service targets. At least now, such questions can be addressed quantitatively instead of speculatively.

You can also use the data in Table 6 to model the performance using a performance-prediction tool like PDQ. (See the box titled "PDQ in Python.")

The spam server model in PyDQ (PDQ in Python) is shown in Listing 4. Running this PDQ model produces a report that contains the output shown in Listing 5.

The stretch factor predicted by PDQ is a little bigger than we calculated using equation (3). Why is that? To learn why, you must examine the section of the PDQ report that presents server performance information (Listing 6).

Given the rate at which work is arriving (2376 emails per hour), each CPU

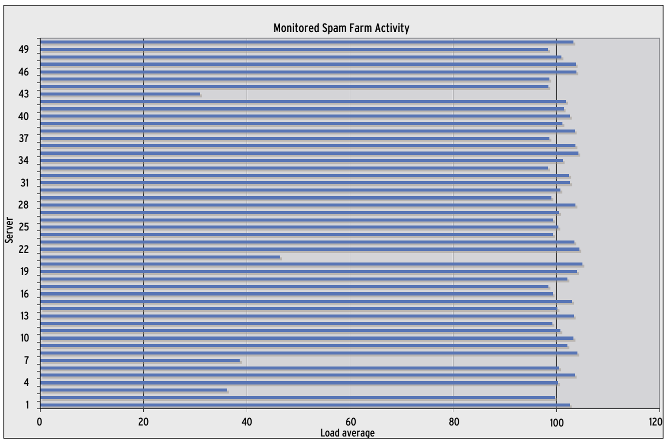

Figure 2: Measured load averages showing the unbalanced work distribution across a sample of 50 spam-farm servers.

Fixed-Point Arithmetic

The cryptic comment that precedes the *CALC_LOAD* macro in Listing 3 alerts us to the fact that fixed-point, rather than floating-point, arithmetic is used to calculate the load average. A fixed-point representation means that only a fixed number of digits, either decimal or binary, are used to express any number, including those that have a fractional part (mantissa) following the decimal point. Suppose, for example, that 4 bits of precision were allowed in the mantissa. You could precisely represent:

```
0.1234, -12.3401, 1.2000,
1234.0001
```

However, numbers like:

```
0.12346, -8.34051
```

could not be represented exactly and would be rounded off. Too much rounding can cause insignificant errors to compound into significant errors. One way around this is to increase the number of bits used to express the mantissa, assuming enough storage is available to accommodate the greater precision.

Suppose 10 bits are allowed for the integer part and 11 bits for the factional part. This is called an M.N = 10.11 format. The rules for fixed-point addition are the same as for integer addition; however, an important difference occurs with fixed-point multiplication. The product of two M.N fixed-point numbers is:

$$M.N \bullet M.N = (M + M),(N + N)$$

To get back to M.N format, the lower order bits are eliminated by shifting N bits.

CALC_LOAD uses serveral fixed-point constants. The first is the number *1*, which is labeled *FIXED_1*. In Table 2, the top row corresponds to *FIXED_1* expressed in 10.11 format, whereas the leading zeros and the decimal point have been dropped in the second row. The digits of the resulting binary *100000000000*$_2$ are indexed *0* through *11* on the last row of Table 2. This establishes that *FIXED_1* is equivalent to 2 to the11th power, or decimal 2048.

Using the C left-shift bitwise operator (<<), *100000000000*$_2$ can be written as *1 << 11, which is* in agreement with line 111 of the macro code. Alternatively, we can write *FIXED_1* as a decimal integer:

$$FIXED\_1 = 2048_{10}$$

to simplify calculation of the remaining constants: *EXP_1*, *EXP_5*, and *EXP_15*, for the 1-, 5-, and 15-minute metrics.

Consider the 1-minute metric as an example. If we denote the sample period as σ and the reporting period as *r*:

$$EXP\_1 \equiv e^{-\sigma/r}$$

σ = 5 seconds and for the 1-minute metric and *r* = 60 seconds. Furthermore, the decimal value of *EXP_1* is:

$$e^{-5/60} = 0,920044414643$$

To convert this to a 10.11 fixed-point fraction, you only need to multiply it by the fixed-point constant *FIXED_1* or *1* to produce:

$$[2048 \bullet 0,92004441463] = 1884_{10}$$

and round it to the nearest 11-bit integer. Each of the other magic numbers can be calculated in the same way, and the results are summarized in Table 3.

The results in Table 3 agree with the kernel defines:

```
#define EXP_1 1884
#define EXP_5 2014
#define EXP_15 2037
```

Listing 4: PDQ Spam Farm Model

```
#!/usr/bin/env python import pdq
# Measured performance parameters
cpusPerServer = 4
emailThruput = 2376 # emails per hour
scannerTime = 6.0 # seconds per email
pdq.Init("Spam Farm Model")
# Timebase is SECONDS ...
nstreams = pdq.CreateOpen("Email", float(emailThruput)/3600)
nnodes = pdq.CreateNode("spamCan", int(cpusPerServer), pdq.MSQ)
pdq.SetDemand("spamCan", "Email", scannerTime)
pdq.Solve(pdq.CANON)
pdq.Report()
```

PDQ in Python

PDQ (Pretty Damn Quick) is a modeling tool for analyzing the performance characteristics of computational resources, for example, processors disks and a set of processes that make requests for those resources. A PDQ model is analyzed using algorithms based on queueing theory. The current release facilitates building and analyzing performance models in C, Perl, Python, Java, and PHP.

The Python PDQ functions and procedures used in this section are:

- *pdq.Init()* initializes internal PDQ variables
- *pdq.CreateOpen()* creates a workload
- *pdq.CreateNode()* creates a server
- *pdq.SetDemand()* sets the workload service time on the server resource
- *pdq.Solve()* calculates performance metrics
- *pdq.Report()* generates a generic performance report

PDQ is maintained by Peter Harding and me. You'll find more information about the PDQ library online [5].

should be 99% busy. This utilization is higher than seen in the actual spam farm because of the load imbalance. PDQ is assuming ideal load balance across all servers, so more work is getting done. The predicted load average (Queue length metric in the PDQ report) is closer to 100 emails; therefore, the predicted stretch factor of *25.45* is a little larger than the calculated value of *24.59*.

Either stretch factor value was considered to be borderline acceptable under peak load conditions. Since all the servers are close to saturated, one recourse is to upgrade with faster CPUs or, more likely, procure new 4-way servers to handle the expected additional work. PDQ helps to size the number of new servers based on current and expected stretch factors. Clearly, it is the stretch factor ratio that provides a more meaningful indicator for performance management than the absolute load average by itself.

Number Cruncher

You can use a similar PyDQ model to see what it means to have no waiting line with all the CPUs busy. In this case, each Linux process takes 10 hours to complete because it is transforming oil-exploration data for further analysis by geophysicists. The corresponding PyDQ model is shown in Listing 7.

The PDQ resource performance report corresponding to Listing 7 is in Listing 8. The waiting line is essentially zero length and all four CPUs are busy, though only 25% utilized. If you were to look at the CPU statistics while the system was running, you would observe that each CPU was actually 100% busy. To understand what PDQ is telling us, look at the System Performance section of the PDQ report (Listing 9).

The stretch factor is 1 (service period) because there is no waiting line. It takes 10 hours for each job to finish, so the response is about 10 hours.

Table 6: Daily Spam Server Statistics

Number of CPUs	4
Spam detected	33901
Ham accepted	23123
Emails processed	57024
Emails per hour	2376
Per CPU/hour	594
CPU busy %	99
Secs per email	6
Load average	97.36

Listing 5: PDQ System Performance Output

```
****** SYSTEM Performance *******
Metric Value Unit
------ ----- ----
Workload:                "Email"
Number in system         100.7726 Trans
Mean throughput          0.6600 Trans/Sec
Response time            152.6858 Sec
Stretch factor           25.4476
```

Listing 6: PDQ Resource Performance Report

```
****** RESOURCE Performance *******
Metric Resource Work Value Unit
------ -------- ---- ----- ----
Throughput spamCan Email        0.0660 Trans/Sec
Utilization spamCan Email       99.0000 Percent
Queue length spamCan Email      100.7726 Trans
Waiting line spamCan Email      96.8126 Trans
Waiting time spamCan Email      146.6858 Sec
Residence time spamCan Email    152.6858 Sec
```

Listing 7: PyDQ Model

```
#!/usr/bin/env python import pdq
processors = 4 # Same as spam farm example
arrivalRate = 0.099 # Jobs per hour (very low arrivals)
crunchTime = 10.0 # Hours (very long service time)

pdq.Init("ORCA LA Model")
s = pdq.CreateOpen("Crunch", arrivalRate)
n = pdq.CreateNode("HPCnode", int(processors), pdq.MSQ)
pdq.SetDemand("HPCnode", "Crunch", crunchTime)
pdq.SetWUnit("Jobs")
pdq.SetTUnit("Hour")
pdq.Solve(pdq.CANON)
pdq.Report()
```

Listing 8: Resource Performance Output

```
****** RESOURCE Performance *******
Metric Resource Work Value Unit
------ -------- ---- ----- ----
Throughput HPCnode Crunch      0.0990 Jobs/Hour
Utilization HPCnode Crunch     24.7500 Percent
Queue length HPCnode Crunch    0.9965 Jobs
Waiting line HPCnode Crunch    0.0065 Jobs
Waiting time HPCnode Crunch    0.0656
```

The reason this appears a little odd is that PDQ makes predictions based on steady-state behavior (i.e., how the system looks in the long run). With a service time of 10 hours, you really need to observe the system for much longer than that to see what it looks like in steady state. Much longer here means on the order of 100 hours or longer. You don't actually need to do that, but PDQ is telling us how things would look if you did.

Since the average service period is relatively large, the request rate is correspondingly small so that no waiting line forms. This, means that the processor utilization of 25% is also low – in the long view. Looking at the system for just a few minutes while it is crunching 10 hours worth of oil-exploration data corresponds to an instantaneous snapshot of the system, not a steady-state view.

Both of the preceding stretch-factor examples involve CPU-bound workloads. I/O-bound workloads (either disk or network) will tend to exhibit smaller load averages than CPU-bound work if those processes become suspended or sleep waiting on data. In that state, they are neither runnable nor running and therefore do not contribute to $n(t)$ in equation (1). Conversely, when the Linux I/O driver is performing work, it runs in kernel mode on a CPU and does contribute to $n(t)$.

Listing 9: System Performance Output

```
****** SYSTEM Performance *******
Metric Value Unit
------ ----- ----
Workload:                  "Crunch"
Number in system            0.9965 Jobs
Mean throughput             0.0990 Jobs/Hour
Response time              10.0656 Hour
Stretch factor              1.0066
```

The load average value Q measures the total number of requests; both waiting and in service. It is not a very meaningful quantity because it is an absolute value. Combining it, however, with the number of configured processors (m) and their average measured utilization (p), the stretch factor f provides a better performance management metric for symmetric multiprocessor and multicore servers because it is a relative performance indicator that can be compared directly with established SLOs.

Conclusion

The load average provides information about the trend in the growth of the run queue, which is why there are three metrics. Each metric captures trend information from the run queue as it was 1, 5, and 15 minutes ago. Compared with today's graphical data display capabilities, this approach to data representation looks antique. In fact, the load average is one of the earliest forms of operating-system instrumentation (circa 1965).

This article presented the stretch factor as a better way to make use of load average data for managing the performance of application service-level targets on multicore servers. ■

THE AUTHOR

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INFO

[1] Linux 2.6.20.1 source code: *http://lxr.linux.no/source/*

[2] Linux scheduler C code: *http://lxr.linux.no/source/kernel/timer.c*

[3] Financial forecasting: *http://bigcharts.marketwatch.com*

[4] SpamAssassin: *http://spamassassin.apache.org/*

[5] PDQ library: *http://www.perfdynamics.com/Tools*