You don't Know Jack about

Application Performance

Toronto Linux User Group,
12 Sept 2006

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Everyone thinks performance has to do with resources

- Most programmers think if a program runs too slow, we should throw CPU at it, or memory or disk...
- But what about program that has all the CPU, memory and disk in the world, but still stubbornly refuses to deliver more than ten transactions per second?
- Should we perhaps find the bottleneck instead?

But it doesn't

- Resources are easy to measure, but customers don't care.
- Customers care about guaranteed low response times and lots of transactions per second, all at a low price.

- We need to measure performance first, then diagnose, and only if we *have* a resource prob-lem throw resources at it
- This is the old story of looking under the bright streetlight for the ring lost in the shadowy garden.

This talk is about

- **What performance is, and why**
- Measuring performance
- Programming for performance
- Benchmarking for performance
- Tuning for performance

What is Performance?

- Response to a load, in TPS or bytes/second
- Response in reasonable time.
  - Latency
  - Response time
- What's “reasonable” mean?
  - 1/10 second is fast
  - One second is not fast
  - Ten seconds is bad
  - Thirty is very bad

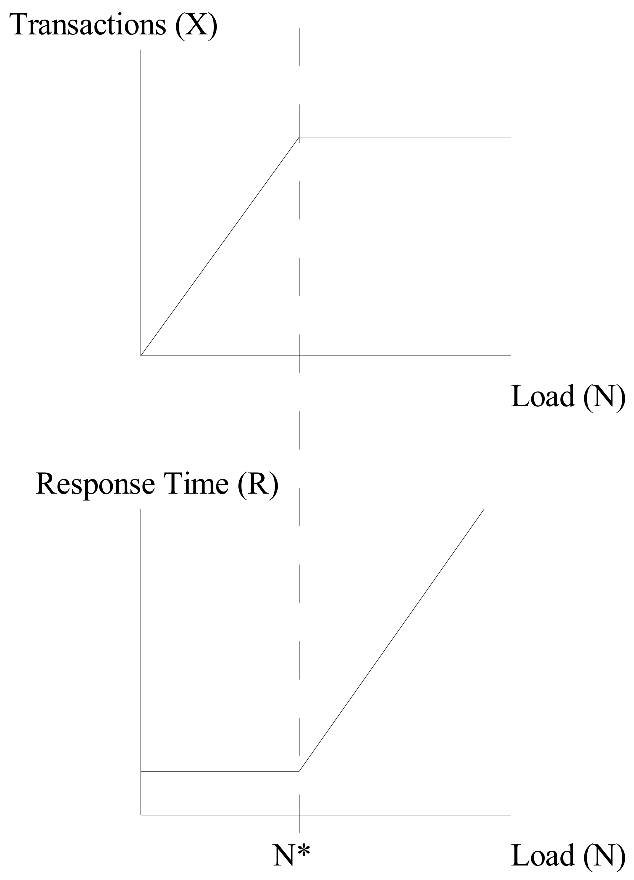
Why don't we measure it?

- It's hard
  - Or, optionally, brutally expensive
- Vendors could report it
  - They used to in the mainframe days
  - But they got screwed when they did
- So we make do with resources
  - And often we luck out, when there is a CPU or memory bottleneck

But things have changed

- Many applications use TCP/IP
- There are lots of packet capture tools to use
- There are also free benchmark tools (JMeter)

The Laws of Performance



- You may remember these diagrams from a textbook
- The operational laws dictate the shape of the throughput and response time curves
- They're only high-school algebra, but they led to queuing theory

The Queue (no theory involved)

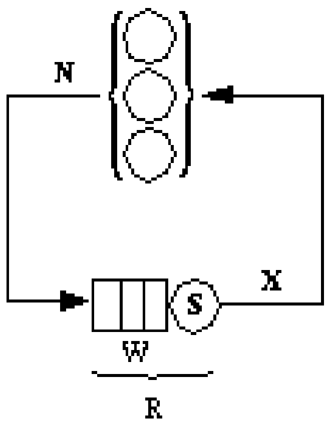


Figure 2. Simple benchmark, drawn as a closed queuing network.

- N users
- N requests/second
- S sec. service time
- W sec. Wait time
- R sec . response time
- D sec .demand
- Z sec. think time (hidden)

yields

- X transactions/second

The Throughput Curve

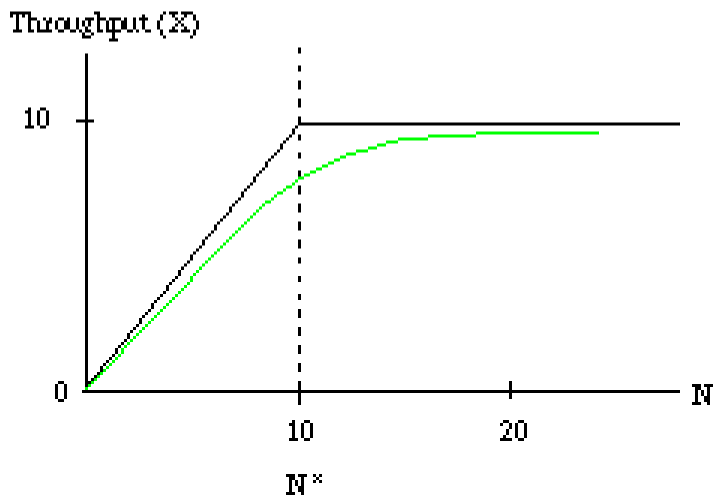


Figure 3. Throughput, expected and measured.

- The first curve is the upper bound on throughput (X),
- It rises with load until the program reaches 100% utilization and then levels off.
- Measured curves don't actually have sharp corners.

The Throughput Curve II

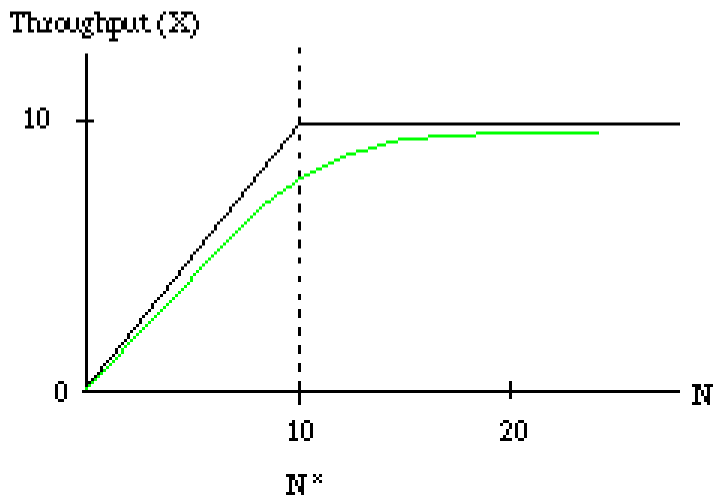


Figure 3. Throughput, expected and measured.

- If we measure the service time, S we can use the...
- Utilization law,
  U = X . S
  where U = B/T
- Consider the case where S = 0.10 sec.

The Throughput Curve III

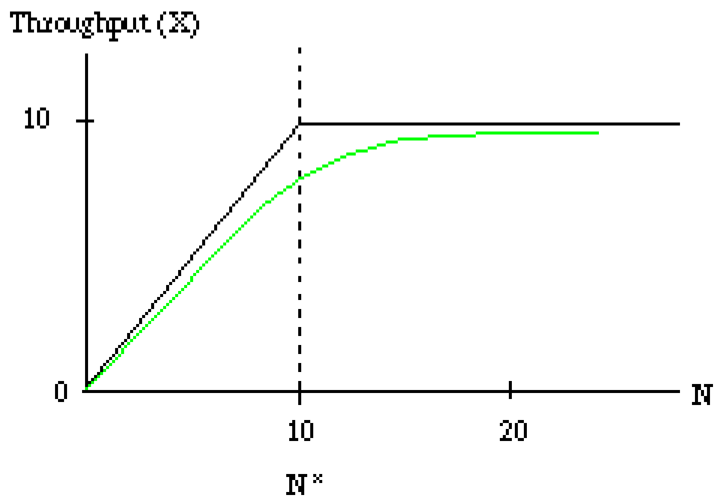


Figure 3. Throughput, expected and measured.

- If S = 0.10, 10 transactions will fit in one second
- 10 TPS is all we'll get
- If S = 0.05, 20 TPS is possible
- And 10 TPS is only 50%

The Throughput Curve, IV

- You can't get utilization above 100%, because then 1/10 if a second would have to go into a second more than ten times.
- This is the reason that the throughput curve isn't a straight line to infinity: it always rises with increasing load, but then levels off at 100% utilization.

Calculating 100%

- We can compute the load that yields 100% utilization
- The user load at 100% utilization
  - Is called N*
  - is equal to 1/S
- We computed it by setting S to a tenth of a second, U to 1 and solving the utilization-law equation for X.

The Throughput Curve V

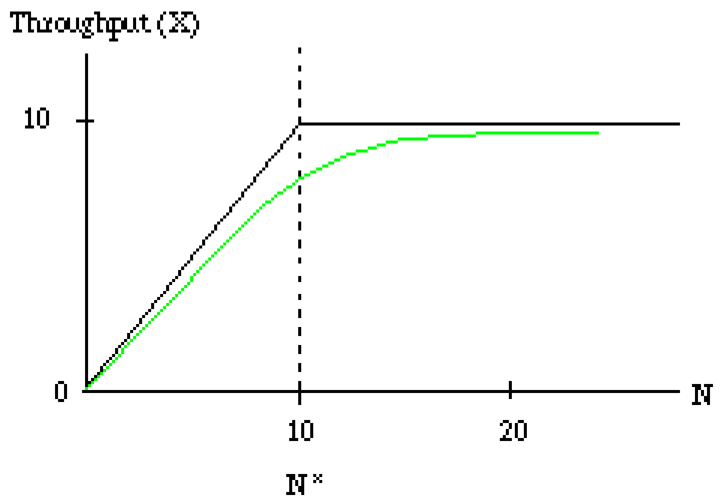


Figure 3. Throughput, expected and measured.

- Why doesn't it have square corners?
- Initially requests arrive independently, and don't interfere.
- As we get closer and closer to 100% utiliza-tion, there's more and more likelihood that two will be requested at the same time, and the second will have to wait.

Queue Buildup

- Past 100% utilization, requests have to wait. In our example, the 11th request has to wait for the other 10 to complete.

- The queue length is computed from
- Little's Law
  Q = X . R

- In our example, a load of 50 would yield a queue length of 50/10 = 5, and the average Re-sponse time would be (40*0.1 + 0.1) = 4.1 seconds

Queue Buildup II

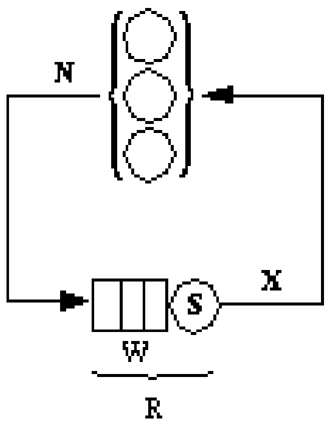


Figure 2. Simple benchmark, drawn as a closed queuing network.

- In the queuing circuit in Figure 2, the queue is represented by the sequence of boxes to the left of S.
- The queue delay or wait time is W, and the total response time under load is R, the sum of W and the service time S.

Queueing and Response Time

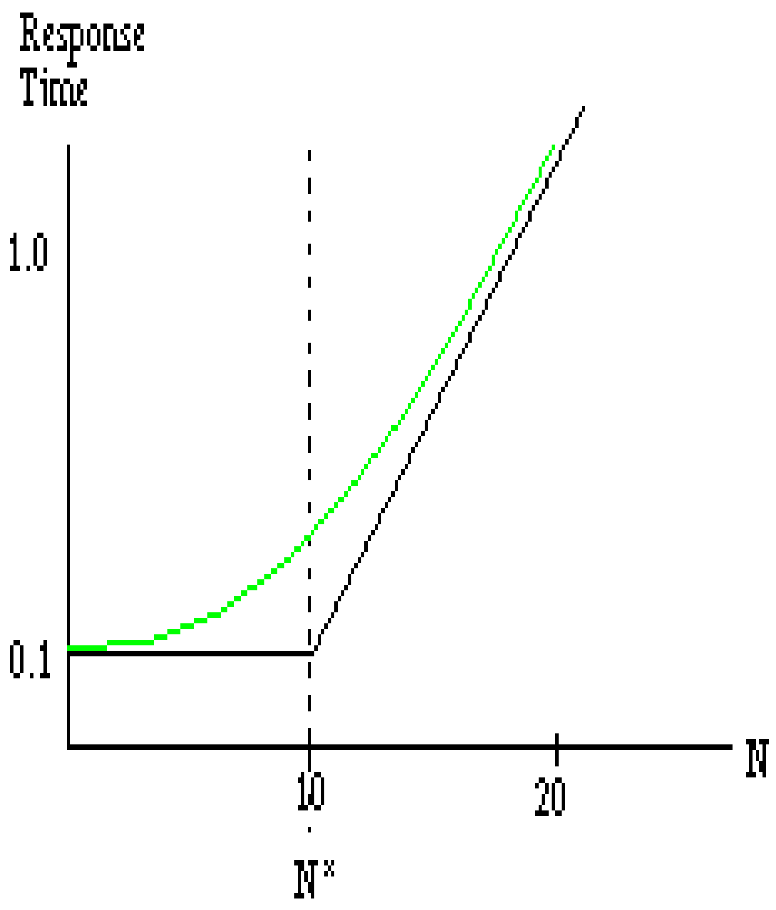


Figure 4. Response time, expected and measured.

- Response time is the second curve in Figure 1, which starts out fairly level and then rises as we approach and pass N*.
- The slowdown is from all the waiting in queue.

Response Time II

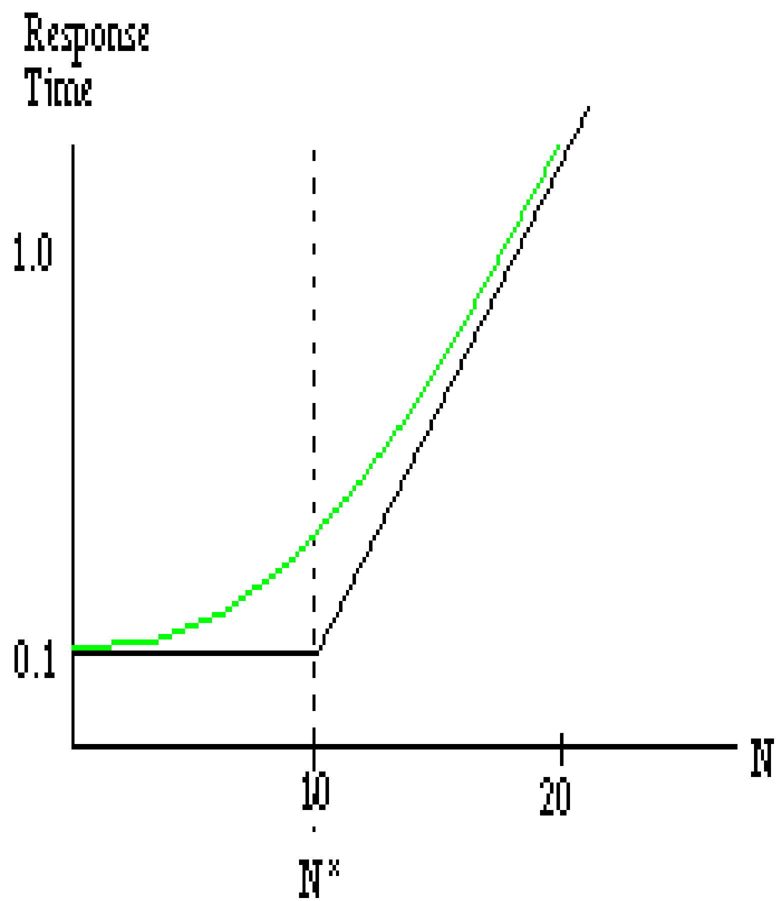


Figure 4. Response time, expected and measured.

- If we did a bench-mark, the response time would
  - start off horizontal, just like our diagram's initial line
  - then start to drift upwards fairly quickly towards paralleling the second.

What Everyone Doesn't Know

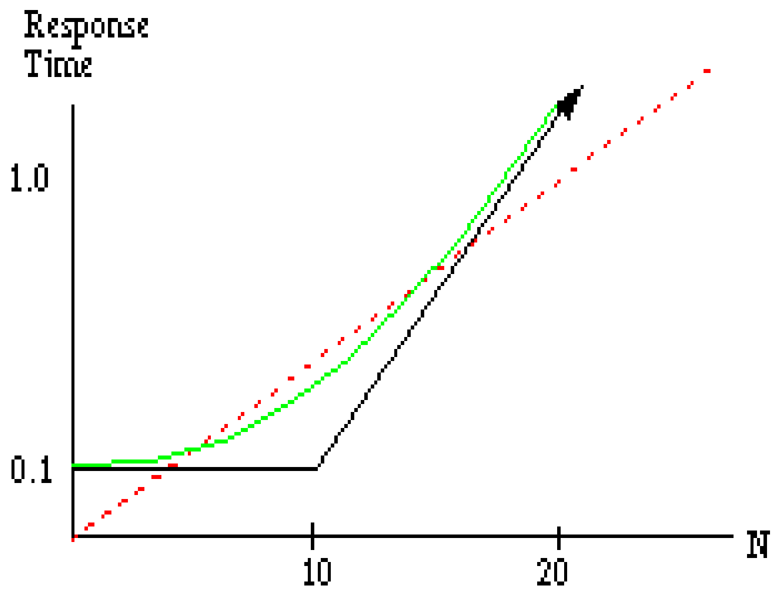


Figure 5. Bad linear estimate of response time

- Benchmarkers ``-know" response time grows gently and lin-early because their benchmark from 0 to 10 requests per second was relatively linear.
- They never tried at 20 requests/second!

This is *A Very Bad Thing*

- Consider the two response times that we mentioned before, one second and ten.
- The proper equation predicts we'll hit the ten second mark at 107 requests per second.
- The bad/linear equation would estimate we wouldn't hit the ten-second mark until 280 requests per second.

- Only the customers (YorkU.CA)will know the real performance is less than half what they were promised. They and their lawyers.

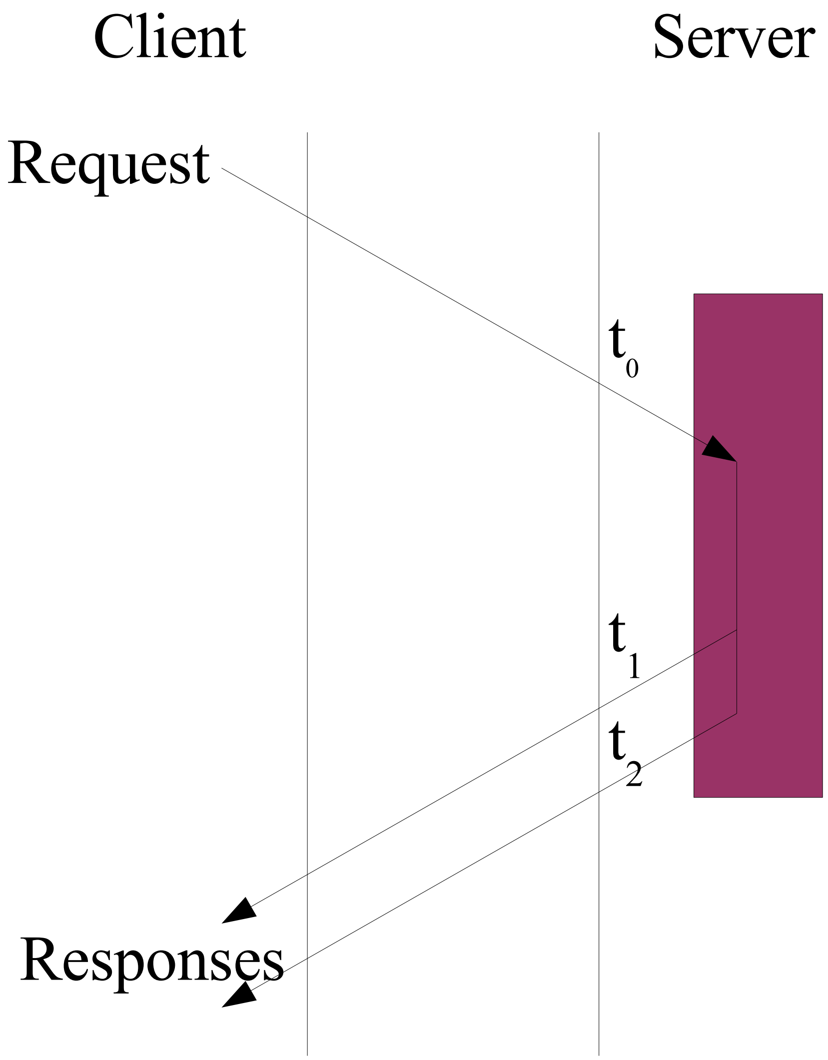
Agenda

- What performance is, and why
- **Measuring performance**
- Programming for performance
- Benchmarking for performance
- Tuning for performance

Measuring Performance

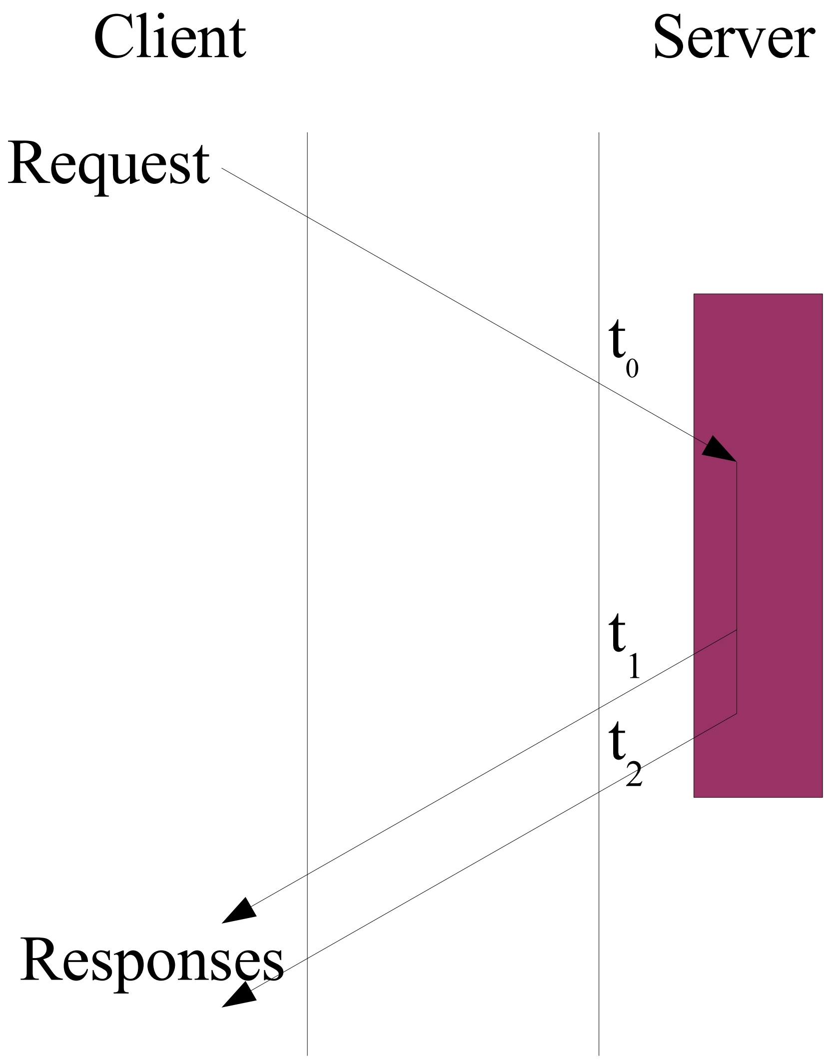
- Many programs use TCP/IP, even locally
  - These you can measure with a packet capture
  - And there's a free benchmarking tool, Jmeter
- If it sends requests and receives responses, we can
  - measure the speed
  - predict both the curves

A Transaction Looks Like...



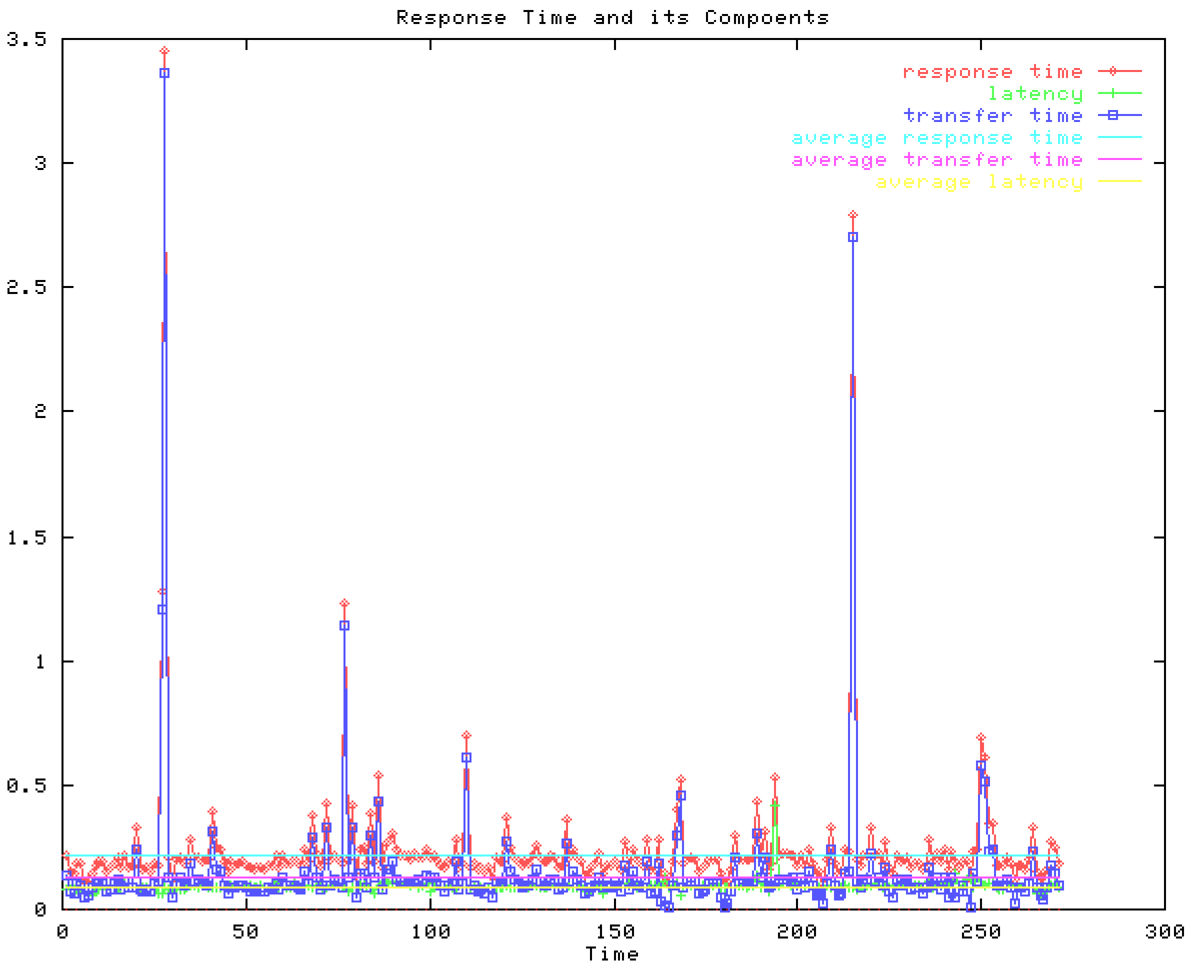
- At t0, the request arrives
- At t1, the first byte of the response is sent
- At t2, the last byte is sent
- And we also record bytes transferred

We Measure



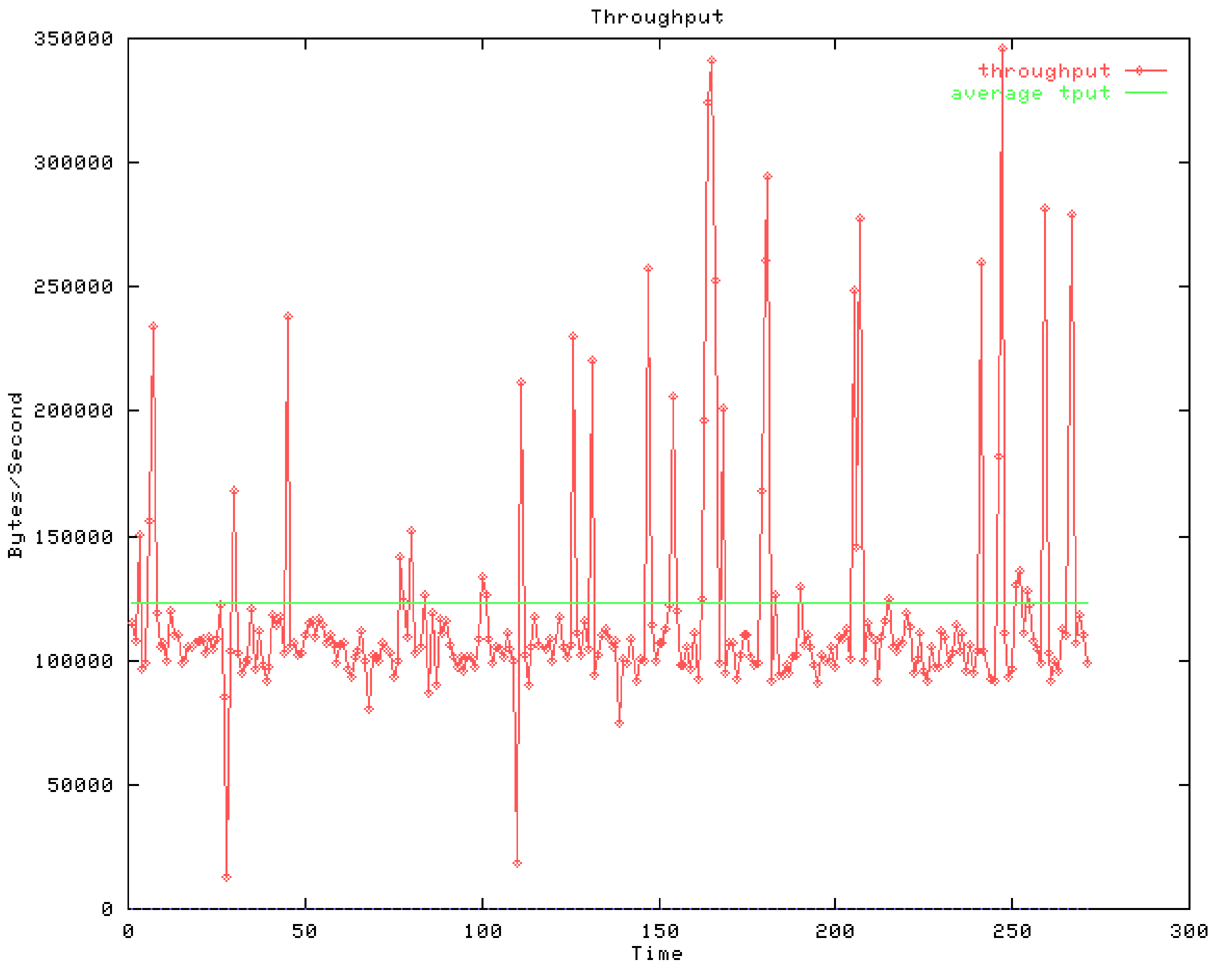
- Latency
  = t1 – t0
- Response Time
  = t2 – t0
- Transfer Time
  = t2 – t1
- Throughput
  = bytes/(t2 – t1)
- Think Time
  = t0 - t2

Response Time Looks Like



- Response time is latency plus transfer time
- This is a good sample, by construction
- Note the average, which we'll use in a moment

Throughput (Bytes/Second)

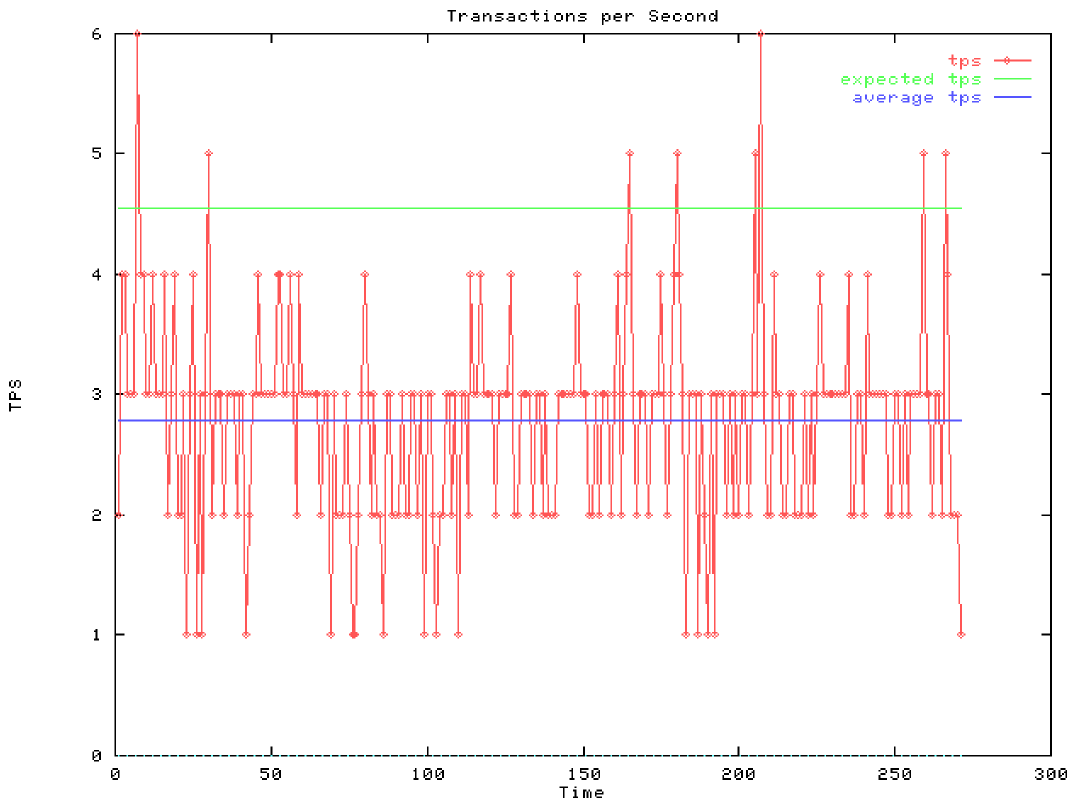


- The other kind of throughput
- Used for bulk transfers, like ftp
- Variable, but it didn't mess up the response time

We Can Compute

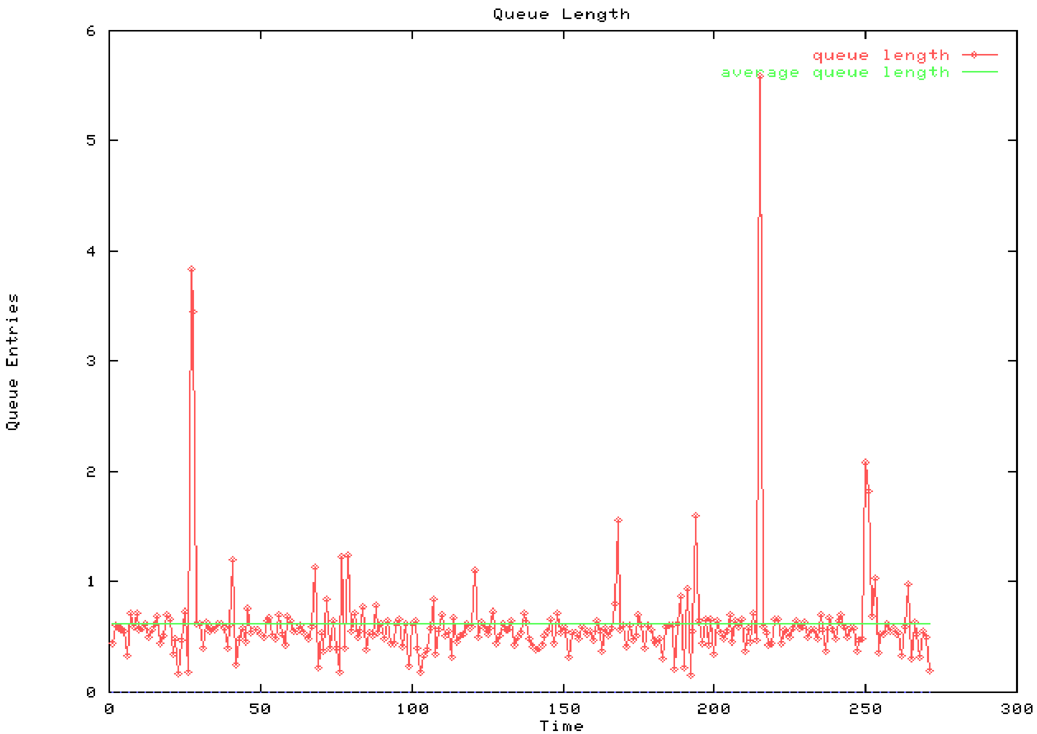
- *If and only if* we're below 100% and there's no queue
  - We ensured that when we measured it
  - The load was from wget with a sleep time
- TPS at 100% Utilization
  - Computed as 1/ Response Time
- Actual as a % of Maximum
- Queue length
  - By Little's Law, $Q = XR$
- And the the Slowdown due to Queuing

Transactions per Second (TPS)



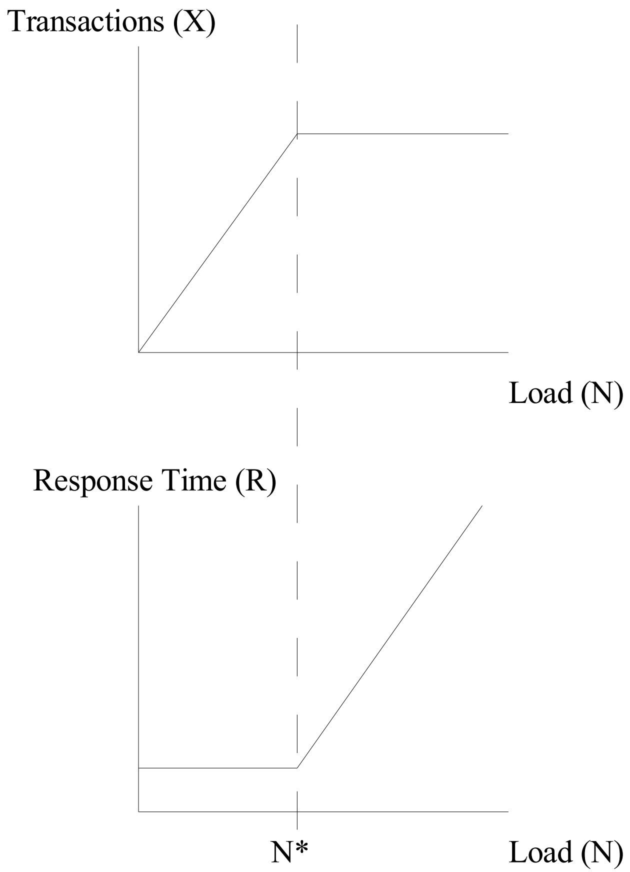
- The expected line is 1/Dmax, which we arranged to be equal to 1/R
- For one CPU, we're averaging 2.8/4.5 = 62%

Queue Length



- This is from one of the Operational laws, Little's Law, Q=XR
- Waiting in queue is what makes programs slow

Working with the Data



- Throughput (X) = min(1/Dmax, N/D+Z)
- Response Time (R) =max(D,Dmax-Z)
- Where D is demand
- N is users
- Z is think time
- Dmax is the largest demand
- And D ≈ S•1

The Results We just Saw

- A few slow transactions
- We're at about 60% of capacity
- The queue length was about .6, and spiked to approximately 5.5
- At 7 TPS per CPU, we hit 100% utilization
  - At 28 requests/second, R will be 3 seconds, which is not what we want, but sort of ok
  - At 150 requests/second, R will be 15-30 seconds, which is bad

Why 3 and 30 Seconds?

- 1/10 second is fast
- One second is slow
  - Three seconds is the upper bound for slow with a watch cursor or some other apologetic message
- If the response time grows to 30 second, humans think the program is more than slow: they'll think it's crashed!
  - 30 seconds happens to be the cache time of human short-term memory

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Programming for Performance

- Make performance part of your design
- Build the performance test framework *first*.
- For example, the first day the code works...

- Consider this test-directed performance design

Code and Tune for "Good Enough"

- If your target is 1/10 second, set your back end to almost that (maybe 0.09) , and see if the front end gets in the way
- As soon as it's good enough, **STOP.** Don't waste your efforts making a fast part faster

- The maximum TPS will be set by the slowest part, and will be $1/D_{max}$
- Where D = S * Visit count
- And visit count is number of calls to the slow part, such as a database or disk

Tuning

- Your tuning in the front end will mostly be looking at code-path length with your frame-work and a profiler .
- The “HP” community is your resource here (High Performance as in Cray, not Hewlett-Packard)
- One reference is "Performance Optimization of Numerically Intensive Codes” by Stefan Go-decker (Society for Industrial and Applied Mathematics)

Then Switch to tuning the SQL

- Build a script that submits the SQL and measure it.
- Now you can tune the queries and the database structure.
- See “Optimizing Oracle Performance” by Cory Millsap (O'Reilly, 2003)

If you Have Middleware

- Arrange for it to communicate via sockets
  - It probably does anyway
- Measure it's performance the same way
- If you can't:
  - measure the front end and database
  - What's left is the middleware

And *Now* Look at Resources

- Find out how much CPU, memory and I/O each transaction takes at 1 TPS
- Now test up past 100% utilization, and see where it goes “haywire”

- Save that information for properly sizing your production system
- If you under-size a production system, you will introduce an artificial bottleneck
- That's what most “tuners” find and fix (and yes, that includes me)

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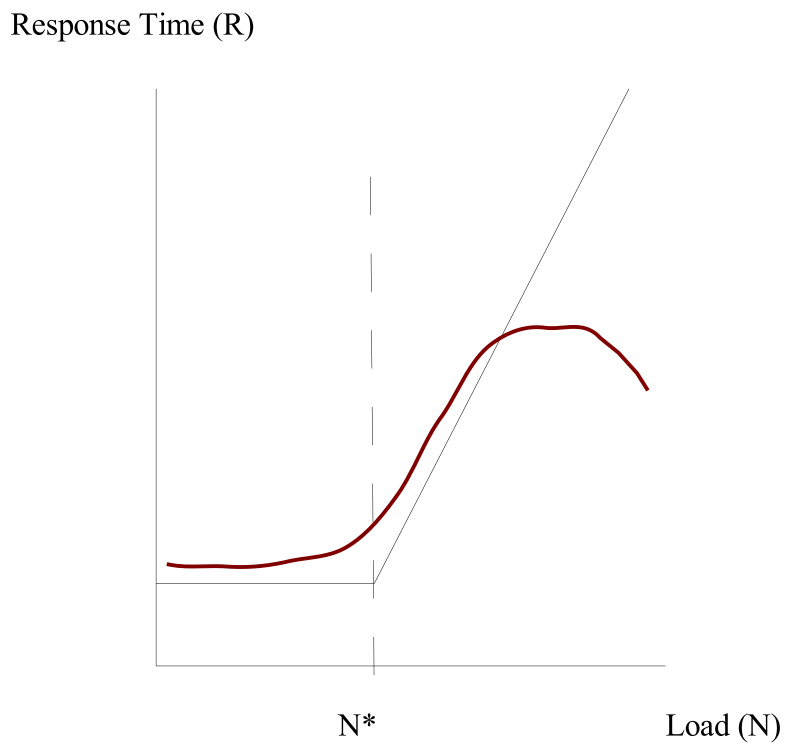
Benchmarking for Performance

- In a TCP/IP world, benchmarking is easier
- First, check out JMeter
  - And Loadrunner, if you're rich or already have it
- If not, try
  wget -O /dev/null -w Z/2 –random-wait
- Run for at least a minute at each load
- Don't just write down the results

Benchmarking Bugs Like to Hide



- **Graph your results** and look at the shapes
- Variations from the expected shapes identify the bugs
- Also, X >> 1/Dmax, your load generator's lying (a common er-ror)

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Tuning for Performance

- The first thing is have enough CPUs
  - Not cpu speed, or % CPU, the *number* of CPUs
- Then look at latency versus transfer time
  - If removing either of these will make you fast enough, then you know where to look next
- Latency is sensitive to CPU and network speeds
  - But network bandwidth doesn't help here
- Transfer time is bandwidth-sensitive
  - Look at disk bandwidth first
  - Then at code length and code cost
  - Then look for resource starvation

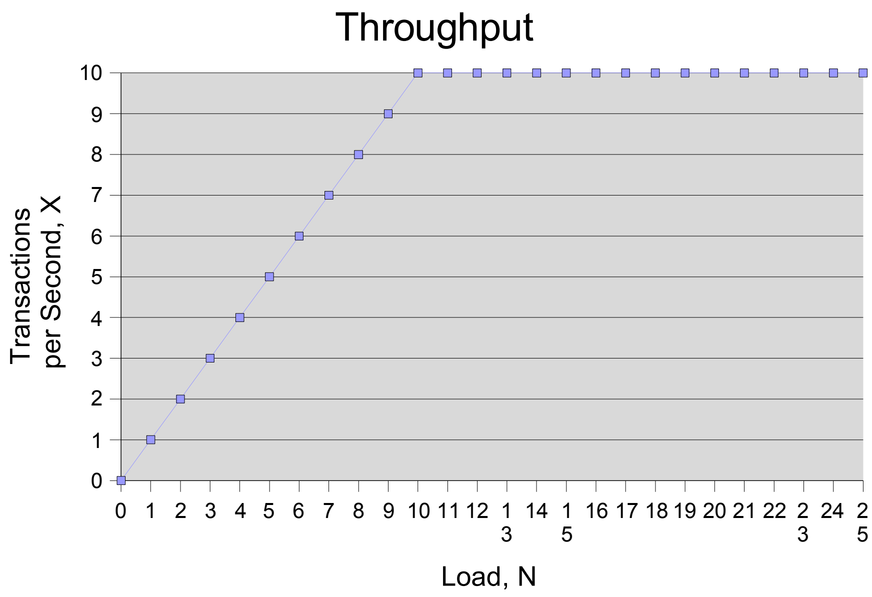
Conclusions

- Start early
- Measure R
- Compute X at 100% utilization
- See how you're doing

and finally

- Draw the graphs

Graphs as a OO Spreadsheet



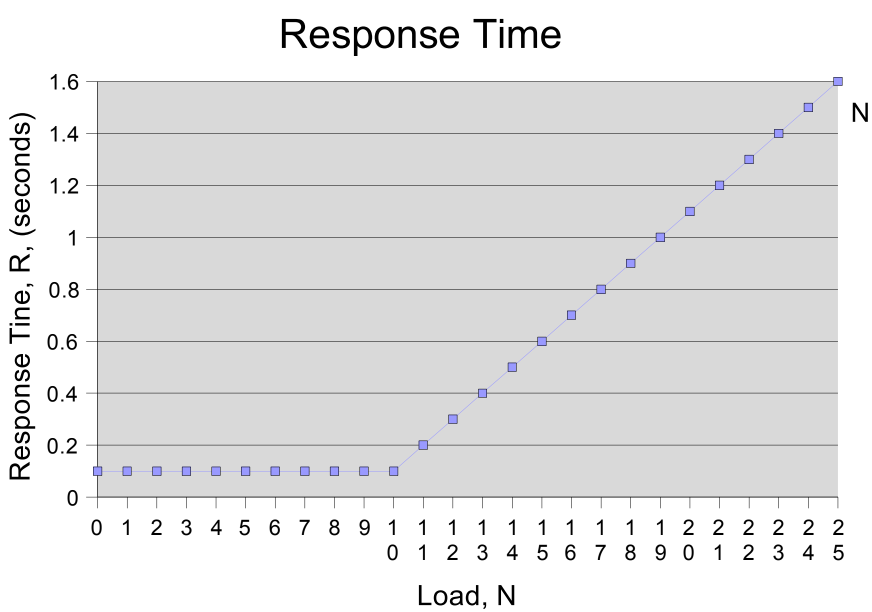
Upper bounds of throughput = min(1/Dmax, N/(D+Z))
Lower bounds of response time, R = max(D, N * Dmax – Z)

To compute the throughput and response time curves, we start by measuring the response time at a very low load, so no queuing happens.
Response time, R, at minimum load = 0.1

We now set the simulated users to issue 1 request per second, which allows think time, Z, to be 1 – R = 0.9
This only works if R is less than one second, so that Z is positive.

The maximum throughput will occur at N*, the load where N = 1/R
N* = 10
After N*, no improvement in throughput will be possible, and a queue will of work waiting to be processed will build up, causing the response time to grow without bound.

Our estimate for D and Dmax is initially always 1 * R, so the variables are now all known.
D = 0.1
Dmax = 0.1
Z = 0.9



Throughput	N		Response Time	Queue Length
0	0	0	0.1	0
1	1	1	0.1	0.1
2	2	2	0.1	0.2
3	3	3	0.1	0.3
4	4	4	0.1	0.4
5	5	5	0.1	0.5
6	6	6	0.1	0.6
7	7	7	0.1	0.7
8	8	8	0.1	0.8
9	9	9	0.1	0.9
10	10	10	0.1	1