Architecture: Microservices

17-313 Spring 2025

Foundations of Software Engineering

https://cmu-313.github.io

Michael Hilton, Austin Henley, and Nadia Nahar

Administrivia

- Teamwork assessments due every Monday
- Midterm 1 on February 27 in class
  - We will release sample / practice exams for recitation next week

Smoking Section

- Last full row

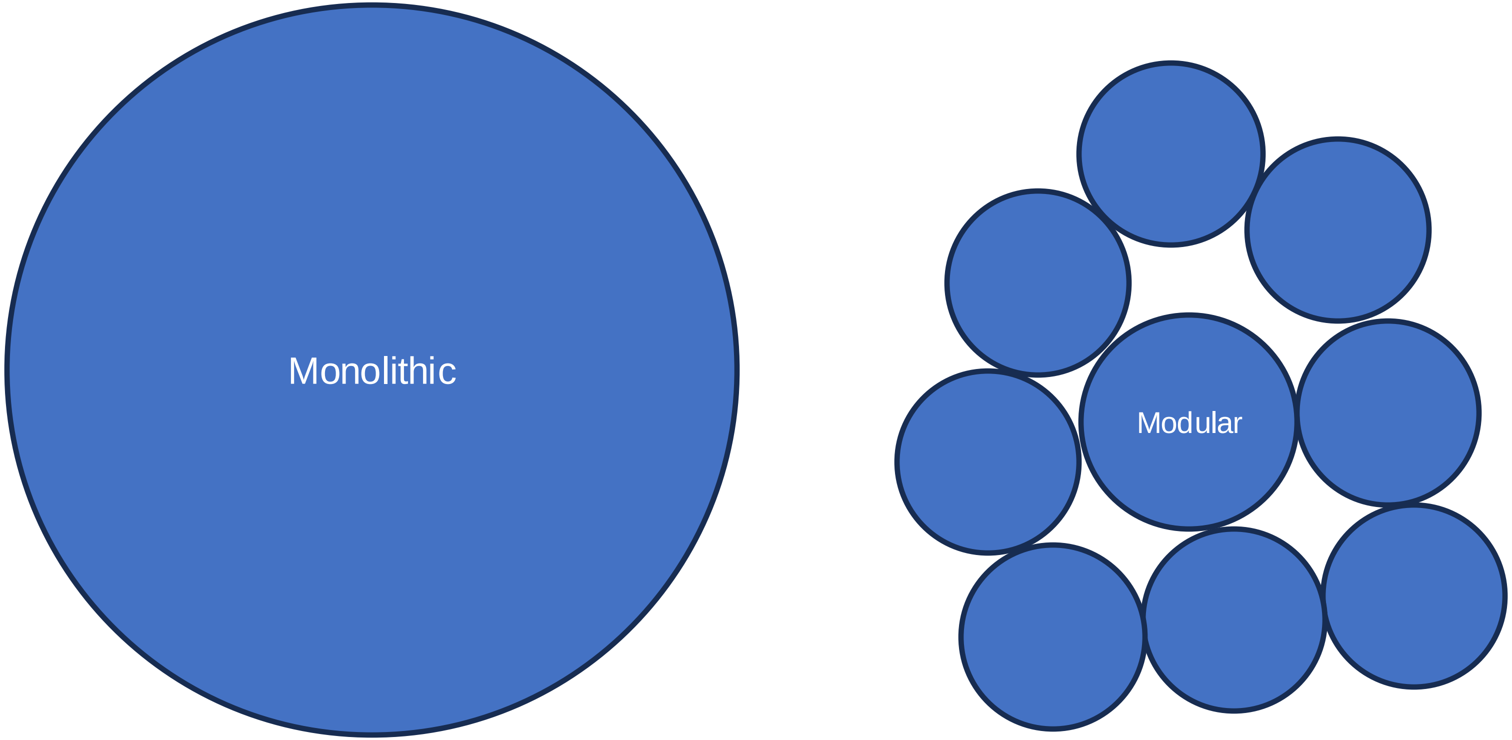
Learning Goals

- Contrast monolithic vs. modular software architectures.
- Enumerate various types of modularity including plug-in architectures, service-oriented architectures, and microservices.
- Reason about tradeoffs of microservices architectures.
- Principles of microservices: how to benefit and avoid their pitfalls

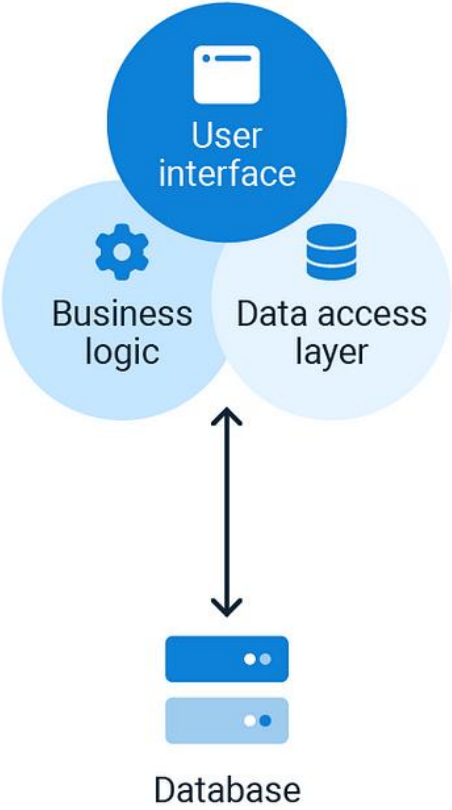
Outline

- Monoliths vs. Modular Architecture
- Service-based Architecture
    - Case Study: Chrome Web Browser
- Microservices
- Principles of Microservices
- Advantages and Challenges of Microservices

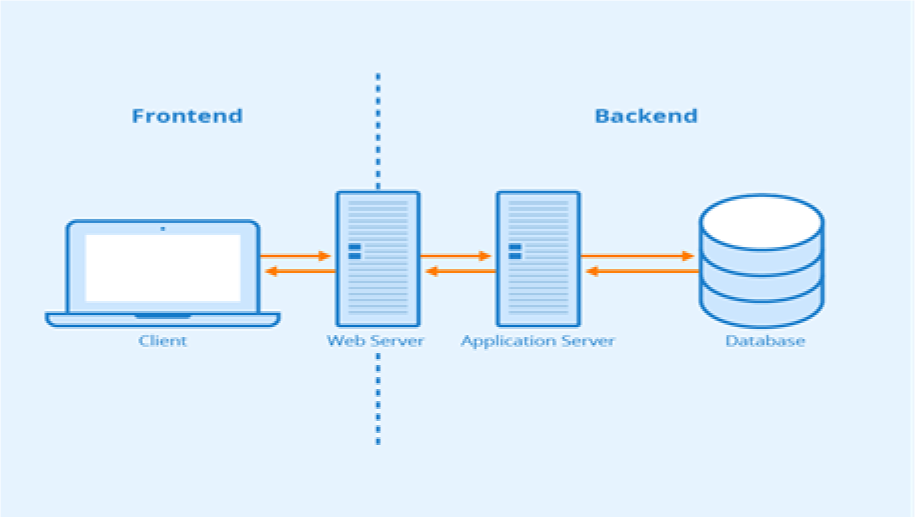
Monolithic vs. Modular architecture


Monolithic
Modular

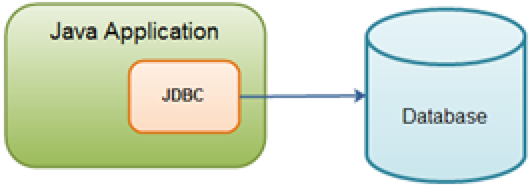
Monolithic Architecture



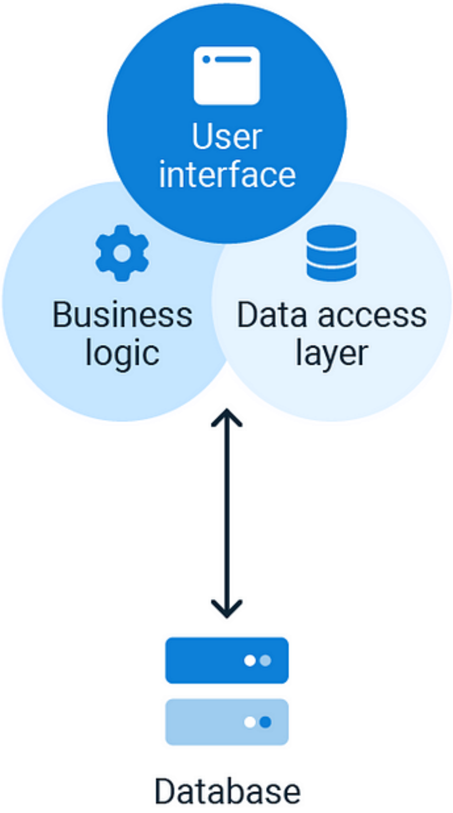
Monolithic styles



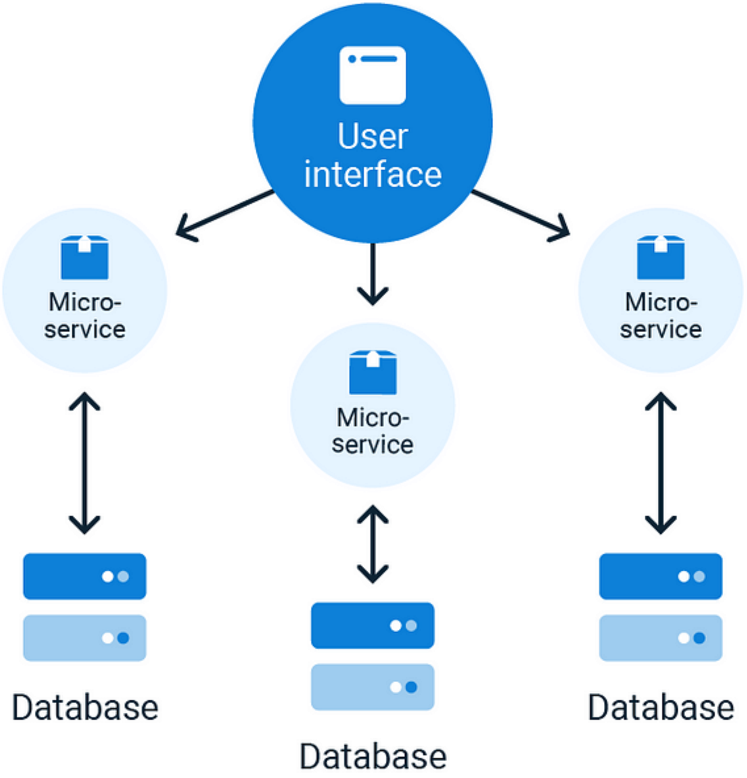
Source: https://www.seobility.net (CC BY-SA 4.0**)**



Monolithic Architecture

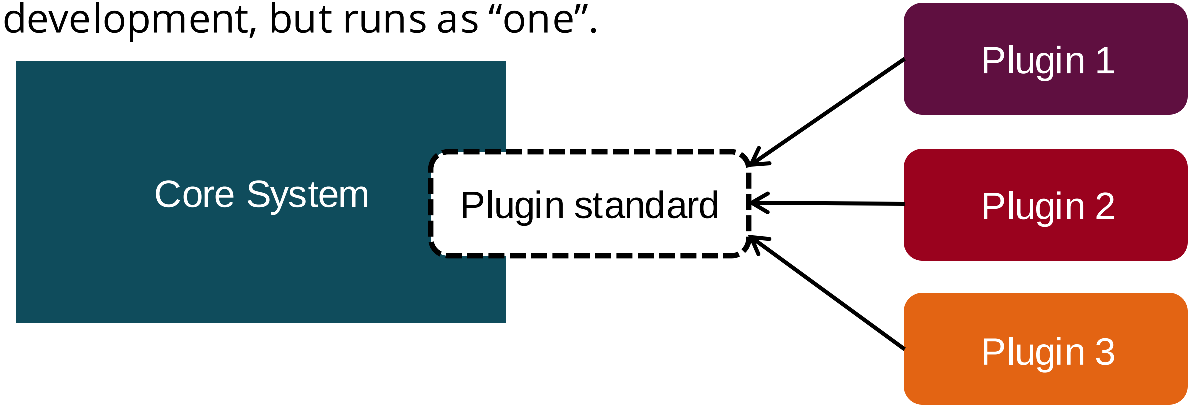


Microservice Architecture



Modularity comes in many ways

- Plug-in architectures
  - Distinct code repositories, linked-in to a monolithic run-time
  - Examples:
    - Linux kernel modules
    - Themes in NodeBB, WordPress
    - Language packs for Visual Studio, IntelliJ, Sublime Text
  - Separates development, but runs as “one”.



Modularity comes in many ways

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  - Examples:
    - Linux kernel modules
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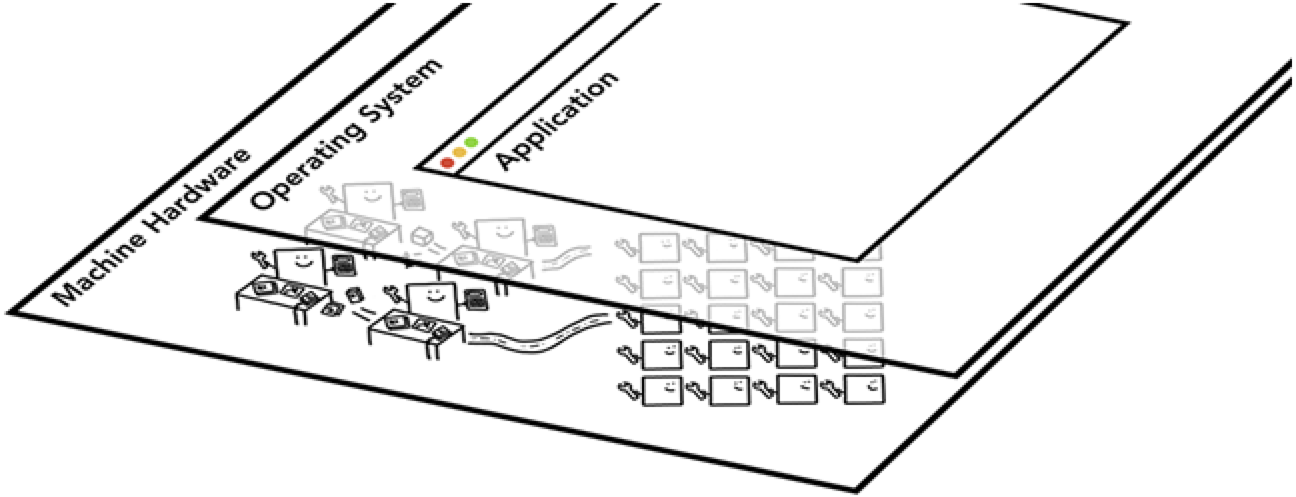
  - Separates development, but runs as “one”.
- Service-oriented architectures
  - Distinct processes communicating via messages (e.g., Web browsers)
  - Separates run-time resource management and failure / security issues.
- Distributed micro-services
  - Independent, autonomous services communicating via web APIs
  - Separates almost all concerns

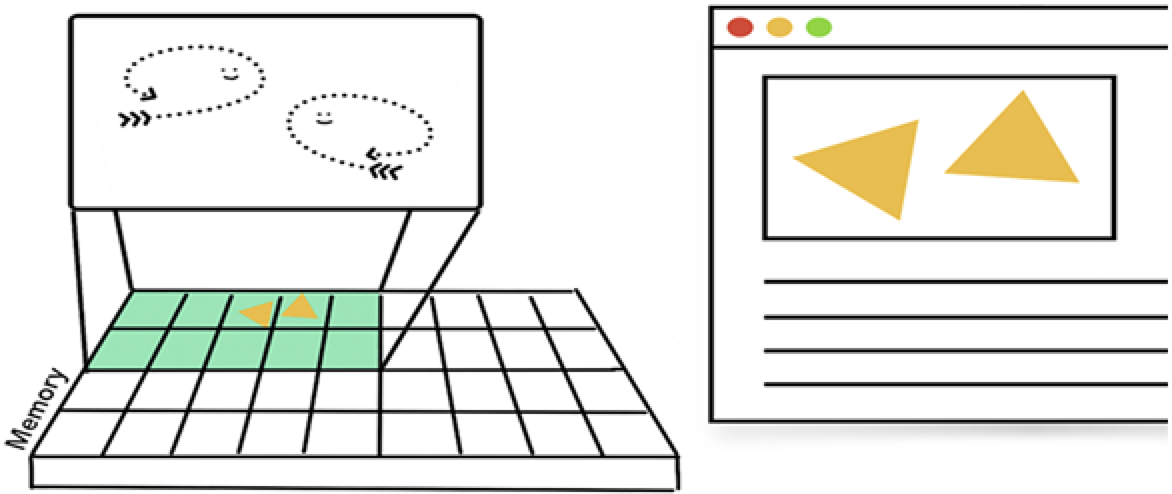
SERVICE-BASED ARCHITECTURE

Case Study: Web Browsers



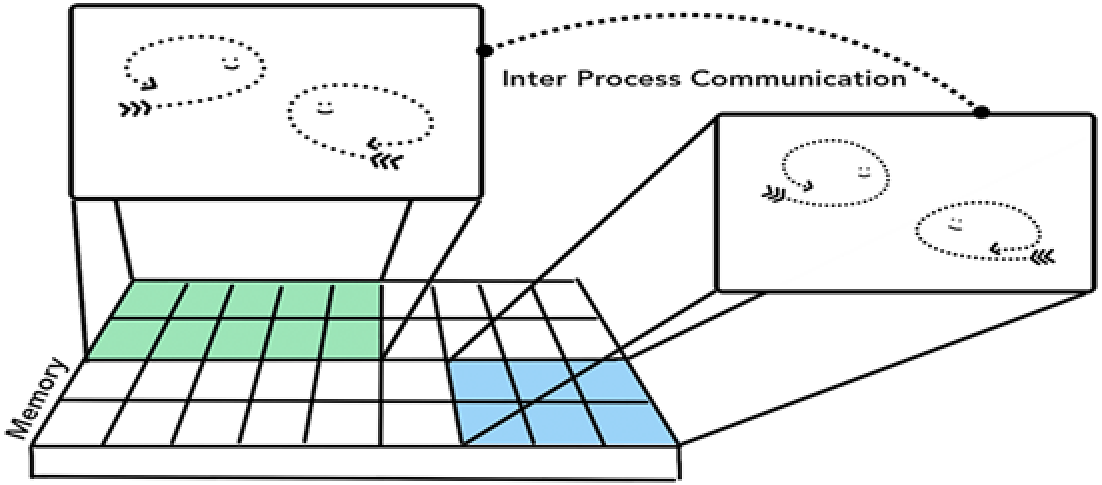
Source: https://developers.google.com/web/updates/2018/09/inside-browser-part1 (CC BY 4.0)

Multi-threaded browser in single process



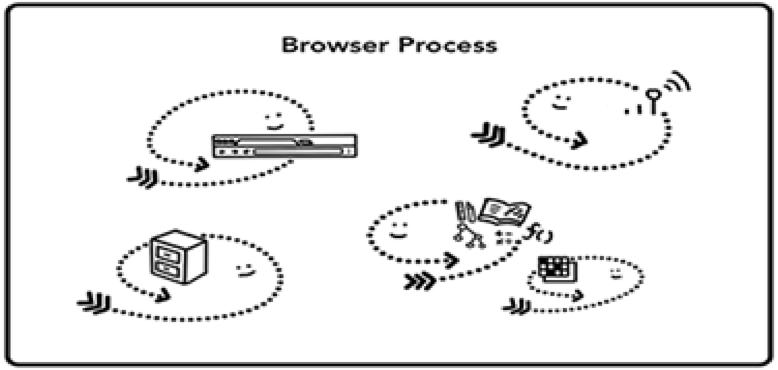
Source: https://developers.google.com/web/updates/2018/09/inside-browser-part1 (CC BY 4.0)

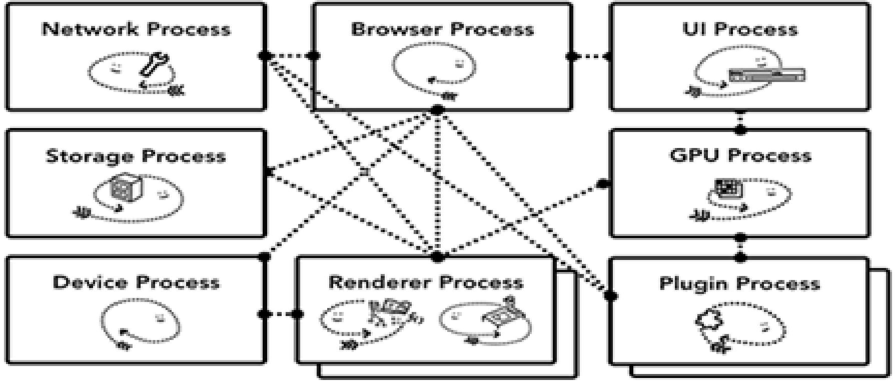
Multi-process browser with IPC



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

Service-based browser architecture





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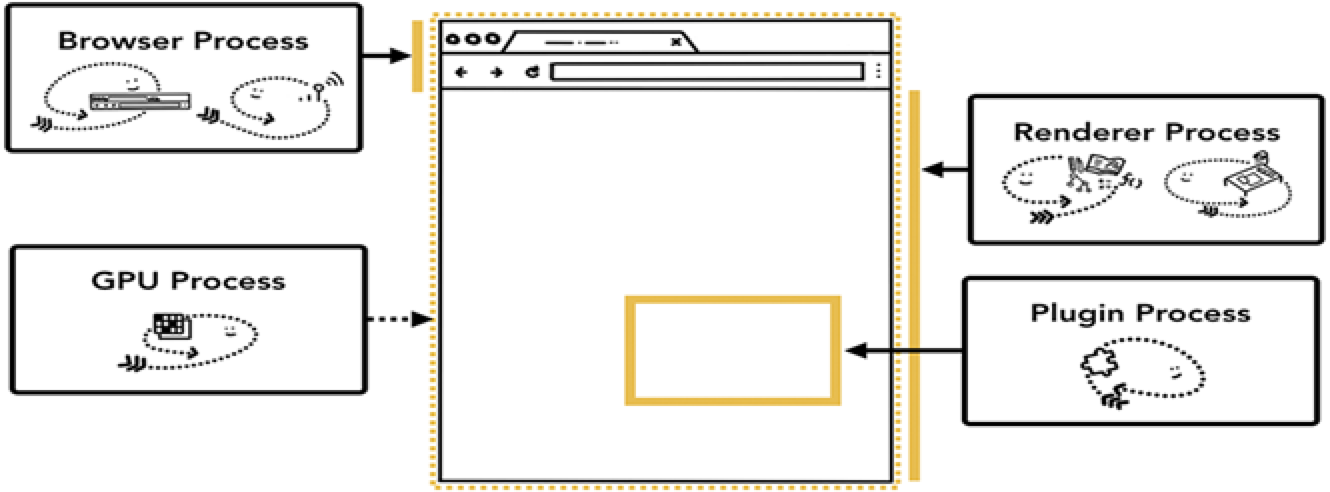
Service-based browser architecture



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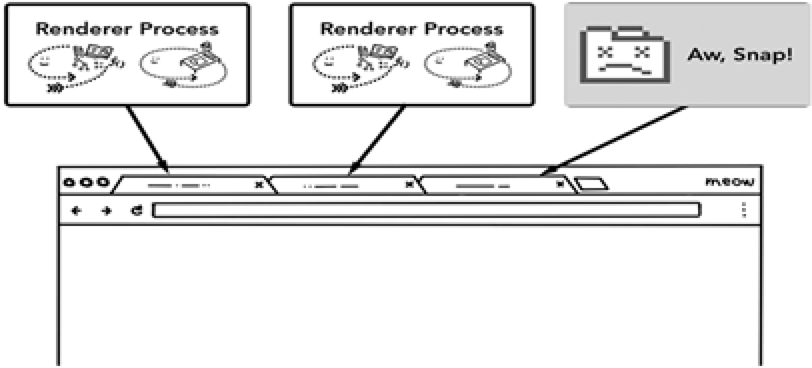
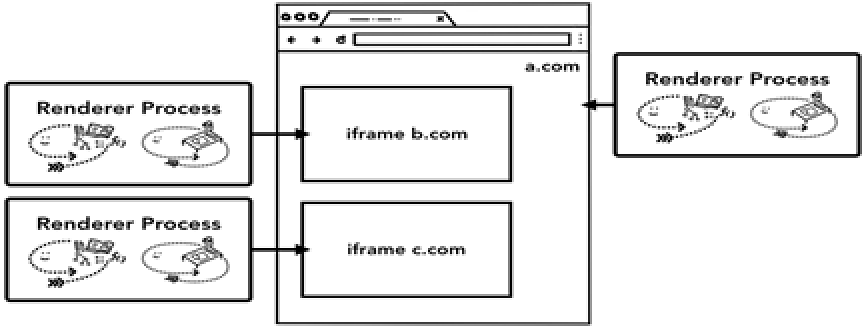
Service-based browser architecture





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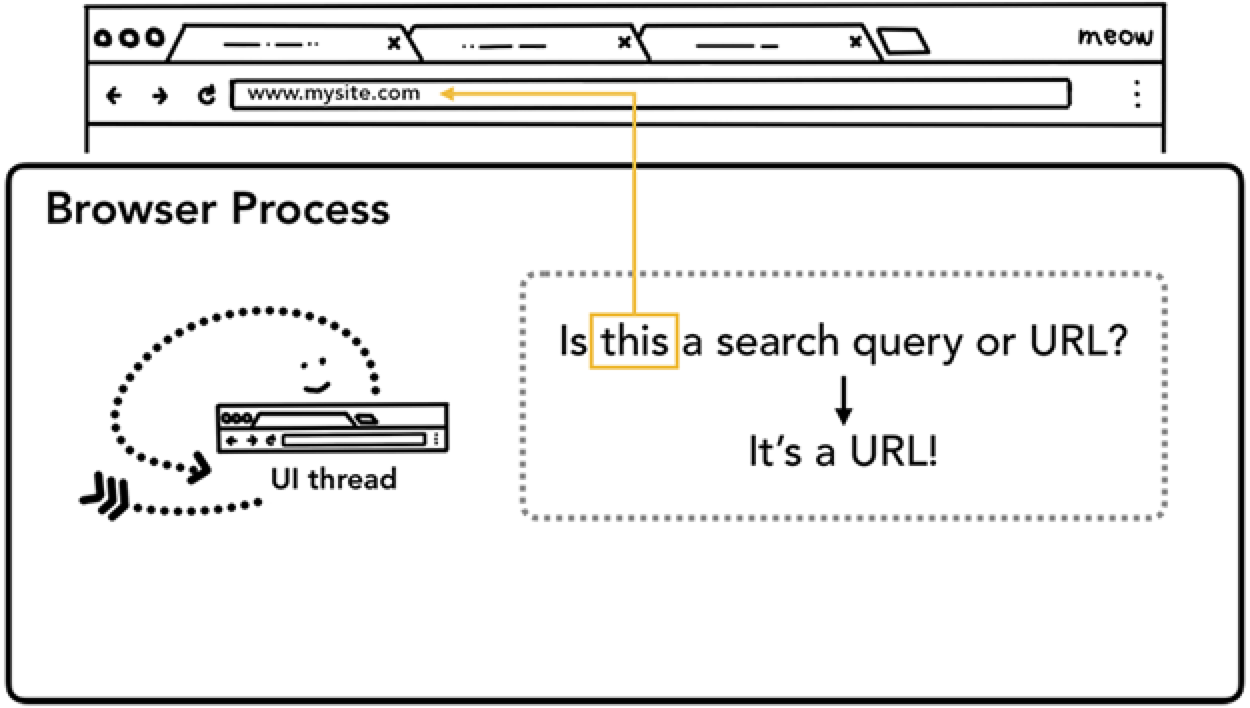
Navigating to a web site uses service requests



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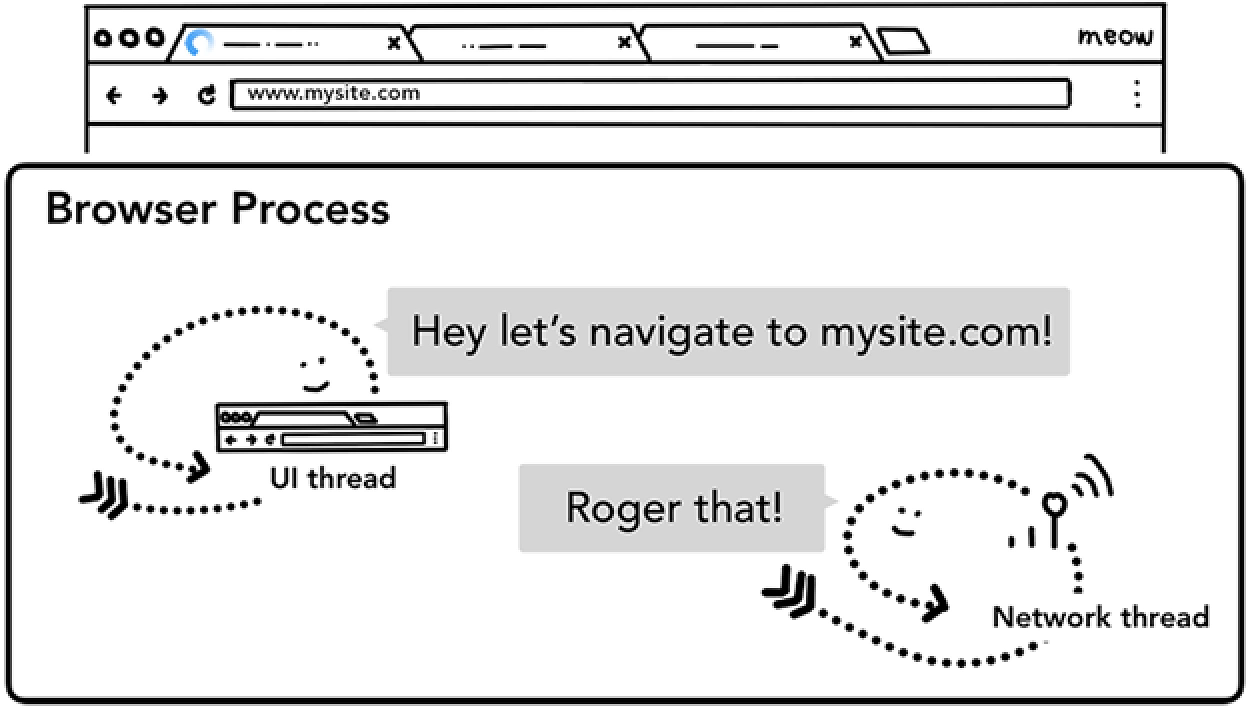

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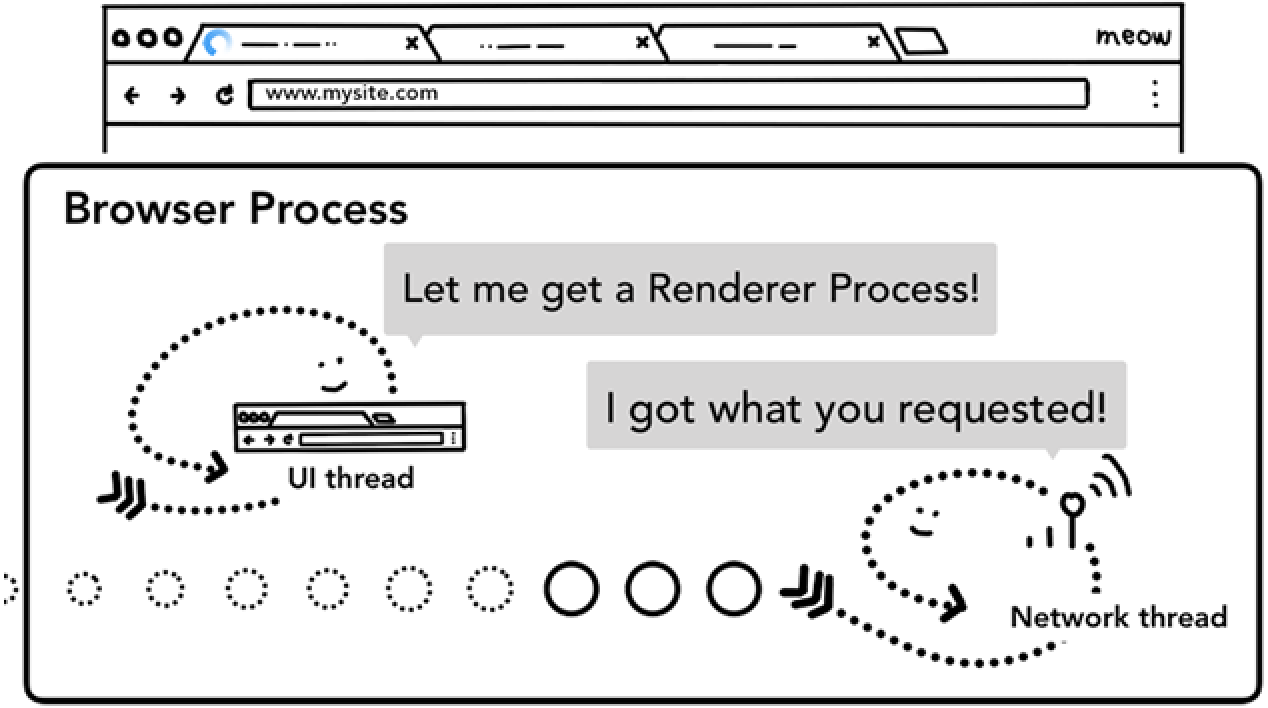

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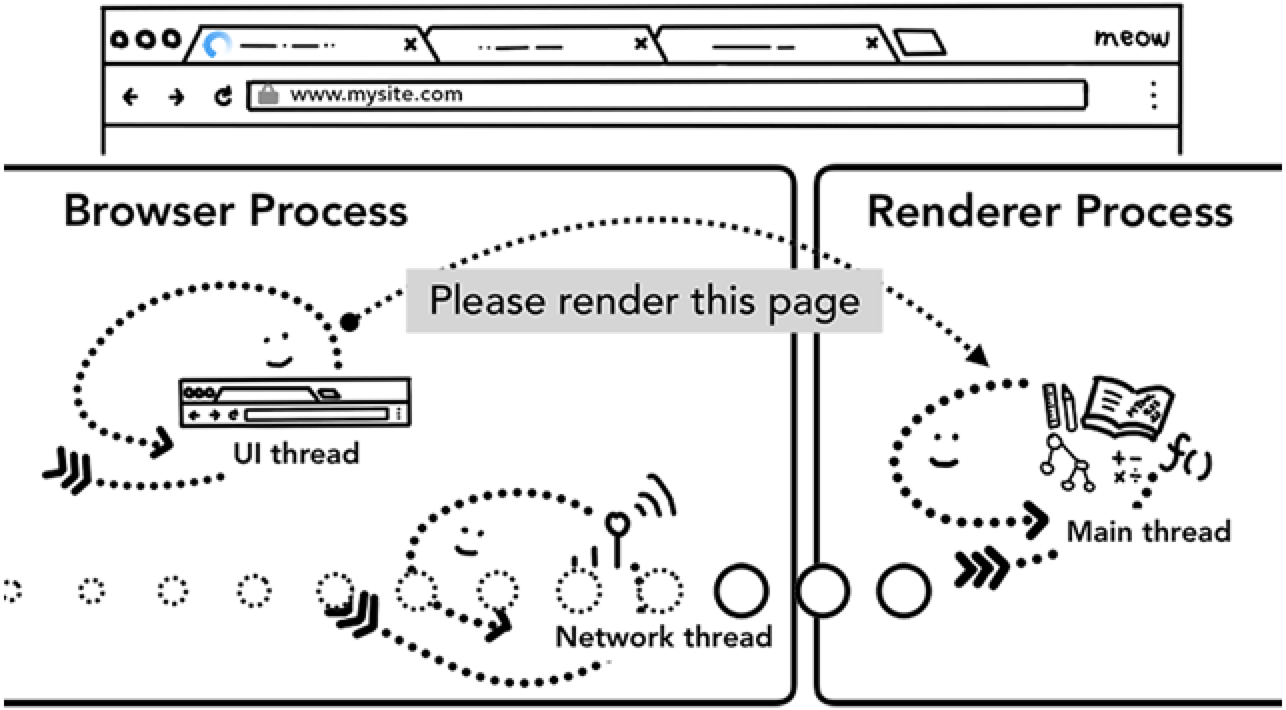

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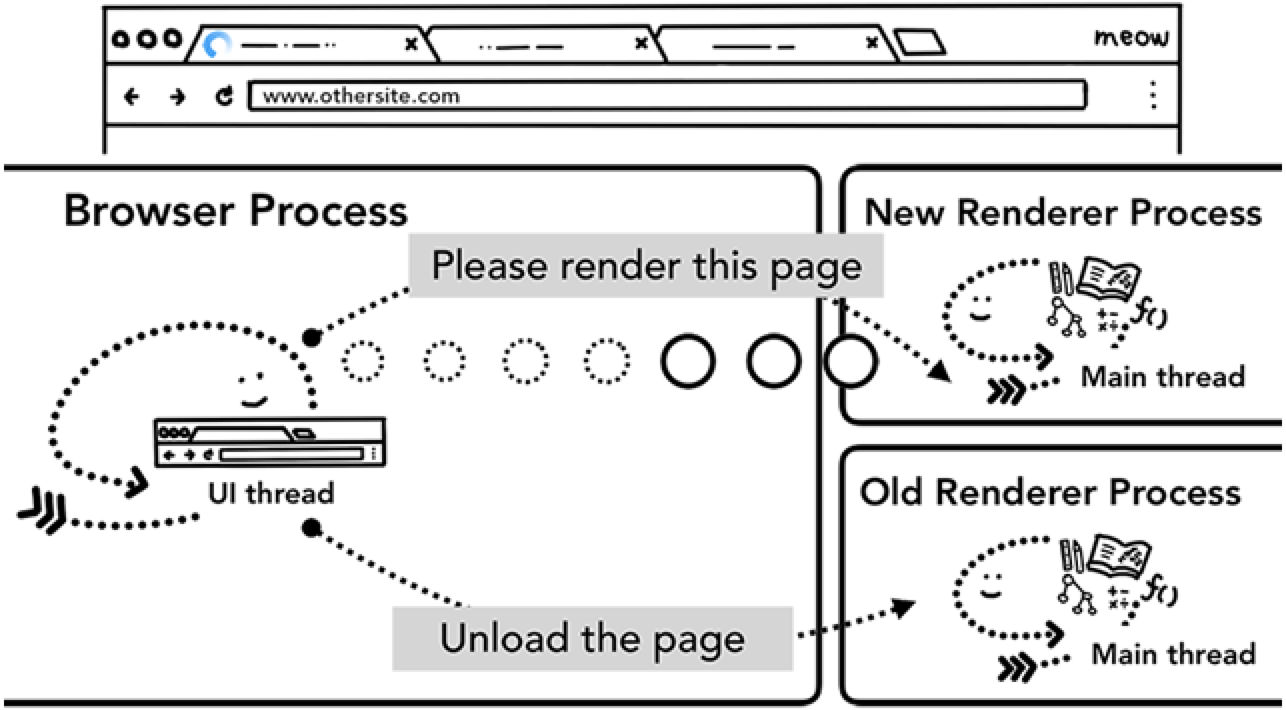
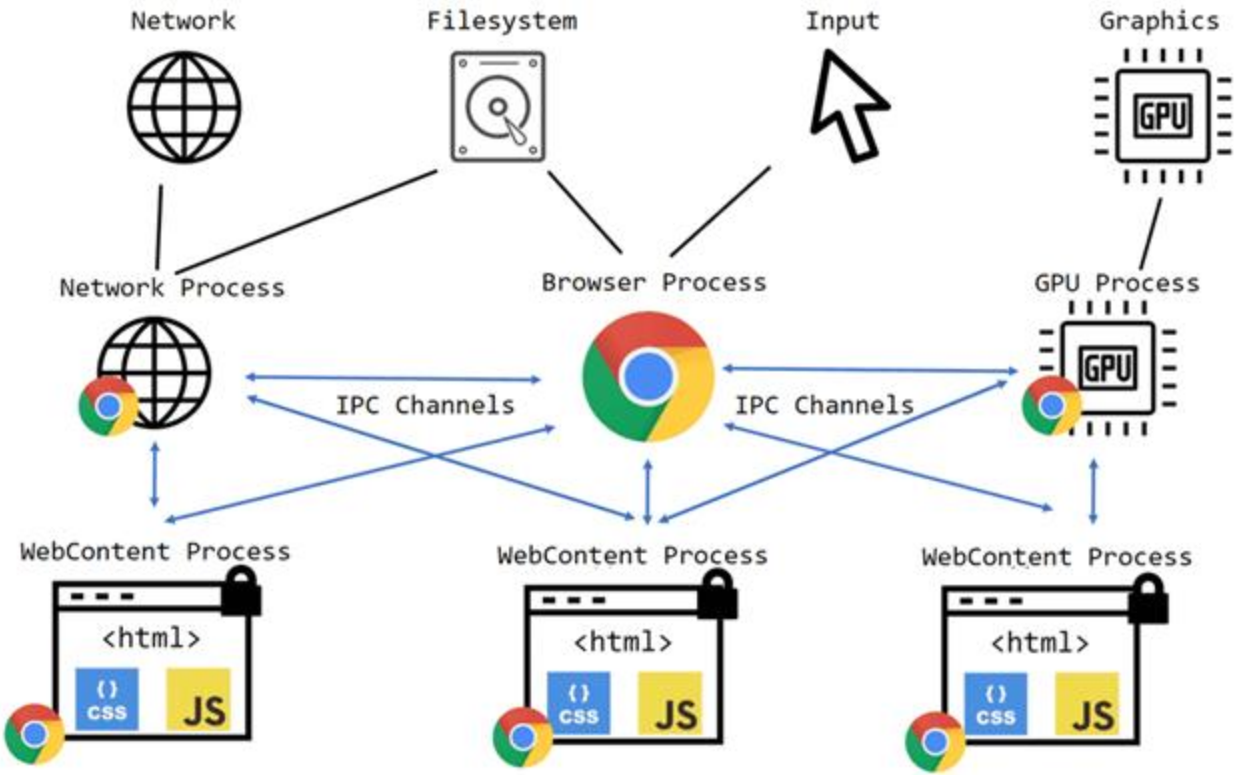
Navigating to a web site uses service requests



Please render this page

Unload the page

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



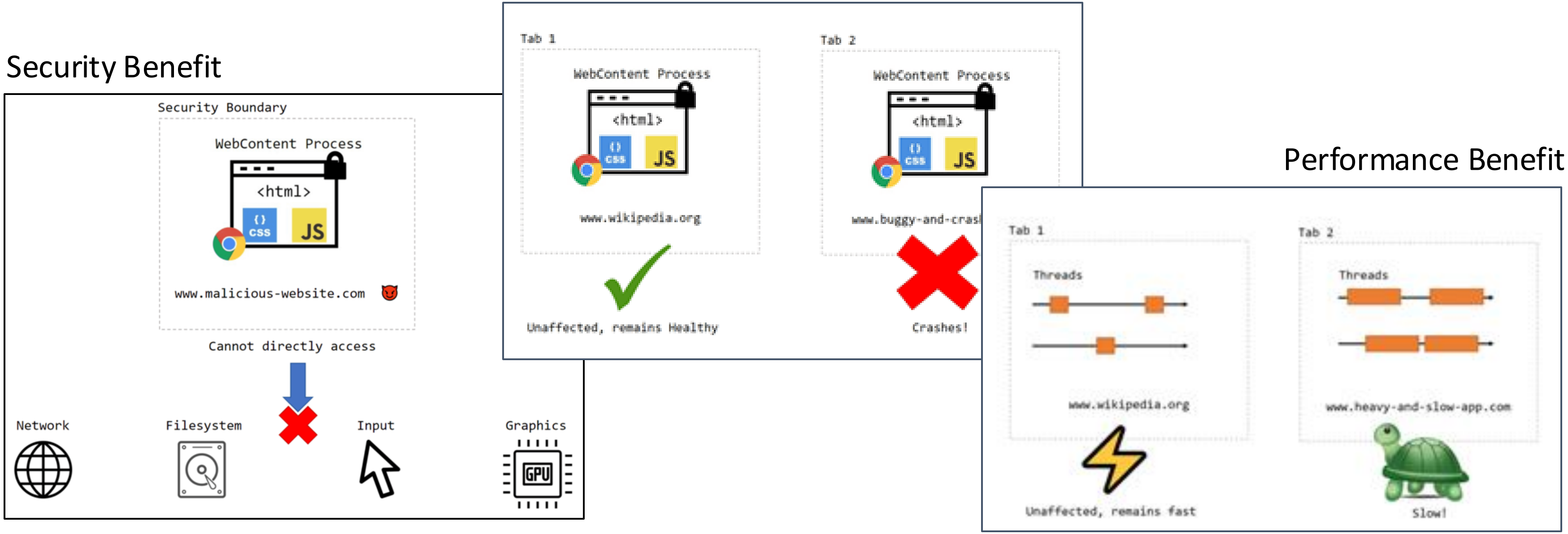
https://webperf.tips/tip/browser-process-model/

Multi-Process Model Benefits

Security Benefit

Reliability Benefit

Performance Benefit



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

Pros and Cons of Service-based architecture

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

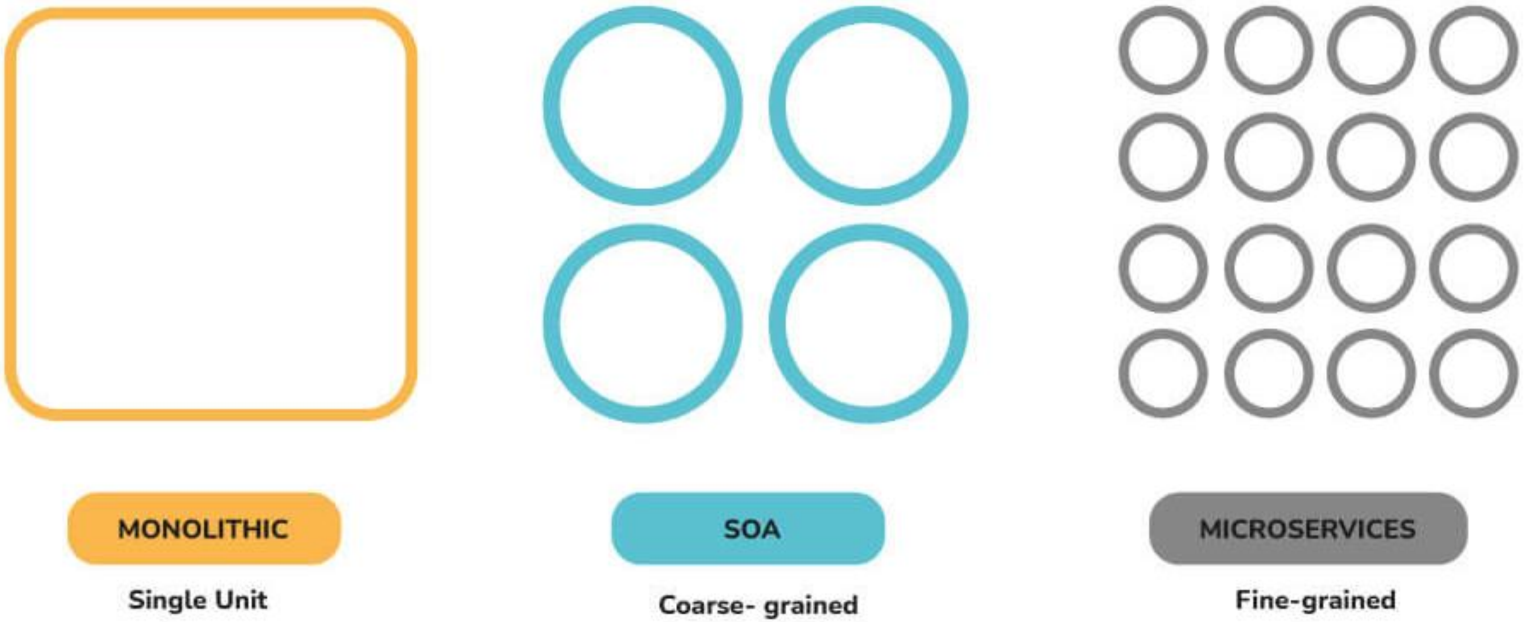
MICROSERVICES

Microservices
Microservices Everywhere

“*Small autonomous services that work well together*”

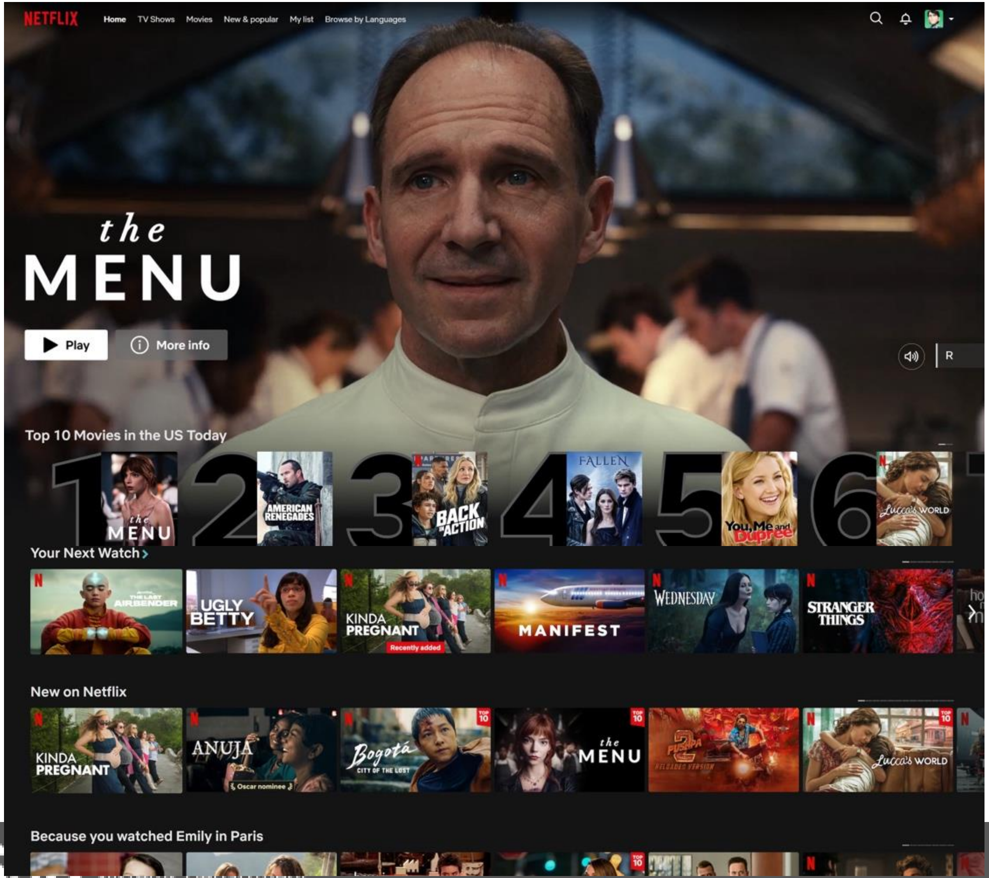
Sam Newman

Monolithic vs. Service-based vs. Microservice



Microservices

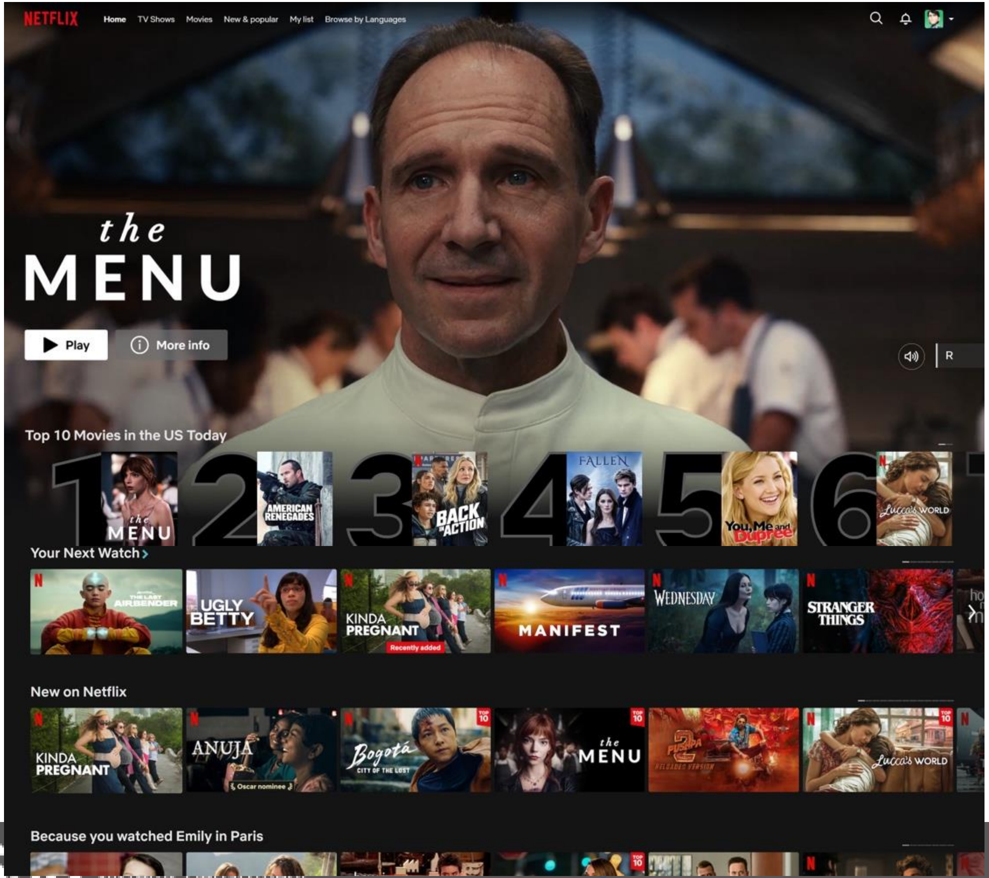
Netflix Microservices



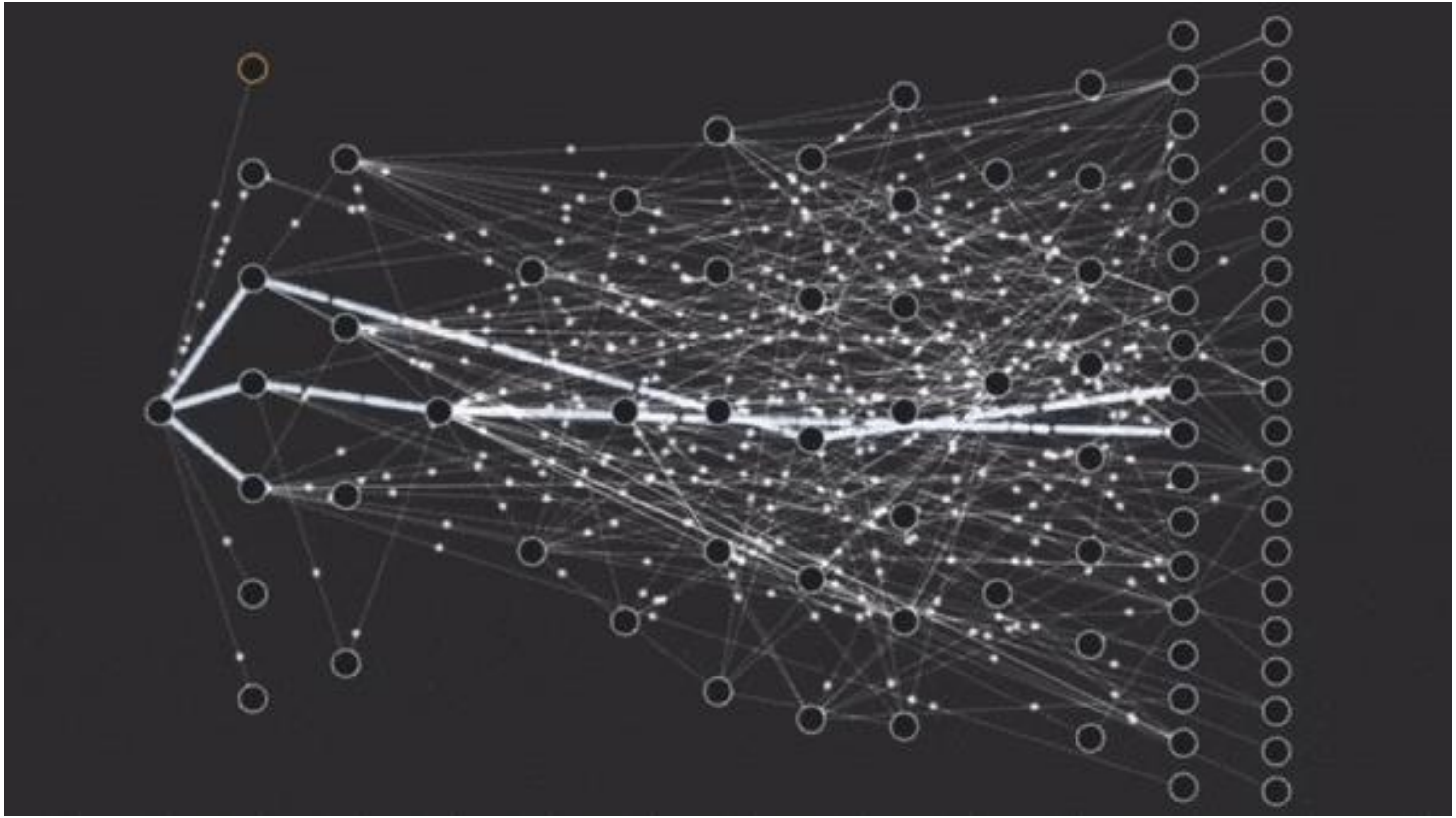
Why Can't Netflix Use a Monolithic Architecture?

- Require 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**

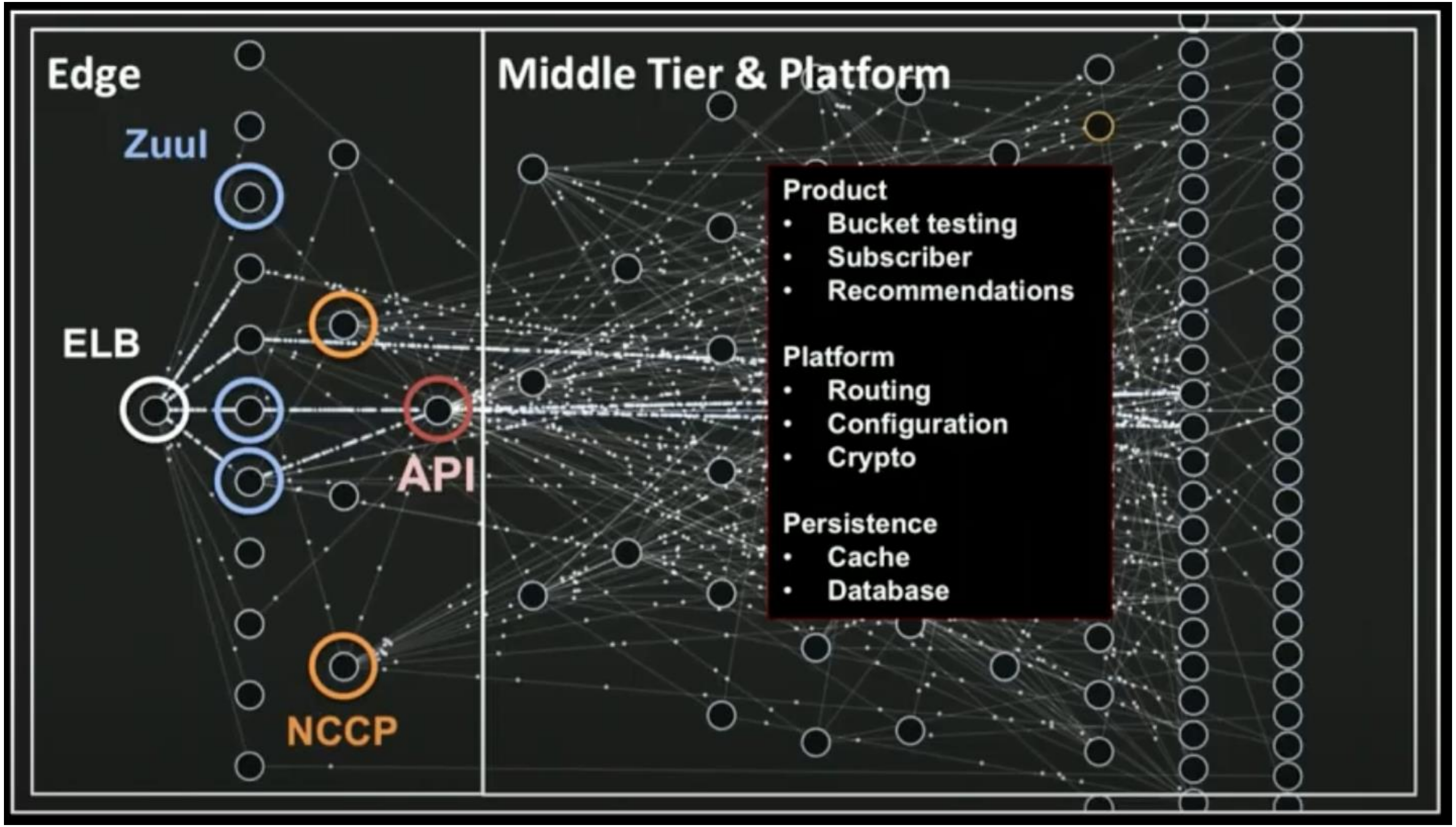
Netflix Microservices



- User subscriptions
- Banner Ad
- Popular Shows
- Trending Now
- Continue Watching
- My List (saved shows)
- Notifications
- User management
- …



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



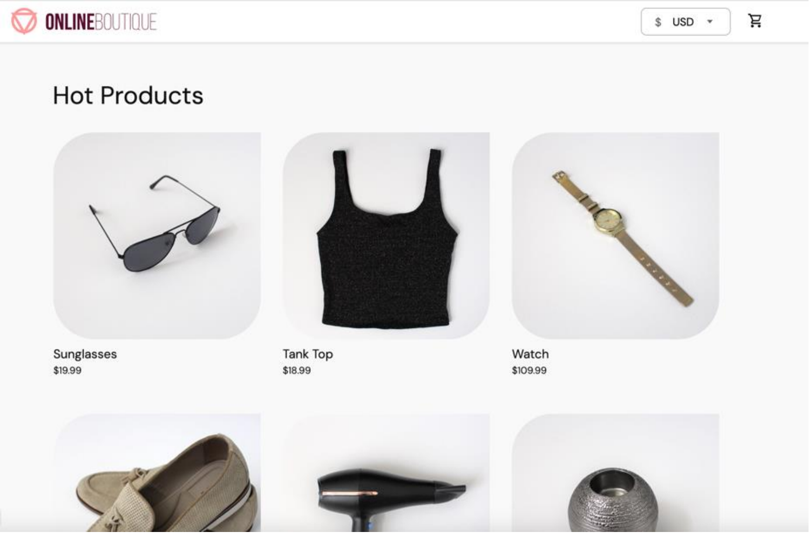
Product
- Bucket testing
- Subscriber
- Recommendations

Platform
- Routing
- Configuration
- Crypto

Persistence
- Cache
- Database

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

Online Boutique: Guess some microservices

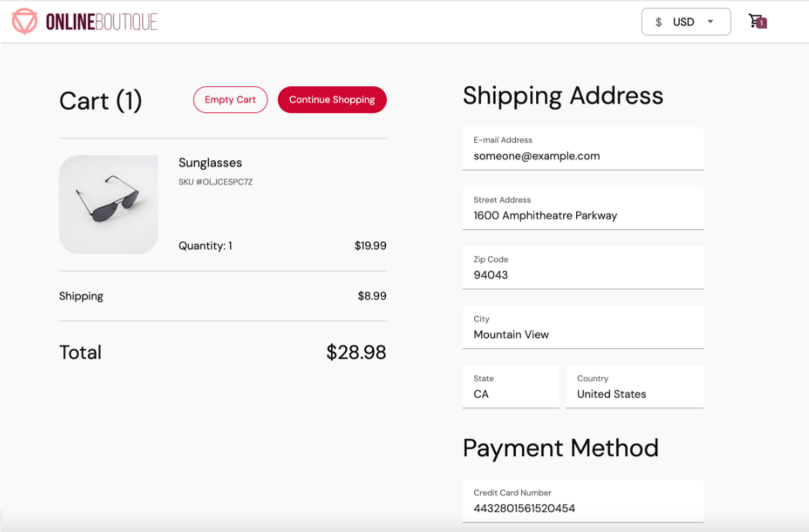


Hot Products

Sunglasses
$19.99

Tank Top
$18.99

Watch
$109.99



Cart (1)

Sunglasses
SKU #OLJCESPC7Z

Quantity: 1	$19.99
Shipping	$8.99
Total	$28.98

Shipping Address

E-mail Address
someone@example.com

Street Address
1600 Amphitheatre Parkway

Zip Code
94043

City
Mountain View

State
CA

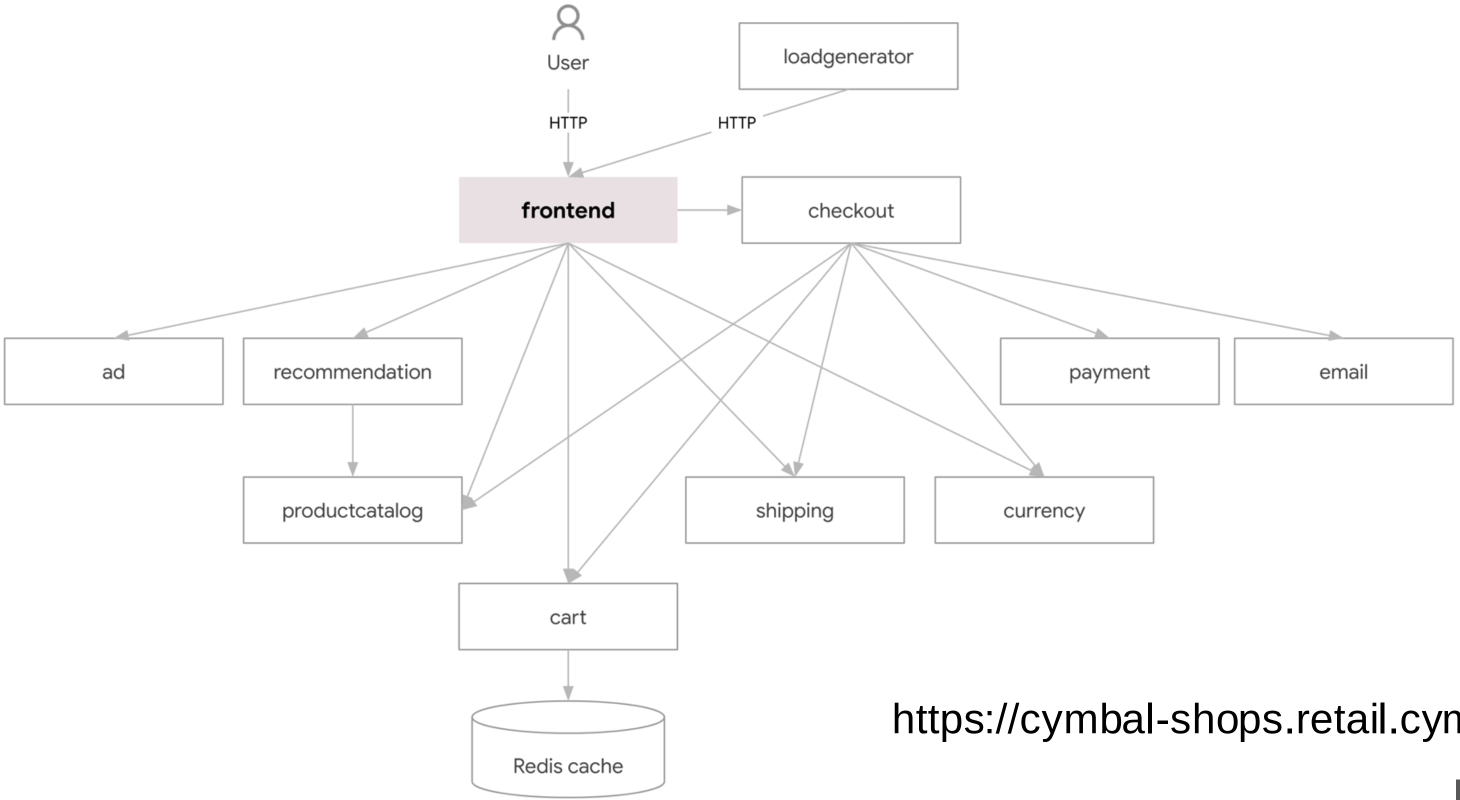
Country
United States

Payment Method

Credit Card Number
4432801561520454

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

Online Boutique: Microservice Architecture

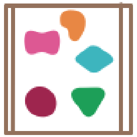


https://cymbal-shops.retail.cymbal.dev/

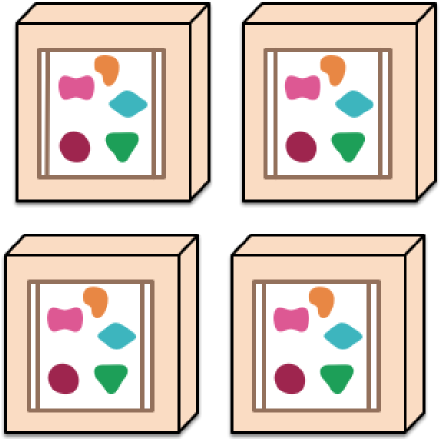
Service	Language	Description
frontend	Go	Exposes an HTTP server to serve the website. Does not require signup/login and generates session IDs for all users automatically.
cartservice	C#	Stores the items in the user's shopping cart in Redis and retrieves it.
productcatalogservice	Go	Provides the list 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

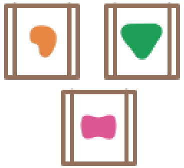
A monolithic application puts all its functionality into a single process...



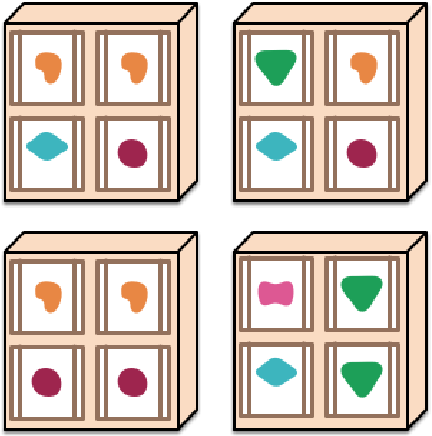
... and scales by replicating the monolith on multiple servers



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



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

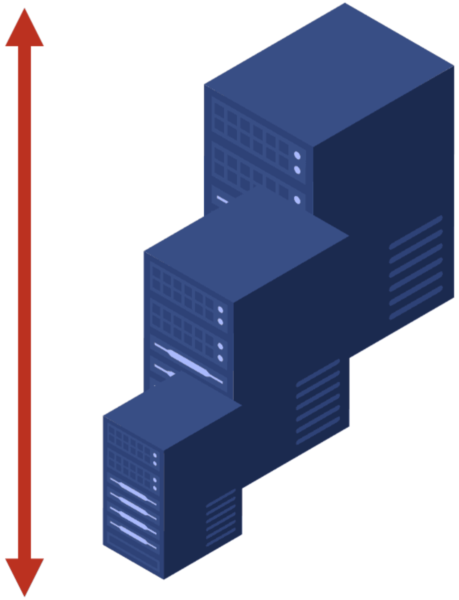


Source: http://martinfowler.com/articles/microservices.html

Types of Scaling: Vertical vs. Horizontal

Vertical Scaling

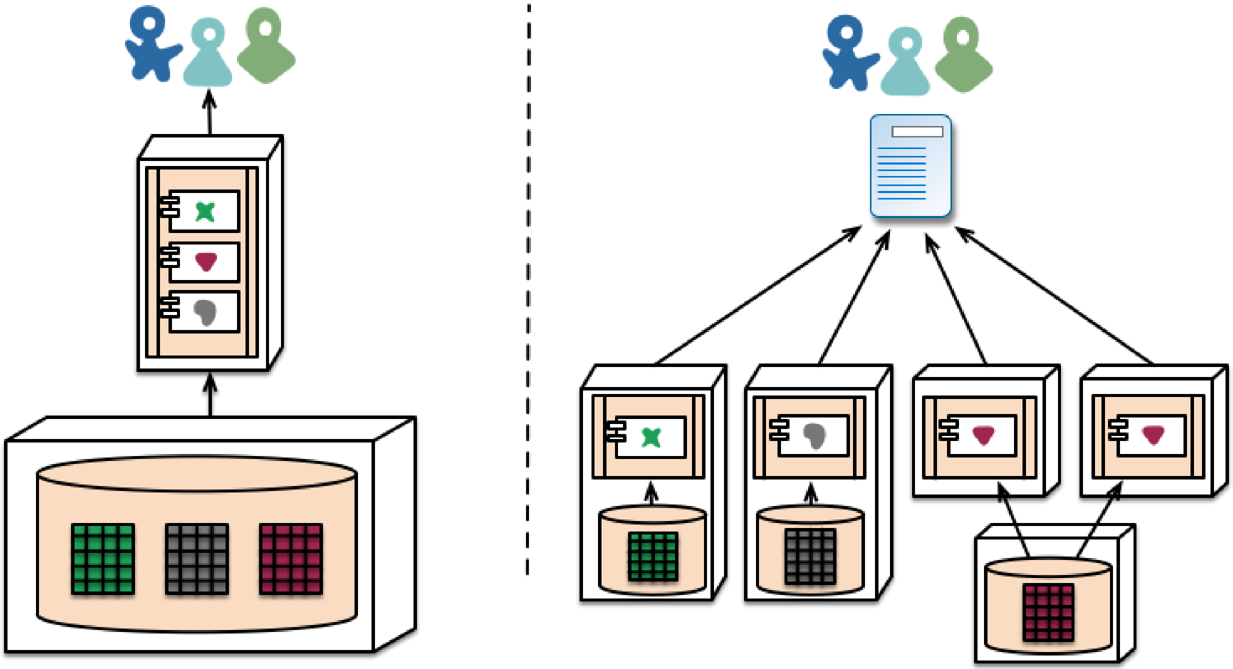
Increase or decrease the capacity of existing services/instances.



Horizontal Scaling

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

Data Management and Consistency

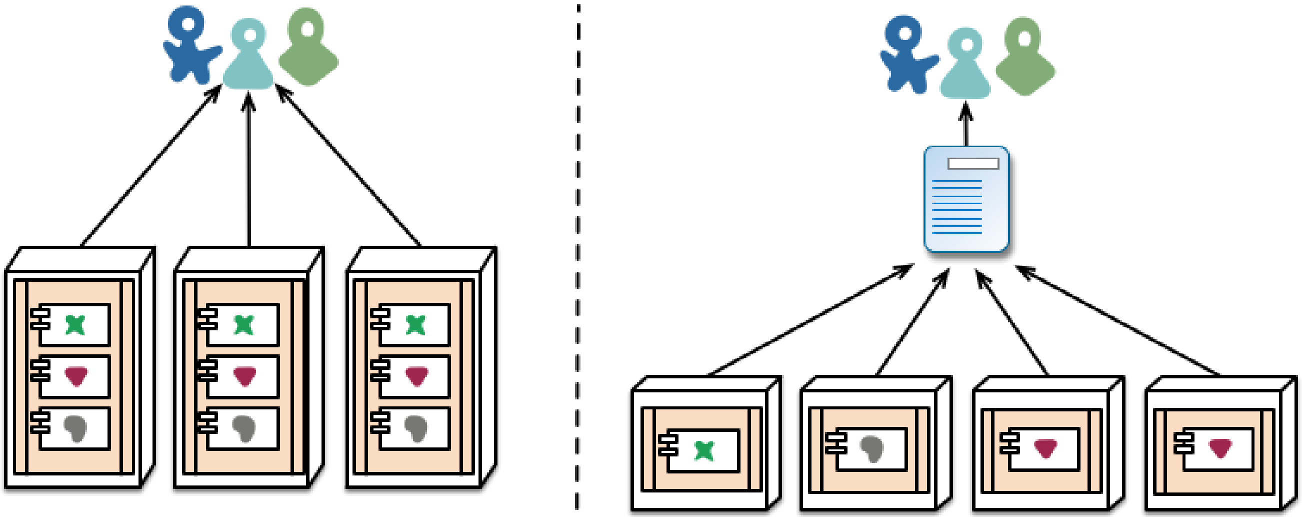


monolith - single database

microservices - application databases

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

Deployment and Evolution



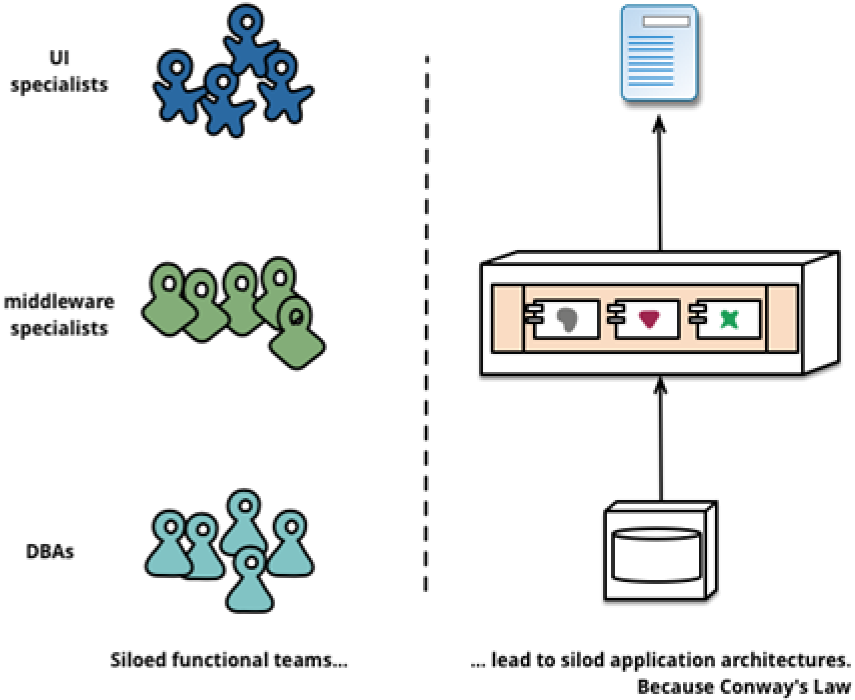
monolith - multiple modules in the same process

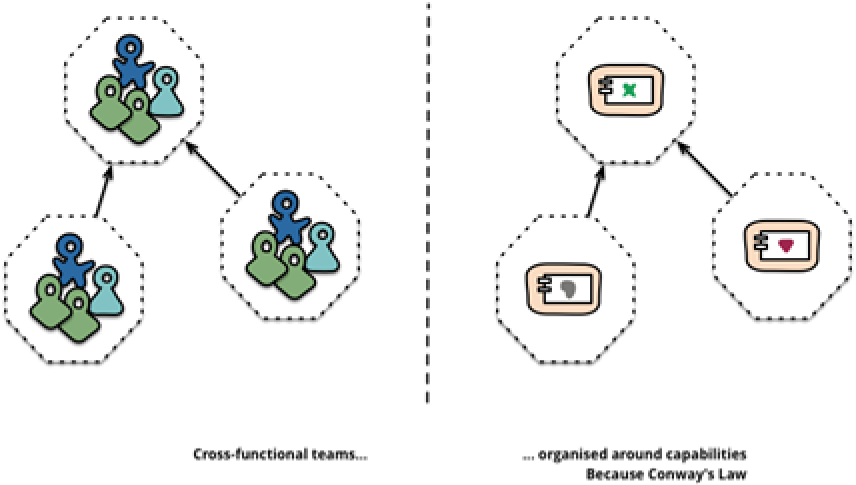
microservices - modules running in different processes

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

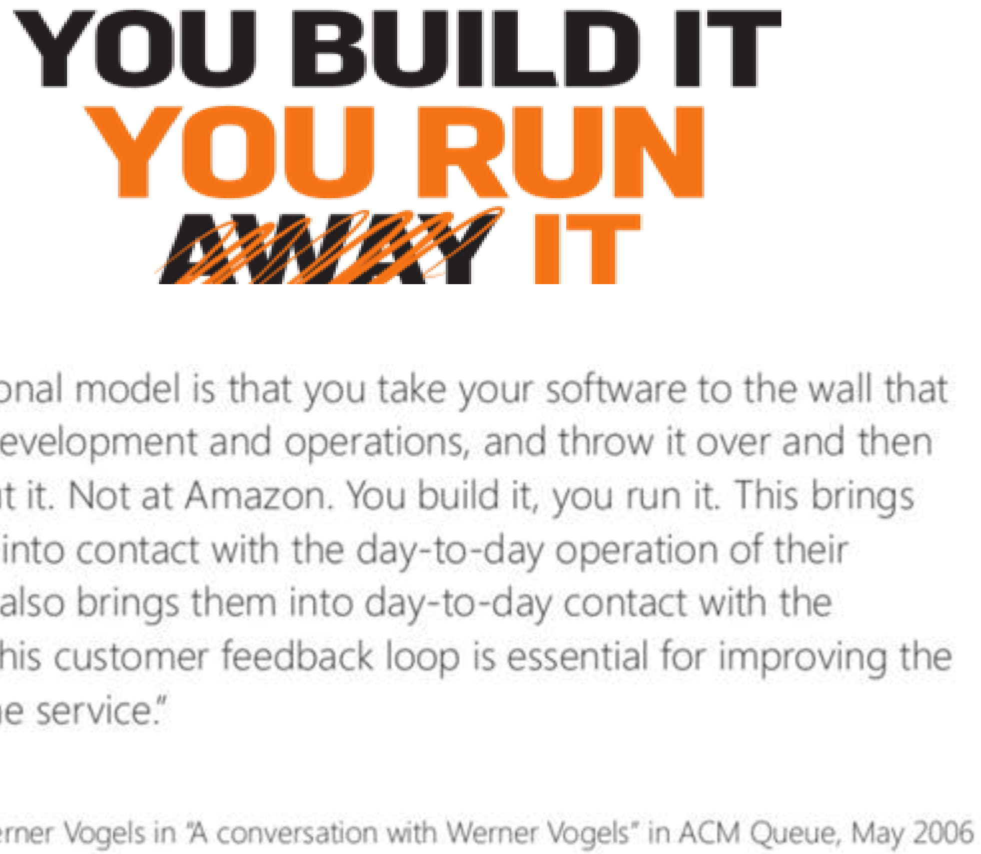
Conway’s Law

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


UI specialists
middleware specialists
DBAs
Siloed functional teams...
... lead to silod application architectures.
Because 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

MICROSERVICES: PRINCIPLES

Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

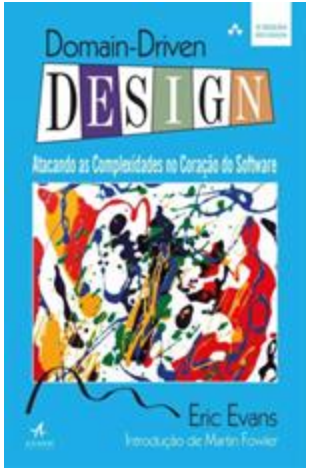
Consumer First

Isolate Failures

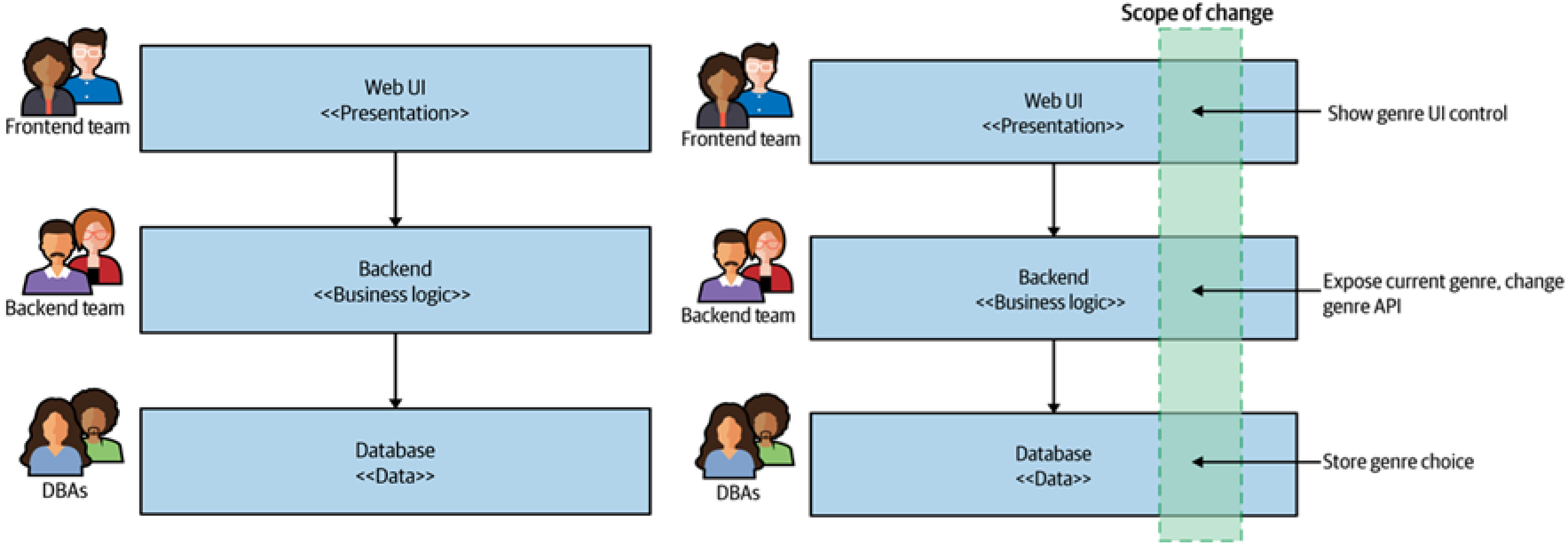
Sam Newman’s Principles of Microservices

Domain-driven modeling

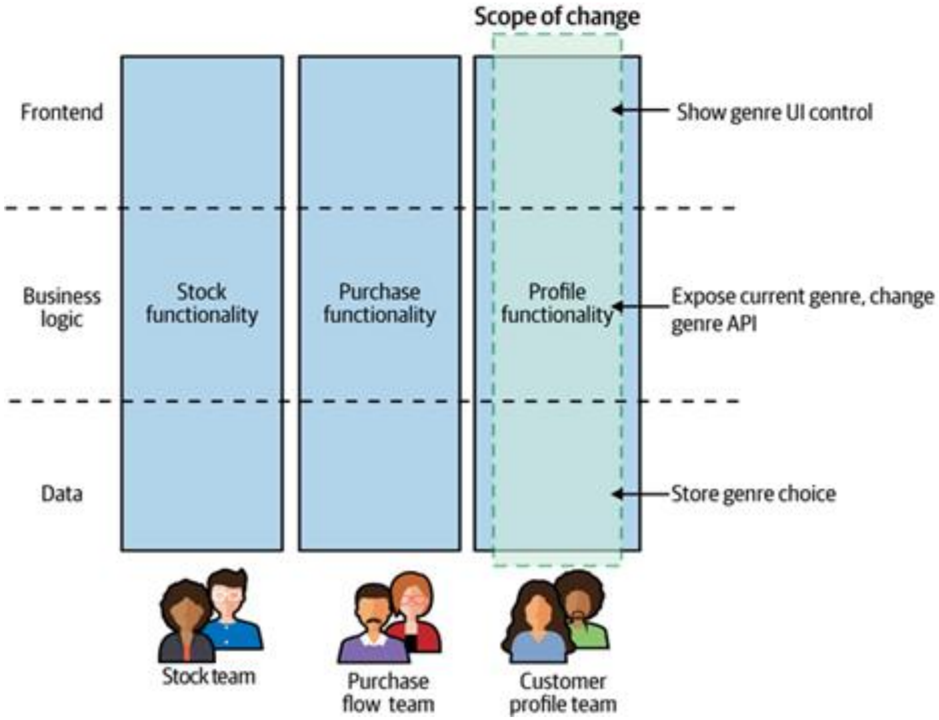
Model services around business capabilities


Domain-Driven
DESIGN
Atacando as Complexidades no Coração do Software
Eric Evans
Introdução de Martin Fowler

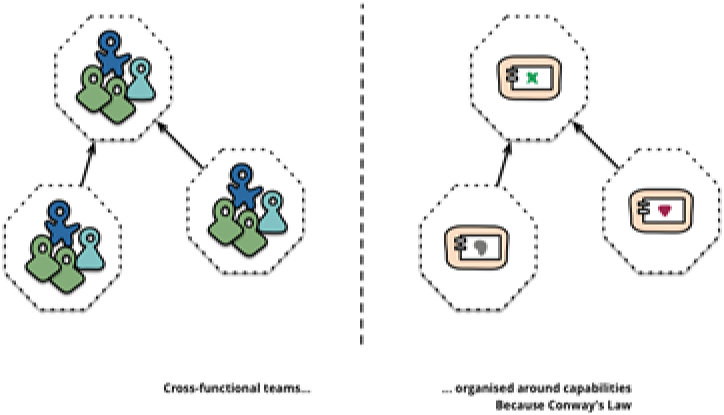
Domain-driven modeling

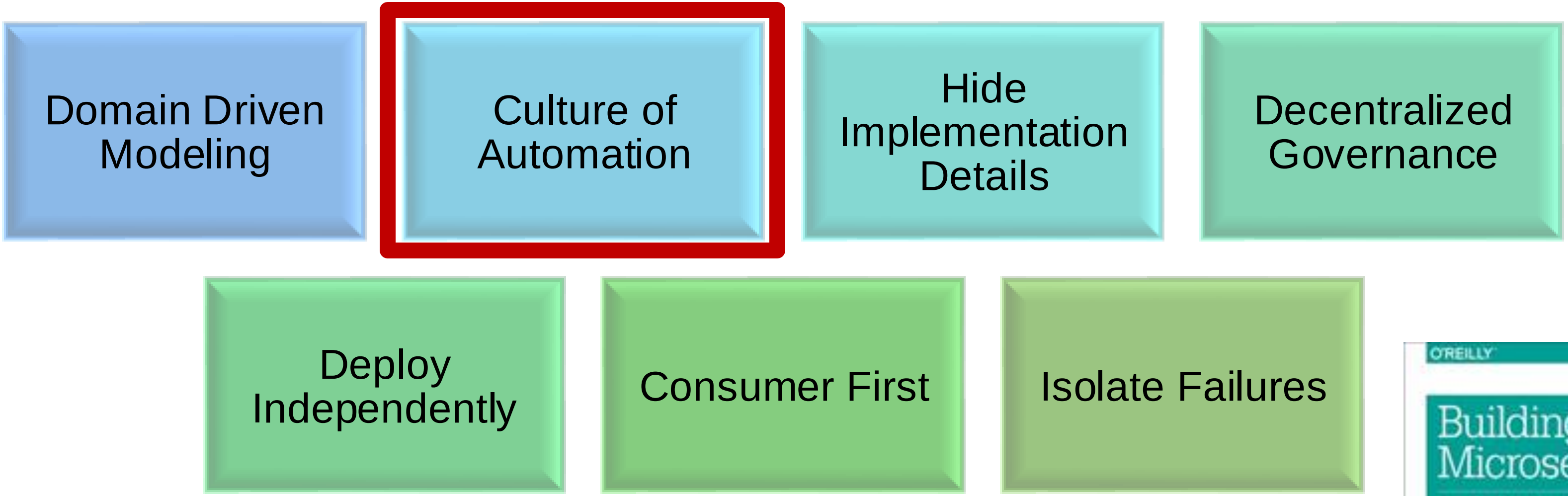


Domain-driven modeling



Remember Conway’s Law?





Domain Driven Modeling

Culture of Automation

Hide Implementation Details

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Isolate Failures

Sam Newman's Principles of Microservices

Culture of Automation

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

Continuous Delivery

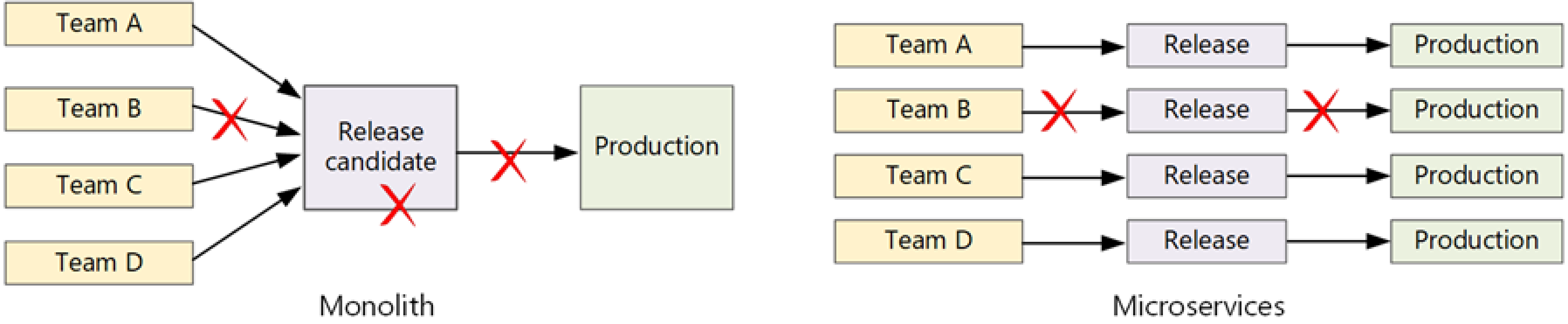

Image Source: https://learn.microsoft.com/en-us/azure/architecture/microservices/ci-cd

Domain Driven Modeling

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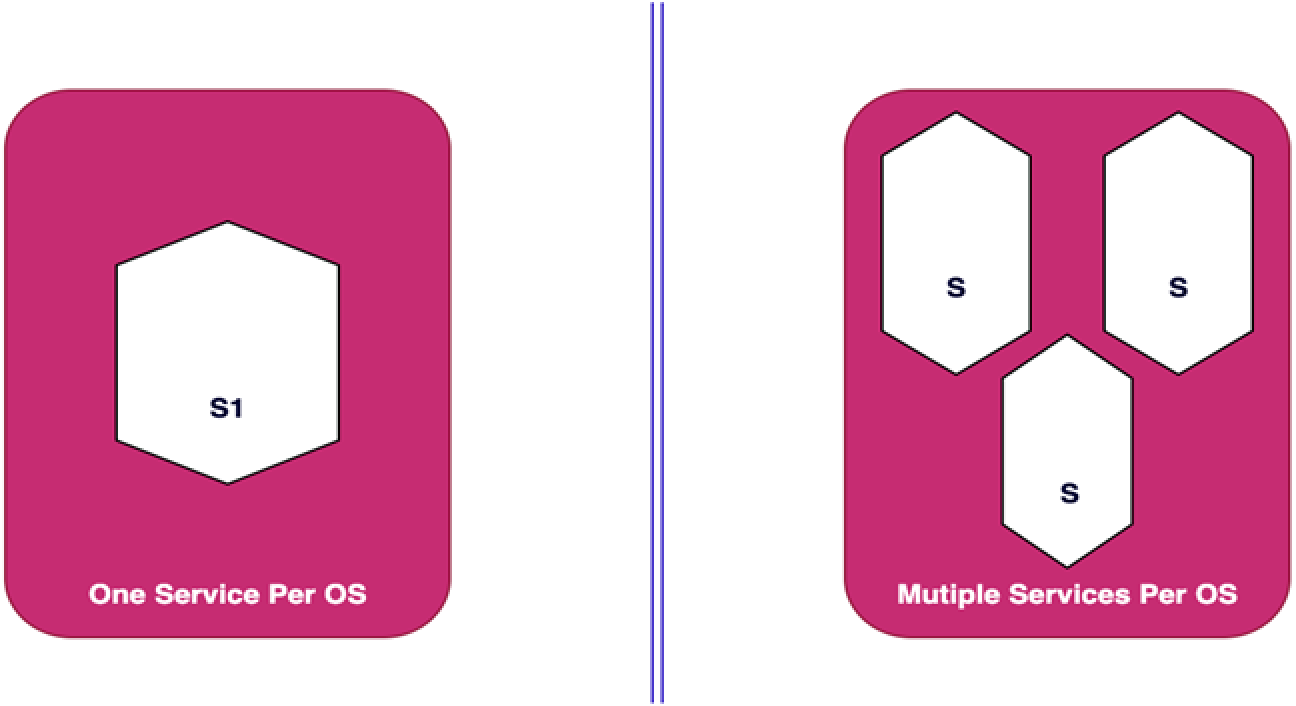
Sam Newman's Principles of Microservices

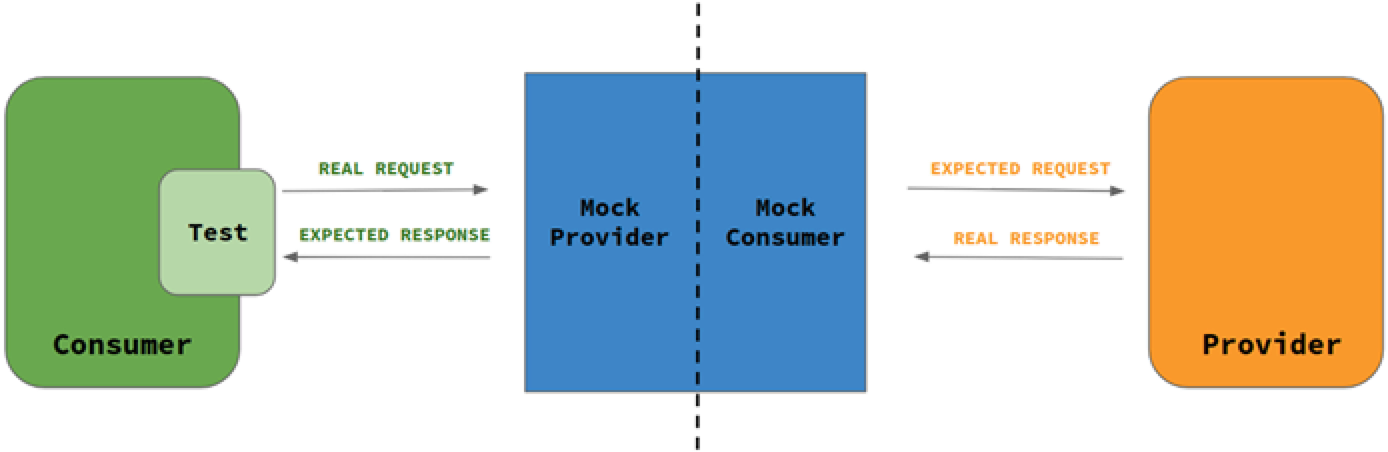
Deploy Independently

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

One Service Per OS



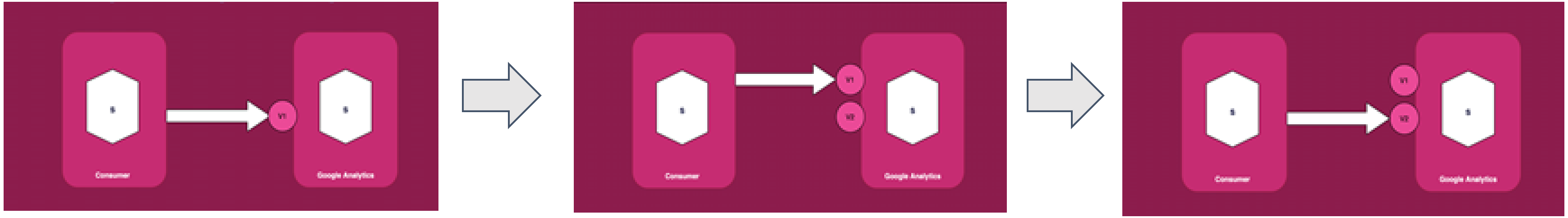
Consumer-Driven Contracts



{...} Swagger™

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

Multiple coexisting versions



Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

Consumer First

Isolate Failures

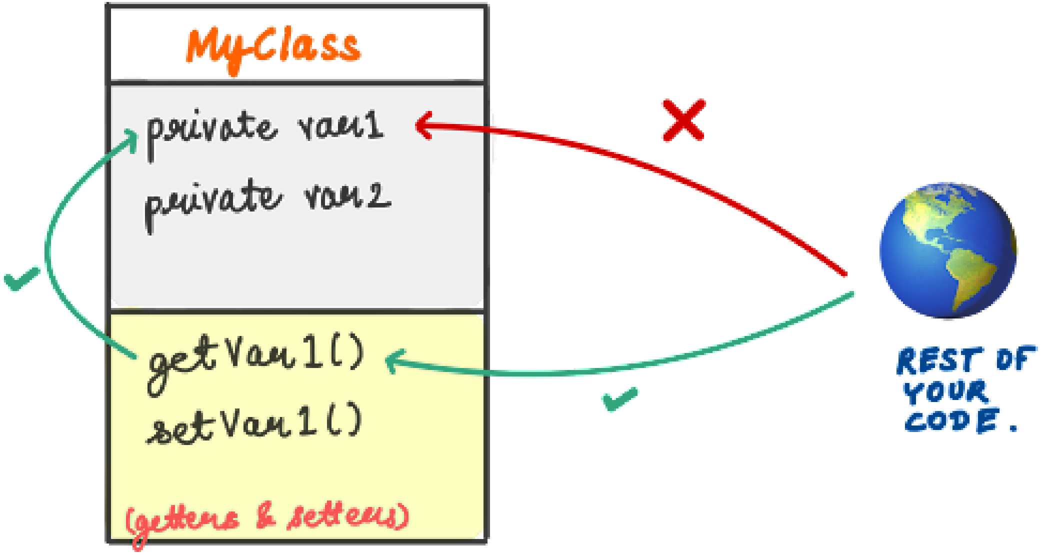
Sam Newman's Principles of Microservices

Hide implementation details

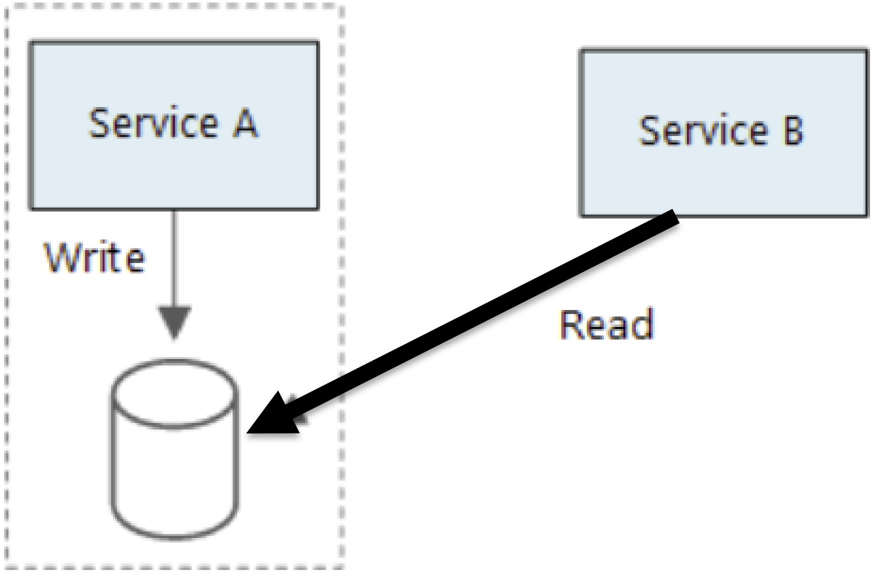
- Design your APIs carefully
- It’s easier to expose some details later than hide them
- Do not share your database!

Hide implementation details

Recall: Encapsulation in OOP



Sharing database: Anti-pattern



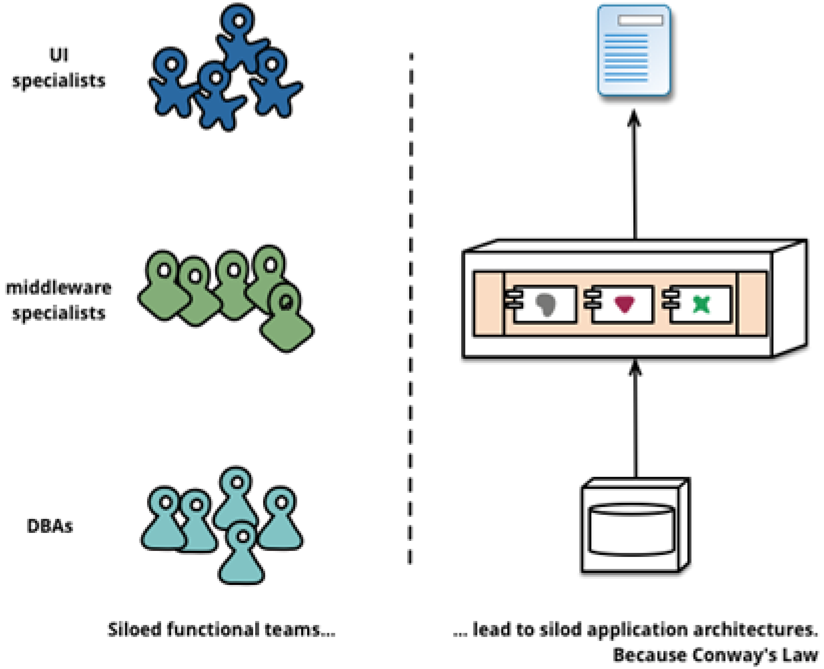
- Domain Driven Modeling
- Culture of Automation
- Hide Implementation Details
- **Decentralized Governance**
- Deploy Independently
- Consumer First
- Isolate Failures

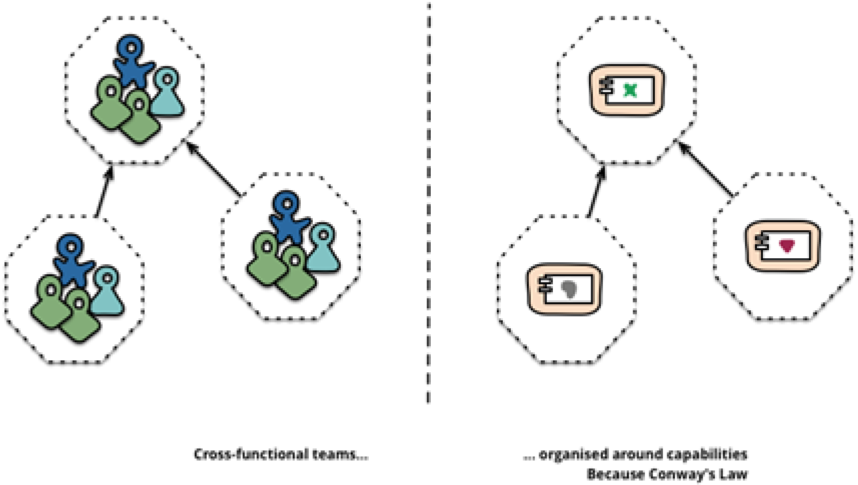
Sam Newman's Principles of Microservices

Decentralized Governance

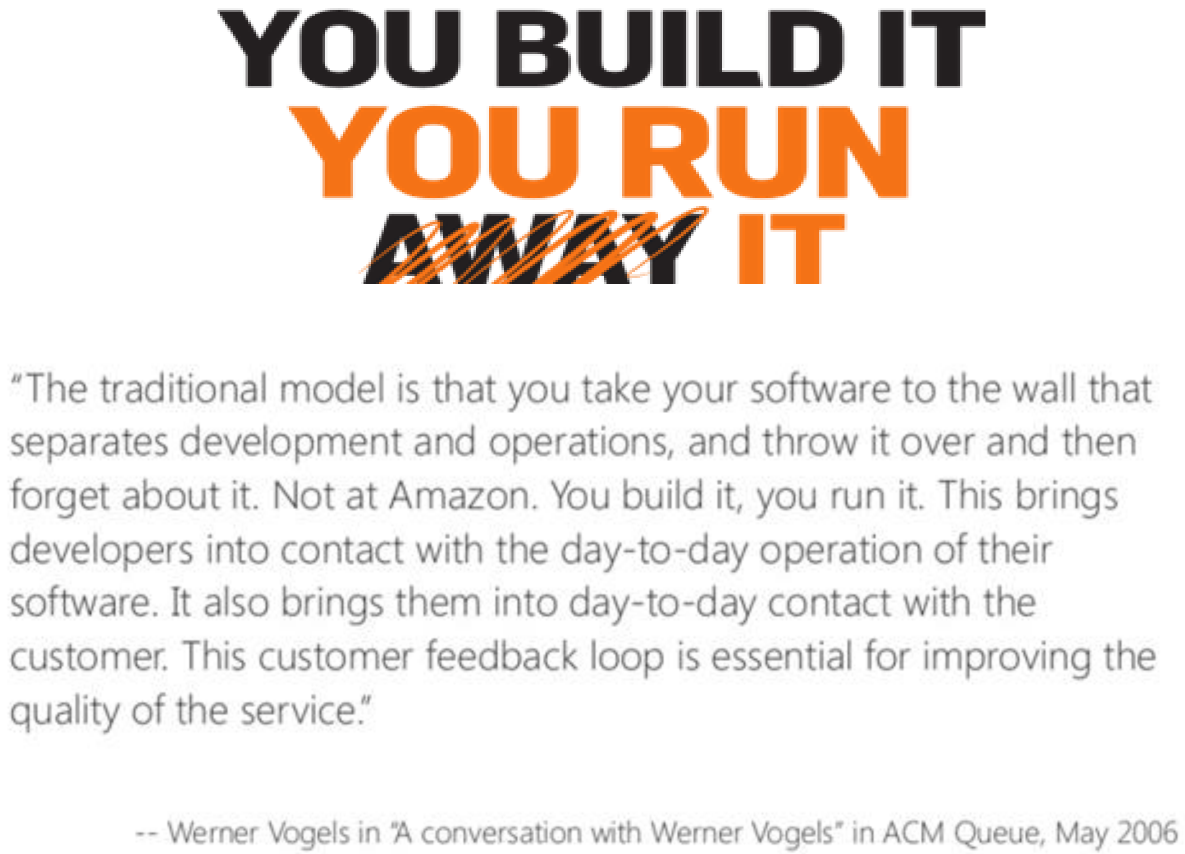
- Mind Conway’s Law
- You Build It, You Run It
- Embrace team autonomy
- Internal Open Source Model

Mind Conway’s Law


UI specialists
middleware specialists
DBAs
Siloed functional teams...
... lead to silod application architectures. Because Conway's Law


Cross-functional teams...
... organised around capabilities Because Conway's Law

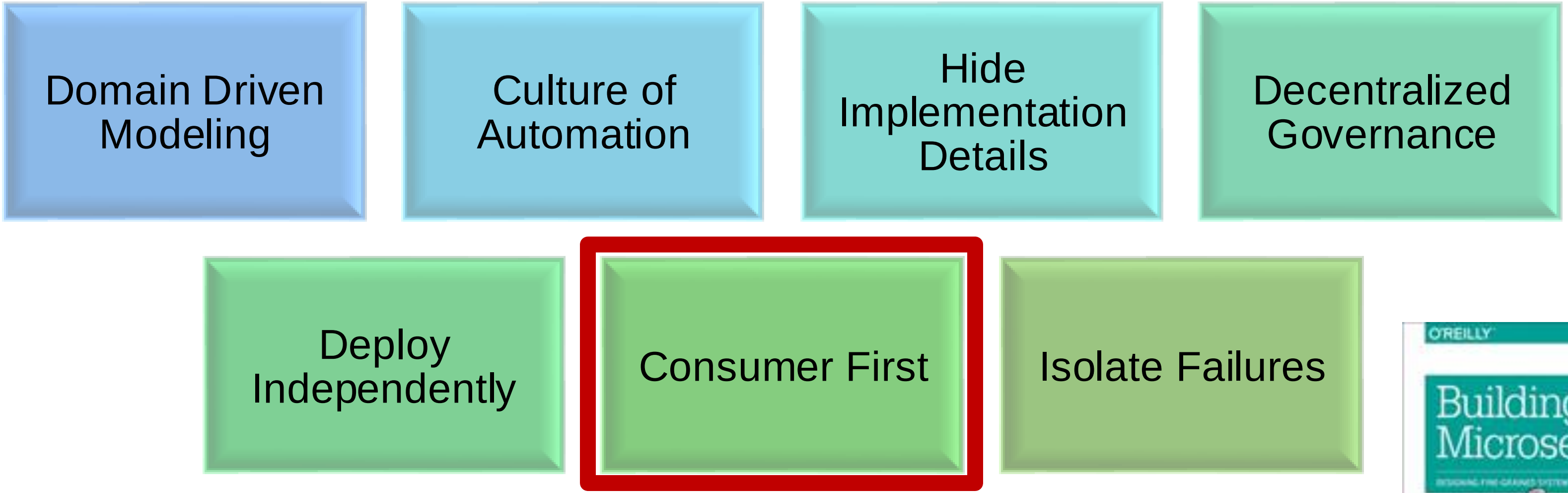
“Products” not “Projects”



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



Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

Consumer First

Isolate Failures

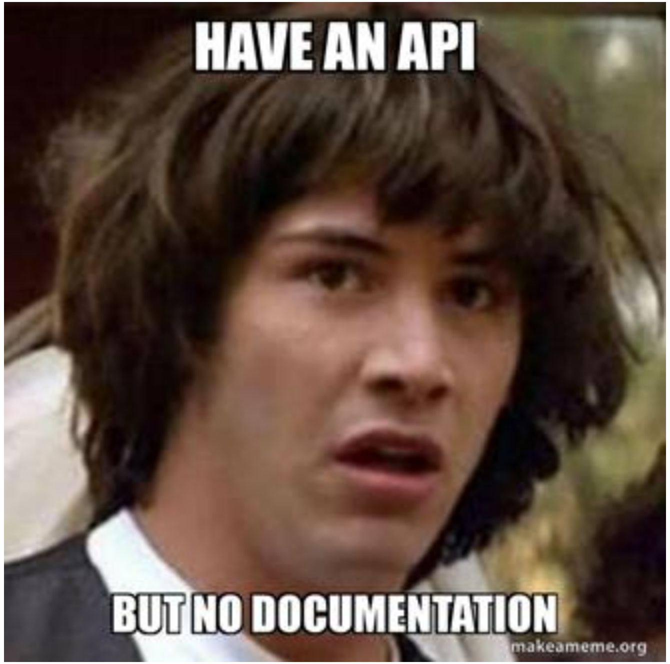
Sam Newman's Principles of Microservices

Consumer First

- Encourage conversations
- API Documentation
- Service Discovery

Encourage conversations

API Documentation



Swagger™

Domain Driven Modeling

Culture of Automation

Hide Implementation Details

Decentralized Governance

Deploy Independently

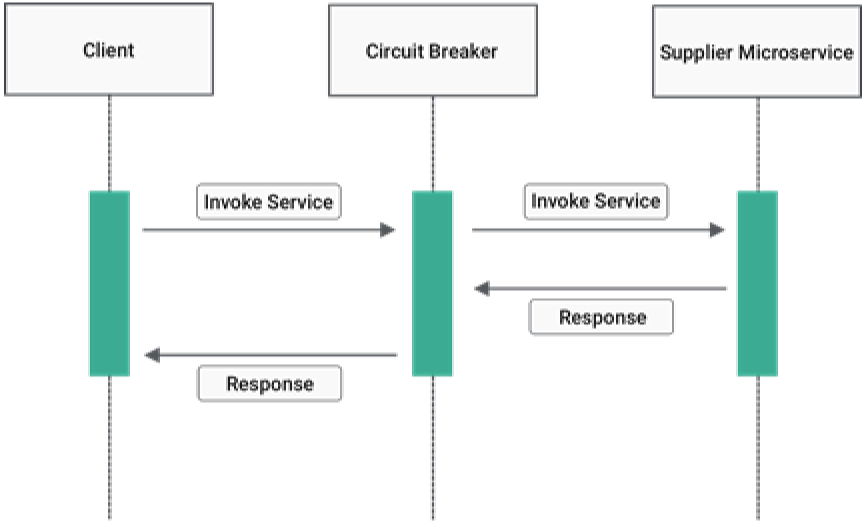
Consumer First

Isolate Failures

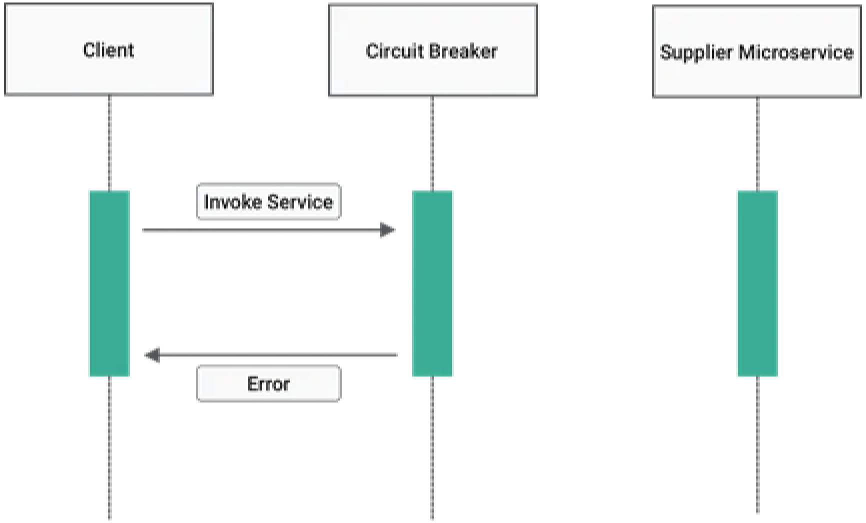
Sam Newman's Principles of Microservices

Isolate Failure

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



Closed circuit



Open circuit

Image source: blogs.halodoc.io

Are microservices always the right choice?

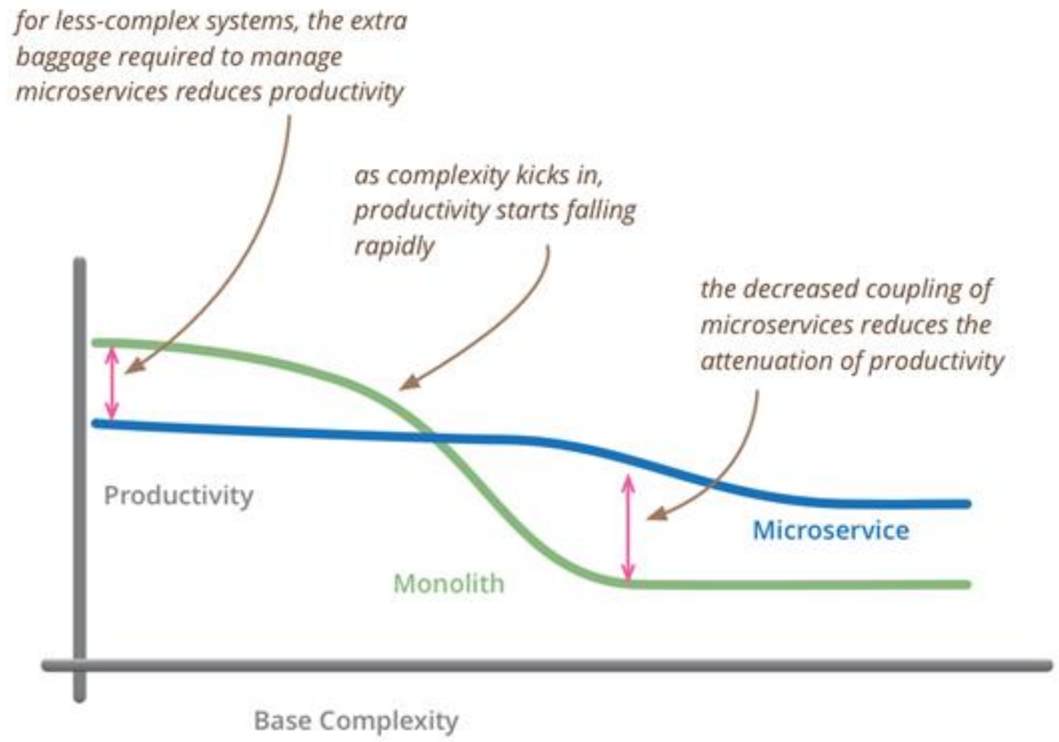
Advantages of Microservices

- Ship features faster and safer
- Scalability
- Target security concerns
- 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
- Delay 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



for less-complex systems, the extra baggage required to manage microservices reduces productivity
as complexity kicks in, productivity starts falling rapidly
the decreased coupling of microservices reduces the attenuation of productivity
Productivity
Microservice
Monolith
Base Complexity