# Principles of Software Construction: Objects, Design, and Concurrency

## **Object-oriented Design**

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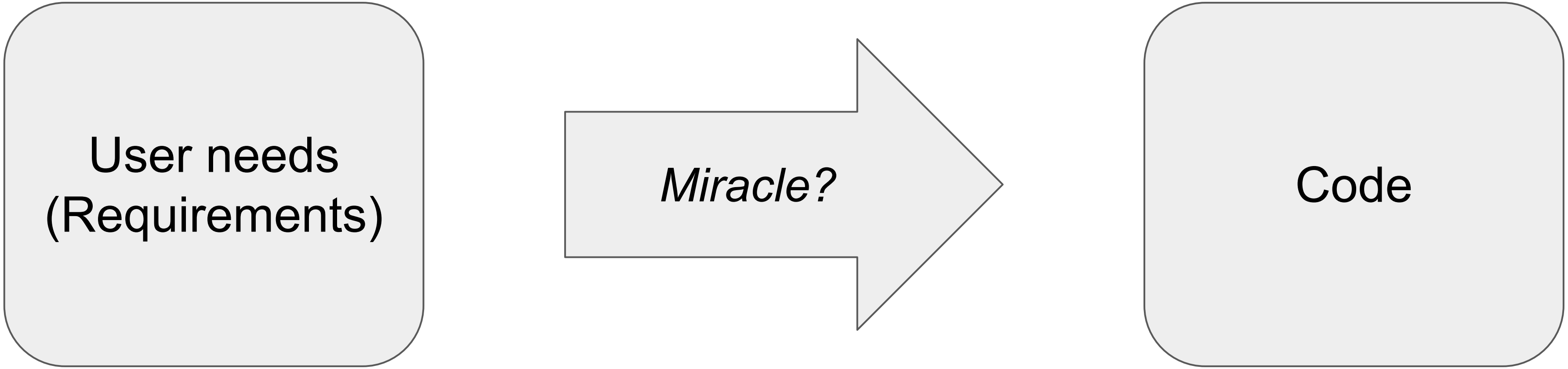
# Administrative issues

- Midterm 1 next week Tuesday
  - Sample questions out shortly
  - Come to OH for help
- Homework 3 (Santorini game engine) out
  - Must start early
- Recitation this week: UML design diagrams
- Piazza:
  - v Google
  - Private v public
  - Mark resolved

# Learning Goals

- Apply GRASP patterns to assign responsibilities in designs
- Use UML notation for sequence and object models
- Reason about tradeoffs among designs
    - Discuss tradeoffs in terms of coupling and cohesion


User needs
(Requirements)
*Miracle?*
Code

## Problem Space

(Domain Model)

→

## Solution Space

(Object Model)

- Real-world concepts
- Requirements, Concepts
- Relationships among concepts
- Solving a problem
- Building a vocabulary

- System implementation
- Classes, objects
- References among objects and inheritance hierarchies
- Computing a result
- Finding a solution

# An object-oriented design process

Model / diagram the problem, define concepts

- **Domain model** (a.k.a. conceptual model), **glossary**

Define system behaviors

- **System sequence diagram**
- **System behavioral contracts**

Assign object responsibilities, define interactions

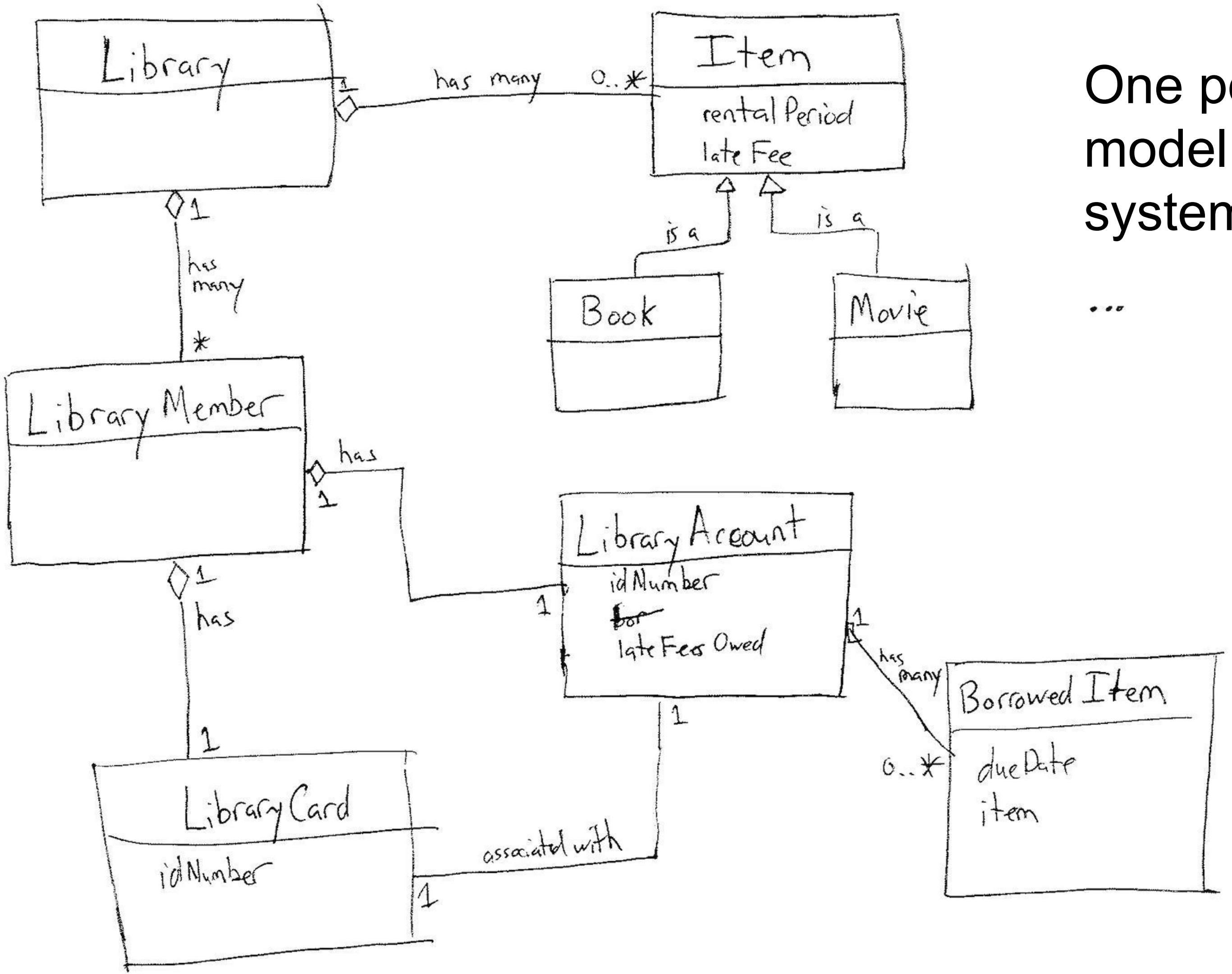
- **Object interaction diagrams**

Model / diagram a potential solution

- **Object model**

OO Analysis: Understanding the problem

OO Design: Defining a solution




One possible domain model for the library system

...

Today

# Modeling Implementations with UML

# A Word on UML

UML is a standard, established notation

Most software engineers can read it, many tools support it

Few practitioners use is rigorously

Commonly used *informally* for sketching, communication, documentation, wall art

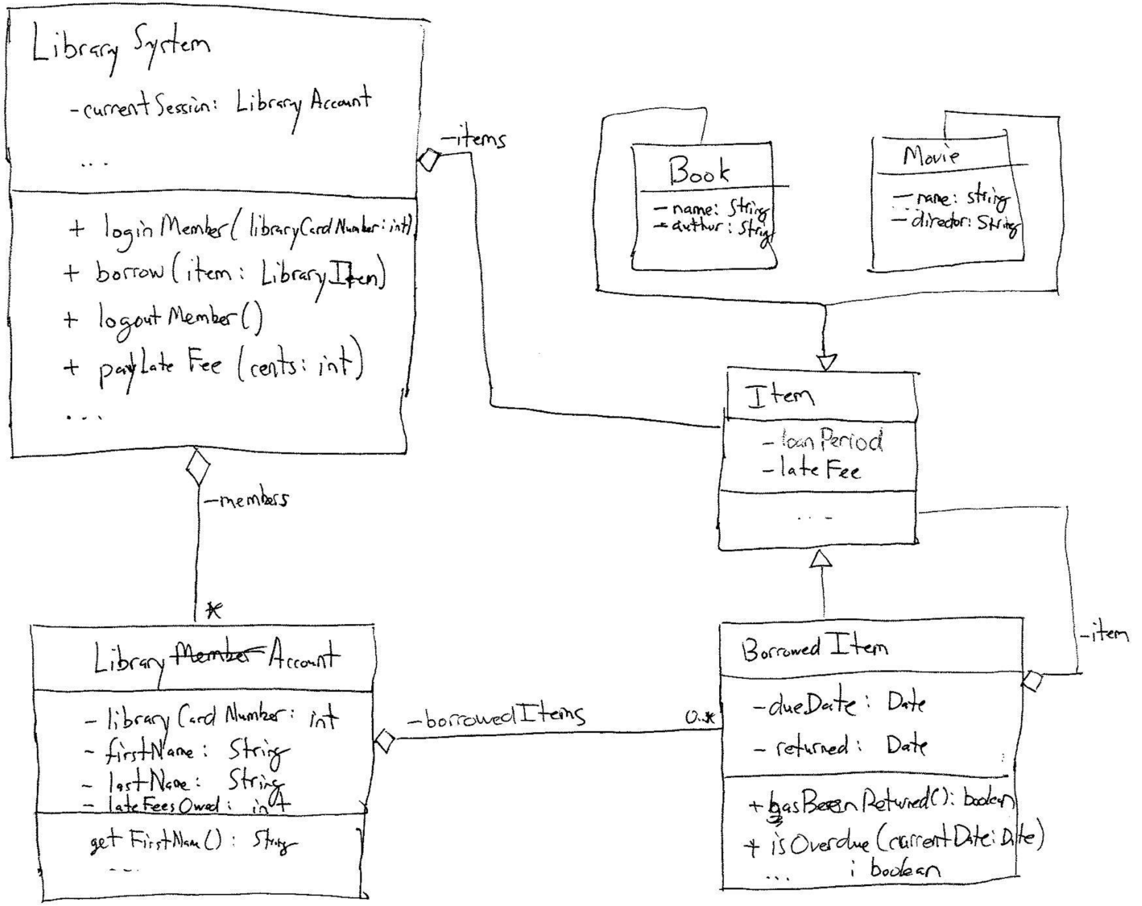
*In this course:* Use UML for communication; follow notation somewhat rigorously, but won't care about all details

# Object Diagrams

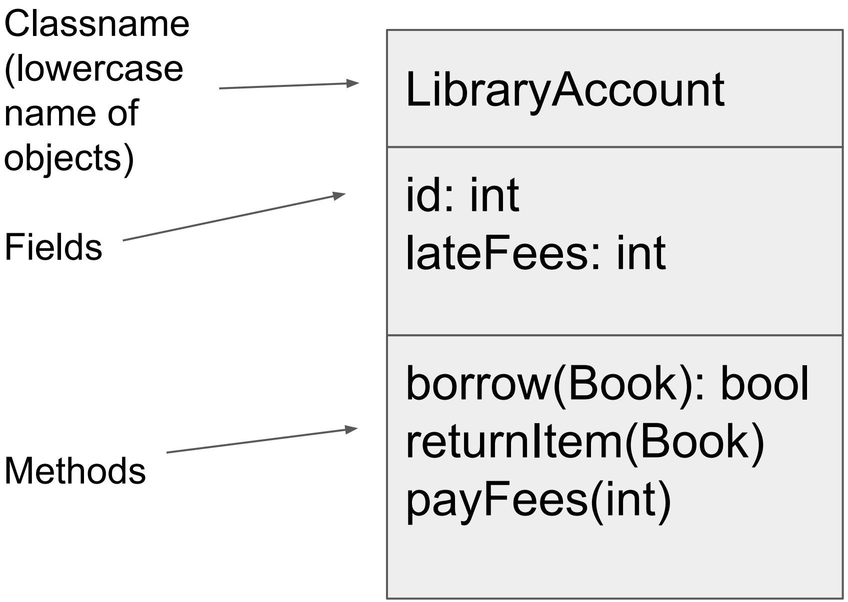
Objects/classes with fields and methods

Interfaces with methods

Associations, visibility, types

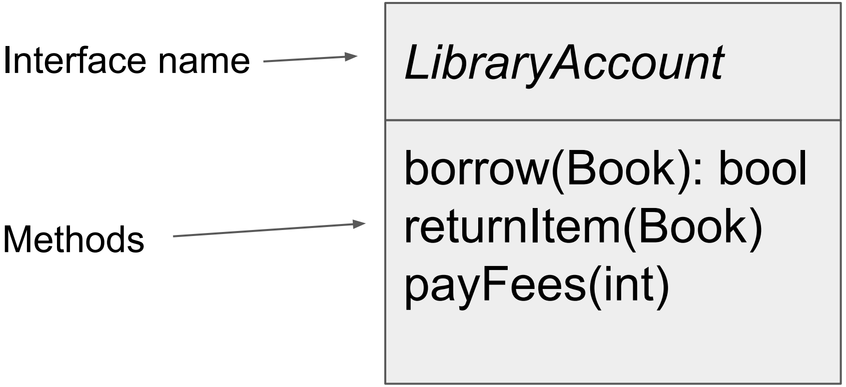


# Object Diagram Notation: Classes/Objects



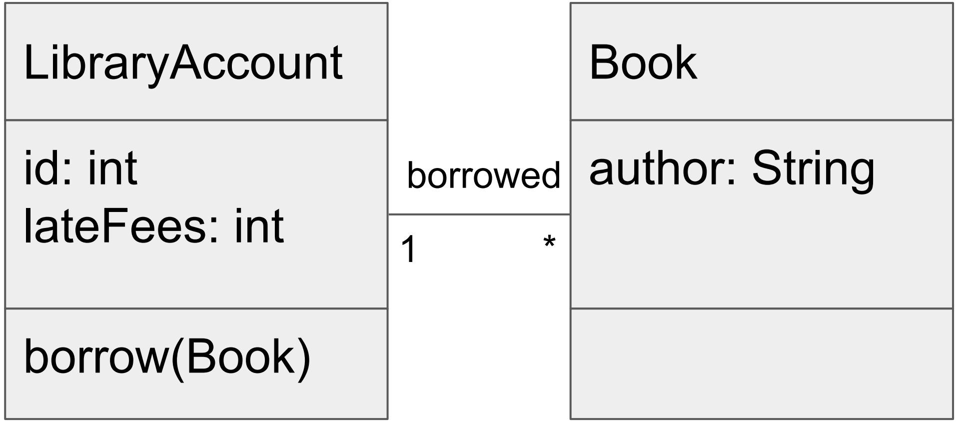

```
class LibraryAccount {
    id: int;
    lateFees: int;
    boolean borrow(Book b) {…}
    void returnItem(Book b) {…}
    void payFees(int payment) {…}
}
```

# Object Diagram Notation: Interfaces



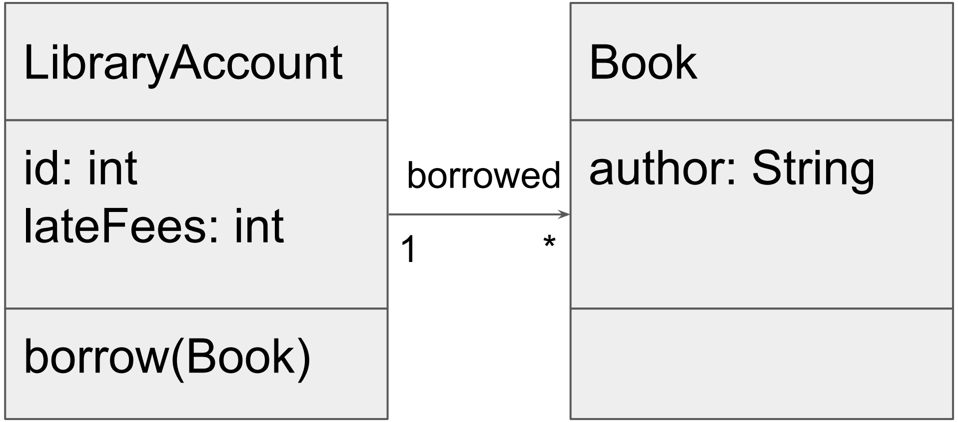

```java
interface LibraryAccount {
    boolean borrow(Book b);
    void returnItem(Book b);
    void payFees(int payment);
}
```

# Object Diagram Notation: Associations



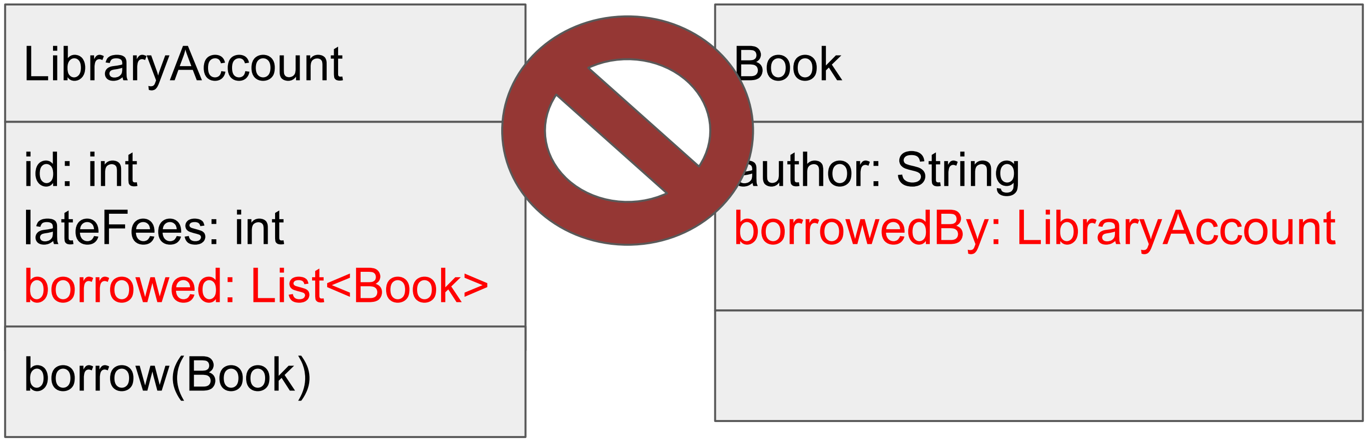

```
class LibraryAccount {
    ...
    List<Book> borrowedBooks;
}
class Book {
    ...
    LibraryAccount borrowedBy;
}
```

# Object Diagram Notation: Associations




```
class LibraryAccount {
    ...
    List<Book> borrowedBooks;
}
class Book {
    ...
}
```

# Object Diagram Notation: Associations



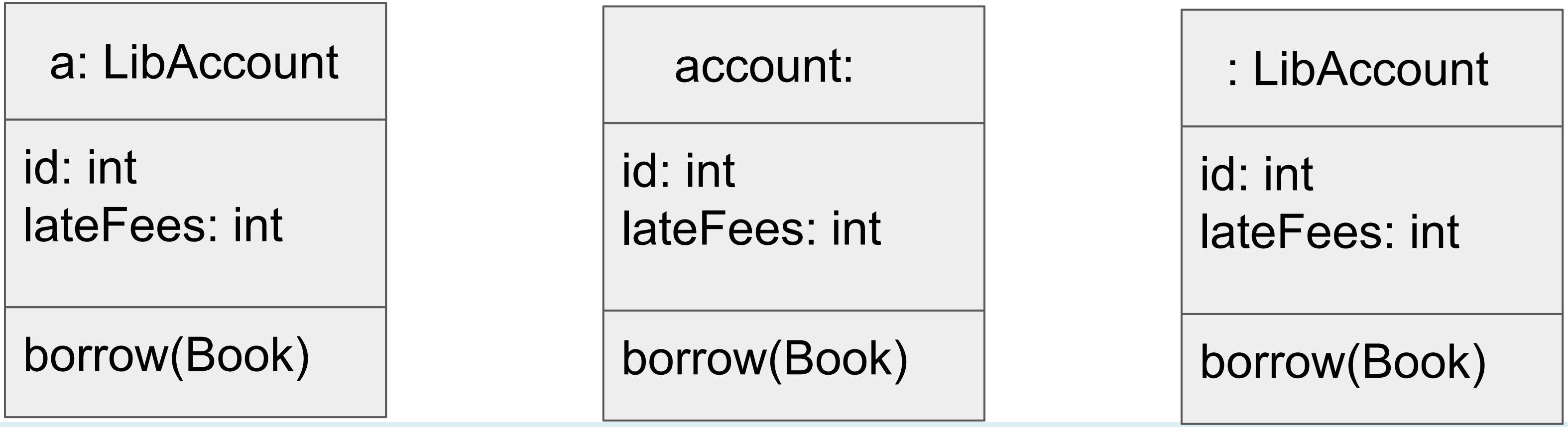

Don't use fields instead or in addition to associations. Use fields only for basic types

# Class Diagram vs Object Diagram

Can model both classes and objects

Terms often used interchangeably

If specific objects should be modeled use “objectId: Class” notation



# Class Diagrams and JavaScript/TypeScript

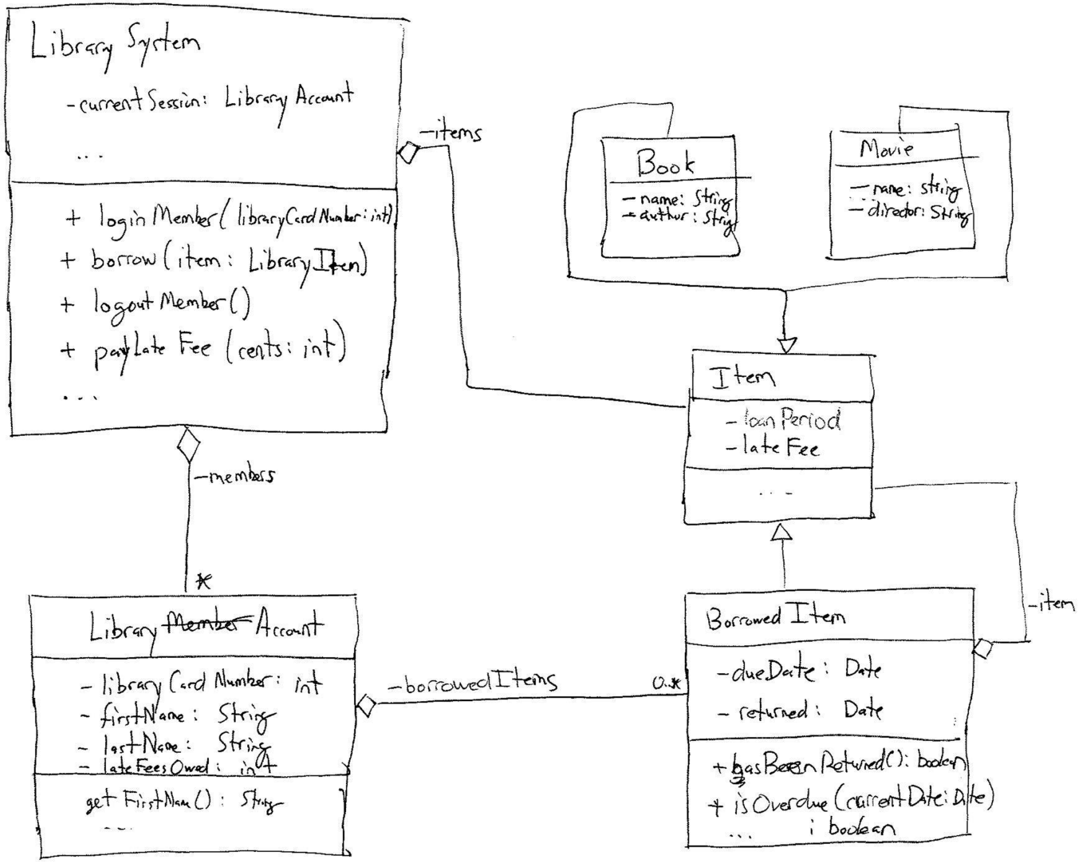
Even when not using classes, use the notation for representing the same idea: many objects sharing a shape

TypeScript interfaces match to class diagram notation

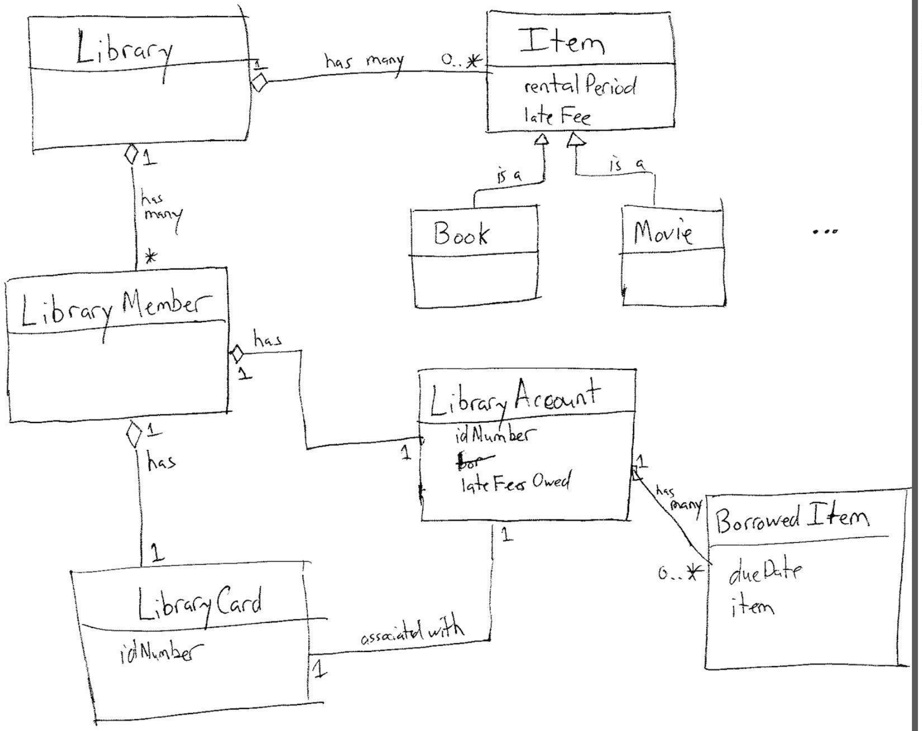
| LibraryAccount |
| --- |
| id: int<br>lateFees: int |
| borrow(Book): bool<br>returnItem(Book)<br>payFees(int) |

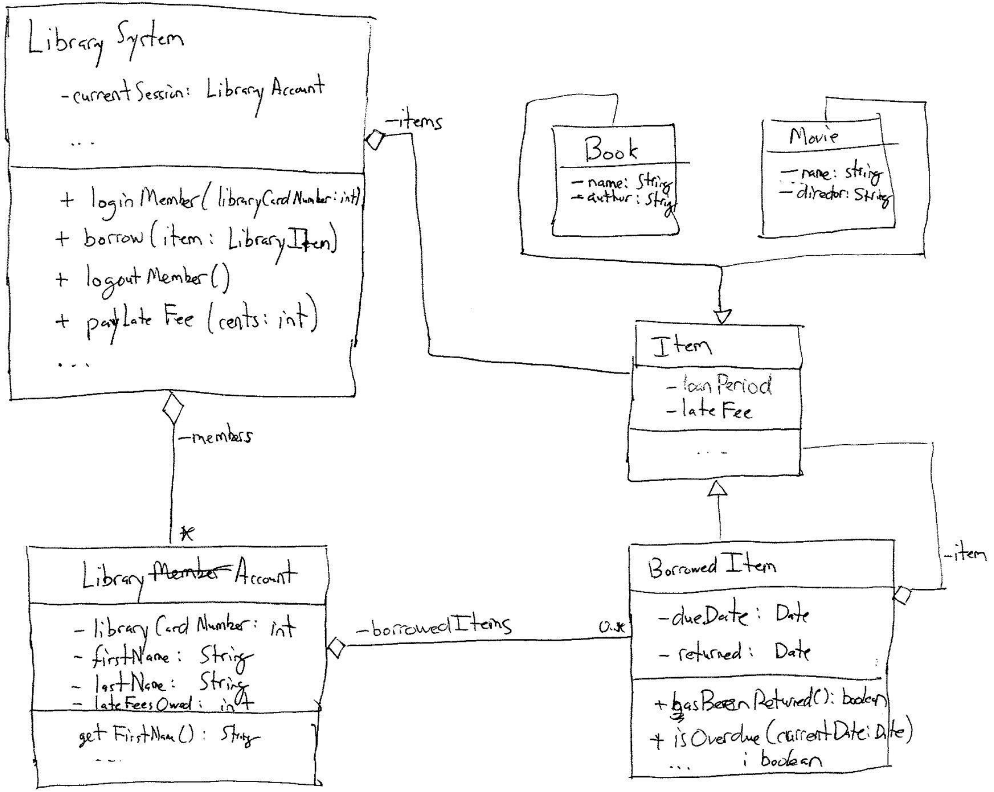
```
function newLibraryAccount(id, lateFees) {
    return {
        borrow: function(book) {…},
        returnItem: function(book) {…},
        payFees: function(payment) {…}
    }
}
```

# One object model for the library system



# Domain model (left) vs object model (right)



# Object diagram notation requirements

We won’t be very picky on notation, but:

- Use boxes with 2 or 3 parts for fields, methods as appropriate for classes/objects, interfaces, concepts
- Include types for fields and methods
- Use associations, not fields, where appropriate
- Use association names and cardinalities (we don’t care about arrow types, except “is-a”)

slido

# Audience Q&A Session

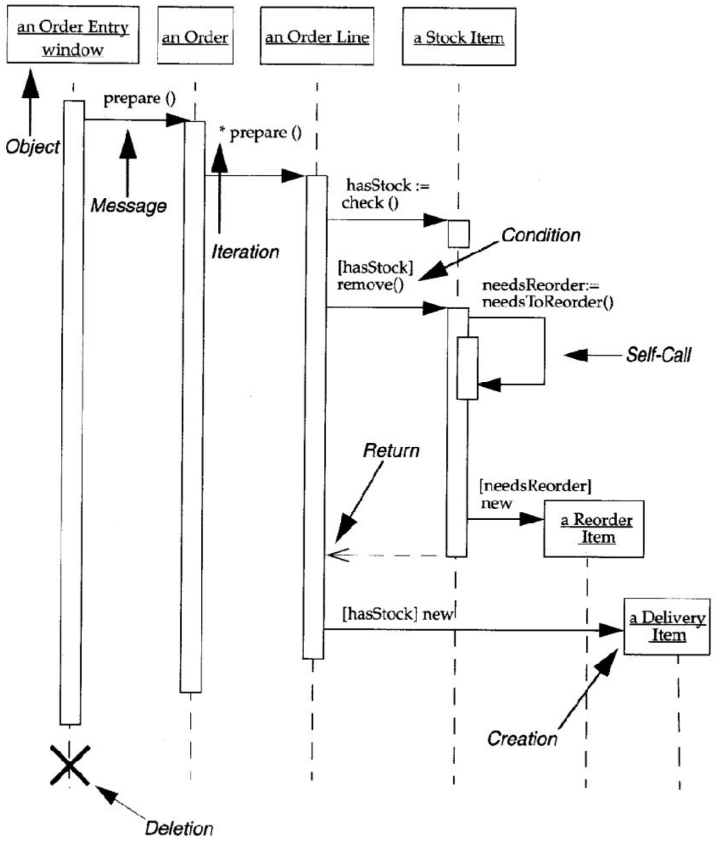
ⓘ Start presenting to display the audience questions on this slide.

# Interaction Diagrams

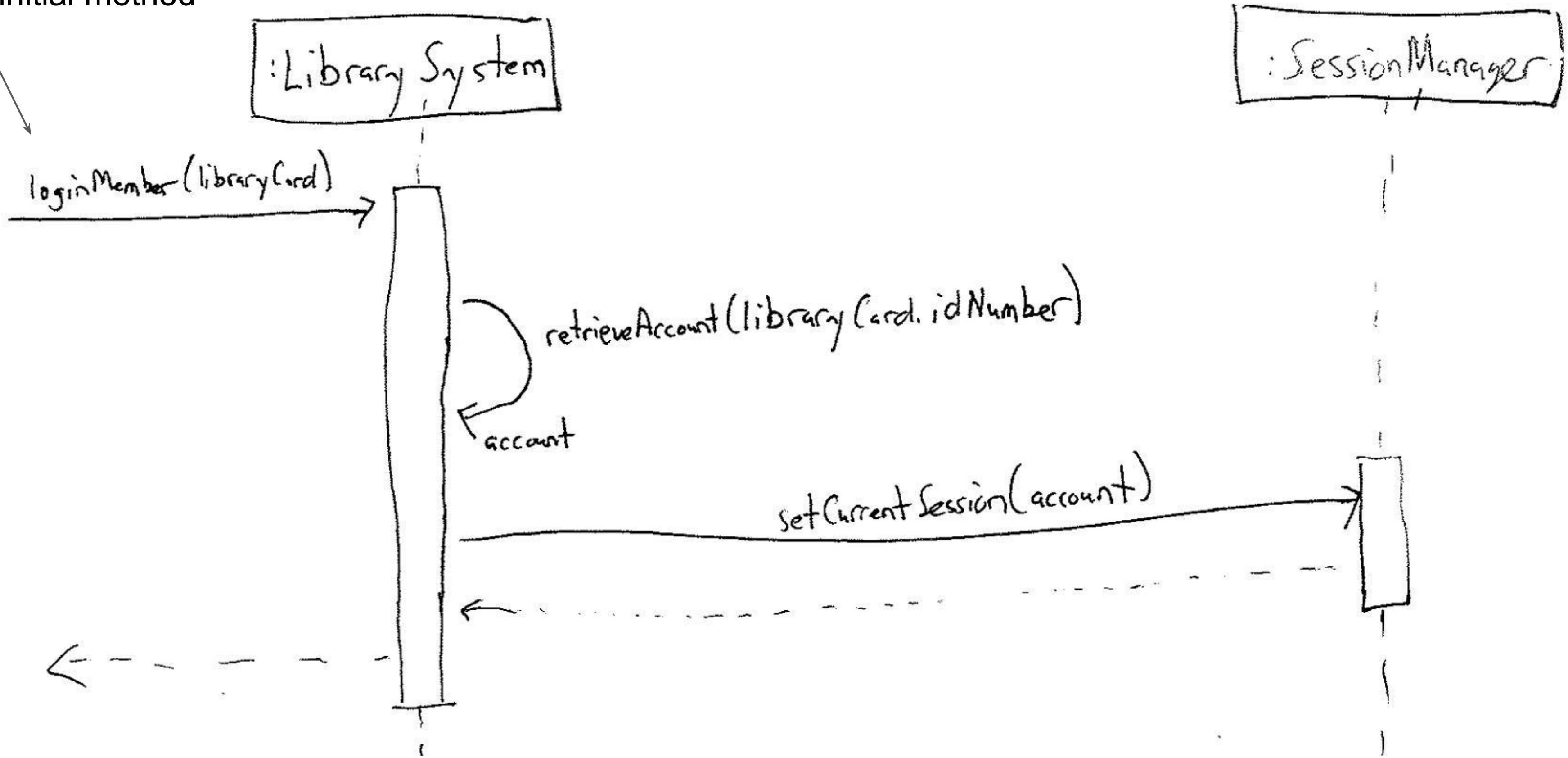
Interactions between objects

Two common notations: sequence diagrams and communication diagrams

Sequence diagrams like system sequence diagrams, but depicting interactions between objects/classes

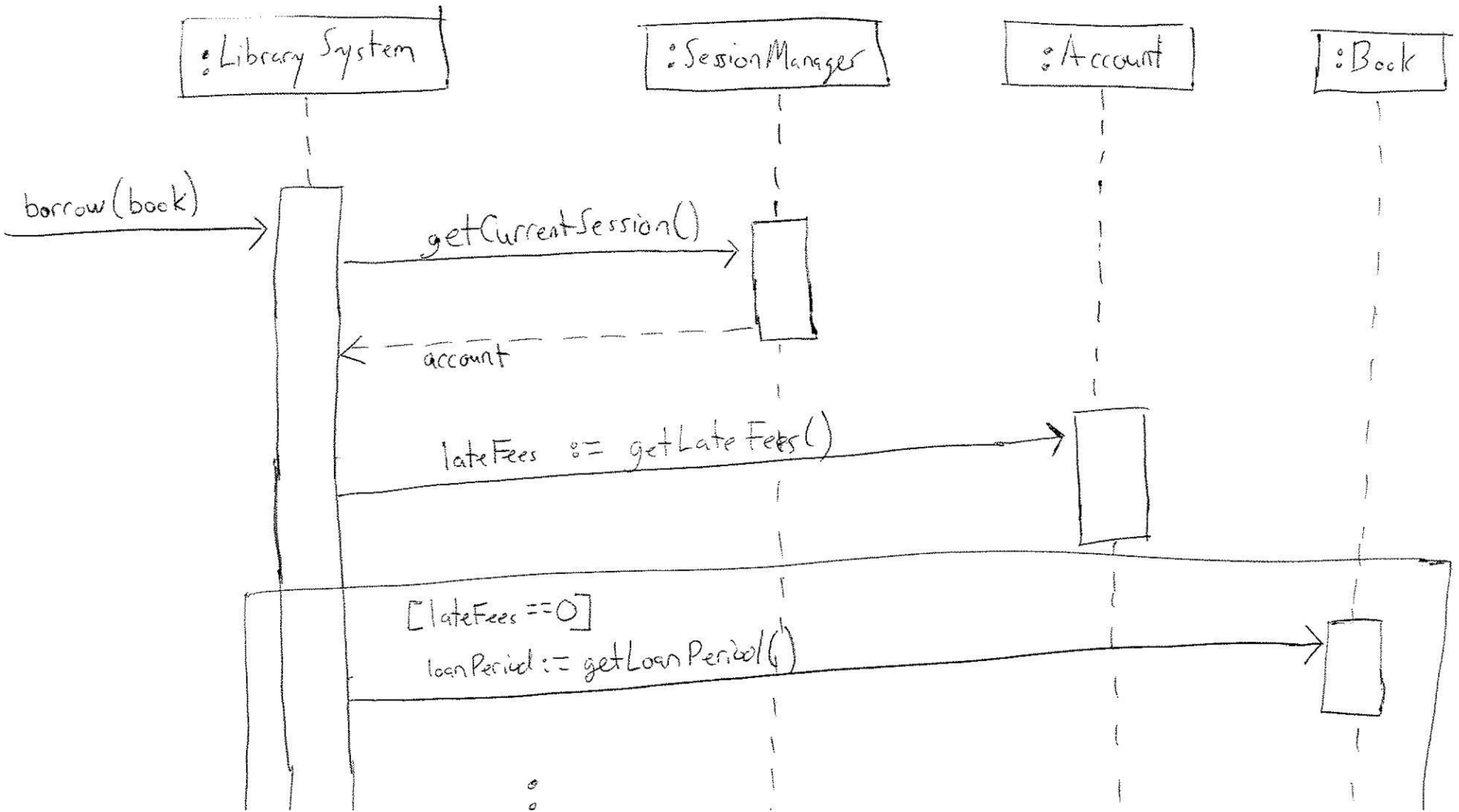


always start with
an initial method



# Interaction Diagram Practice:

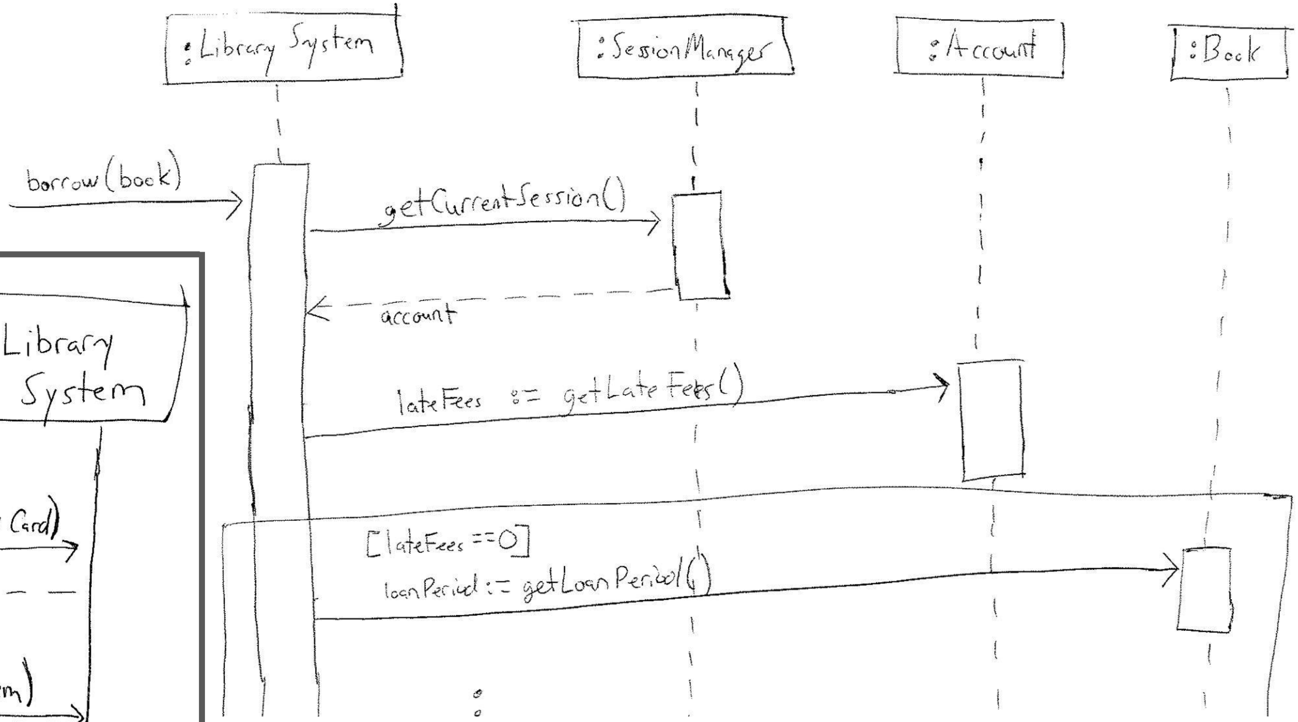
Use case scenario: …and borrow a book.  After confirming that the member has no unpaid late fees, the library system should determine the book's due date by adding its loan period to the current day, and record the book and its due date as a borrowed item in the member's library account.

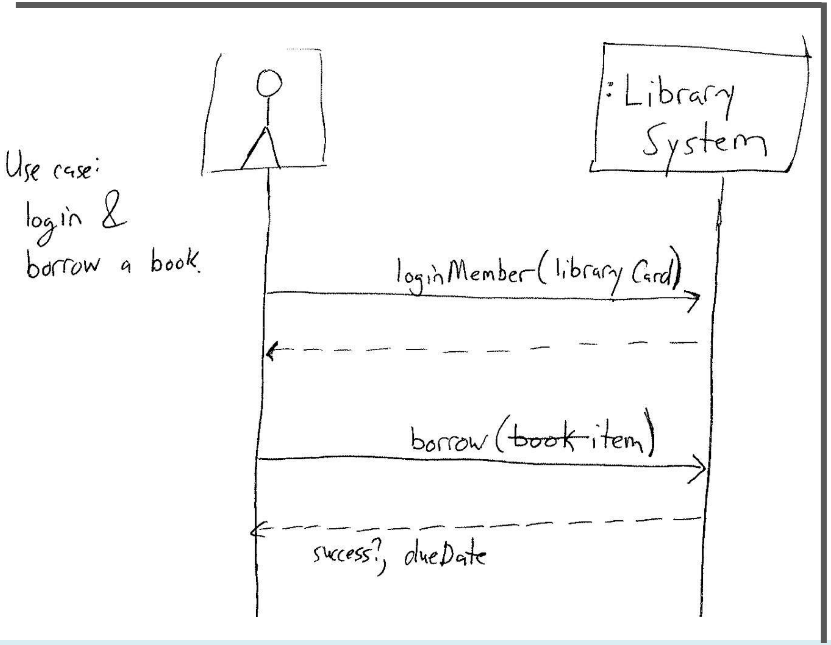

:Library System
:SessionManager
:Account
:Book
borrow(book)
getCurrentSession()
account
lateFees := getLateFees()
[lateFees == 0]
loanPeriod := getLoanPeriod()

# Interaction diagrams help evaluate design alternatives

- Explicitly consider design alternatives
- For each, sketch the interactions implied by the design choice
  - Interactions correspond to the components' APIs

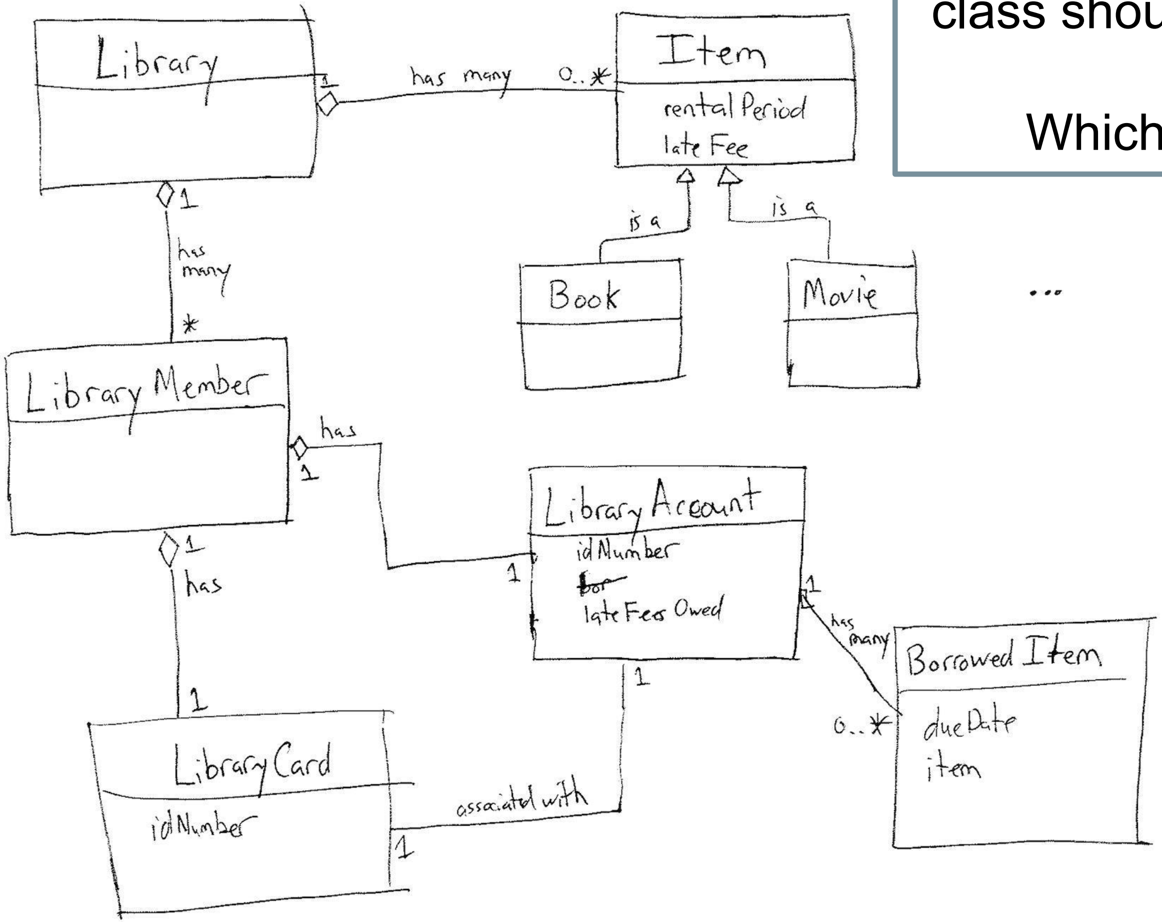
# Sys seq diag. (left) vs interaction diag. (right)



# Object-Level Design

Considering the Library problem, which class should **know** which items have been borrowed by a user?
Which should **compute** late fees?



# Doing and Knowing *Responsibilities*

Responsibilities are related to the obligations of an object in terms of its behavior.

<u>Doing</u> responsibilities of an object include:

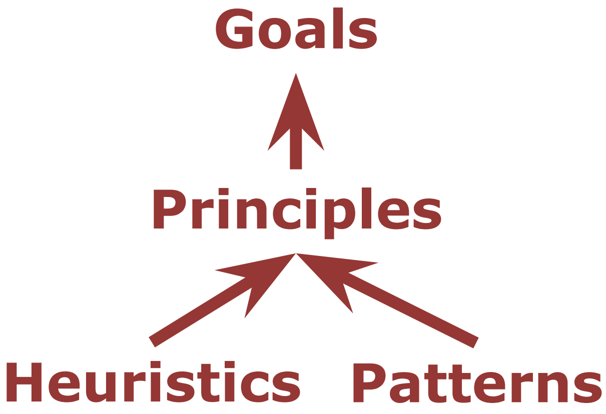
- doing something itself, such as creating an object or doing a calculation
- initiating action in other objects
- controlling and coordinating activities in other objects

<u>Knowing</u> responsibilities of an object include:

- knowing about private encapsulated data
- knowing about related objects
- knowing about things it can derive or calculate

# Design Goals, Principles, and Patterns

- Design Goals
  - Design for change, understanding, reuse, division of labor, …
- Design Principle
  - Low coupling, high cohesion
  - Low representational gap
- Design Heuristics
  - Law of demeter
  - Information expert
  - Creator
  - Controller

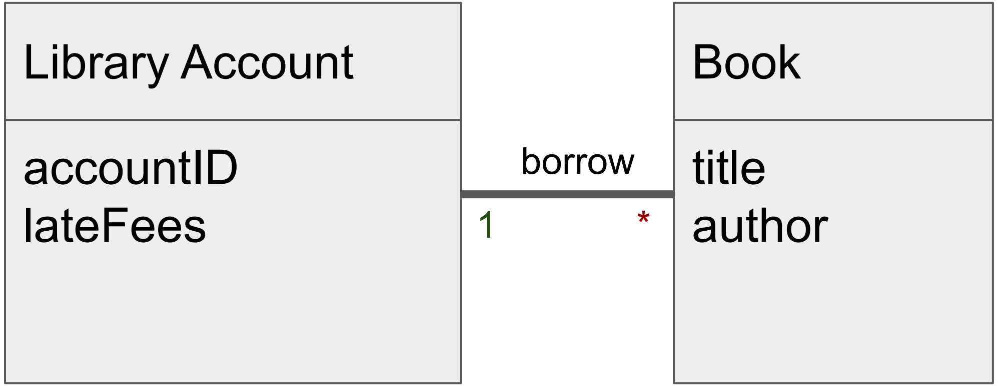


# Design Principle: Low Representational Gap

# Low Representational Gap

Identified concepts provide inspiration for classes in the implementation

Classes mirroring domain concepts often intuitive to understand, rarely change (low representational gap)

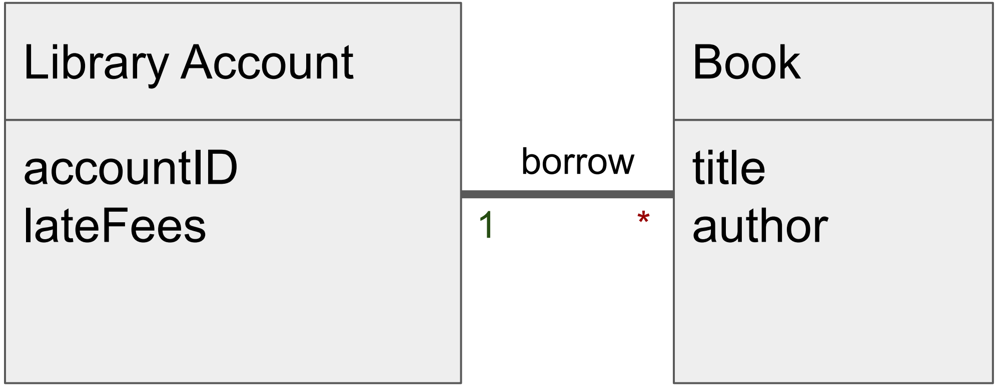



```
class Account {
    id: Int;
    lateFees: Int;
    borrowed: List<Book>;
    boolean borrow(Book) { … }
    void save();
}
class Book { … }
```

# Low Representational Gap

Identified concepts provide inspiration for classes in the implementation

Classes mirroring domain concepts often intuitive to understand, rarely change (low representational gap)




```
class LibraryDatabase {
    Map<Int, List<Int>>
        borrowedBookIds;
    Map<Int, Int> lateFees;
    Map<Int, String>
        bookTitles;
}
class DatabaseRow { … }
```

# Designs with Low Representational Gap

- Create software class for each domain class, create corresponding relationships
- Design goal: Design for change
- This is only a starting point!
  - Not all domain classes need software correspondence
  - Pure fabrications might be needed
  - Other principles often more important

# Lo… tional C…

**Problem Space**

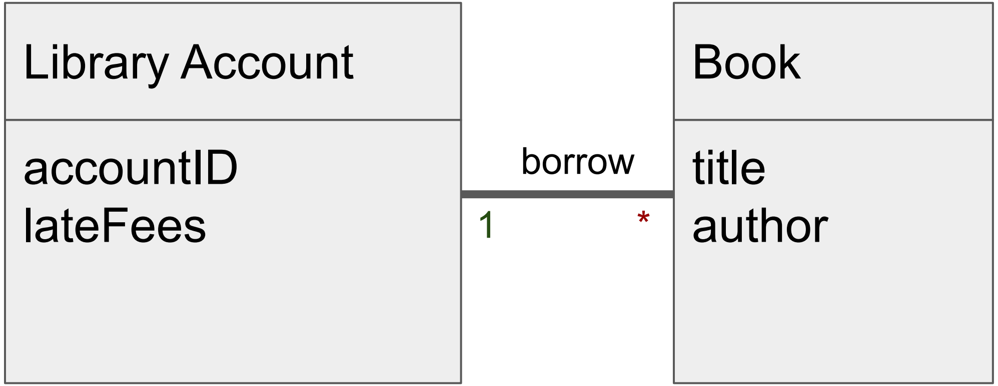
**(Domain Model)**

**Solution Space**

**(Object Model)**

Id… iration fo… n

Cla… ncepts often intuitive …
(low representational gap)




```
    lateFees: Int;
    borrowed: List<Book>;
    boolean borrow(Book) { … }
    void save();
}
class Book { … }
```

# DESIGN PRINCIPLE: LOW COUPLING

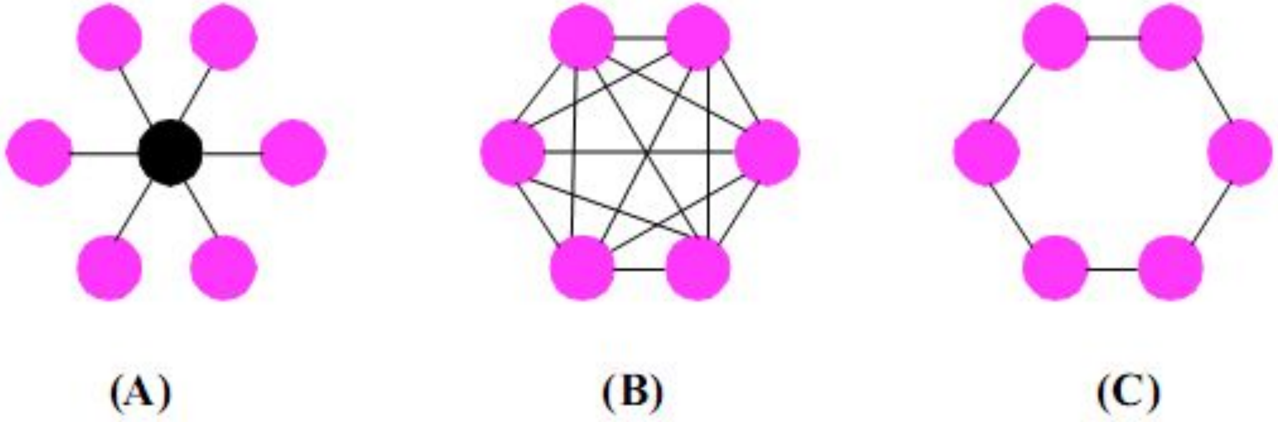
# Design Principle: Low Coupling

A module should depend on as few other modules as possible

- Enhances understandability (design for underst.)
  - Limited understanding of context, easier to understand in isolation
- Reduces the cost of change (design for change)
  - Little context necessary to make changes
  - When a module interface changes, few modules are affected (reduced rippling effects)
- Enhances reuse (design for reuse)
  - Fewer dependencies, easier to adapt to a new context

# Topologies with different coupling

*Types of module interconnection structures*



# High Coupling is undesirable

- Element with low coupling depends on only few other elements (classes, subsystems, …)
  - “few" is context-dependent
- A class with high coupling relies on many other classes
  - Changes in related classes force local changes; changes in local class forces changes in related classes (brittle, rippling effects)
  - Harder to understand in isolation.
  - Harder to reuse because requires additional presence of other dependent classes
  - Difficult to extend – changes in many places

```
class Shipment {
    private List<Box> boxes;
    int getWeight() {
        int w=0;
        for (Box box: boxes)
            for (Item item: box.getItems())
                w += item.weight;
        return w;
}
class Box {
    private List<Item> items;
    Iterable<Item> getItems() { return items;}
}
class Item {
    Box containedIn;
    int weight;
}
```

**Which classes are coupled?**
**How can coupling be improved?**

We ran out of time here. To be continued

**Draw an interaction diagram to illustrate what's happening.**

**How can coupling be improved?**

```
class Box {
    private List<Item> items;
    private Map<Item,Integer> weights;
    Iterable<Item> getItems() { return items;}
    int getWeight(Item item) { return weights.get(item);}
}
class Item {
    private Box containedIn;
    int getWeight() { return containedIn.getWeight(this);}
}
```

# Design Heuristic: Law of Demeter

- *Each module should have only limited knowledge about other units: only units "closely" related to the current unit*
- In particular: Don’t talk to strangers!
- For instance, no a.getB().getC().foo()

```
for (let i of shipment.getBox().getItems())
   shipmentWeight += i.getWeight() …
```

# Coupling: Discussion

- High coupling to very stable elements is usually not problematic
  - A stable interface is unlikely to change, and likely well-understood
  - *Prefer coupling to interfaces over coupling to implementations*
- (Details next time:) Subclass/superclass coupling is particularly strong
  - protected fields and methods are visible
  - subclass is fragile to many superclass changes, e.g. change in method signatures, added abstract methods
  - *Guideline: prefer composition to inheritance, to reduce coupling*
- Coupling is one principle among many
  - Consider cohesion, low repr. gap, and other principles

# Design Goals

- Explain how low coupling supports
  - design for change
  - design for understandability
  - design for division of labor
  - design for reuse
  - …

# Design Goals

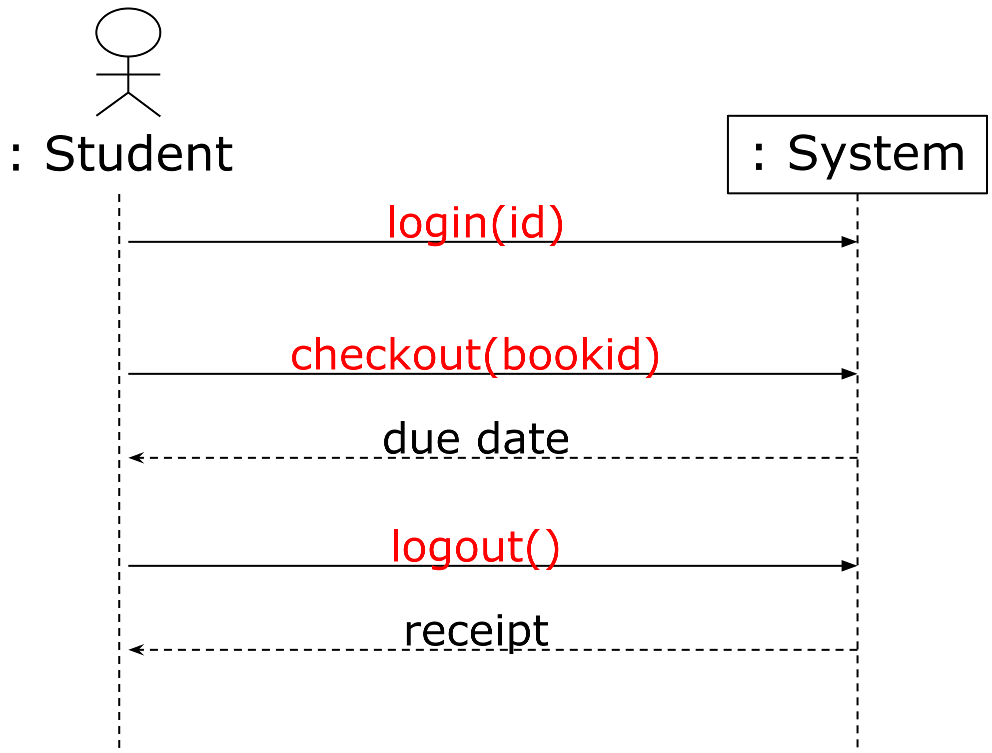
- design for change
  - changes easier because fewer dependencies on fewer other objects
  - changes are less likely to have rippling effects
- design for understandability
  - fewer dependencies to understand (e.g., a.getB().getC().foo())
- design for division of labor
  - smaller interfaces, easier to divide
- design for reuse
  - easier to reuse without complicated dependencies

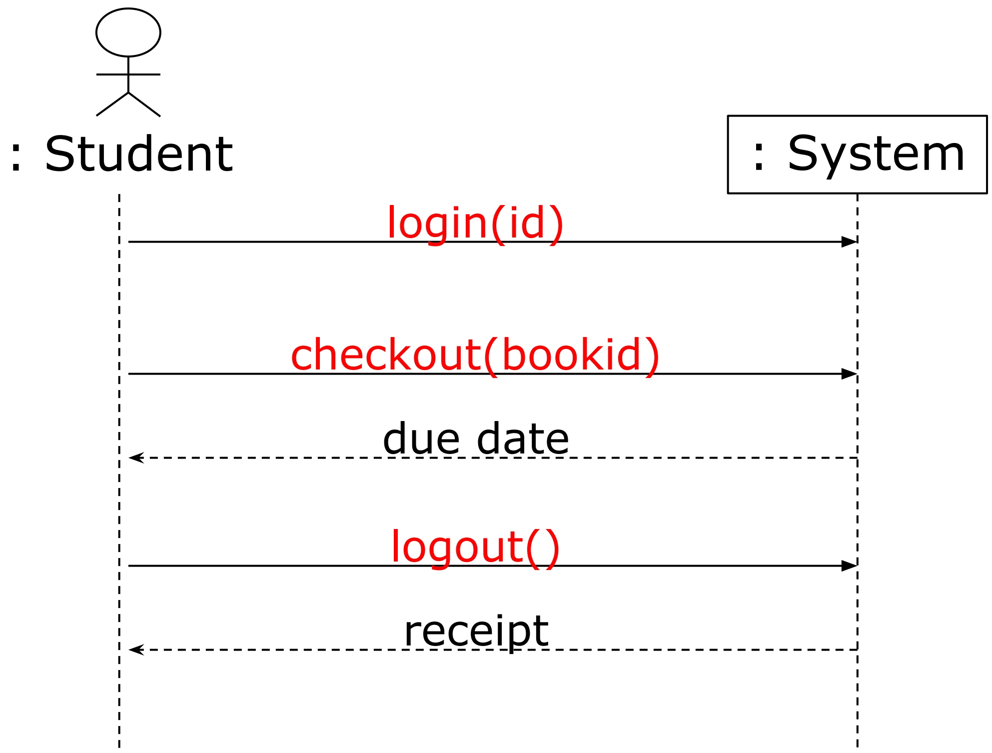
# Design Heuristic: CONTROLLER

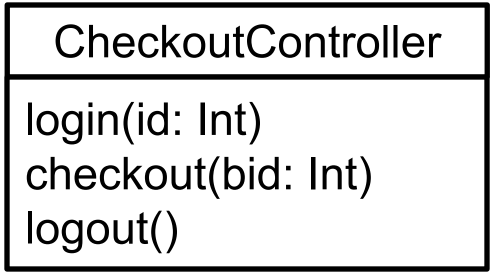
## (also DESIGN PATTERN: FAÇADE )

# Controller (Design Heuristic)

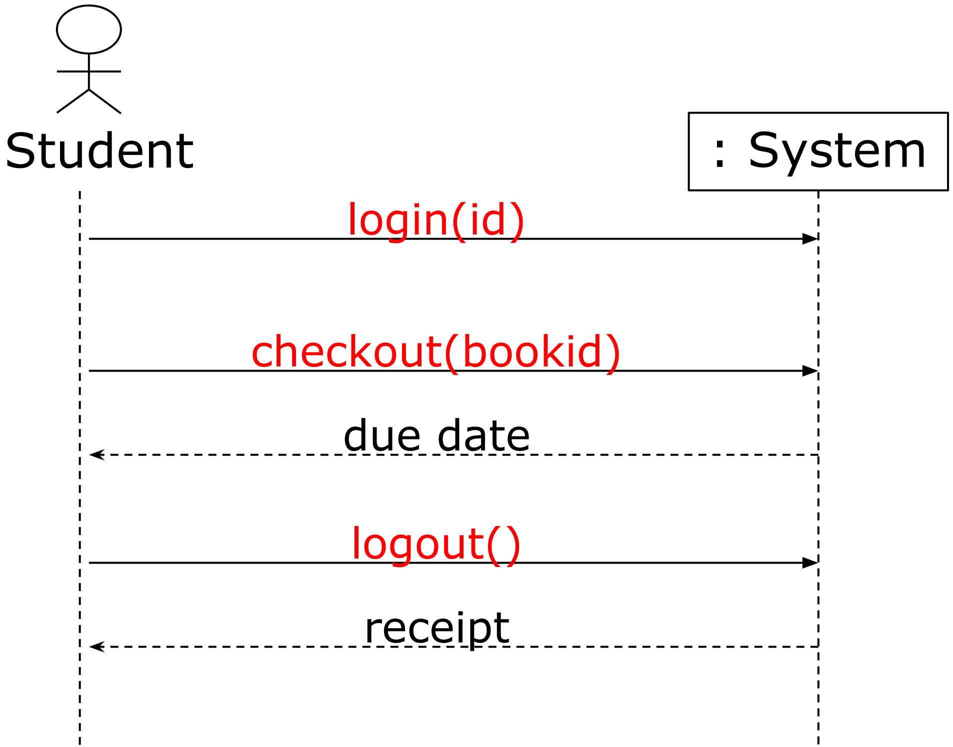
- Problem: What object receives and coordinates a system operation (event)?
- Solution: Assign the responsibility to an object representing
  - the overall system, device, or subsystem (façade controller), or
  - a use case scenario within which the system event occurs (use case controller)
- Process: Derive from system sequence diagram (key principles: Low representational gap and high cohesion)


: Student
: System
login(id)
checkout(bookid)
due date
logout()
receipt

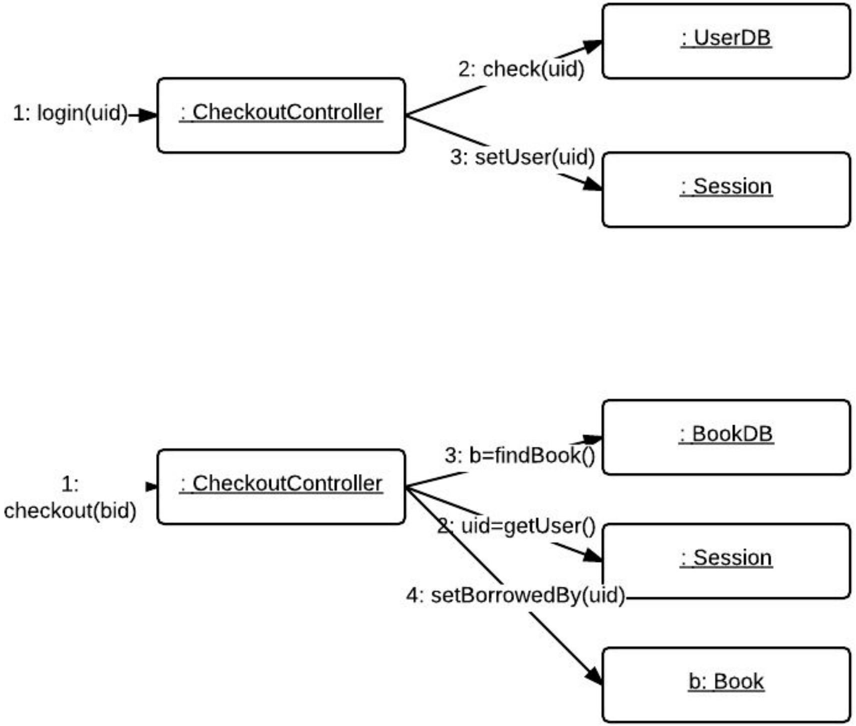

: Student
: System
login(id)
checkout(bookid)
due date
logout()
receipt


CheckoutController
login(id: Int)
checkout(bid: Int)
logout()

## Requirements Analysis




## Object-Level Design



# Controller: Discussion

- A Controller is a coordinator
  - does not do much work itself
  - delegates to other objects
- Façade controllers suitable when not "too many" system events
  - -> one overall controller for the system
- Use case controller suitable when façade controller "bloated" with excessive responsibilities (low cohesion, high coupling)
  - -> several smaller controllers for specific tasks

- Closely related to Façade design pattern (future lecture)

# Controller: Design Tradeoffs

Decreases coupling

- User interface and domain logic are decoupled from each other
  - Understandability: can understand these in isolation, leading to:
  - Evolvability: both the UI and domain logic are easier to change
- Both are coupled to the controller, which serves as a mediator, but this coupling is less harmful
  - The controller is a smaller and more stable interface
  - Changes to the domain logic affect the controller, not the UI
  - The UI can be changed without knowing the domain logic design

Supports reuse

- Controller serves as an interface to the domain logic
- Smaller, explicit interfaces support evolvability

But, bloated controllers increase coupling and decrease cohesion; split if applicable

# Controller in Flash Cards Project?

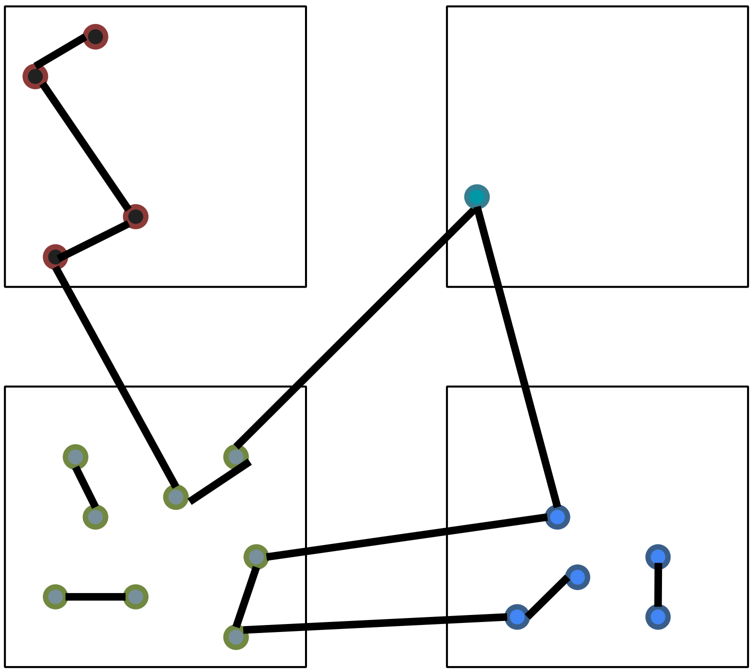
# DESIGN PRINCIPLE: HIGH COHESION

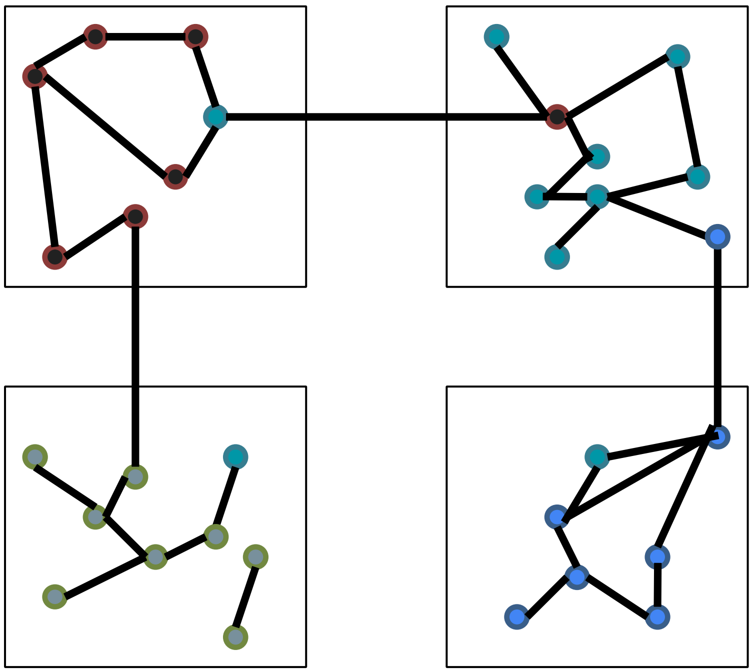
## (OR SINGLE RESPONSIBILITY PRINCIPLE)

# Design Principle: Cohesion

A module should have a small set of related responsibilities

- Enhances understandability (design for understandability)
    - A small set of responsibilities is easier to understand
- Enhances reuse (design for reuse)
    - A cohesive set of responsibilities is more likely to recur in another application





```
class DatabaseApplication
    public void authorizeOrder(Data data, User currentUser, ...){
        // check authorization
        // lock objects for synchronization
        // validate buffer
        // log start of operation
        // perform operation
        // log end of operation
        // release lock on objects
    }
    public void startShipping(OtherData data, User currentUser, ...){
        // check authorization
        // lock objects for synchronization
        // validate buffer
        // log start of operation
        // perform operation
        // log end of operation
        // release lock on objects
    }
}
```

# Anti-Pattern: God Object

```
class Chat {
    List<String> channels;
    Map<String, List<Msg>> messages;
    Map<String, String> accounts;
    Set<String> bannedUsers;
    File logFile;
    File bannedWords;
    URL serverAddress;
    Map<String, Int> globalSettings;
    Map<String, Int> userSettings;
    Map<String, Graphic> smileys;
    CryptStrategy encryption;
    Widget sendButton, messageList;
}
```

# Anti-Pattern: God Object

```
class Chat {
    List<String> channels;
    Map<String, List<Msg>> messages;
    Map<String, String> accounts;
    Set<String> bannedUsers;
    File logFile;
    File bannedWords;
    URL serverAddress;
    Map<String, Int> globalSettings;
    Map<String, Int> userSettings;
    Map<String, Graphic> smileys;
    CryptStrategy encryption;
    Widget sendButton, messageList;
```

```
class Chat {
    Content content;
    AccountMgr accounts;
    File logFile;
    ConnectionMgr conns;
}
class ChatUI {
    Chat chat;
    Widget sendButton, …;
}
class AccountMgr {
    … acounts, bannedUsr…
}
```

# Façade vs God Object?

# Cohesion in Graph Implementations

```
class Graph {
    Node[] nodes;
    boolean[] isVisited;
}
class Algorithm {
    int shortestPath(Graph g, Node n, Node m) {
        for (int i; …)
            if (!g.isVisited[i]) {
                …
                g.isVisited[i] = true;
            }
        }
        return v;
    }
}
```

Is this a good implementation?

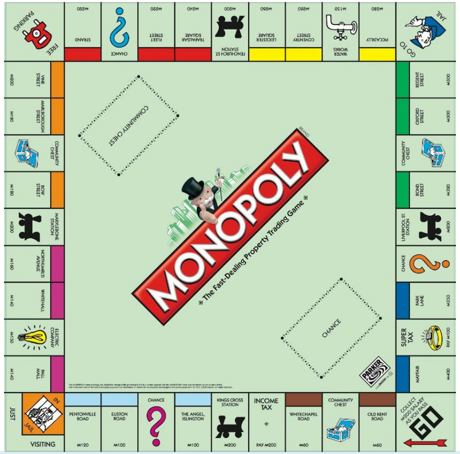
# Cohesion in Graph Implementations

```
class Graph {
    Node[] nodes;
    boolean[] isVisited;
}
class Algorithm {
    int shortestPath(Graph g, Node n, Node m) {
        for (int i; …)
            if (!g.isVisited[i]) {
                …
                g.isVisited[i] = true;
            }
        }
        return v;
    }
}
```

Graph is tasked with not just data, but also algorithmic responsibilities

# Monopoly Example

**Which design has higher cohesion?**




```
class Player {
    Board board;
    /* in code somewhere… */ this.getSquare(n);
    Square getSquare(String name) { // named monopoly squares
        for (Square s: board.getSquares())
            if (s.getName().equals(name))
                return s;
        return null;
}}
```

```
class Player {
    Board board;
    /* in code somewhere… */ board.getSquare(n);
}
class Board{
    List<Square> squares;
    Square getSquare(String name) {
        for (Square s: squares)
            if (s.getName().equals(name))
                return s;
        return null;
}}
```

# Hints for Identifying Cohesion

- Use one color per concept
- Highlight all code of that concept with the color
- => Classes/methods
  should have few colors

# Hints for Identifying Cohesion

- There is no clear definition of what is a “concept”
- Concepts can be split into smaller concepts
  - Graph with search vs. Basic Graph + Search Algorithm vs. Basic Graph + Search Framework + Concrete Search Algorithm etc
- Requires engineering judgment

# Coupling vs Cohesion (Extreme cases)

All code in one class/method

- very low coupling, but very low cohesion

Every statement separated

- very high cohesion, but very high coupling

Find good tradeoff; consider also other principles, e.g., low representational gap

# Cohesion in Flash Cards Project?

# Design Heuristic: INFORMATION EXPERT

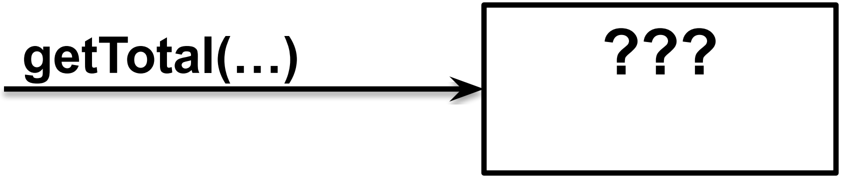
# Information Expert (Design Heuristic)

- Heuristic: **Assign a responsibility to the class that has the information necessary to fulfill the responsibility**
- Typically follows common intuition
- Software classes instead of Domain Model classes
  - If software classes do not yet exist, look in Domain Model for fitting abstractions (-> correspondence)
- Design process: Derive from domain model (key principles: Low representational gap and low coupling)

**Which class has all the information to compute the shipment's weight?**

```
class Shipment {
    private List<Box> boxes;
    int getWeight() {
        int w=0;
        for (Box box: boxes)
            for (Item item: box.getItems())
                w += item.weight;
        return w;
}
class Box {
    private List<Item> items;
    Iterable<Item> getItems() { return items;}
}
class Item {
    Box containedIn;
    int weight;
}
```

**Who should be responsible for knowing the grand total of a sale?**





TARGET

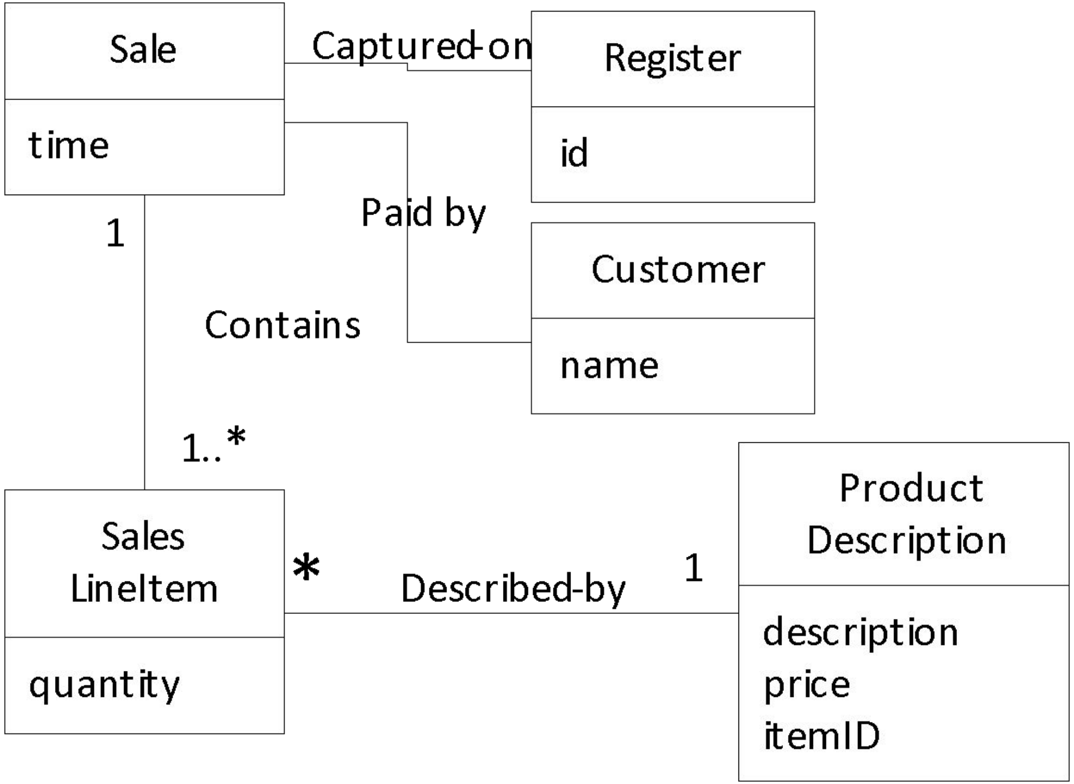
07/20/02 10:40 AM
RETURN BEFORE 10/18/02

GIVING A GIFT? Include a gift receipt!
A receipt dated within 90 days is
required for all returns & exchanges.

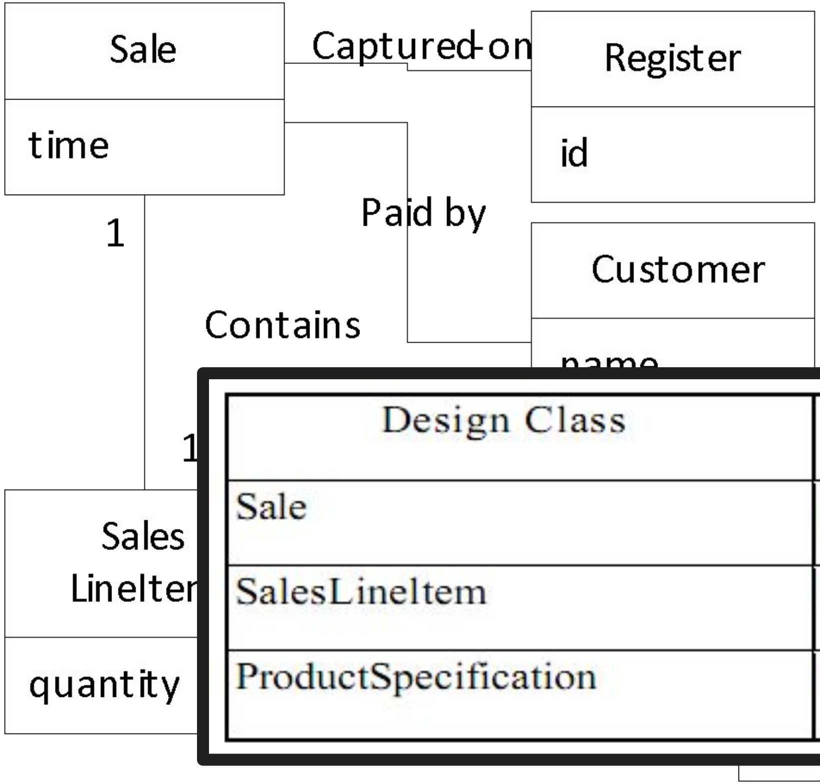
| | | | | |
|---|---|---|---|---|
| 001 | 212460341 | GENERAL MILL | FN | 2 89 |
| 002 | 071100015 | RITZ CRCKERS | FN | 2.54 |
| 003 | 212480045 | PILLSBURY | FN | 1 29 |
| 004 | 212140335 | BC CHKN HLPR | FN | 1.69 |
| 005 | 071100009 | WHEAT THINS | FN | 1 99 |
| 006 | 203700129 | OCEAN SPRAY | FN | 1.89 |
| 007 | 212080143 | W BONE DRSNG | FN | 1.79 |
| 008 | 284010136 | DIGIORNO | FN | 2.54 |
| 009 | 003060057 | DAWN | T | 1.99 |
| 010 | 071090122 | CHIPS AHOY | FN | 2.54 |
| | | SUBTOTAL | | 21.15 |
| | | T= 5.000% TAX | | .10 |
| | | TOTAL | | 21.25 |

**Register**
**Sale**
**LineItem**
**Product Descr.**

**Who should be responsible for knowing the grand total of a sale?**

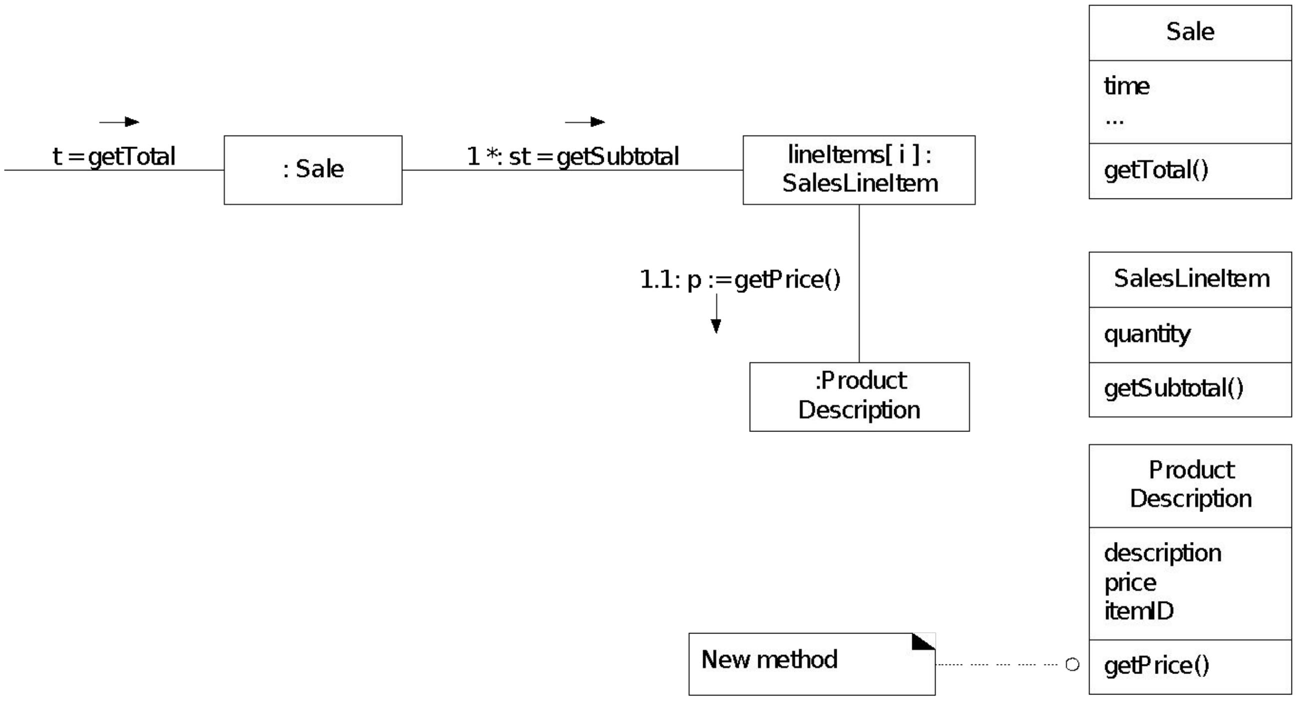



# Who should be responsible for knowing the grand total of a sale?





| Design Class | Responsibility |
|---|---|
| Sale | knows sale total |
| SalesLineItem | knows line item subtotal |
| ProductSpecification | knows product price |


t = getTotal
: Sale
1 *: st = getSubtotal
lineItems[ i ] :
SalesLineItem
1.1: p := getPrice()
:Product
Description
New method
Sale
time
...
getTotal()
SalesLineItem
quantity
getSubtotal()
Product
Description
description
price
itemID
getPrice()

# Information Expert -> "Do It Myself Strategy"

Expert usually leads to designs where a software object does those operations that are normally done to the inanimate real-world thing it represents

- a sale does not tell you its total; it is an inanimate thing

In OO design, all software objects are "alive" or "animated," and they can take on responsibilities and do things.

They do things related to the information they know.

# Information Expert in Flash Cards Prj.

Who knows the text on a card?

Who checks correctness of an answer?

Who processes command-line options?

Who stores past answers?

Who knows how to flip cards?

Who tracks which achievements have been achieved?

# Design Heuristic: CREATOR

# Creator (Design Heuristic)

**Problem:** Who creates an A?

**Solution:** Assign class responsibility of creating instance of class A to B if

- B aggregates A objects, B contains A objects, B records instances of A objects, B closely uses A objects, B has the initializing data for creating A objects (the more the better)
- where there is a choice, prefer B aggregates or contains A objects

**Key idea:** Creator needs to keep reference anyway and will frequently use the created object

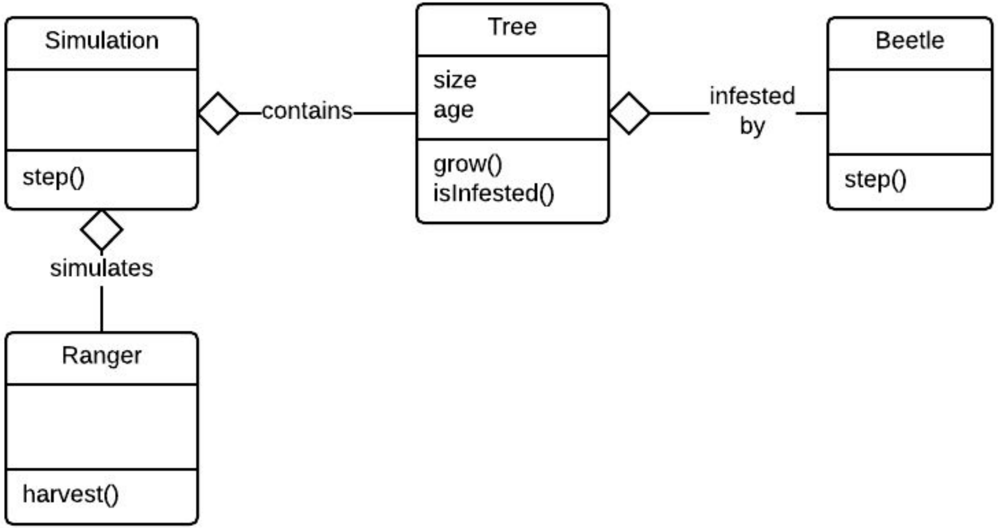
**Process:** Extract from domain model, interaction diagrams (key principles:  Low coupling and low representational gap)

# Creator heuristic

- Design process: Extract from domain model, interaction diagrams
  - Key principles: Low coupling and low representational gap

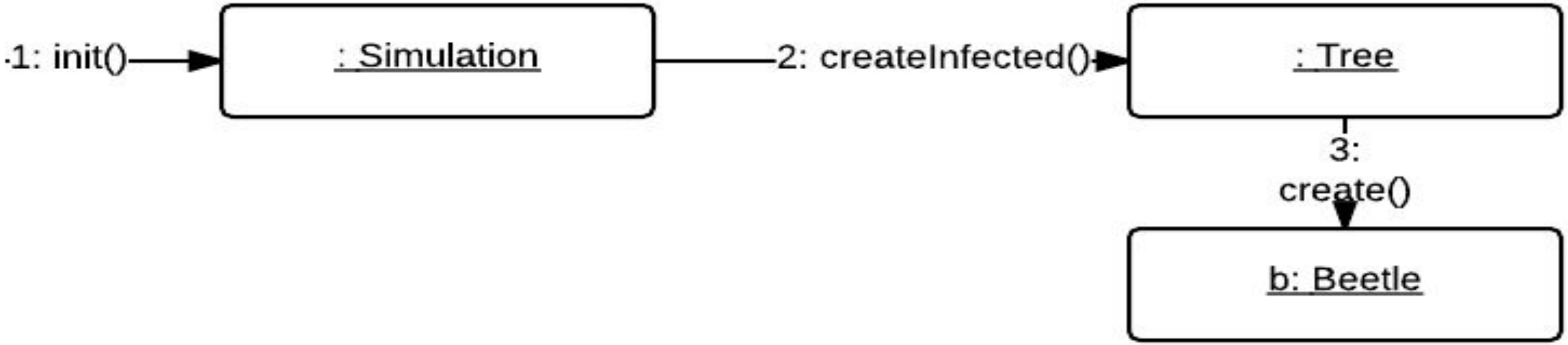
# Creator (GRASP)

- Who is responsible for **creating** Beetle objects? Tree objects?



# Creator : Example

- Who is responsible for creating Beetle objects?
  - Creator pattern suggests Tree
- Interaction diagram:



# Creator (GRASP)

- Problem: Assigning responsibilities for creating objects
  - Who creates Nodes in a Graph?
  - Who creates instances of SalesItem?
  - Who creates Children in a simulation?
  - Who creates Tiles in a Monopoly game?
    - AI? Player? Main class? Board? Meeple (Dog)?

# Creator: Discussion of Design Goals/Principles

Promotes **low coupling**, **high cohesion**

- class responsible for creating objects it needs to reference
- creating the objects themselves avoids depending on another class to create the object

Promotes **evolvability** (design for change)

- Object creation is hidden, can be replaced locally

Contra: sometimes objects must be created in special ways

- complex initialization
- instantiate different classes in different circumstances
- *then **cohesion** suggests putting creation in a different object*: see *design patterns* such as builder, factory method

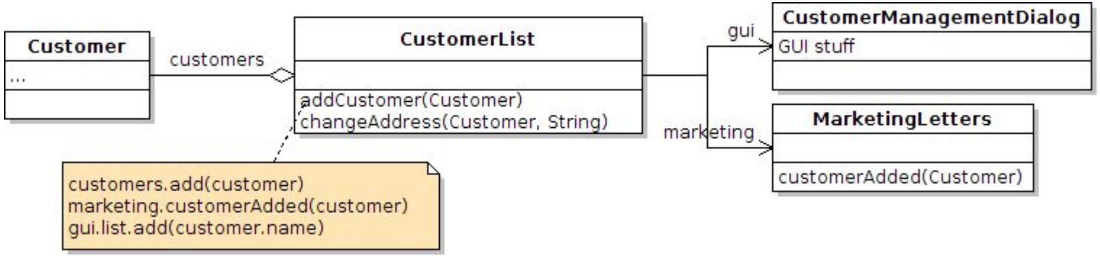
# Creator in Flash Cards Project

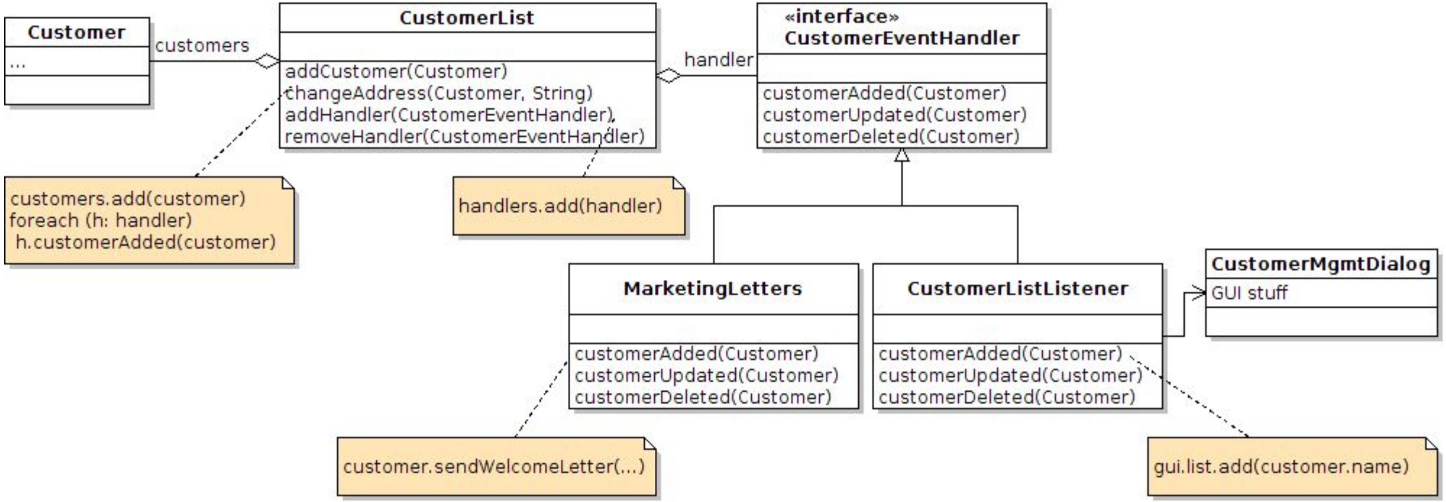
Who creates cards?

Who creates a card deck?

Who creates achievements?

# Which design is better? Argue with design goals, principles, heuristics, and patterns that you know






* old midterm question

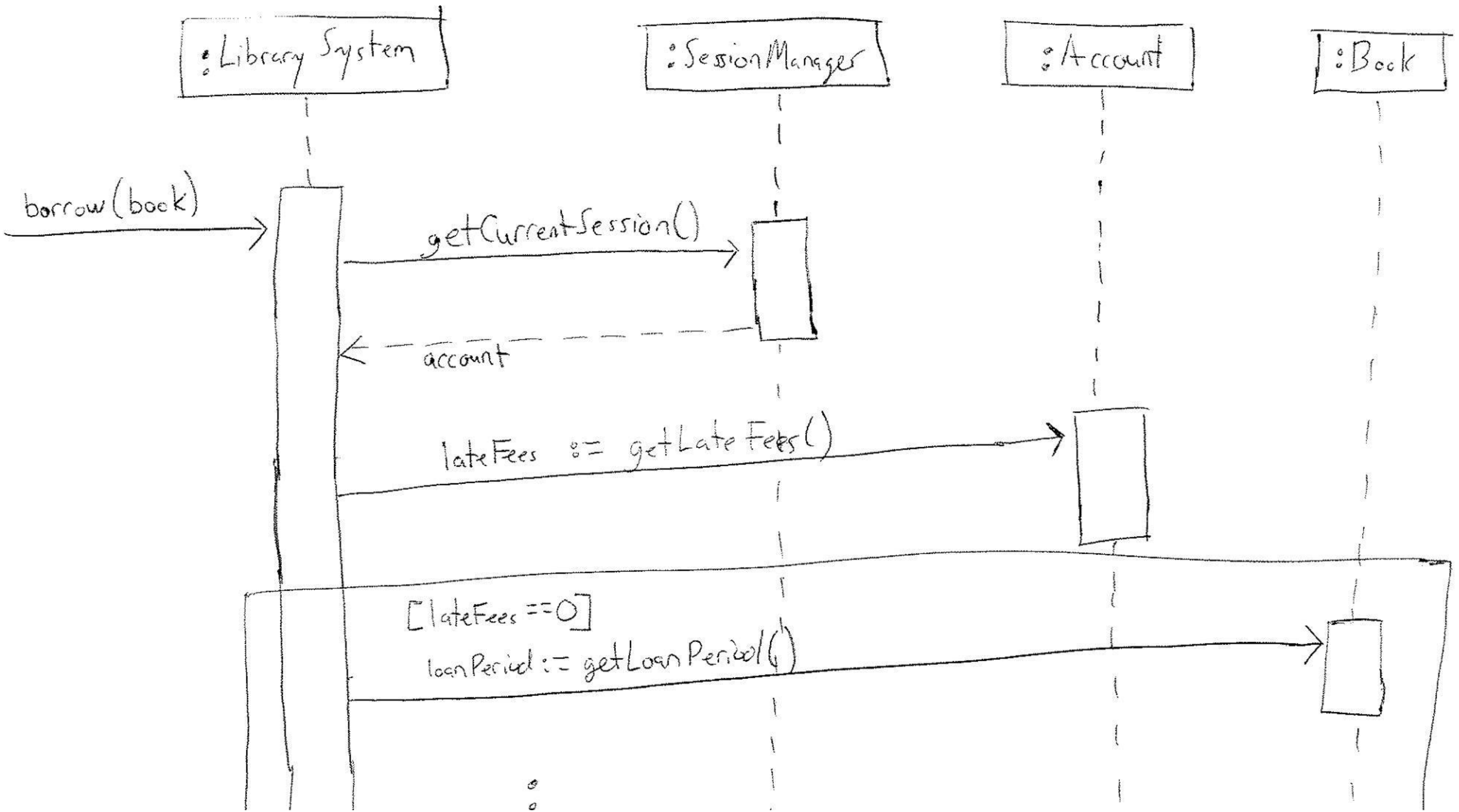
# Other Design Heuristics

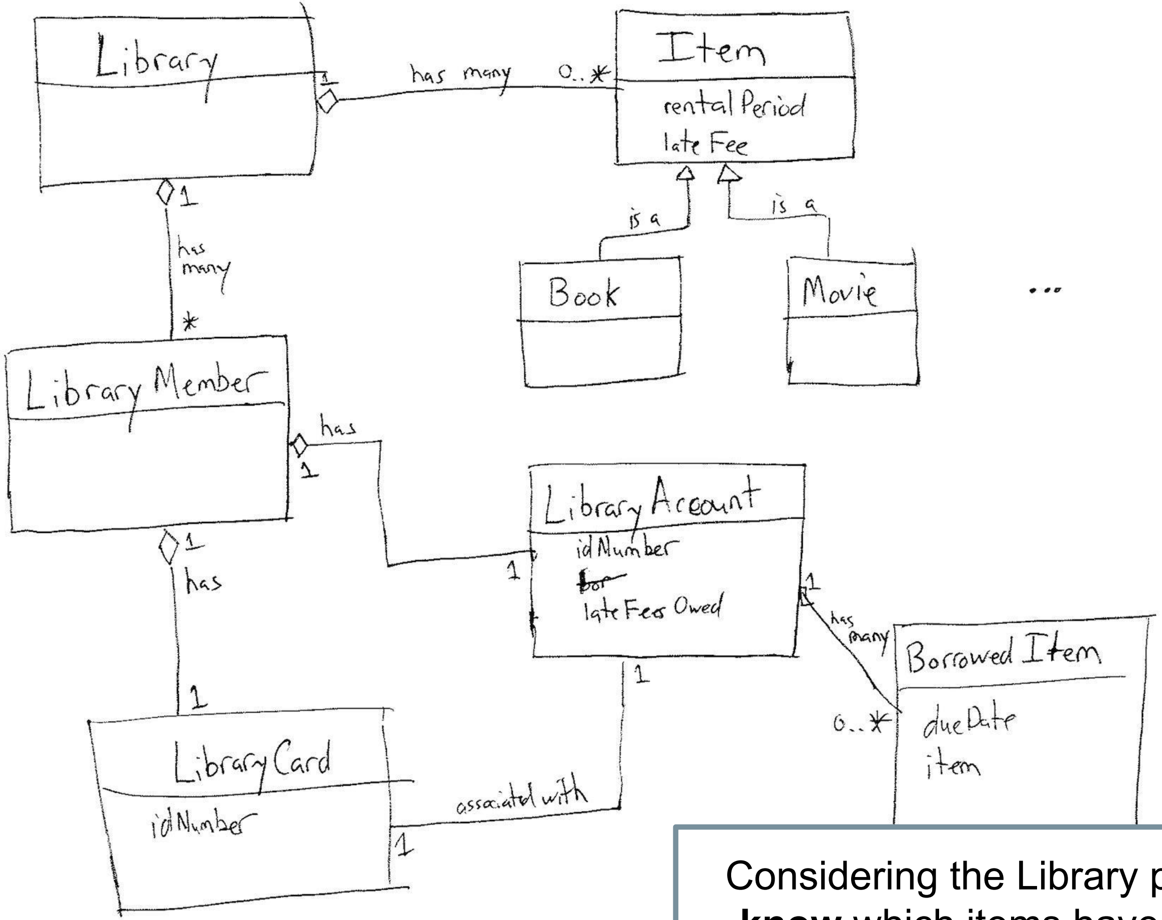
In future lectures:

- Minimize mutability
- Minimize conceptual weight
- Favor composition/delegation over inheritance
- Use indirection to reduce coupling
- …

# Object-level artifacts of this design process

- Object interaction diagrams add methods to objects
  - Can infer additional data responsibilities
  - Can infer additional data types and architectural patterns
- Object model aggregates important design decisions
  - Is an implementation guide

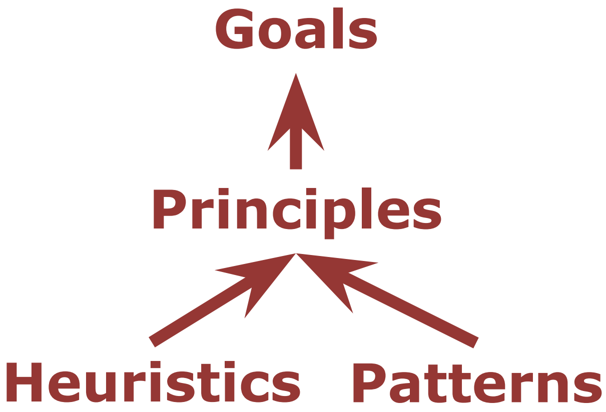

:Library System
:SessionManager
:Account
:Book
borrow(book)
getCurrentSession()
account
lateFees := getLateFees()
[lateFees == 0]
loanPeriod := getLoanPeriod()




Considering the Library problem, which class should **know** which items have been borrowed by a user? Which should **compute** late fees?

# Design Goals, Principles, and Patterns

- Design Goals
  - Design for change, understanding, reuse, division of labor, …
- Design Principle
  - Low coupling, high cohesion
  - Low representational gap
- Design Heuristics
  - Law of demeter
  - Information expert
  - Creator
  - Controller



# Take-Home Messages

Design is driven by quality attributes

- Evolvability, separate development, reuse, performance, …

Design principles provide guidance on achieving qualities

- Low coupling, high cohesion, high correspondence, …

GRASP design heuristics promote these principles

- Creator, Expert, Controller, …