Domain Models

CSE 3311 & 5324
Christoph Csallner
University of Texas at Arlington (UTA)

Sources

- [FS] Bill Curtis, Herb Krasner, and Neil Iscoe: A field study of the software design process for large systems. CACM, volume 31, issue 11, Nov. 1988
  - https://dl.acm.org/doi/10.1145/50087.50089
- [HB] Albert Endres & Dieter Rombach: A Handbook of Software and Systems Engineering. Pearson 2003

Curtis's Law [HB]

- **Good designs require deep application domain knowledge**
  - Bill Curtis et al.

- Domain knowledge is knowledge needed to solve a problem in that domain

- Studied design process in several organizations
  - Emphasis on defense industry
- Applies to various project types
  - Software, hardware, hybrid

Curtis 1986 Study [HB]

- Interviewed developers & managers in 17 projects
  - Projects ranged from 25 kLOC to 1 MLOC (lines of code)

- Findings
  - Domain knowledge was spread thinly
    - "System engineer: ***Writing code isn't the problem, understanding the problem is the problem***.'' [FS]
    - Software development needs time to learn application domain
  - Typically 1 or 2 people with most knowledge took prime responsibility for the design
  - Design meetings had task of converting design into a shared vision among all team members

Need To Acquire More Knowledge [HB]

- Project success requires knowledge of software (programming languages, ..) and project domain

- Few people have expert-level knowledge in both software and problem domain
  - Domain stakeholders usually have excellent domain knowledge but don't have time/resources to acquire software knowledge
  - Software people typically have excellent software knowledge but need to acquire domain knowledge
- When software people work on next project
  - Typically need to acquire new domain knowledge

Software Maintains Model of World

- We expect application to interact with our world

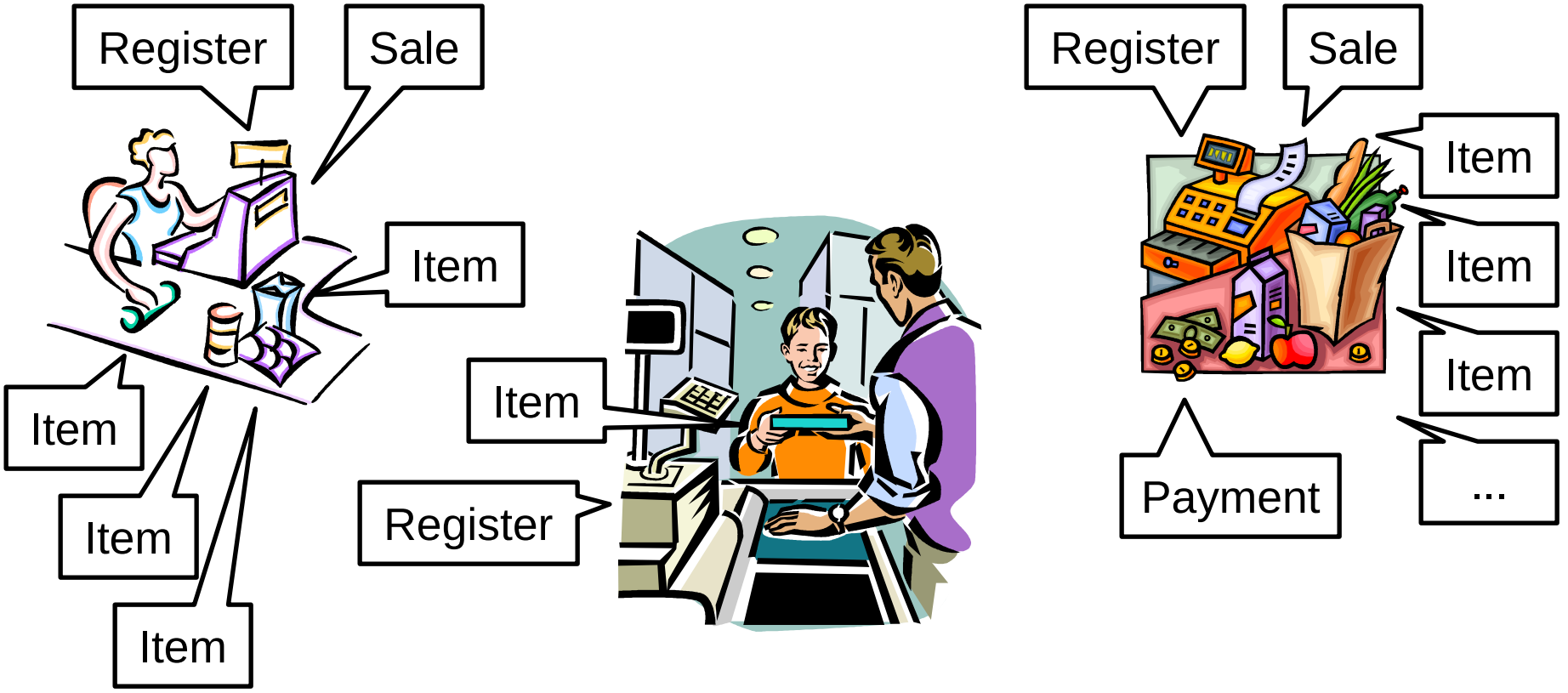
- Application must maintain an **up-to-date model of the current state** of our world, e.g.:
  - POS system must sum up the customer's actual items the customer wants to buy today
    - Don't add in items from earlier shopping trips
  - POS system must calculate with current tax rate
    - Don't use old (outdated) tax rate

Gameplan

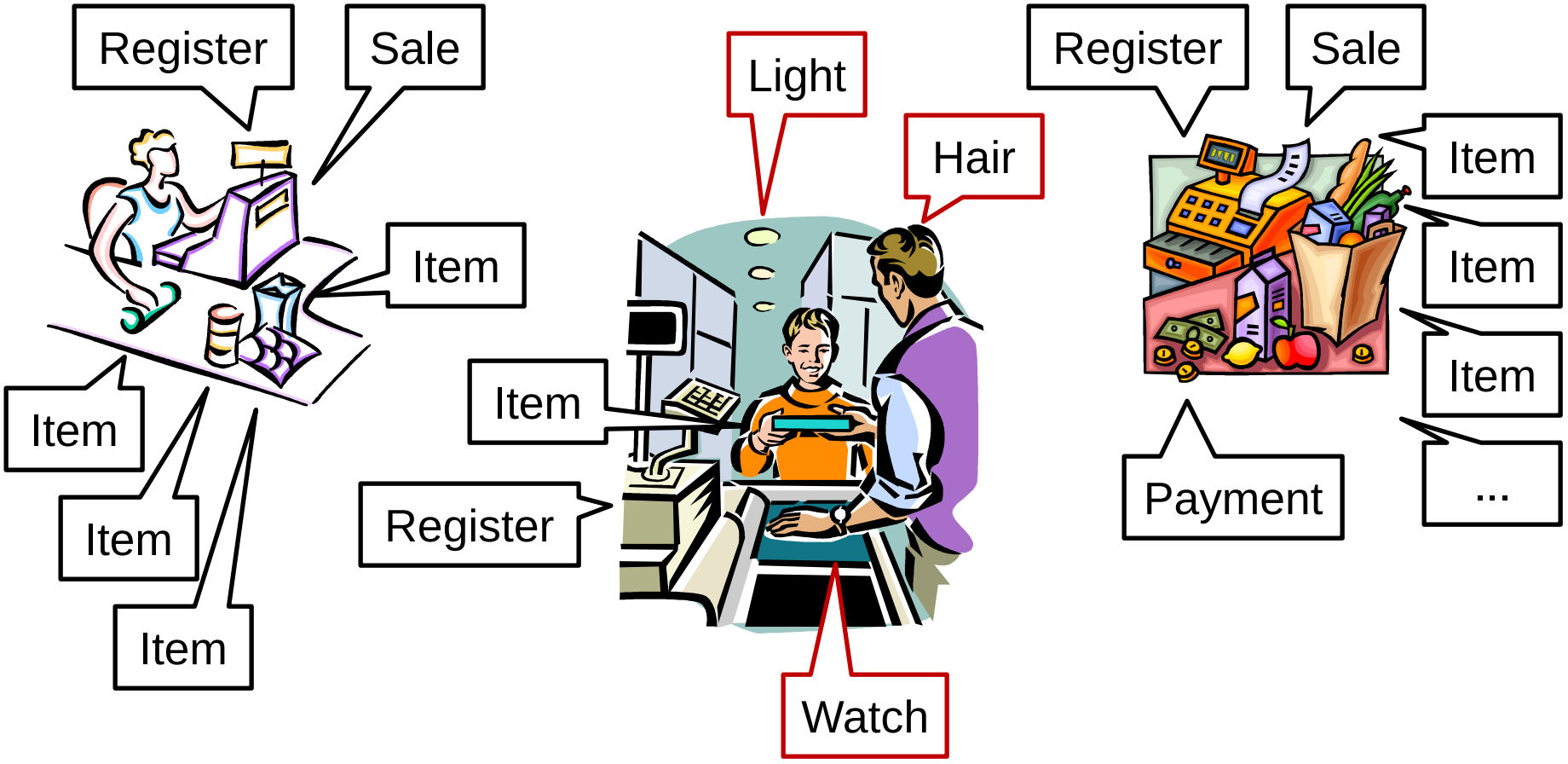
Domain Models: CL, Chapter 9

- Many names for “domain model” (CL, pp. 133-134)
  - Conceptual model, conceptual perspective model
  - Conceptual **entity-relationship model**
  - Domain object model, analysis object model
- Simple idea:
  1. Concepts / things / **entities** of problem / project domain
  2. Relationships between (**relations** on) problem / project domain concepts / things / entities
  3. Constraints on entities and relations
  4. **That’s it!**
     - At this point we don’t think about implementation / code

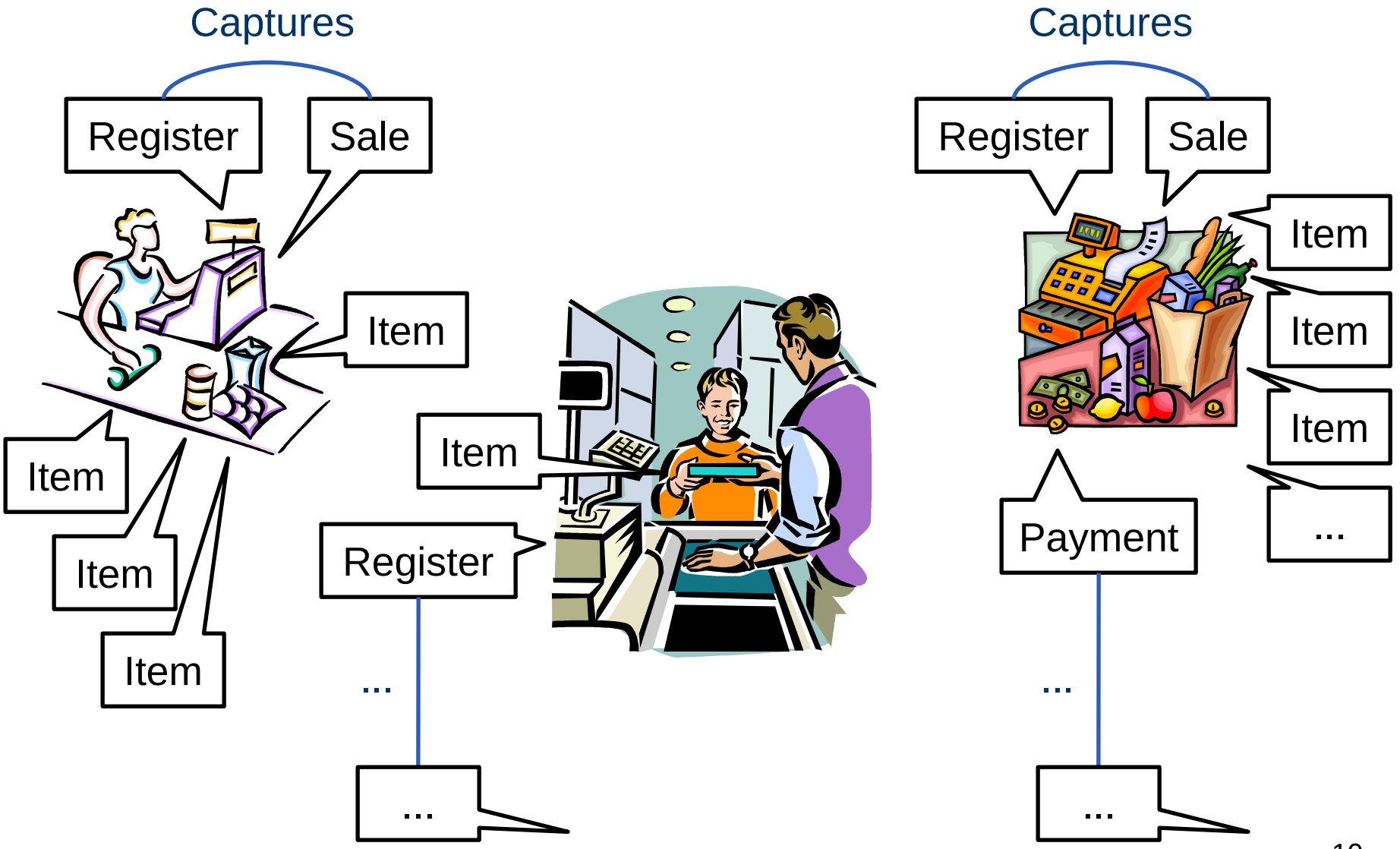
Example: Things in Point of Sale (POS) Domain



Which Things Do We Care About in a Given Project?



Some Relationships Between Things



Example POS Domain Model

- Represent all registers by Register set
- Represent all sales by Sale set
- **Represent each set with a box**

- Represent all “register—sale” relationships by “Captures” relation
- **Represent relation with a connection**

UML Class Diagram: Box & Connection

- Class (box)
  - Named, e.g.: “Sale”
  - Here we don’t think of it as a Java, C#, C++, etc. class

- Association (line)
  - Named, e.g.: “records-current”
  - Connects two boxes
    - Or one box with itself
    - Other lines rare in UML

UML Class Diagram: Multiple Uses

- Remember: A diagram is just a diagram
  - Just boxes and connections

- Several uses for “class diagram”. E.g., a box is:
  - **Here: Requirements Concept (set of things)**
  - Later use: Class in an object-oriented program

- **Do not automatically think “code” when you hear “class diagram”**
  - Here we do not talk about Java / C# / etc. classes

Recap: Map World to Class Diagram

- Map real world problem / project domain to UML class diagram
  - **Project domain → class diagram**

- Problem / project domain concepts / things / entities
  - **Set of similar items in domain → box**

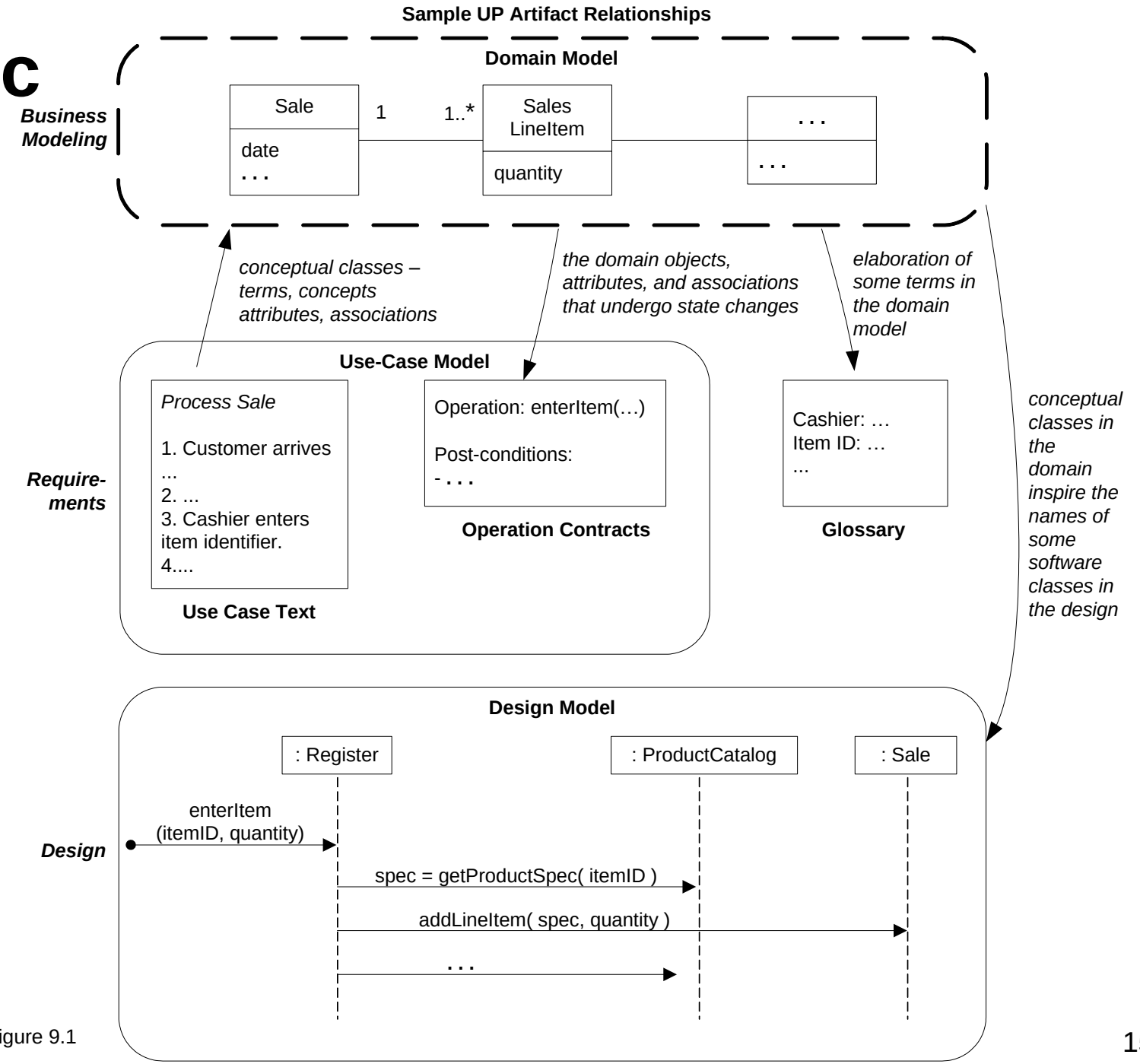
- Relationships between (relations on) problem / project domain concepts / things / entities
  - **Relationship between sets of domain items → line**

Big Pic

Domain Model

Use-Cases

Sequence Diagram

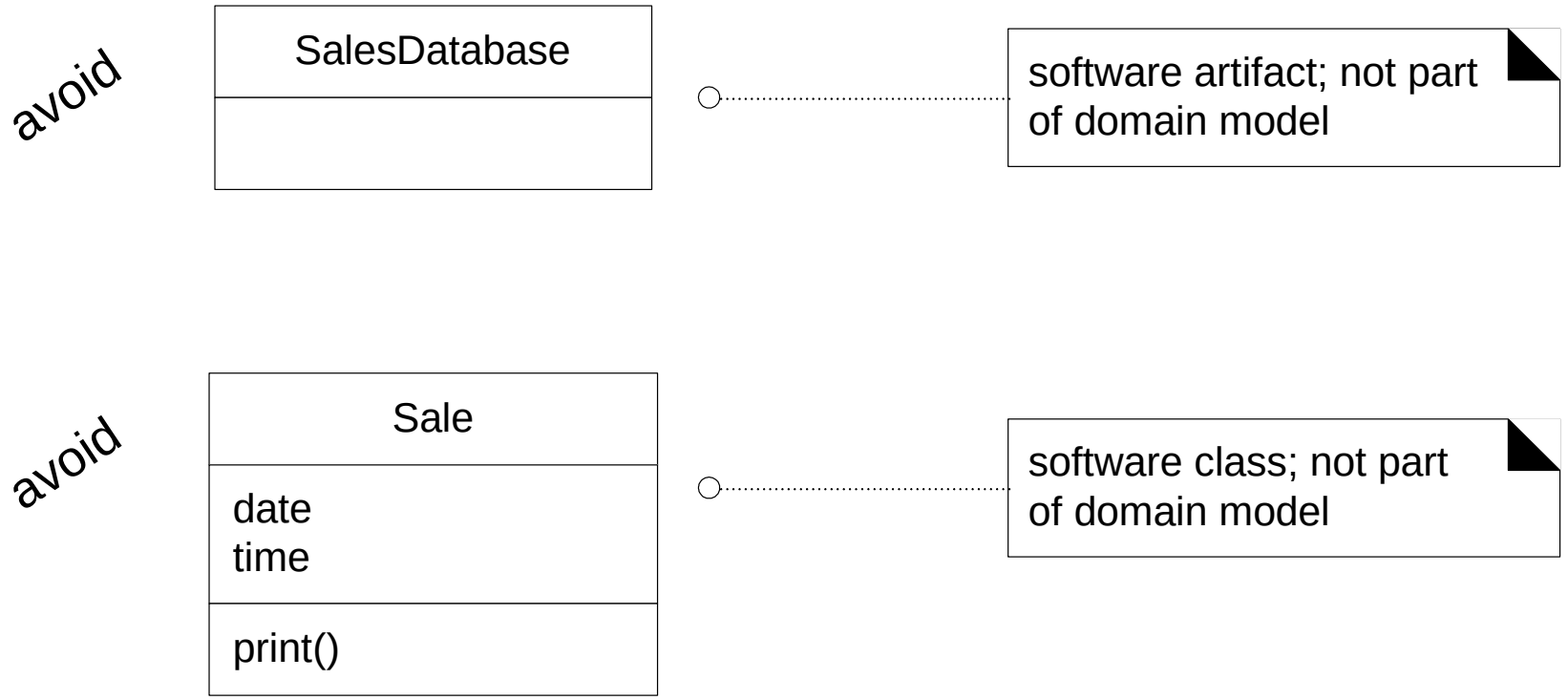


CL Figure 9.1

Documenting a Set / Concept Box

- Example from the textbook:
  - **Name**: Sale
  - **Definition**: The event of a purchase transaction, has a date and time
  - **Examples**: Example sales in the domain
    - (CL talks about all sales in the universe, which is confusing, unless they mean the universe of the domain)

Examples of Sets / Concepts to Avoid



CL Figure 9.4

Later: Map Domain Model to Code

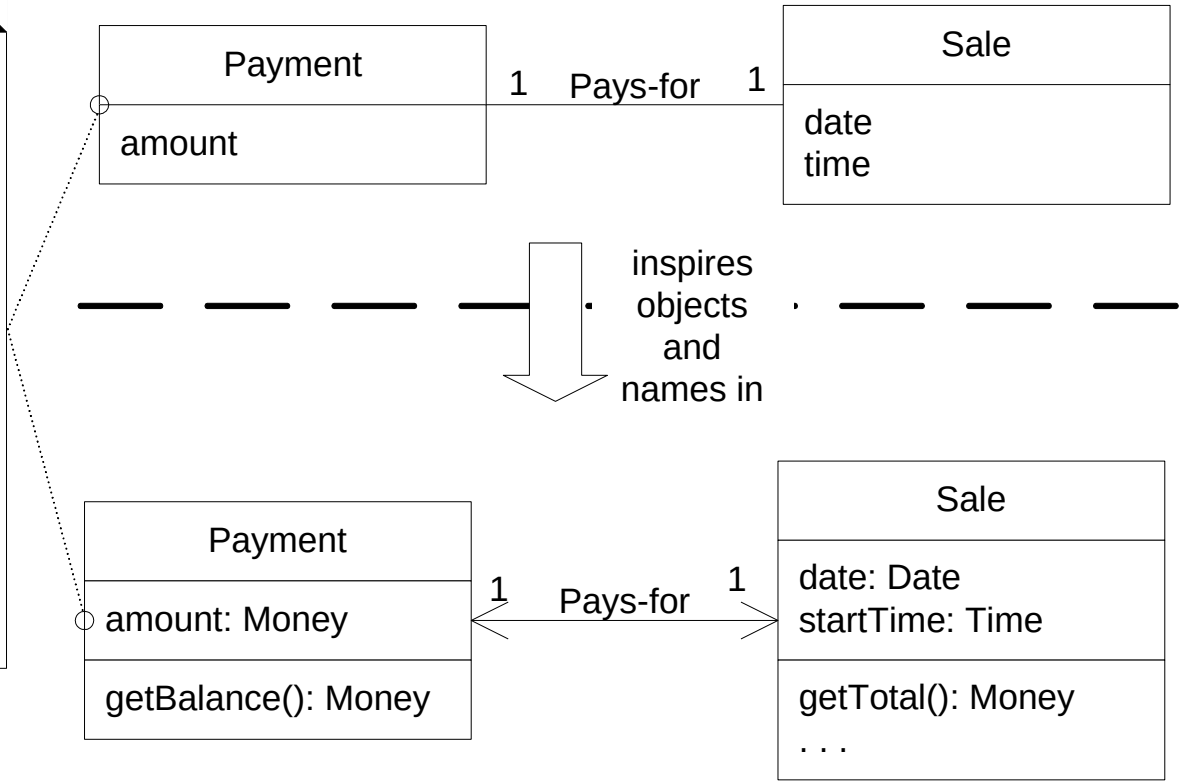
A Payment in the Domain Model is a concept, but a Payment in the Design Model is a software class. They are not the same thing, but the former *inspired* the naming and definition of the latter.

This reduces the representational gap.

This is one of the big ideas in object technology.

UP Domain Model

Stakeholder's view of the noteworthy concepts in the domain.



UP Design Model

The object-oriented developer has taken inspiration from the real world domain in creating software classes.

Therefore, the representational gap between how stakeholders conceive the domain, and its representation in software, has been lowered.

CL Figure 9.5

How to Create a Domain Model

1. Find the conceptual classes
   - Reuse or modify existing models
   - Use books on domain model patterns (CL, page 139)
   - Use a category list (next slides)
   - Identify noun phrases (next slides)

2. Draw conceptual classes in a UML class diagram

3. Add associations and constraints

Use a Category List (1/2)

- Look at an existing list of concept categories, e.g.:
  - Business transactions
  - Transaction line items
  - Product / service related to transaction (line item)
  - Where is the transaction recorded?
  - Roles of people or organizations related to the transaction
  - Actors in the use case
  - Place of transaction / service
  - Events, with time & place, we need to remember
  - Physical objects

- This is the example list from CL, pp. 140—141

Use a Category List (2/2)

- Example list: CL, pp. 140—141 (continued):
  - Description of things
  - Catalogs
  - Containers of things (physical or information)
  - Things in a container
  - Other collaborating systems
  - Records of finance, work, contracts, legal matters
  - Financial instruments
  - Schedules, manuals, documents that are regularly referred to in order to perform work

Identify Noun Phrases

- Nouns and noun phrases in domain descriptions
- Roughly:
  Noun in use-case / other requirement document
  →
  Conceptual class in domain model

- Deal with imprecision of natural language
  - Two nouns in use-cases may refer to same concept
    → Detect and fix use-case
  - Same noun in two use-cases may refer to different concepts
    → Detect and fix use-case

Revisit Definitions: Conceptual Class

- **Set** of similar things, e.g., employees
- Important: Set contains all items **that exist at a particular moment**

  – BL, page 272
- Example: Employee set does not include:
  - Past or future employees
  - "All employees in the universe"
  - Otherwise "Employee" becomes more like "Person"
- May need separate relation for former employees
  - So better to not mix them together into same class

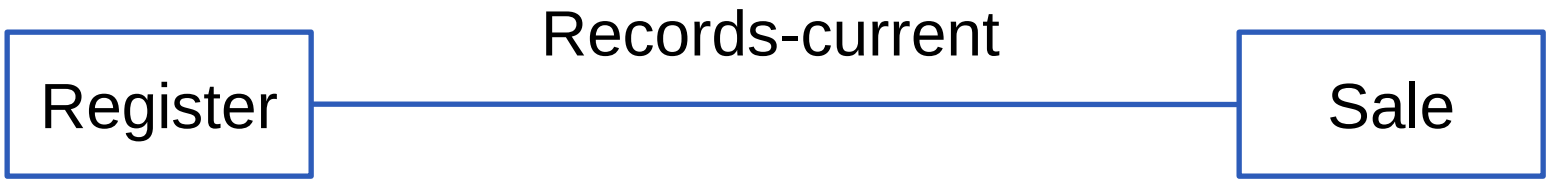
IN-CLASS EXERCISE: IDENTIFY DOMAIN CONCEPTS

Identify Domain Concepts / Entities

- Get together with your team
- Identify the entities / conceptual classes in your project's domain model
  - Use case actors
  - Nouns in uses cases
  - Business transactions
  - Events we need to remember
  - Physical objects, collaborating systems
- Draw each conceptual class as a box in a UML class diagram
- Share your results in Teams class meeting chat

Association

- Relationship between instances of one or more classes
- Example:



Association Name

- Name = descriptive **verb phrase**
  - **Class name – *verb phrase* – class name**
- Example: **Sale *paid by* cash payment**
  - Bad (why?) example: Sale uses cash payment

- Name reading direction
  - By default left-to-right
  - Arrow is optional
  - At this point: No code meaning such as field access etc.

How to Find Associations?

- Look at list of common association categories, e.g.:
  - Two transactions are related
  - A is a line item of transaction B
  - A is a product or service for transaction (line item) B
  - A is a role related to transaction B
  - A is a physical or logical part of B
  - A is physically or logically contained in B
  - A is a description of B
  - A is known/logged/recorded/reported/captured in B

- Above is example list from CL, page 155

Common Association Categories

- (Continued)
  - A is a member of B
  - A is an organizational subunit of B
  - A uses or manages or owns B
  - A is next to B

Guideline: Include Association X?

- Is X a **“Need-to-Remember Association”**?

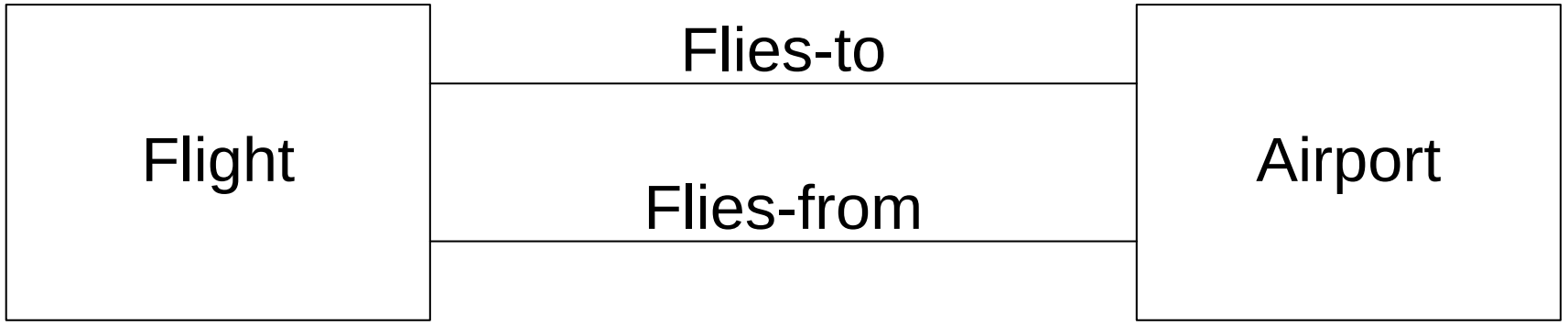
- Does system need to **preserve knowledge of the relationship for some time?**
  - Include those associations in the domain model

- Avoid adding other relationships that may exist in the domain but are less important
  - Don’t want to flood your models

Multiple Relationships between A, B

- More than one association between conceptual classes A and B

- Example:



CL Figure 9.16

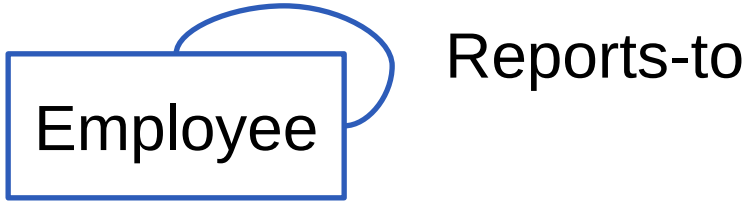
Revisit Definitions: Association

- **Relation** on conceptual classes, e.g., reports-to
- Important: Relation contains exactly the tuples **that exist at a particular moment**

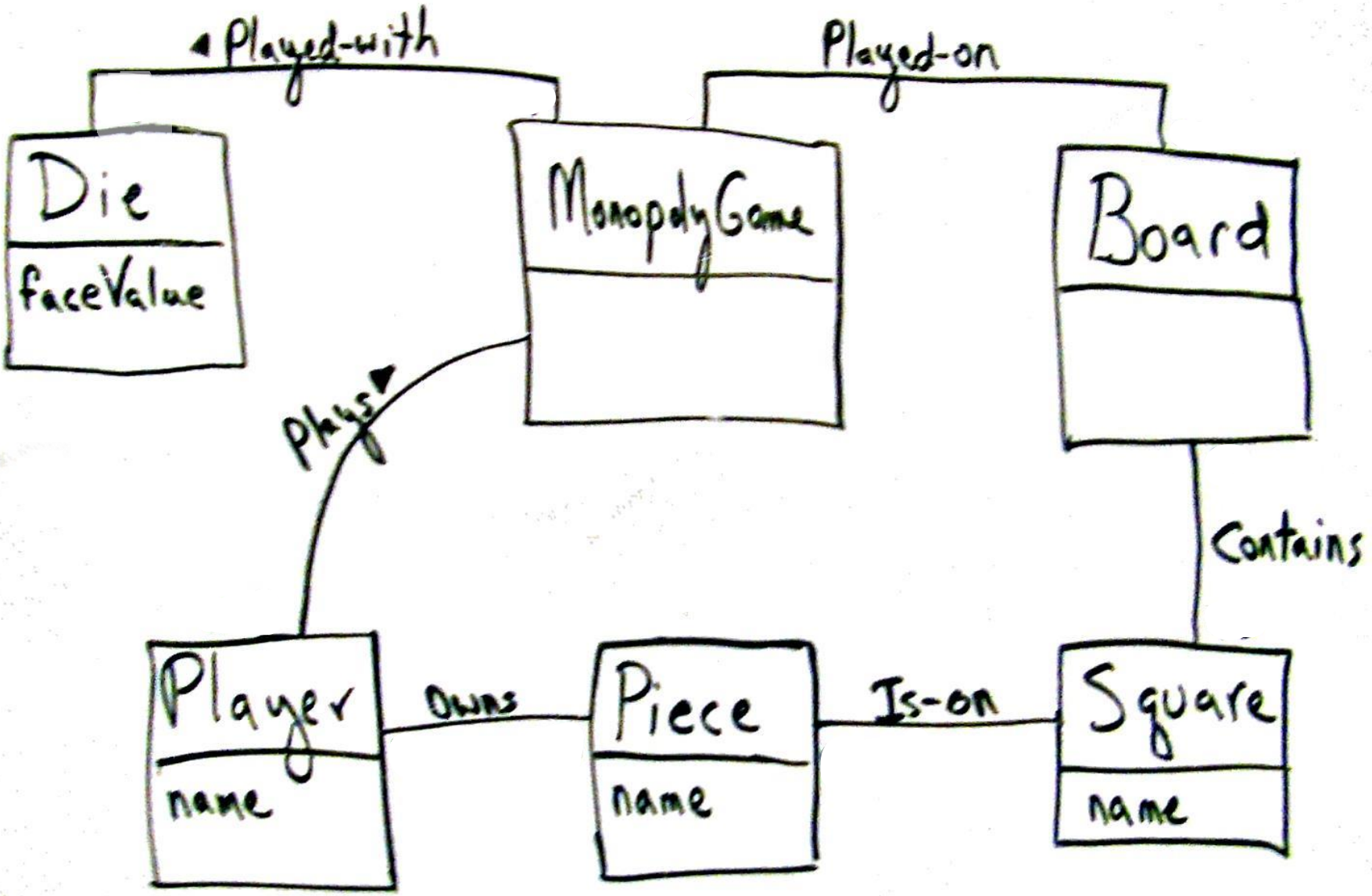
- Example: Reports-to relation does not include:
  - Past employee-manager relationships
  - Future employee-manager relationships
- Relation may have had different constraints in the past (e.g., no employee can have more than one manager)
  - So better to not mix old and current relation together

Revisit Definitions: Domain Model

- We said “concept=set” and “relationship=relation”
- Classic set and binary relation on that set:
  - Natural numbers: {0, 1, 2, 3, ...}
  - Less-than: {(0,1), (0,2), (0,3), ...}
- Business-related concept (=set) and relation (-ship):
  - Employee: {Amy, Belinda, Carl}
  - Reports-to: {(Amy, Carl), (Carl, Belinda)}
- Corresponding domain model as a UML class diagram:



Example: Monopoly



CL Figure 9.18

Guideline: Avoid Attributes

- Avoid attributes
- Avoid attributes
- **Avoid attributes**
  - Because it will simplify your life

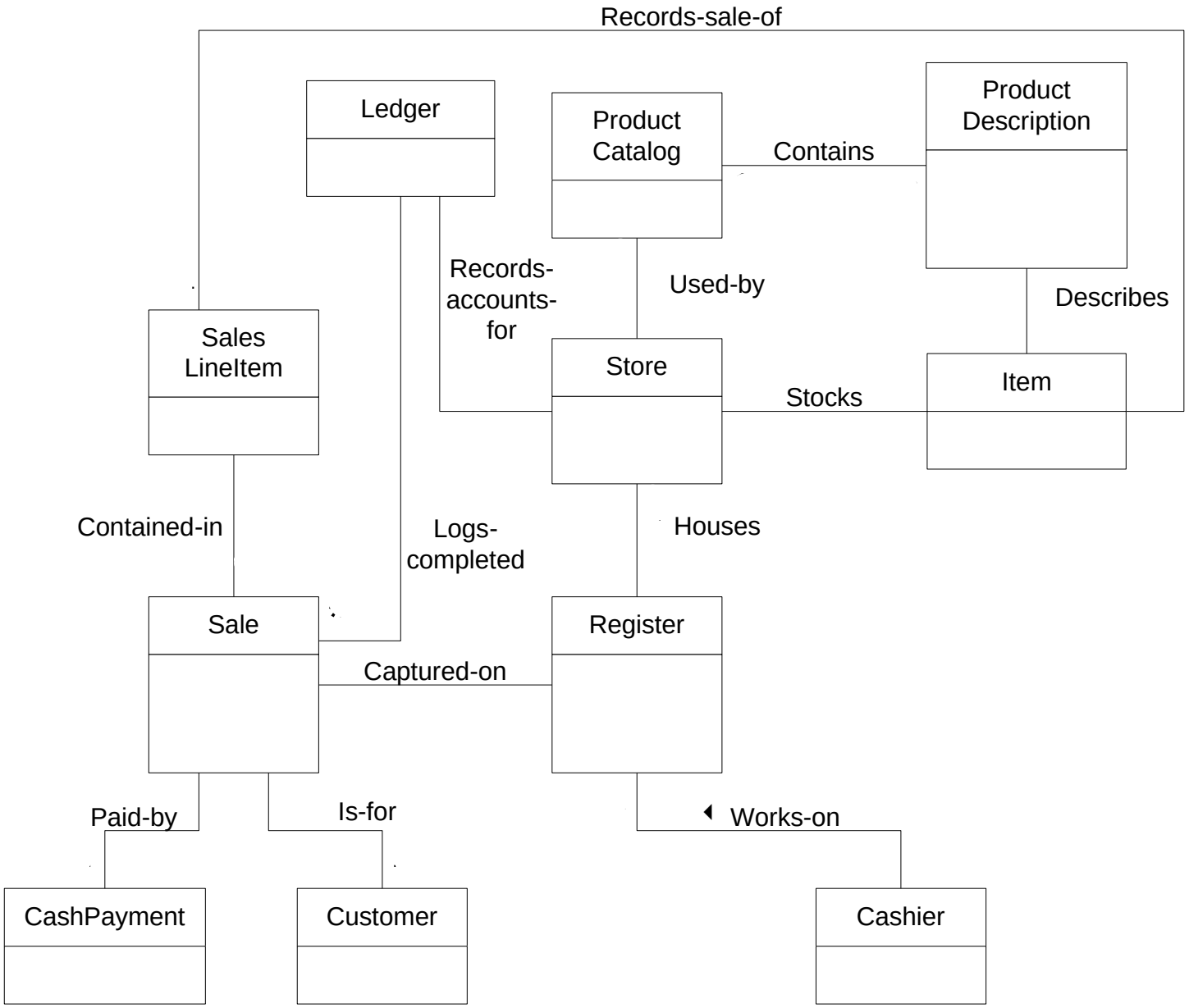
- If you add attribute A to conceptual class C ...
  - ... you implicitly add a new kind of relationship between A and C
  - This relationship is similar to (but different from) the explicit “line” relationship between conceptual classes
  - **Why two kinds of “relationship” when one is enough?**

Example From Monopoly

- What is the relation between set and its attribute?
- Is it a “1:1” mapping?
  - Each square has 1 name, each name used for 1 square
  - Each piece has 1 name, each name used for 1 piece
- Or is it a “n:1” mapping?
  - Each player has 1 name, but two players cannot have same name?

- We may want to specify which option to use for each such relation → Easier to do if we explicitly treat each relation as a relation on sets

Example: Point of Sale (POS)



CL Figure 9.17

IN-CLASS EXERCISE: CREATE YOUR TEAM'S DOMAIN MODEL

Create Your Team's Domain Model

- Get together with your team

- Create a draft of your domain model
  1. Find your conceptual classes (e.g.: "Register", "Sale")
  2. Avoid attributes
  3. Find the associations between your conceptual classes (e.g.: "Register records current Sale")
  4. Draw a UML class diagram that contains one box per conceptual class and one line per association

- Be prepared to present your results
  - Share your result in the Teams chat

For the following, both the CL textbook and the UML User Guide 2nd edition may be confusing. I recommend you

- Ask questions
- Look up Entity-Relationship Models in a database book
- Read **Program Development in Java** by Barbara Liskov [BL]

WARNING

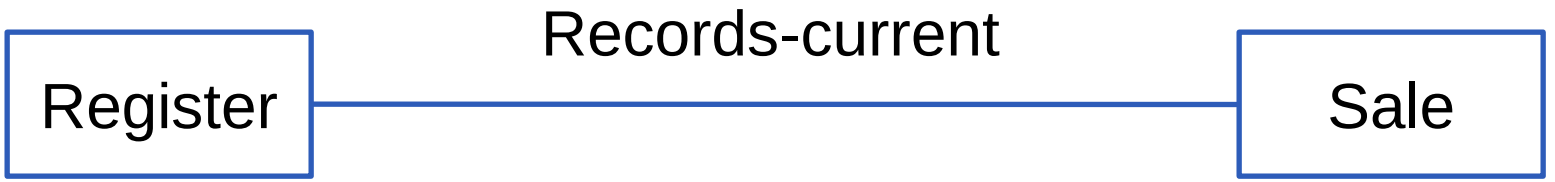
Association Arity

- By default, an association is binary
  - Relationship between instances of one or two classes

- N-ary (n>2) associations exist, but very rare in UML
  - UML User Guide 2nd edition (400+ pages) [UMLUG2] mentions it very briefly
    - 2 lines on page 65
    - 1 line on page 457
    - UMLUG2 claims to be the “definite guide to the use of the UML”

Association = Relation on Classes

- Relationship between instances of one or more classes
- Example:



- Recall that a relation is just a set of tuples
  - Association ≈ Table in a relational database
  - Conceptual class ≈ Column in a relational database
  - Tuple ≈ Row in a relational database

Content Change

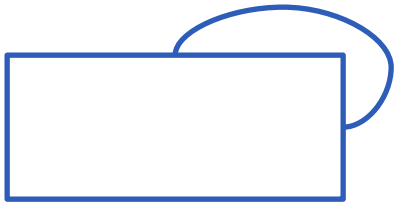
- What do we mean with this domain model?
- Should our software only work for the employees Amy, Belinda, and Carl?
  - No! Employee is not one concrete set, but a **set variable**
  - Allows state to change over time, e.g., to {Amy, Carl}
- Should our software only allow Amy to report to Carl and Carl to report to Belinda?
  - No! Similar to above, Reports-to is a **relation variable**
  - Allows state to change over time, e.g., to {(Carl, Amy)}

- See BL, Section 12.1

Relational DB, OO App

- Put two definitions together:
  - Concept = set variable
  - Set contains all items that exist at a particular moment
- Items in the set may change over time
- Set does not contain all past and future items

- Compare with
  - Column in relational database
  - Set variable in a program
  - **Instances of a class in an object-oriented app**



Association Relation

- Put two definitions together:
  - Association = relation variable
  - Relation contains all tuples that exist at a particular moment
    - Does not contain all past and future tuples
- May change over time
- Compare with
  - Table in a relational database
  - **An instance field in an OO program**
    - “class X {F f;}” maps X instances to F instances

Intuitive in Code

```
public class Employee {  // snippet of object-oriented program, e.g., in Java
    protected String name = null;
    protected Employee reportsTo = null;
    public Employee(String id, Employee manager) {
      //..
    }
}
```

- {Amy, Belinda, Carl} means that we currently have three Employee instances
  - May change, e.g., by calling “new Employee(..)”
- {(Carl, Amy)} means that: carl.reportsTo==amy
  - May change, e.g., by setting: carl.reportsTo = null

Other Class Diagram Elements

- Several other elements of UML class diagram are essentially different kinds of constraints on
  - (Concept) set variables
  - Relation variables
- Example: Multiplicity constraint on association
  - 1:N relation, ..
- The important assumption is that
  Each such constraint has to evaluate to true at each point in time

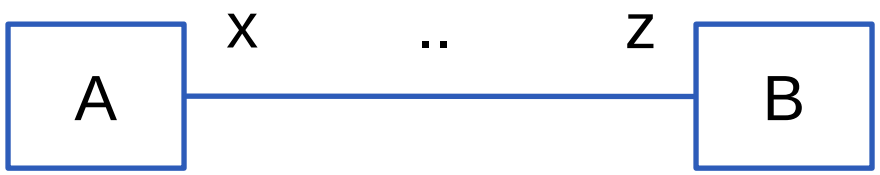
This is a Common Notion

- Each constraint has to evaluate to true at each point in time

- Compare with relational database:
  - Multiplicity constraint: Key constraint, rule, etc.
  - We expect key constraints to hold at any point in time

Important: Multiplicity Constraints

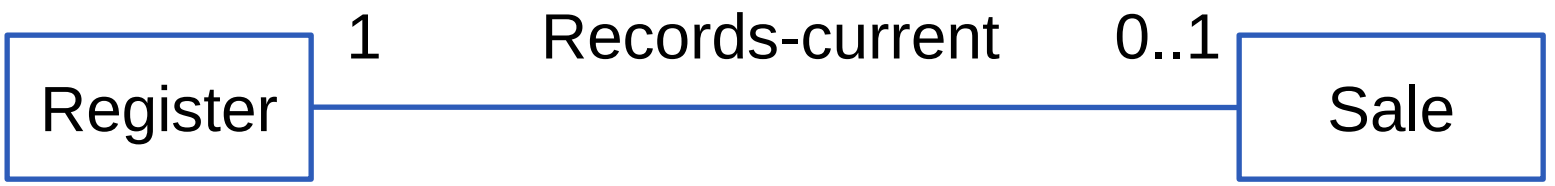
- Use it to restrict (constrain) an association
  - To a function or a special relation
- If present, must be present at each end of line



- **Each item in A maps to z items in B**
- **Each item in B maps to x items in A**
- Each annotation x, z is a range, e.g.: 1..5
  - Collapse single element ranges, e.g.: “1..1” to “1”
- Star (*) means “zero or more”

Example: Register—Sale

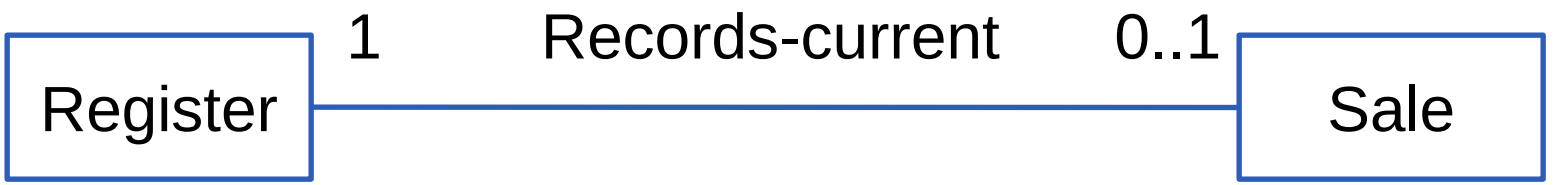
- We want to capture the currently recorded sales
- Records-current relation with multiplicity constraint:



- At any particular moment, a register may record zero or one sales (but not more) → 0..1
- A sale is recorded by exactly one register → 1

Example: Legal Relation State 1

- Arlington Walmart, Feb.16, 4:00:00 am
  - Registers: {1, 2, 3, .., 25}
  - Sales: {s1, s2}

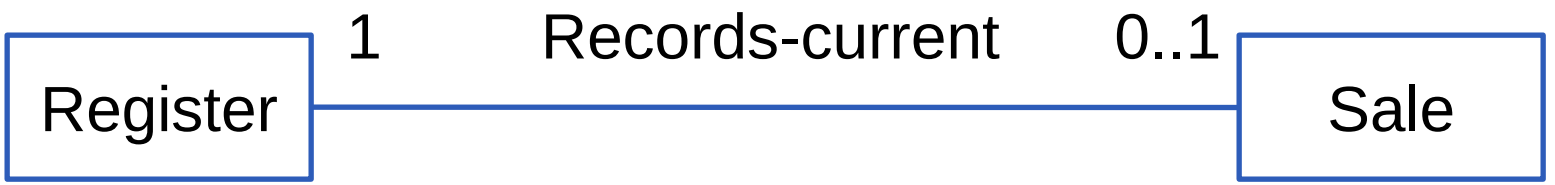


- Records-current:

{
(1, s1),
(3, s2)
}

Example: Legal Relation State 2

- Arlington Walmart, Feb. 16, 4:30:00 am
  - Registers: {1, 2, 3, .., 25}
  - Sales: {s3, s4, s5}

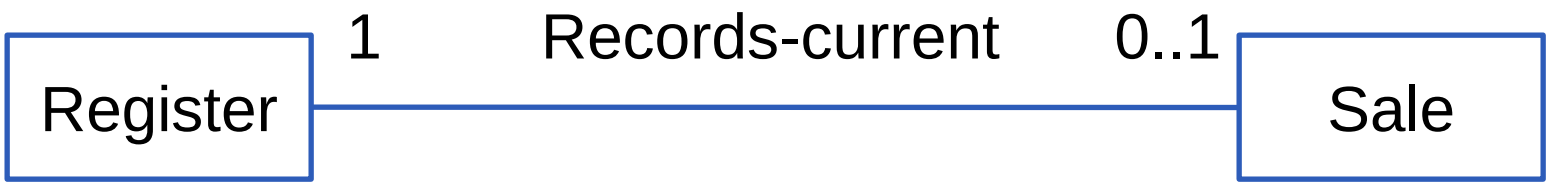


- Records-current:

{
(1, s3),
(3, s4),
(9, s5)
}

Counter-Examples: Illegal States (1/2)

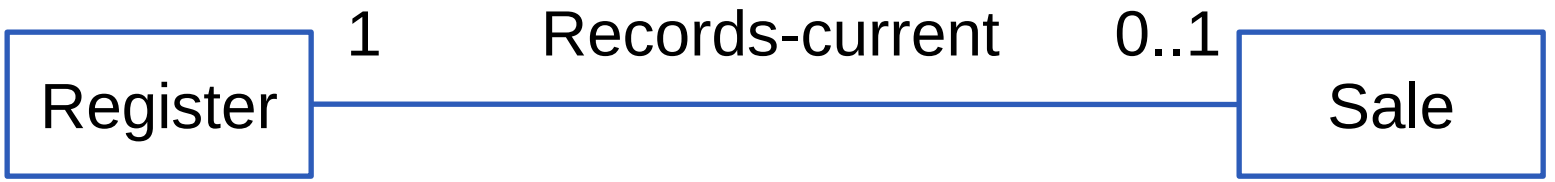
- Arlington Walmart, never
  - Registers: {1, 2, 3, .., 25}
  - Sales:{sa, sb}



- Records-current: Why?
  - {(1, sa), (1, sb)}
  - {(1, sa)}
  - {(1, sa), (2, sa)}

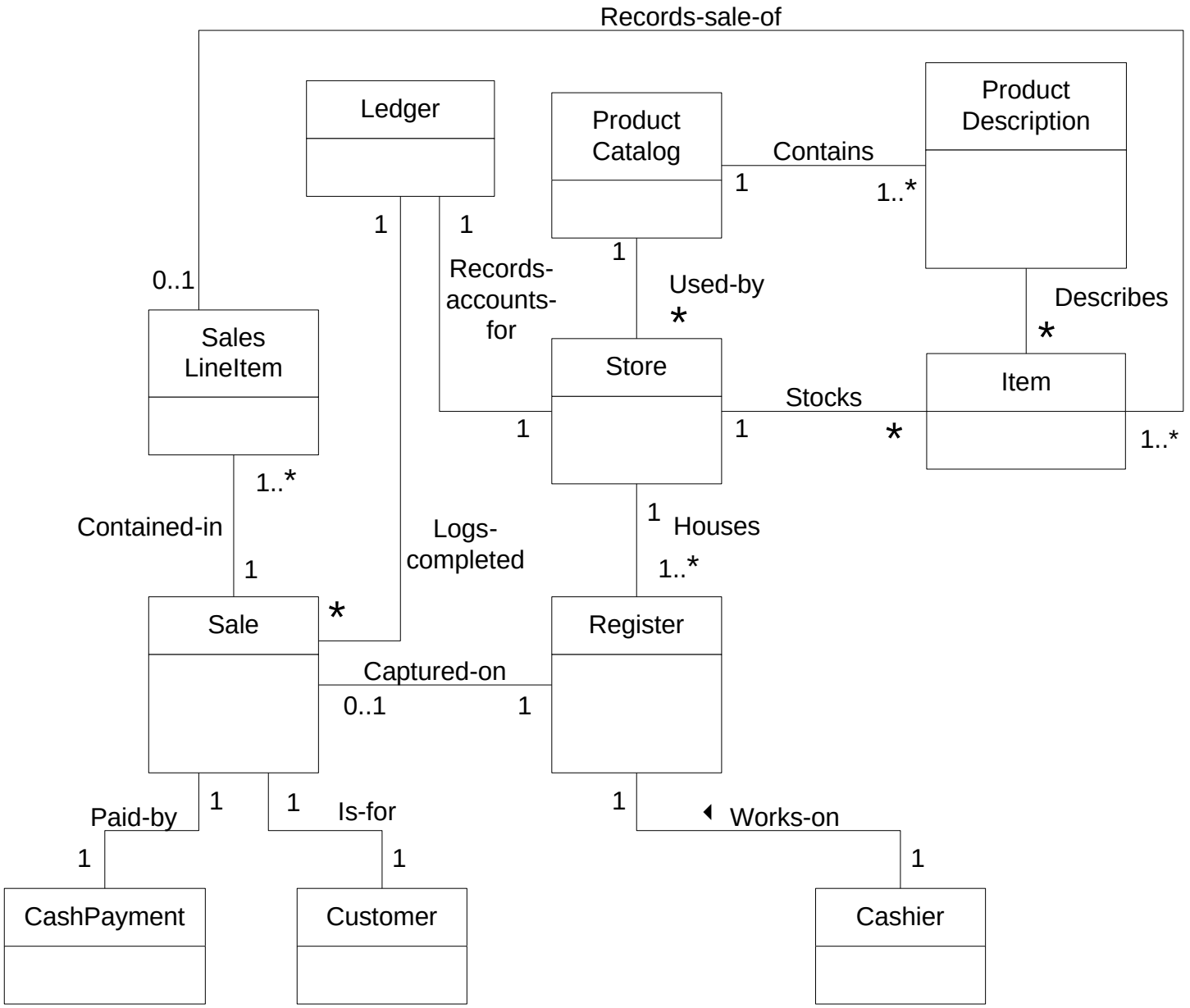
Counter-Examples: Illegal States (2/2)

- Arlington Walmart, never
  - Registers: {1, 2, 3, .., 25}
  - Sales:{sa, sb}



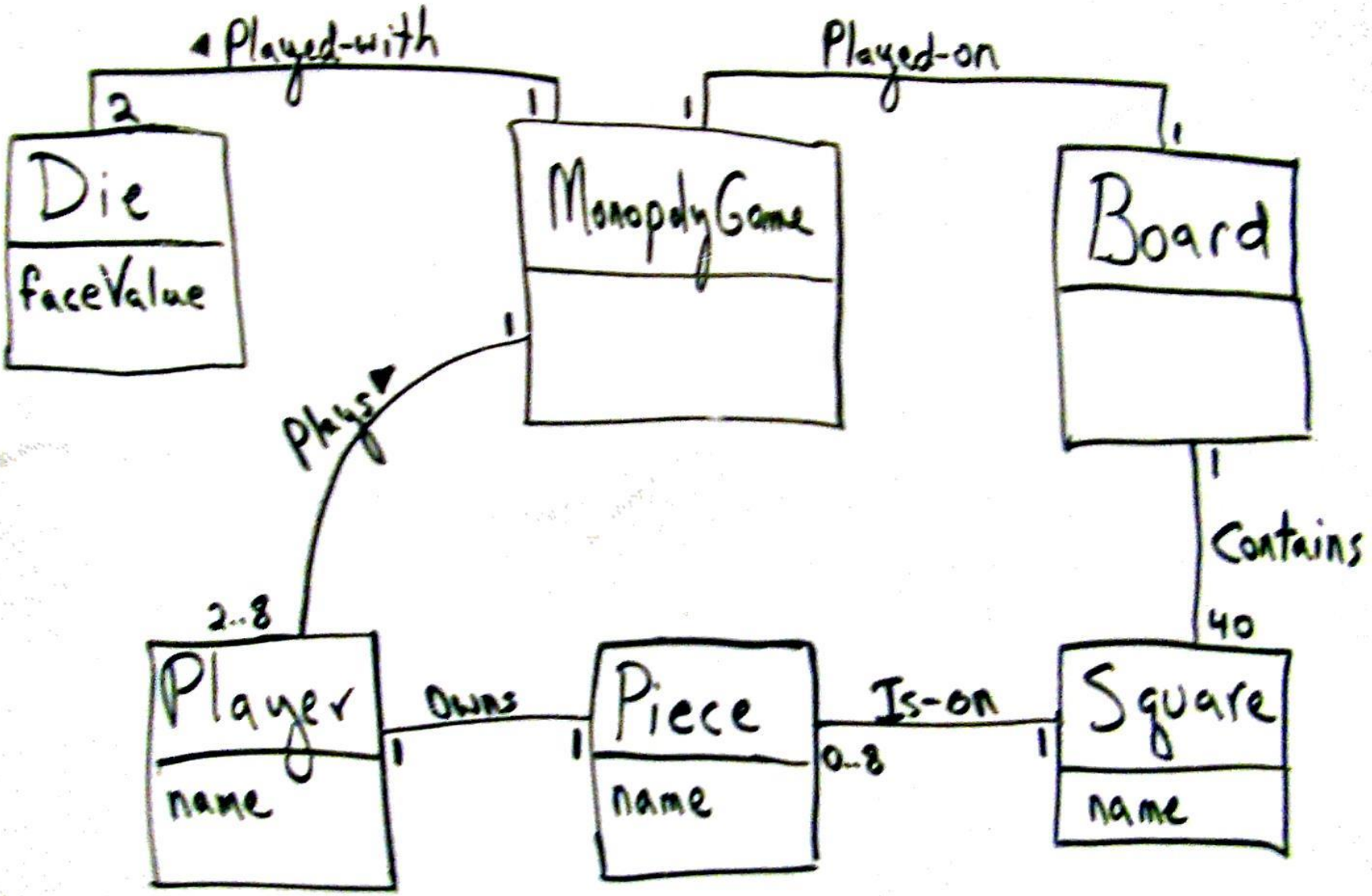
- Records-current: Why?
  - {(1, sa), (1, sb)} Register 1 has to map to 0..1 sales
  - {(1, sa)} Sale sb has to map to 1 register
  - {(1, sa), (2, sa)} Sale sb has to map to 1 register
- Would all be legal without multiplicity constraint!

Point of Sale (POS) – Updated



CL Figure 9.17

Monopoly – Updated

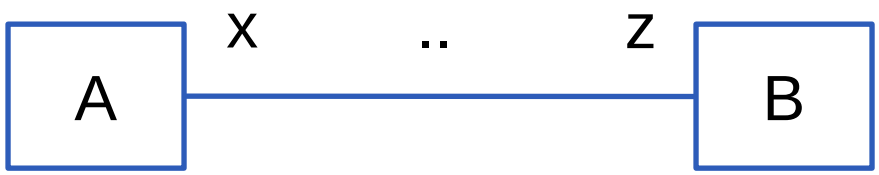


CL Figure 9.18

IN-CLASS EXERCISE: ADD MULTIPLICITY CONSTRAINTS

Add Multiplicity Constraints

- Get together with your team
- Add multiplicity constraints to your domain model:



- **Each item in A maps to z items in B**
- **Each item in B maps to x items in A**
- Each annotation x, z is a range, e.g.: 1..5

- Be prepared to present your results
  - Post your result to Teams chat

Things That Should be in the UML

- We have seen a relation constraint: multiplicity
- Where are corresponding constraints on concepts?
  - They are in BL, Section 12.1.1 ;-)
  - Not sure if they are in the UML

- Examples:
  - Fixed: Set membership is fixed (constant set)
  - Size: How many elements the set contains
    - Singleton (1), Java-style enumeration, etc.

CL, Chapter 31, but warning still applies

DOMAIN MODEL REFINEMENT

Subset

- Recall: Conceptual class = Set of similar things
- Sometimes, want to structure set
- Classic way to structure a set: Define subsets

Subset: A ⊆ B

- Sets A, B
- Every element of A is also an element of B
  - A is a subset of B
  - B is a superset of A
  - A is included in B
  - B includes A
  - A and B may be the same

Subset: Is-A Test

- Natural language formulation of subset relation
  - Informal, easy
- Quick first check if two conceptual classes are related by subtype relation

- Examples:
  - CashPayment is-a Payment
  - CreditPayment is-a Payment
  - CheckPayment is-a Payment

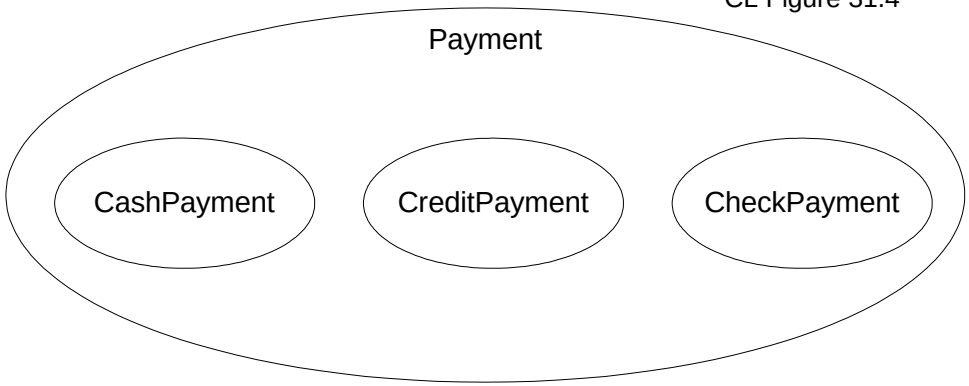
Example: Cash payment ⊆ Payment

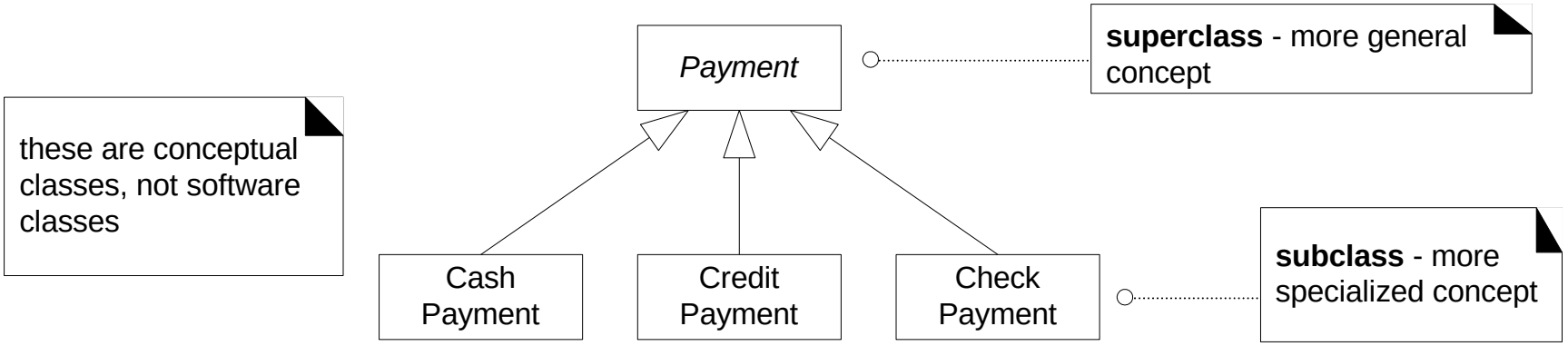
- Conceptual classes: Payment, Cash payment
- Every Cash payment is also a Payment
- Cash payment is a subset of Payment
- Etc.

Class Diagram Terminology

- (Generalization-specialization) class hierarchy
  - Subset relation on conceptual classes
- Superclass
  - Superset
  - Example: Payment
- Subclass
  - Subset
  - Example: Cash payment

CL Figure 31.4





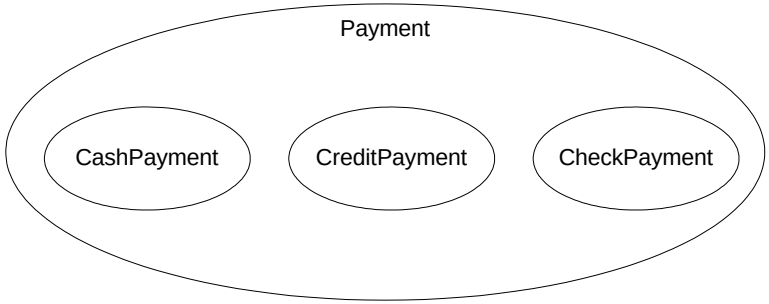
CL Figure 31.1

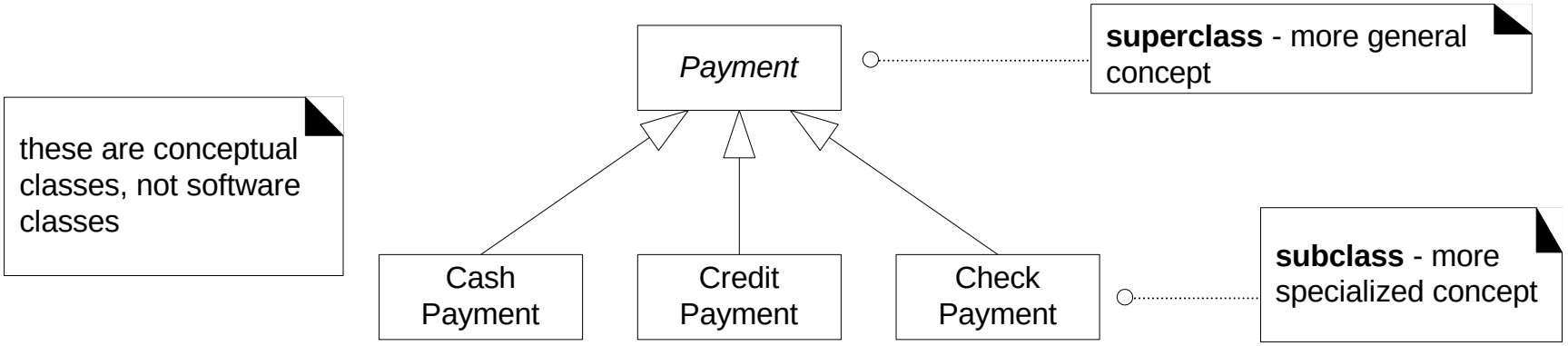
Class Hierarchy

- Subset relation on conceptual classes
- Example:

{
(CashPayment, Payment),
(CreditPayment, Payment),
(CheckPayment, Payment)
}

CL Figure 31.4





CL Figure 31.1

Subset Relation – OO Subtype Relation

- Compare with subtype polymorphism in object-oriented programming languages, e.g.:
- Cash payment ⊆ Payment
  - Conceptual classes: Cash payment, Payment
  - Every Cash payment is also a Payment
  - **Cash payment is a subset of Payment**
- Java: class CashPayment extends Payment {..}
  - Types (classes): CashPayment, Payment
  - Every CashPayment instance is also a Payment instance
  - **CashPayment is a subtype (subclass) of Payment**

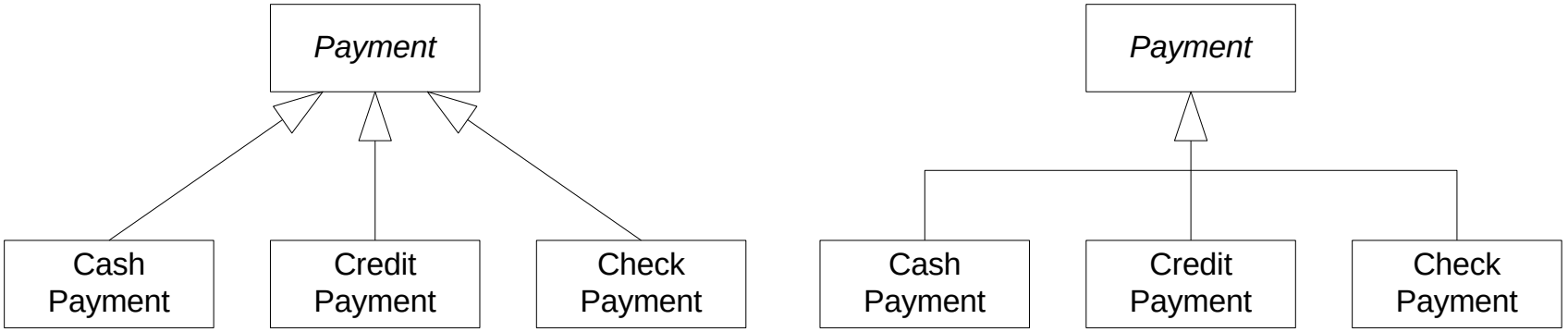
Subtype Polymorphism Example

- One of:
  - `class Dog extends Animal {}`
  - `class Dog implements Animal {}`
- ```
  public class C {
    public static void foo(Animal a) {/*…*/}
    public static void bar(Dog d) {/*…*/}
  }
  ```
- ```
  public class X {
     C.foo(new Dog());
     C.bar(new Dog());
  }
  ```

Subtype (Dog) is **poly-** (“many”) **morphic** (“shaped”): Can use a Dog in place of itself and in place of (each of) its supertype(s) (here: Animal)

UML Class Diagram Notation

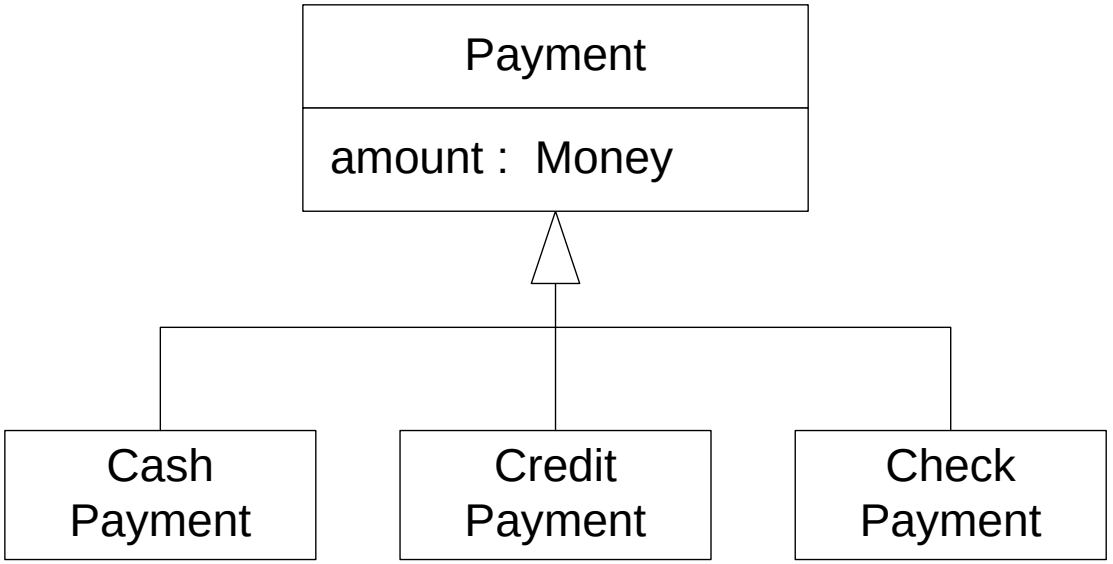
- $A \subseteq B$
  - A is a subset of B
  - Directed edge from A to B
  - Large hollow triangle
  - Edge may be shared with $C \subseteq B$ etc.
  - Edge sharing just layout (unlike BL, see BL page 273)
- Example:



CL Figure 31.2

Subclass “Inherits” Attributes

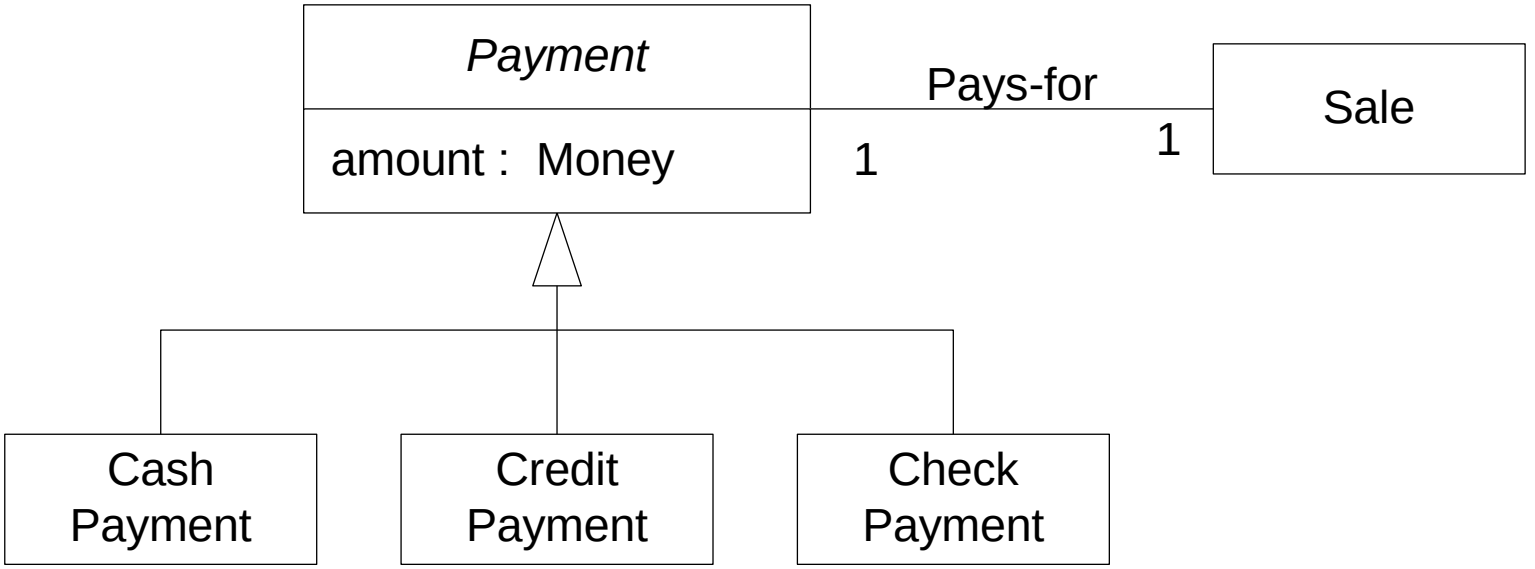
- Recall: Class hierarchy = Subset relation
  - Each element of subclass is an element of superclass
- Each payment has an amount attribute → Each element of each subclass of Payment has an amount attribute



CL Figure 31.5

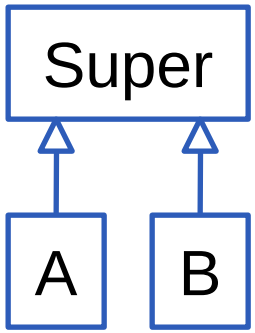
Subclass “Inherits” Associations

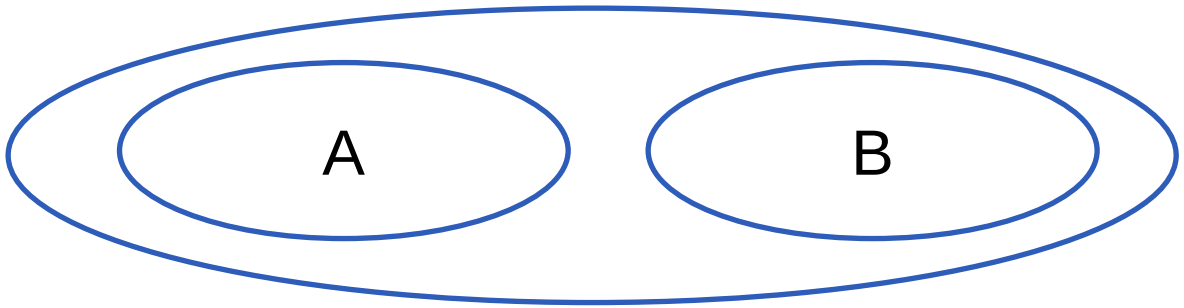
- Recall: Class hierarchy = Subset relation
  - Each element of subclass is an element of superclass
- Each payment is associated with one sale → Each element of each subclass of Payment is associated with one element of Sale



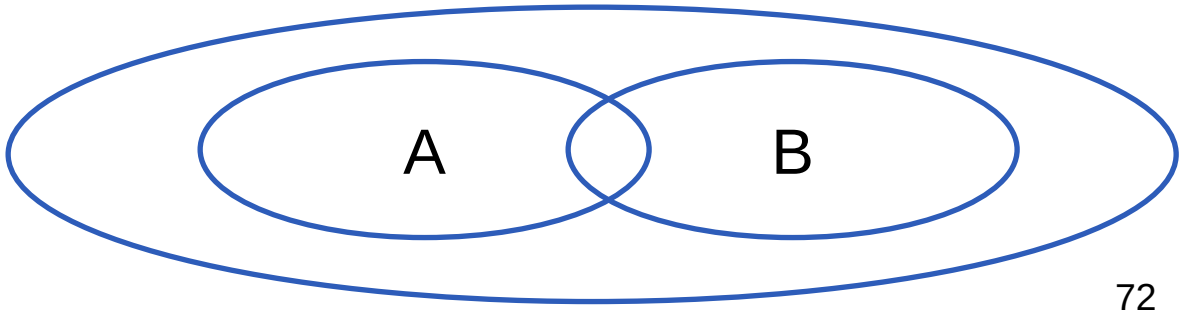
CL Figure 31.5

Can Subsets Overlap Each Other?



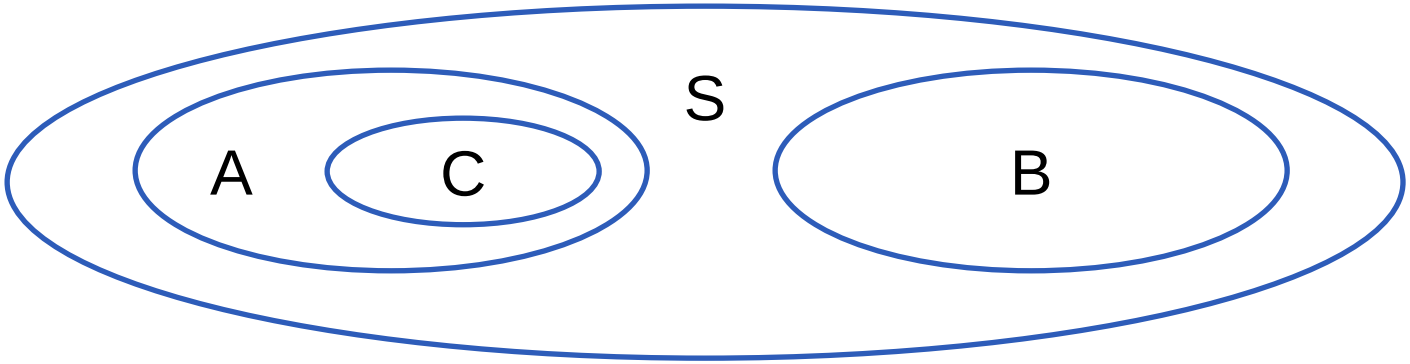


- Or:



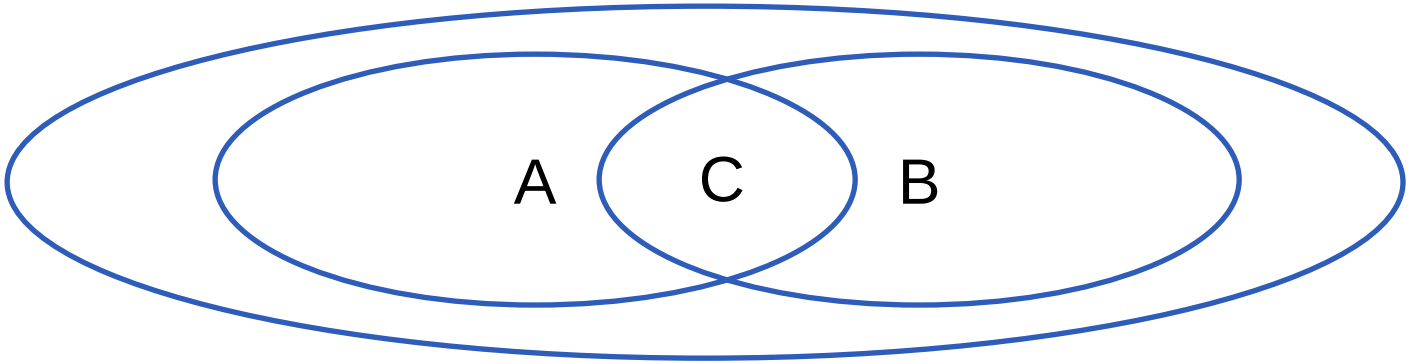
Java: Non-overlapping Subsets

- Single class inheritance (sub-classing)
  - class A extends S {..}
  - class B extends S {..}
  - Instance of A cannot be an instance of B
  - Member of set A cannot be a member of class B
  - class C extends A {..} // but not B



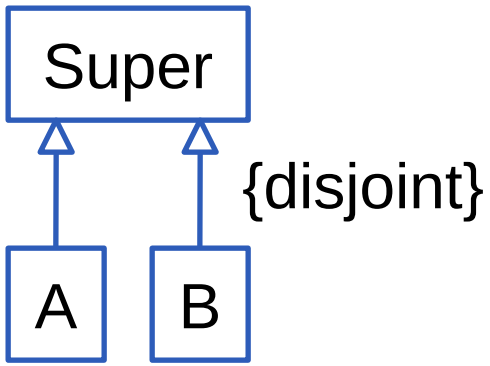
Java: Overlapping Subsets

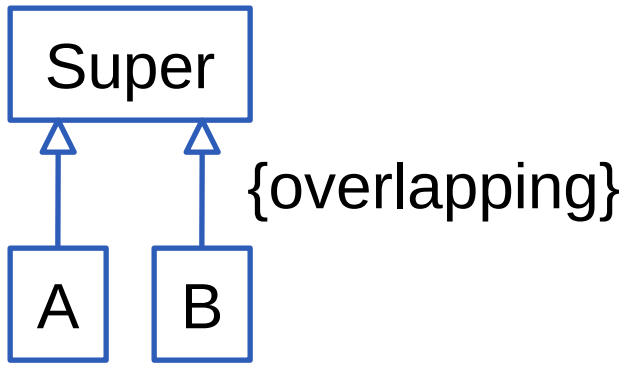
- Multiple interfaces inheritance
  - interface A extends S {..}
  - interface B extends S {..}
  - Instance of A can also be an instance of B
  - Member of set A can also be a member of set B
  - class C implements A, B {..}



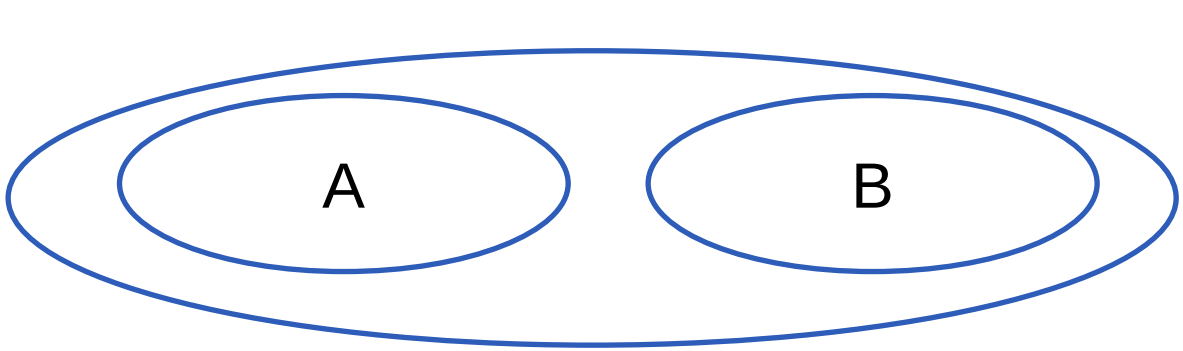
Subset (Non-) Overlap in UML

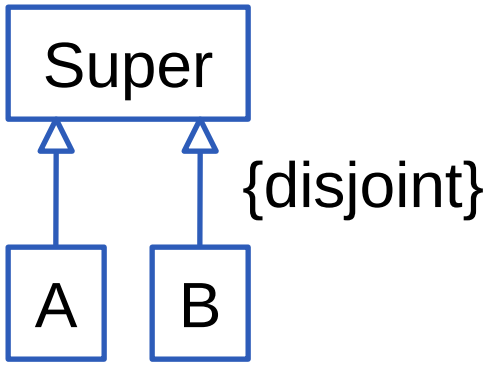
- Both possible in both Java & UML
- Default: disjoint (mutually exclusive)
  - CL, page 514: Subclasses disjoint (mutually exclusive)
  - UMLSS version 2.1.2, Section 7.3.21
    - UMLSS = UML “Superstructure” Specification
    - http://www.omg.org/spec/UML/2.1.2/
- Constraint on subclass arrow:

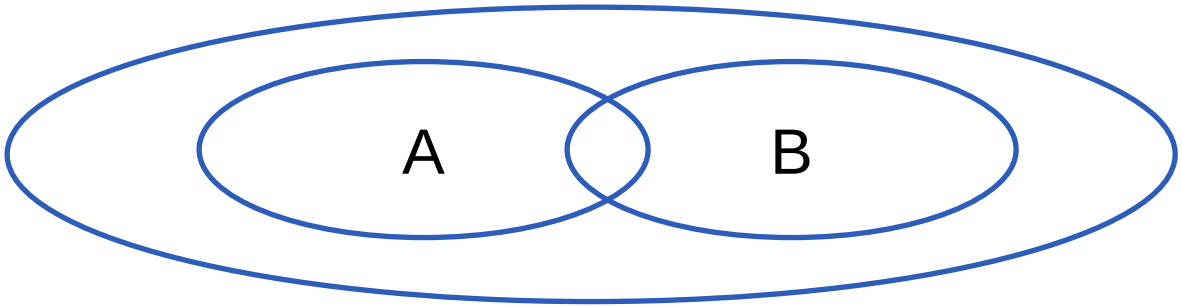


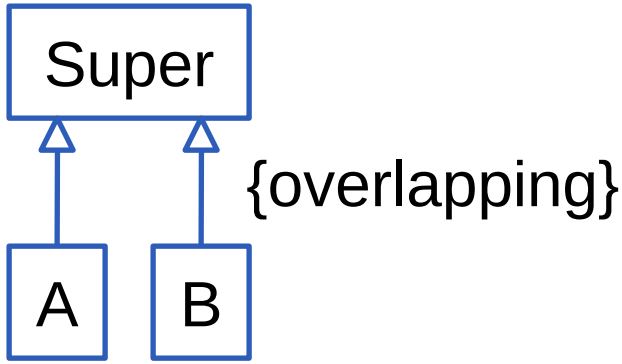


Subset Overlap: Example UML





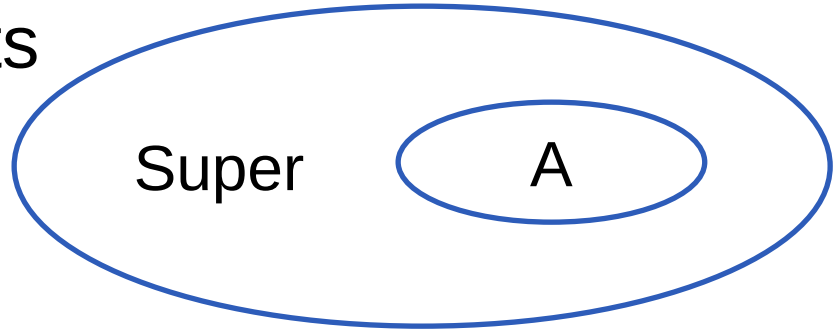




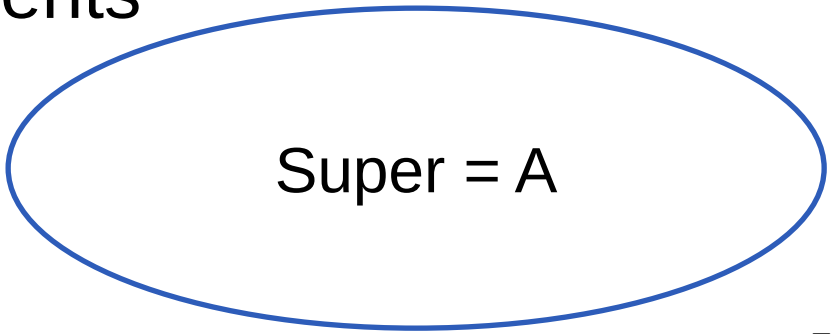
Exclusively Super Elements?

- Does an element exist that is an element of a superclass but not an element of any subclass?

- Exclusively super elements
  - A ⊆ Super
  - e element of Super
  - e not element of A



- No exclusively super elements
  - A ⊆ Super
  - e element of Super
  - e element of A



Exclusively Super Elements in Java

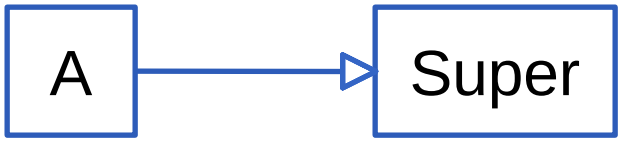
- There may exist elements of the superclass that are not element of any subclass
- Concrete classes in Java
  - class Super {..}
  - class A extends Super {..}
- It is possible that an instance of Super is not an instance of any subtype of Super
  - It is possible that an element of the Super set is not an element of any subset of Super

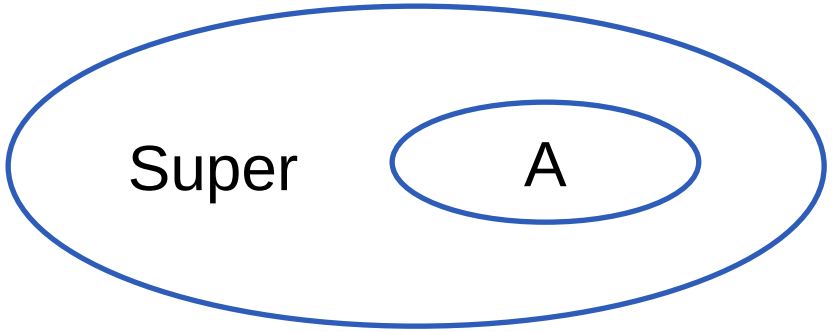
No Exclusively Super Elements in Java

- Each element of a superclass is also an element of a subclass
- Abstract types in Java
  - interface Super {..}
  - abstract class Super {..}
- Each instance of abstract type Super also has to be an instance of a subtype of Super
  - Each element of set Super also has to be an element of a subset of Super

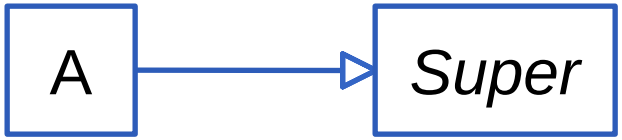
(No) Exclusively Super Element: UML

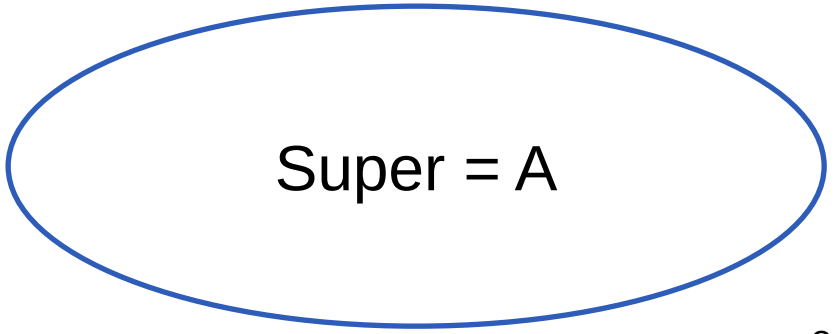
- Does an element exist that is an element of a superclass but not an element of any subclass?
- Both possible in UML
- Default:



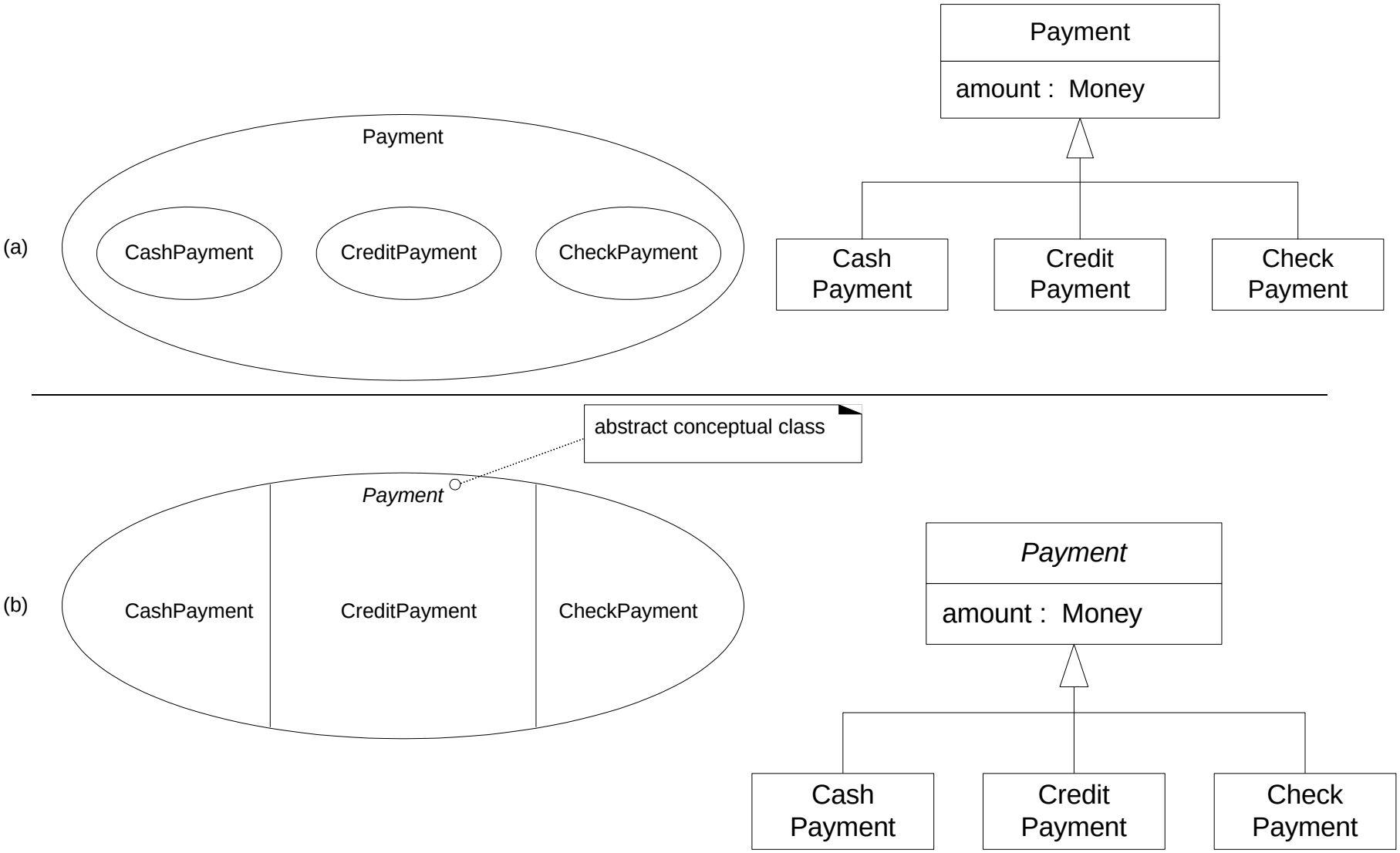


- Abstract conceptual superclass in *italic*





Payment Example



IN-CLASS EXERCISE: SUBSETS

Subsets

- Get together with your team
- Add subclasses to your domain model
  - Pick a class (box) that is complex or plays different roles & add subclasses to that class
  - Decide if there should be exclusively super-elements
  - Add disjoint/overlapping constraints
- Post your results in class's Teams chat