Software Design and Architecture

Software Modeling with UML

Agenda

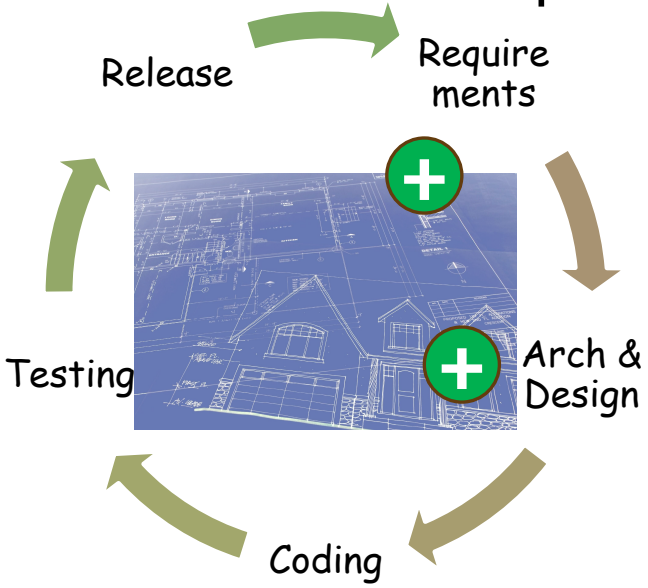
- why model software
- notation: UML
- component diagram
- class diagram

Spring 2026

Acknowledgements: slides adapted from previous versions by Mei Nagappan and Shane McIntosh, which are adapted from previous versions by Zhen Ming Jiang, Ahmed E. Hassan, Reid Holmes.

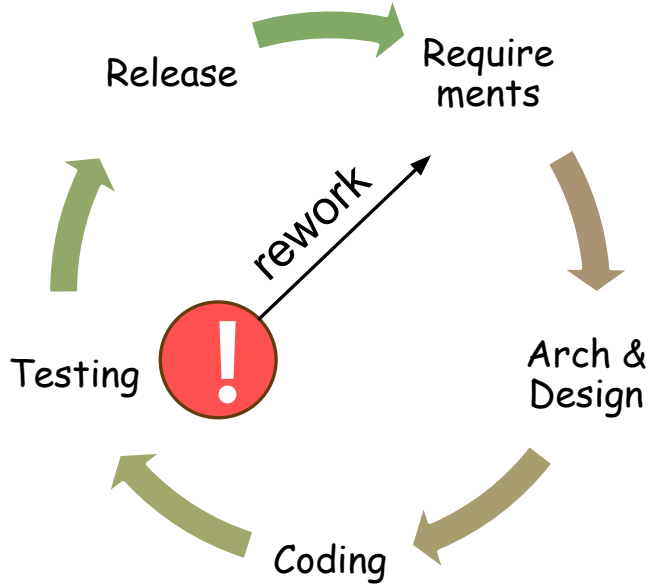
Why Model Software

- Document architecture and design decisions
- Reduce ambiguity; reason about missing requirements, risk, change, etc.
- Align teammates on responsibilities



document & iterate decisions early
(when changes are cheap)

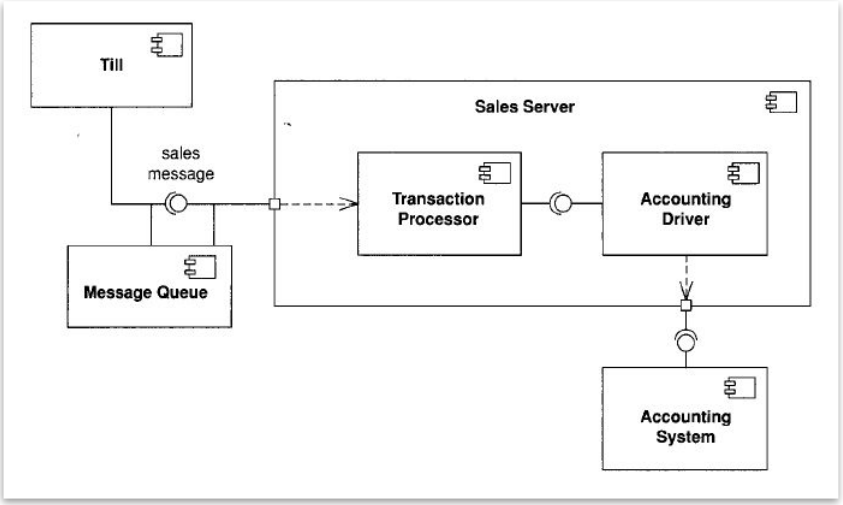
vs



risk bigger rework later

What is a Software Model?

- An abstract representation of a software for a purpose
  - focus on one aspect / component / process
  - can be graphical or textual
- General principles of software modeling
  - model the essentials
  - provide perspective
  - enable effective communication



UML (unified modeling language)

```
public class BankingExample {
    public static final int MAX_BALANCE = 1000;
    private /*@ spec_public @*/ int balance;
    private /*@ spec_public @*/ boolean isLocked = false;

    //@ public invariant balance >= 0 && balance <= MAX_BALANCE;

    //@ assignable balance;
    //@ ensures balance == 0;
    public BankingExample() {
        this.balance = 0;
    }

    //@ requires 0 < amount && amount + balance < MAX_BALANCE;
    //@ assignable balance;
    //@ ensures balance == \old(balance) + amount;
    public void credit(final int amount) {
        this.balance += amount;
    }
```

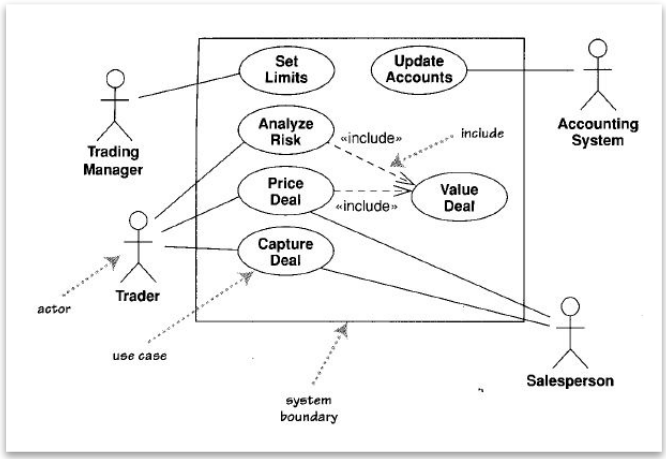
JML (java modeling language)

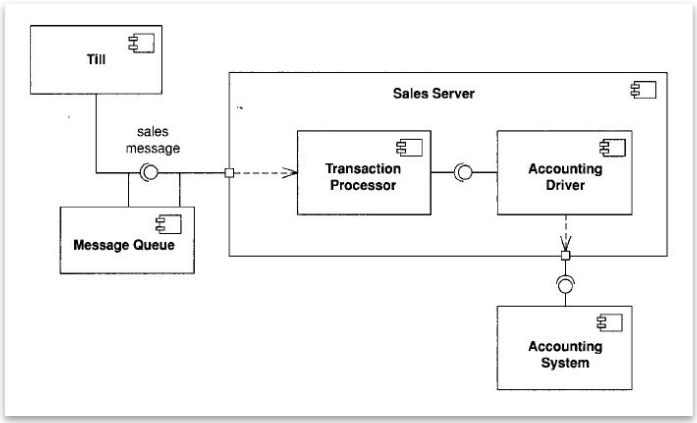
Reference: https://www.computer.org/resources/software-engineering-models#modeling

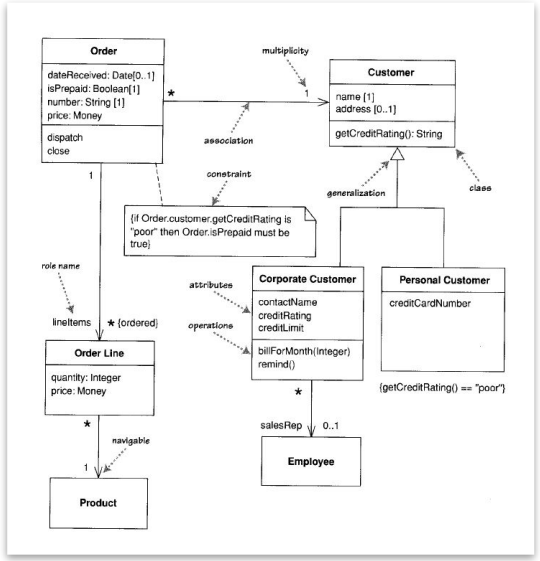
Software Modeling x Lifecycle

Requirements → Architecture → Design → Coding

Focus	goals & user scenarios	components & communication	classes & APIs
Example UML diagrams	• use case diagram	• component diagram • communication diagram • activity diagram	• class diagram • sequence diagram • state machine diagram

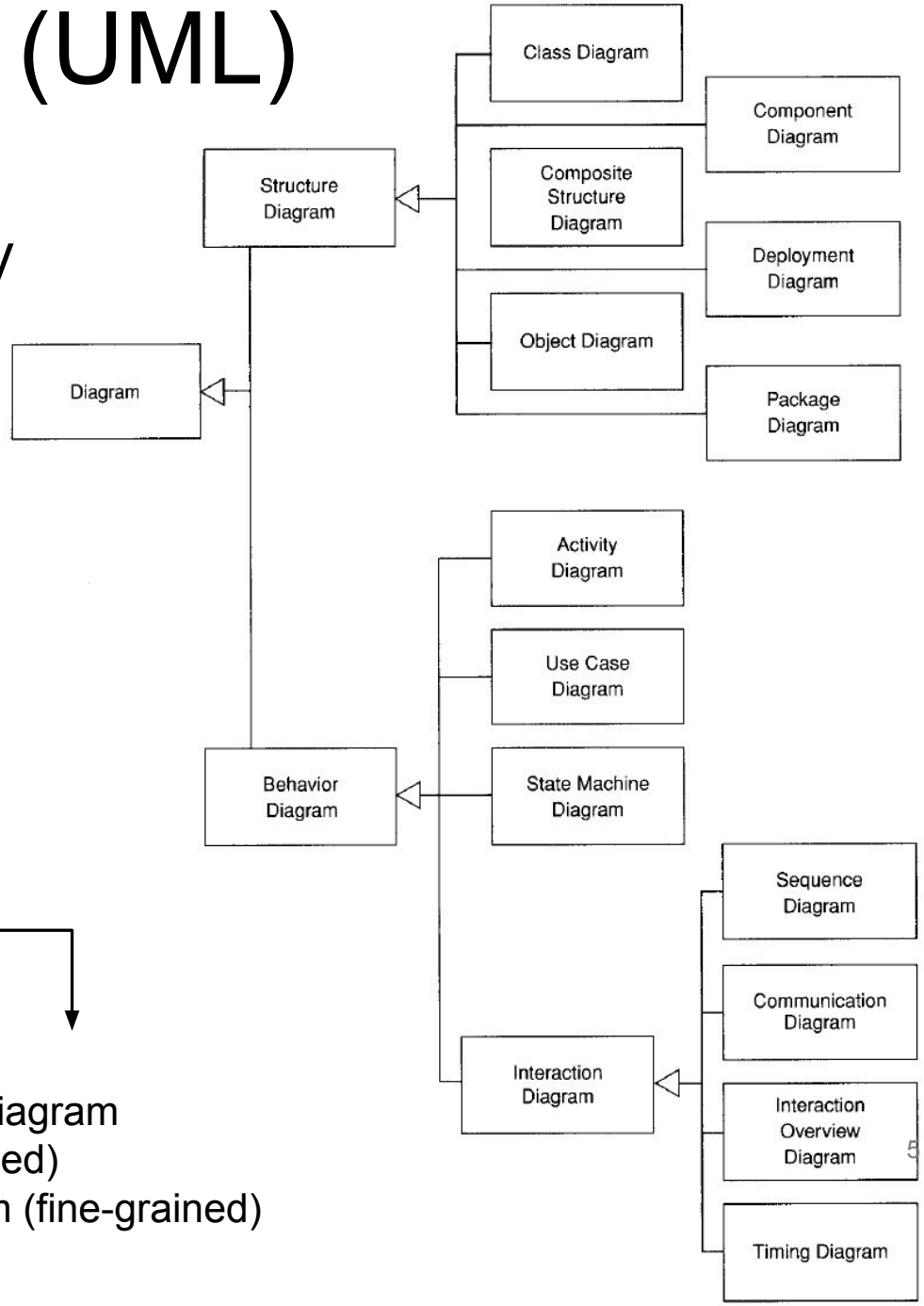






Unified Modeling Language (UML)

- UML is a set of notations, not a methodology or process
  - official standard backed by OMG, version 2.5.1
- UML doesn't solve your problems for you, it gives you a way of writing them down
- Focus on the parts that are useful to you



classification of UML diagram types
overall two classes:
- for static structure
- for dynamic behavior

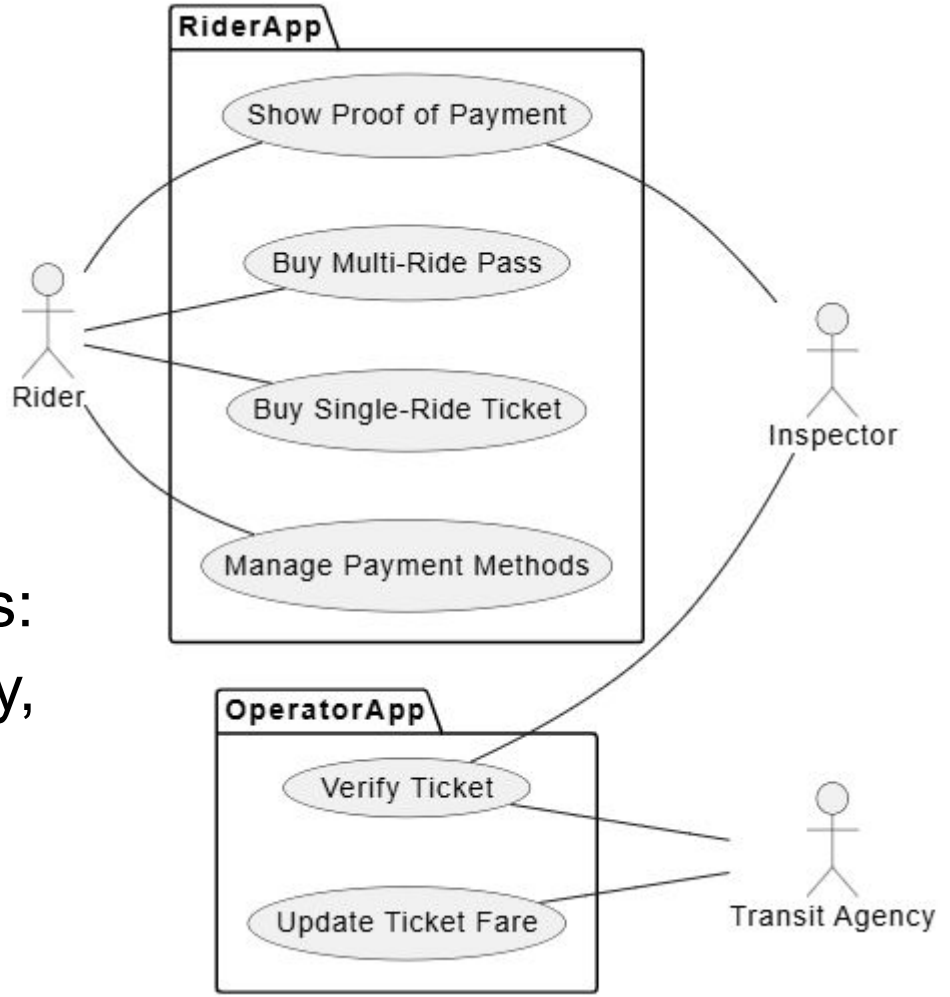
today's focus
- component diagram (coarse-grained)
- class diagram (fine-grained)

UML Tools

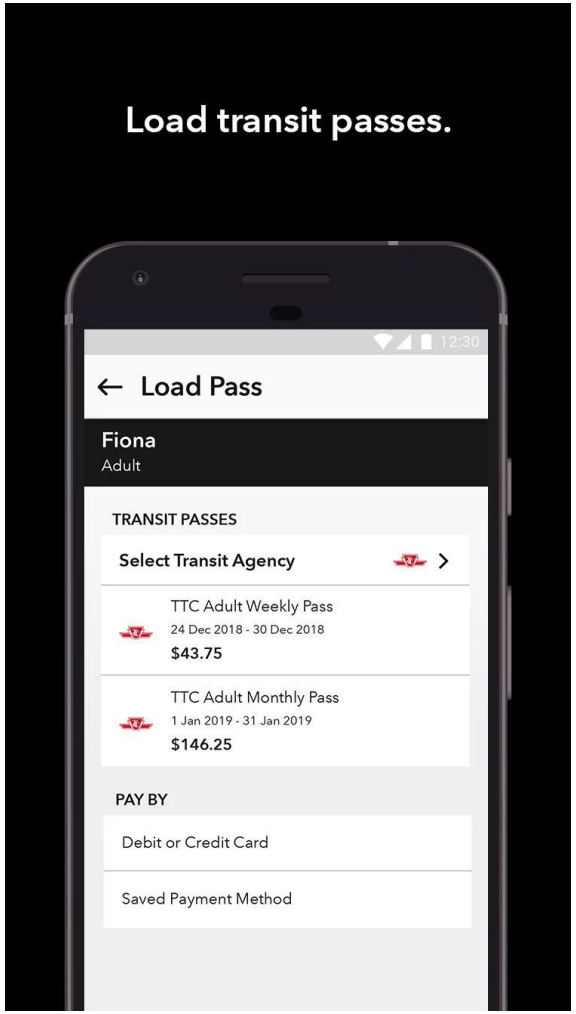
- Drawing
  - Microsoft whiteboard https://whiteboard.office.com
  - draw.io https://app.diagrams.net/
- UML-specific drawing
  - ArgoUML, Microsoft Visio, OmniGraffle, etc.
- UML in plain text (as programming language)
  - Mermaid https://mermaid.live/edit
  - PlantUML https://www.plantuml.com/
- Different tools produce slightly different diagrams
  - don’t get stuck in the details
  - make sure the notations in your diagrams are consistent

Running Example

- Transit ticketing app
- Features:
  single-ride ticket,
  day/week/month pass,
  ticket wallet, …
- Non functional requirements:
  usability, efficiency, reliability,
  security, …

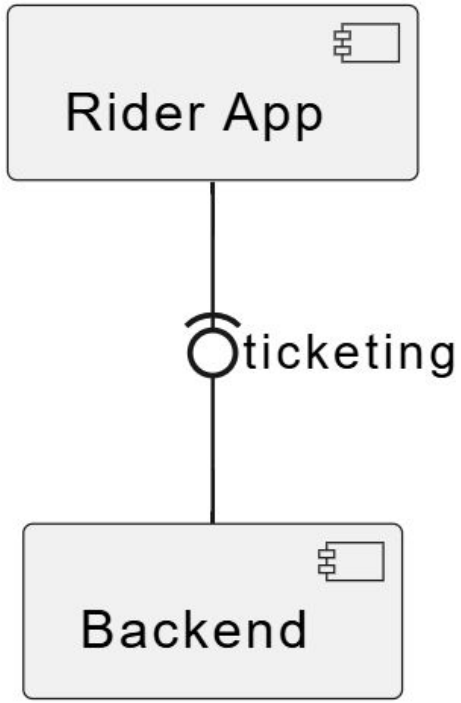


Use Case Diagram



Component Diagram

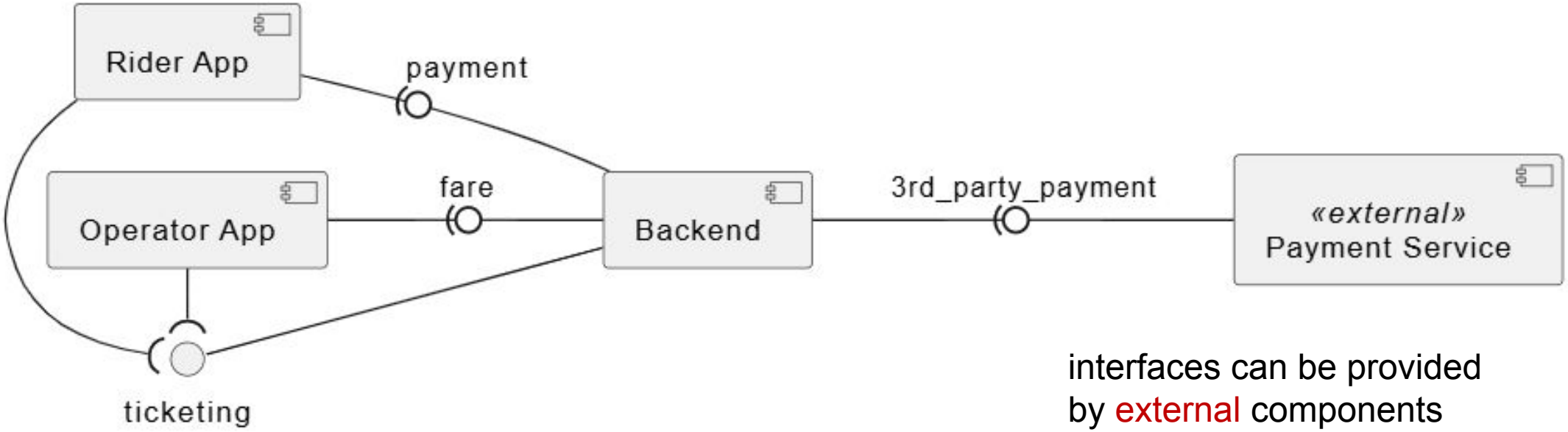
- Shows the organization and dependencies between components/subsystems



component

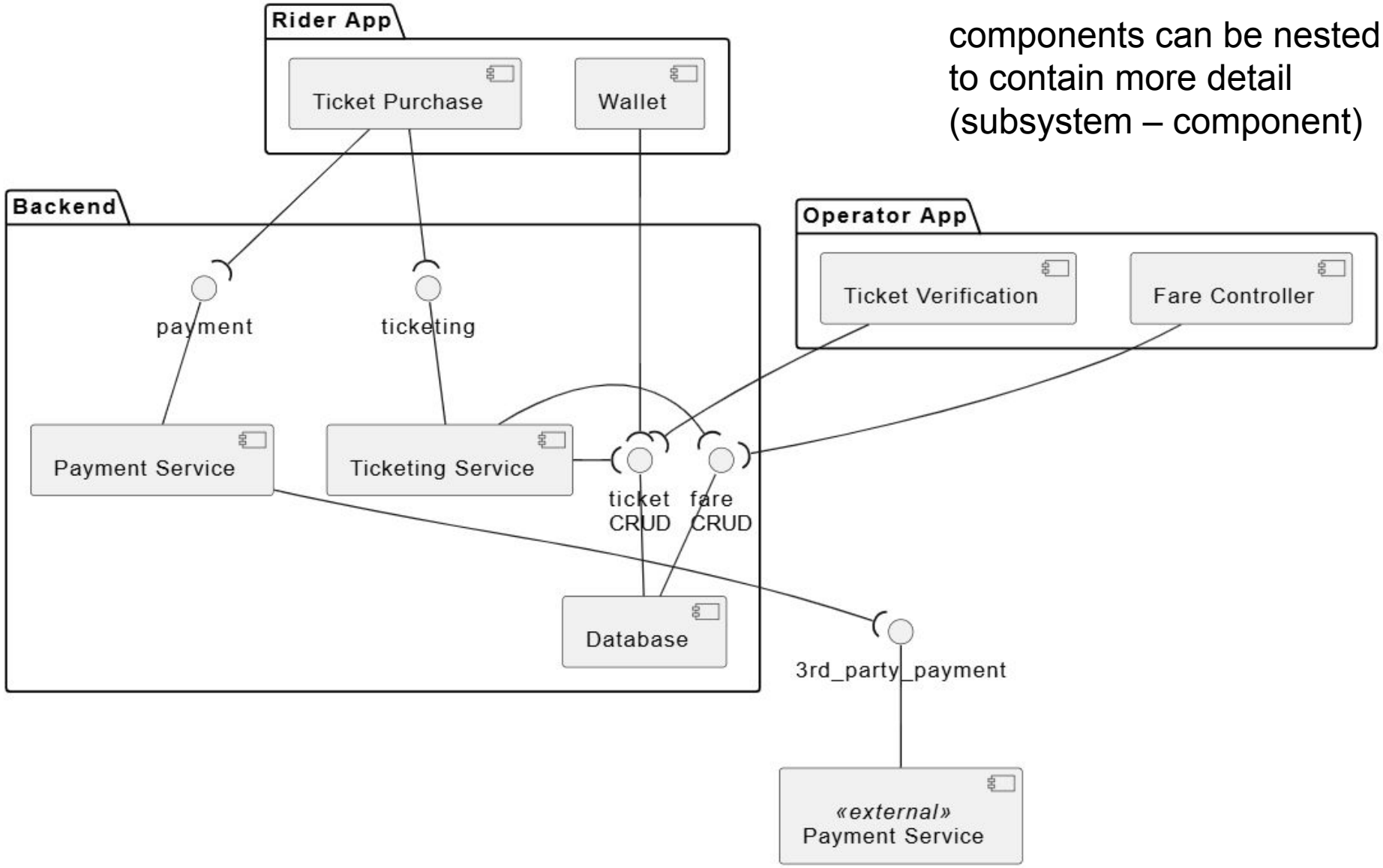
interface
connectors between two components
lollipop: provide an interface
socket: use an interface

Component Diagram



interfaces can be provided
by external components

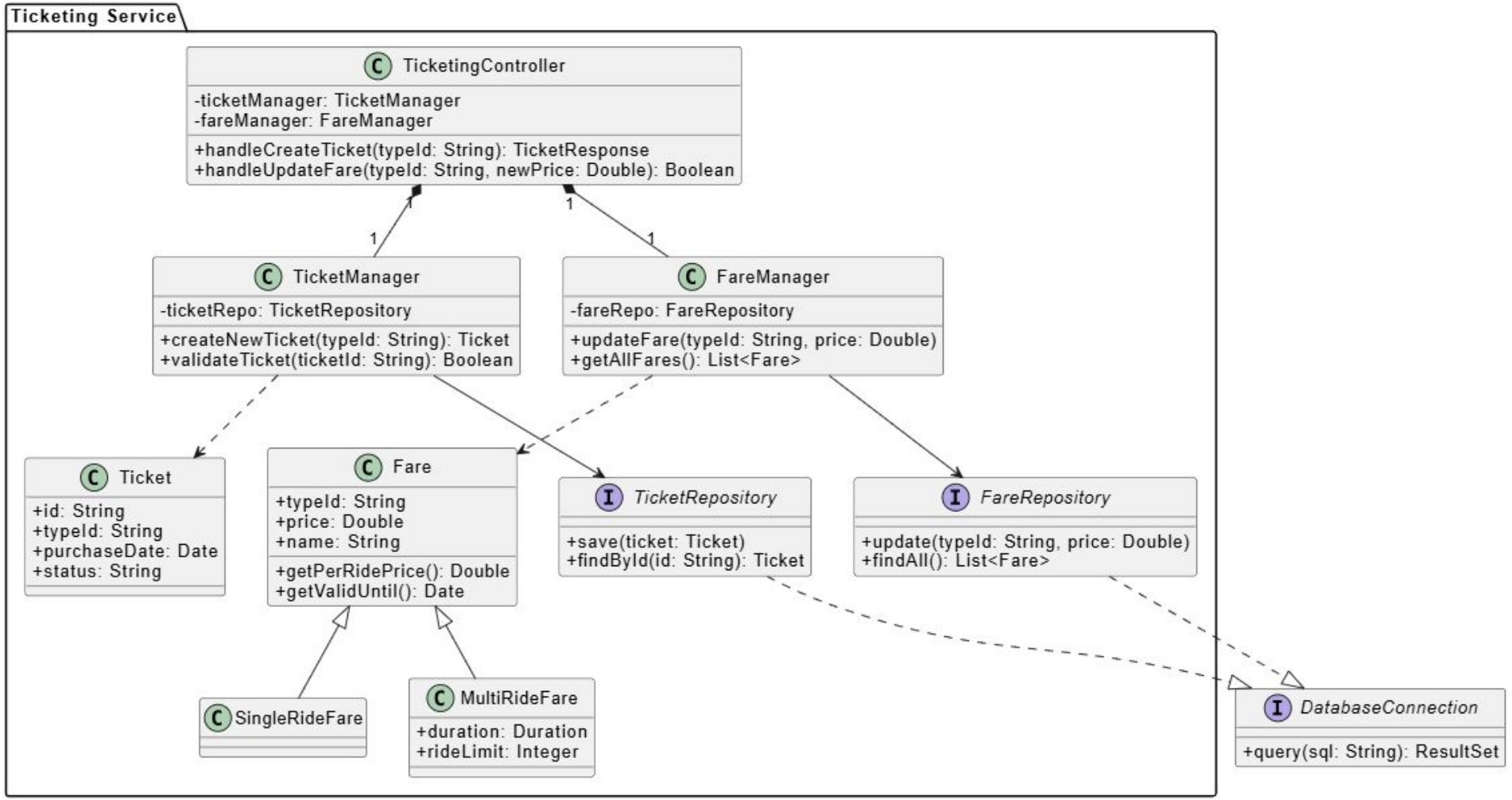
Component Diagram



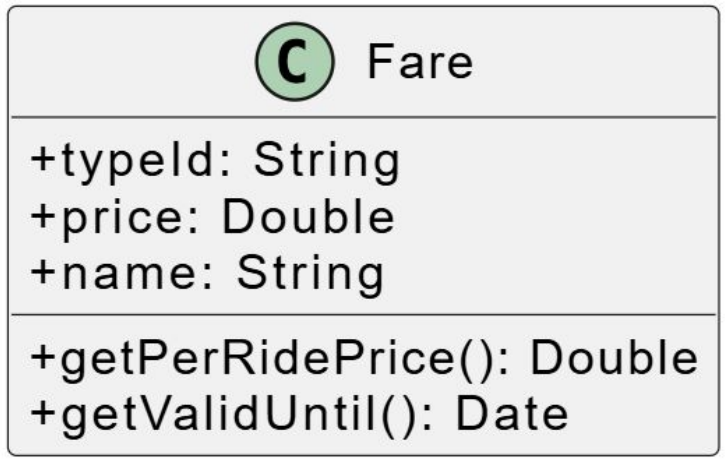
components can be nested…
to contain more detail
(subsystem – component)

Class Diagram

- Describe the types of objects in a component/system and their relationships



Class Diagram – Class



class name (required)
attributes (optional)
~= fields
structural features of a class
operations (optional)
~= methods/functions
actions that a class knows to carry out

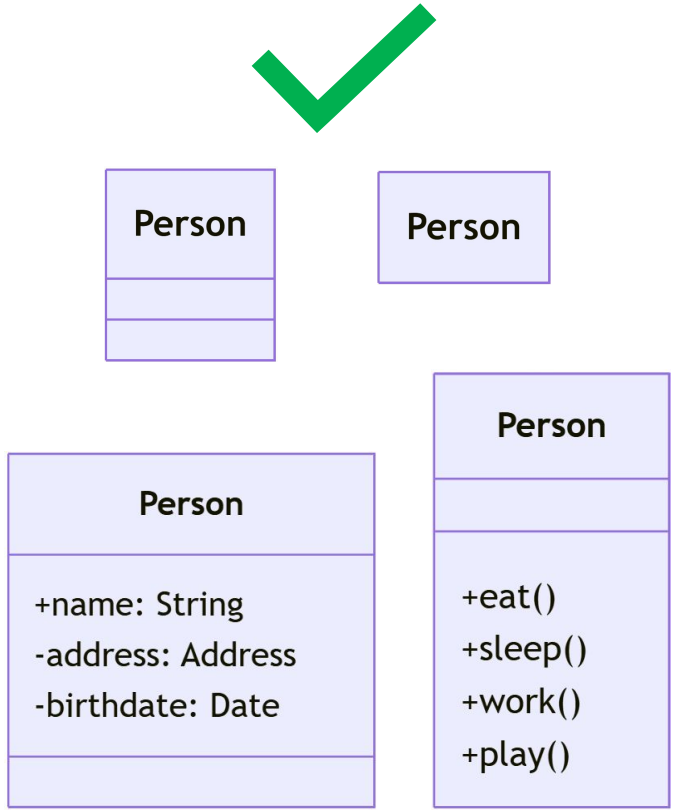
attribute format

```
visibility name: type [multiplicity] = default {property-string}
```

operation format

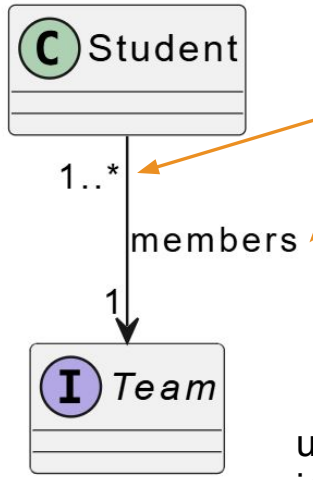
```
visibility name (parameter-list): return-type {property-string}
```

+: public -: private
~: package #: protected



Class Diagram – Association

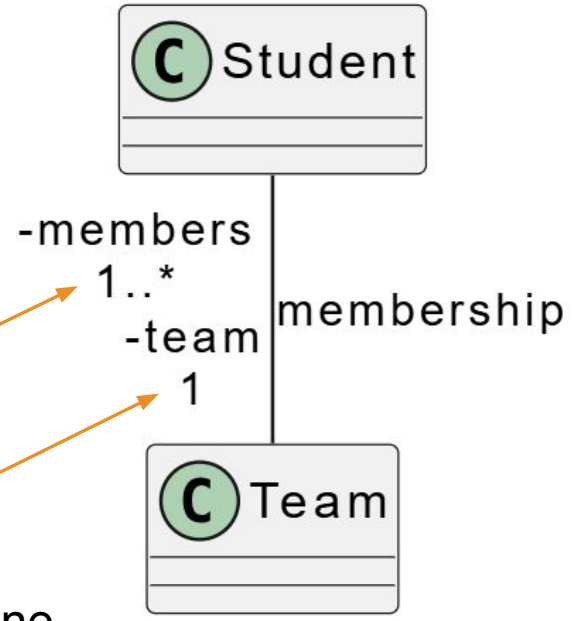
association
two classes that communicate with each other
another way to notate a property (other than attributes)



unidirectional ver.
implies some kind of flow

role name (optional)

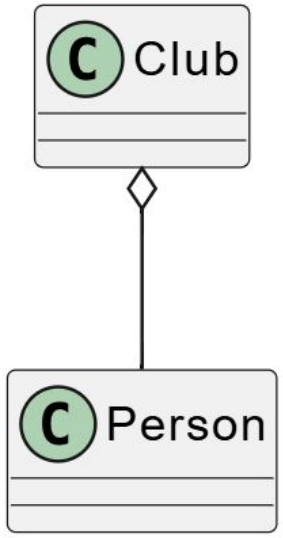
multiplicity (optional)
1: single-valued, exactly one
0..1: optional, zero or one
*: any number, zero or more
1..*: one or more

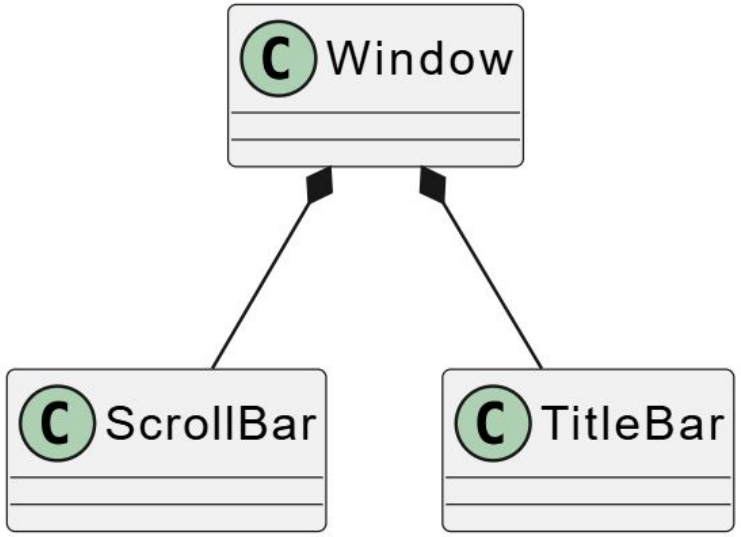


association name (optional)

bidirectional ver.

Class Diagram – Aggregation & Composition

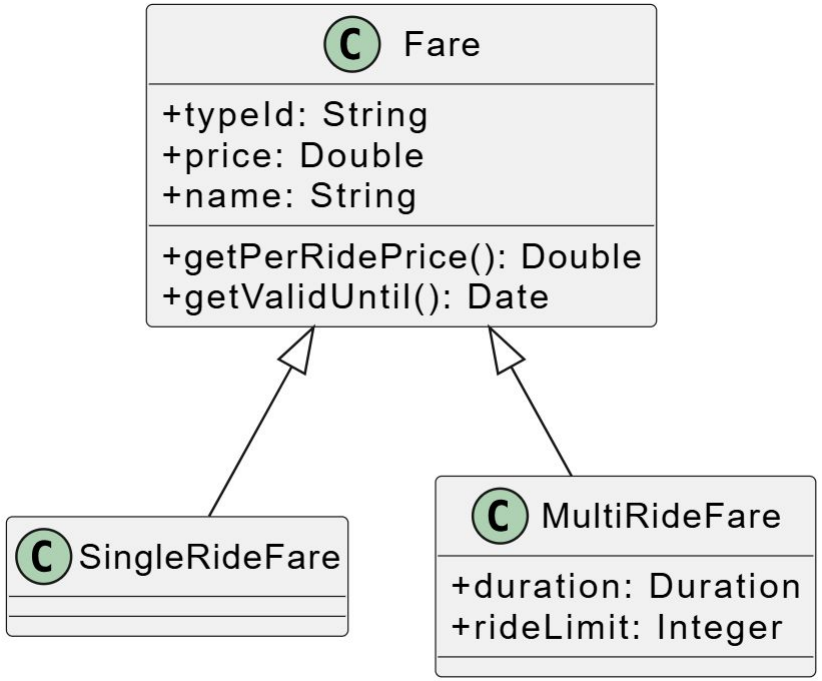




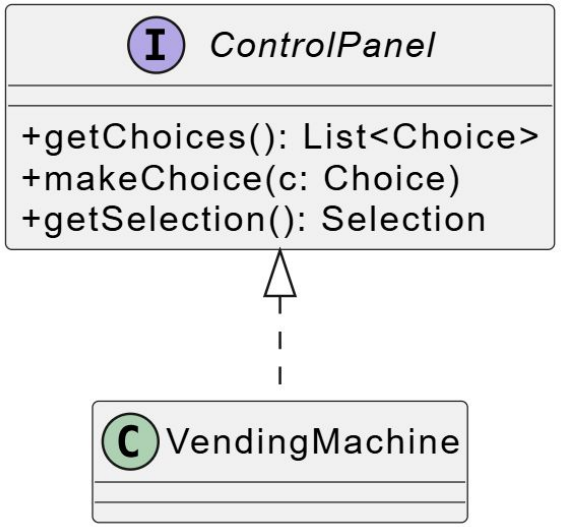
aggregation
a whole-part relationship between
an aggregate (whole) and a constituent part,
where the part can exist independently from the aggregate

composition
a strong ownership and coinficient lifetime of
parts by the whole

Class Diagram – Generalization & Realization

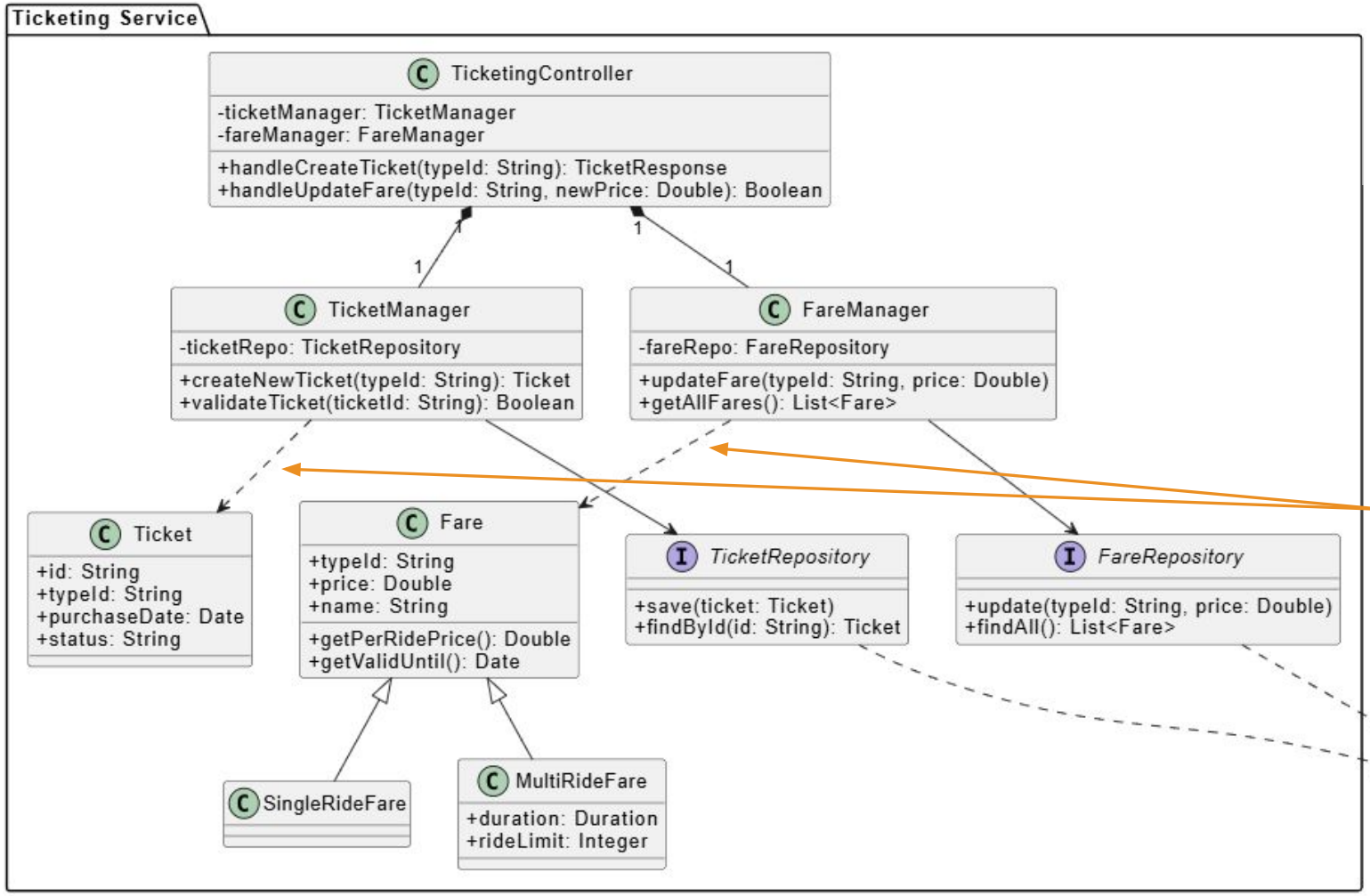


generalization `extends`
connects a subclass to its superclass
inheritance of attributes and operations from the superclass to the subclass



realization `implements`
connects a class with an interface that supplies its behavioral specification

Class Diagram – Dependency & Package

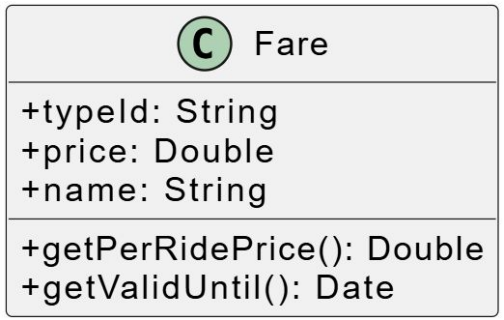


package
container-like element for organizing other elements (classes, packages) into groups

dependency
a semantic relationship between two elements
(e.g., used as parameter or return type)

Class Diagram -> Data Model

- Class diagram can be a handy tool for designing your data model
  - data model: describing how real-world data is conceptually represented as computerized information, and the types of operations available to access and update this information

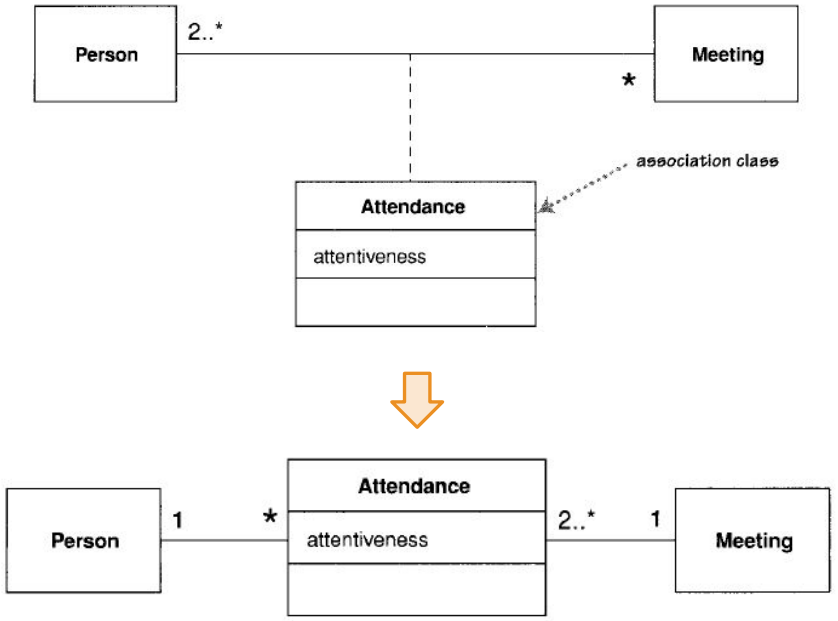


class name -> *table name*

attributes -> *columns* (name and type)

select/add an attribute as *primary key*

association -> *relationship*



Recap

- why model software
- notation: UML
  - (use case diagram)
  - component diagram
  - class diagram