Introduction to Software Architecture

17-313: Foundations of Software Engineering

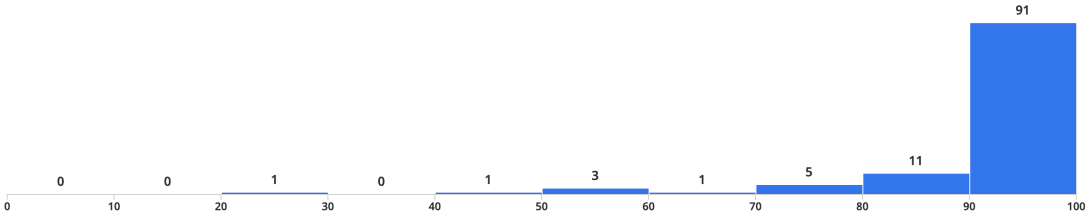
https://cmu-313.github.io

Michael Hilton and **Chris Timperley**

Fall 2025

Administrivia

- **Regrades:** “requests can be submitted via Gradescope. The regrade period is open for one week after grades have been released for a particular assignment.”
- P1B Reopened for Late Submissions (needed for feedback!)
- **P1B Score Distribution:**



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

Outline

- Views and Abstraction
- Case Study: Autonomous Vehicles
- Software Architecture
  - Definitions, Importance
  - Software Design vs. Software Architecture
- Architecting Software
  - Integrating Architectural Decisions into the SW Development Process
  - Common Software Architectures
  - Documentation

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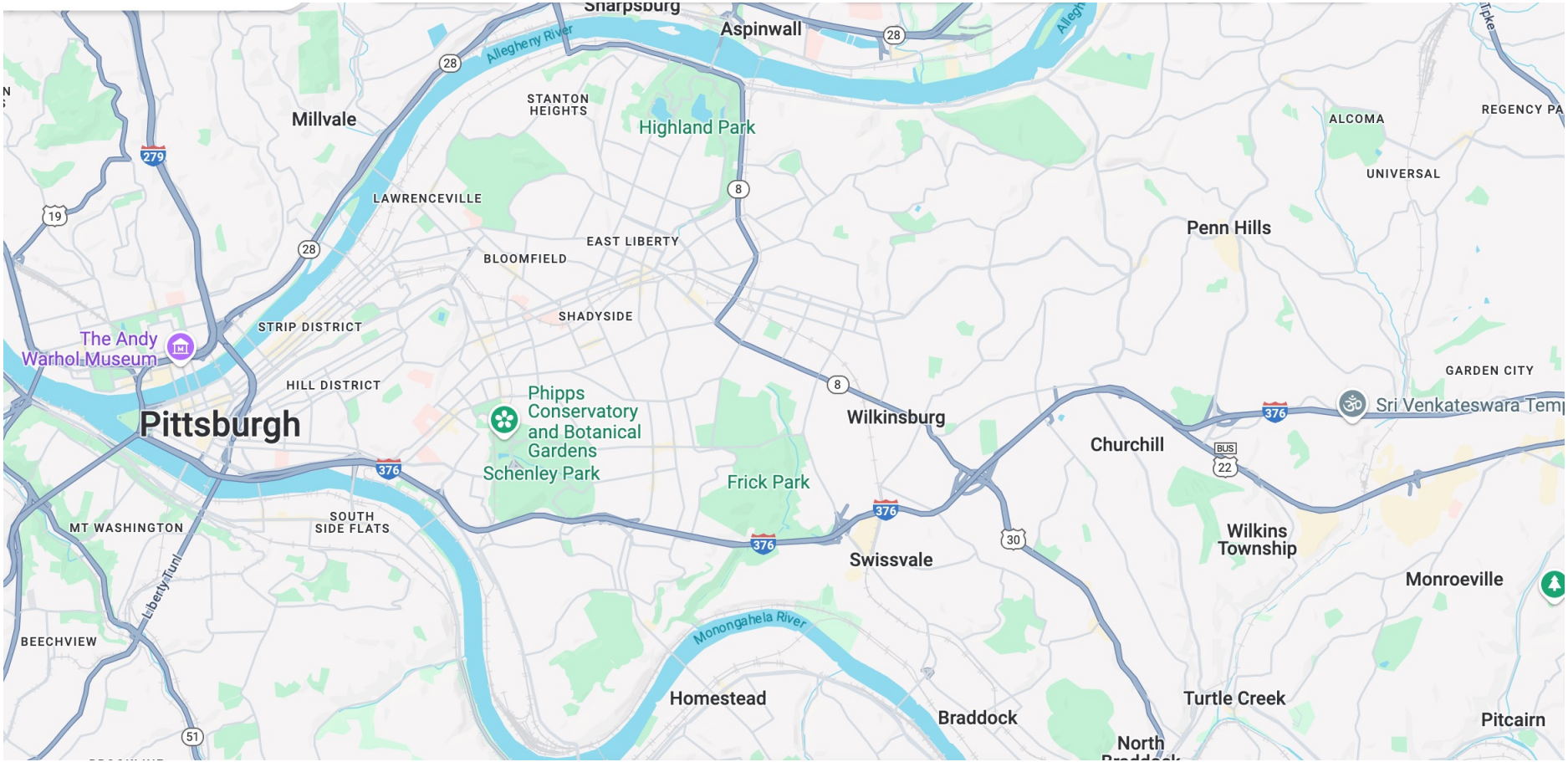
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The Andy Warhol Museum
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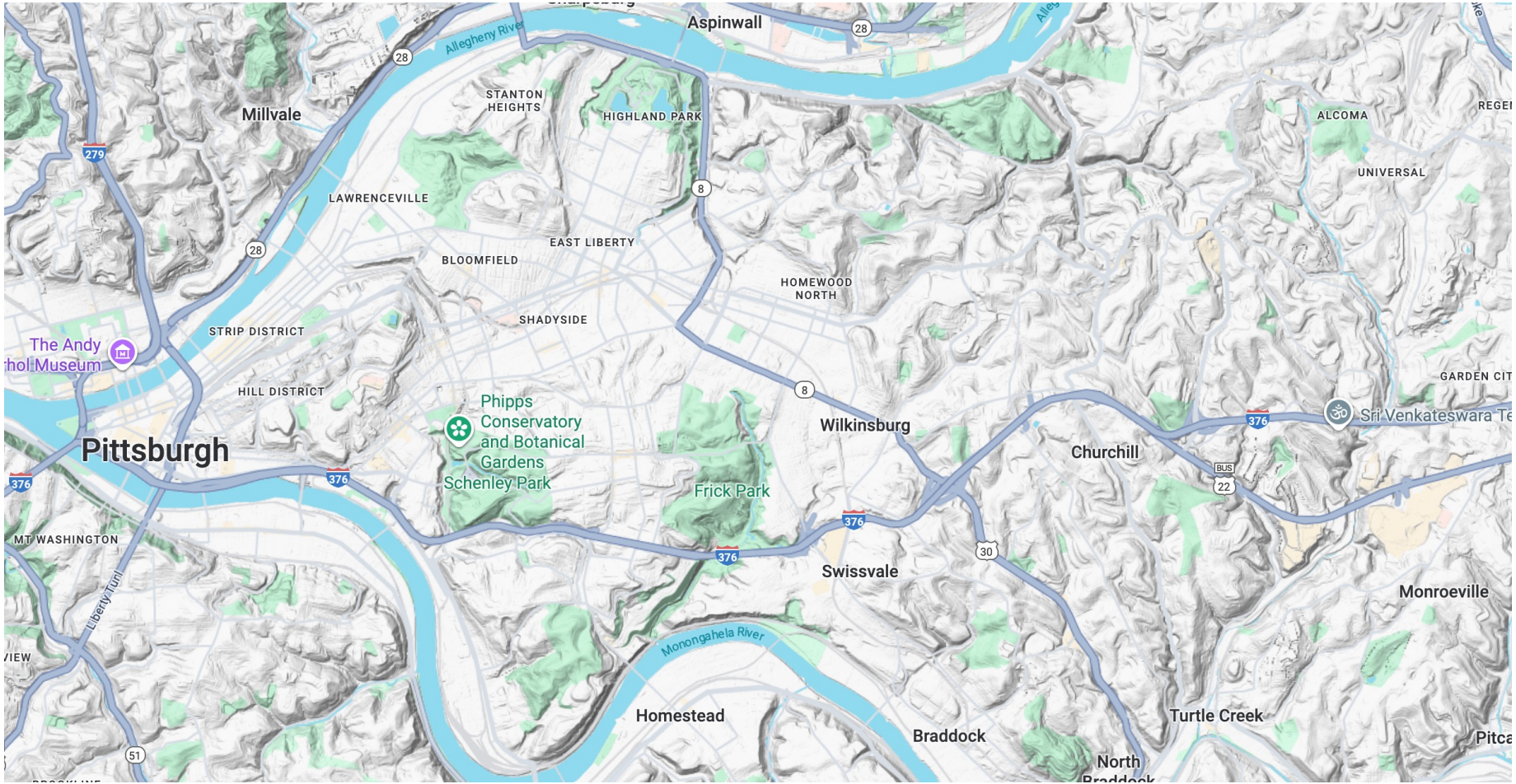
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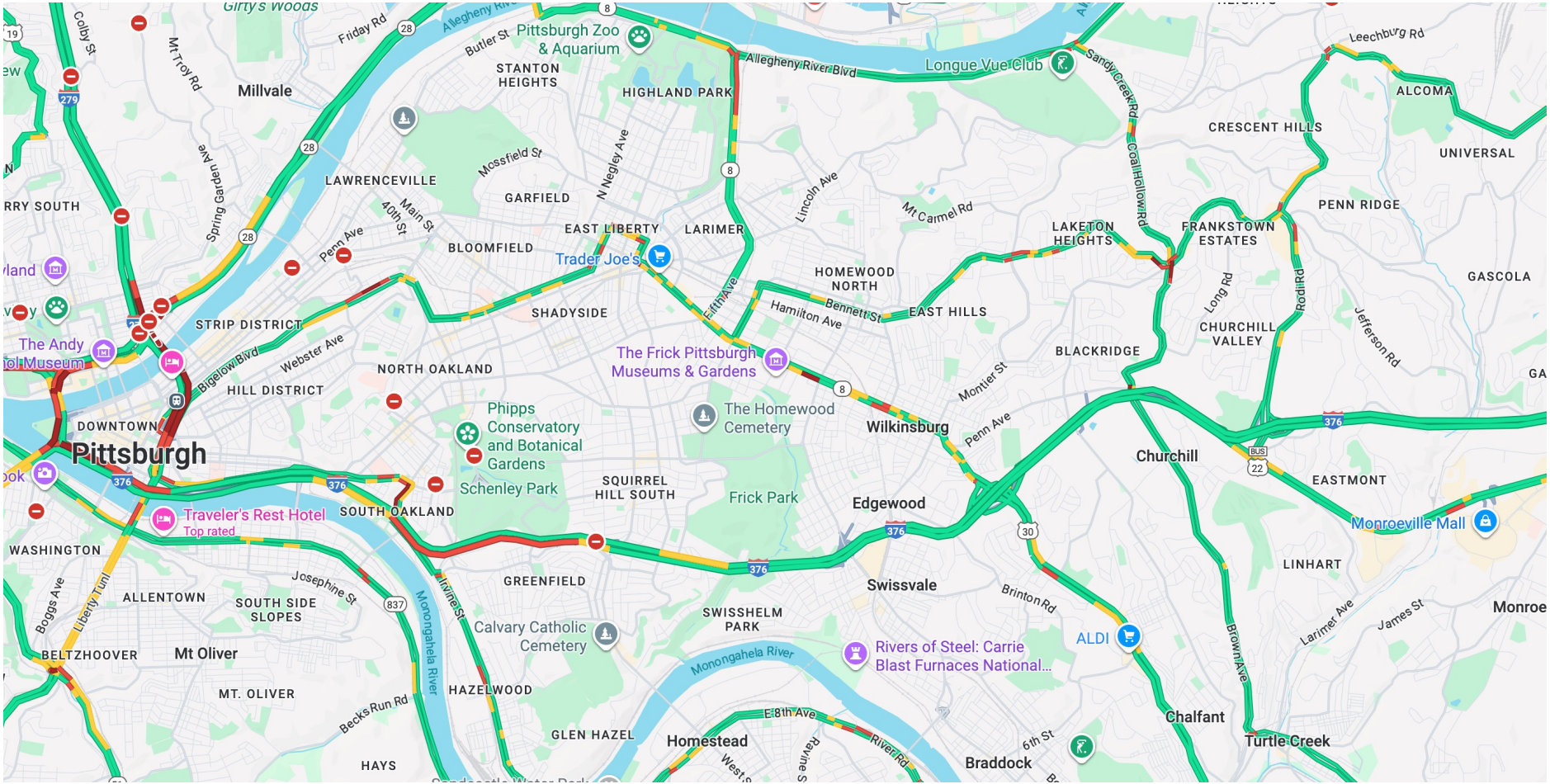
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Edgewood
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Top rated
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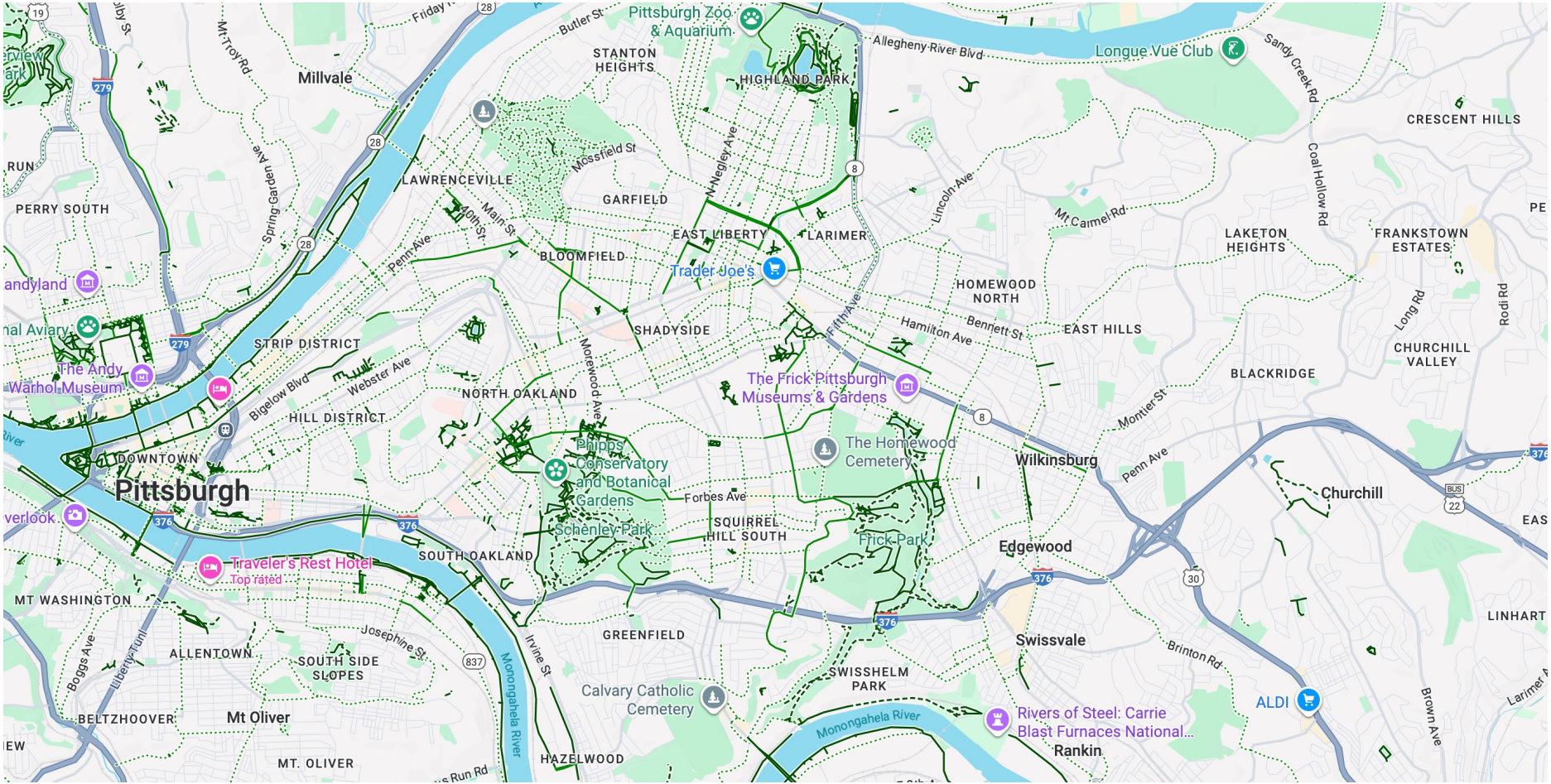
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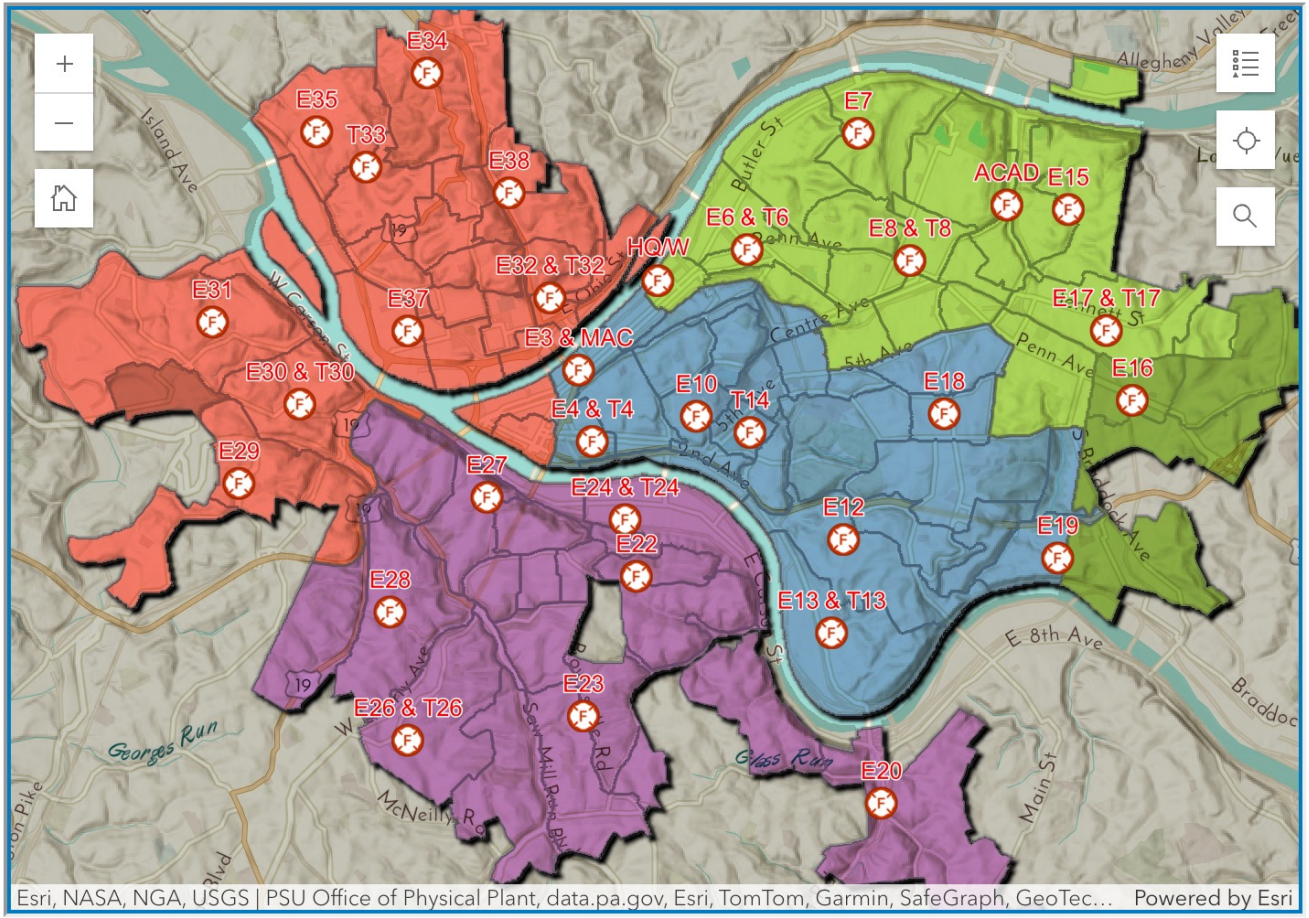
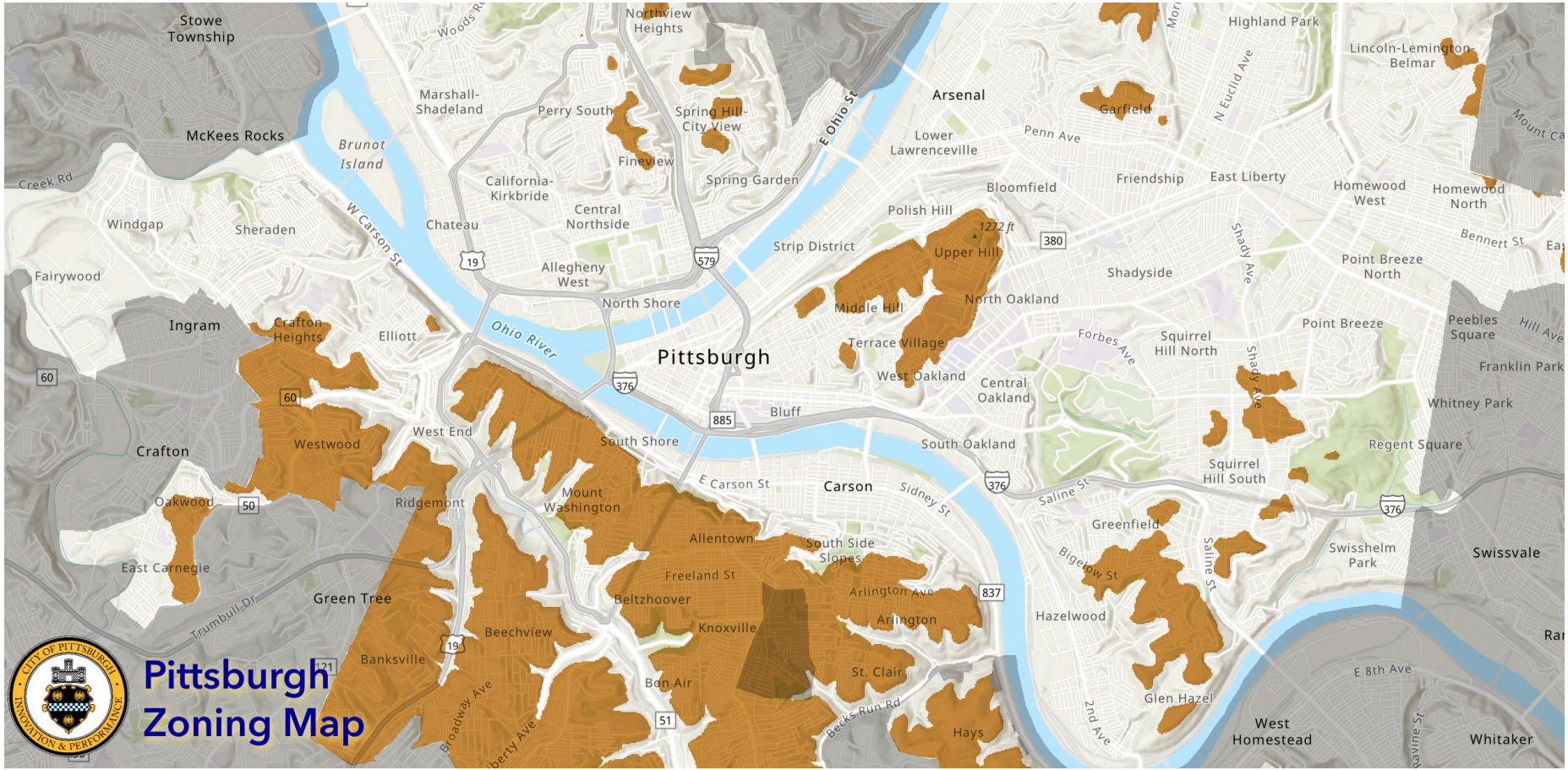


Fire Station

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
Central Northside
Allegheny Center
Allegheny West
Strip District
Polish Hill
Bloomfield
Upper Hill
Bedford Dwellings
Middle Hill
North Oakland
Shadyside
UPMC Shadyside
Acrisure Stadium
North Shore
Point State Park
Downtown Pittsburgh
Crawford-Roberts
Terrace Village
University of Pittsburgh
Carnegie Mellon University
Squirrel Hill North
West Oakland
Central Oakland
The Bob O'Connor Golf Course at Schenley Park
Schenley Park
Duquesne University
Bluff
South Shore
South Oakland
Carson
Mount
Allentown
South Side Slopes
Greenfield


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
Squirrel Hill South
Oakwood
Ridgemont
Mount Washington
E Carson St
Carson
Sidney St
Saline St
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
E 8th Ave
Bon Air
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**

Outline

- Views and Abstraction
- **Case Study: Autonomous Vehicles**
- Software Architecture
  - Definitions, Importance
  - Software Design vs. Software Architecture
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Case Study: Autonomous Vehicle Software

Case Study: Apollo

Check out the **“side pass”** feature from the video:

Case Study: Apollo

Goal: Try to have a high-level understanding of how the **side pass feature** is built and integrated into the system.

Let’s explore the code and the documentation of Apollo to find parts associated with the **side pass feature**:

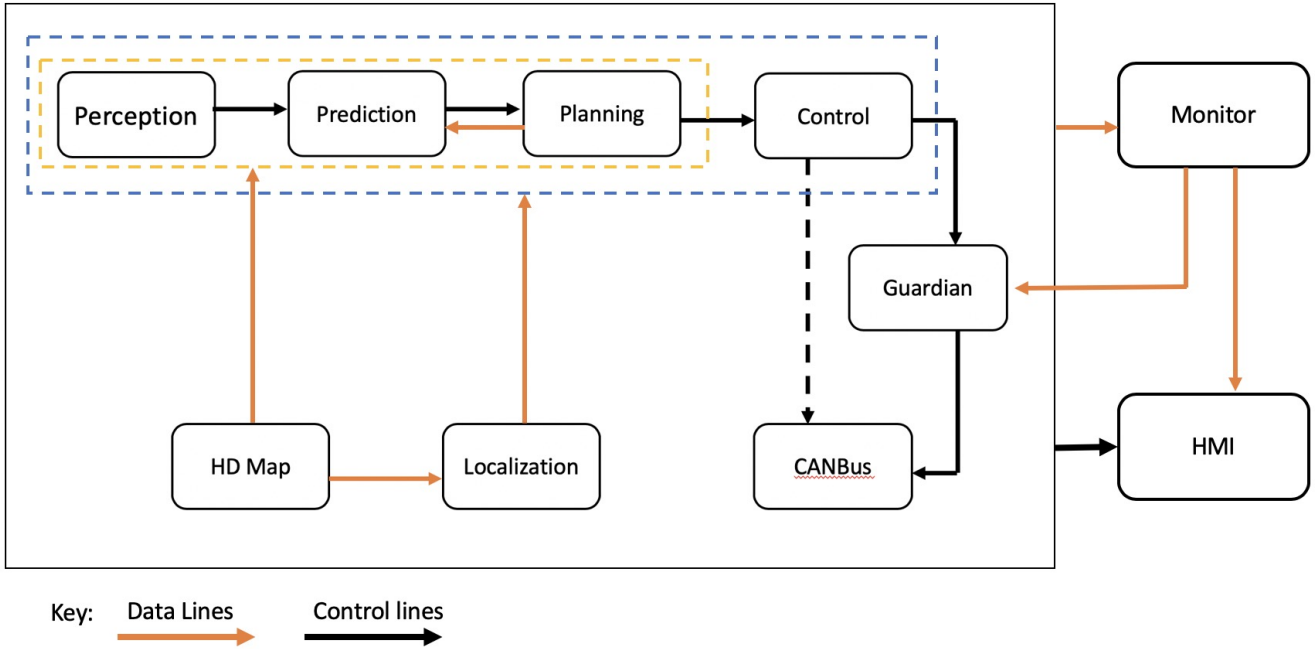
Source: https://github.com/ApolloAuto/apollo
Doc: https://hidetoshi-furukawa.github.io/apollo-doxygen/index.html

Activity: Apollo

Discuss in teams of 3 - 4 on what parts are associated with the **side pass feature** based on the 6 diagrams in the handout:

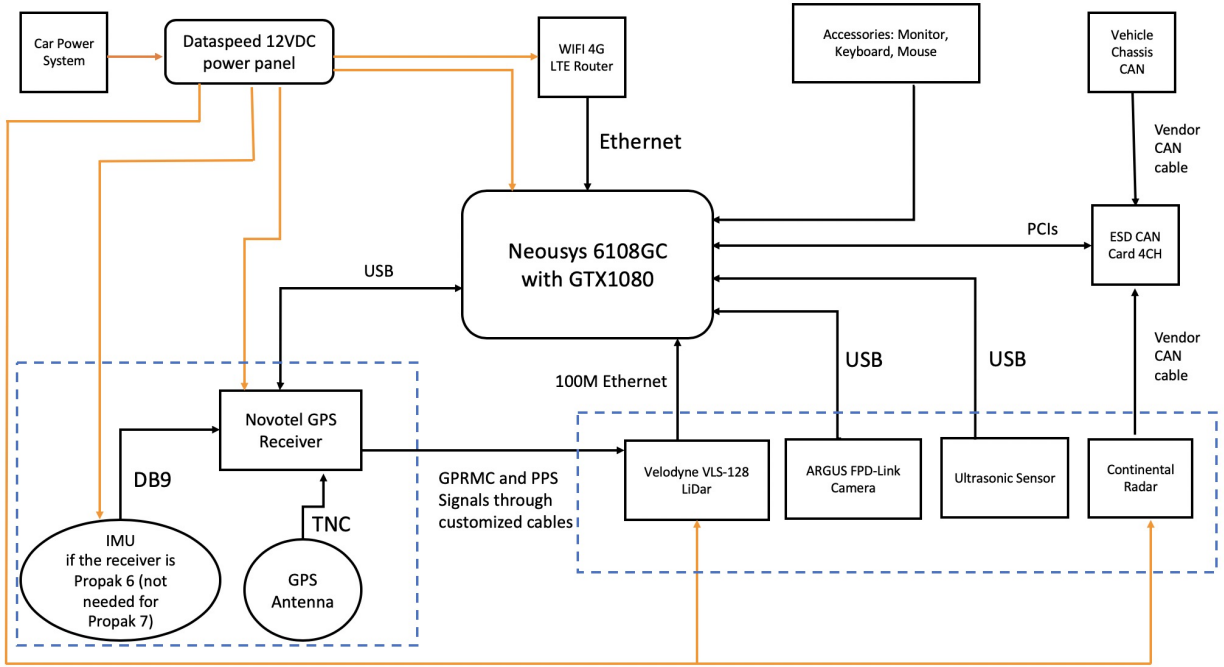
- circle components that you think implement this feature

Apollo Software Architecture



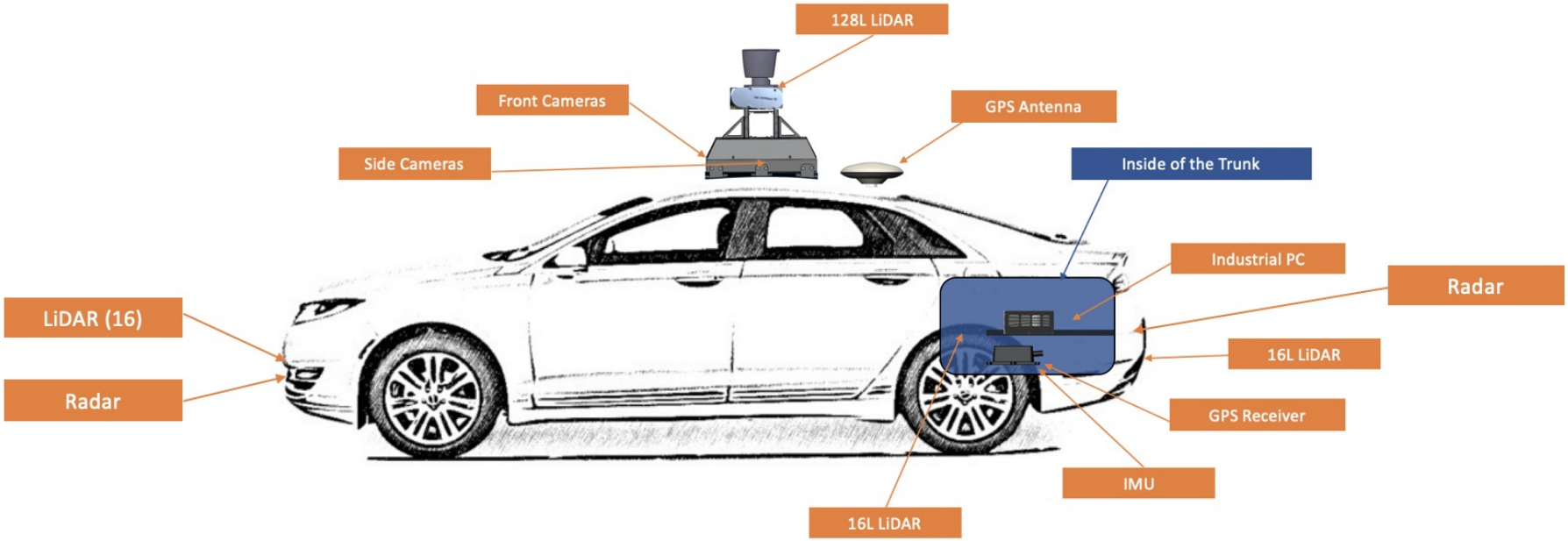
https://github.com/ApolloAuto/apollo/blob/v6.0.0/docs/specs/Apollo_5.5_Software_Architecture.md

Apollo Hardware Interface Architecture



https://github.com/ApolloAuto/apollo/blob/v6.0.0/README.md

Apollo Hardware / Vehicle Overview



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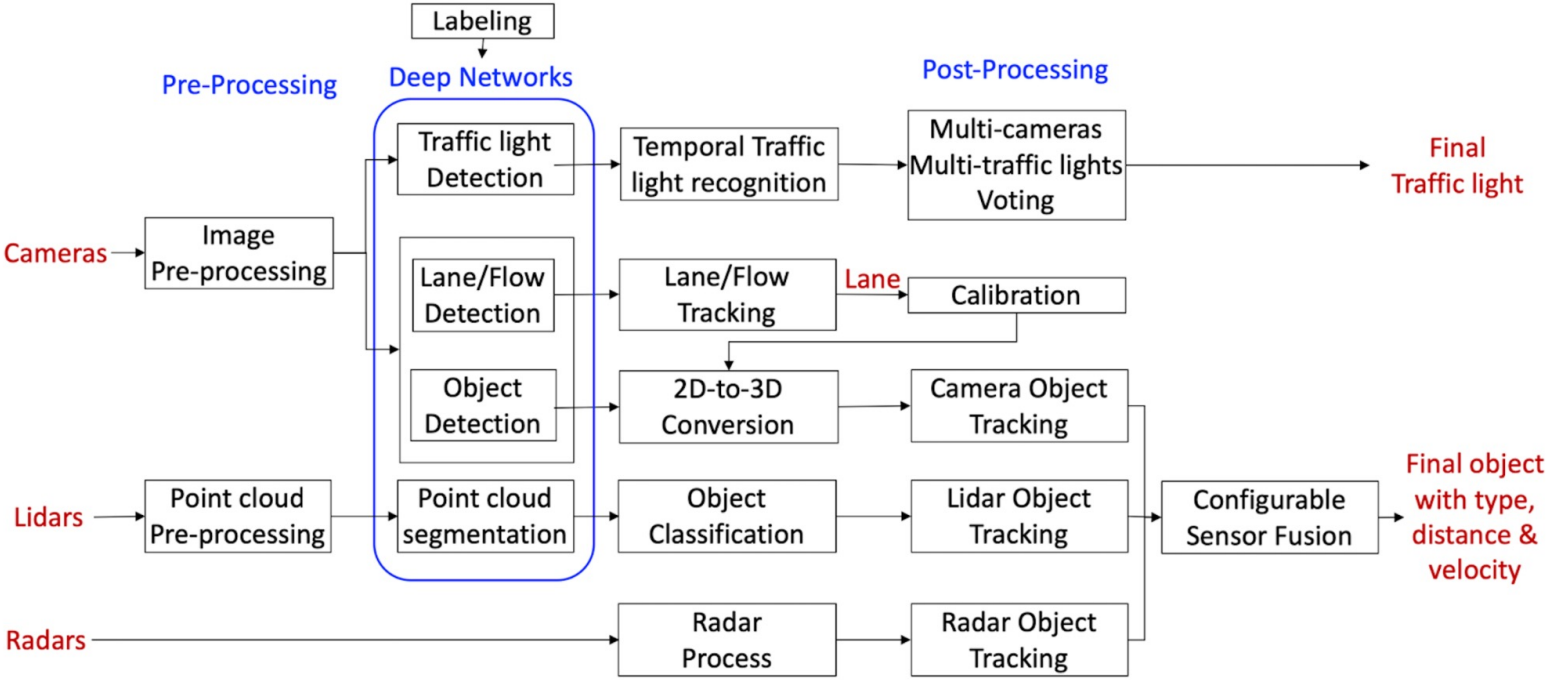
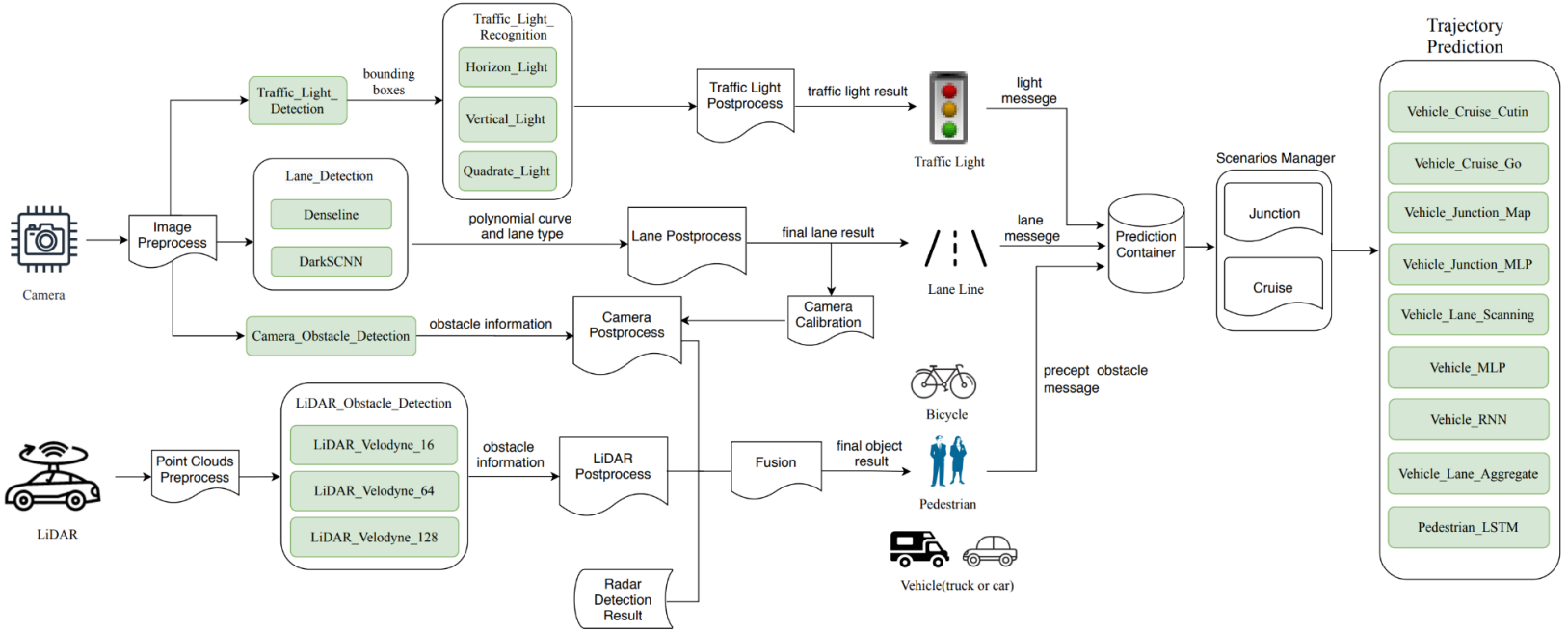
Apollo Perception Module



Apollo Machine Learning (ML) Models



Source: Zi Peng, Jinqiu Yang, Tse-Hsun (Peter) Chen, and Lei Ma. 2020. A First Look at the Integration of Machine Learning Models in Complex Autonomous Driving Systems: A Case Study on Apollo. In Proceedings of the 28th ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE '20), https://doi.org/10.1145/ 3368089.3417063

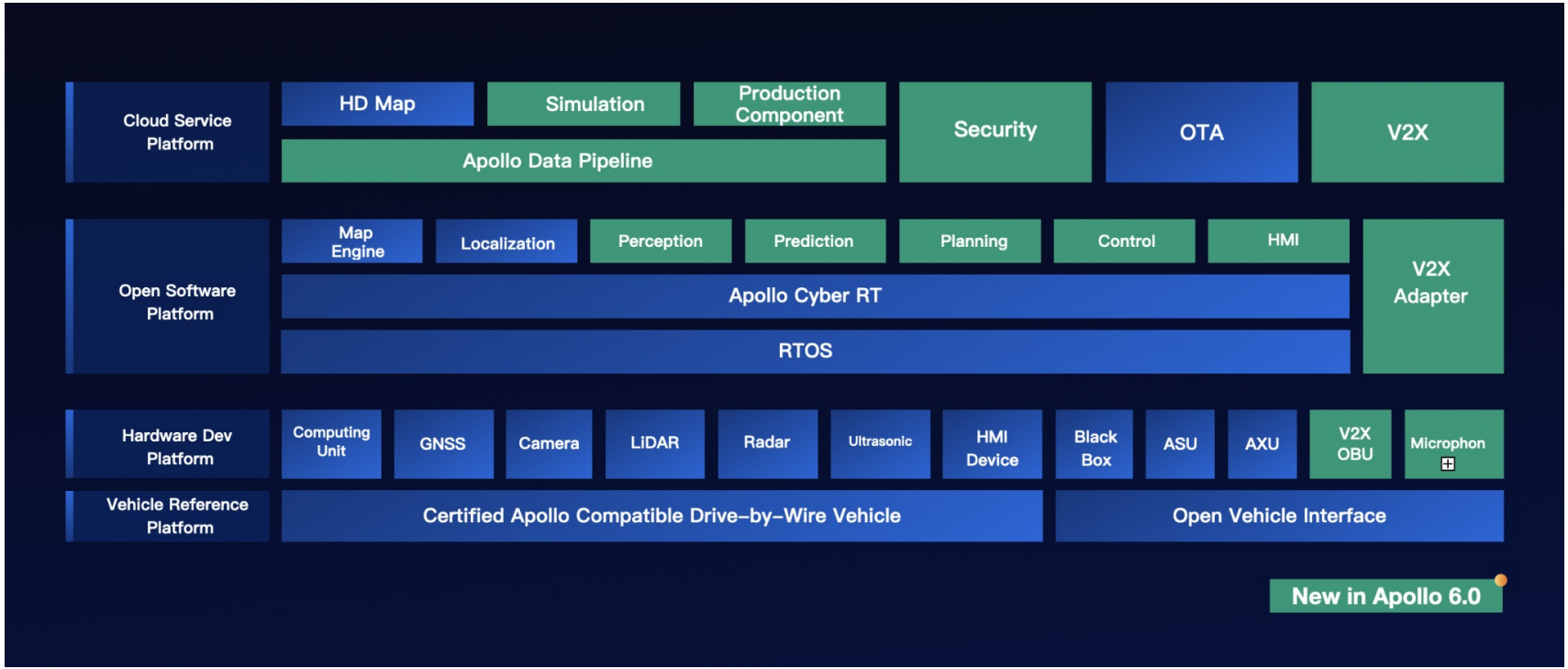
Apollo Software Stack

Cloud Service Platform	HD Map	Simulation	Data Platform	Security	OTA	DuerOS	Volume Production Service Components		V2X Roadside Service
Open Software Platform	Map Engine	Localization	Perception	Planning	Control	End-to-End	HMI		V2X Adapter
	Apollo Cyber RT Framework								
	RTOS								
Hardware Development Platform	Computing Unit	GPS/IMU	Camera	LiDAR	Radar	Ultrasonic Sensor	HMI Device	Black Box	Apollo Sensor Unit	Apollo Extension Unit	V2X OBU
Open Vehicle Certificate Platform	Certified Apollo Compatible Drive-by-wire Vehicle								Open Vehicle Interface Standard		

Major Updates in Apollo 3.5

https://github.com/ApolloAuto

Apollo Software Stack (Evolution)



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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!

Architectural Views

Abstraction

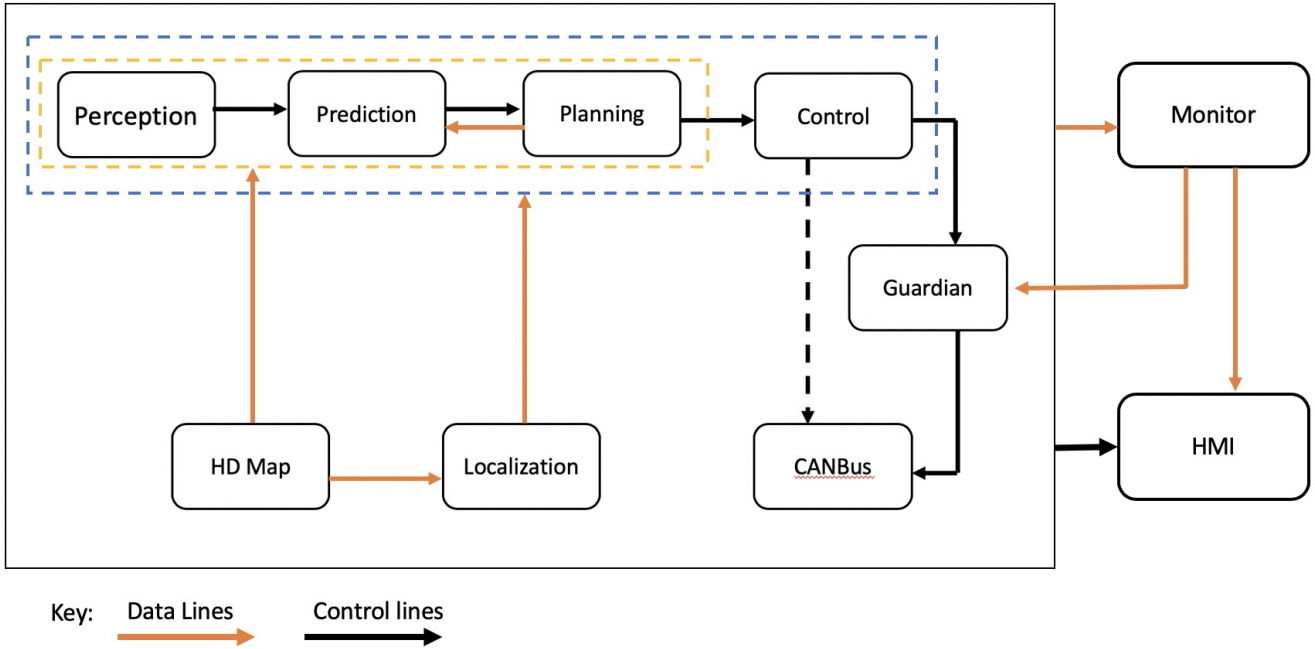
Elements: roles, responsibilities, behaviors, properties

Relationships between elements

Relationships to non-software elements

- Hardware, external systems

Apollo Software Architecture



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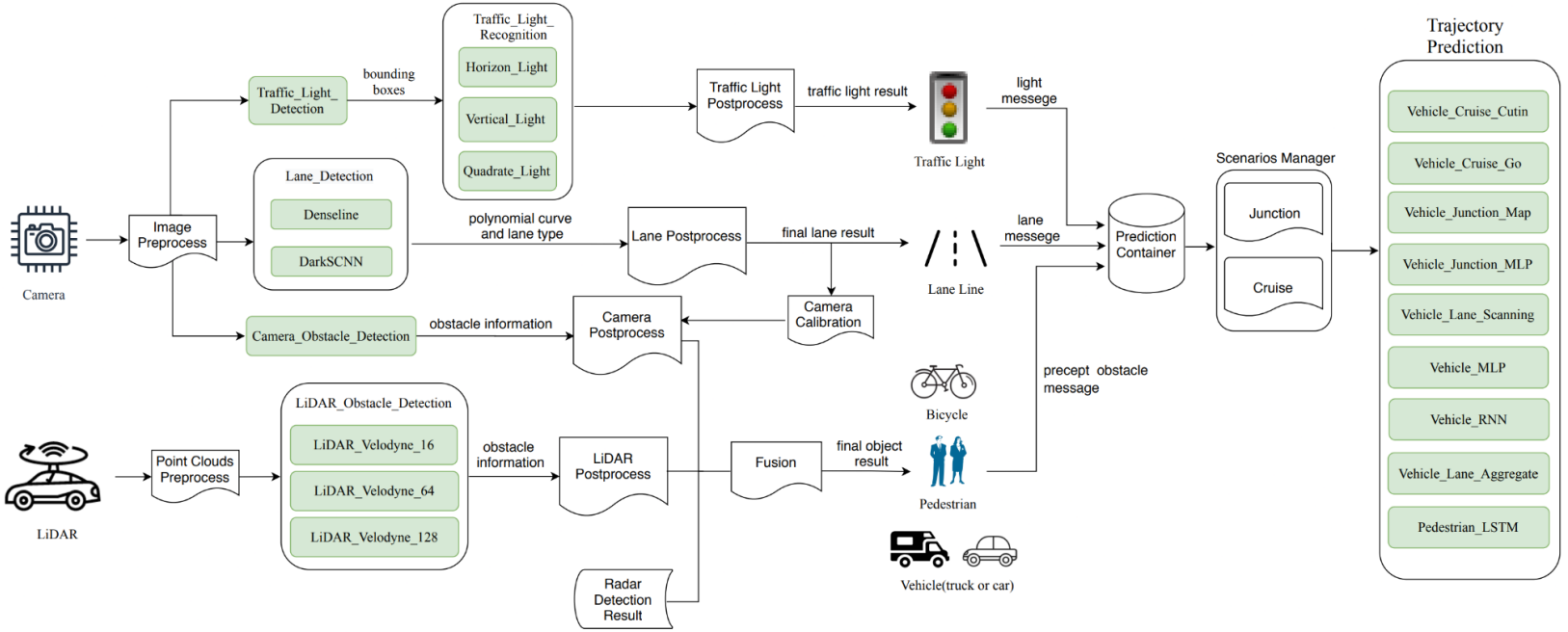

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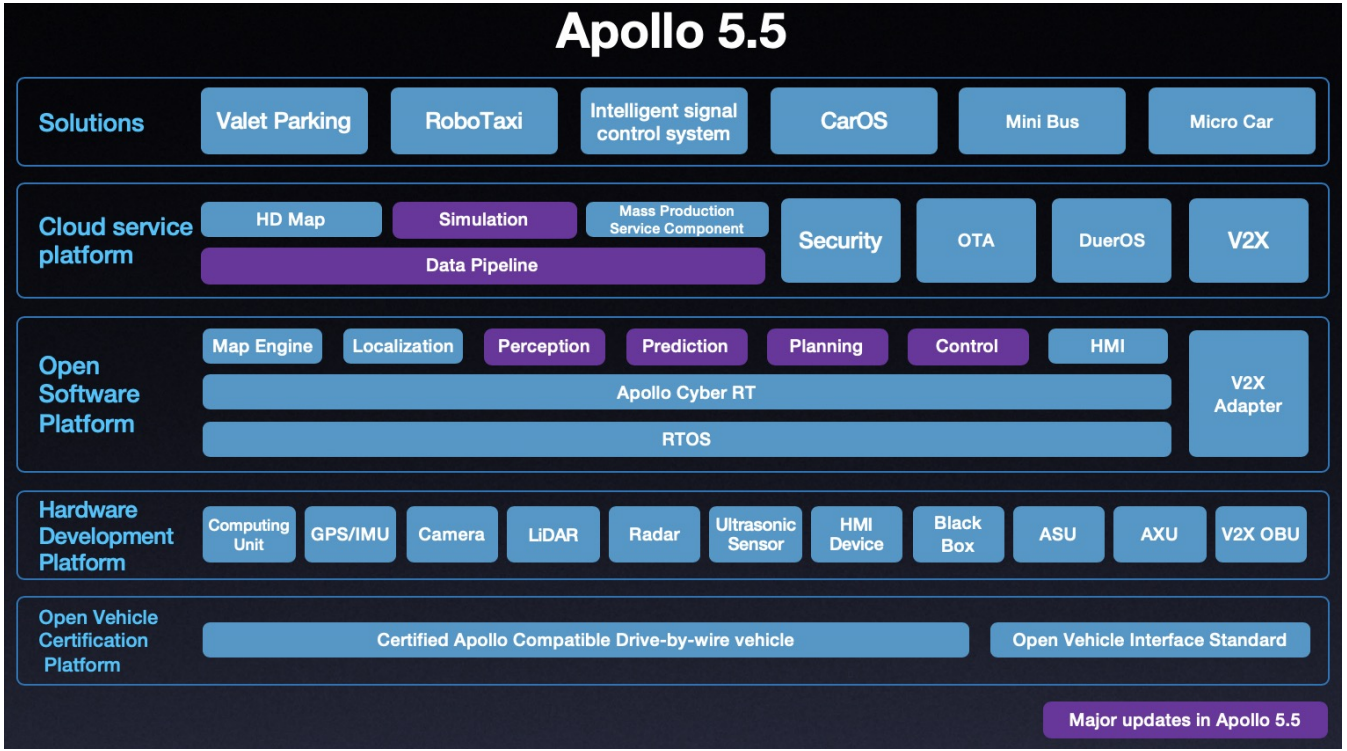
Why do we use Architectural Views?

- **Reduce complexity** through abstraction
- Facilitate internal and external **communication**
- Describe **design decisions**
- Prescribe **implementation constraints**

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

Apollo Software Stack



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- Relates to **organizational structure**

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Conway's Law

Company Structure **influences** Software Architecture

Why do we use Architectural Views?

- **Reduce complexity** through abstraction
- Facilitate internal and external **communication**
- Describe **design decisions**
- Prescribe **implementation constraints**
- Relates to organizational structure
- **Reason about** and manage **change**

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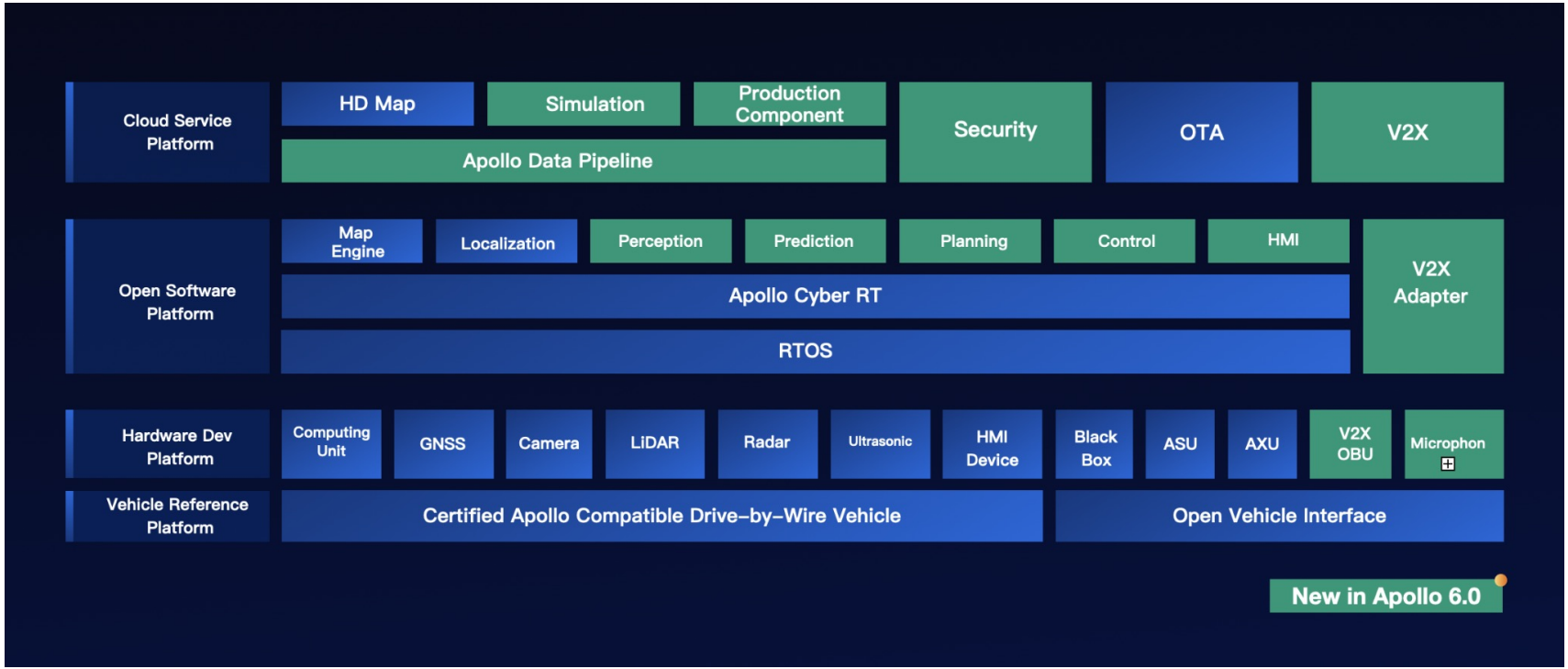
Apollo Software Stack (Evolution)



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

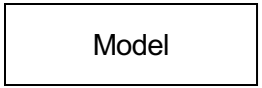
Design Questions

- 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?

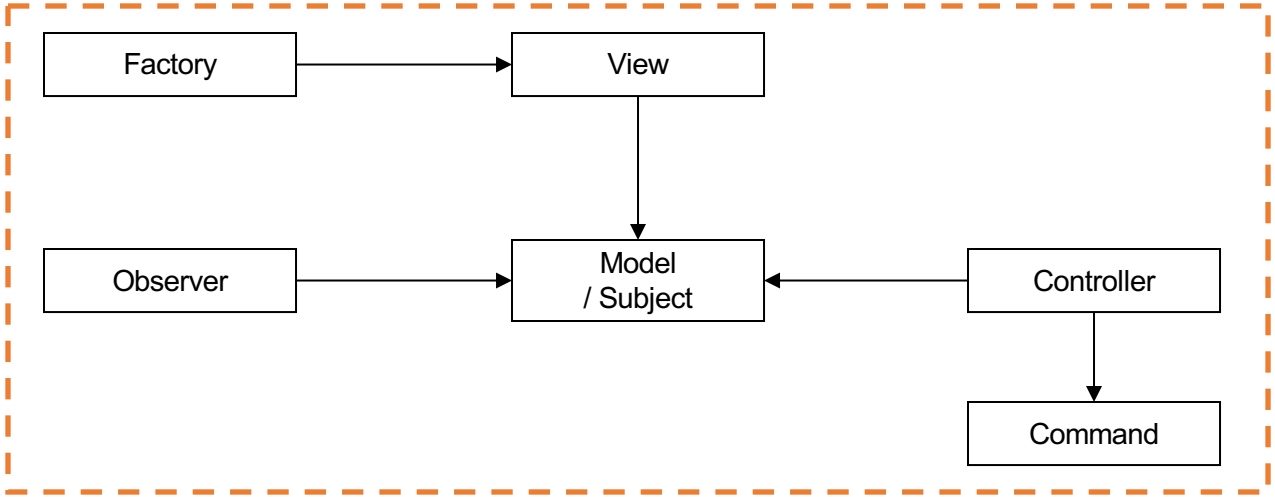
Architectural Questions

- 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?

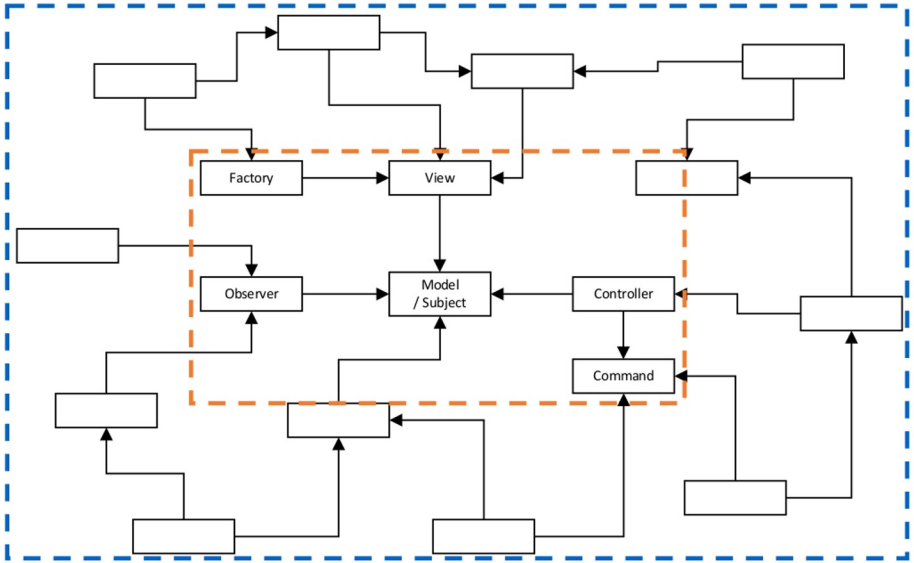
Objects



Objects → Design Patterns



Design Patterns



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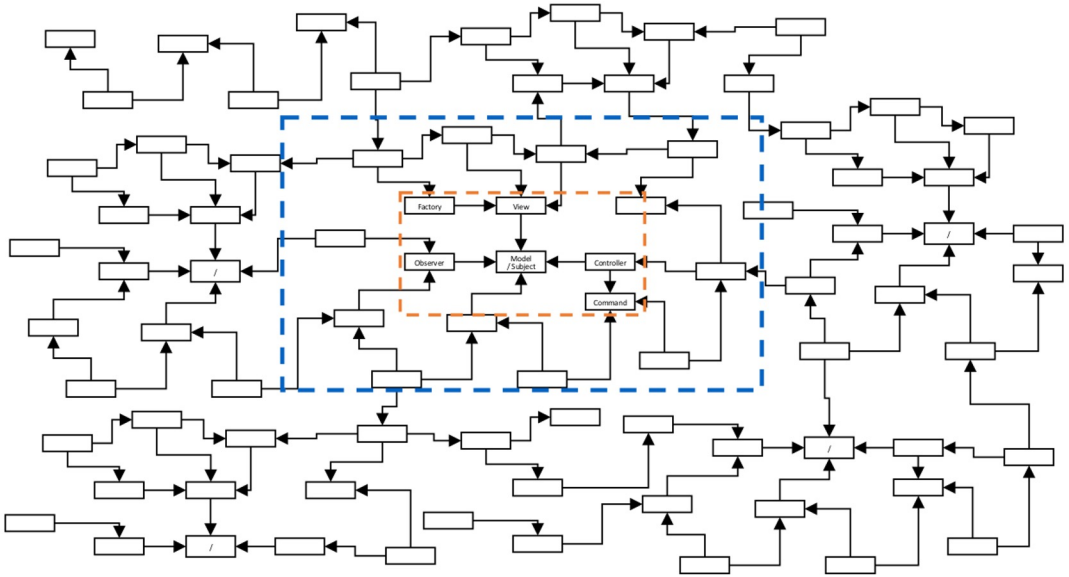
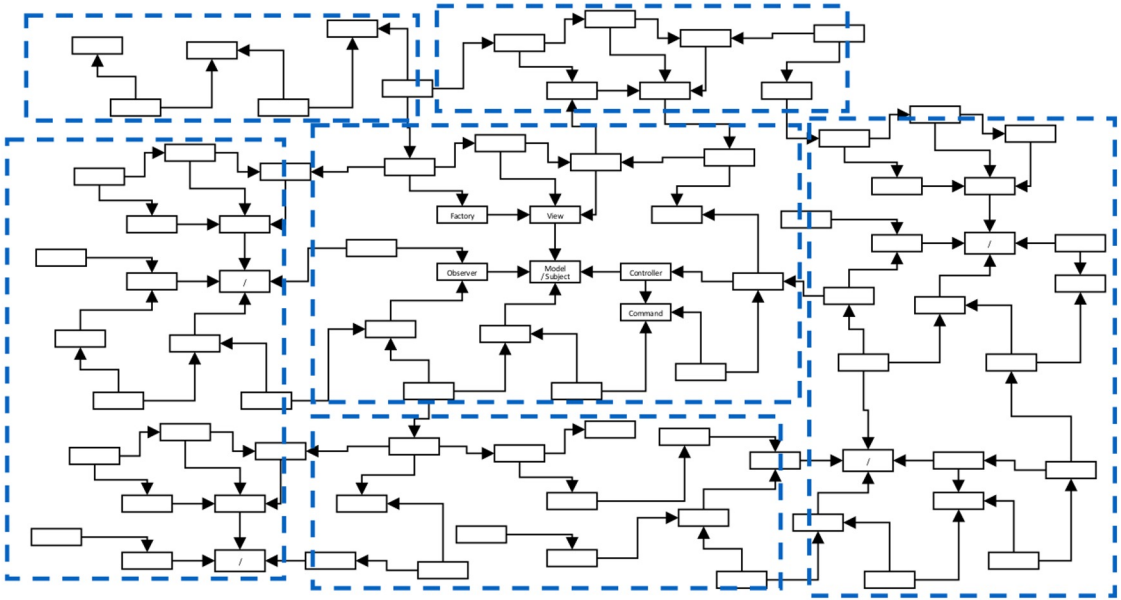


Architecture



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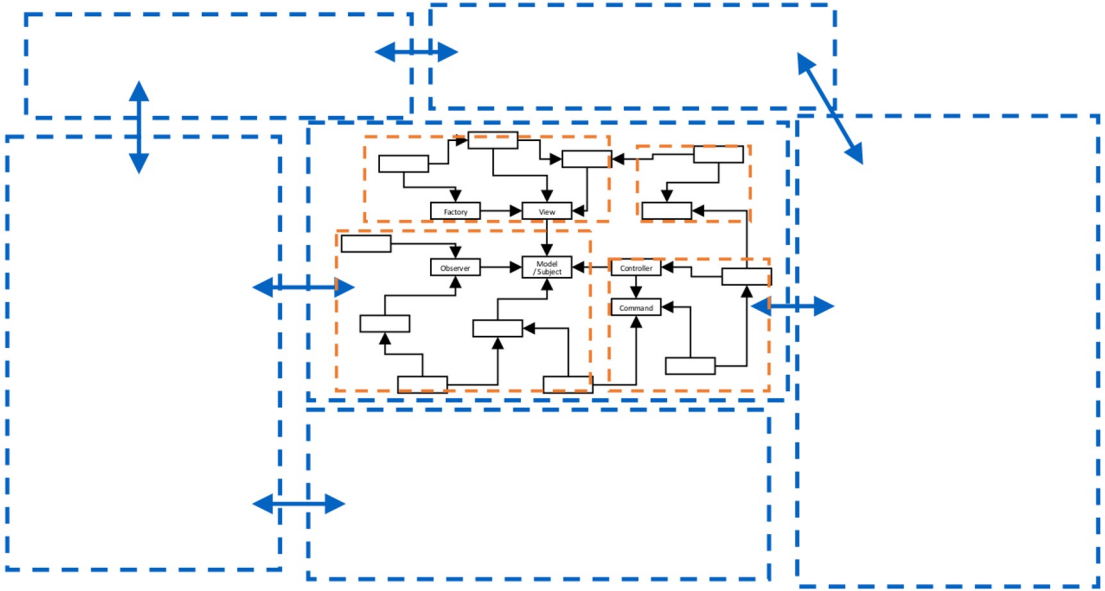

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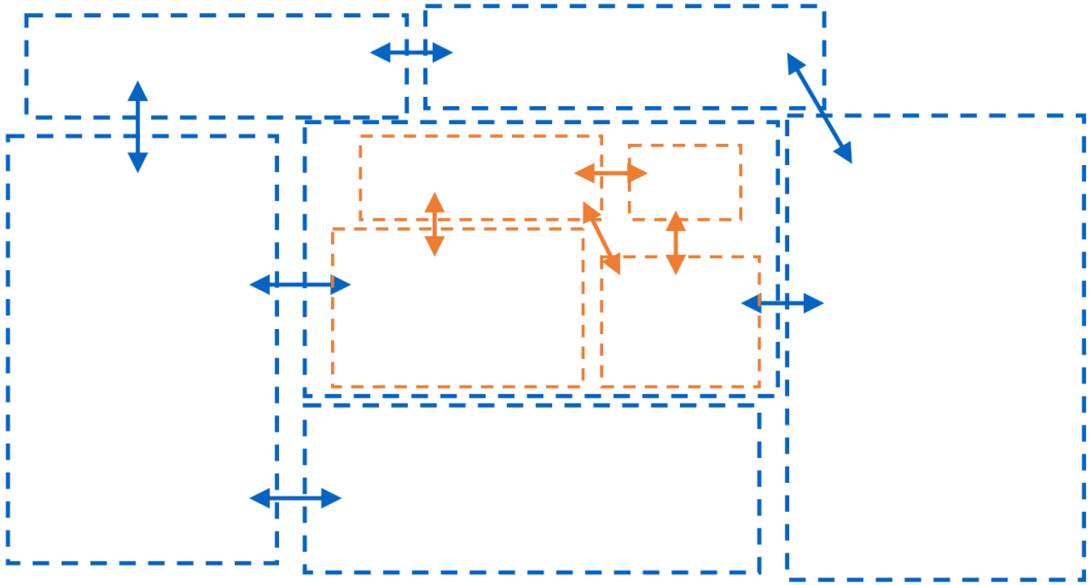

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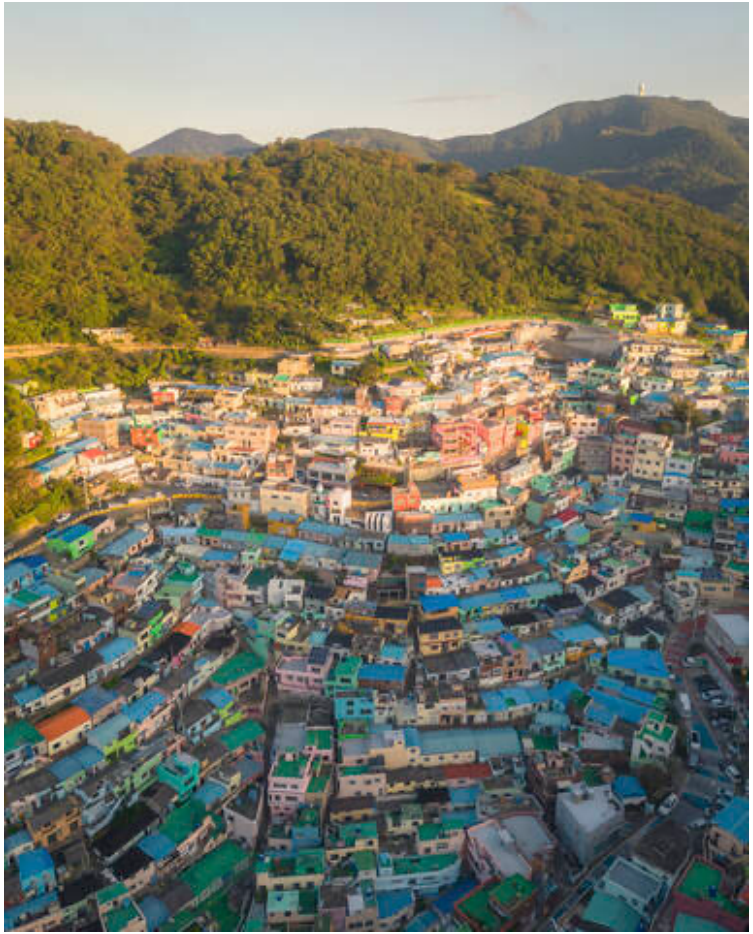
https://www.archdaily.com/

https://www.instagram.com/architectanddesign

https://www.mykonosceramica.com/



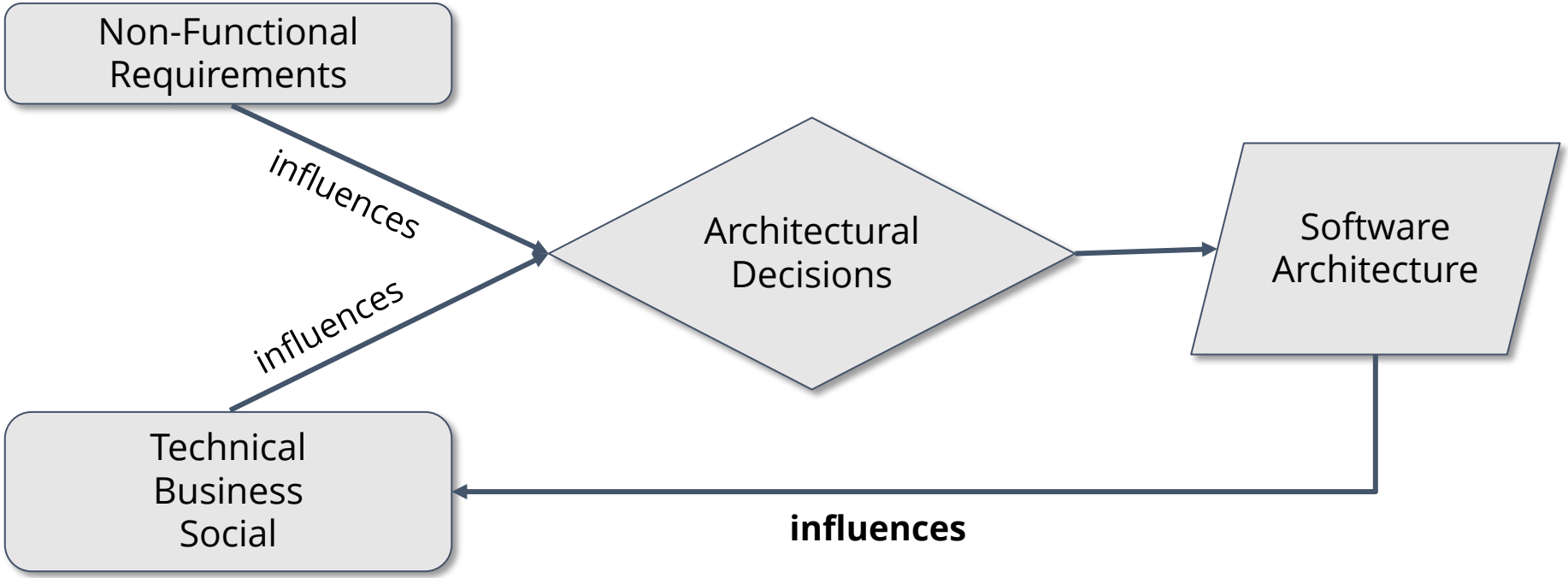
www.over-view.com

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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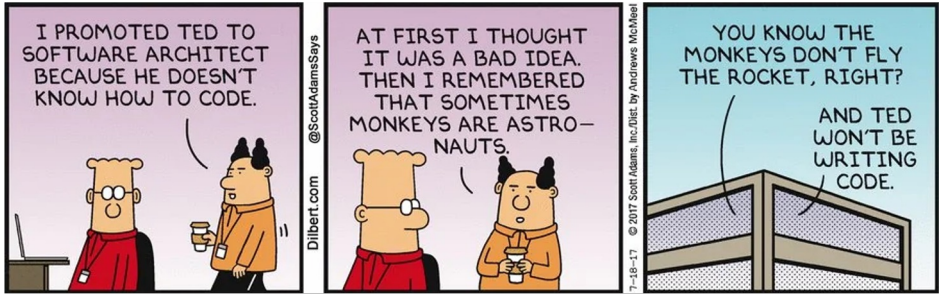
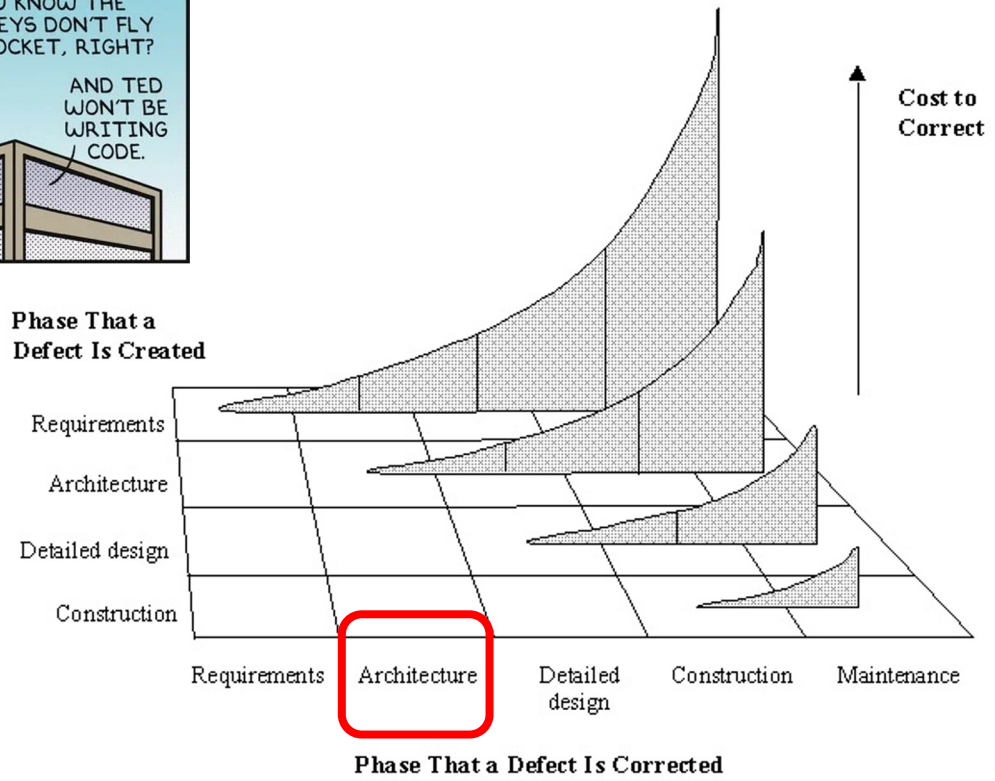
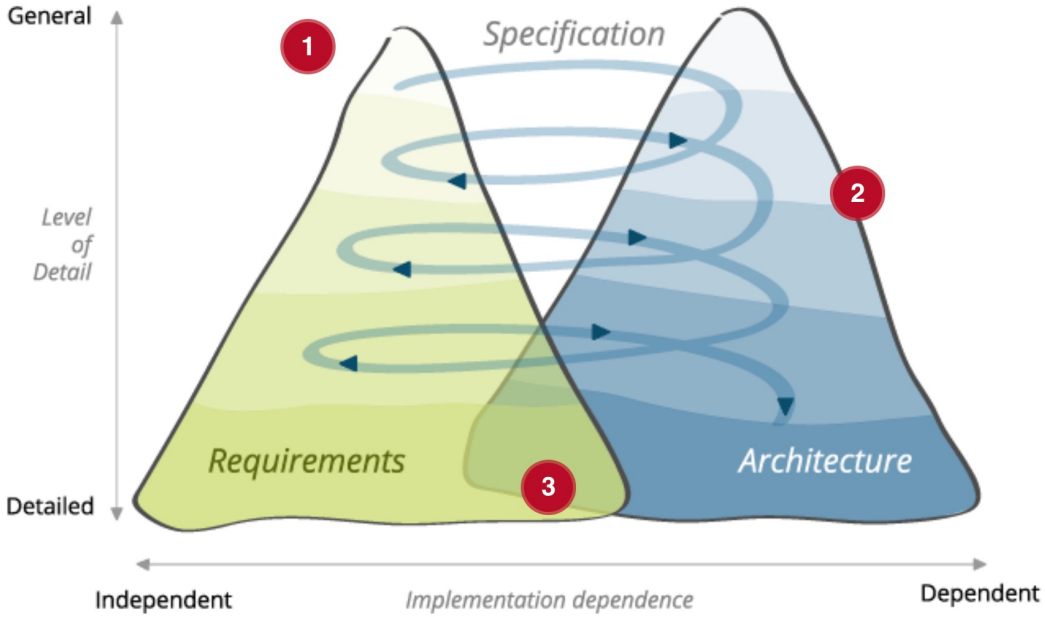




The Twin Peaks Model



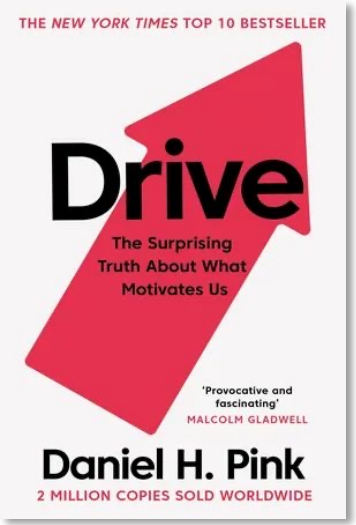
B. Nuseibeh, "Weaving together requirements and architectures". 2001

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

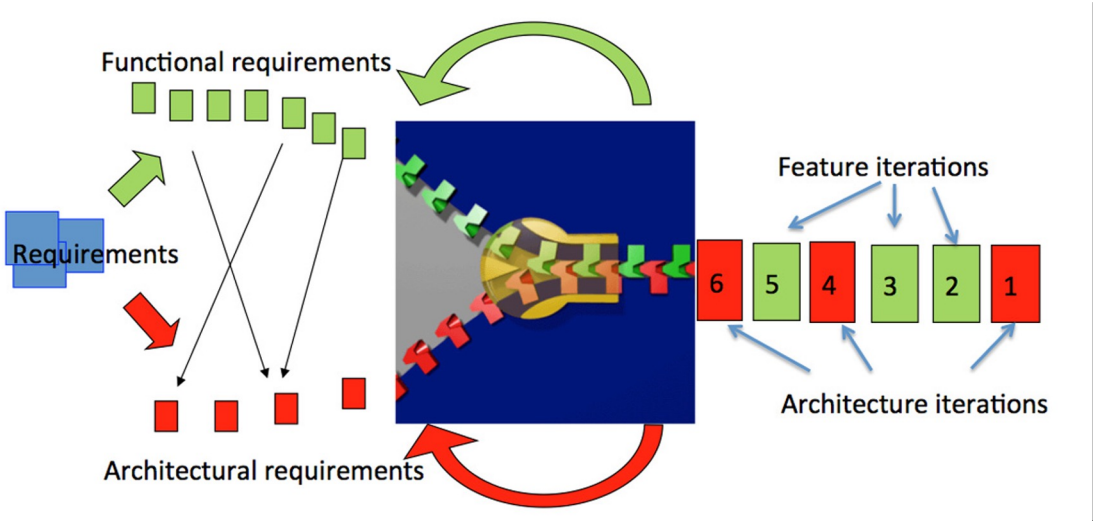


https://medium.com/@beatrix_66005/the-best-architectures-requirements-and-designs-emerge-from-self-organizing-teams-8b54ebc4c6b0

The Zipper Model

How to Agilely Architect an Agile Architecture

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



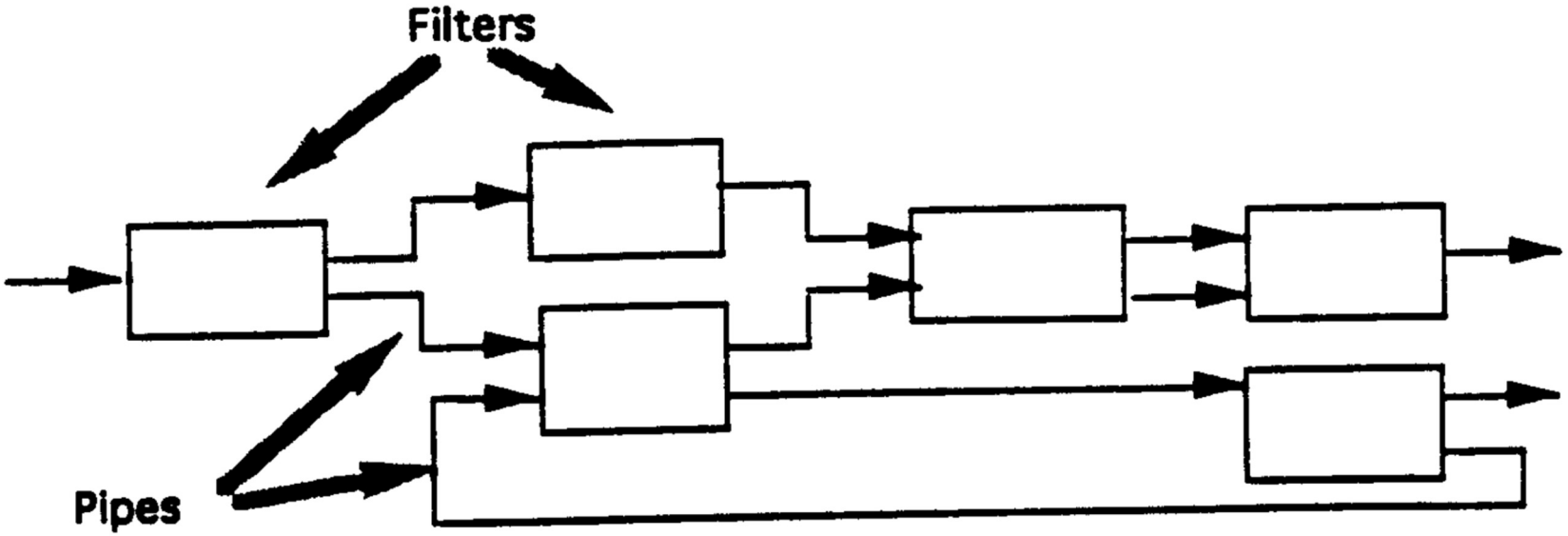
Common Architectural Styles



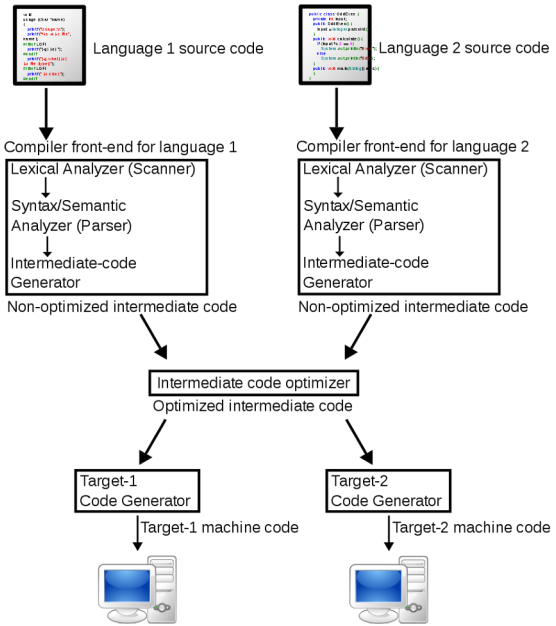


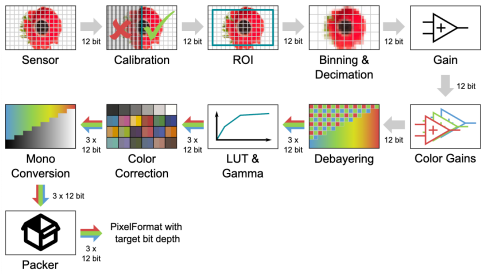

https://www.thespruce.com/top-architectural-styles-4802083

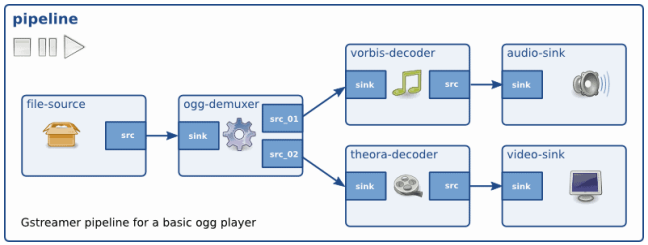
Pipes and Filters

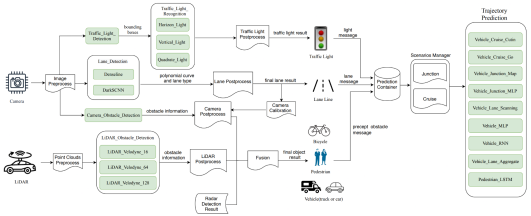


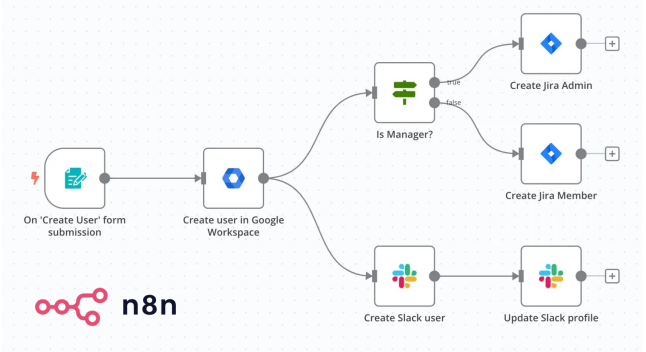
Pipes and Filters in the Wild



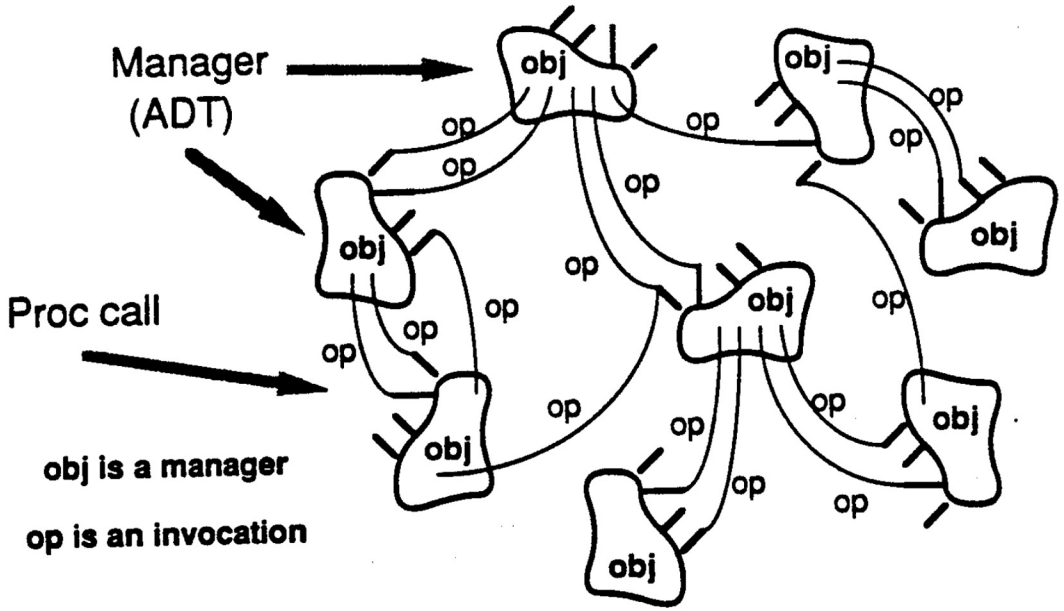




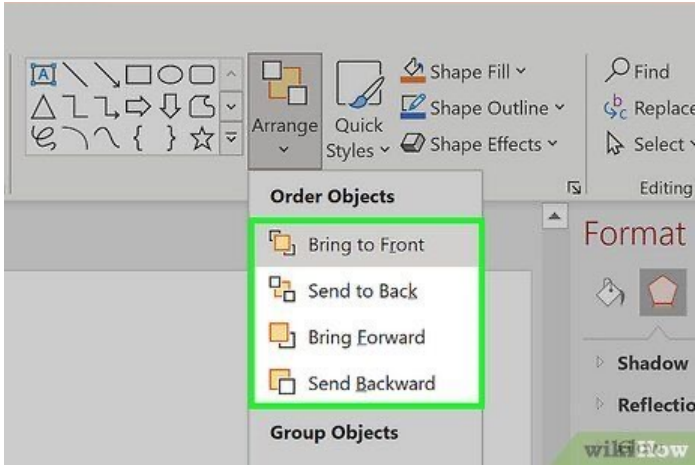


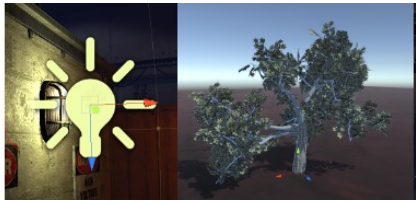


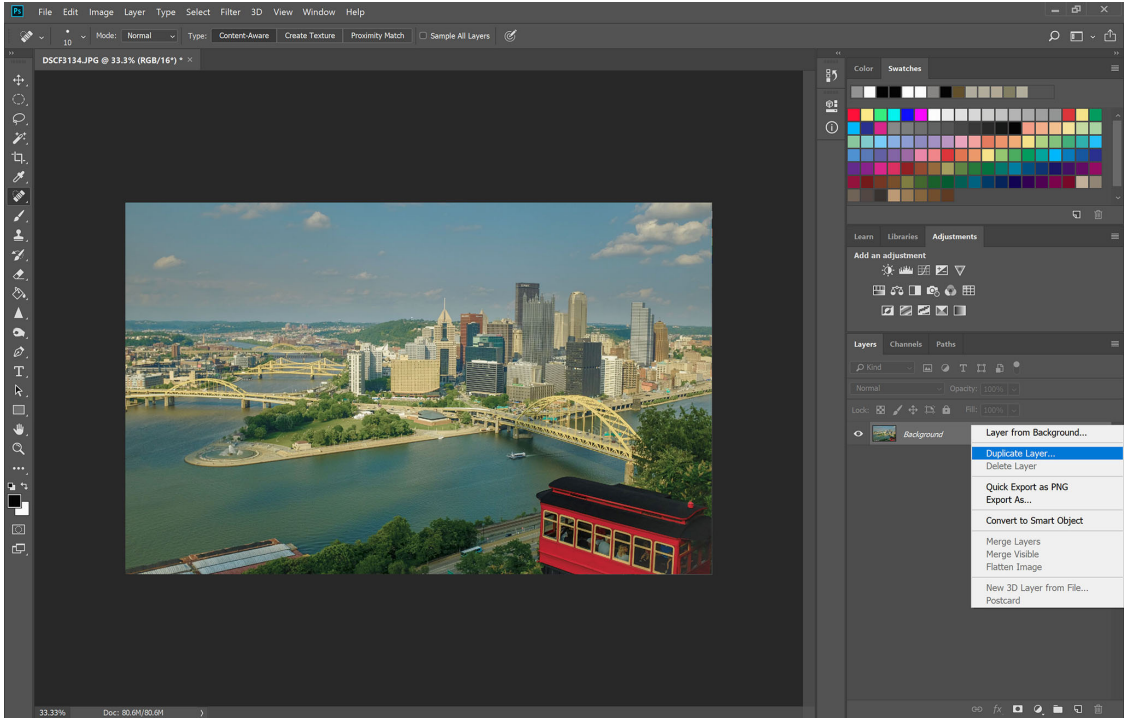
Object-Oriented Organization



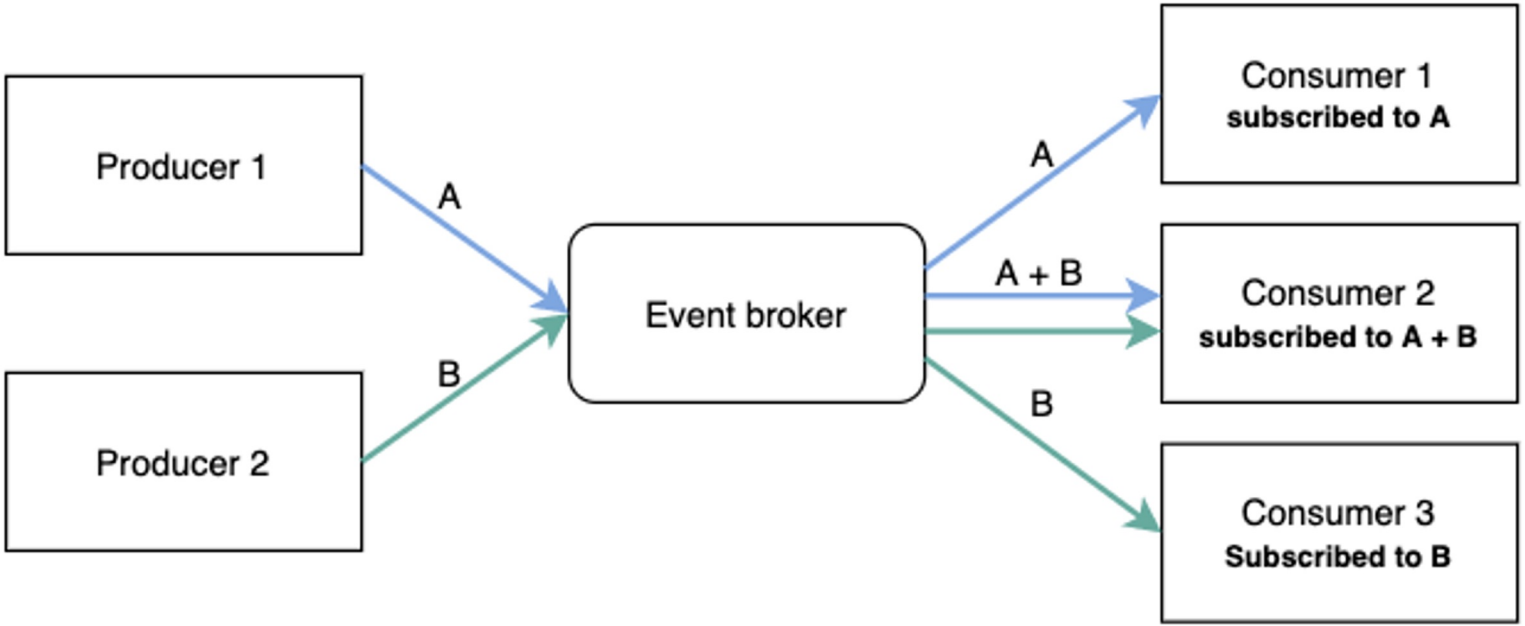
Object-Oriented Organization in the Wild



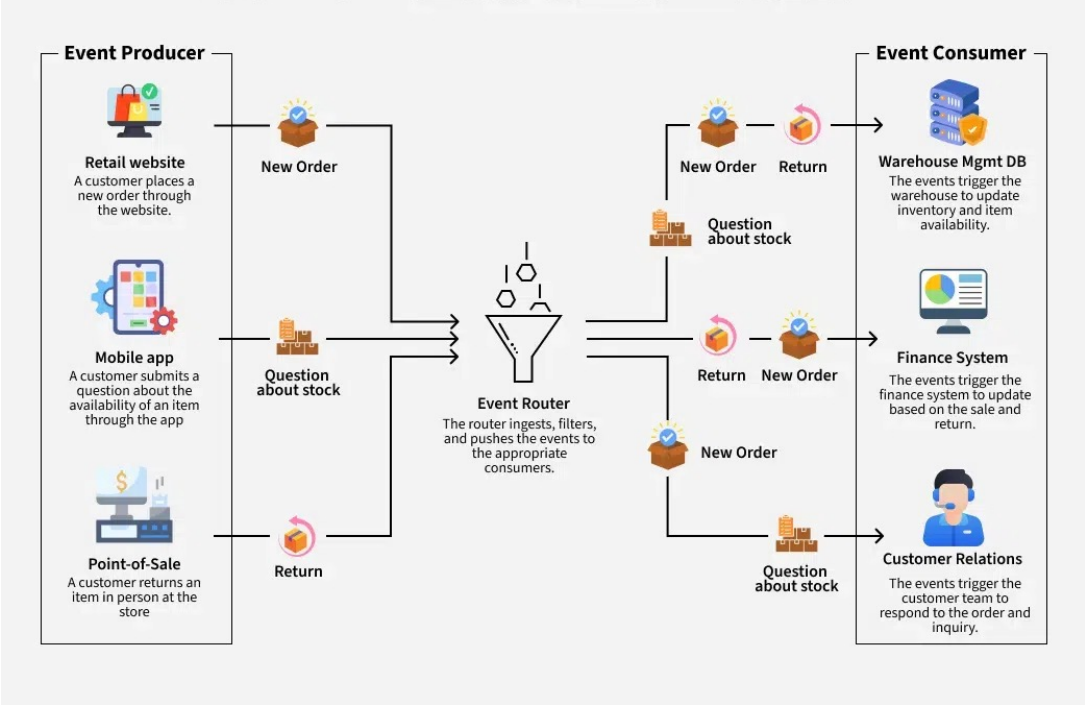




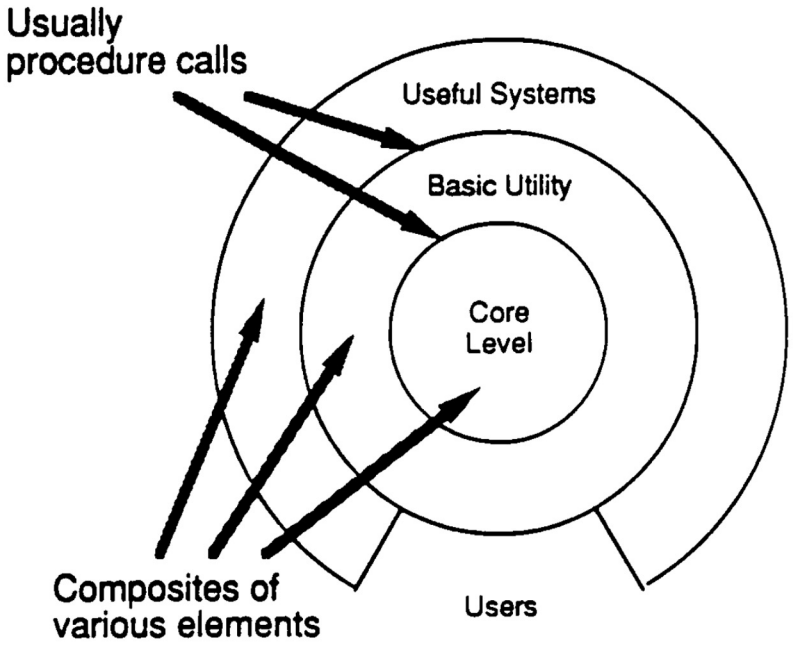
Event-Driven Architecture



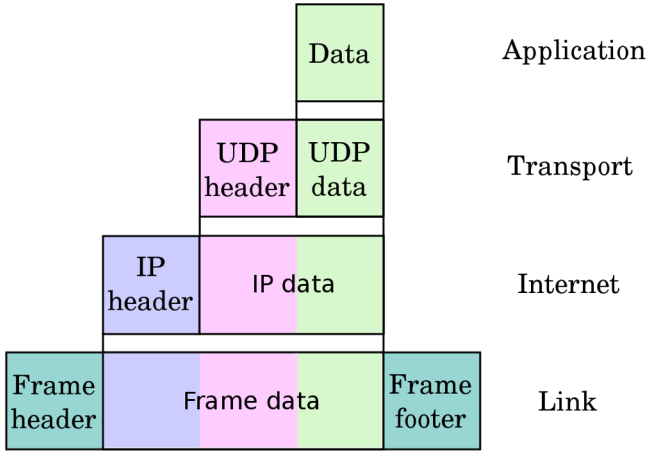
Event-Driven Architectures in the Wild

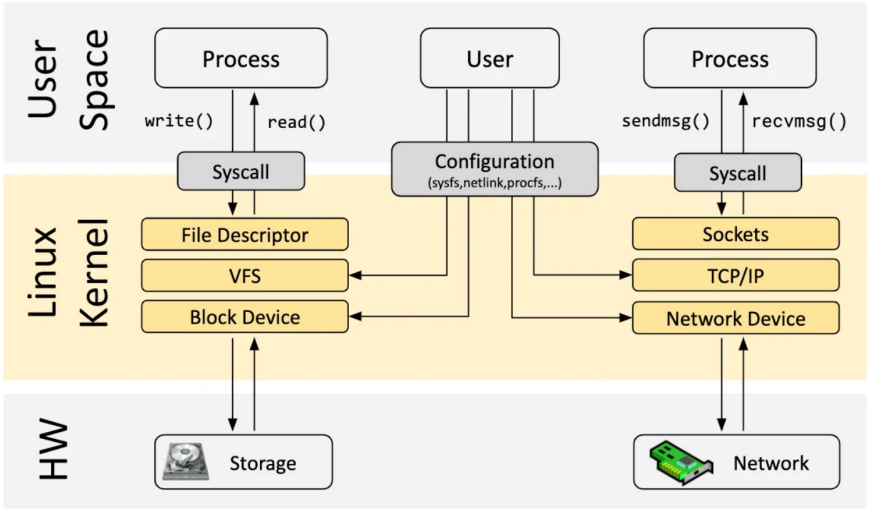


Layered Systems



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

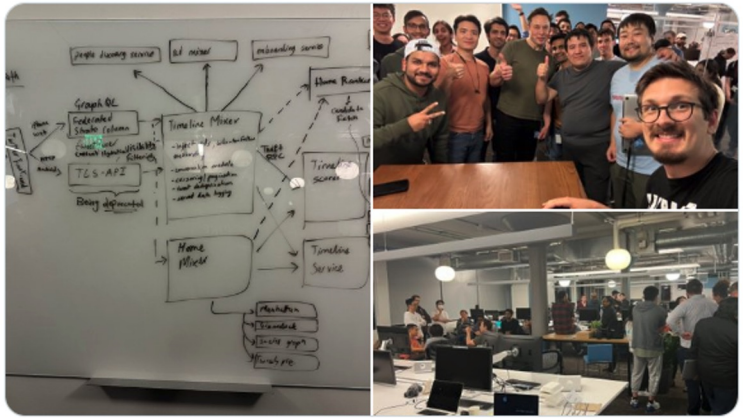
Elon Musk ✓
@elonmusk

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

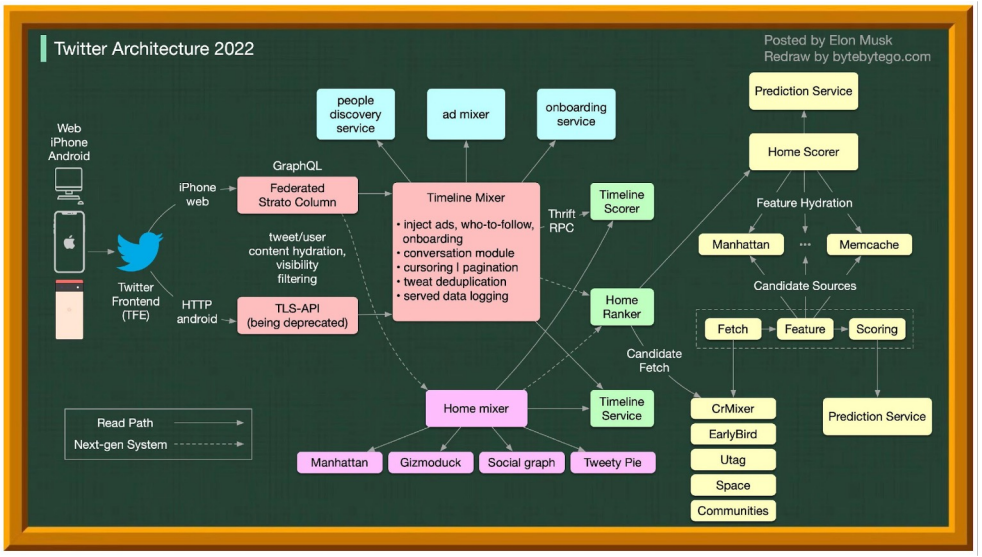
Elon Musk ✓
@elonmusk

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