Introduction to Software Architecture

17-313: Foundations of Software Engineering

https://cmu-313.github.io

Josh Sunshine and Michael Hilton

Spring 2026

Smoking Section

- Last full row

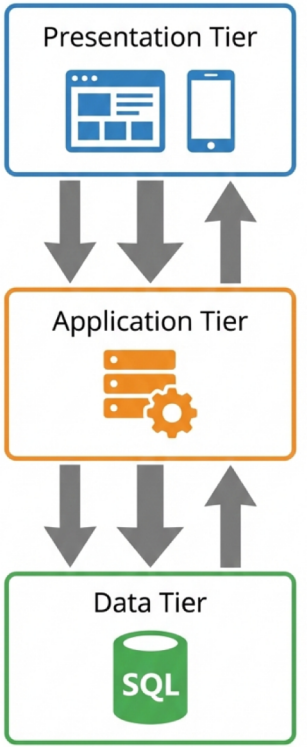
Learning Goals

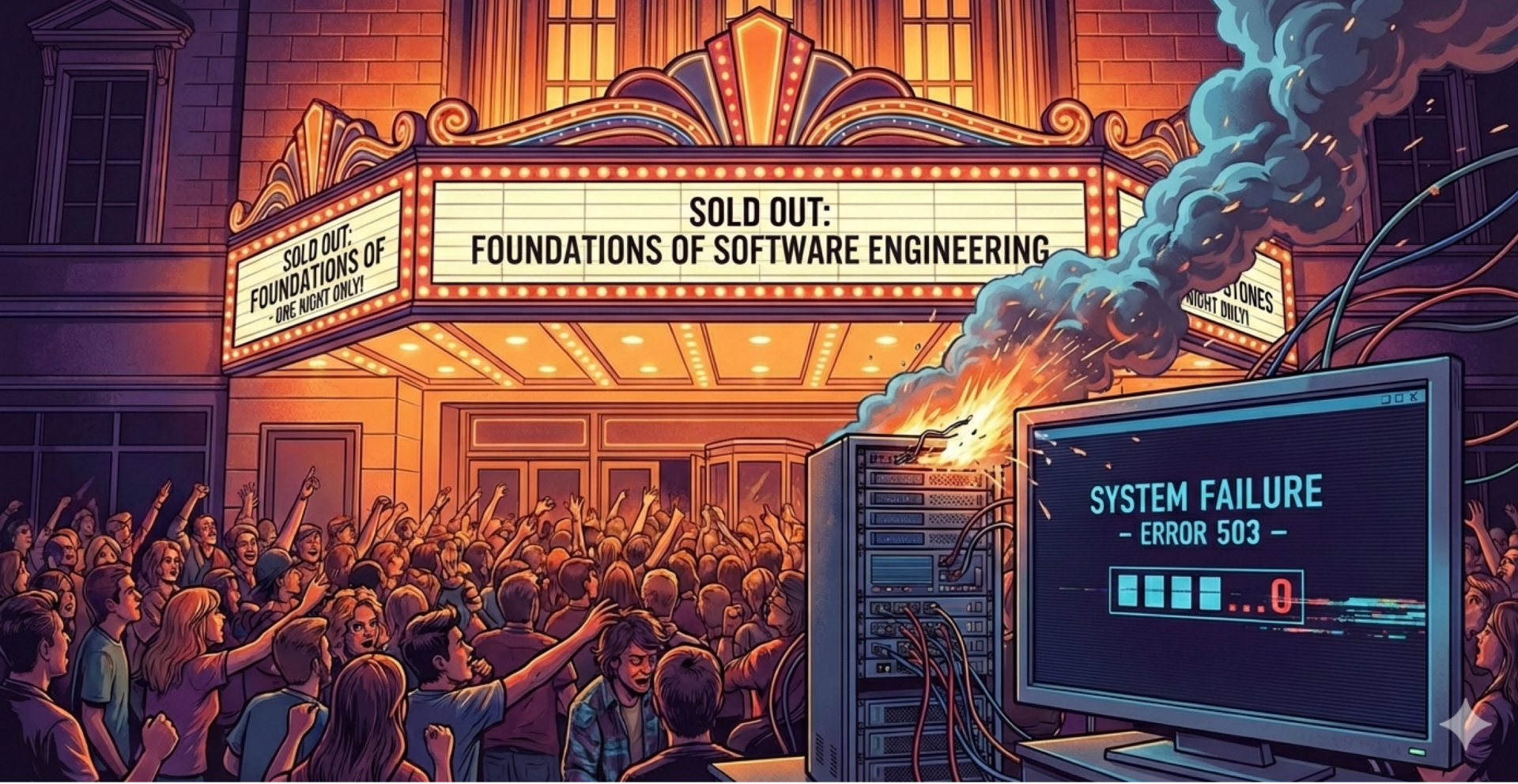
- Understand the abstraction level of architectural reasoning
- Appreciate how software systems can be viewed at different abstraction levels
- Distinguish software architecture from (object-oriented) software design
- Explain the importance of architectural decisions
- Integrate architectural decisions into the software development process
- Document architectures clearly, without ambiguity

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
- ORE NIGHT ONLY!
STONES
NIGHT ONLY!
SYSTEM FAILURE
- ERROR 503 -
...0

In-class activity

Where does the simple architecture of ”Victim of Success Theater” break down?

1. Think on your own
2. Write down a hypothesis or two on your participation sheet
3. Discuss with your neighbor
4. Share with the class

Case Study: Quality Attributes

- **Scalability:** Can we handle the 10:00 AM rush?
- **Reliability:** Can we fail gracefully without double-charging people?
- **Maintainability:** Can we swap adjust the computing resources dedicated to the app without rewriting the code?

Outline

- Views and Abstraction
- Case Study: Victim of Success Theater
- **Software Architecture**
  - **Definitions, Importance**
  - **Software Design vs. Software Architecture**
- Architecting Software
  - Integrating Architectural Decisions into the SW Development Process
  - Common Software Architectures
  - Documentation

Software Architecture

The software architecture of a program or computing system is the structure or structures of the system, which comprise software elements, the externally visible properties of those elements, and the relationships among them.

[Bass et al. 2003]

This definition is ambivalent to whether the architecture is known or whether it's any good!

Software Architecture: Motivation

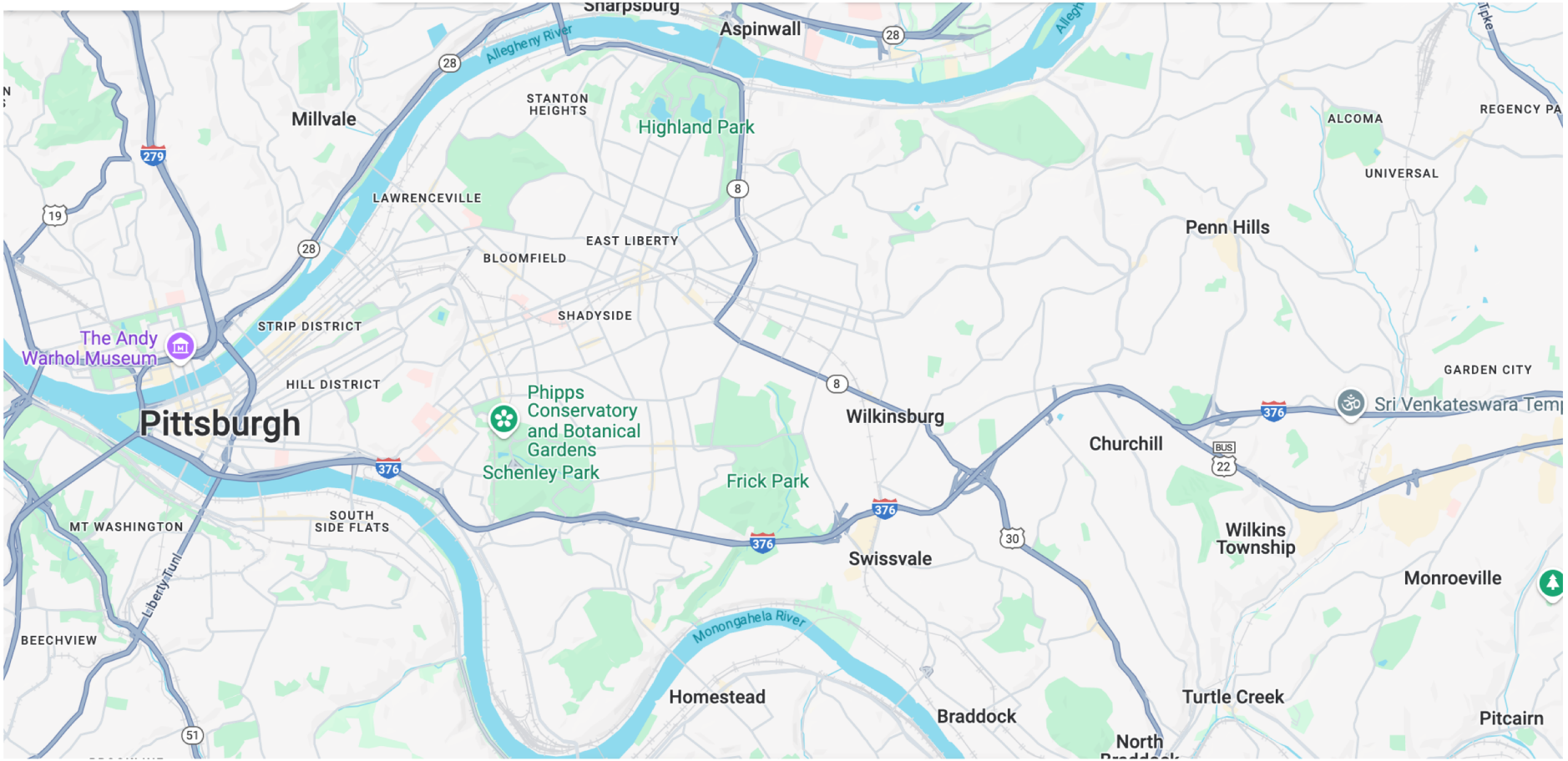
- Facilitates internal and external communication
- Describes design decisions and prescribes implementation constraints
- Relates to organizational structure
- Permits/precludes achieving non-functional requirements
- Control complexity
- Reason about and manage change
- Good basis for effort estimation
- …

Architecting Software the SEI Way - Software Architecture Fundamentals: Technical, Business, and Social Influences. Robert Wojcik. 2012

Conway's Law

Company Structure **influences** Software Architecture

Architectural Views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Allegheny River
Millvale
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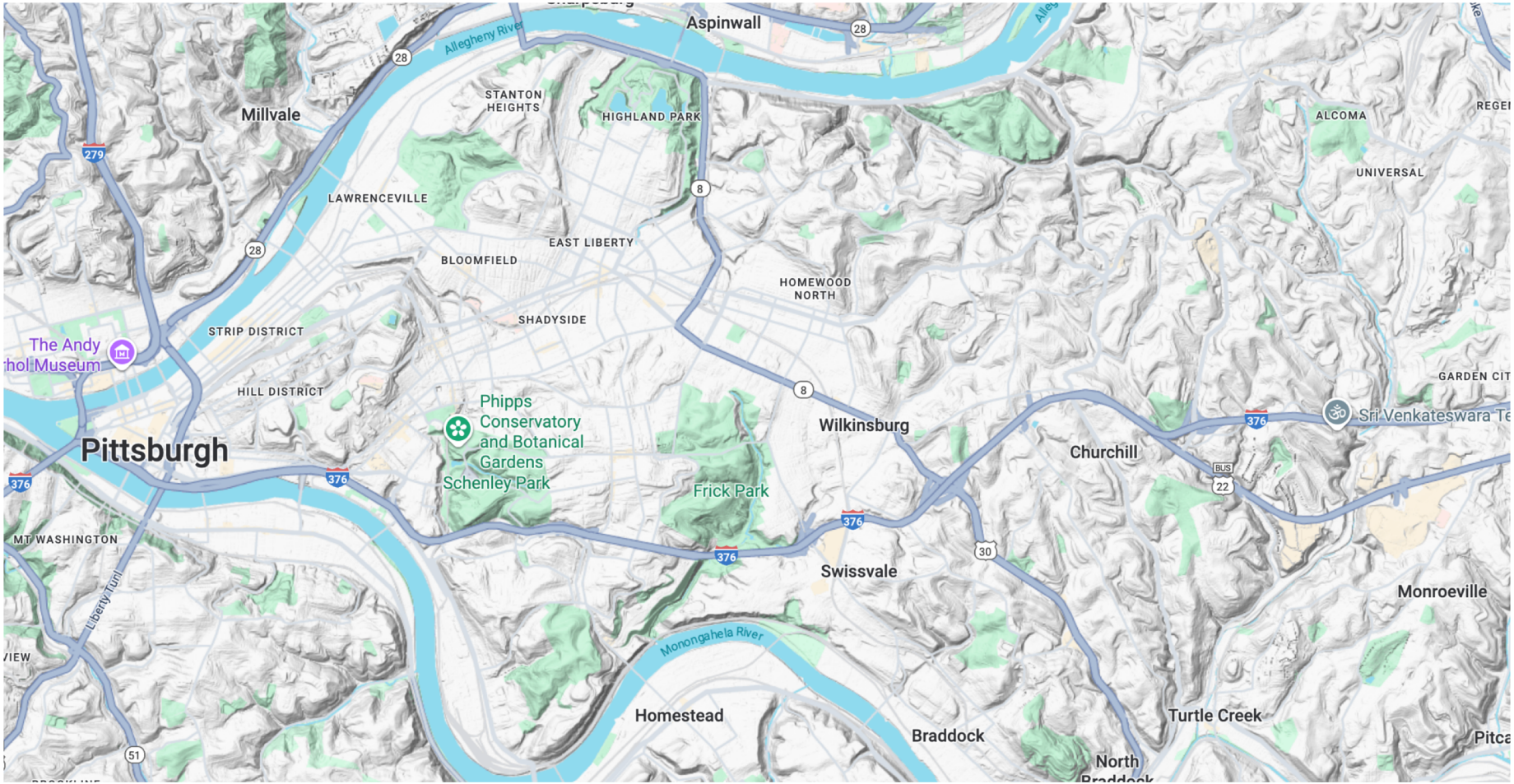
Highland Park
ALCOMA
REGENCY PA
UNIVERSAL
LAWRENCEVILLE
EAST LIBERTY
BLOOMFIELD
Penn Hills
SHADYSIDE
STRIP DISTRICT
The Andy Warhol Museum
HILL DISTRICT
Pittsburgh
Phipps Conservatory and Botanical Gardens
Schenley Park
Frick Park
Wilkinsburg
GARDEN CITY
Sri Venkateswara Temp
Churchill
MT WASHINGTON
SOUTH SIDE FLATS
Swissvale
Wilkins Township
Monroeville
BEECHVIEW
Monongahela River
Homestead
Braddock
Turtle Creek
Pitcairn
North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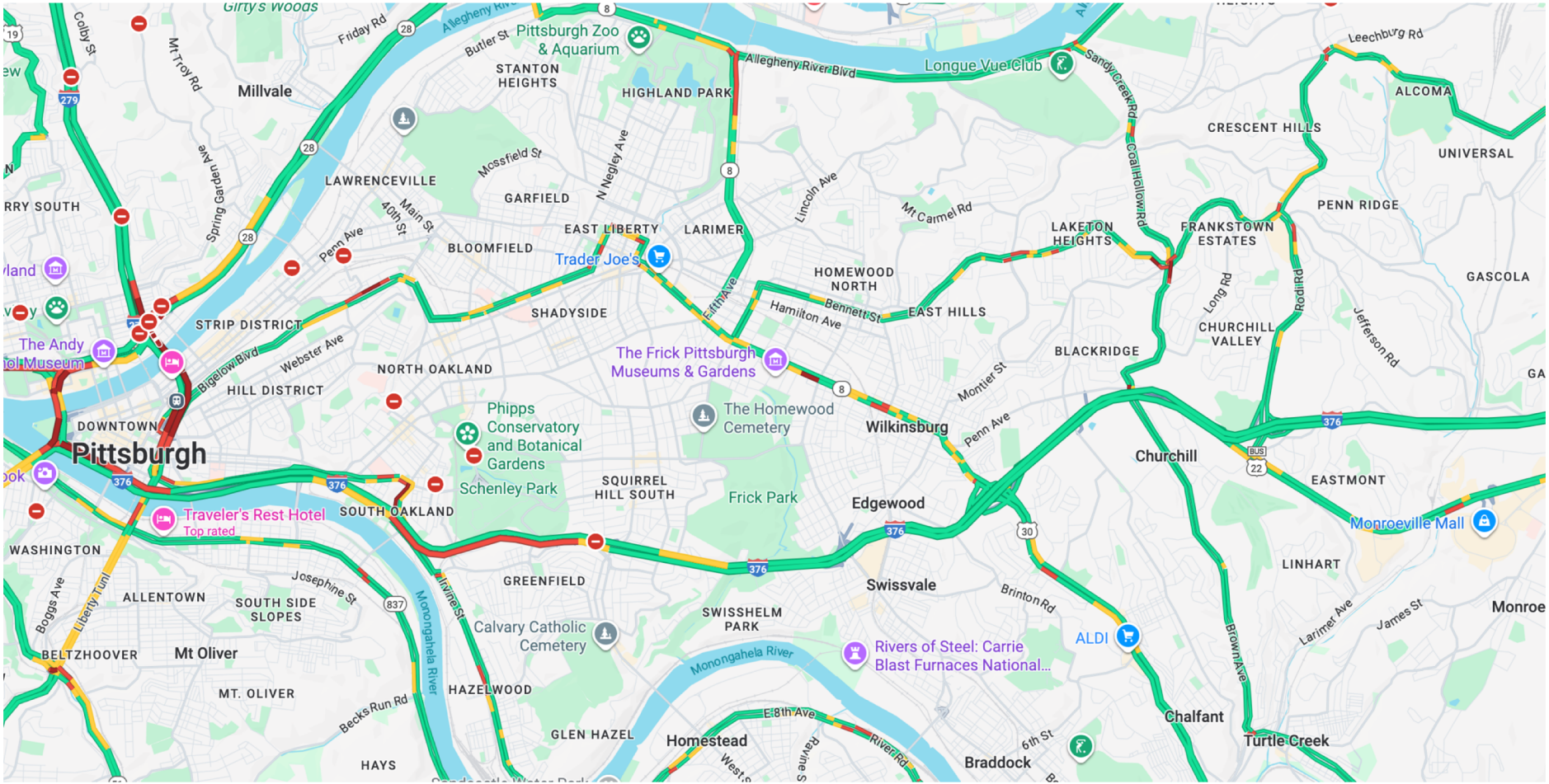
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Millvale
Pittsburgh Zoo & Aquarium
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Allegheny River Blvd
Longue Vue Club
Leechburg Rd
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CRESCENT HILLS
UNIVERSAL
LAWRENCEVILLE
GARFIELD
EAST LIBERTY
LARIMER
BLOOMFIELD
Trader Joe's
HOMEWOOD NORTH
LAKETON HEIGHTS
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PENN RIDGE
GASCOLA
STRIP DISTRICT
SHADYSIDE
EAST HILLS
CHURCHILL VALLEY
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Wilkinsburg
Churchill
EASTMONT
Schenley Park
SQUIRREL HILL SOUTH
Frick Park
Edgewood
Traveler's Rest Hotel
Top rated
SOUTH OAKLAND
Monroeville Mall
WASHINGTON
LINHART
GREENFIELD
Swissvale
ALLENTOWN
SOUTH SIDE SLOPES
SWISSHELM PARK
Calvary Catholic Cemetery
Rivers of Steel: Carrie Blast Furnaces National...
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Mt Oliver
MT. OLIVER
HAZELWOOD
Monongahela River
Chalfant
GLEN HAZEL
Homestead
Braddock
Turtle Creek
HAYS
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Millvale
Spring Garden Ave
Friday Rd
Butler St
Allegheny River
Sandy Creek Rd
Coal Hollow Rd
Mossfield St
N Negley Ave
Lincoln Ave
Mt Carmel Rd
Penn Ave
Main St
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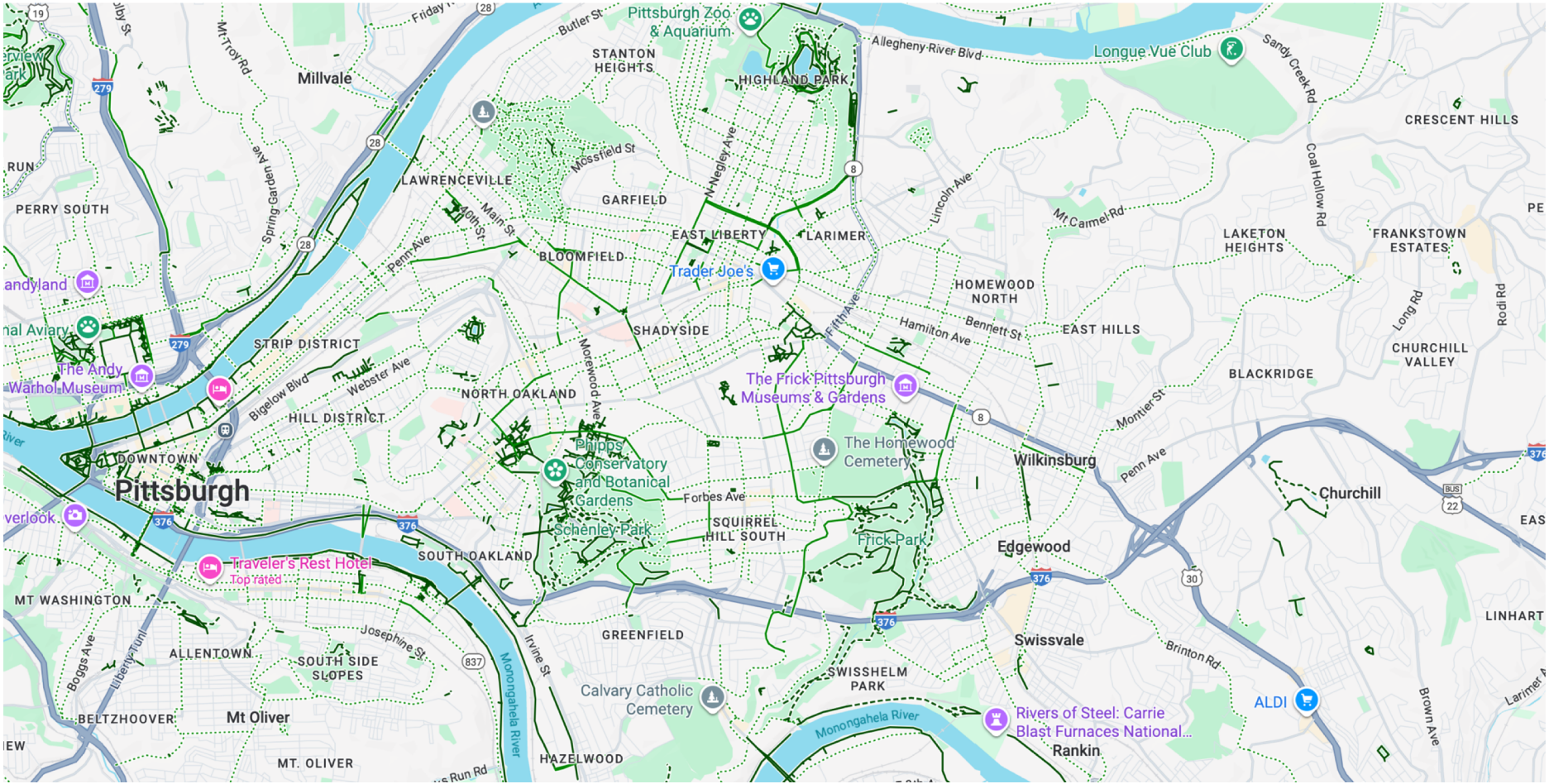
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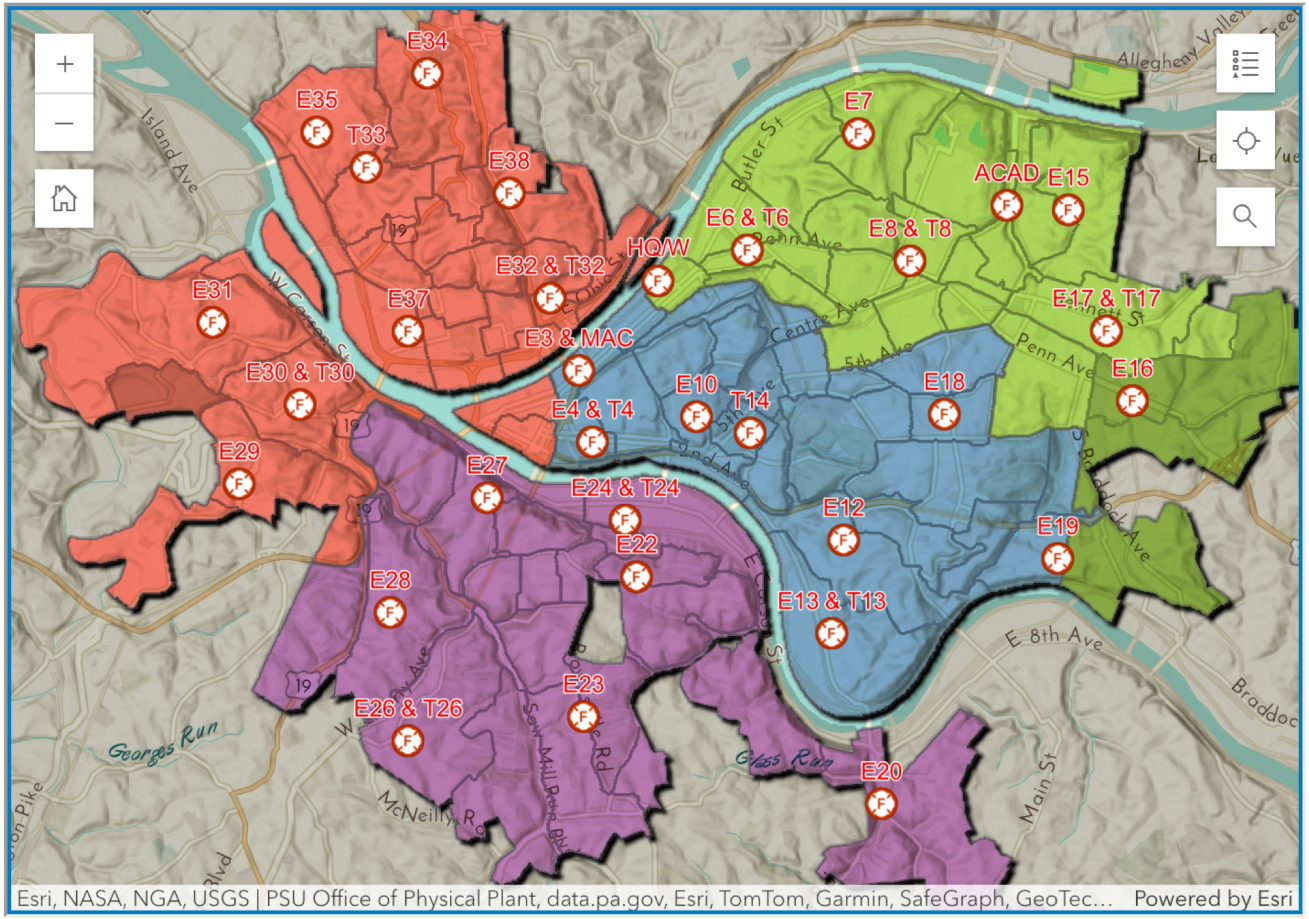
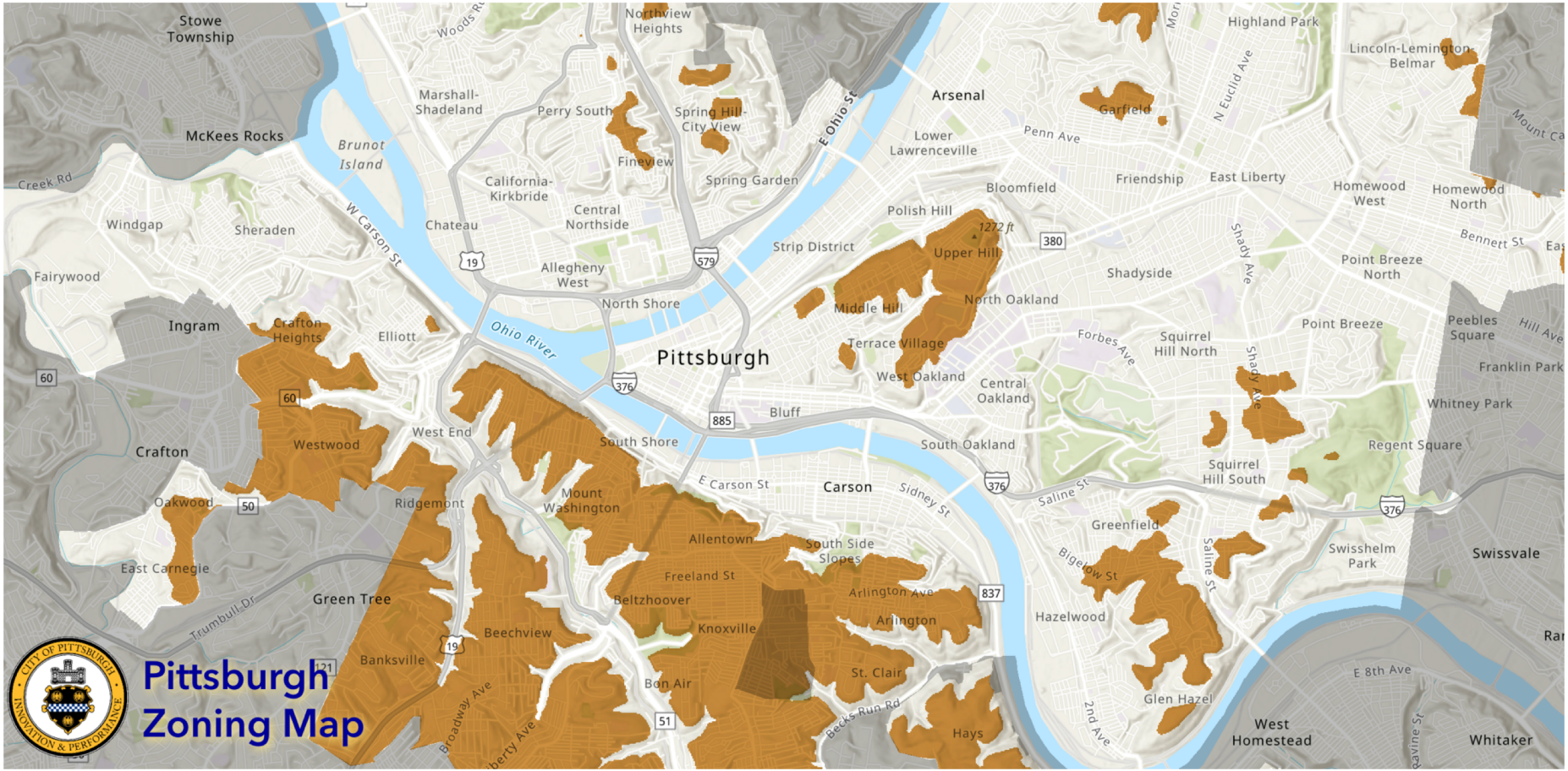


Fire Station

Fire Districts

1
2
3
4


Zoning
Zoning Districts
Uptown Public Realm
Riverfront
Specially Planned
Planned Unit Development
Educational/Medical Institution
Neighborhood Office
Parks
Hillside
General Industrial
Neighborhood Industrial
Urban Industrial
Highway Commercial
Local Neighborhood Commercial
Urban Neighborhood Commercial
Urban Center Employment
Urban Center Mixed Use
Single-Unit Attached Residential
Single-Unit Detached Residential
Two-Unit Residential
Three-Unit Residential
Pittsburgh
Downtown Pittsburgh
Strip District
North Shore
Central Northside
Allegheny Center
Allegheny West
Acrisure Stadium
Point State Park
Bedford Dwellings
Middle Hill
Upper Hill
Polish Hill
Bloomfield
Crawford-Roberts
Terrace Village
West Oakland
North Oakland
Central Oakland
South Oakland
University of Pittsburgh Department
Carnegie Mellon University
The Bob O'Connor Golf Course at Schenley Park
Schenley Park
Shadyside
UPMC Shadyside
Squirrel Hill North
Greenfield
Duquesne University
Bluff
South Shore
Carson
South Side Slopes
Allentown

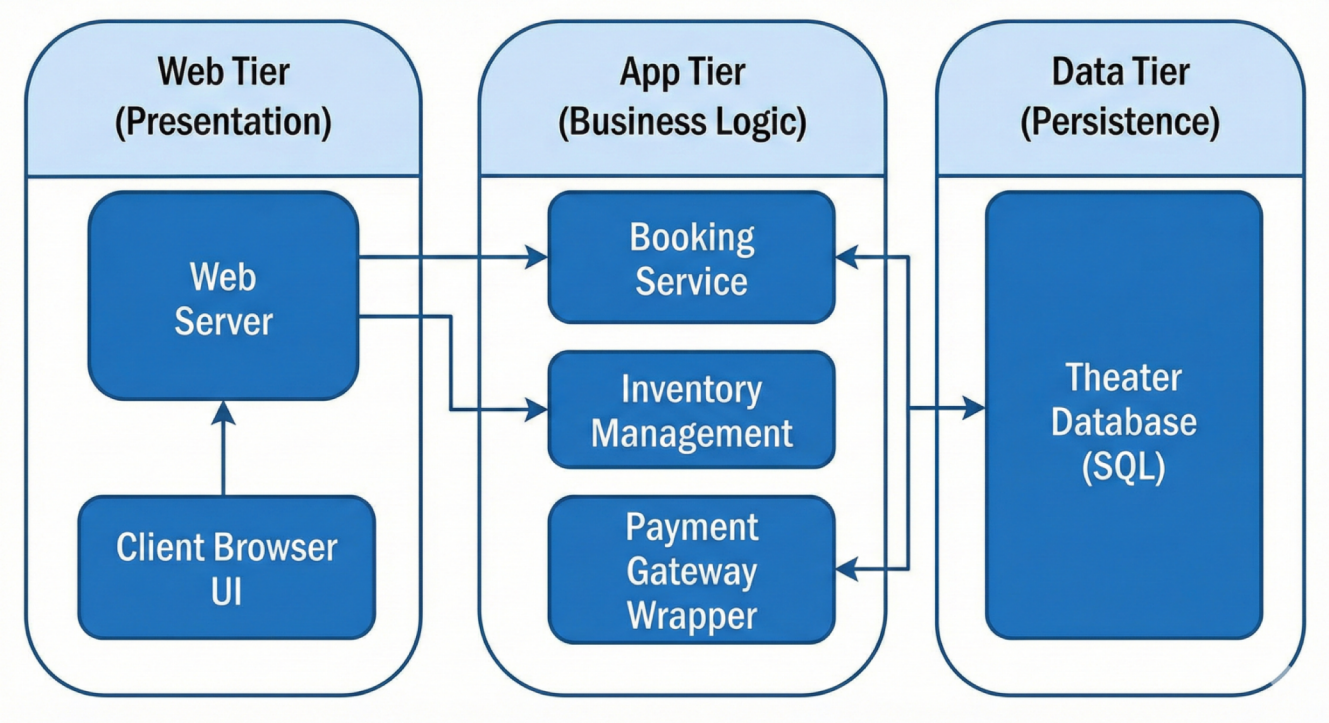

Stowe Township
Northview Heights
Highland Park
Lincoln-Lemington-Belmar
Marshall-Shadeland
Perry South
Spring Hill-City View
Arsenal
Garfield
McKees Rocks
Brunot Island
Fineview
Lower Lawrenceville
Penn Ave
Creek Rd
California-Kirkbride
Spring Garden
Bloomfield
Friendship
East Liberty
Homewood West
Homewood North
Windgap
Sheraden
Chateau
Central Northside
Polish Hill
1272 ft
Bennett St
Fairywood
Allegheny West
Strip District
Upper Hill
Shadyside
Point Breeze North
North Shore
Middle Hill
North Oakland
Ingram
Crafton Heights
Elliott
Ohio River
Pittsburgh
Terrace Village
Forbes Ave
Squirrel Hill North
Point Breeze
Peebles Square
Hill Ave
Franklin Park
West Oakland
Central Oakland
Whitney Park
Crafton
Westwood
West End
South Shore
Bluff
South Oakland
Regent Square
E Carson St
Carson
Sidney St
Saline St
Squirrel Hill South
Oakwood
Ridgemont
Mount Washington
Greenfield
Allentown
South Side Slopes
Swisshelm Park
Swissvale
East Carnegie
Freeland St
Bigelow St
Green Tree
Beltzhoover
Arlington Ave
Arlington
Hazelwood
Trumbull Dr
Knoxville
Beechview
Banksville
St. Clair
Bon Air
E 8th Ave
Glen Hazel
Broadway Ave
Becks Run Rd
Hays
2nd Ave
West Homestead
Whitaker
Pittsburgh
Zoning Map

Each views abstracts reality to focus on conveying specific information

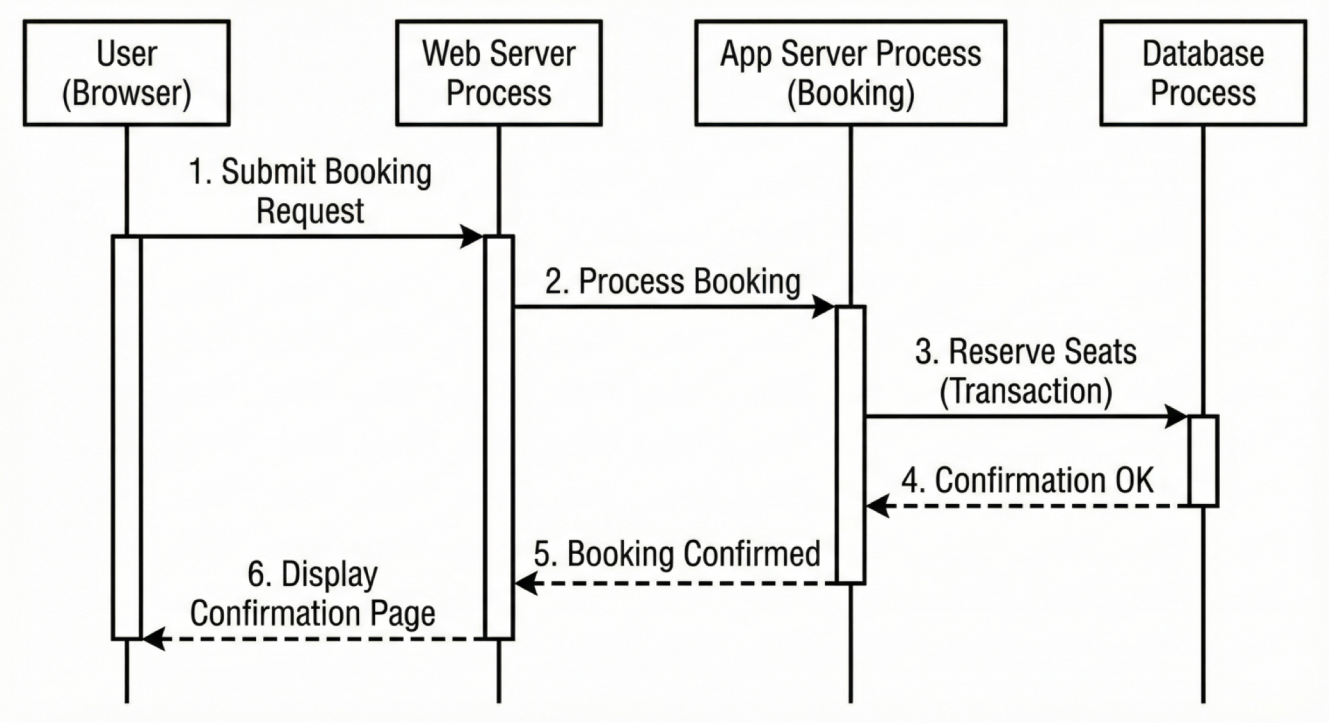
- They have a **well-defined purpose**
- Show only **necessary information**
- **Abstract away** unnecessary details
- Use legends and annotations to **remove ambiguity**

- **Multiple views** together produce a **richer understanding**

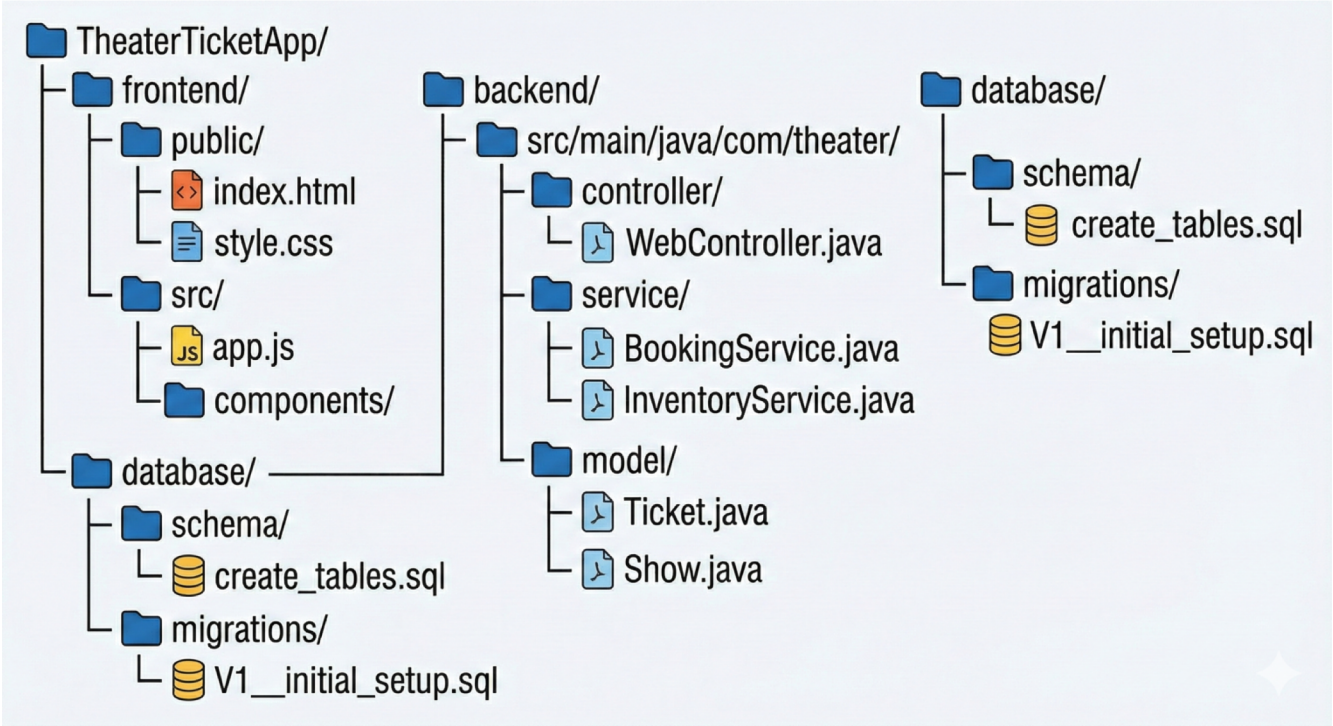
Logical View



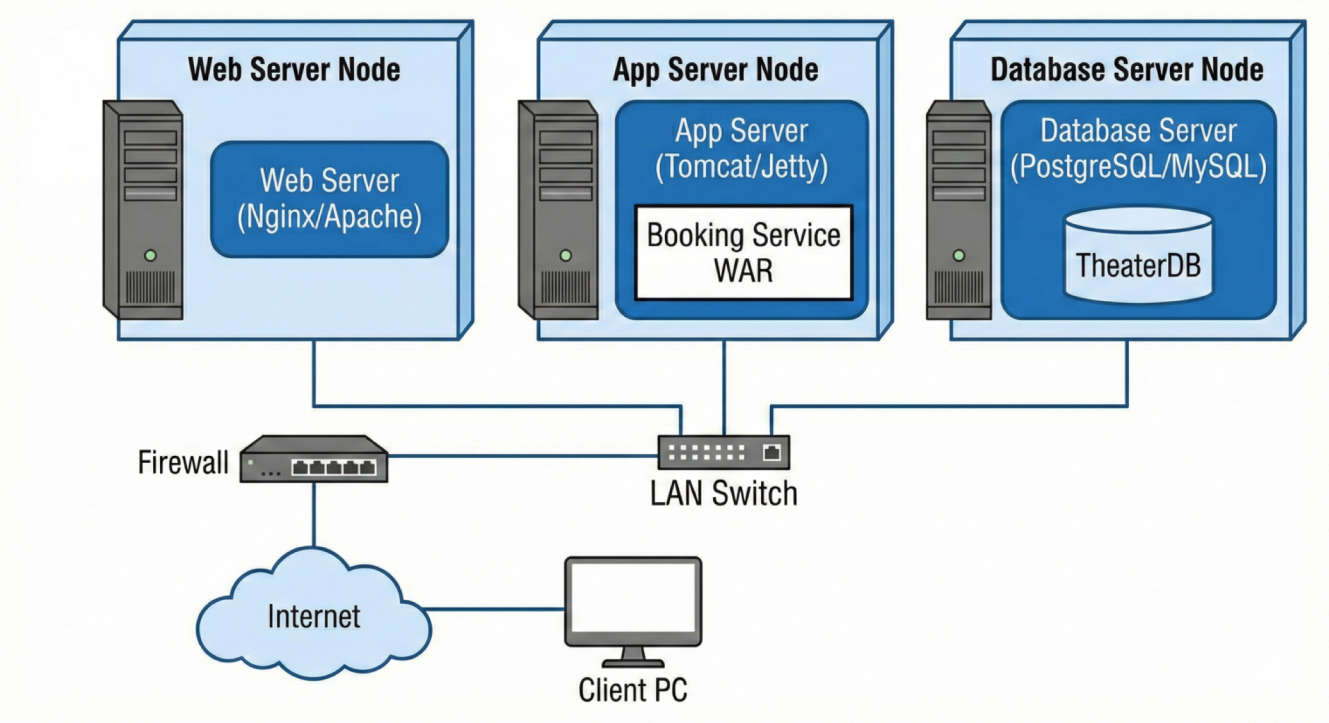
Process View



Development View



Physical View



Software Design vs. Architecture

Levels of Abstraction

Requirements

- high-level “what” needs to be done

Architecture (high-level design)

- high-level “how”, mid-level “what”

Software Design (low-level design, e.g., design patterns)

- mid-level “how”, low-level “what”

Code / Implementation

- low-level “how”

Design vs. Architecture

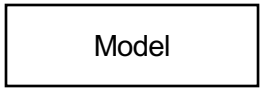
Design Questions

- How do I add a menu item in NodeBB?
- How can I make it easy to create posts in NodeBB?
- What lock protects this data?
- How does Google rank pages?
- What encoder should I use for secure communication?
- What is the interface between objects?

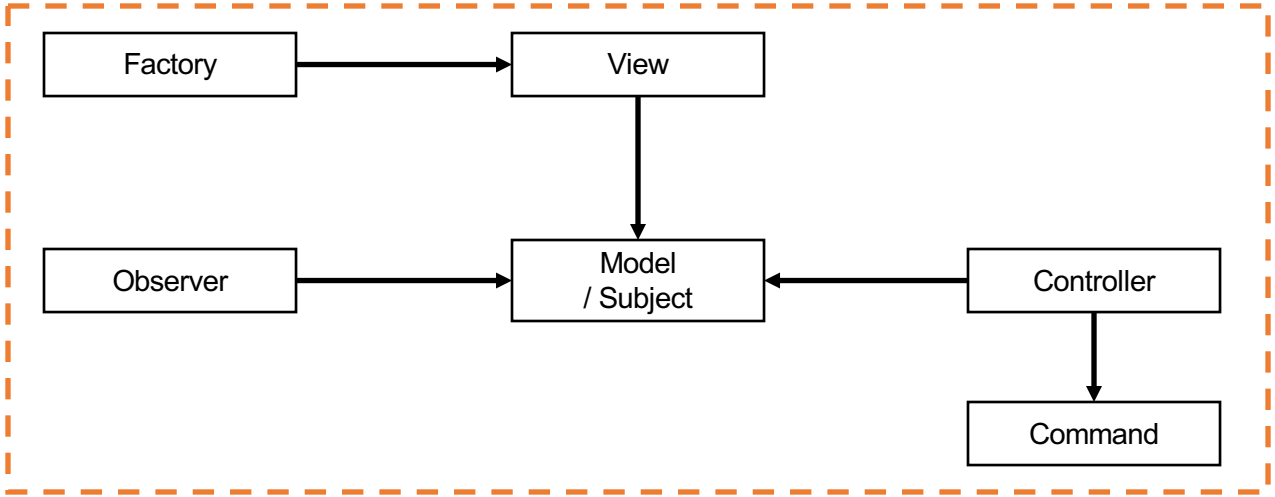
Architectural Questions

- How do I extend NodeBB with a plugin?
- What threads exist and how do they coordinate?
- How does Google scale to billions of hits per day?
- Where should I put my firewalls?
- What is the interface between subsystems?

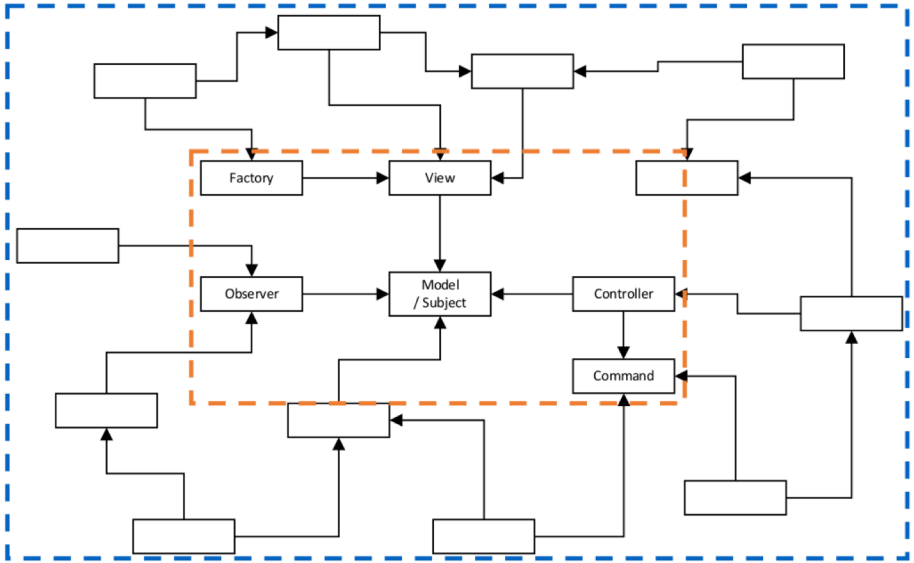
Objects



Objects → Design Patterns



Design Patterns



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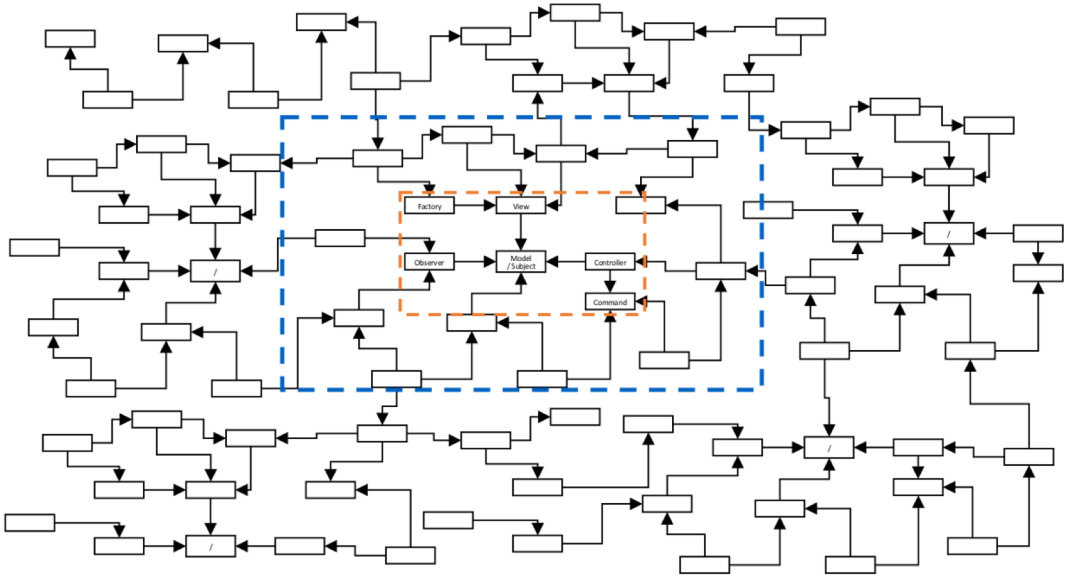
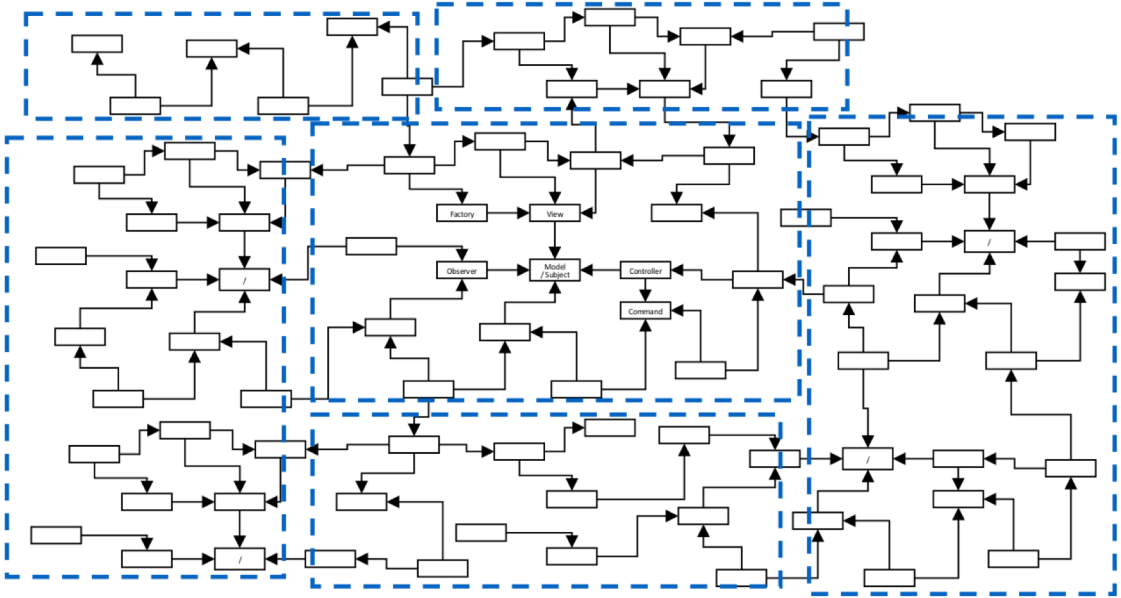
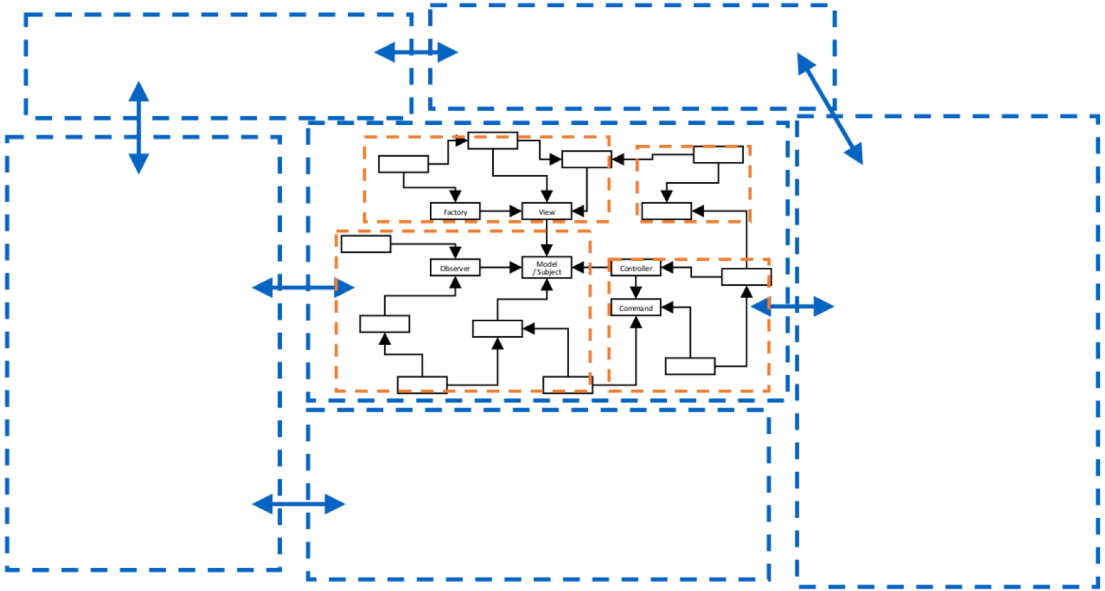


Architecture



Architecture



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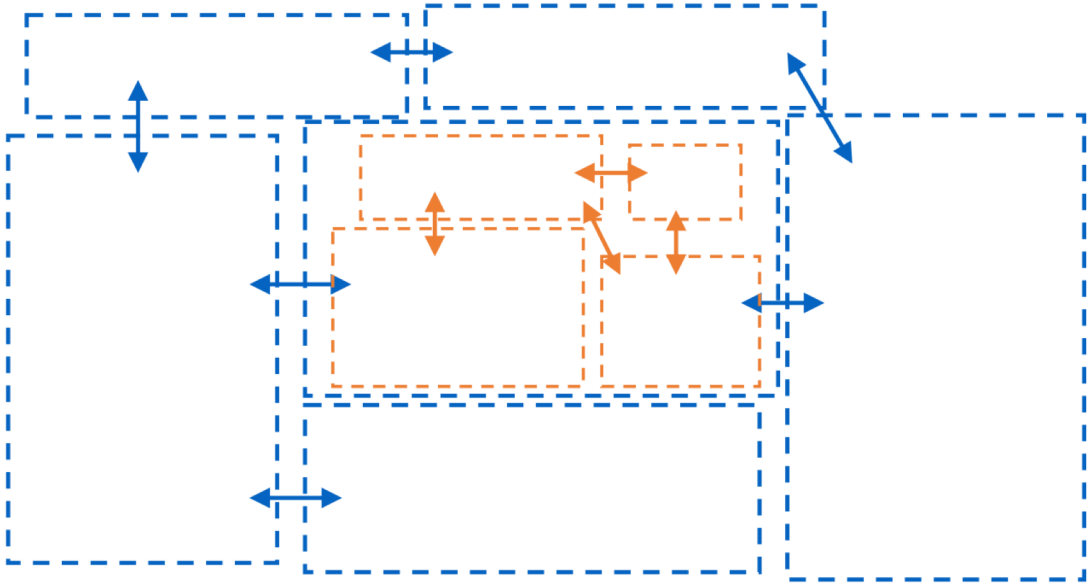
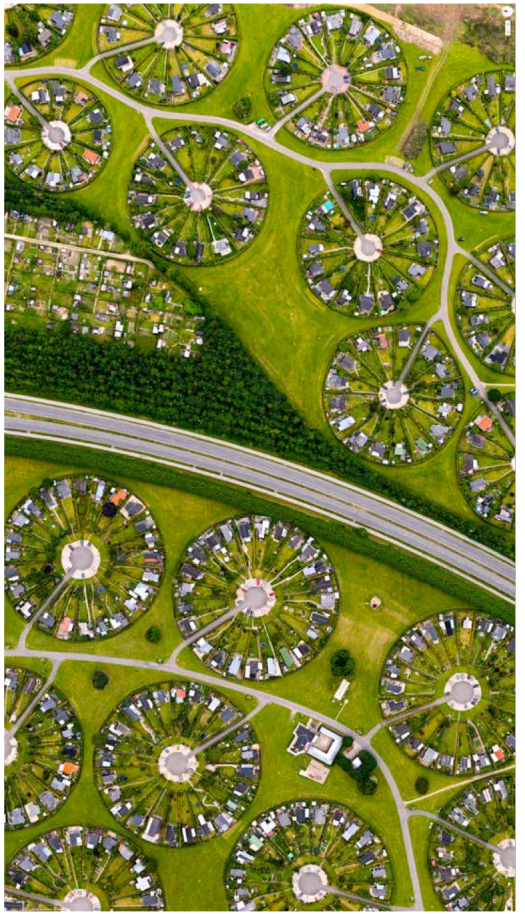


Architecting Software

https://www.archdaily.com/

https://www.instagram.com/architectanddesign



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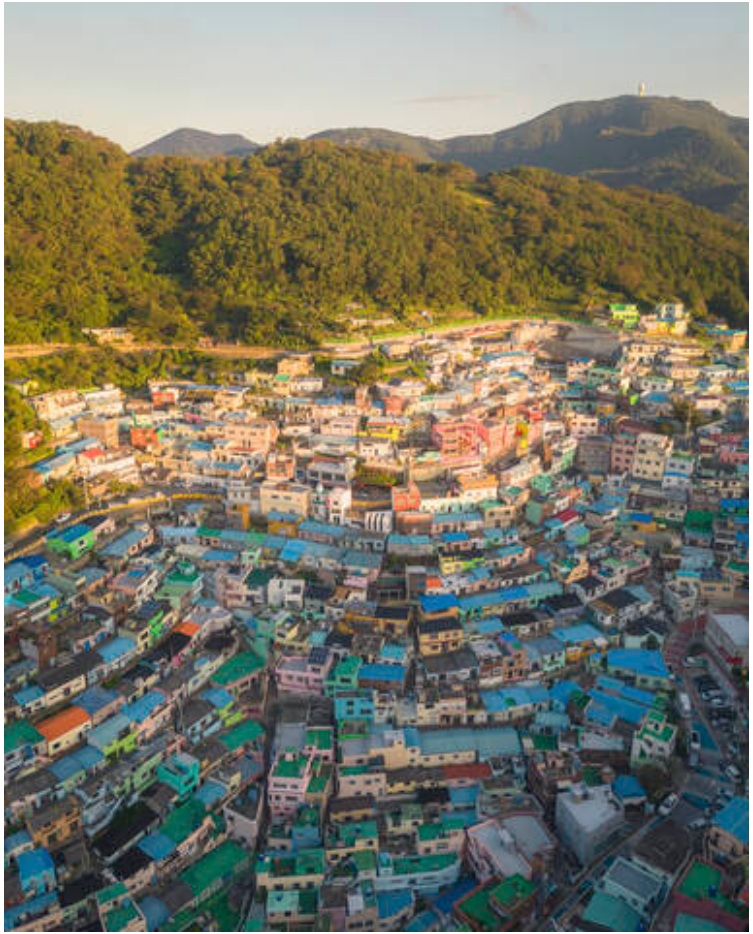


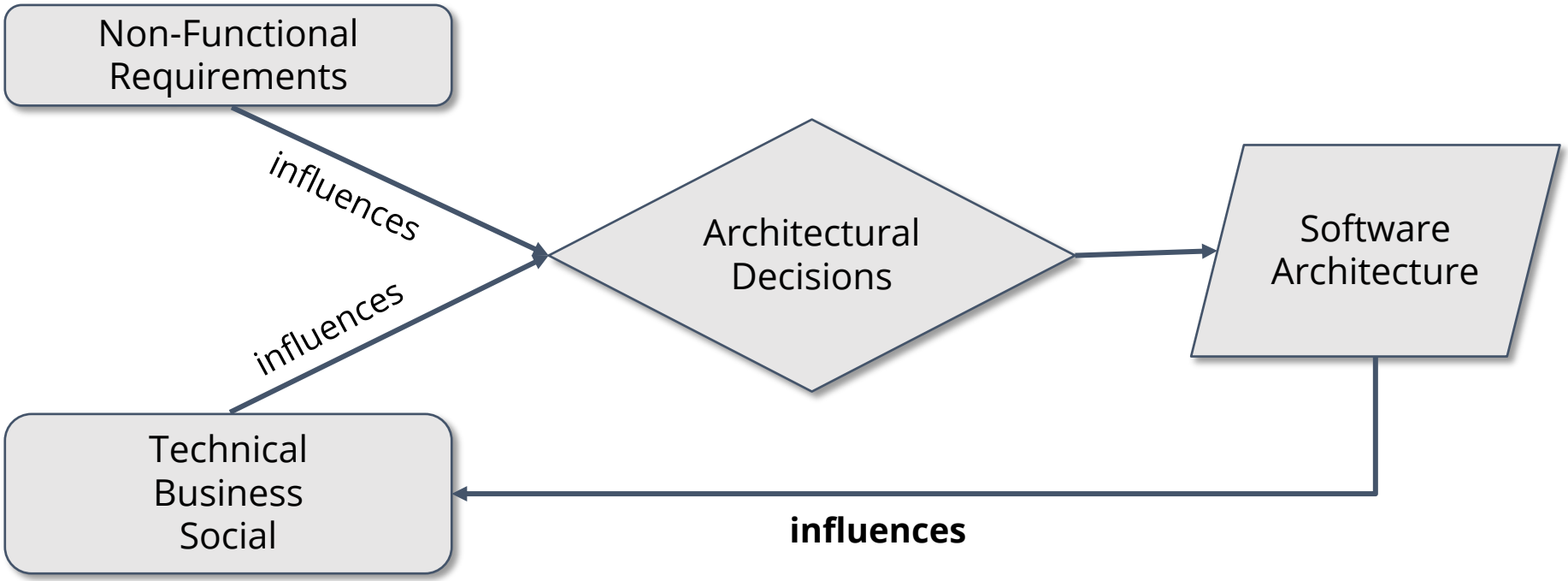
www.over-view.com

Every system has an architecture

- Whether you know it or not
- Whether you like it or not
- Whether it is documented or not

If you don’t consciously elaborate the architecture, it will evolve by itself!

Architecting Software the SEI Way - Software Architecture Fundamentals: Technical, Business, and Social Influences. Robert Wojcik. 2012



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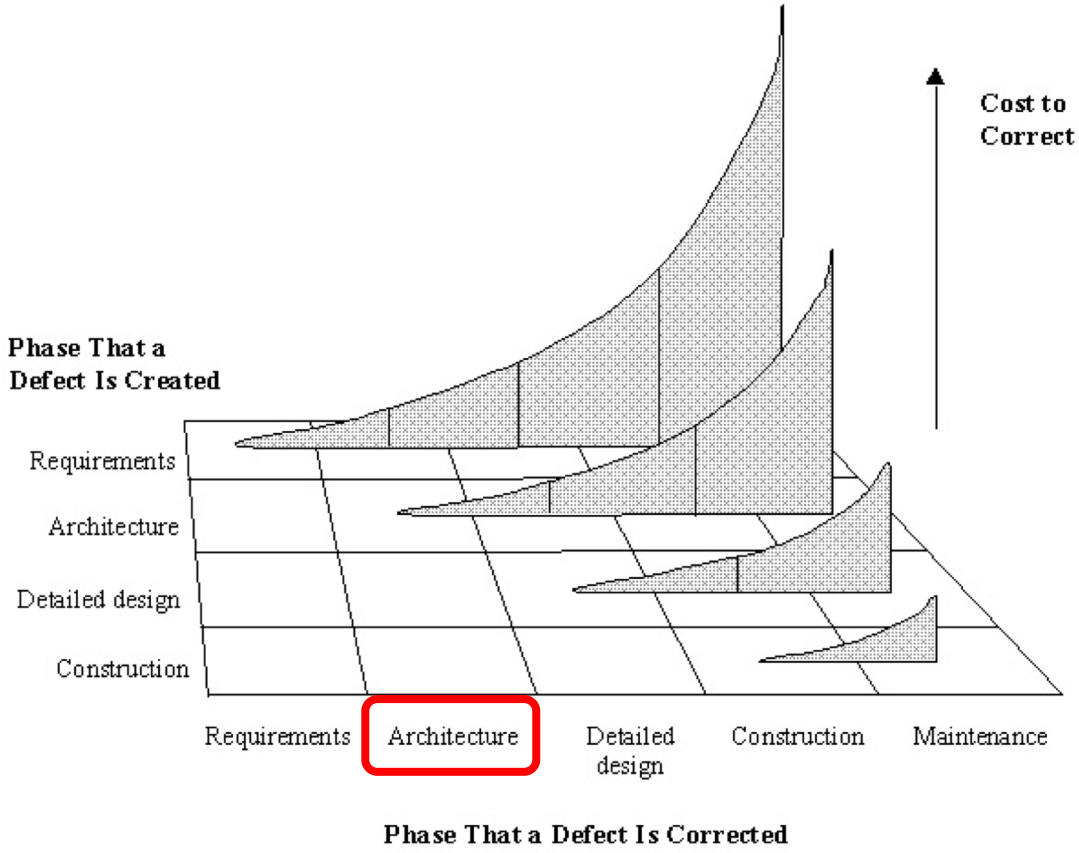
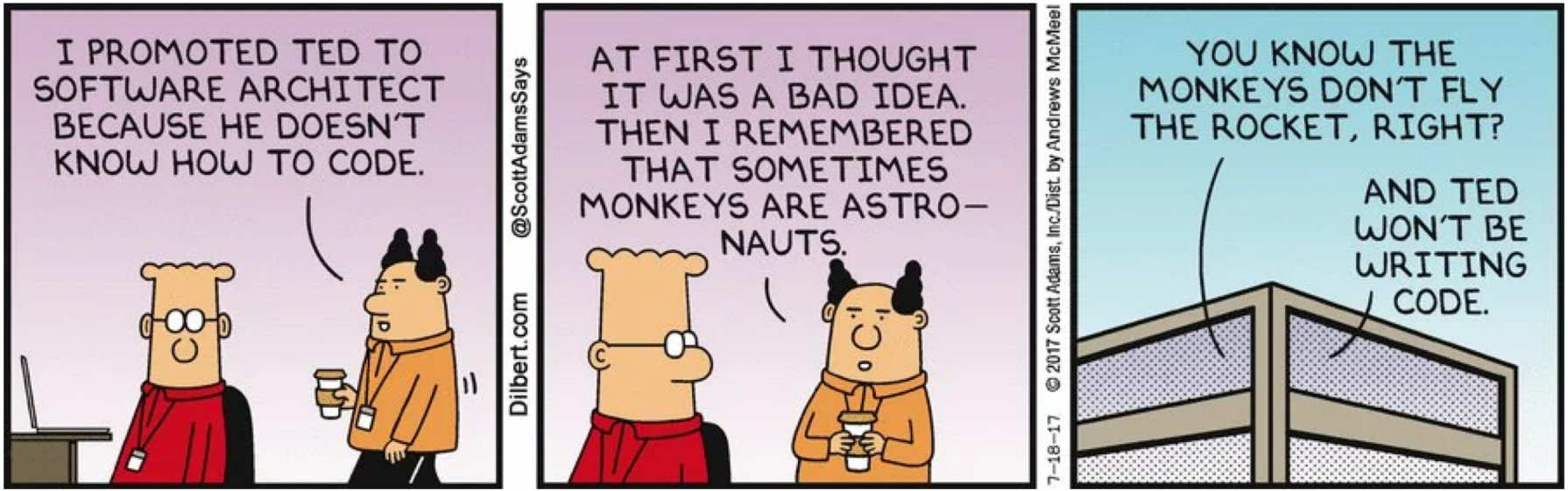
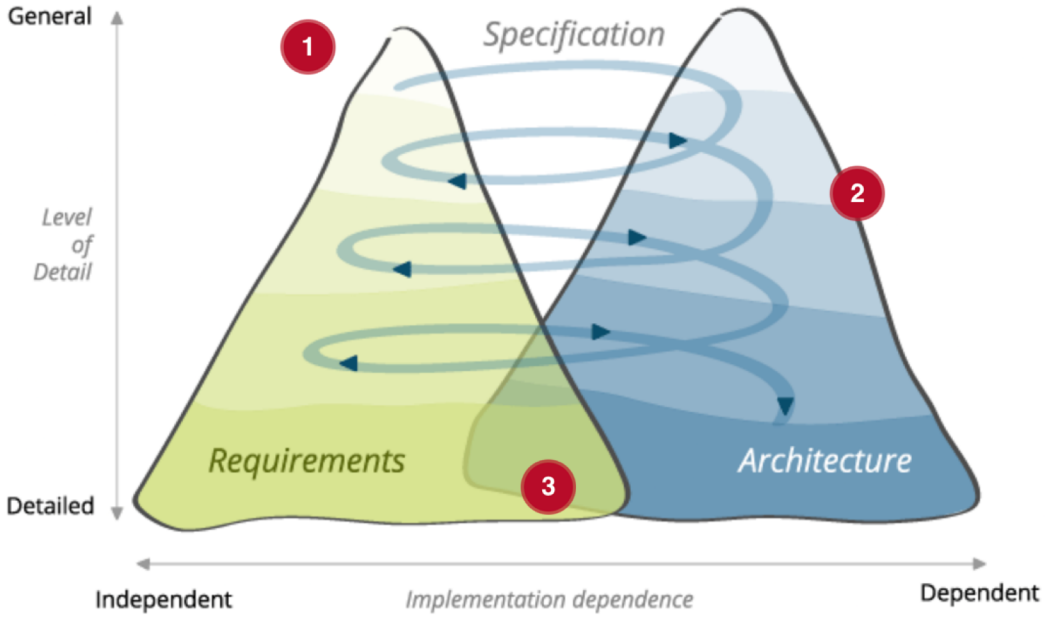



I PROMOTED TED TO SOFTWARE ARCHITECT BECAUSE HE DOESN'T KNOW HOW TO CODE.
Dilbert.com @ScottAdamsSays
AT FIRST I THOUGHT IT WAS A BAD IDEA. THEN I REMEMBERED THAT SOMETIMES MONKEYS ARE ASTRO-NAUTS.
7-18-17 © 2017 Scott Adams, Inc./Dist. by Andrews McMeel
YOU KNOW THE MONKEYS DON'T FLY THE ROCKET, RIGHT?
AND TED WON'T BE WRITING CODE.

The Twin Peaks Model



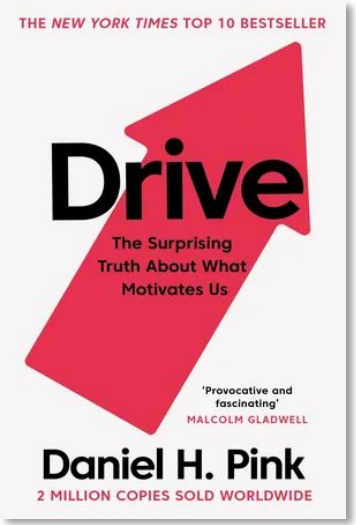
B. Nuseibeh, "Weaving together requirements and architectures". 2001

Agile and Architecture

*"The best architectures, requirements, and designs **emerge** from **self-organizing teams**".* [The Twelve Principles of the Agile Manifesto]

"Control leads to compliance; autonomy leads to engagement."

Daniel H. Pink

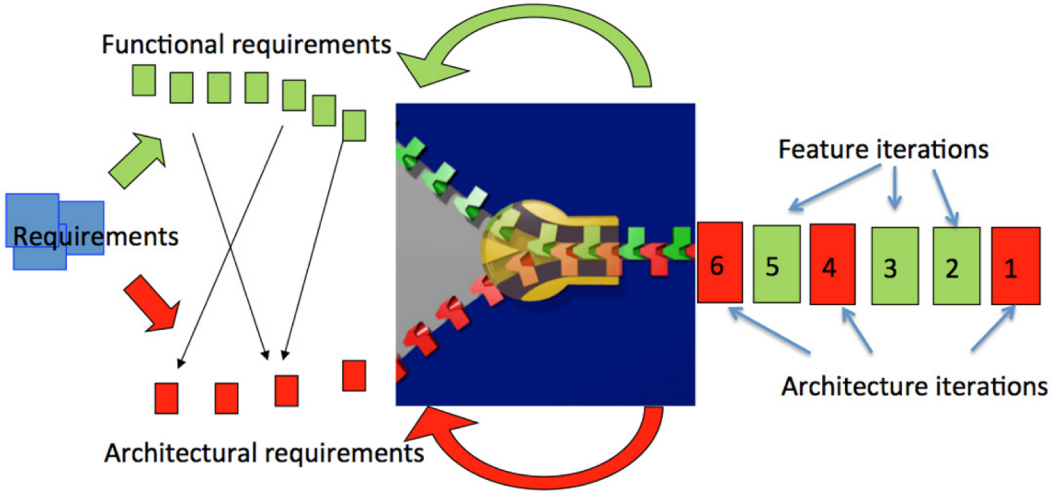


https://medium.com/@beatrix_66005/the-best-architectures-requirements-and-designs-emerge-from-self-organizing-teams-8b54ebc4c6b0

The Zipper Model

How to Agilely Architect an Agile Architecture

by Stephany Bellomo, Philippe Kruchten, Robert L. Nord, and Ipek Ozkaya



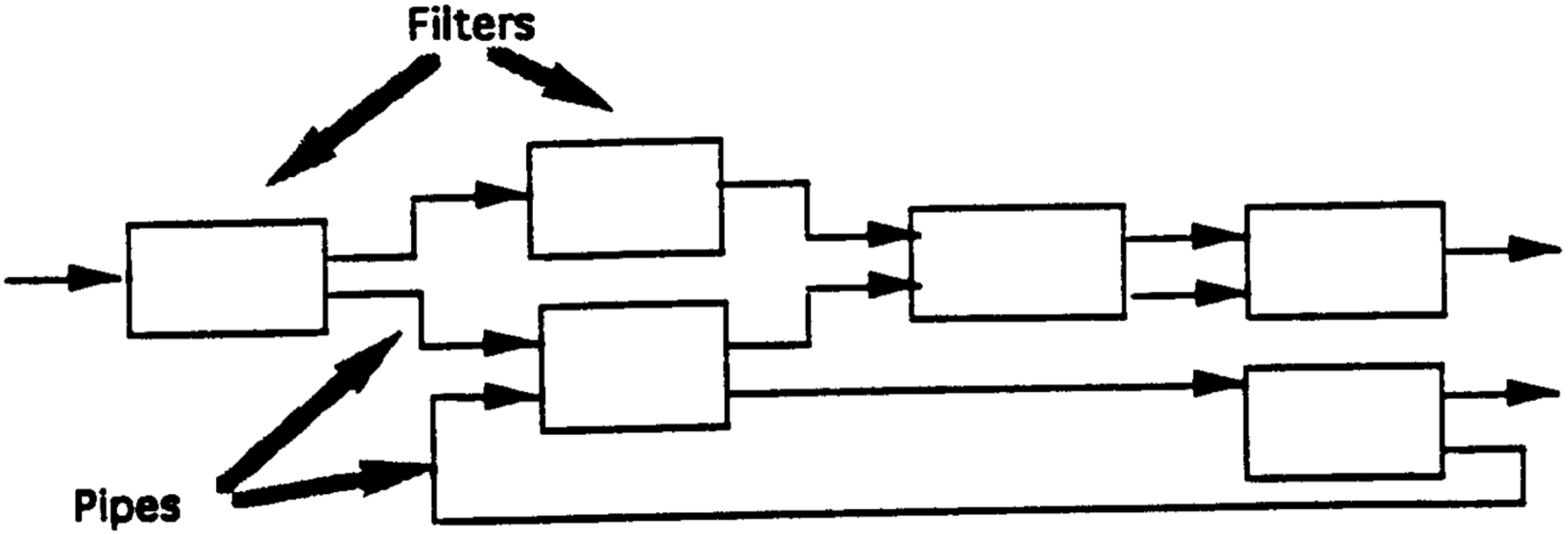
Common Architectural Styles



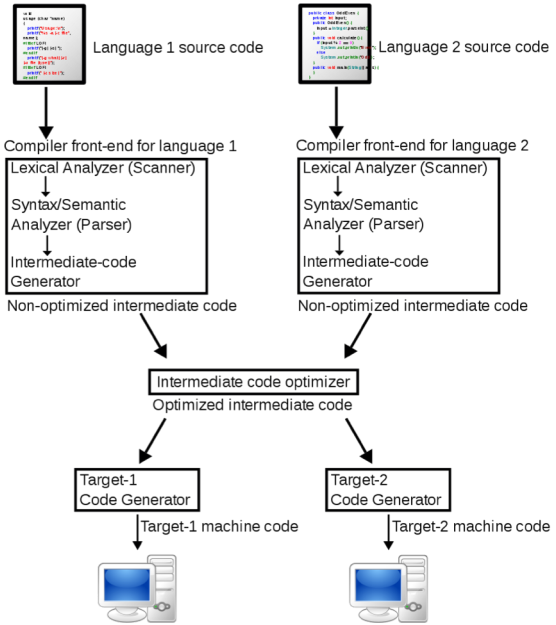


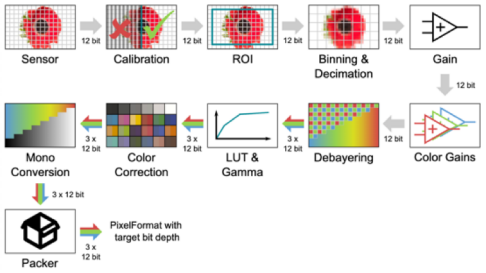

https://www.thespruce.com/top-architectural-styles-4802083

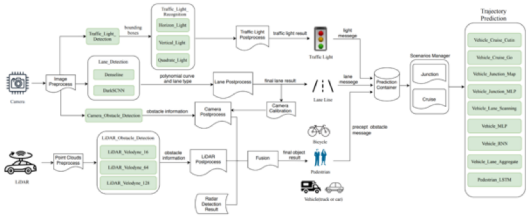
Pipes and Filters

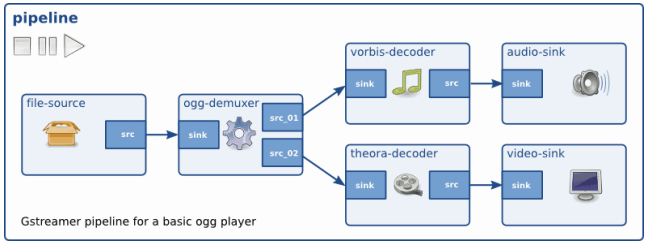


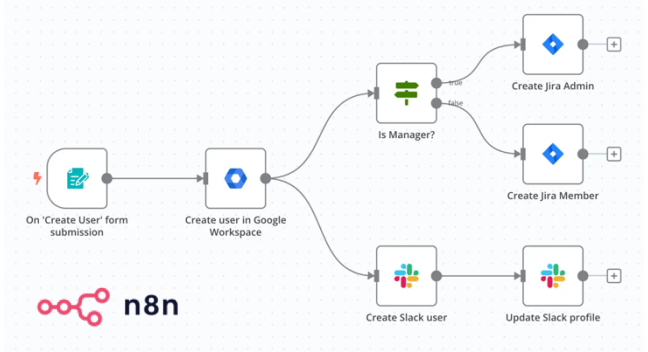
Pipes and Filters in the Wild



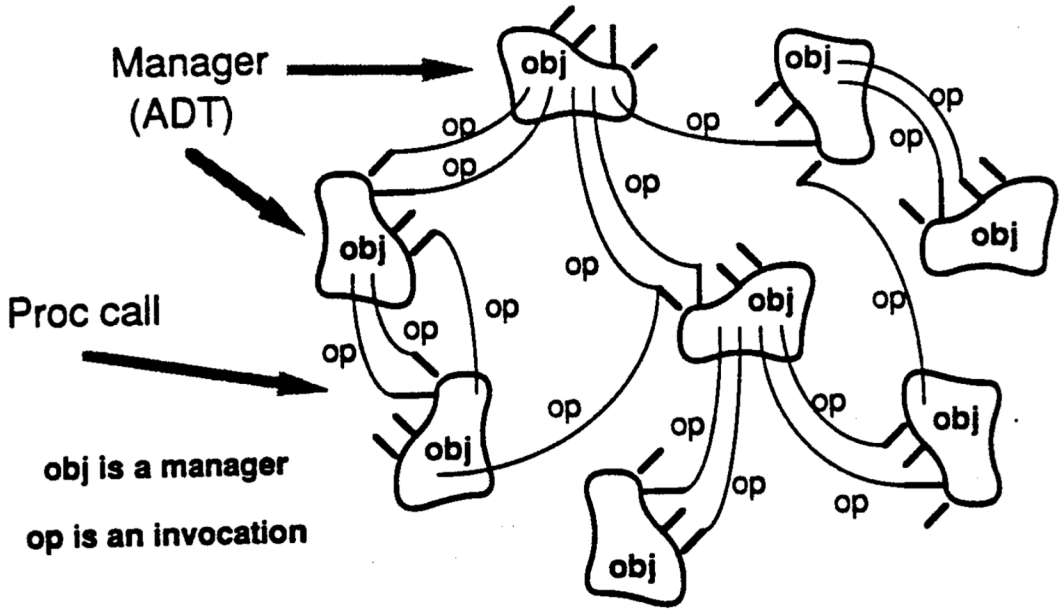




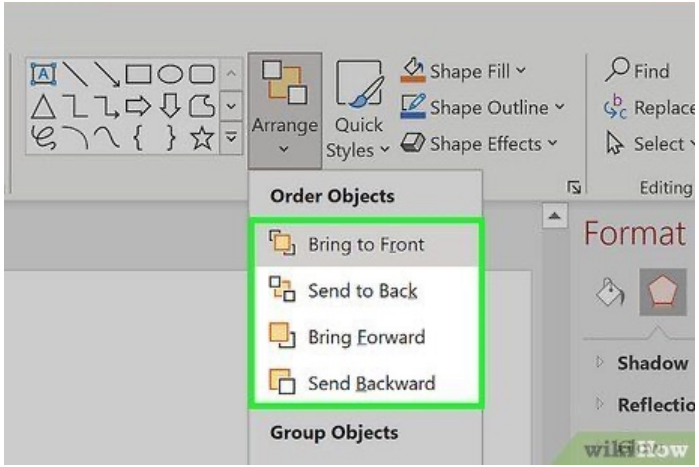


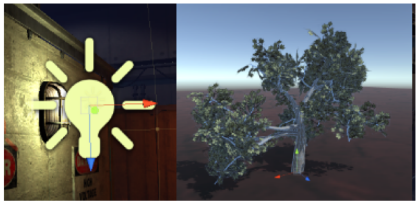


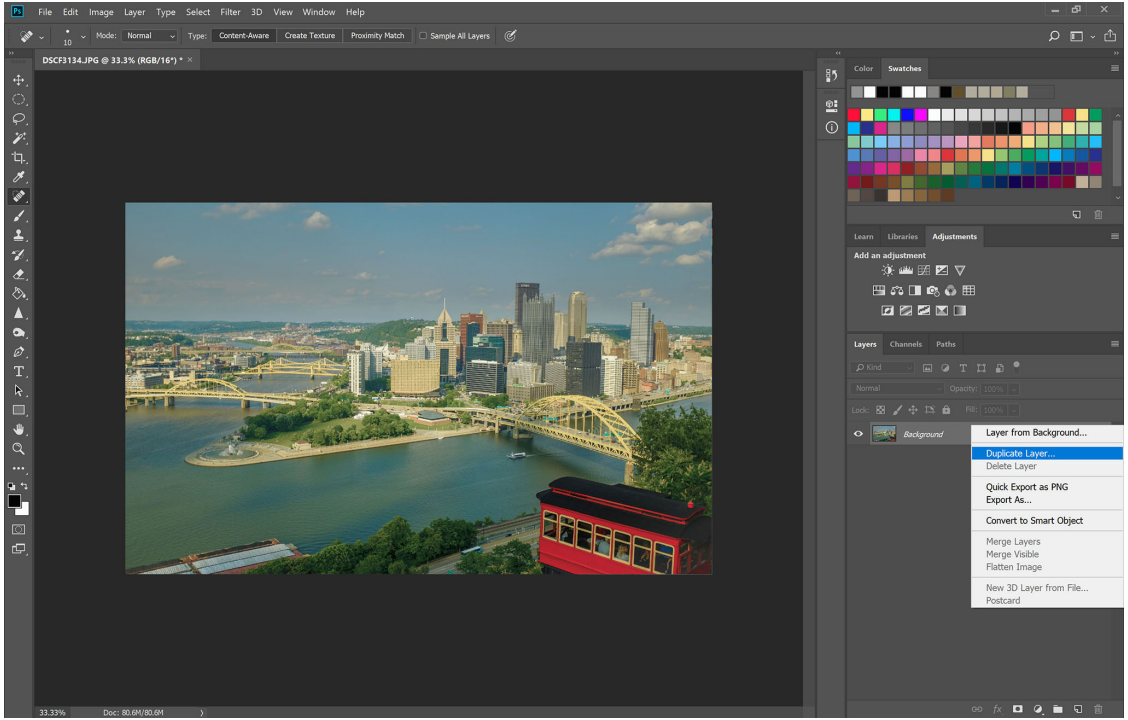
Object-Oriented Organization



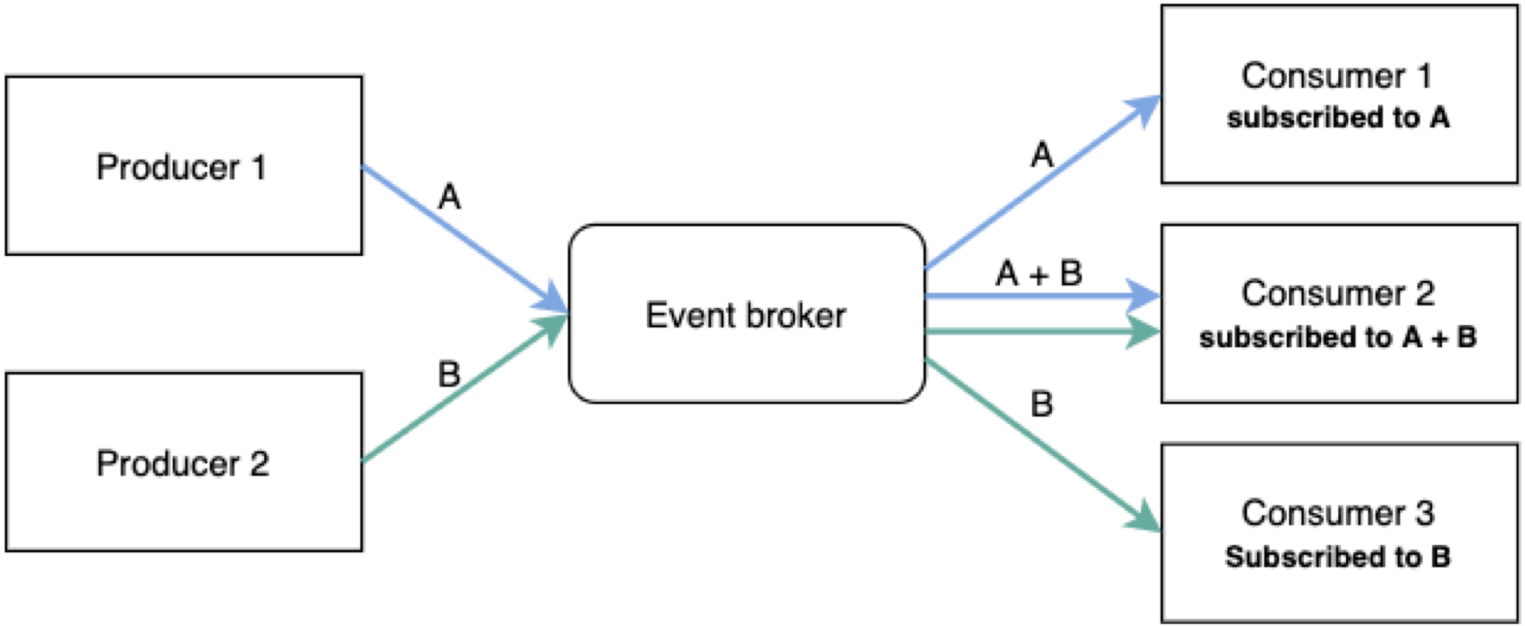
Object-Oriented Organization in the Wild



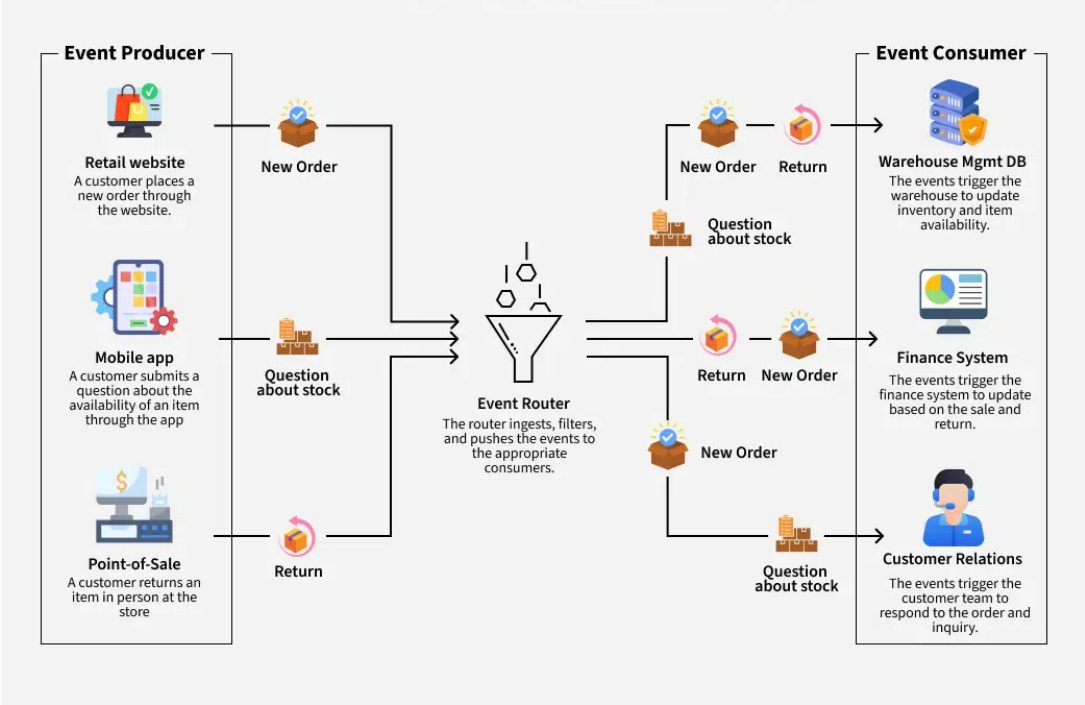




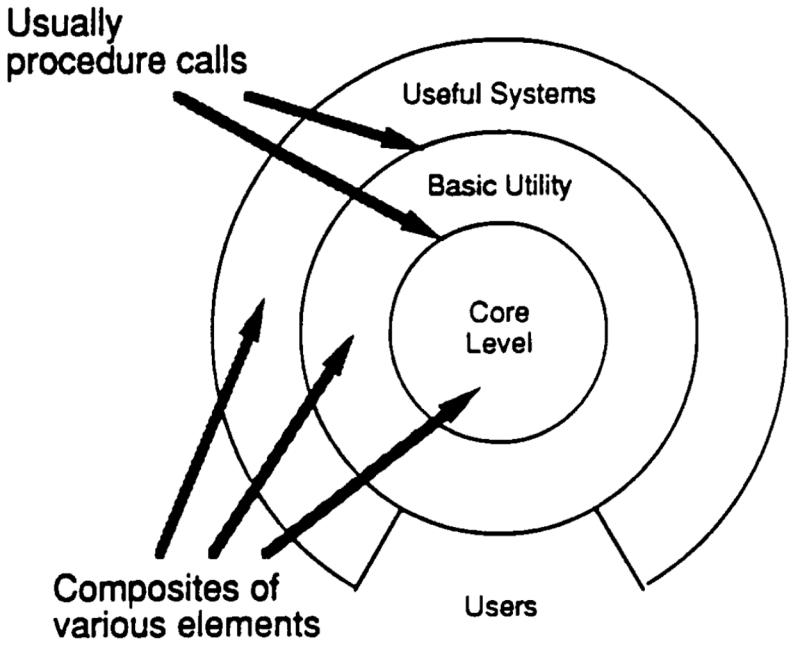
Event-Driven Architecture



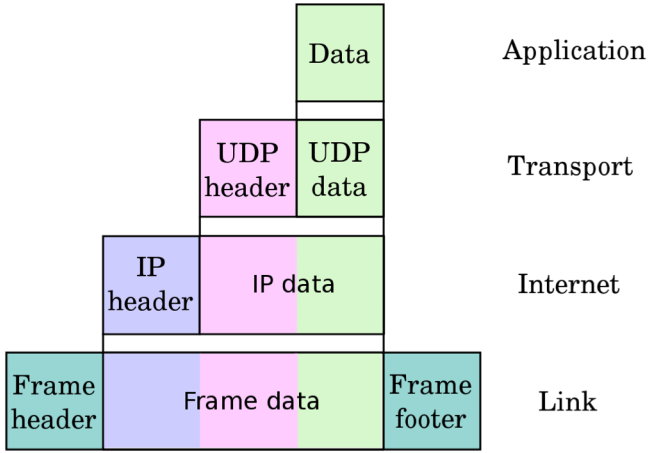
Event-Driven Architectures in the Wild

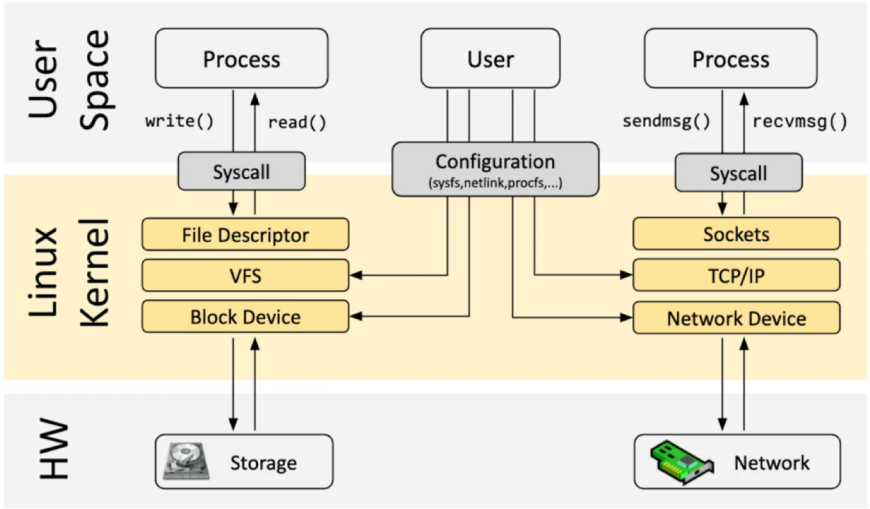


Layered Systems



Layered Systems in the Wild





Why Document Architecture?

- Blueprint for the system
  - Artifact for early analysis
  - Primary carrier of quality attributes
  - Key to post-deployment maintenance and enhancement
- Documentation speaks for the architect, both today and 20 years from today
  - As long as the system is built, maintained, and evolved according to its documented architecture
- Support traceability

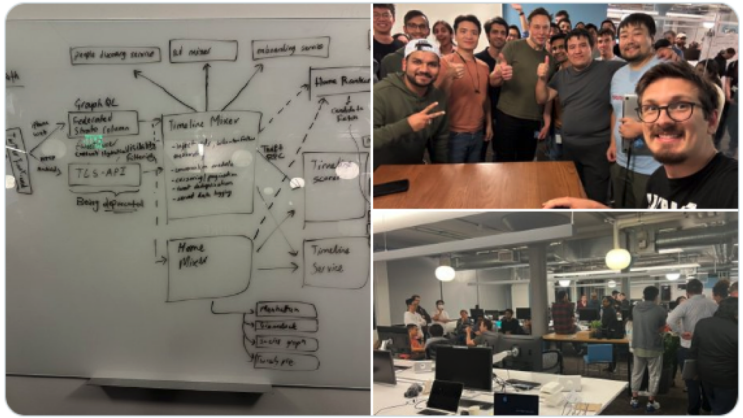
Elon Musk ✓
@elonmusk

Btw, I'd like to apologize for Twitter being super slow in many countries.
App is doing >1000 poorly batched RPCs just to render a home timeline!

1:00 PM · Nov 13, 2022

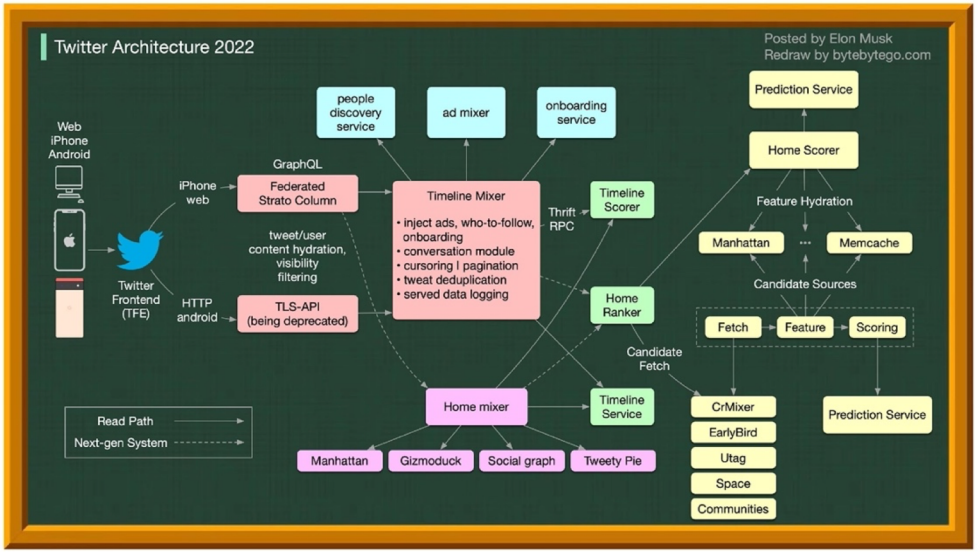
Elon Musk ✓
@elonmusk

Just leaving Twitter HQ code review



4:28 AM · Nov 19, 2022

36.9K Retweets **16.1K** Quote Tweets **464K** Likes



Guidelines for selecting a notation

- Suitable for purpose
- Often visual for compact representation
- Usually, boxes and arrows
- UML possible (semi-formal), but possibly constraining
  - Note the different abstraction level – Subsystems or processes, not classes or objects
- Formal notations available
- Decompose diagrams hierarchically and in views
- Always include a legend
- Define precisely what the boxes mean
- Define precisely what the lines mean
- Do not try to do too much in one diagram
  - Each view of architecture should fit on a page
  - Use hierarchy