The SRE's Crystal Ball

Predicting Performance with Queues and USL

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About Me

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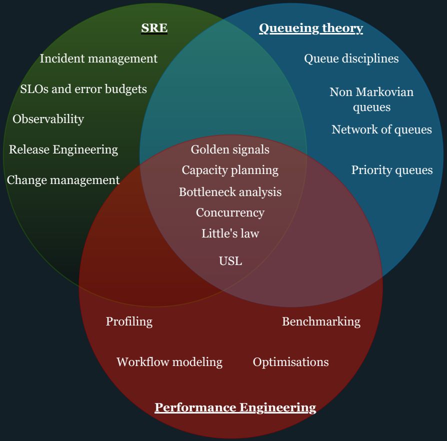
Background

- High Performance Computing (HPC)
- Storage Systems
- Performance Engineering

The big picture



The big picture

- Let's have some fun.
- Aimed at inspiring you, my peer practitioners to apply these concepts in ways I haven't thought of.
- A system/service is a chain of bottlenecks - removing one reveals the next.

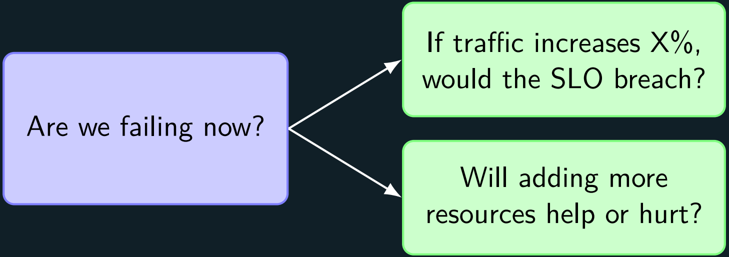
Credits

- Dr. Neil J. Gunther authored Universal Scalability Law and taught GCAP workshop.
- Stefan Moeding maintains the R package that I use in Demo.

Why bother?

Most SLOs are reactive alarms

- **Availability SLO Miss:** *"We're down."*
- **Latency SLO Miss:** *"We're slow."*



Move from firefights to preventing *some* issues entirely — think in **queues** and **scalability models**.

Agenda

- Thinking in queues
- Golden signals through the lens of queueing theory
- Predicting scalability with Universal Scalability Law(USL)
- See it in action

The Birth of Queueing Theory

Figure: A. K. Erlang (1878-1929) Source: Wikipedia

- In the early 1900s, Danish mathematician **Agner Krarup Erlang** had to figure out how many telephone circuits were needed to handle a given number of calls without excessive waiting or dropped connections.
- His work created queueing theory — the mathematical study of waiting lines (or queues).

Thinking in queues

- Queues are everywhere - Loadbalancers, connection pooling, Jira boards..
- Queueing systems are non-linear - It is not intuitive. Double the instance count and you can serve double the load right?
- Queues occur even if there is enough average capacity - Grocery store
  - High variance in arrvivals
  - High variance in service times

Thinking in queues

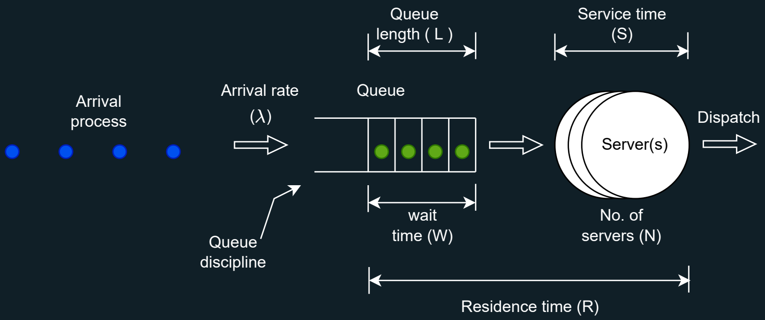


Figure: A simple queue.

Thinking in queues - Terminology

Queue length (L)	Number of requests in the system or queue(L_q)
Arrival Rate (λ)	The rate at which requests enter the system (e.g., requests/sec). aka "demand" or "load".
Service Time (S)	The time required for a single server to process one request.
Waiting Time (W)	The time a request spends waiting in the queue before its service begins.
Response Time aka Latency(R)	The total time a request is in the system. The sum of waiting and service time ($R = W + S$).
Utilization (ρ)	The fraction of time a server is busy.
Number of servers (N)	The number of servers in the system(node/cpu/thread/instance).
Throughput (X)	Completion rate of requests. In a stable system, ($X = \lambda$).

Golden signals through queueing theory

- Latency $=$ Service time $+$ Waiting time
  - Utilisation drives waiting time
  - Coefficient of variation is a leading indicator
- Traffic as Arrival rate(λ): The demand driver
- Errors as symptoms of overload
- Saturation as high Utilisation(ρ): The harbinger of Doom

Little's Law and Related Formulae

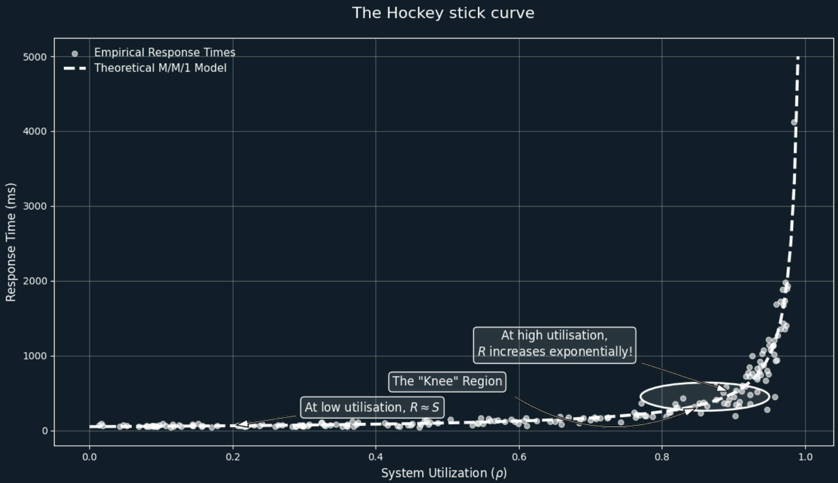
$$L = \lambda R$$

$$\rho = \lambda S$$

or

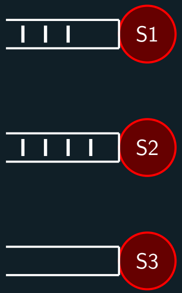
$$\rho = \frac{\lambda S}{N}$$

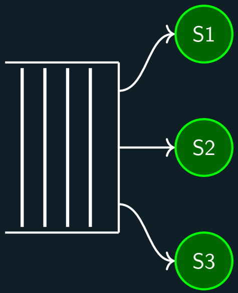
Utilisation curve and the "Knee"



A little intuition

Which design performs better?





Applied Theory: The Case of the Sluggish API

- 🔔 An API endpoint (‘/api/v1/resource‘) is timing out. Latency has spiked!

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What do we know?

- **Arrival Rate (λ):** 180 requests/second.
- **Avg. Service Time (S):** 50 milliseconds per request.
- **Number of Servers (N):** 4 API server pods.

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- **Number of Servers (N):** 4 API server pods.

- *"Should we scale up to 8 pods? "*
- *"Would it be enough?"*

Applied Theory: The Case of the Sluggish API

$$\rho = \frac{\lambda S}{N} = \frac{\text{Arrival Rate} \times \text{Service Time}}{\text{Number of Servers}}$$

$$\rho = \frac{180 \text{ req/s} \times 0.05 \text{ s/req}}{4 \text{ pods}} = \frac{9}{4} = \mathbf{2.25}$$

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- Utilisation ($\rho > 1.0$ or 100%) $\Rightarrow$ the system is unstable. In other words, the queue is growing infinitely.
- Increase N to 8 pods? $\Rightarrow \rho$ will compute to 1.125 (still > 1.0).
- Let's increase N to at least 10 pods ($\rho = 0.9$) to also accommodate variance.

USL

I promised a crystal ball. Lets do some predictions.

USL

Scalability
A mathematical function of being able to perform more work (RPS, TPS etc) while work per server[1] remains constant and the number of servers increases.[*]

Universal Scalability Law(USL)
A formal definition of scalability.

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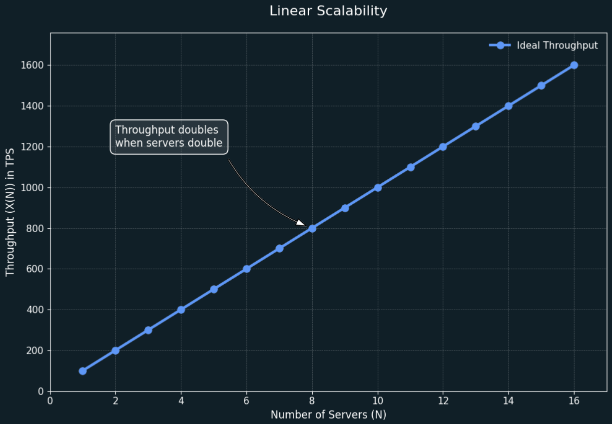
[1] (node/instance, cpu/thread etc)
[*] Improvised from a definition by Dr. Neil J Gunther

USL - Linear Scalability

The ideal condition. We all want that right?

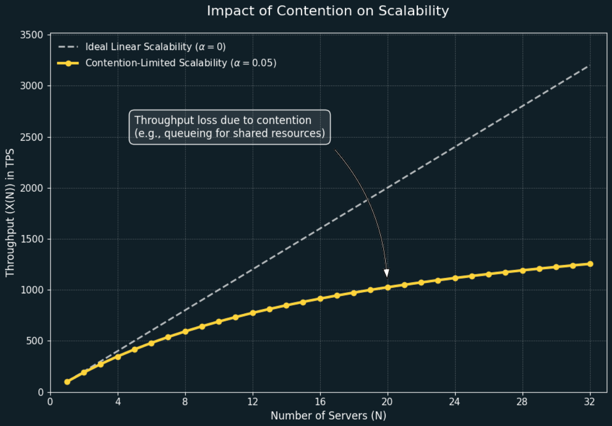


$$X(N) = \frac{\gamma N}{1}$$

Where:

- $X(N)$ is the throughput with N servers.
- γ is the ideal throughput of a single server.
- N is the number of servers.

USL - Scalability villain no.1 - Contention

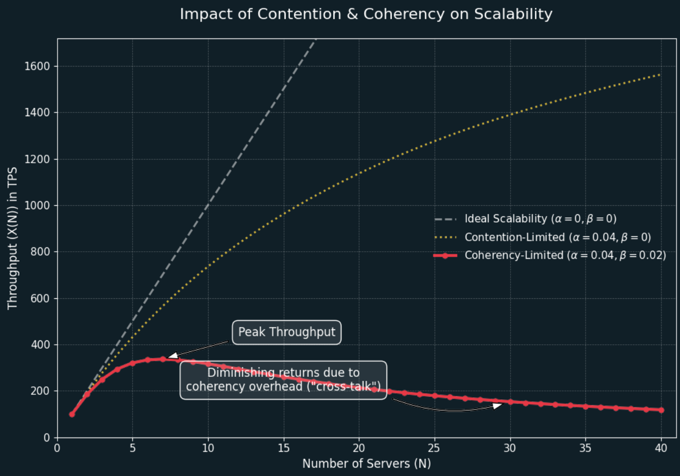


$$X(N) = \frac{\gamma N}{1 + \alpha(N - 1)}$$

Where:

- α represents contention.
- contention is non-parallelisable serialised work.

USL - Scalability villain no.2 - Coherency (a.k.a. Crosstalk)



USL

$$X(N) = \frac{\gamma N}{1 + \alpha(N-1) + \beta N(N-1)}$$

Where:

- γ represents ideal single server throughput.
- α represents contention.
- β represents coherency penalty.

USL - What do we do with it?

Model system/scalability (obviously).

1. Apply observed system/service behaviour metrics.
2. Estimate α, β, and γ using non-linear least squares regression.
3. Interpret the results to know scalability limits and improve bottlenecks.

USL

Demo

USL - Limits

- Noisy data - real-world data is quite noisy(network jitter, OS scheduler, GC pauses etc.).
- Distributed systems - harder to model aggregate functions(/order depends on 10 microservices).
- Asynchronous and event driven architecture pattern is hard to model.
- Coherency factor(β) assumes 1-1 coordination.
- Systems dont always behave the same way at scale. E.g switch to a different algorithm or co-ordinate in batches etc.
- Noisy neighbours - multi-tenancy.
- Rate limits and throttling at dependencies.

Common pitfalls - USL

Keep these in mind while working with USL.

- Garbage In Garbage Out - be diligent about noise. Noise will have non linear effects.
- Over-extrapolation - Dont forecast too far(new constraints emerge at scale). 2x is the rule of thumb.
- Max throughput if often NOT the goal - max throughput @desired latency is.

Key takeaways

- Start thinking in queues. Enrich your monitoring - capture service times and waiting times in histograms, queue lengths.
- Use Little's law for napkin math of fundamental relationship between Utilisation, Throughput/arrival rate, and response time.
- Use USL as a diagnostic compass to identify coarse contention and coherance penalties - rethink design choices to achieve practical goals.
- Keep queing theory wisdom in mind while designing services:
    - Favour pooled resources - single queue and a shared pool of workers.
    - Attack variability - Use caching strategies, optimisations for slower code paths etc to reduce service time variability.
    - Heavy-tailed service times? consider priority queues or size based routing.

References and further reading

- Dr. Neil J Gunther's page on Scalability and USL.
- Baron Schwartz's The essential Guide to QueueingTheory.
- Neil J. Gunther and Stefan Moeding's USL R package
- Eben Freeman's LISA 17 talk on Queueing theory in practice
- Kavya Joshi's talk on Applied Performance Theory.

Thank You!

Questions?

Get in Touch

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Slides Available At:

aravindh.net/srecon2025.pdf