Design Abstractions

17-423/723 Designing Large-Scale Software Systems

Lecture 3
Jan 22, 2025

Learning Goals

- Describe the role of abstraction in communicating designs
- Describe common types of design abstractions
- Select and apply a suitable notation to model an aspect of a design
- Generate questions to explore further design decisions given a model

Logistics

- Homework 1 is out on Canvas; due next Wednesday, Jan 29
- Practice on building a context model (last lecture) & design models (today)
- Submission through Gradescope
- Recitation this week: How to work effectively in a team!
- Project teams will be announced before the recitation

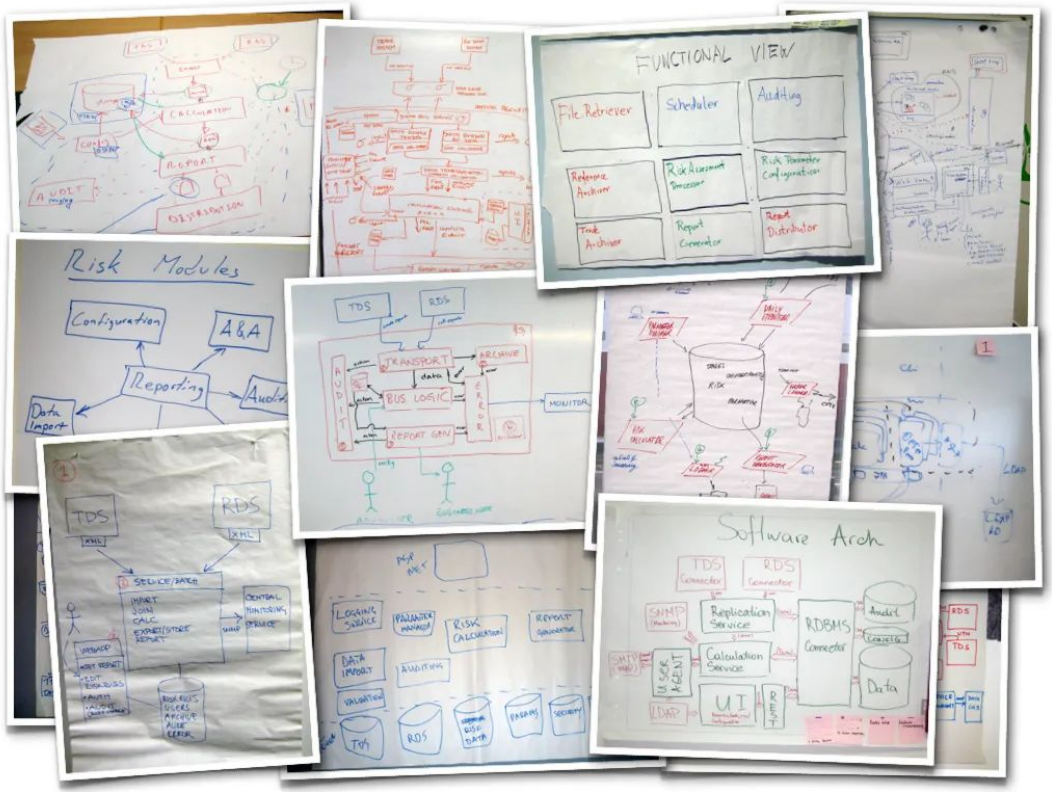
Communicating Designs

Last class: Use of a context model to understand the **problem space** (entities & assumptions)

This class: Models for communicating design ideas in the **solution space**

How do software designers communicate ideas?

Designers use sketches

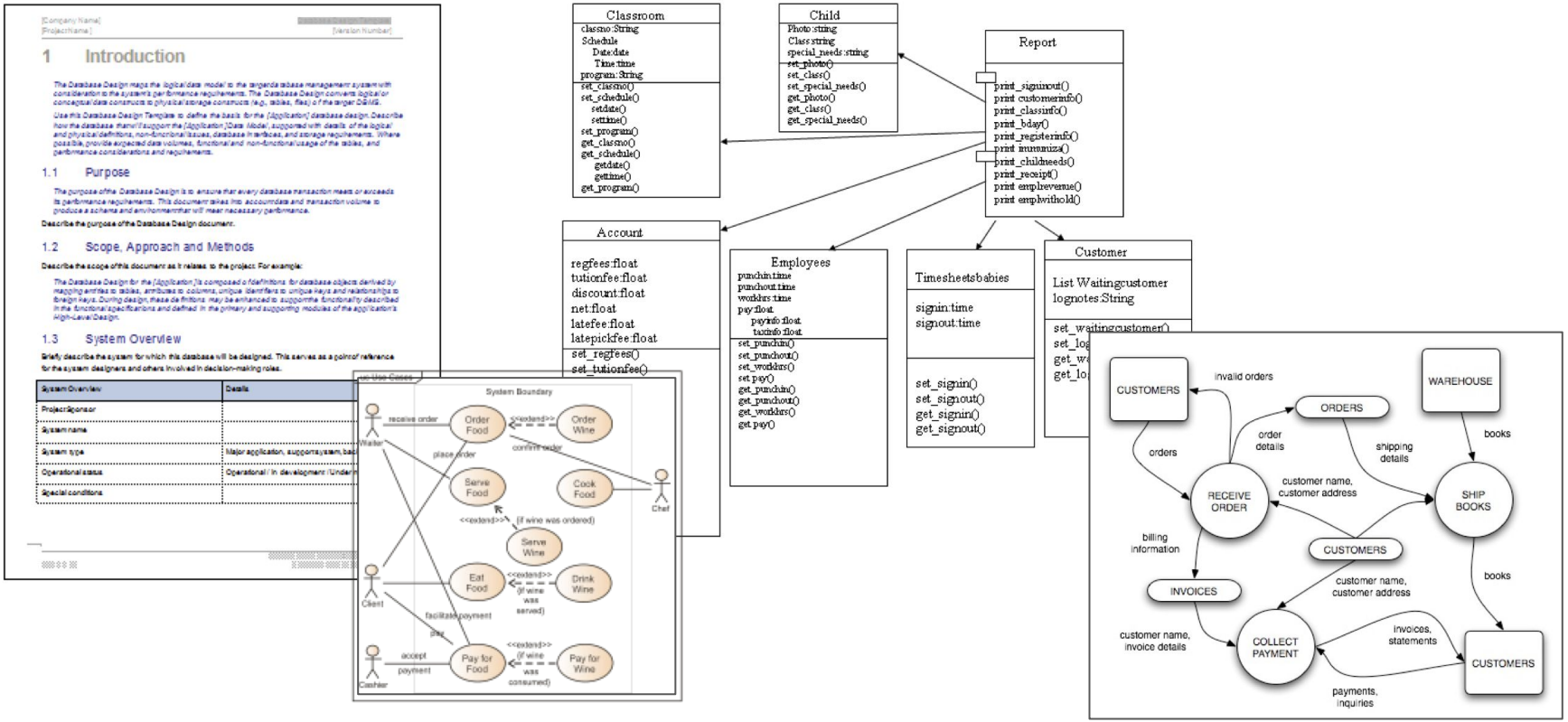


To brainstorm ideas

To explain how a design works

To ask questions about designs

Designers document their work



Viewpoint: Code as Design

Code is the final design and the only source of the truth

Source code listing is the only design documentation that we need

Q. What do you think? Arguments for & against?

Jack W. Reeves “Code as Design: Three Essays”
https://www.developerdotstar.com/mag/articles/reeves_design_main.html

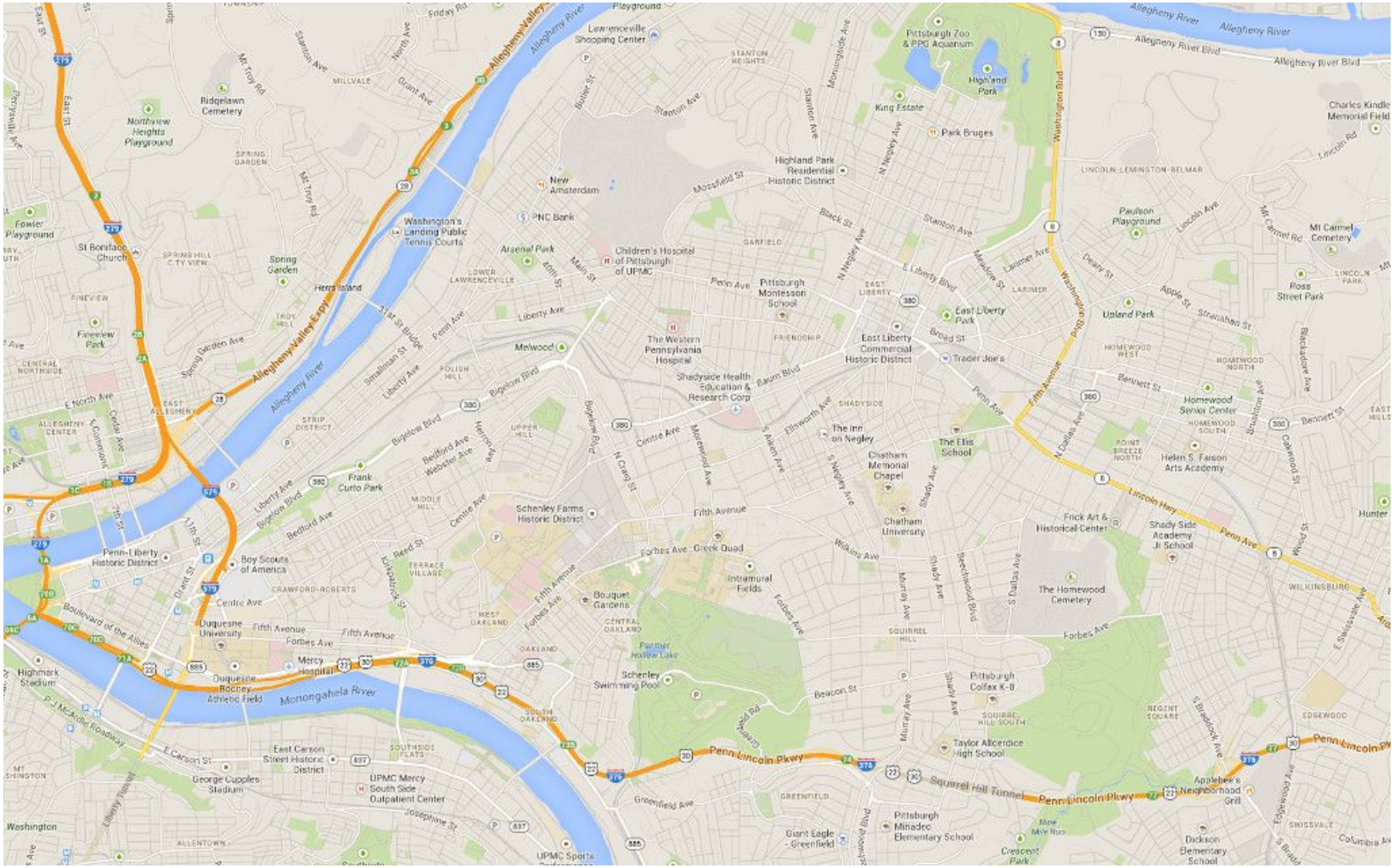
Designers use abstractions

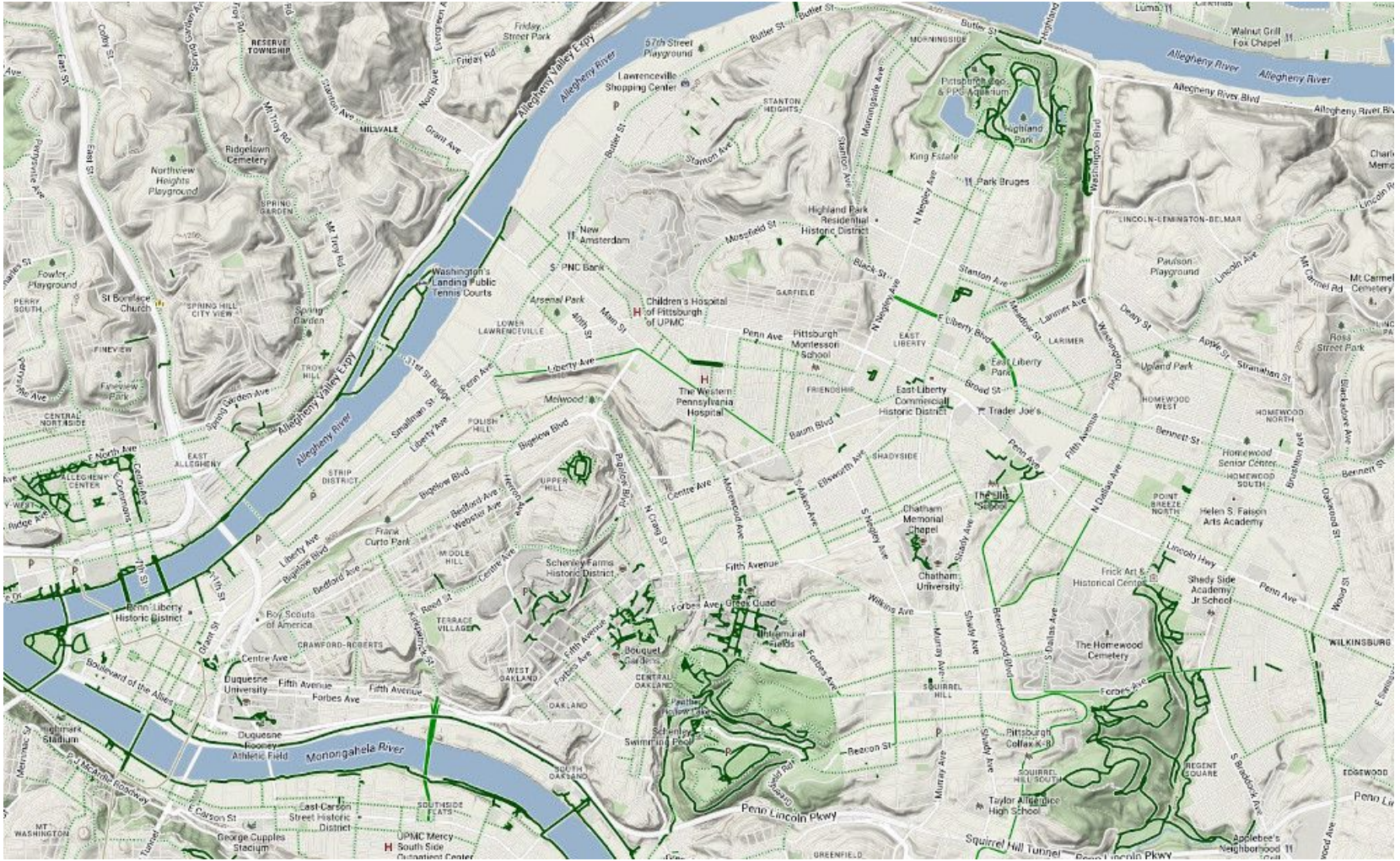
For most systems, code is too complex for a single person to understand

Code is not an ideal medium of communicating ideas

Code does not capture everything about design
- Q. What are some information that is not captured in the code?

Instead, designers communicate through **an abstraction of a system** – a description that focuses on a particular aspect & ignores other details


Allegheny River
Monongahela River
Penn-Liberty Historic District
Schenley Farms Historic District
Penn Lincoln Pkwy
Squirrel Hill Tunnel
Penn Avenue
Fifth Avenue
Forbes Ave
Centre Ave
Liberty Ave
Bigelow Blvd
Boulevard of the Allies
Frank Curto Park
Schenley Park
Schenley Swimming Pool
Bouquet Gardens
Intramural Fields
Greek Quad
Chatham University
Chatham Memorial Chapel
The Inn on Negley
The Ellis School
Frick Art & Historical Center
Shady Side Academy Jr School
The Homewood Cemetery
Helen S. Faison Arts Academy
Homewood Senior Center
East Liberty Commercial Historic District
East Liberty Park
Trader Joe's
Pittsburgh Montessori School
The Western Pennsylvania Hospital
Shadyside Health Education & Research Corp
Children's Hospital of Pittsburgh of UPMC
Highland Park Residential Historic District
Highland Park
Pittsburgh Zoo & PPG Aquarium
King Estate
Park Bruges
Lawrenceville Shopping Center
PNC Bank
New Amsterdam
Washington's Landing Public Tennis Courts
Arsenal Park
Melwood
Ridgelawn Cemetery
Northview Heights Playground
Fowler Playground
St Boniface Church
Spring Garden
Herrs Island
Fairview Park
Paulson Playground
Mt Carmel Cemetery
Ross Street Park
Upland Park
Charles Kindle Memorial Field
Duquesne University
Mercy Hospital
Duquesne Boccey Athletic Field
Highmark Stadium
George Cupples Stadium
East Carson Street Historic District
UPMC Mercy South Side Outpatient Center
UPMC Sports
Giant Eagle - Greenfield
Pittsburgh Minadeo Elementary School
Pittsburgh Colfax K-8
Taylor Allderdice High School
Applebee's Neighborhood Grill
Dickson Elementary School
Crescent Park
Boy Scouts of America
Penn Lincoln Pkwy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Lincoln Ave
Mt Carmel Cemetery
Mt Troy Rd
Grant Ave
Millvale
Reserve Township
Lincoln-Lemington-Belmar
Morningside
Stanton Heights
Garfield
East Liberty
Friendship
Shadyside
Point Breeze North
Homewood West
Homewood North
Homewood South
Squirrel Hill
Regent Square
Edgewood
Wilkinsburg
Greenfield
Mt Washington
Oakland
Central Oakland
West Oakland
South Oakland
Terrace Village
Crawford-Roberts
Middle Hill
Upper Hill
Polish Hill
Strip District
Central Northside
East Allegheny
Spring Hill City View
Troy Hill
Perry South
Lower Lawrenceville
Stanton Ave
Black St
Penn Ave
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Wilkins Ave
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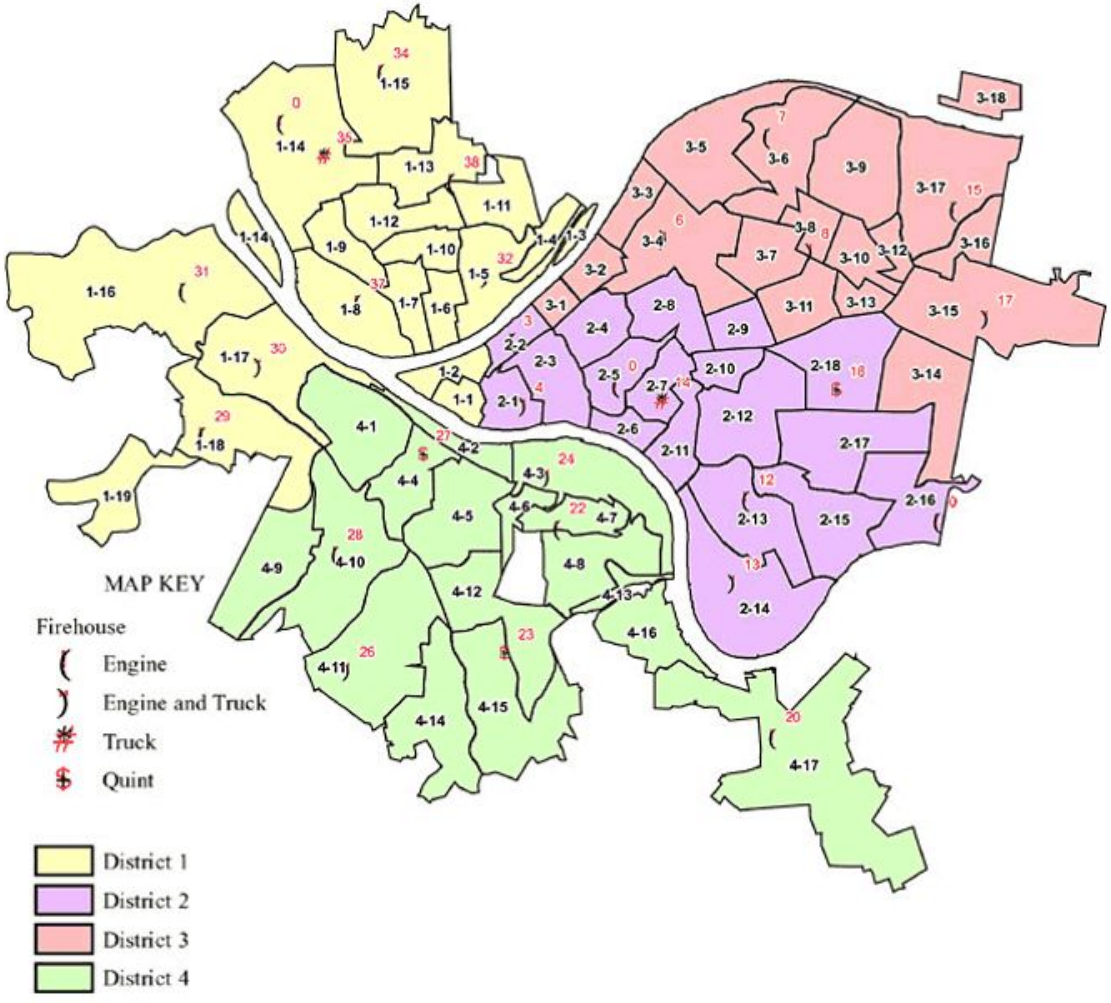

MAP KEY
Firehouse
Engine
Engine and Truck
Truck
Quint
District 1
District 2
District 3
District 4

Purpose of an Abstraction

Abstractions aid in understanding

Each abstraction highlights particular aspects of a system and deliberately hides other details

Abstractions facilitate reasoning

Each abstraction answers certain types of questions about the system

Abstractions are reusable

Each abstraction captures a commonality across multiple systems (within a single domain or sometimes across multiple domains)

What can we reason about?

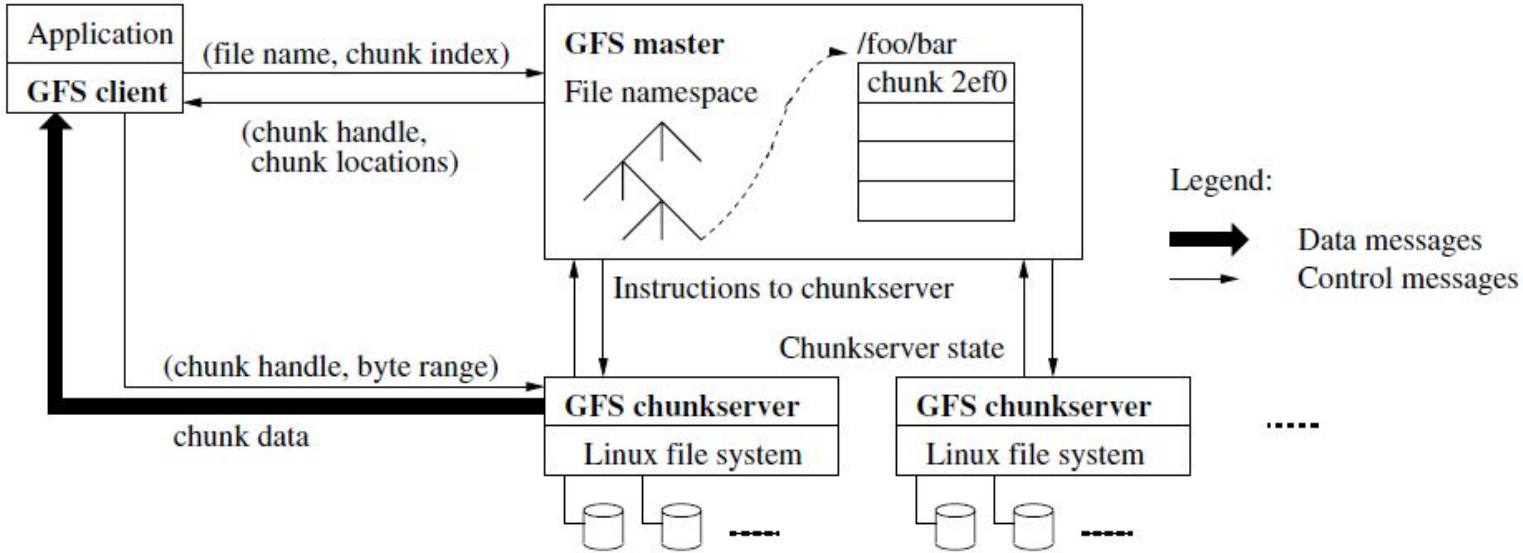
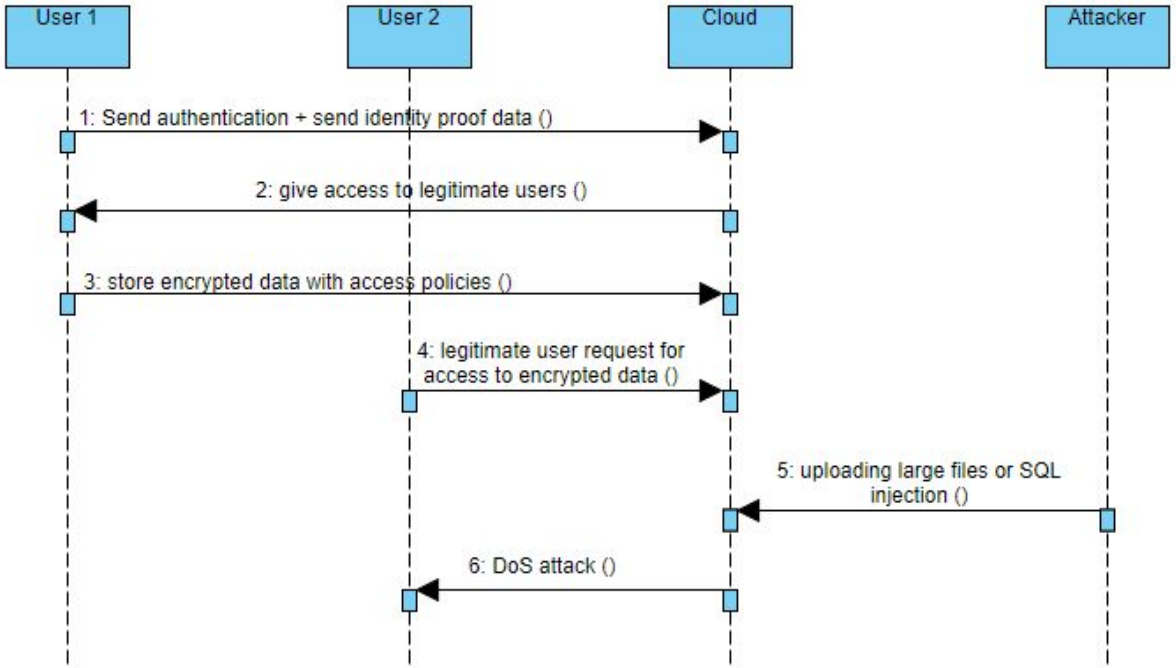


Figure 1: GFS Architecture

Ghemawat, Sanjay, Howard Gobioff, and Shun-Tak Leung. "The Google file system." ACM SIGOPS operating systems review. Vol. 37. No. 5. ACM, 2003.

What can we reason about?



Web of Things: Security Challenges and Mechanisms. Rhumba Sardar and Tayyaba Anees. IEEE Access (2021).

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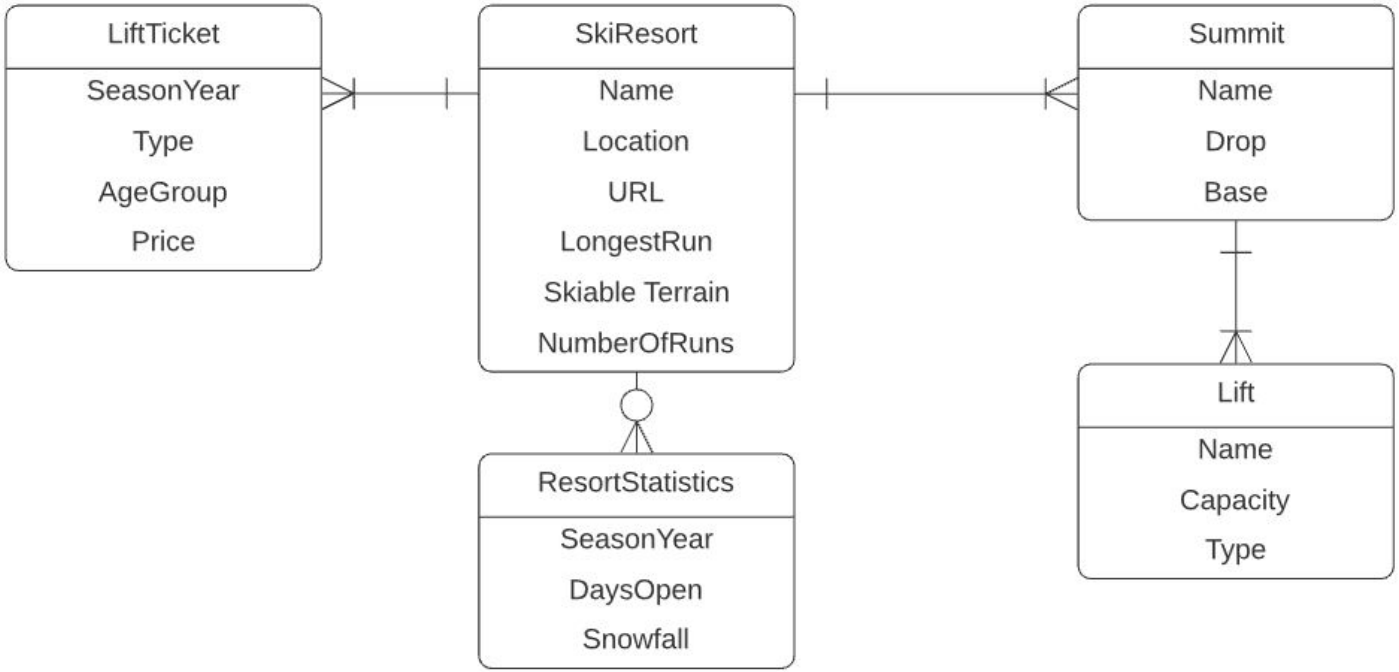


Notations for Common Design Abstractions

Component diagrams: What are major components in the system and how do they communicate with each other?

Data models: What types of data does the system store and what are their relationships?

Sequence diagrams: How different actors (domain entities & system components) collaborate to carry out some functionality?

State machines: What states can the system be in and what events cause it to change its state?

Modeling in this class

Sometimes, models are themselves developed as a formal, first-class artifact

- To rigorously specify & verify properties about the system
- To generate a working implementation (e.g., model-driven engineering, automatic code generation, AI-driven development)

In this class, the goal is to **communicate**

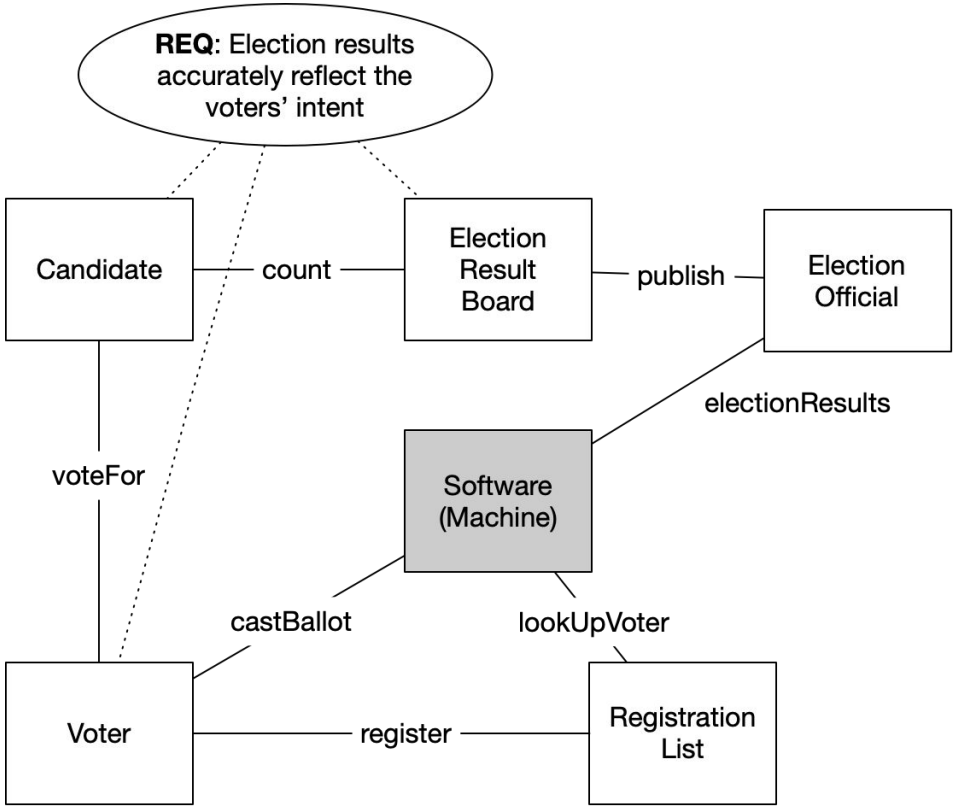
- To explain a design to someone who will work on the system later (sometimes, yourself)
- To provide a high-level overview of the system
- To explain an aspect of the system that is particularly complex

Example: Electronic Voting System

Voting System: Workflow

- A voter walks to an electronic voting machine and enters their voter ID information.
- The voting software checks whether the voter is registered to vote.
- The voter is presented with an electronic ballot with a list of candidates.
- The voter selects a candidate and casts their ballot by confirming their choice.
- The voting software collects all of the ballots and produces the final count for each candidate.
- The election officials retrieve and post the election results on a public board.

Context Model for the Voting System



Component Diagram

Component Diagram

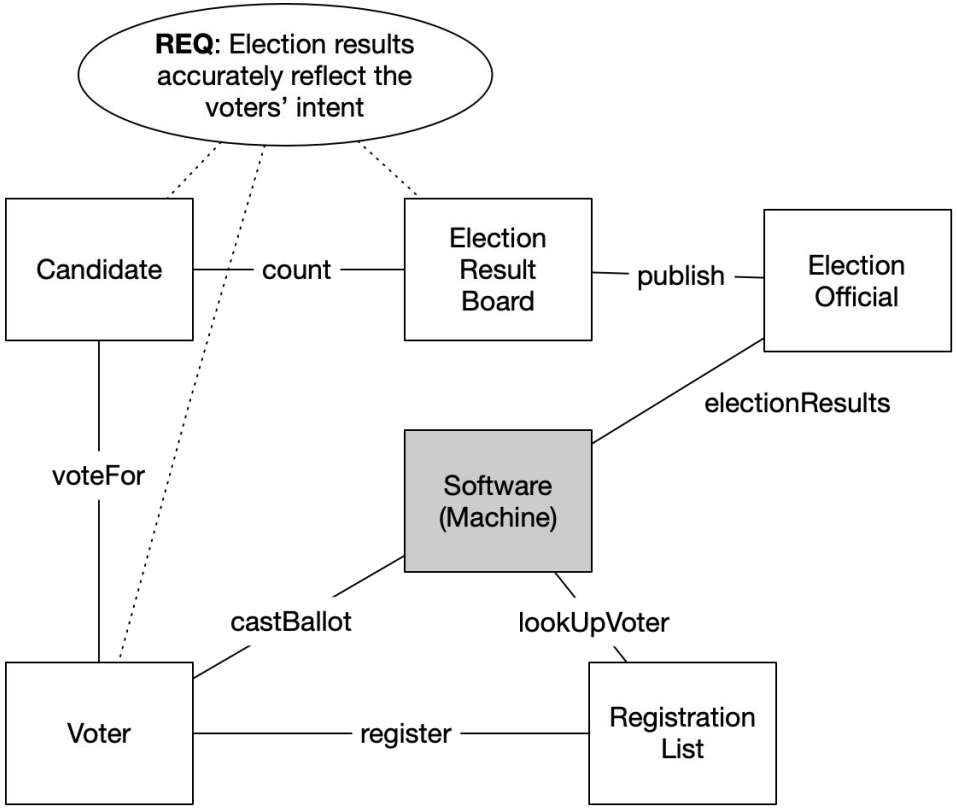
Purpose

Describe the major components in the software system, which components communicate with each other, and how they communicate.

Building blocks

- Component: A software component, responsible for carrying out a distinct unit of functionality
- Connection: A **directed** connection between a pair of components, labeled with an event (e.g., an API call) or data flow
- Component responsibilities (in text annotations): Describe the responsibilities of each component.

Activity: Design the Voting Software



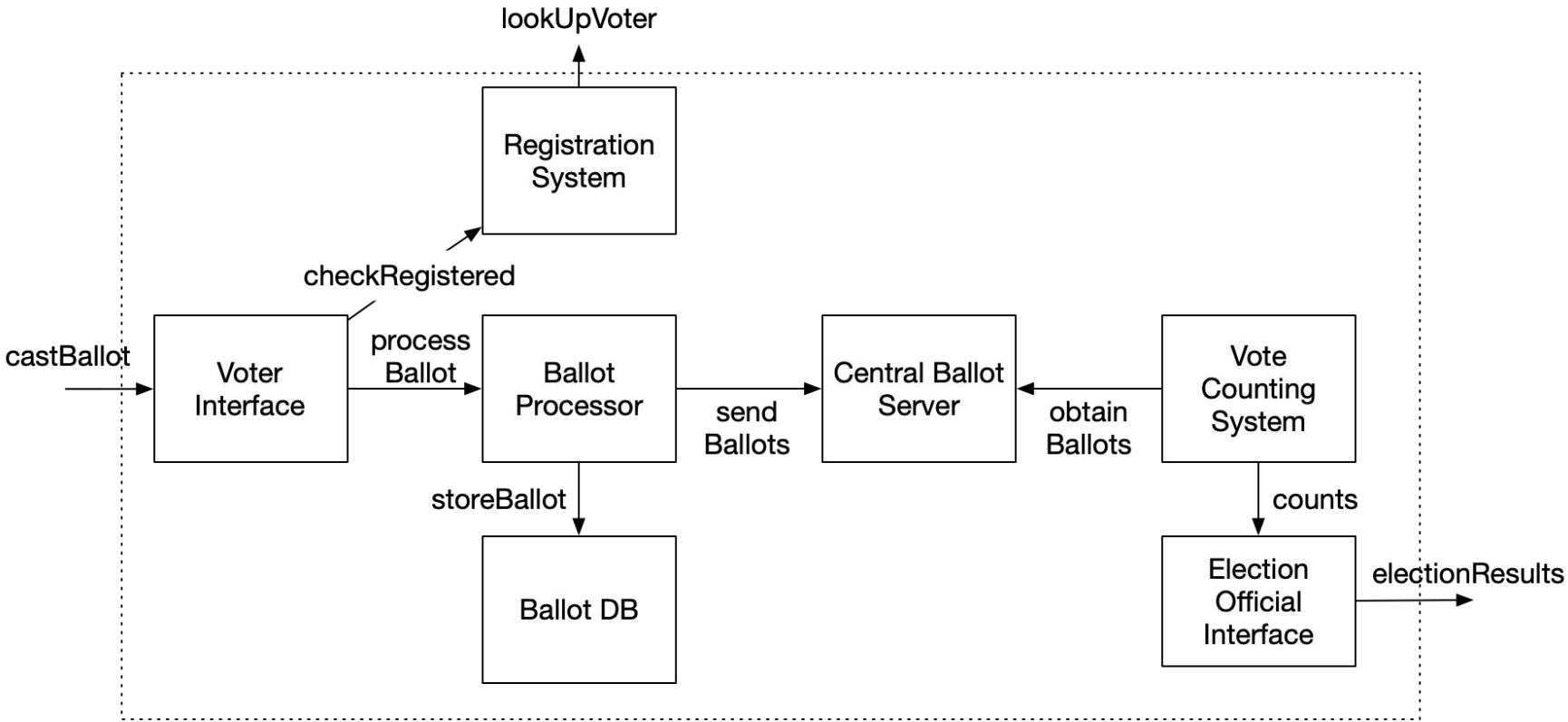
What is the specification of the voting software?

What components does the voting software consist of?

How do the components interact with the domain entities?

How do these components interact with each other?

Component Diagram: Example



Component Responsibilities

Voter Interface: Receives inputs from the voter & forwards ballot information to the Ballot Processor.

Registration System: Checks whether a voter is registered by looking up an external registration list.

Ballot Processor: Processes & stores each ballot on a local database. Uploads all of the ballots to the central server.

BallotDB: Stores the ballots cast so far for a local precinct.

Central Ballot Server: Stores all of the ballots across multiple precincts.

Vote Counting System: Compute the final tally of votes for each candidate.

Election Official Interface: Serves requests from an election official to retrieve election results.

Component Diagram: Design Questions to Ask

Each model is a starting point for asking & discussing further design questions

Different types of models encourage different types of questions

Component Diagram: Design Questions to Ask

What information is passed between one component to another? Is there a return value?

What type of communication mechanism is used for each connection? (e.g., HTTP/S, RPC, Bluetooth) Is the communication synchronous or asynchronous?

Which components interact with the entities in the problem space (e.g., users)?

Which hardware device is each component deployed in? Which components are deployed on the same device?

What if a component changes or fails? What other components does it affect?

Data Model

Data Model

Purpose

- Describe different types of data that the system needs to remember to fulfill its specification
- Serve as the conceptual schema for designing a database

Building blocks

- **Data type**: A collection of data elements or objects
- **Relation**: A **directed** relation between a pair of data types
- **Multiplicity constraints**: A constraint on a relation, specifying how many instances of the two data types can be related to each other

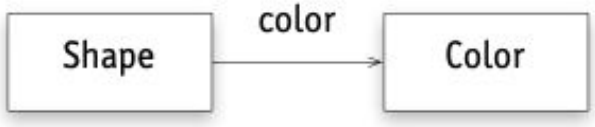
Data Model: Relations

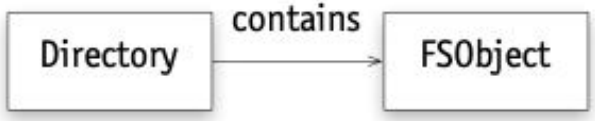
A relationship between different data types

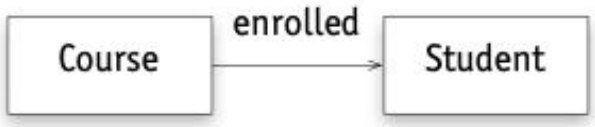
Types of relations:

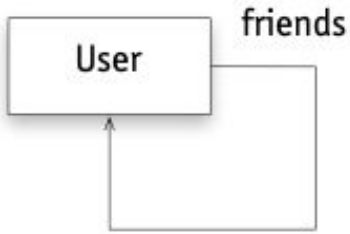
- Property
- Containment
- Association
- Naming

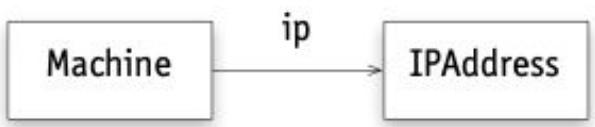
Q. What kinds of relations are these?







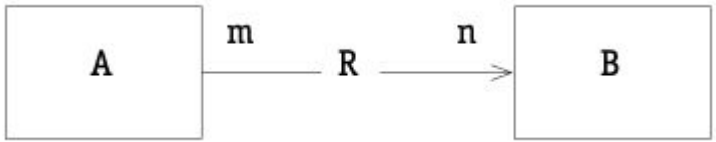




Data Model: Multiplicity Constraints

Constraints on relations

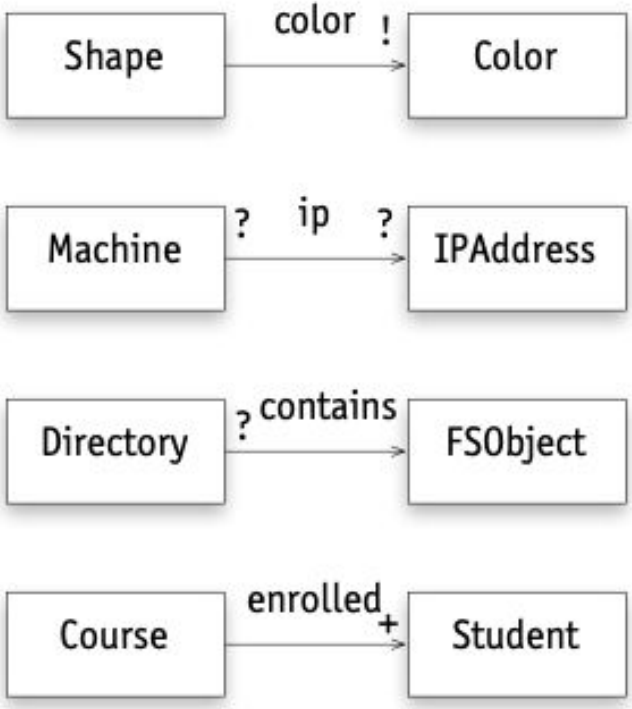
- R is a relation of type A to B
- R maps **m** A's to each B
- R maps each A to **n** B's

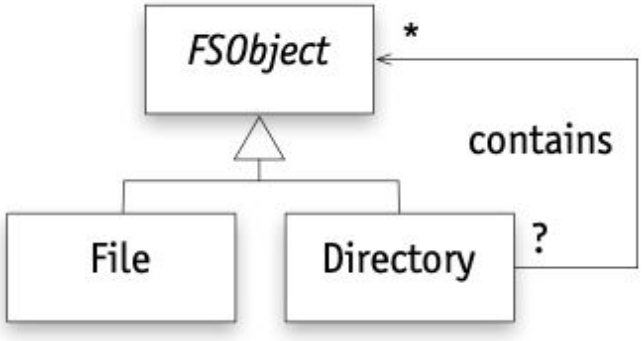


These constraints will eventually need to be enforced in the database design

+ one or more
* zero or more
! exactly one
? at most one
omitted = *

Data Model: Multiplicity Examples





+ one or more
* zero or more
! exactly one
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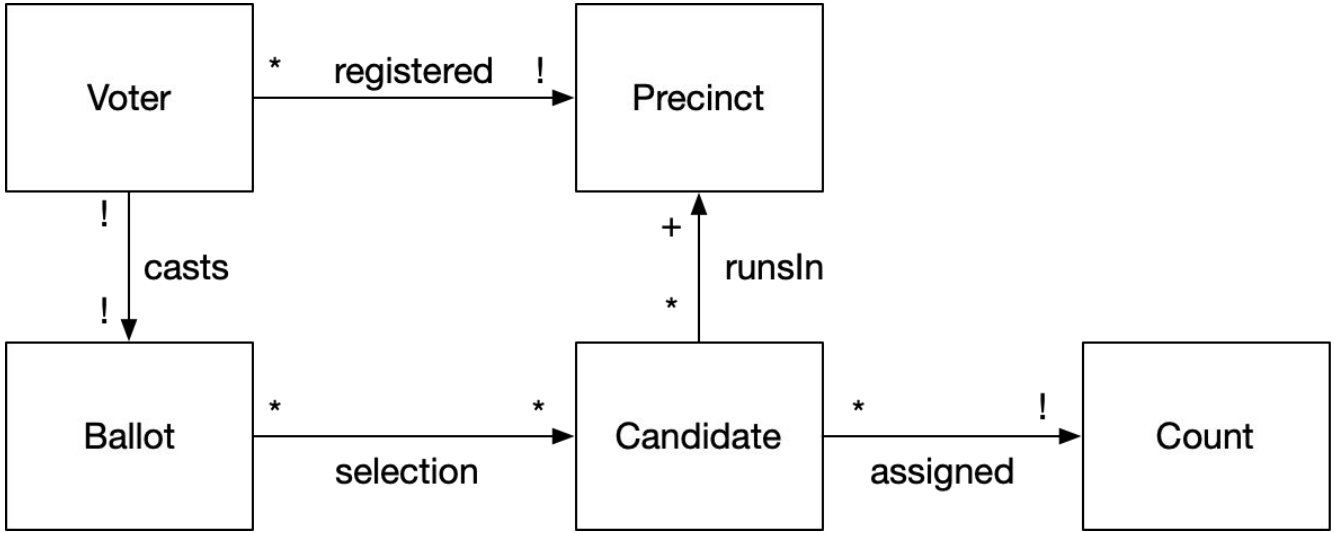
omitted = *

Data Model: Voting System



Data Model: Design Questions to Ask

Are we capturing all information that the system needs to function (and also achieve its quality attributes - e.g., security, availability)?

Do the multiplicity constraints reflect the real world scenarios? Are there any missing constraints? Are some constraints too strong?

Will all relations be stored on the same database, or be distributed across multiple databases? If distributed, do we need to consider consistency issues?

Is some of the data potentially sensitive? Do we need additional security or privacy mechanisms?

Sequence Diagram

Sequence Diagram

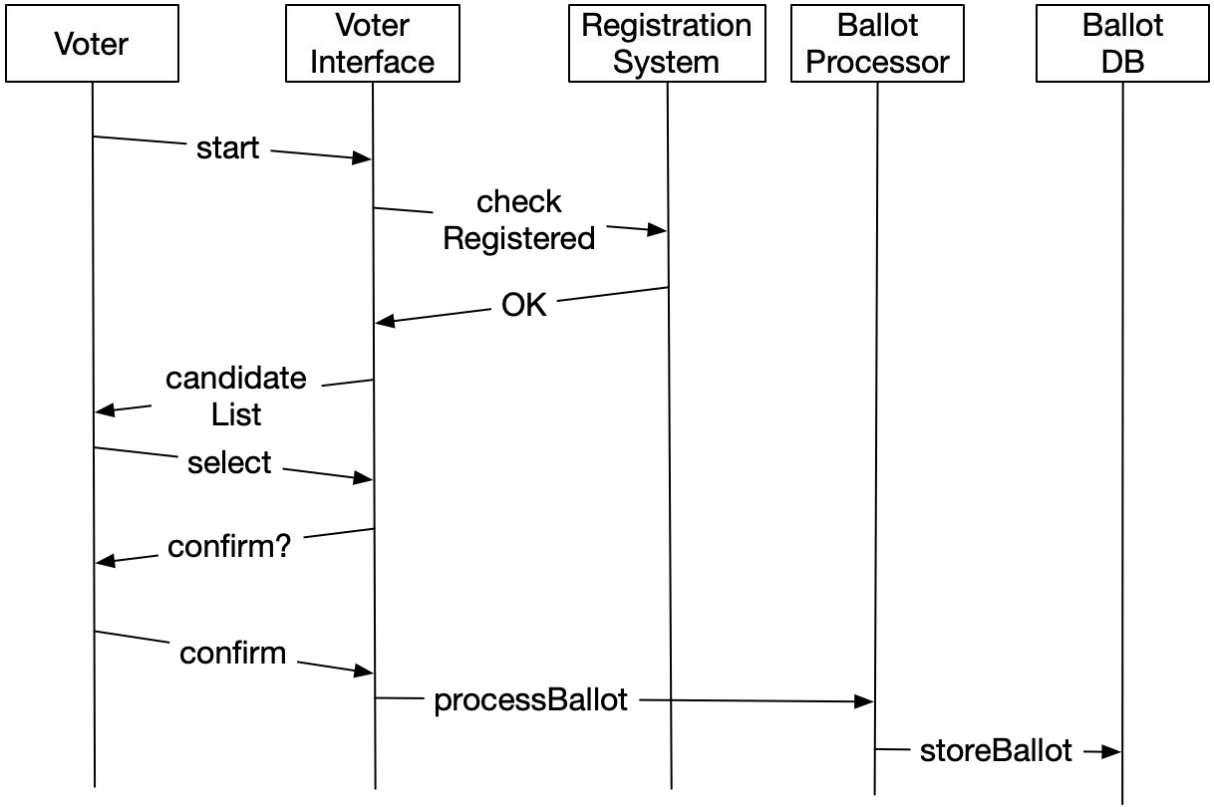
Purpose

Describe how a set of domain entities and system components collaborate in sequence to achieve a piece of functionality

Building blocks

- **Process**: A domain entity or system component
- **Message**: A message passed from one process to another

Sequence Diagram: Example



Sequence Diagram: Design Questions to Ask

What happens if a process terminates its activity early?

Is it possible for a message to be lost, and how does the system handle this? What if it arrives late?

What if a process receives two messages out of order? Does the order of execution matter for functionality or a quality attribute?

Are there any other processes that we are missing in this scenario?

Voter Fraud

FRANKFORT — A former Clay County precinct worker testified Friday that top election officers in the county taught her how to change people's choices on voting machines to steal votes in the May 2006 primary.

Voters walk away from the machine before pressing “confirm”
Election officials enter booth, press “back” & modify the vote

Tips for Building Diagrams

Aim for simplicity & clarity!

Keep diagrams to a reasonable size. If a diagram gets too big, break it into multiple ones.

Annotate a diagram with text to explain a concept (e.g., the responsibility of a component) if its meaning is not obvious from its label

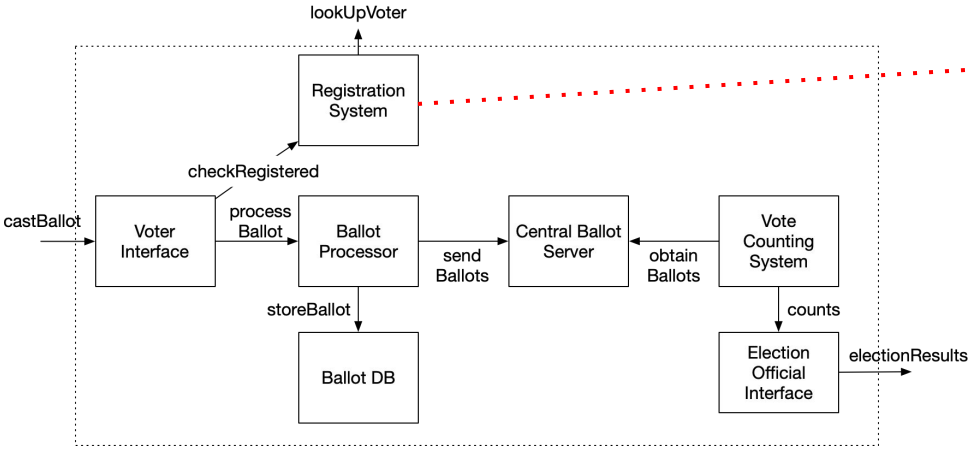
Use intuitive names! Avoid meaningless names (e.g., component named “Service”).

Consistency between Diagrams

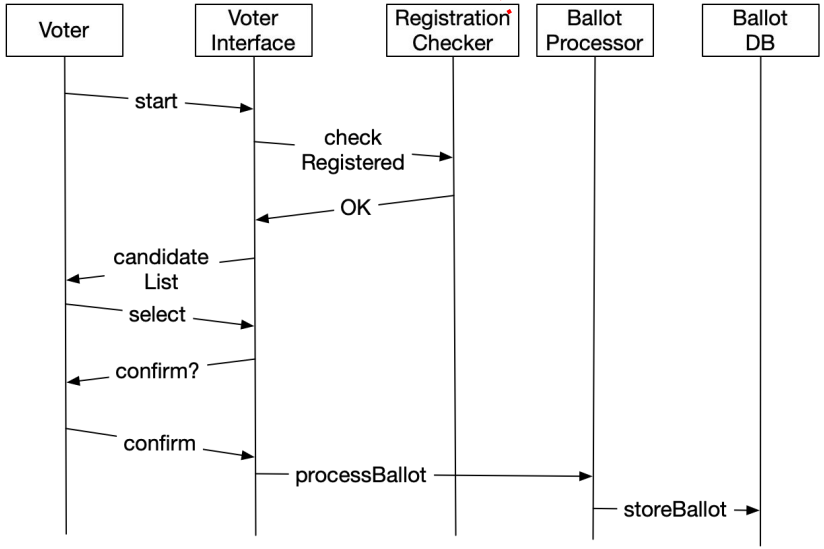
Try to use consistent names for the same concepts (components, events, etc.,) across multiple diagrams

A concept in one diagram may be represented by multiple concepts in another diagram; if so, explain how they are related

Consistency between Diagrams



Are these two the same?



Voter input "castBallot" is implemented by Voter Interface as a sequence of events "start", "select", and "confirm"

Tips for Building Diagrams

We will ask you document your design using some of these models throughout project milestones

Use these models in your team discussions! We will ask for your reflections on how they helped (or not) with designing your system

Treat these models as a tool for brainstorming & communicating, not for documenting everything perfectly

- Focus on aspects that are most important for your system (recall “risk-driven” approach to design)
- Use models to ask further questions about the system!

Summary

Exit ticket!