Spurg-Bench

Wictor Lund

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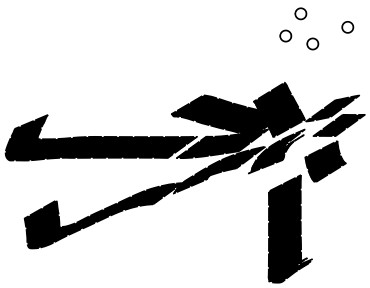

This document will give an overall description of how spurg-bench works. The purpose of spurg-bench is to create load on a system. Since system-wide load is a rather ambiguous concept the program is split into replaceable components. The function of spurg-bench is to generate multi-processable load on a multi-core system where a load-balancer is deciding where tasks are running.

The spurg-bench test is divided into three types of components:

1. The operation
2. The load generator
3. The runner script

The choice of components embodies a *test setup.* Spurg-bench is designed to be an aid in development of energy efficient load-balancing and scheduling strategies. The benchmark is not designed to be used to create results comparable between platforms or operating system. Another design decision is that the algorithms used in the implementation are not simulating any particular real-world workloads. Instead the program is designed to stress the system in a predictive manner to test features and expose properties of the underlying operating system.

1 The Operation

Spurg-bench uses an operation to generate load on a multi-core system. The operation is usually a simple C function performing some calculations using a CPU's computing resources such as ALU's, floating-point unit and cache memories.

The purpose of sprug-bench is to generate a load on the system, where the operation is the dominating type of computation. Because of the interference caused by other processes running concurrently or in parallel, the run time T_{run} of the operation is considered stochastic. Apart from the temporarily uncorrelated stochastic behavior caused by interference T_{run} will also be affected by the current clock frequency.

One should design the operation to be sufficiently short, preferably in the length of microseconds. The operation should be short enough to be smoothly controlled by the load generator, but at the same time be big enough to minimize the overhead caused by the load generator. In Listing 1 is presented an example operation which can be used with Sprug-bench. When run on a fairly new laptop the estimated time of this operation varies between 6 and 11 μs, depending on the frequency.

Generated load will consist of, even in simple cases, different types of computation. Since different kinds of computation stresses the system differently, a long operation with internal phases consisting of different types of load will cause disturbing effects.

Listing 1: Example of a operation using the processors floating-point units.

```
int operation()
{
        int     i;
        double  a  = 2.0;
        for (i = 0; i < 1000; i++) {
                a *= 2.0;
        }
        return 0;
}
```

2 The Load Generator

The load generator runs the operation and sleeps accordingly to generate a particular load. Since system-wide load is not very easily defined there is a need for different load generators to enable different definitions to be utilized.

Load generators in sprug-bench are working in phases. A phase is a sequence of run and sleep intervals where the number of operations and the sleep delay is constant, this is what is illustrated in Figure 1. Phase i consists of $m(i)$ sleep intervals, each of the length $T_{sleep}(i)$[1] and $n(i) \cdot m(i)$ operations each of length T_{run}. The structure of a phase is illustrated with pseudo-code in Algorithm 1. One should note that each instance of $T_{sleep}(i)$ and T_{run} are considered stochastic, which means that it is impossible to calculate the total time of a phase before it is completed. For a phase to be measurable by a system clock, it have to be sufficiently long, but short enough to enable fast control of the load. In practice, should

$$\sum_{k=1}^{m(i)} \left(T_{sleep}(i) + \sum_{l=1}^{n(i)} T_{run} \right) > t_{measure_{min}}, \tag{1}$$

for some minimum measurement interval $t_{measurement_{min}}$. More critical is that the sleep interval is long enough that the operating system is able to cope with it. This means that there is a $t_{sleep_{min}}$ usually defined by the operating system or the system clock. As mentioned, the program is structured using two nested loops. The reason for this is to better be able to control the real-time behaviour of the program to acheive the desired load.

The inner loop, looping the operation $n(i)$ times has the purpose of increasing the needed sleep time. Since it is possible to set $n(i)$ before every phase it is possible to have a minimum sleep time longer than T_{run}.

The outer loop, executing the inner loop and the sleep statement $m(i)$ times, is used to control the time between measurements. For optimal control performance we would need to have a constant measurement interval. However, due to the structure of the program and to the undeterministic real-time behaviour of the operating system this can not be achived. Instead we try to run the program and with adjustments to $m(i)$ achieve desired control performance.

Due to interference it is not in general possible to run a given number of operations and sleep a constant amount of time to retain the reference load.

Due to interference between software processes and hardware components, it is not in general possible to keep the parameter tuple $(t_{sleep}(i), n(i), m(i))$ constant for each i. This has been solved by introducing a controller which estimates the time the operation takes based earlier observations and set the sleep times accordingly. For the estimation of T_{run} it would probably be worthwhile

[1]$T_{sleep}(i)$ is a stochastic variable describing the actual sleep length, while $t_{sleep}(i)$ is the parameter describing how long the sleep period *should* be.

making the assumption that $T_{run} \propto f_{core}$, where f_{core} is the current clockfrequency of the core the load generator is currently running on. Currently this assumption is not being made, because of the added complexity of knowing what core the load generator is currently running on, as well as the clockfrequency of the current core.

The main purpose of the sleep state is to cause a context switch, and to achieve a partial load. The context switch also causes a disruptive behavior which severely decreases the total amount of operations per second. In Algorithm 1 is presented the pseudo-code for achieving the behavior presented in Figure 1.

Algorithm 1 Load generator structure

```
$i \leftarrow 0$, $t_{sleep}(0) \leftarrow 0$, $n(0) \leftarrow 1$
loop
  $t_{wall_1}(i) \leftarrow$ walltime_now()
  $t_{cpu_1}(i) \leftarrow$ cputime_now()
  for $k = 1$ to $m(i)$ do
    for $l = 1$ to $n(i)$ do
      operation()
    end for
    sleep($t_{sleep}(i)$)
  end for
  $t_{cpu_2}(i) \leftarrow$ cputime_now()
  $t_{wall_2}(i) \leftarrow$ walltime_now()

  << calculate $t_{sleep}(i+1)$ and $n(i+1)$ >>

  $i \leftarrow i + 1$
end loop
```

2.1 Load with rusage as the reference

The control algoithm will take the cpu_time and wall_time deltas,

$$\Delta t_{cpu}(i) = t_{cpu_2}(i) - t_{cpu_1}(i)$$

and

$$\Delta t_{wall}(i) = t_{wall_2}(i) - t_{wall_1}(i),$$

as input and give $m(i+1)$, $n(i+1)$ and $t_{sleep}(i+1)$ as output. Internally the algorithm will estimate the time it takes to run an operation $t_{run}(i)$. This estimation is made using a moving average with the formula

$$\hat{t}_{run}(i+1) = \alpha \cdot \frac{\Delta t_{cpu}(i)}{m(i) \cdot n(i)} + (1-\alpha) \cdot t_{run}(i),$$

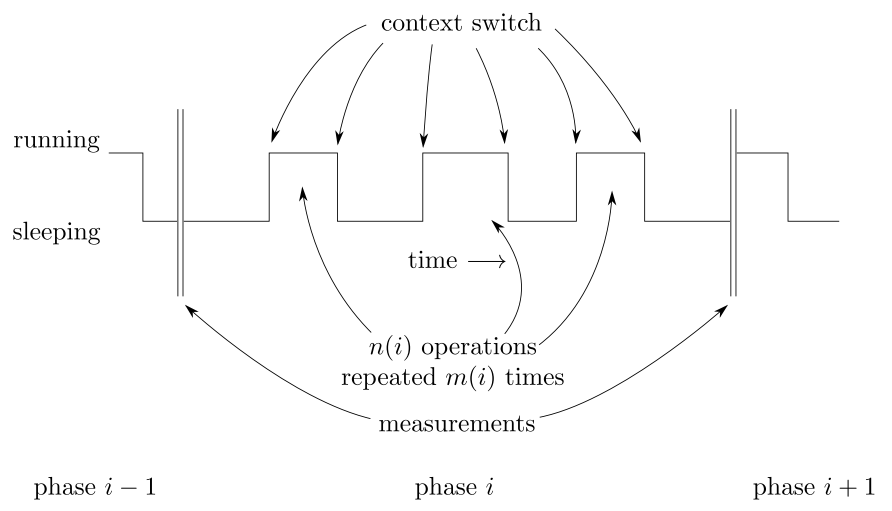

Figure 1: Illustration of a phase in a load generator, with it's context-switches, $m(i)$ sleep intervalls and $m(i) \cdot n(i)$ operations.

where α is a exponential back-off contant[2].

Using this algorithm the model for the load is given as

$$L(i) = \frac{n(i) \cdot t_{run}(i)}{t_{sleep}(i) + n(i) \cdot t_{run}(i)}.$$

This definition of load is very comparable to the load `top` gives, when $t_{sleep}(i) + n(i) \cdot t_{run}(i) = 1s$ and `top`'s delay is set to $1s$.

If now know the target load $L(i)$ and have the estimated operation time $\hat{t}_{run}(i)$, we can now derive an expression for the next sleep interval length $t_{sleep}(i+1)$ using the definition of load, and the fact that $t_{sleep}(i) \geq t_{sleep_{min}} \forall i$. The load definition gives the inner loop length

$$n(i) = \frac{L(i)}{L(i)-1} \cdot \frac{t_{sleep}(i)}{t_{run}(i)}.$$

If we now insert $t_{sleep}(i) \geq t_{sleep_{min}} \forall i$ into the equation and let $n(i)$ be the smallest integer bigger than required and also assume $t_{run}(i) \approx \hat{t}_{run}(i)$, we will get

$$n(i) = \left\lceil \frac{L(i)}{L(i)-1} \cdot \frac{t_{sleep_{min}}}{\hat{t}_{run}(i)} \right\rceil.$$

We can now calculate the sleep interval $t_{sleep}(i)$ using the load definition and the above assumption with

$$t_{sleep}(i) = \frac{L(i)-1}{L(i)} \cdot \hat{t}_{run}(i) \cdot n(i).$$

[2]The value for α which has been used is 0.5.

2.2 Load with operations per second as the reference

Load generator which regulates load with operations per second as a reference.

3 The Runner Script

The runner script starts up several load generators to create multi-processing load.