Architecture: Microservices

17-313: Foundations of Software Engineering

https://cmu-313.github.io

Josh Sunshine and **Michael Hilton**

Spring 2026

Smoking Section

- Last full row

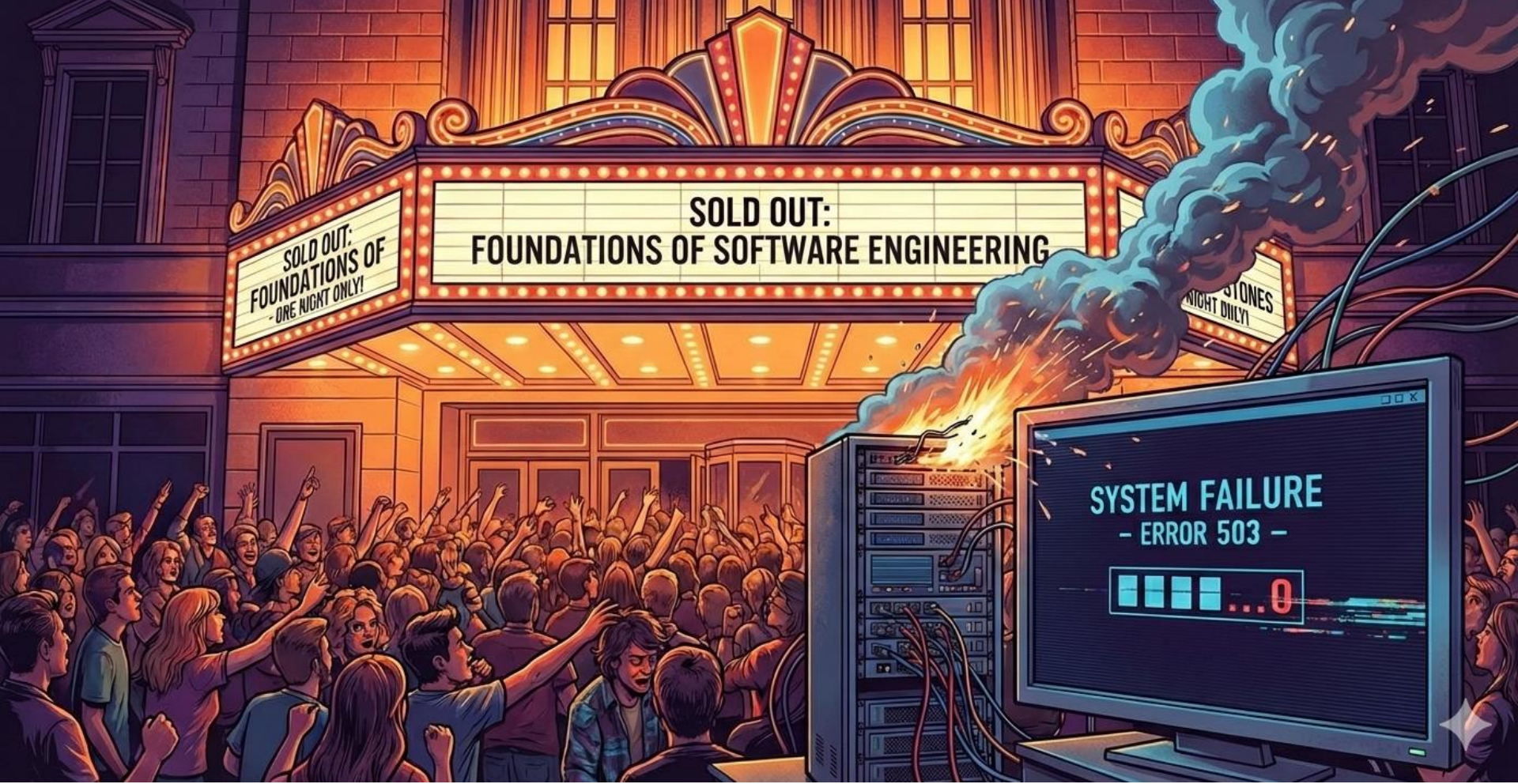
Learning Goals

- Understand the difference between traditional monolithic and modular software architectures
- Explore various approaches to modularity, assess their respective benefits and drawbacks, and reason about **when to use them** and **how to use them well**
  - Monoliths, Plugins, Services, Microservices, Modular Monoliths

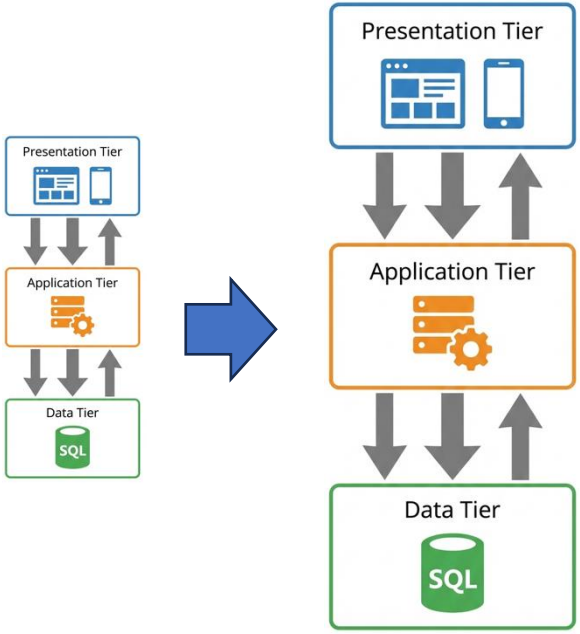
Case Study: Victim of Success Theater

Case Study: Victim of Success Theater

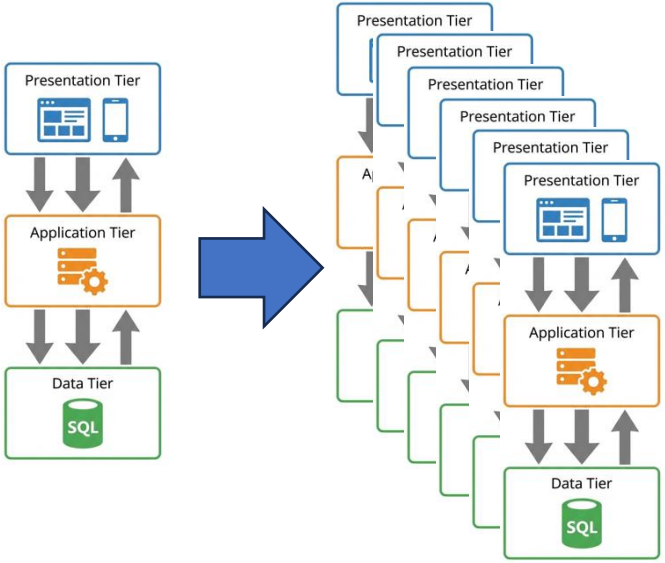
- Simple web application for a local theater:
  - Sell tickets
  - 500 seats
- Architecture: Standard "3-Tier" setup:
  UI → API → Database
- Happy path :
  - A user clicks "Buy”
  - API checks the DB, decrements the ticket count, and sends a confirmation
  - It works perfectly for months.


SOLD OUT:
FOUNDATIONS OF SOFTWARE ENGINEERING
SOLD OUT:
FOUNDATIONS OF
- ONE NIGHT ONLY!
NIGHT ONLY!
SYSTEM FAILURE
- ERROR 503 -
...0

How can we scale to 1000 theaters?



OR?

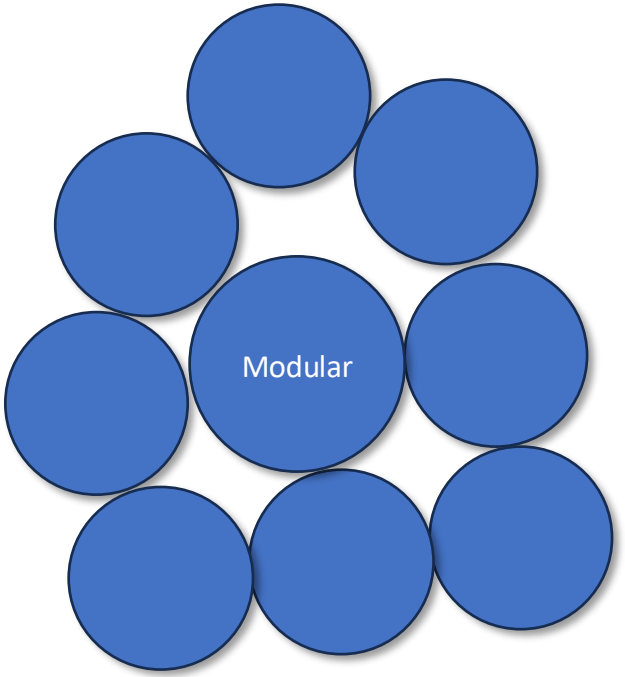


Vertical Scaling

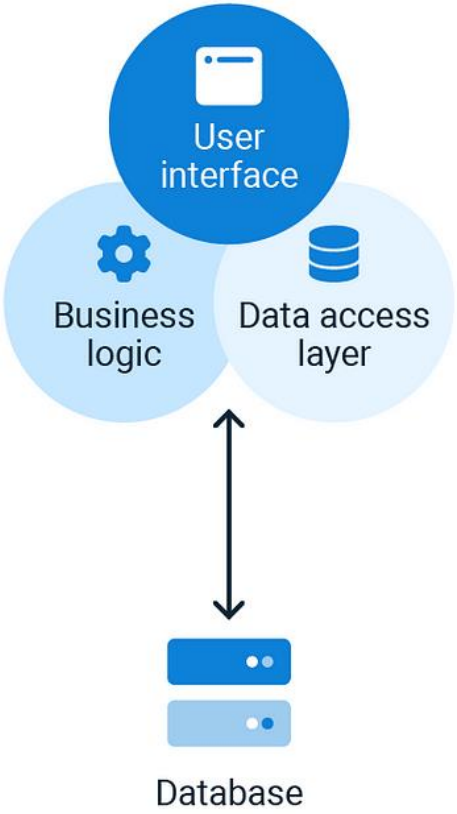
Horizontal Scaling

Monolithic vs. Modular Architectures

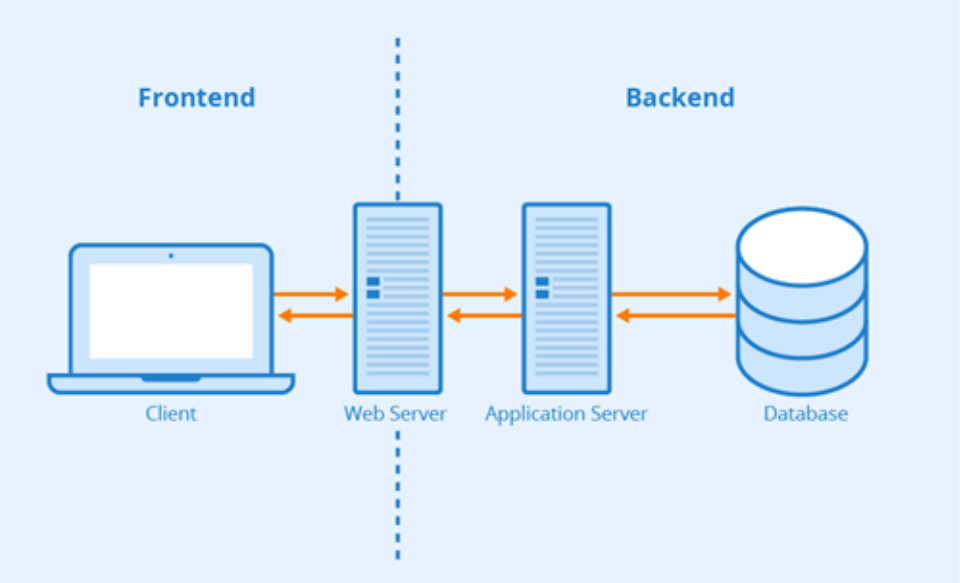

Monolithic

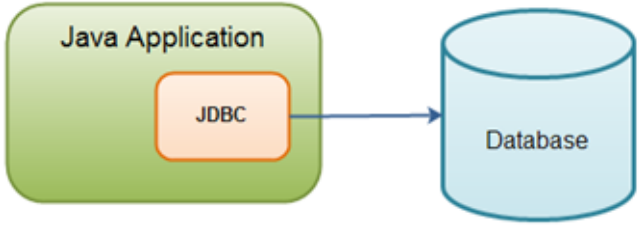

Modular

Monolithic Architecture



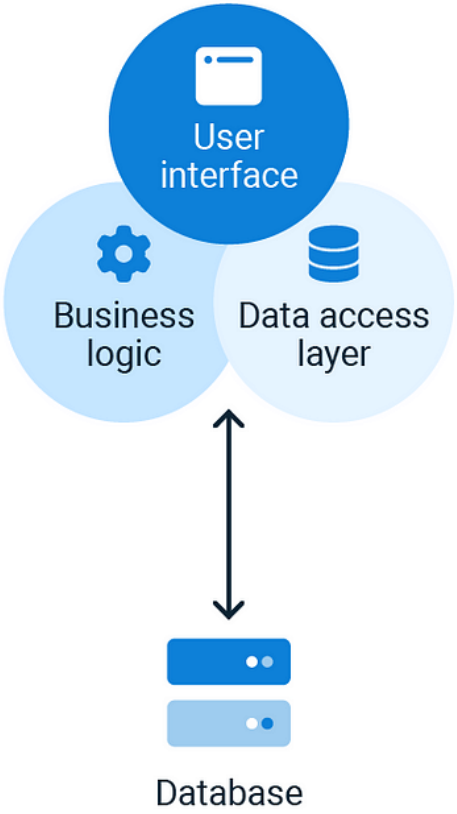
Monolithic Styles



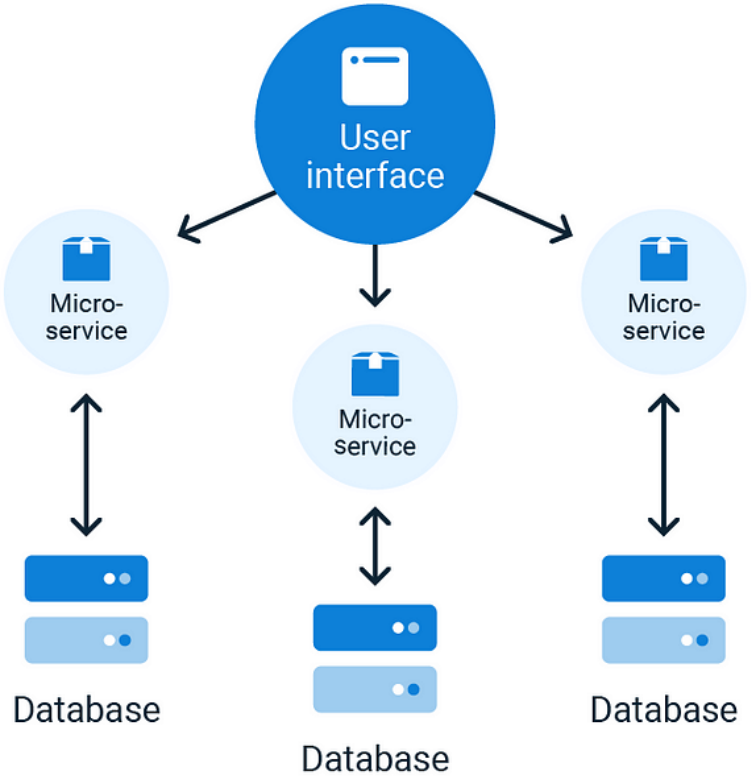


Source: https://www.seobility.net (CC BY-SA 4.0)

Monolithic Architecture

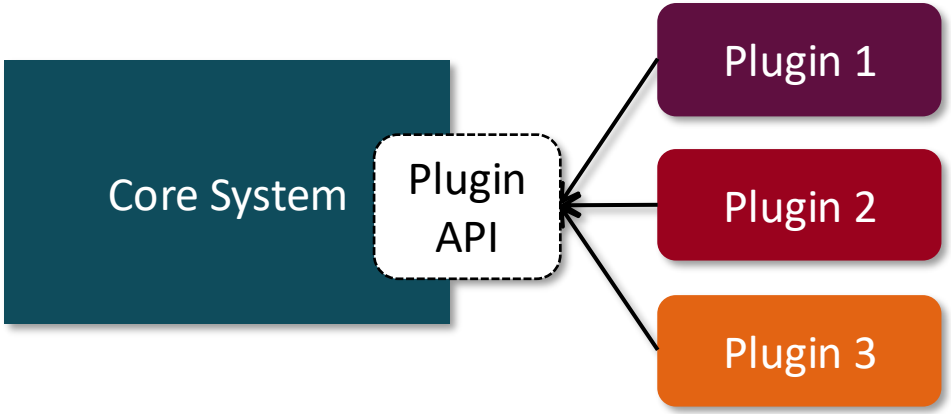


Microservice Architecture



Modularity comes in many ways

- **Plug-in architectures**
  - Distinct code repositories, linked-in to a monolithic run-time
  - Examples: Linux kernel modules, NodeBB themes, VS Code extensions
  - Separates development, but runs as “one”

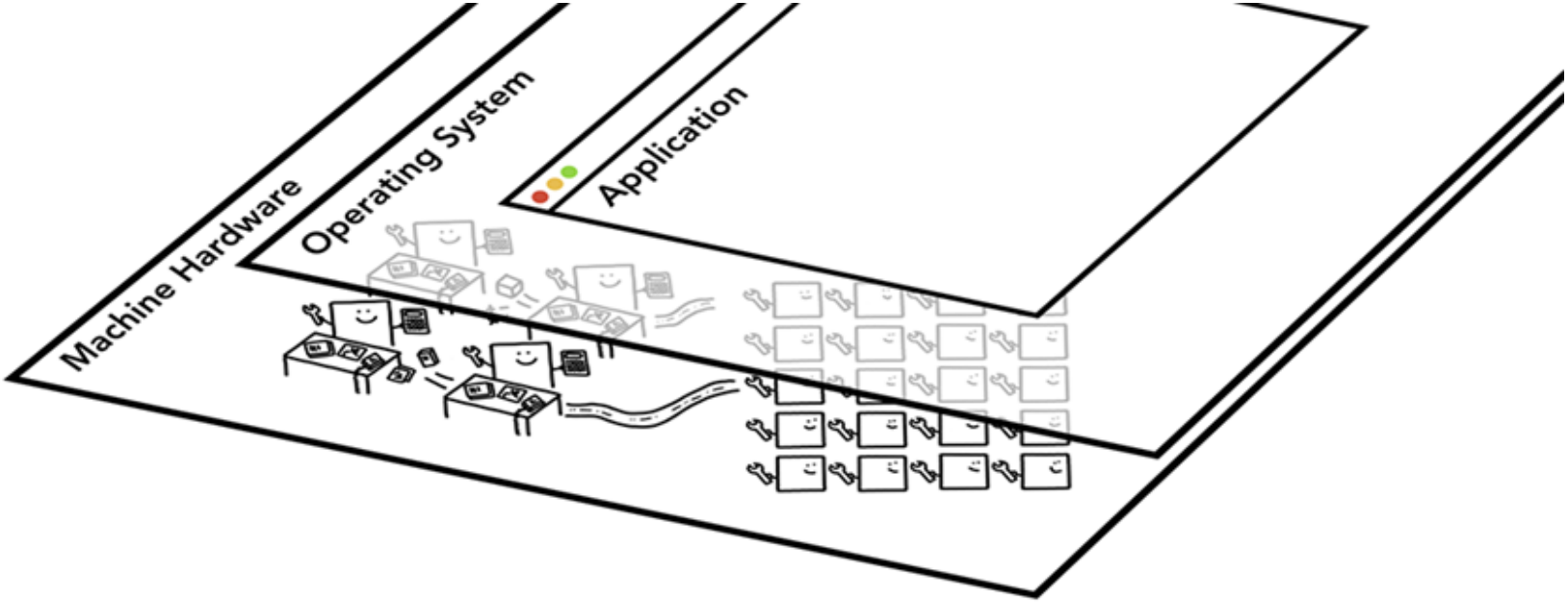


Modularity comes in many forms

- Plug-in architectures
- Service-oriented architectures
  - Distinct processes communicating via messages (e.g., Web browsers)
  - Separates run-time resource management and failure / security issues.
- Distributed micro-services
  - Independent, autonomous services communicating via web APIs
  - Separates almost all concerns

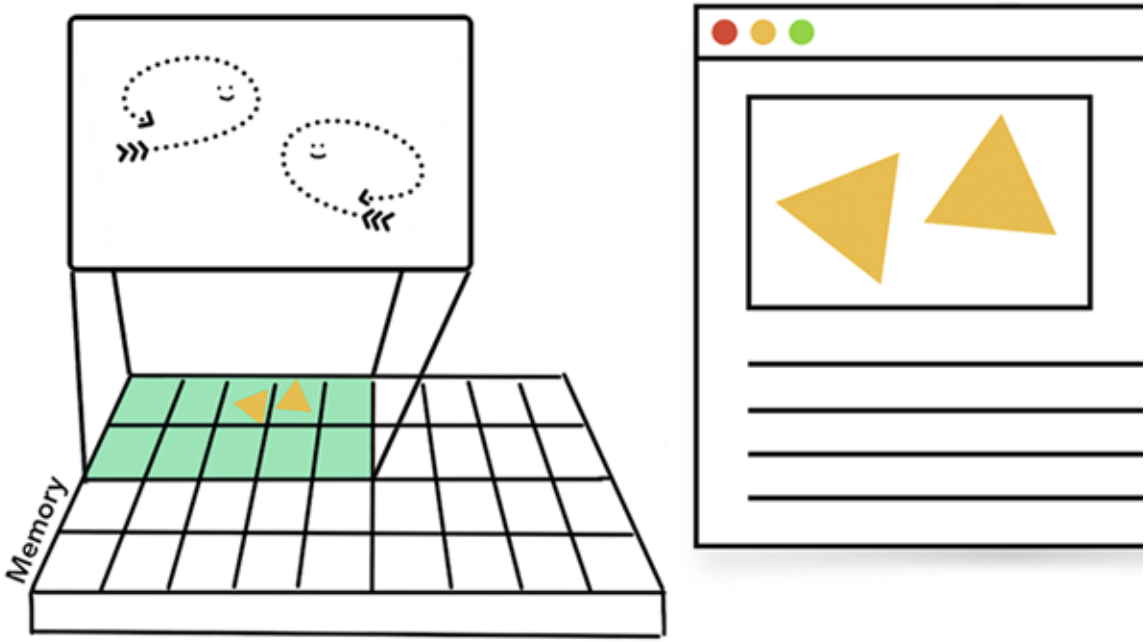
SERVICE-BASED ARCHITECTURES

Case Study: Web Browsers



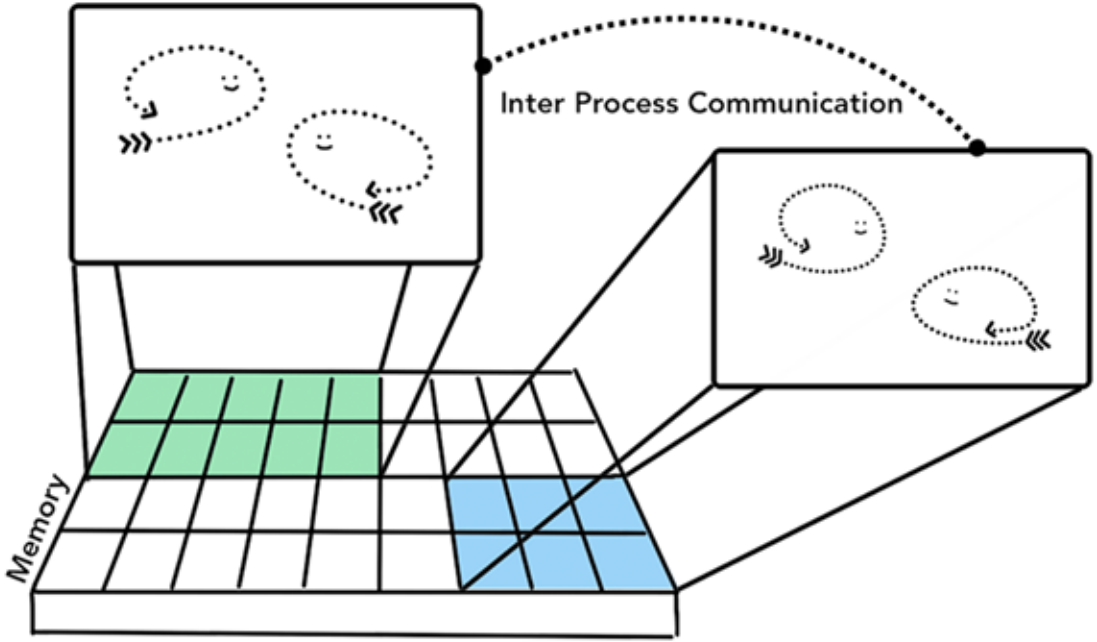
Source: https://developers.google.com/web/updates/2018/09/inside-browser-part1 (CC BY 4.0)

Multi-threaded browser in single process



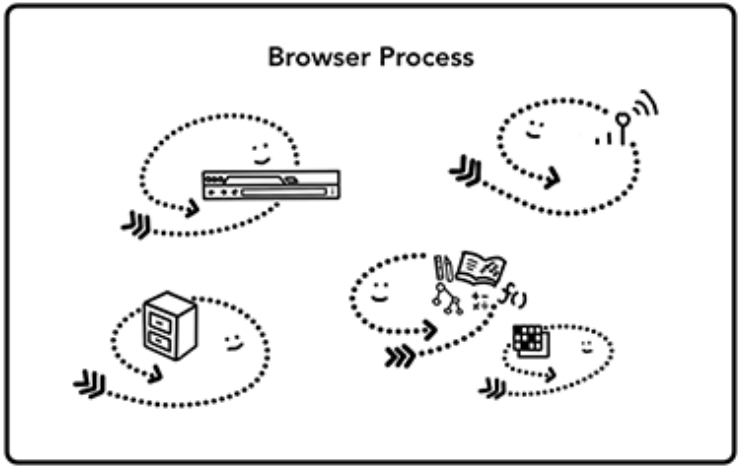
Source: https://developers.google.com/web/updates/2018/09/inside-browser-part1 (CC BY 4.0)

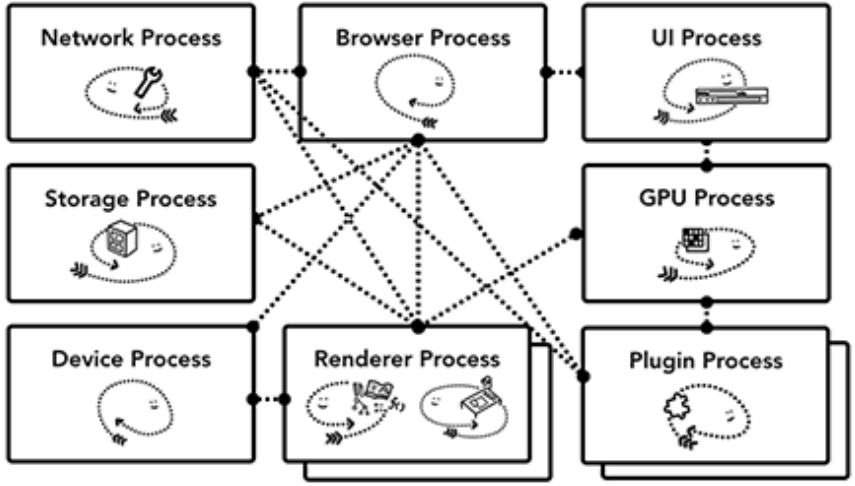
Multi-process browser with IPC



Source: https://developers.google.com/web/updates/2018/09/inside-browser-part1 (CC BY 4.0)

Service-based browser architecture





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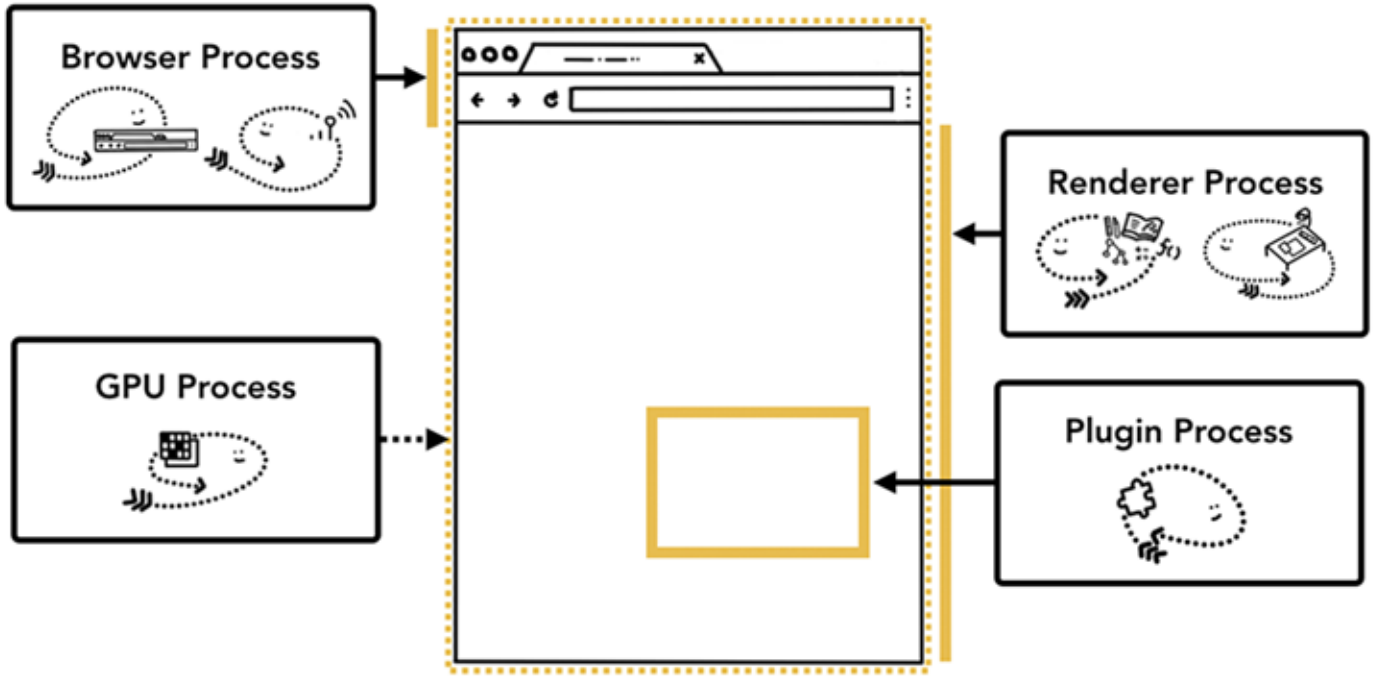
Service-based browser architecture



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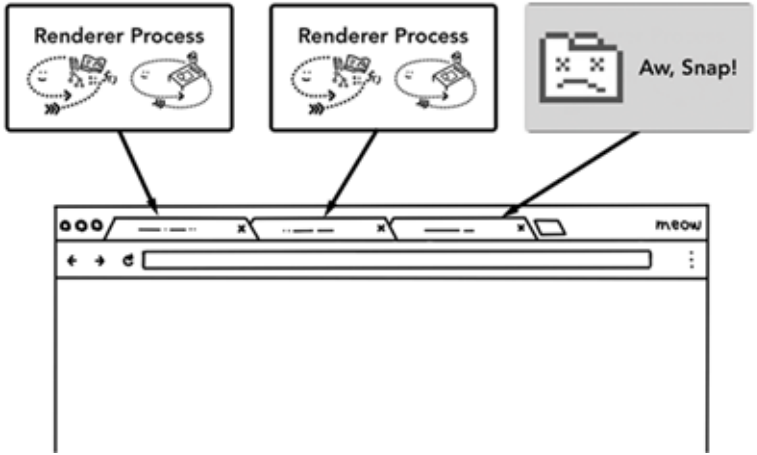
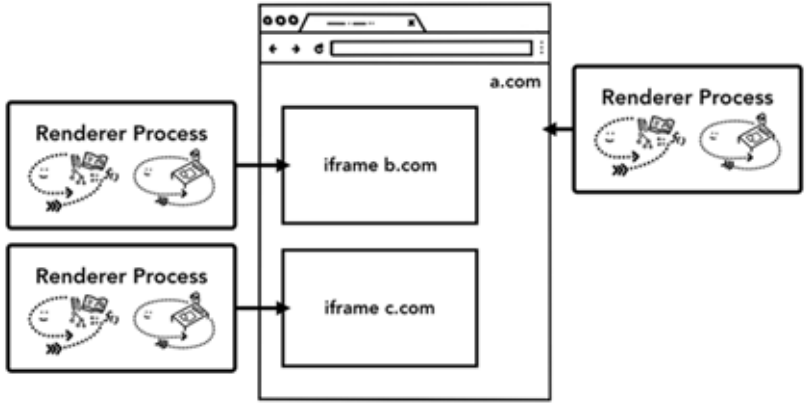
Service-based browser architecture





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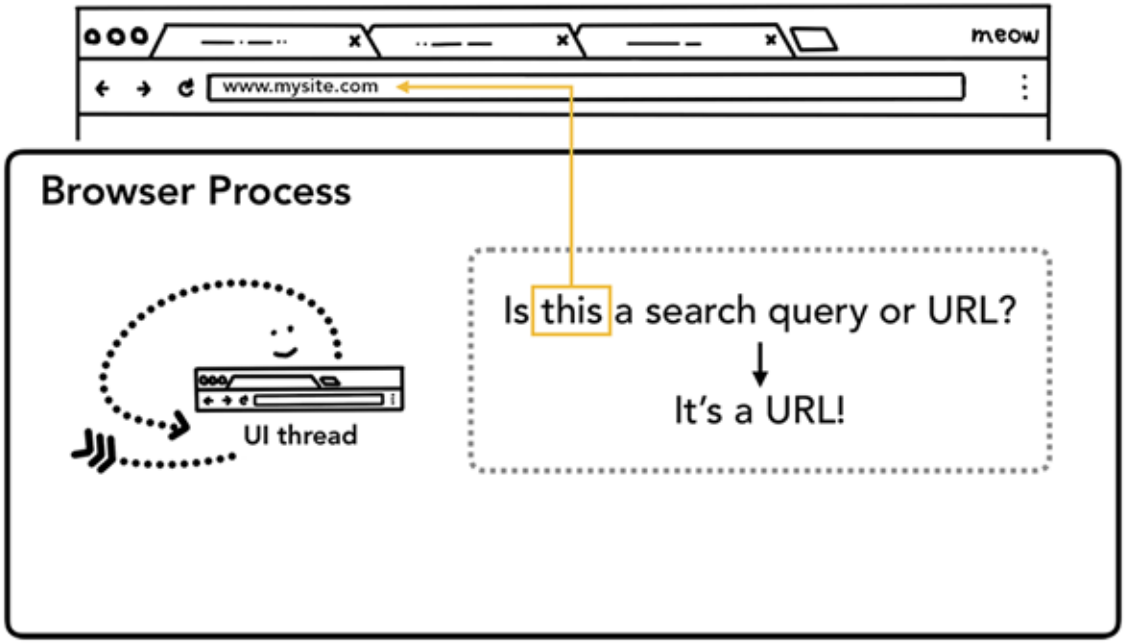
Navigating to a web site uses service requests



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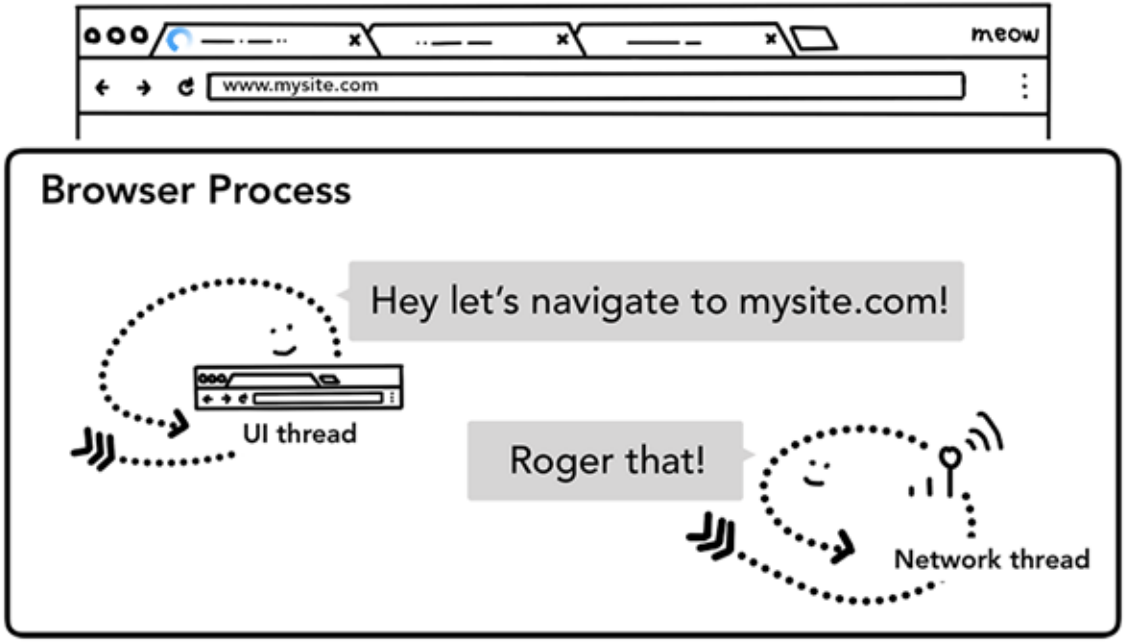

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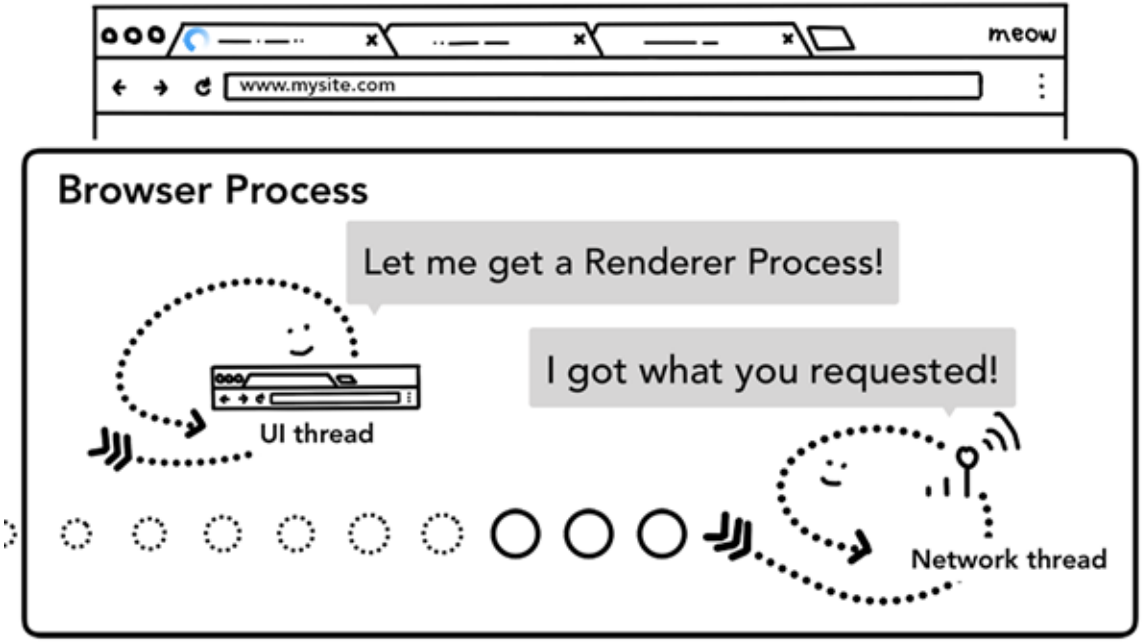

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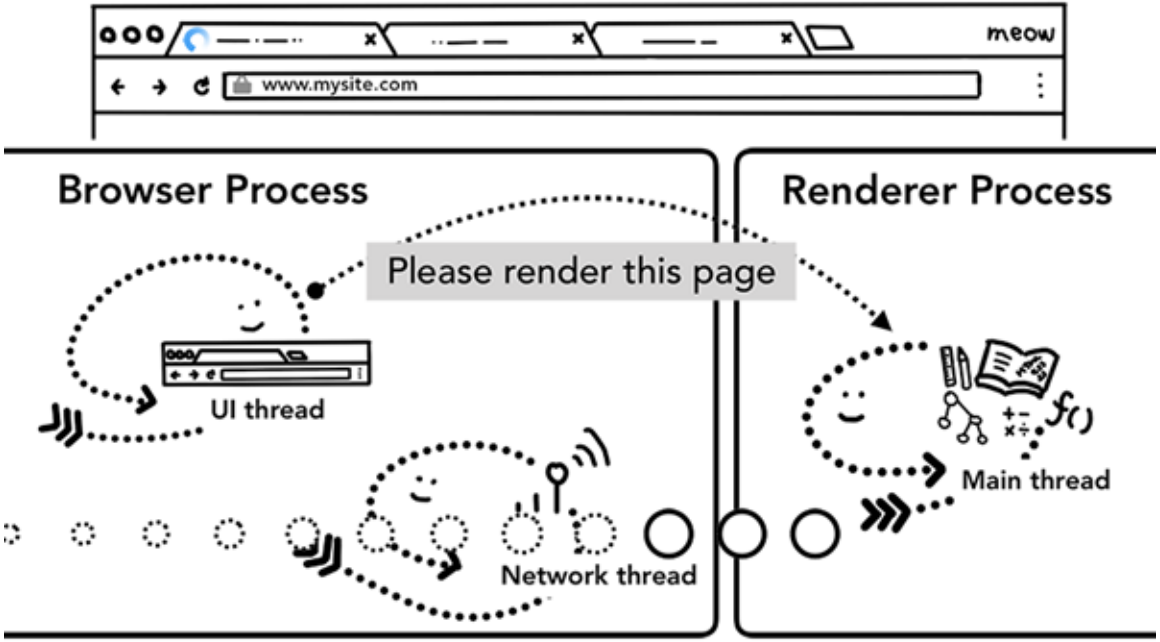

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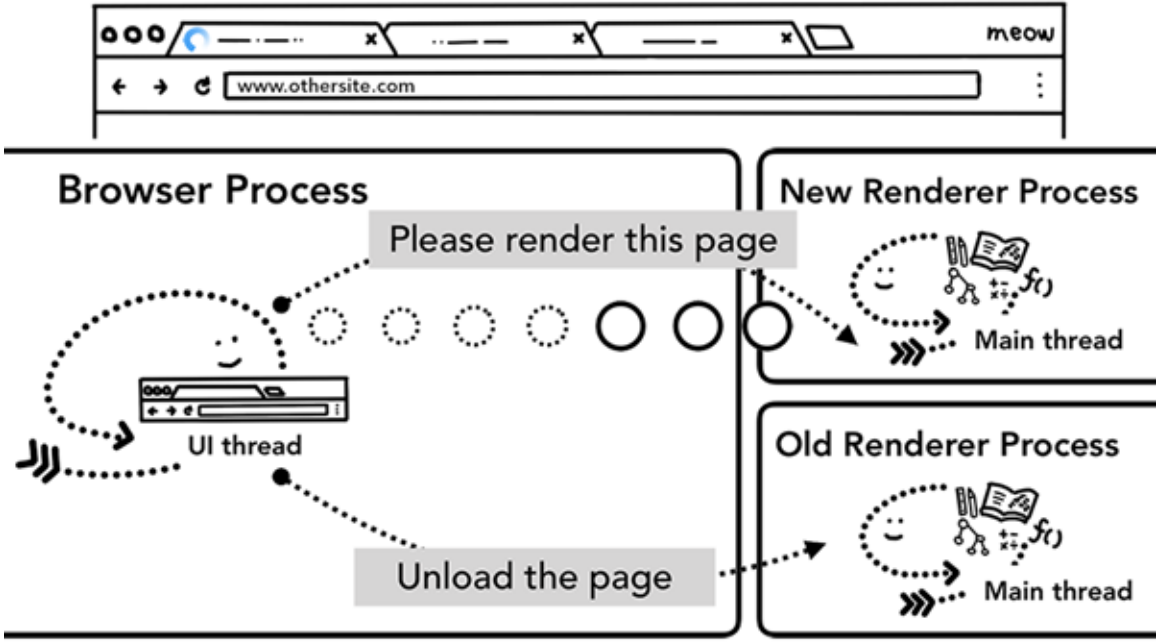

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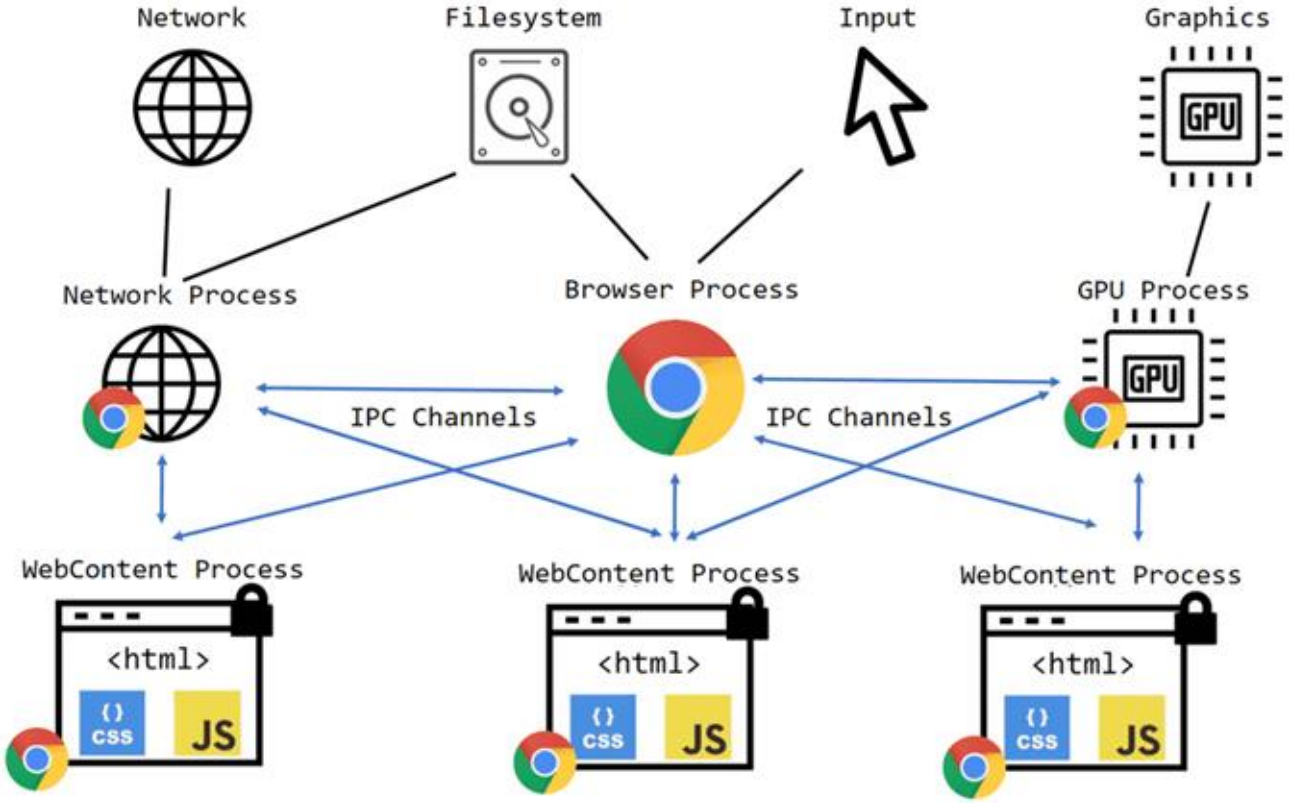
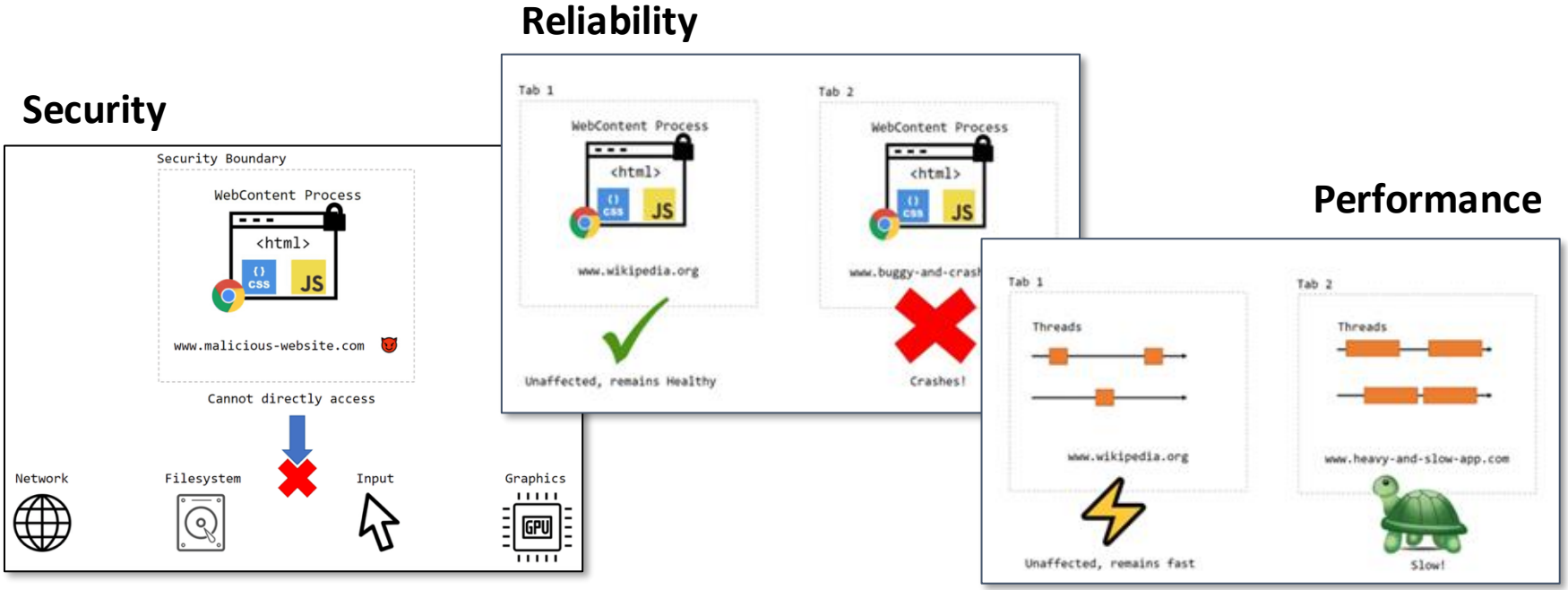


https://webperf.tips/tip/browser-process-model

Multi-Process: Benefits



https://webperf.tips/tip/browser-process-model/

Multi-Process: Costs and Trade-offs

- **Memory Overhead**
  - spinning up new processes requires additional memory allocation
- **Process Creation Overhead**
  - more expensive to create a new process rather than simply a new thread in an existing process
- **IPC Overhead**
  - communicating across processes is slower than keeping communication completely localized within a single process

Service-Based Architectures: Pros and Cons

- ✅ **Pros**
  - Ability to change components independently
  - Independent processes (Isolation, Security)
  - Focusing on doing one thing well

- ❌ **Cons**
  - Increased complexity
  - Increased cost and overheads
  - Difficult to ensure data consistency across different services

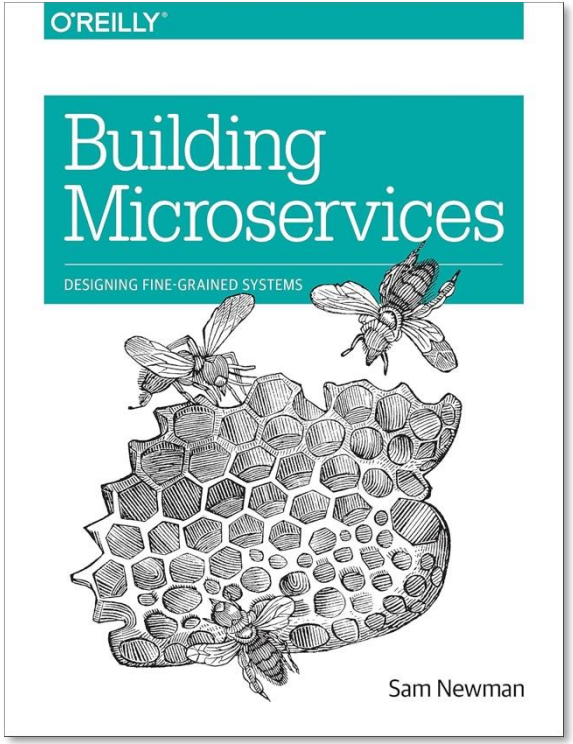
MICROSERVICES


Microservices
Microservices Everywhere

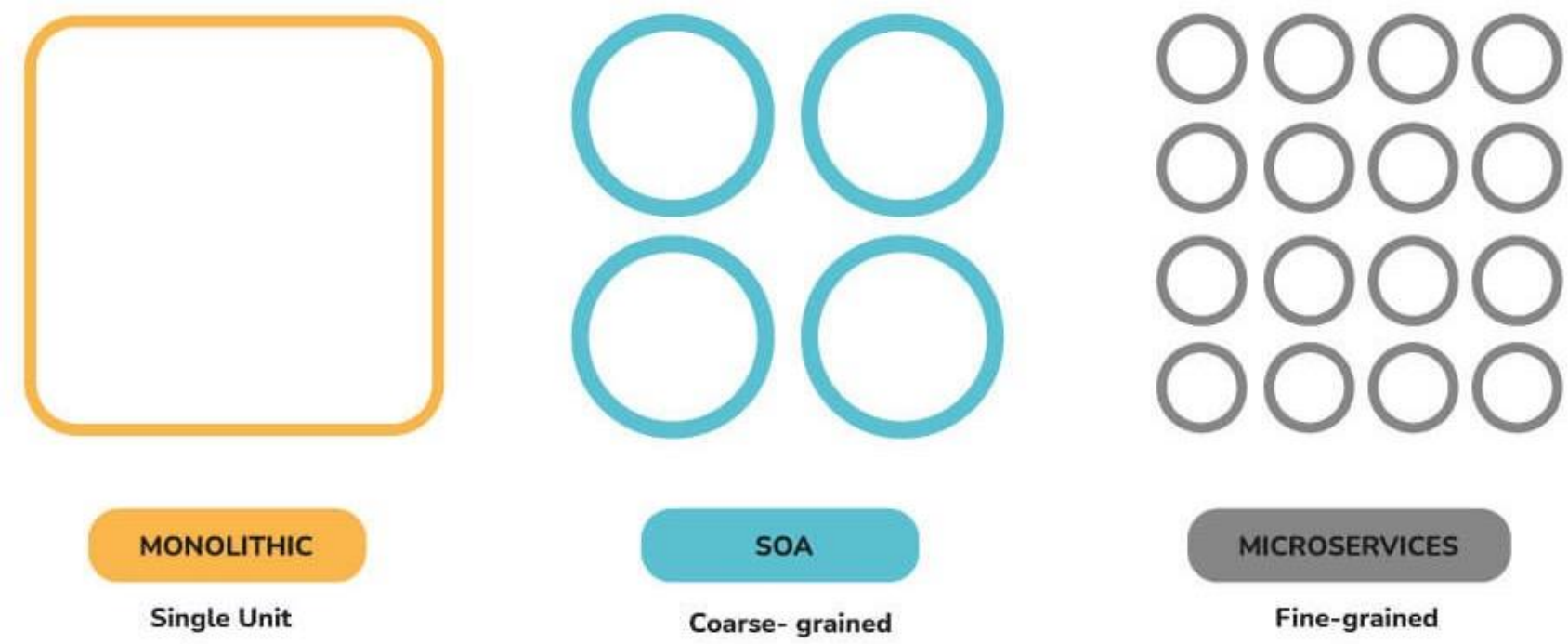
Microservices

"*Small **autonomous** services that work well together*"

Sam Newman



Monolith vs. Service-Based vs. Microservice



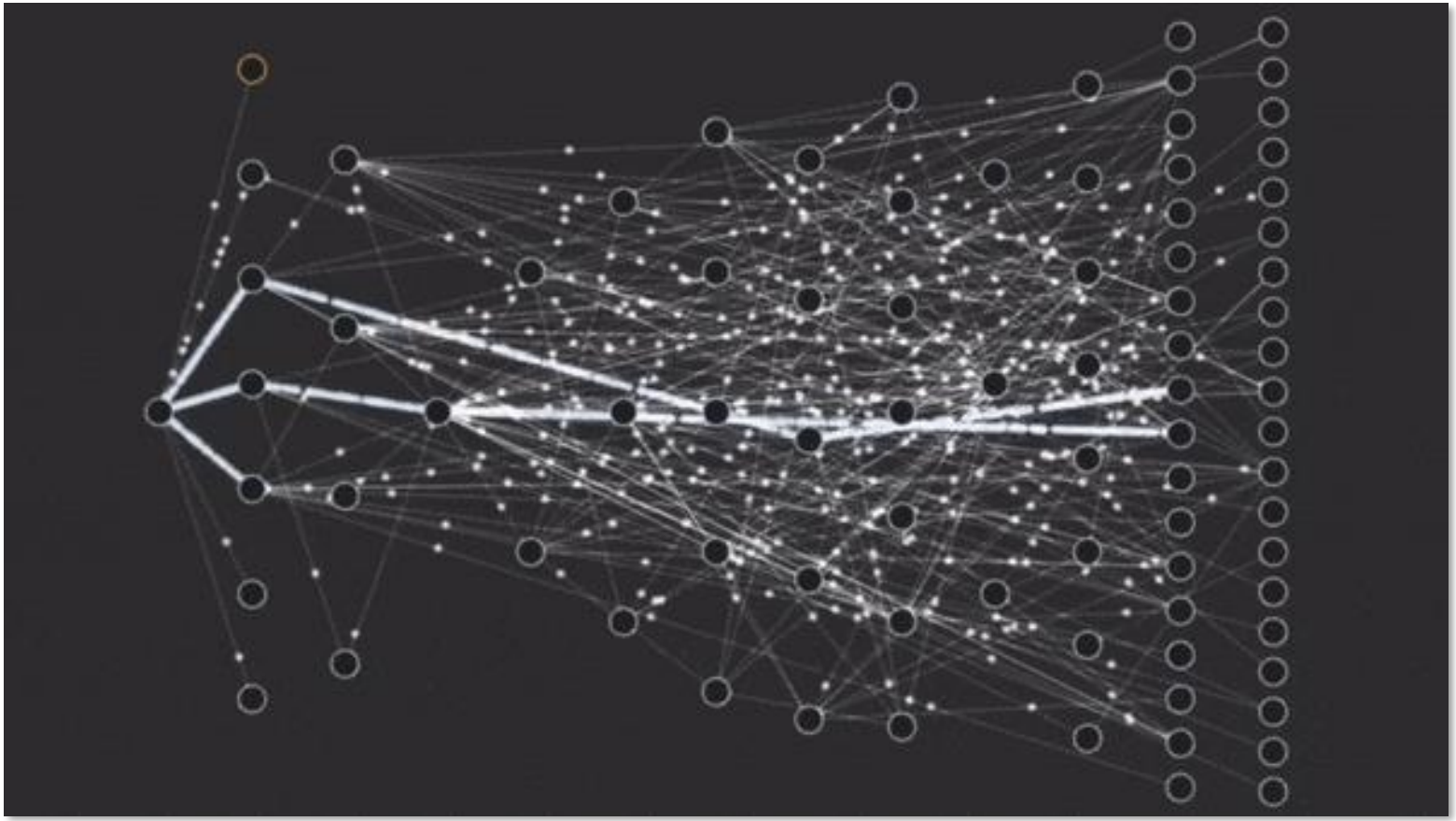
Netflix Microservices

Why Can't Netflix Use a Monolithic Architecture?

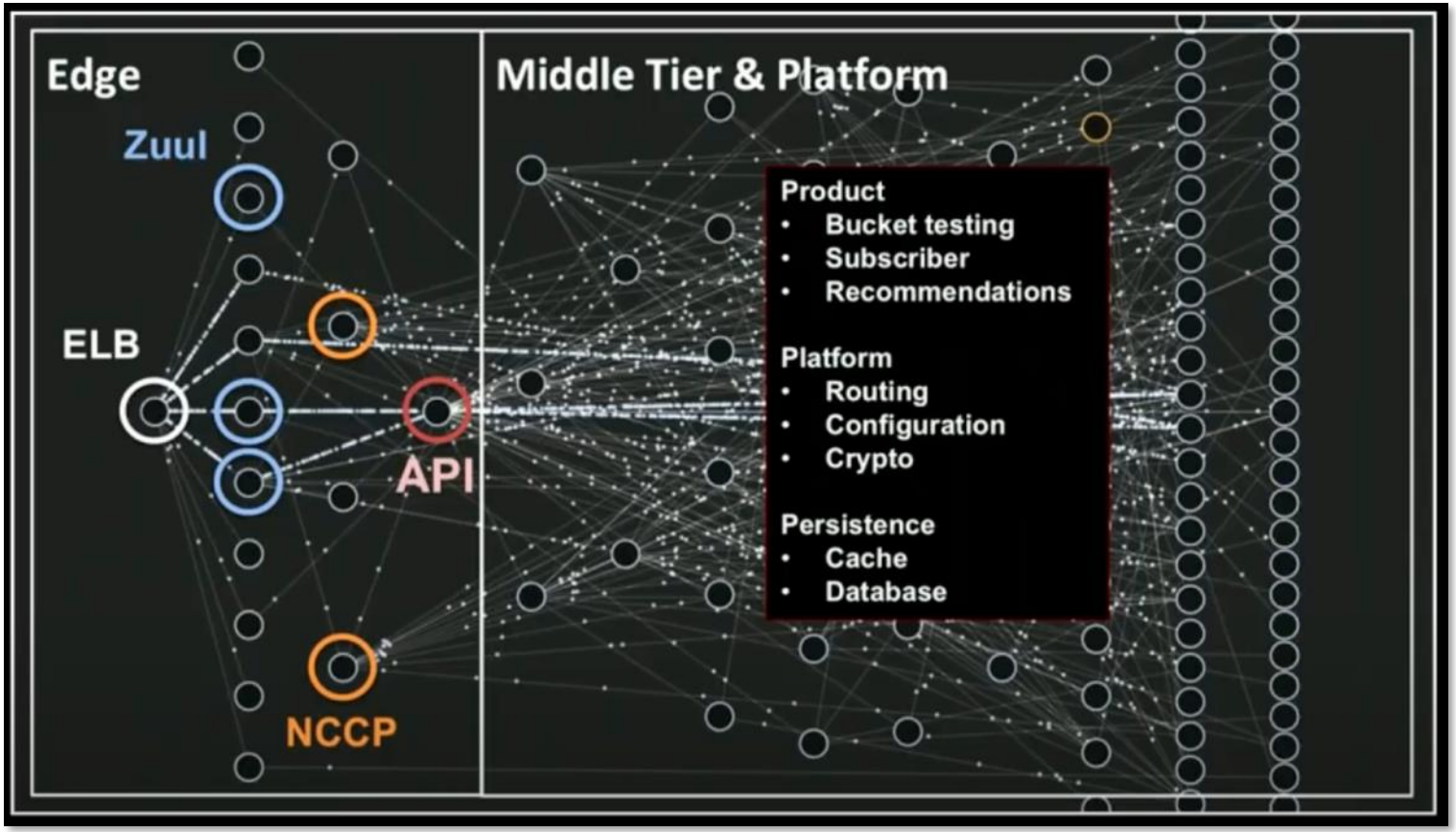
- Requires an architecture that can handle **various computational demands**
- Need scalability must support **millions of users worldwide**
- Need fault tolerance to maintain a **seamless user experience**
- New features and improvements need to be **rolled out rapidly**

Netflix Microservices

- User Subscriptions
- Banner Ad
- Popular Shows
- Trending Now
- Continue Watching
- My List (saved shows)
- Notifications
- User Management
- Subtitles
- …



https://www.youtube.com/watch?v=V_oxbj-a1wQ



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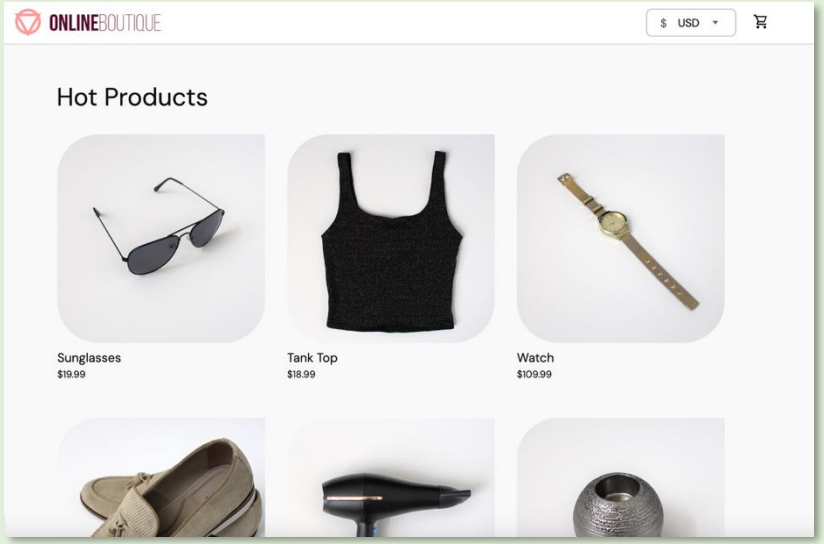
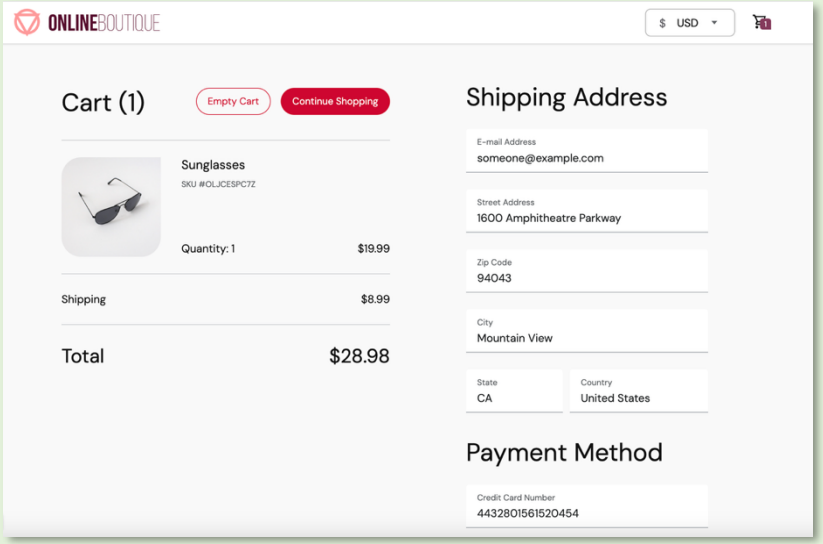
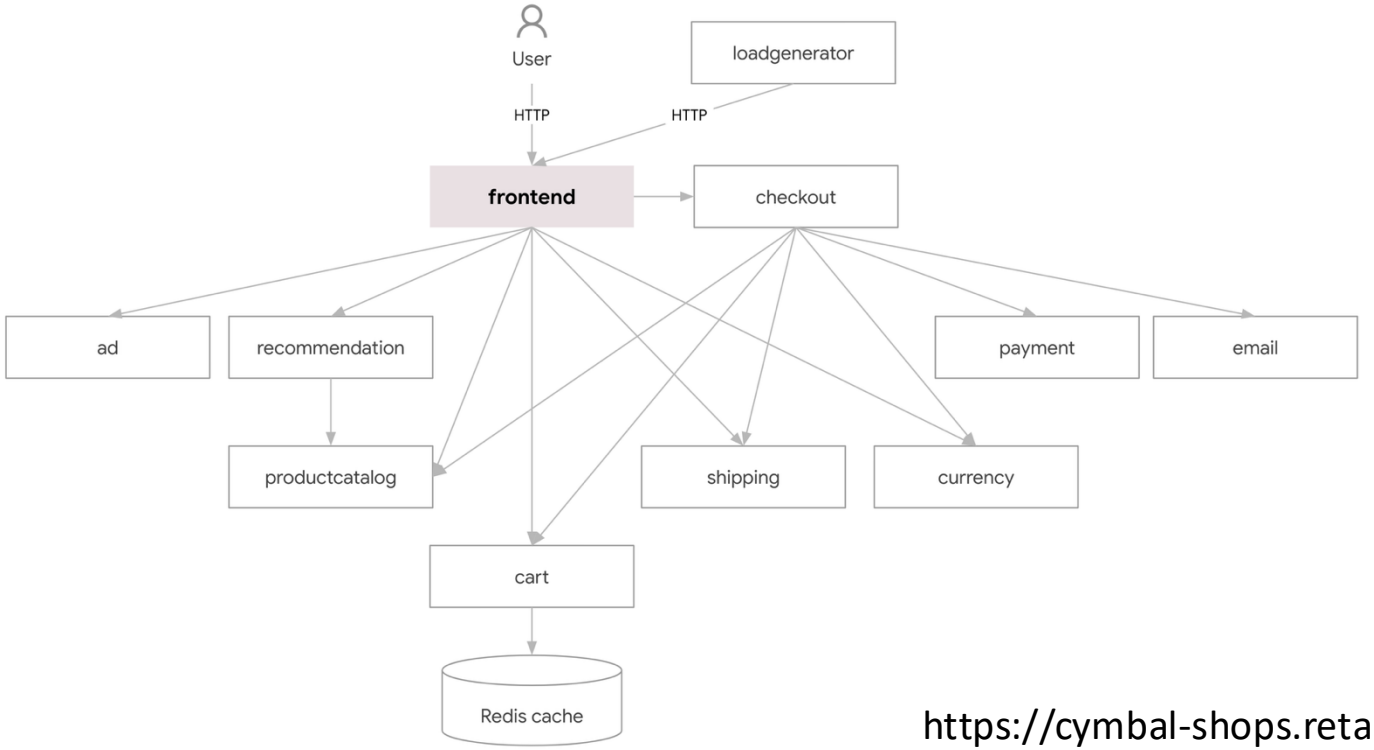
Online Boutique: Guess some microservices





https://cymbal-shops.retail.cymbal.dev

Online Boutique: Microservice Architecture



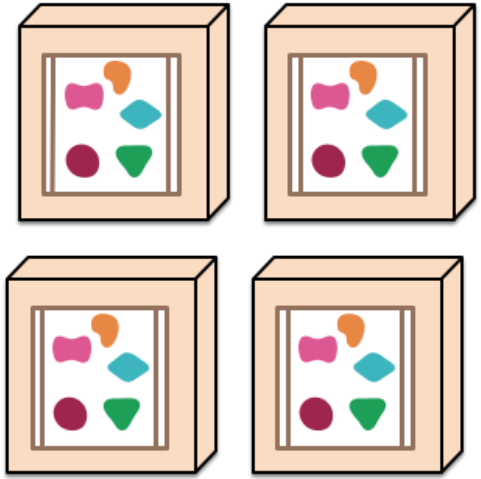
https://cymbal-shops.retail.cymbal.dev

Service	Language	Description
frontend	Go	Exposes an HTTP server to serve the website. Does not require signup/login and generates session IDs for all users automatically.
cartservice	C#	Stores the items in the user's shopping cart in Redis and retrieves it.
productcatalogservice	Go	Provides the list of products from a JSON file and ability to search products and get individual products.
currencyservice	Node.js	Converts one money amount to another currency. Uses real values fetched from European Central Bank. It's the highest QPS service.
paymentservice	Node.js	Charges the given credit card info (mock) with the given amount and returns a transaction ID.
shippingservice	Go	Gives shipping cost estimates based on the shopping cart. Ships items to the given address (mock)
emailservice	Python	Sends users an order confirmation email (mock).
checkoutservice	Go	Retrieves user cart, prepares order and orchestrates the payment, shipping and the email notification.
recommendationservice	Python	Recommends other products based on what's given in the cart.
adservice	Java	Provides text ads based on given context words.
loadgenerator	Python/Locust	Continuously sends requests imitating realistic user shopping flows to the frontend.

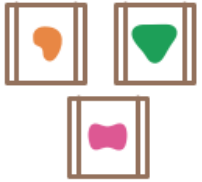
Scalability

A monolithic application puts all its functionality into a single process...

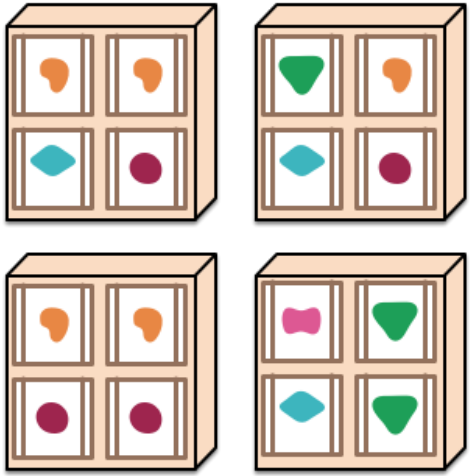
... and scales by replicating the monolith on multiple servers



A microservices architecture puts each element of functionality into a separate service...



... and scales by distributing these services across servers, replicating as needed.

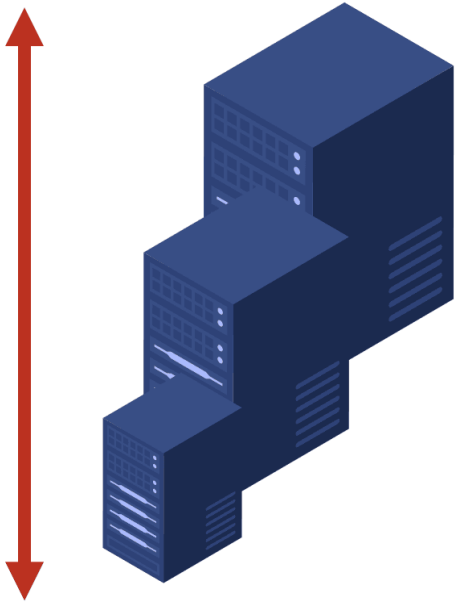


Source: http://martinfowler.com/articles/microservices.html

Types of Scaling: Vertical vs. Horizontal

Vertical Scaling

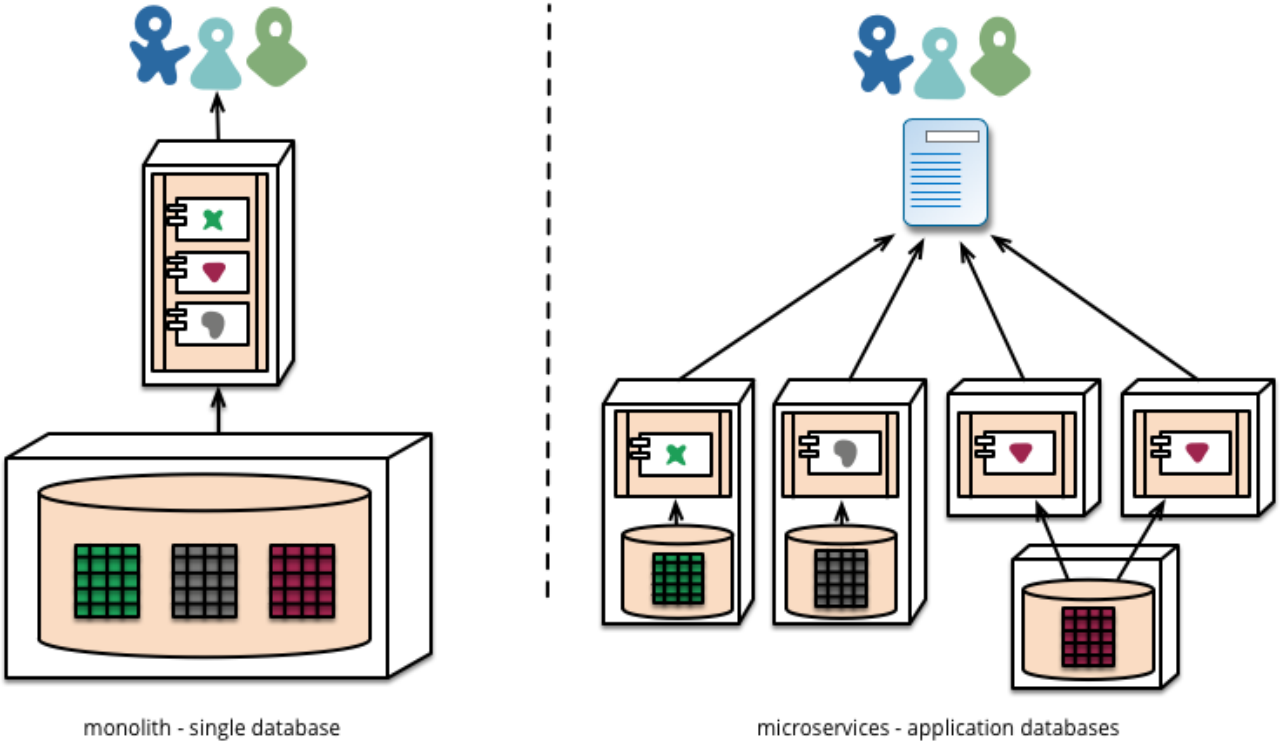
Increase or decrease the capacity of existing services/instances.



Horizontal Scaling

Add more resources like virtual machines to your system to spread out the workload across them.

Data Management and Consistency

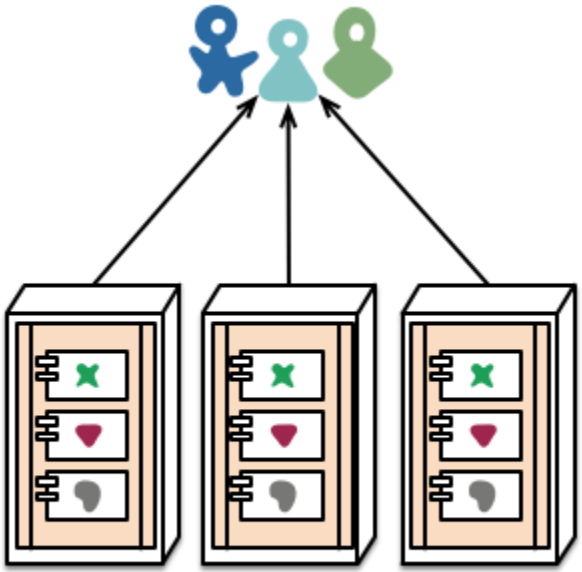


monolith - single database

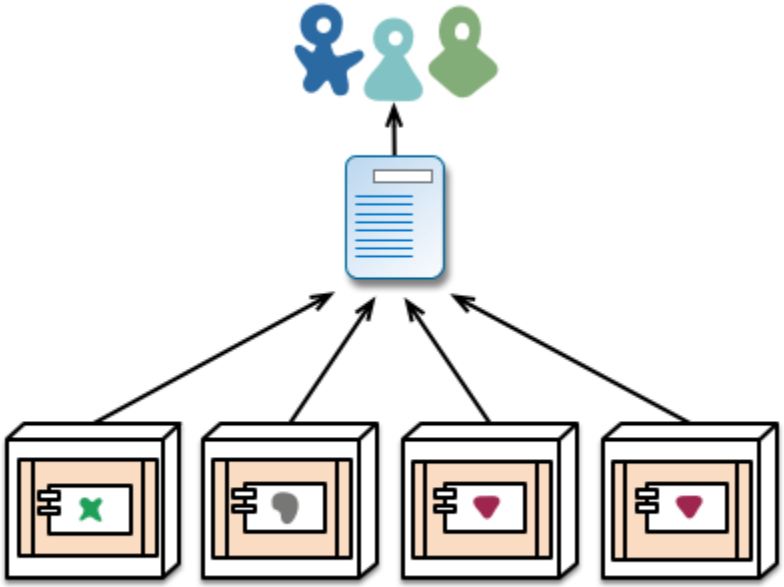
microservices - application databases

Source: http://martinfowler.com/articles/microservices.html

Deployment and Evolution



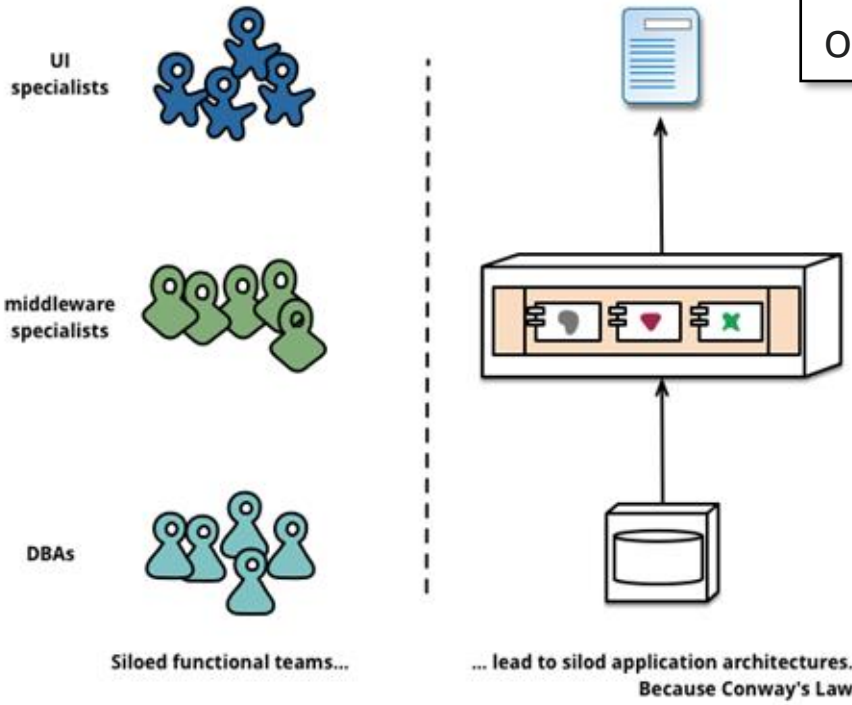
monolith - multiple modules in the same process

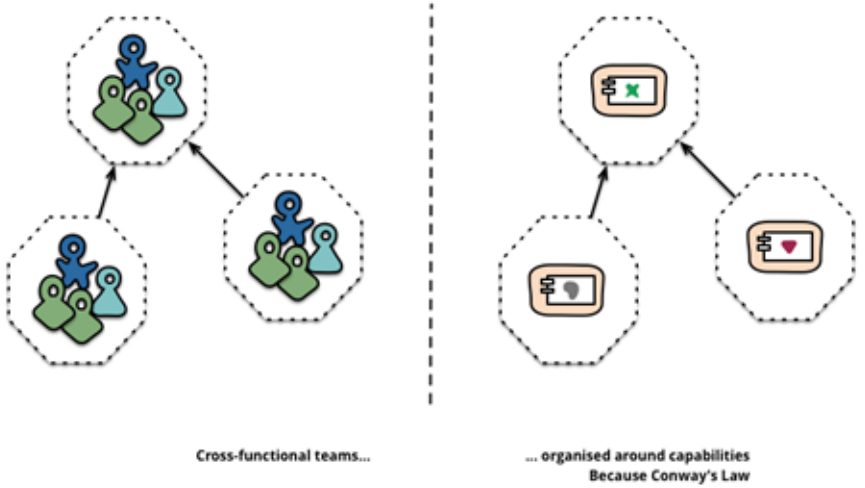


microservices - modules running in different processes

Conway's Law

"Any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure."





"Products" not "Projects"

YOU BUILD IT
YOU RUN
~~AWAY~~ IT

"The traditional model is that you take your software to the wall that separates development and operations, and throw it over and then forget about it. Not at Amazon. You build it, you run it. This brings developers into contact with the day-to-day operation of their software. It also brings them into day-to-day contact with the customer. This customer feedback loop is essential for improving the quality of the service."

-- Werner Vogels in "A conversation with Werner Vogels" in ACM Queue, May 2006

MICROSERVICES: PRINCIPLES

Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

Consumer First

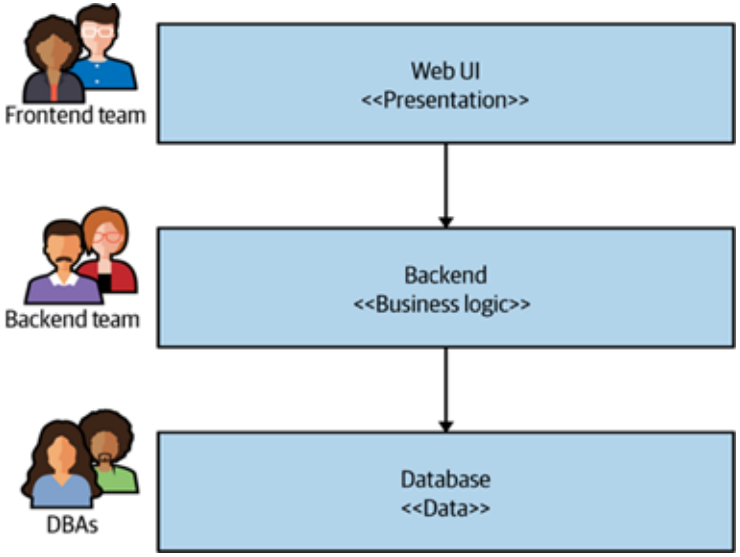
Isolate Failures

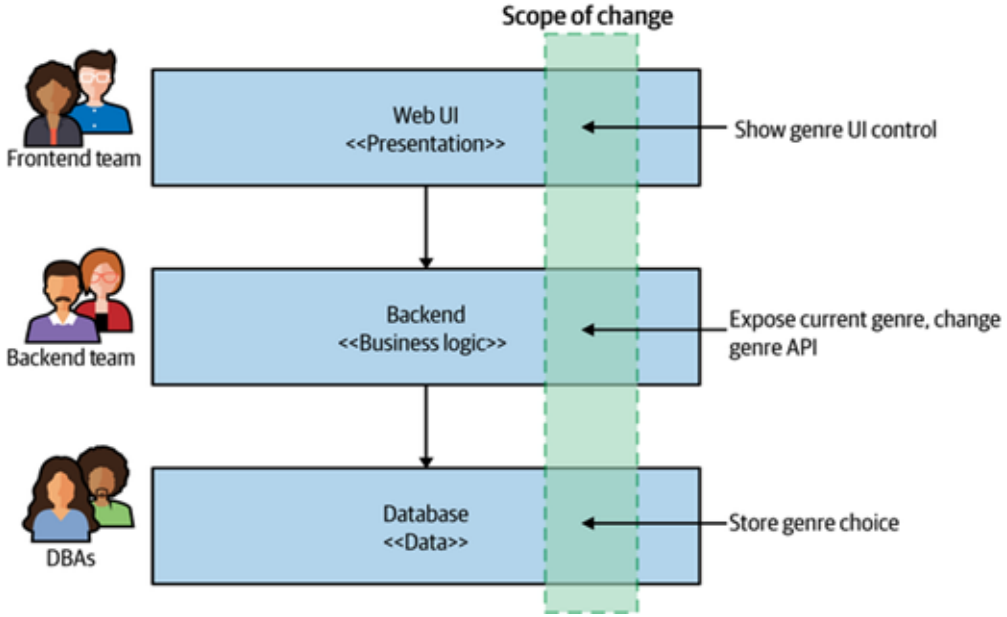
Sam Newman's Principles of Microservices

Domain-driven modeling

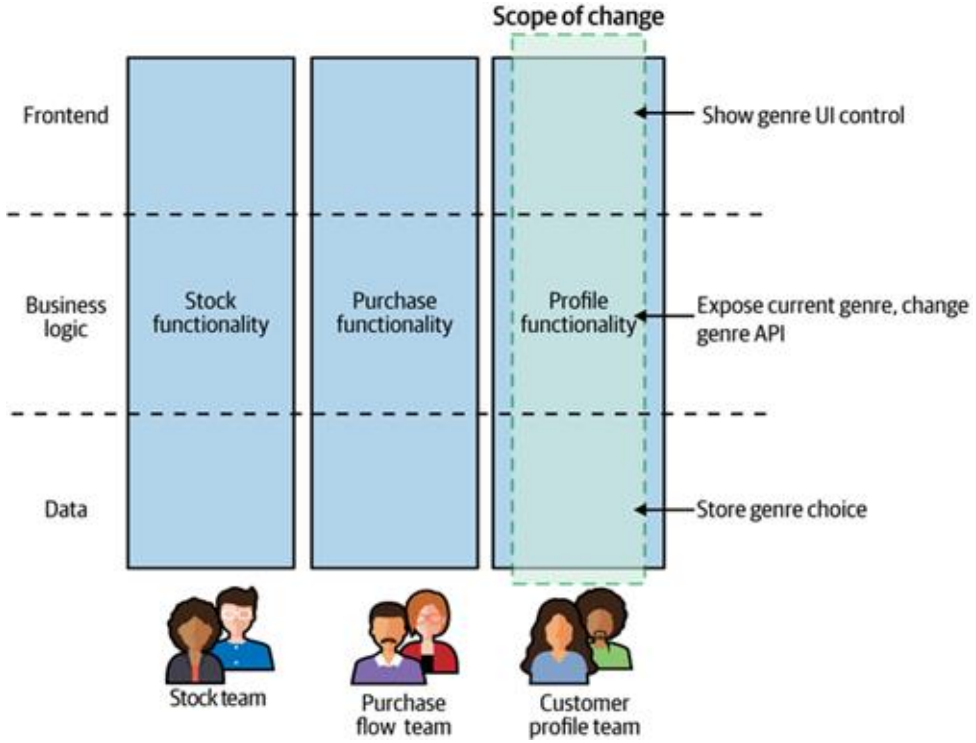
- Model services around business capabilities

Domain-driven modeling

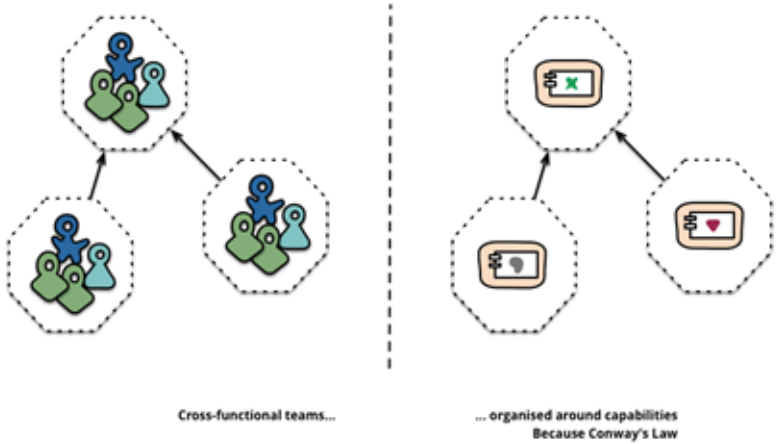




Domain-driven modeling



Remember Conway's Law?



Domain Driven Modeling

Culture of Automation

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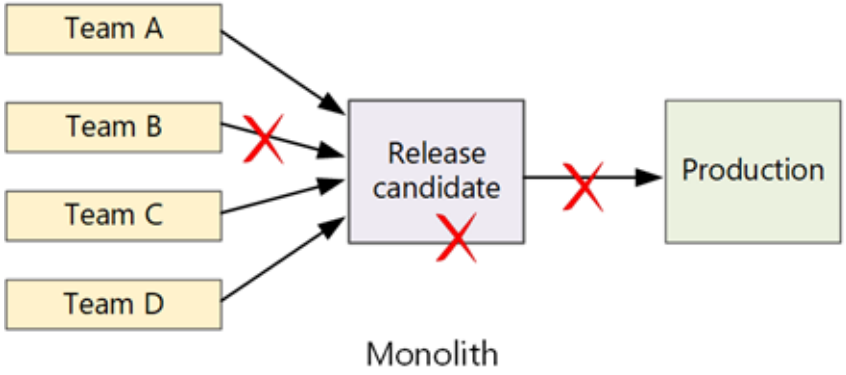
Sam Newman's Principles of Microservices

Culture of Automation

- API-Driven Machine Provisioning
- Continuous Delivery
- Automated Testing

Continuous Delivery



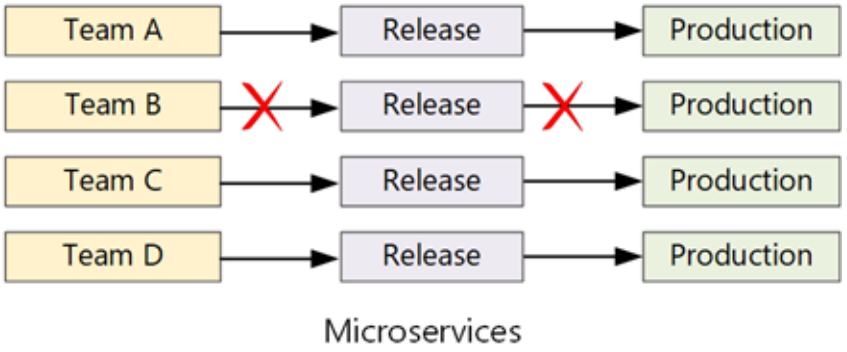


Image Source: https://learn.microsoft.com/en-us/azure/architecture/microservices/ci-cd

Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

Consumer First

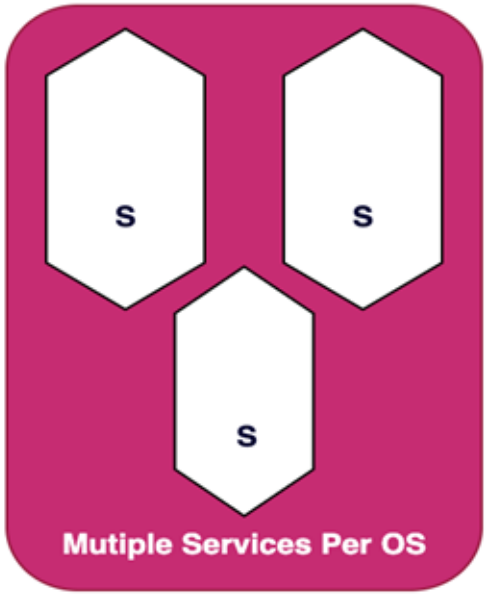
Isolate Failures

Sam Newman's Principles of Microservices

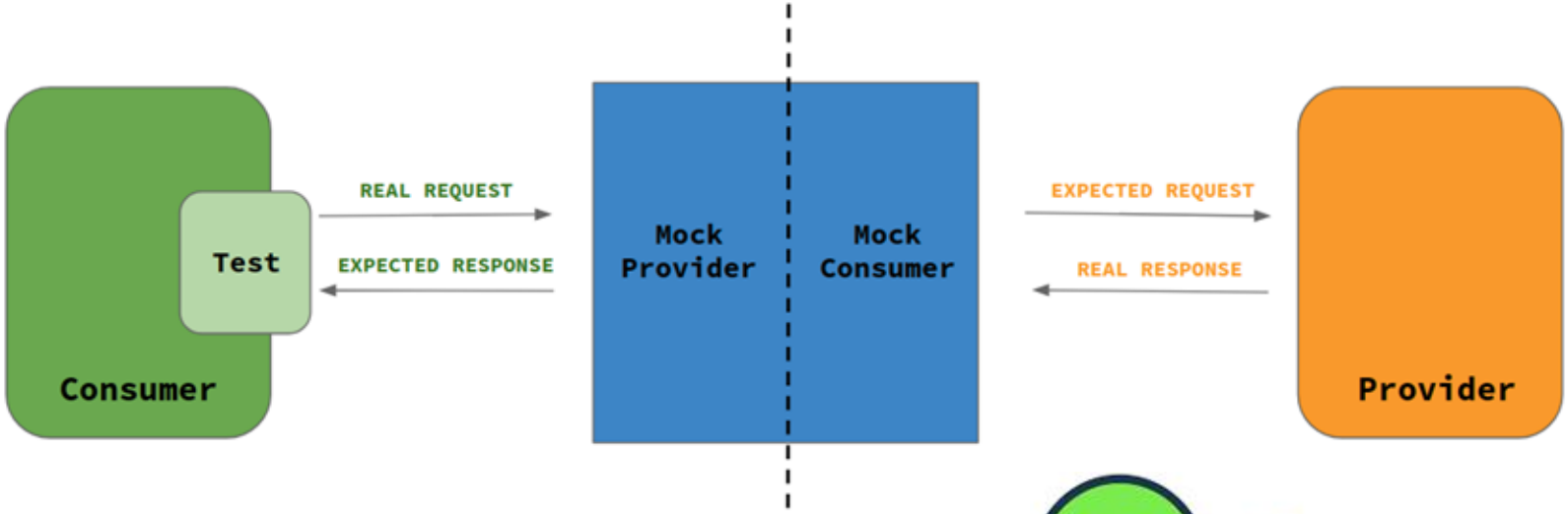
Deploy Independently

- One Service Per OS
- Consumer-Driven Contracts
- Multiple coexisting versions

One Service Per OS

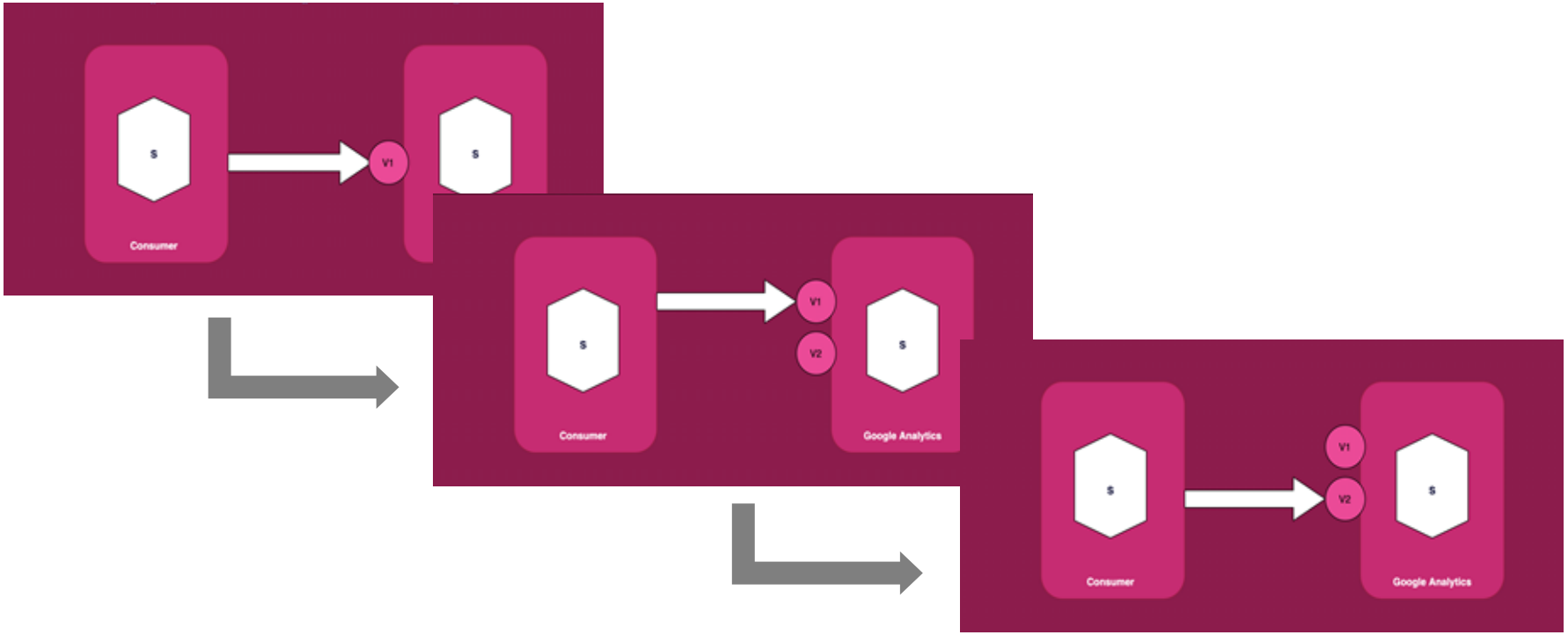


Consumer-Driven Contracts



https://medium.com/@japneetkaur11/contract-testing-with-pact-17909b838de9

Multiple coexisting versions



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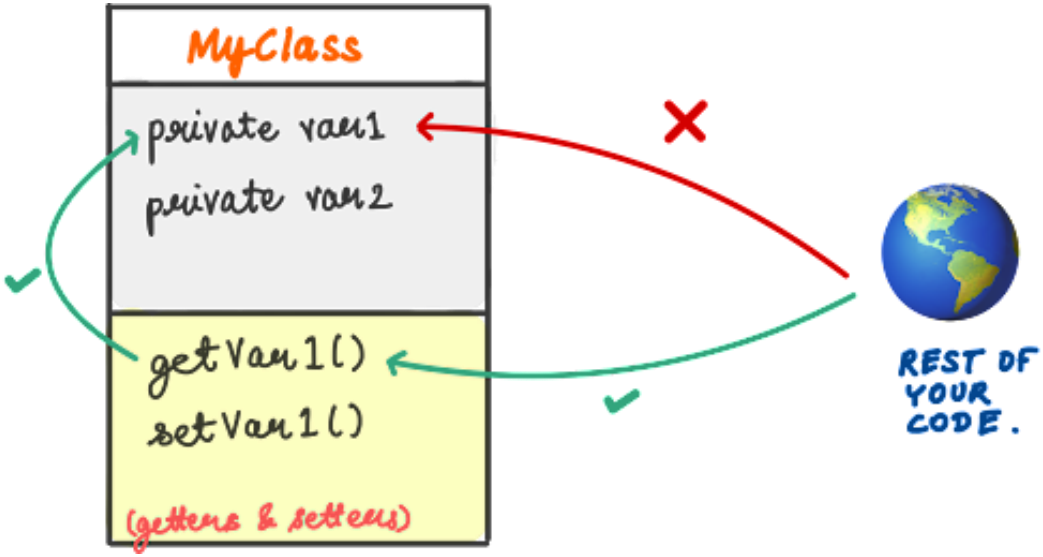
Hide implementation details

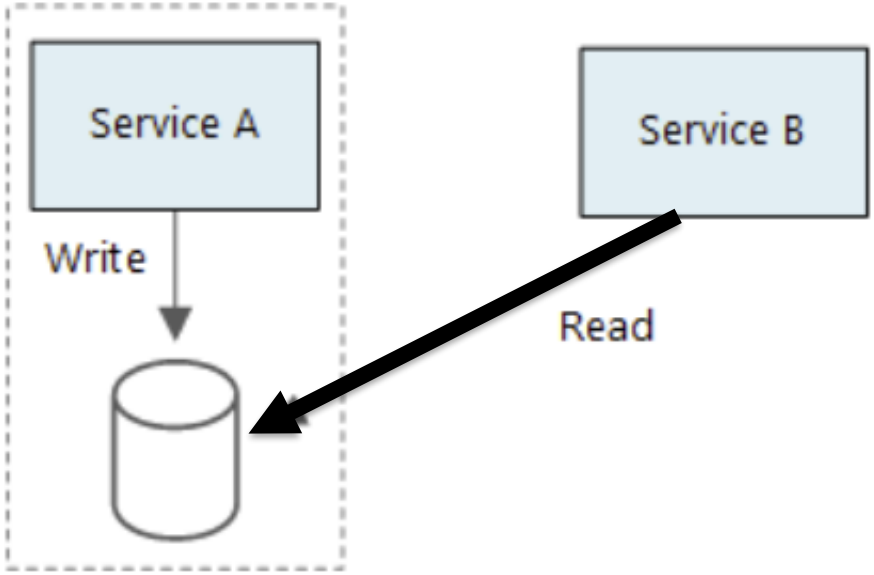
- Design your APIs carefully
- It’s easier to expose details later than hide them
- Do not share your database!

Hide implementation details

Recall: Encapsulation in OOP



Sharing database: Anti-pattern



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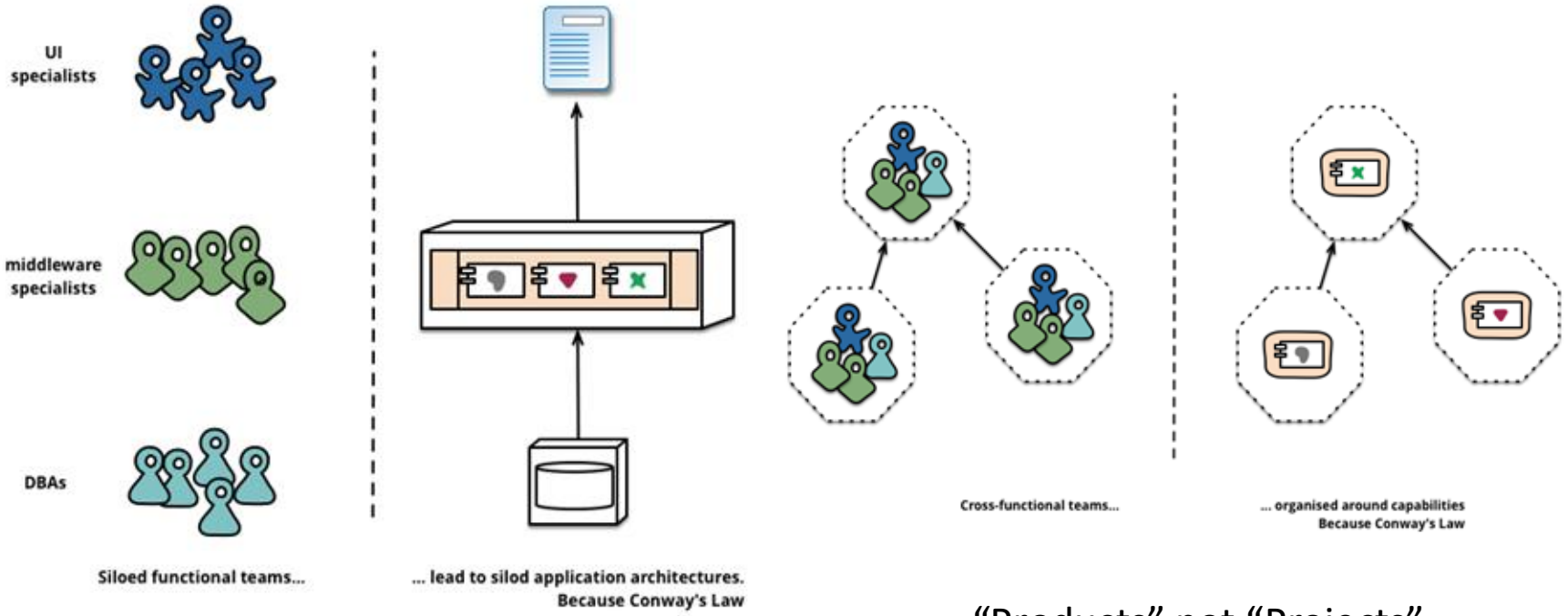
Decentralized Governance

- Mind Conway's Law
- You Build It, You Run It
- Embrace team autonomy
- Internal Open Source Model

Mind Conway's Law



"Products" not "Projects"

YOU BUILD IT YOU RUN AWAY IT

"The traditional model is that you take your software to the wall that separates development and operations, and throw it over and then forget about it. Not at Amazon. You build it, you run it. This brings developers into contact with the day-to-day operation of their software. It also brings them into day-to-day contact with the customer. This customer feedback loop is essential for improving the quality of the service."

-- Werner Vogels in "A conversation with Werner Vogels" in ACM Queue, May 2006

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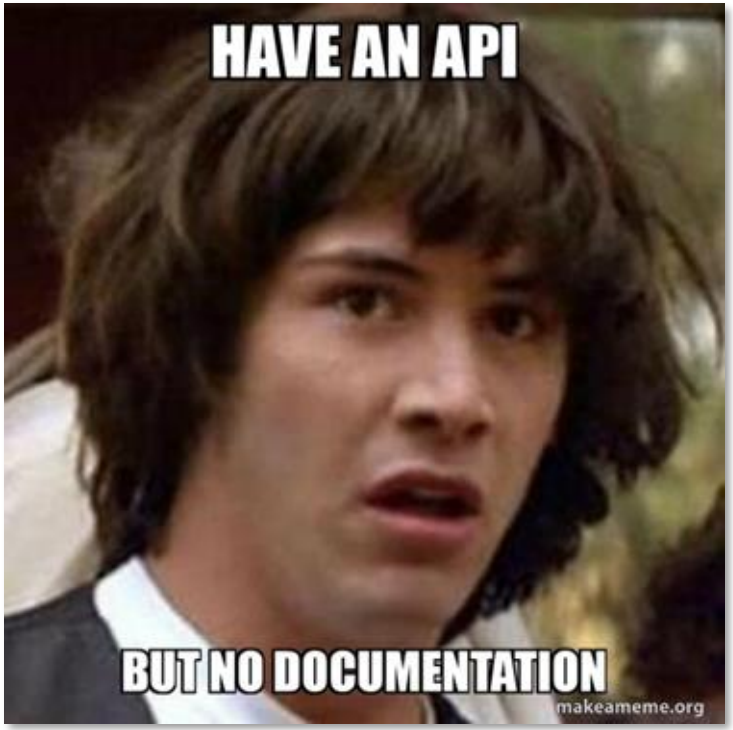
Consumer First

- Encourage conversations
- API Documentation
- Service Discovery

Encourage conversations

Document your APIs!



Swagger™

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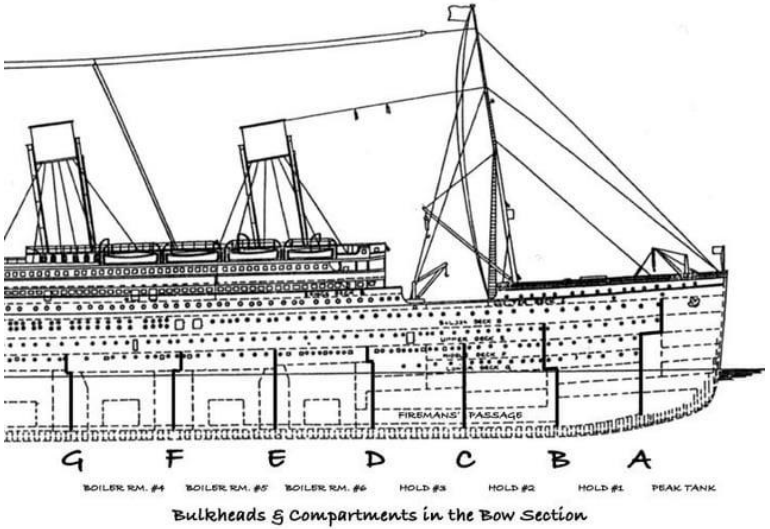
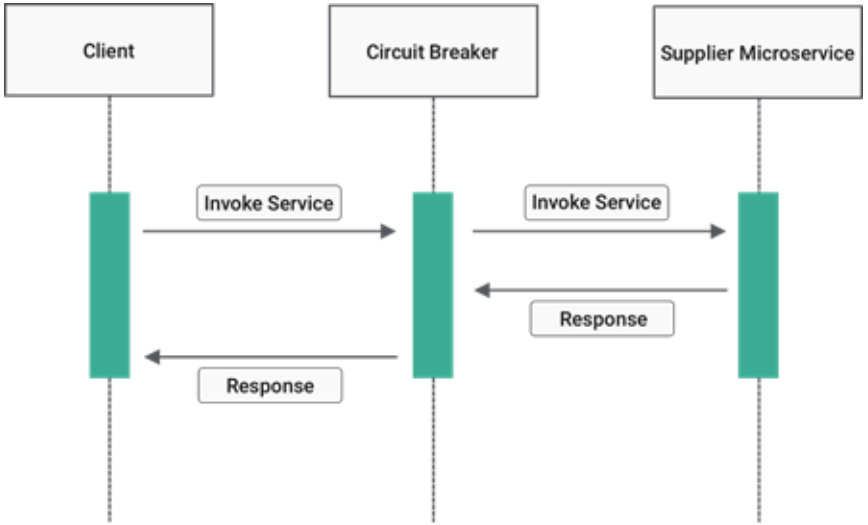
Isolate Failures

Sam Newman's Principles of Microservices

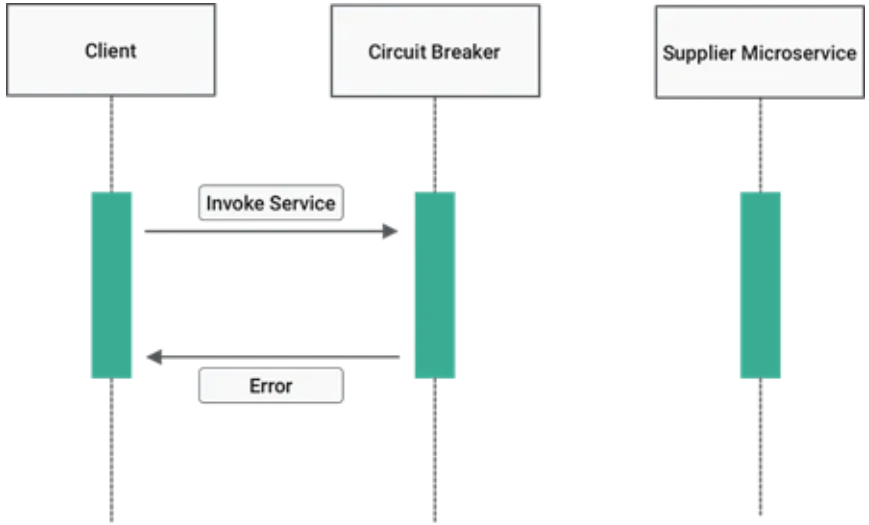
Isolate Failure

- Avoid **cascading failures**
- Timeouts between components
- **Fail fast** aka *Design for Failure*
  - Bulkheading / Circuit breakers





Closed Circuit



Open Circuit

blogs.halodoc.io

Are microservices always the right choice?

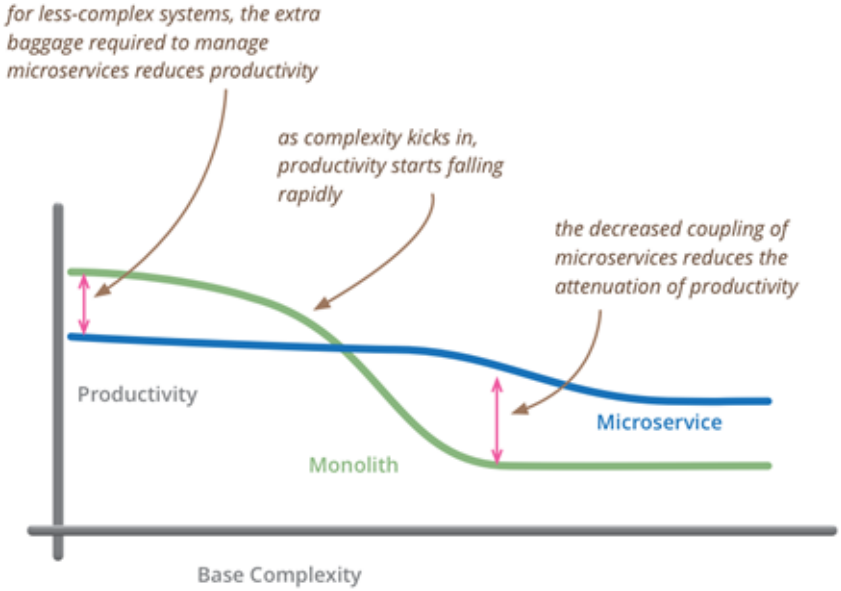
Advantages of Microservices

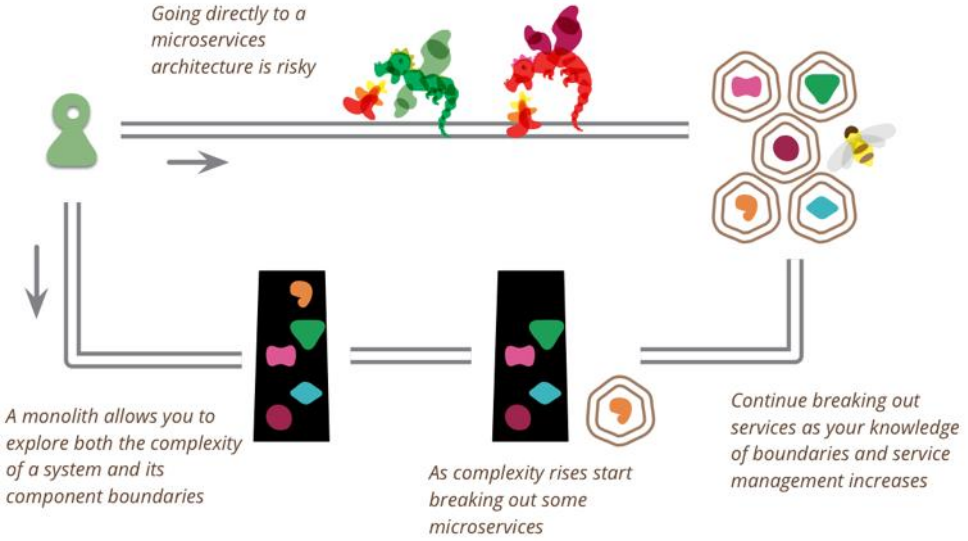
- Ship features faster and safer
- Amenable to horizontal scaling
- Target security concerns via isolation
- Allow the interplay of different systems and languages; no commitment to a single technology stack
- Easily deployable and replicable
- Embrace uncertainty, automation, and faults
- Better alignment with organization structure

Microservice Challenges

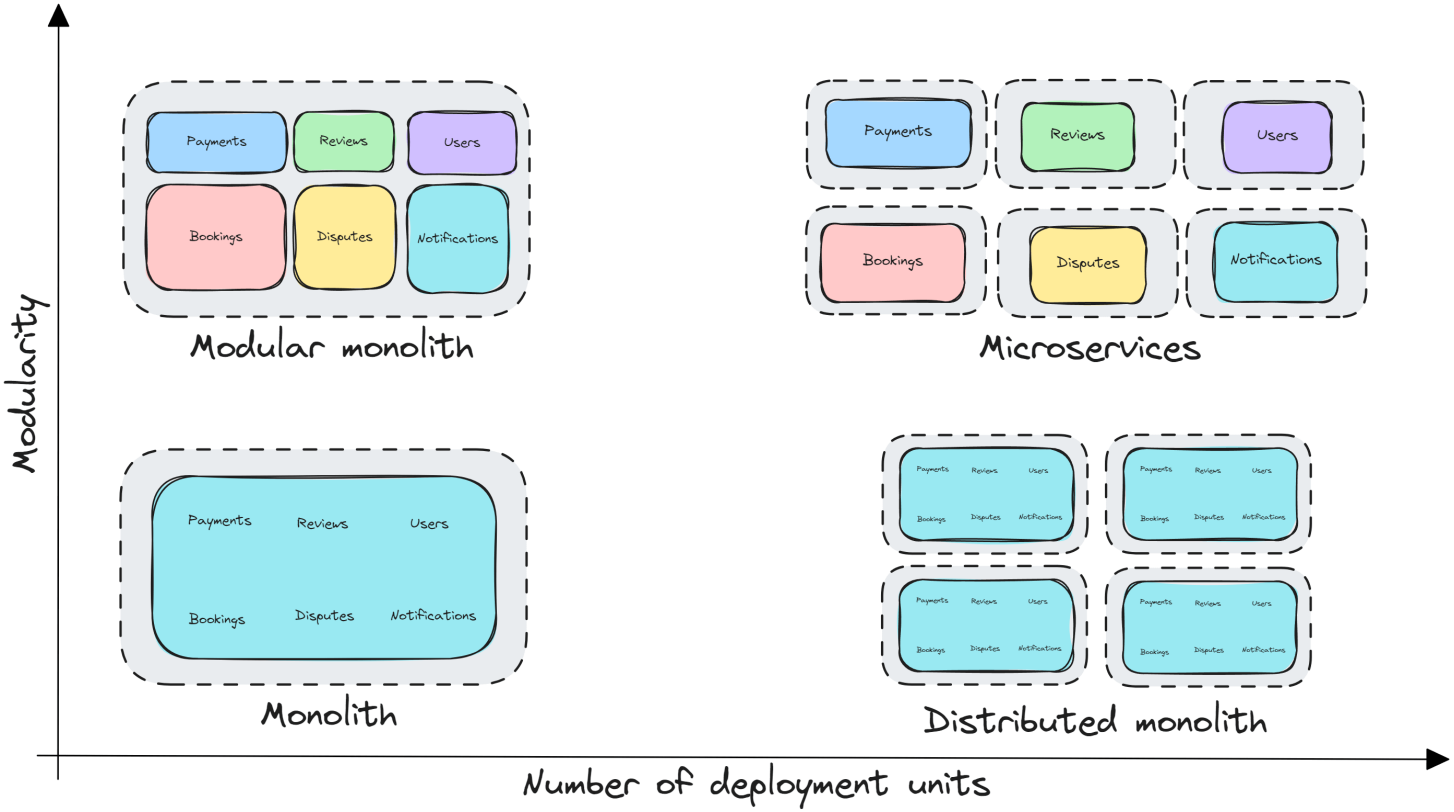
- Too many choices
- Lag between investment and payback
- Complexities of distributed systems
  - network latency, faults, inconsistencies
  - testing challenges
- Monitoring is more complex
- More system states
- More points of failure
- Operational complexity
- Frequently adopted by breaking down a monolithic application

Microservices Overhead





https://martinfowler.com/bliki/MonolithFirst.html



https://www.milanjovanovic.tech/blog/what-is-a-modular-monolith