Overview - Object-Oriented Analysis and Design

- Design thinking
- Object Modeling Technique
  - Object-Oriented Analysis
  - Object-Oriented Design
- Three models
  - Object model
  - Dynamic model
  - Functional model
- Four phases

Design Goals

- Design transforms requirements into
  - an architecture diagram
    - ¤ subsystems, modules and their relationships
  - a detailed design
    - ¤ a specification of the abstract interface, data structures, and algorithms of each module
- Also develops
  - a review plan for ensuring the design meets the requirements
  - a test plan for ensuring the implementation meets the design

Object-Oriented Software Development

- Object-Oriented Methodology
  - development approach used to build complex systems using the concepts of object, class, polymorphism, and inheritance with a view towards reusability
  - encourages software engineers to think of the problem in terms of the application domain early and apply a consistent approach throughout the entire life-cycle
- Object-Oriented Analysis and Design
  - analysis models the "real-world" requirements, independent of the implementation environment
  - design applies object-oriented concepts to develop and communicate the architecture and details of how to meet requirements

Object Modeling Technique Process via UML

- OMT [Rumbaugh et al.,1991] consists of
  - building three complementary models of the system
  - adding implementation details to the models
  - implementing the models
- OMT includes a set of
  - phases [processes]
  - diagramming techniques
- OMT has four phases
  - object-oriented analysis builds a real-world model
  - system design determines overall architecture of system
  - object design decides upon data structures and algorithms
  - implementation translates design into programming language

OMT Stages and Models

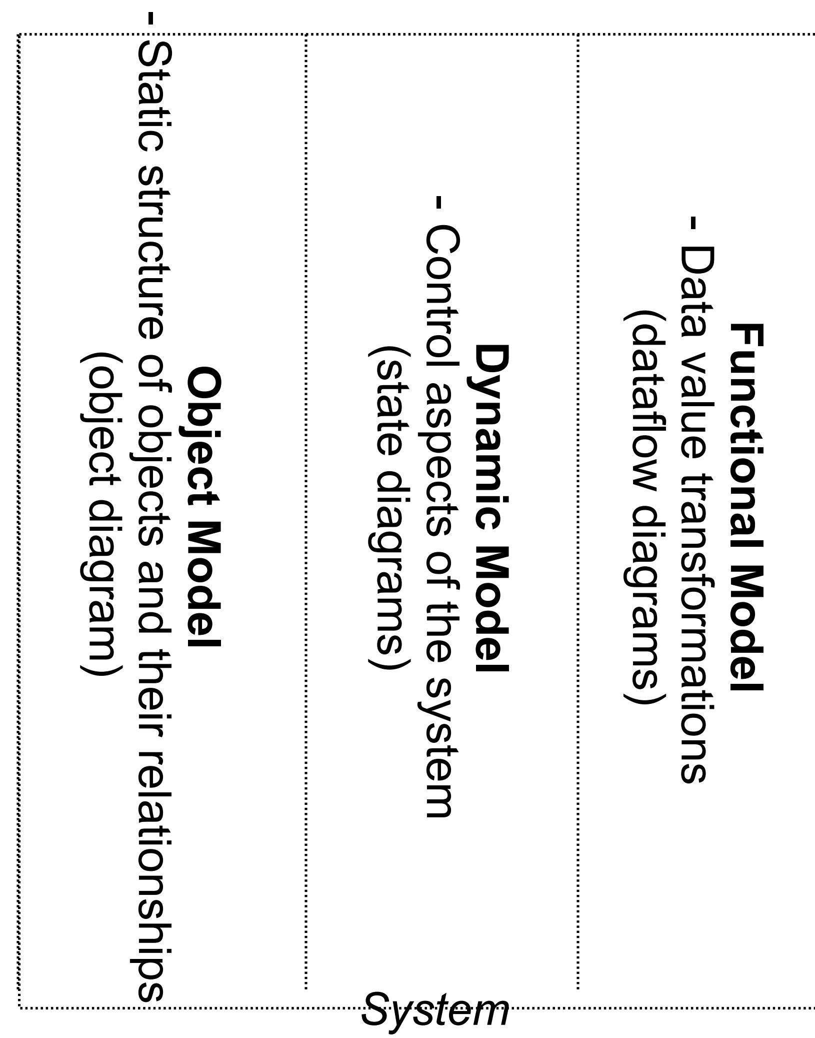
time

Analysis
- Model of real-world situation
- What ?

System Design
- Overall architecture (sub-systems)

Object Design
- Refinement of Design
- Algorithms/data structures to implement each class

Implementation
- Translation of object classes and relationships to a particular object-oriented language



Introduction to Object-Oriented Analysis

- Object-Oriented Analysis is the "requirements phase" of Object-Oriented Software Development
  - think of it as an alternative semi-formal technique

- Semi-formal technique
  - class modeling
  - dynamic modeling
  - functional modeling
- These steps focus on
  - data
  - actions
  - their relationships

- Reuses familiar tools
  - E-R diagrams
  - Finite State Machines
  - Data flow diagrams
- Steps and diagrams
  - typically performed in parallel after initial class definition
  - must be kept in synch

Object-Oriented Analysis

- Builds a "real-world" model from requirements
  - client interviews, domain knowledge, real-world experience collected in use cases and other simple notations
- OOA models address three aspects of the system (its objects)
  - class structure and relationships
  - sequencing of interactions and events
  - data transformations and computations

Models of Object-Oriented Analysis (cf UML)

- Class Model
  - static structure
  - what objects are in the system?
  - how are they related?
- Dynamic Model
  - behavioral aspects
  - what events occur in the system
  - when do they occur and in what order?
- Functional Model
  - data transformations
  - "what" does the system do

- Data-Oriented
- Action-Oriented
- Both Data and Actions

OO Analysis and Design: Steps

- Class Modeling
- Dynamic Modeling
- Functional Modeling
- Add Operations to the Class Model
- Iterate and refine the models
  - After the first iteration, steps may occur in parallel or out of order
  - All models must be kept in synch as changes are made

Class Modeling

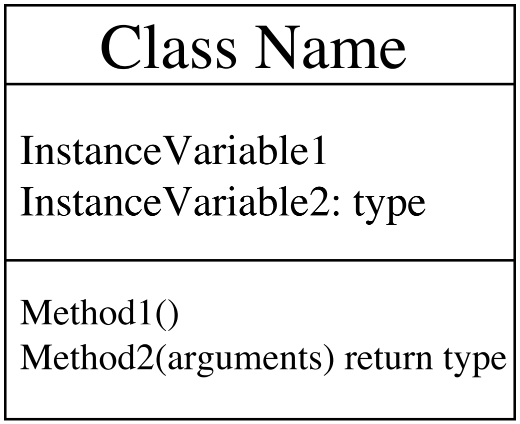
- Identify objects and classes
- Prepare a data dictionary
- Identify associations between objects
- Identify class attributes and initial set of operations
- Organize object classes using inheritance

Classes, Attributes and Operations

- Attributes define the properties of the objects
  - every instance of the class has the same attributes
  - an attribute has a data type
  - the values of the attributes may differ among instances
- Operations define the behavior of the objects
  - action performed on or by an object
  - available for all instances of the class
  - need not be unique among classes

Class	Attributes	Operations
ball	radius, weight	catch, throw
football	air pressure	pass, kick, hand-off
baseball	liveness	hit, pitch, tag

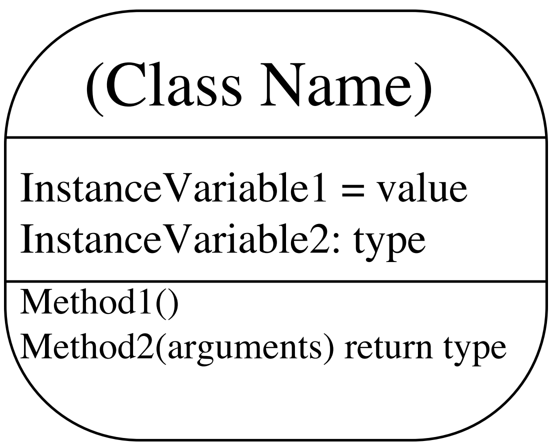
Object Model Notation (refresher)



Classes are represented as rectangles;

The class name is at the top, followed by attributes (instance variables) and methods (operations)

Depending on context some information can be hidden such as types or method arguments

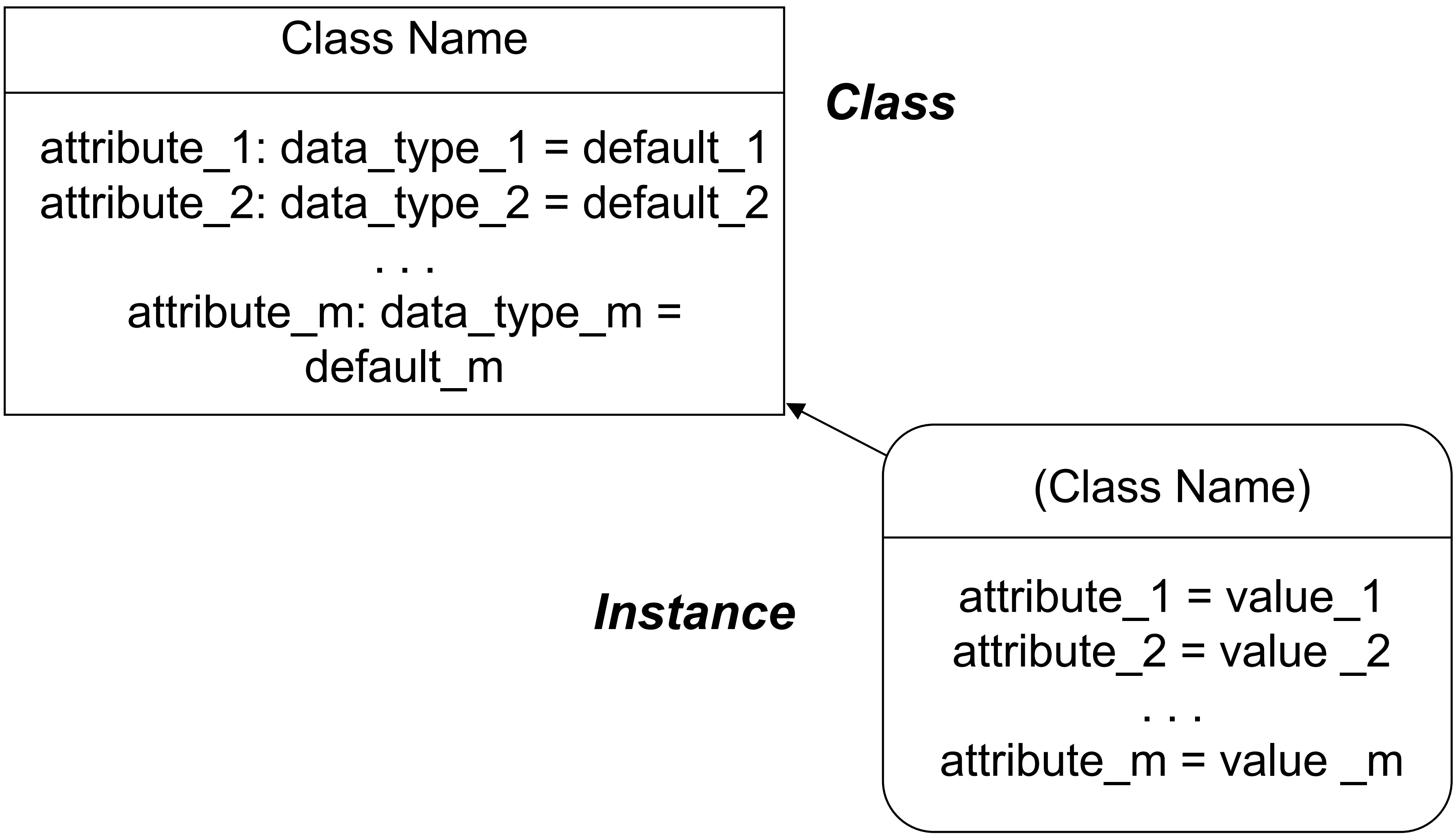


Objects are represented as rounded rectangles;

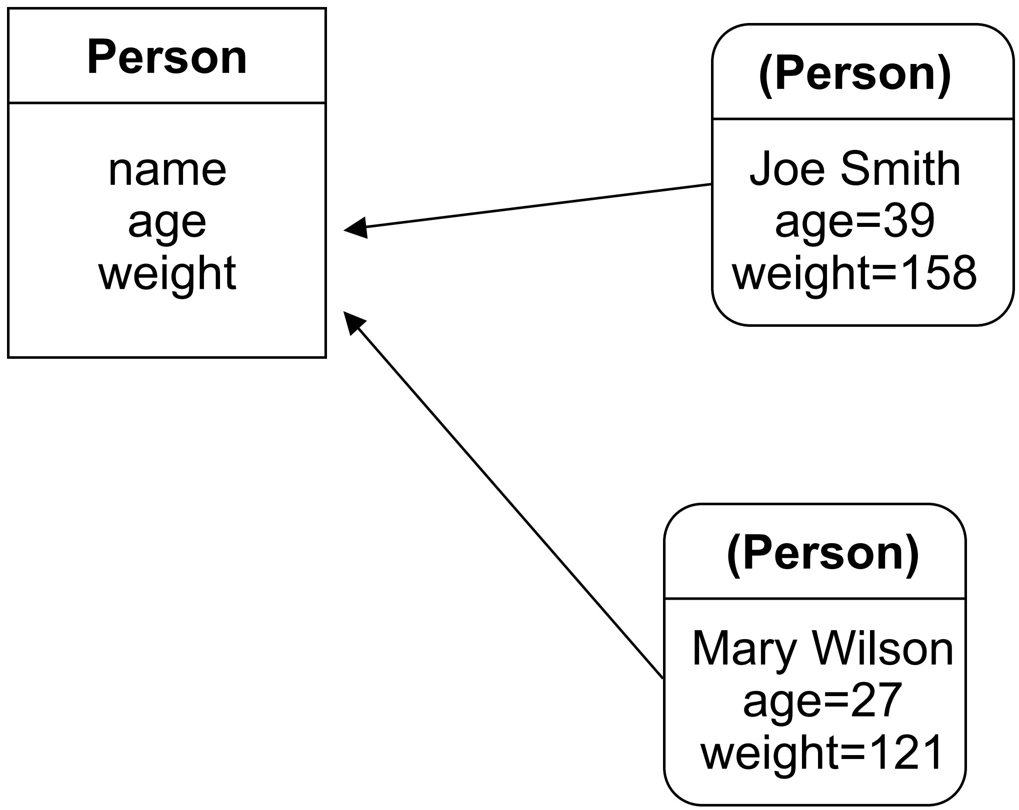
The object's name is its classname surrounded by parentheses

Instance variables can display the values that they have been assigned; pointer types will often point (not shown) to the object being referenced

OMT Instantiation Notation



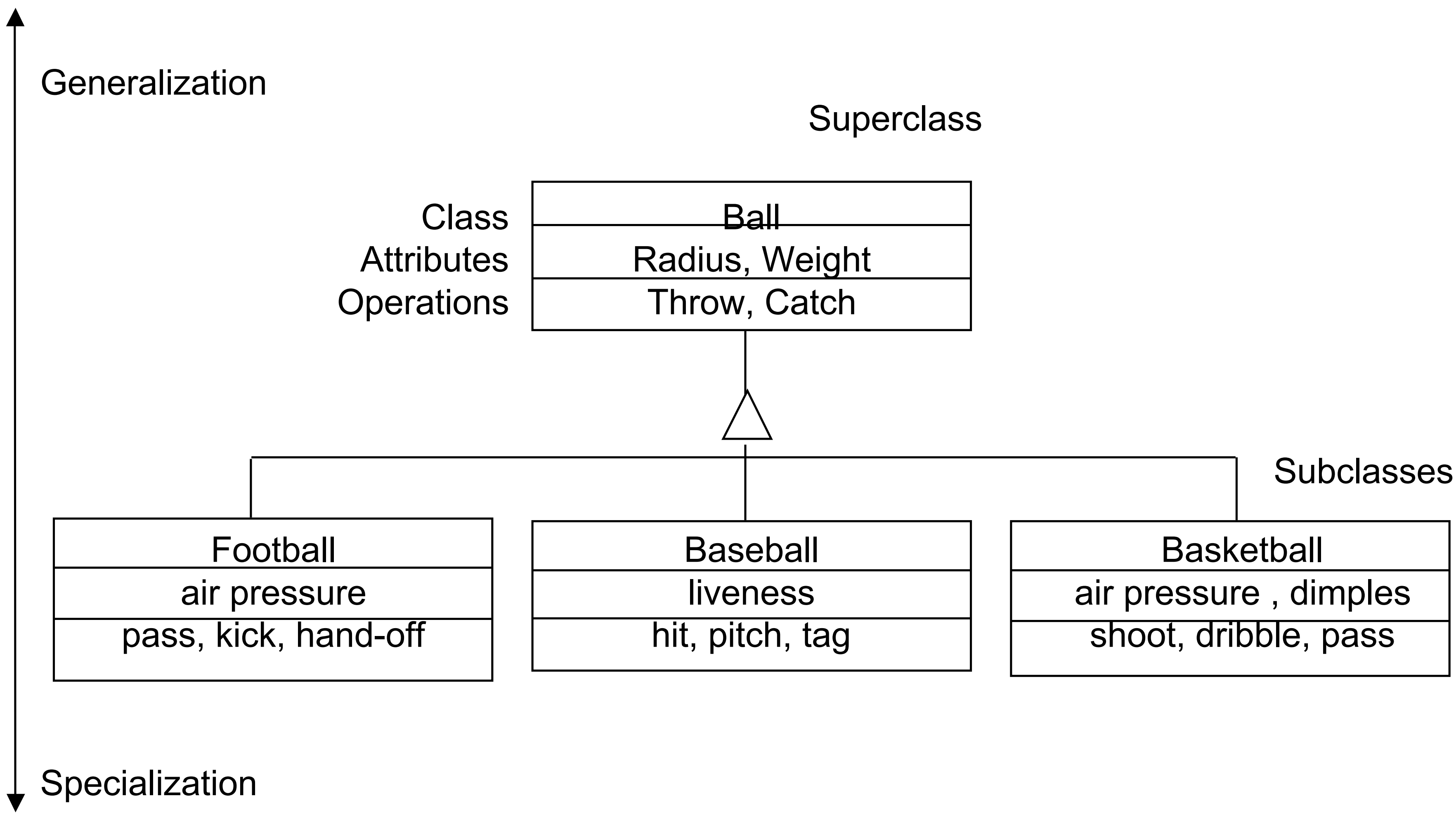
Instantiation - Example



Inheritance

- Classes with similar attributes and operations may be organized hierarchically
- Common attributes and operations are factored out and assigned to a broad superclass (*generalization*)
  - generalization is the "is-a" relationship
  - superclasses are ancestors, subclasses are descendants
- Classes iteratively refined into subclasses that *inherit* the attributes and operations of the superclass (*specialization*)
- Do you see any disadvantages to inheritance?

OMT Inheritance Notation

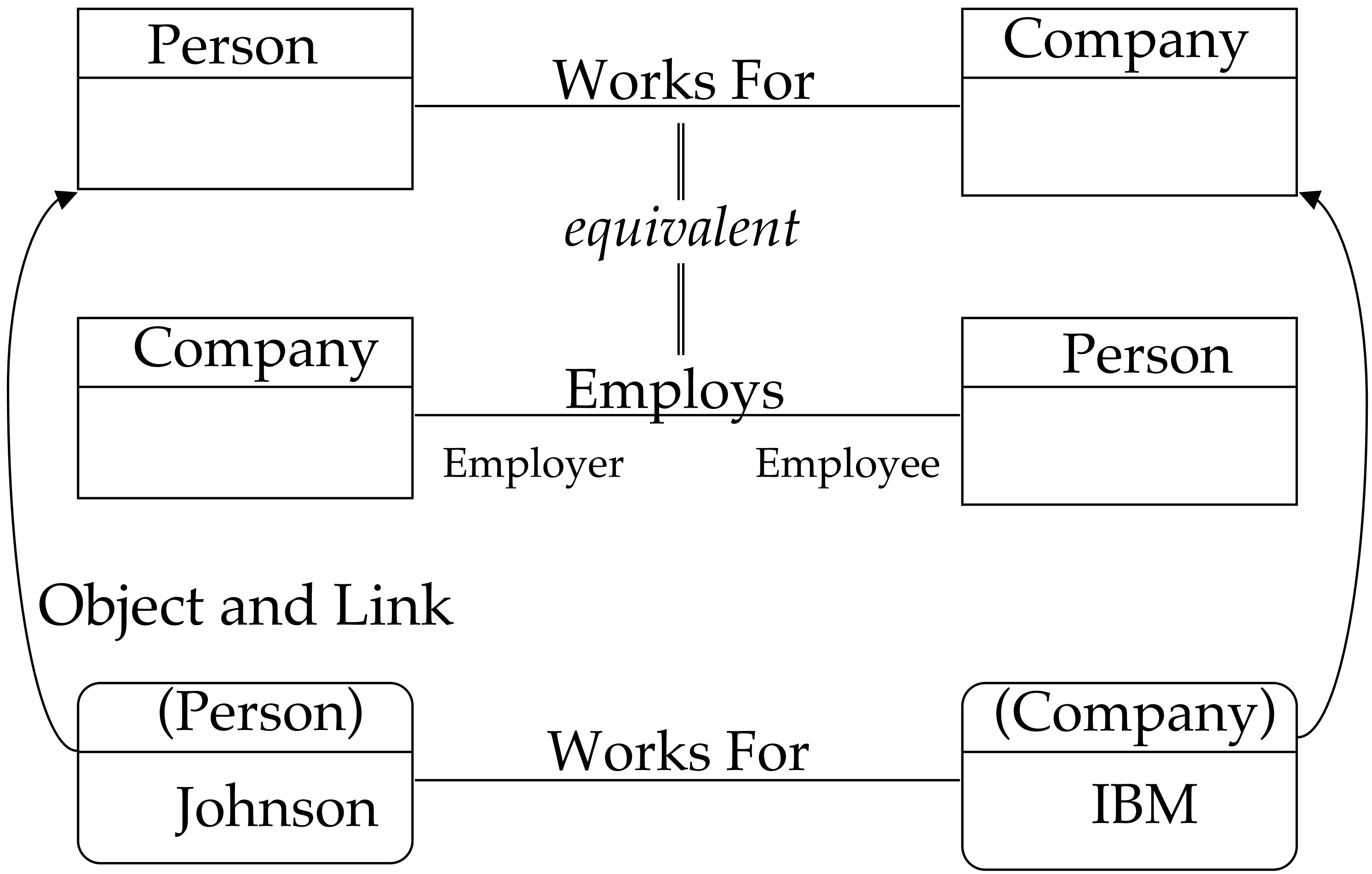


Association and Links

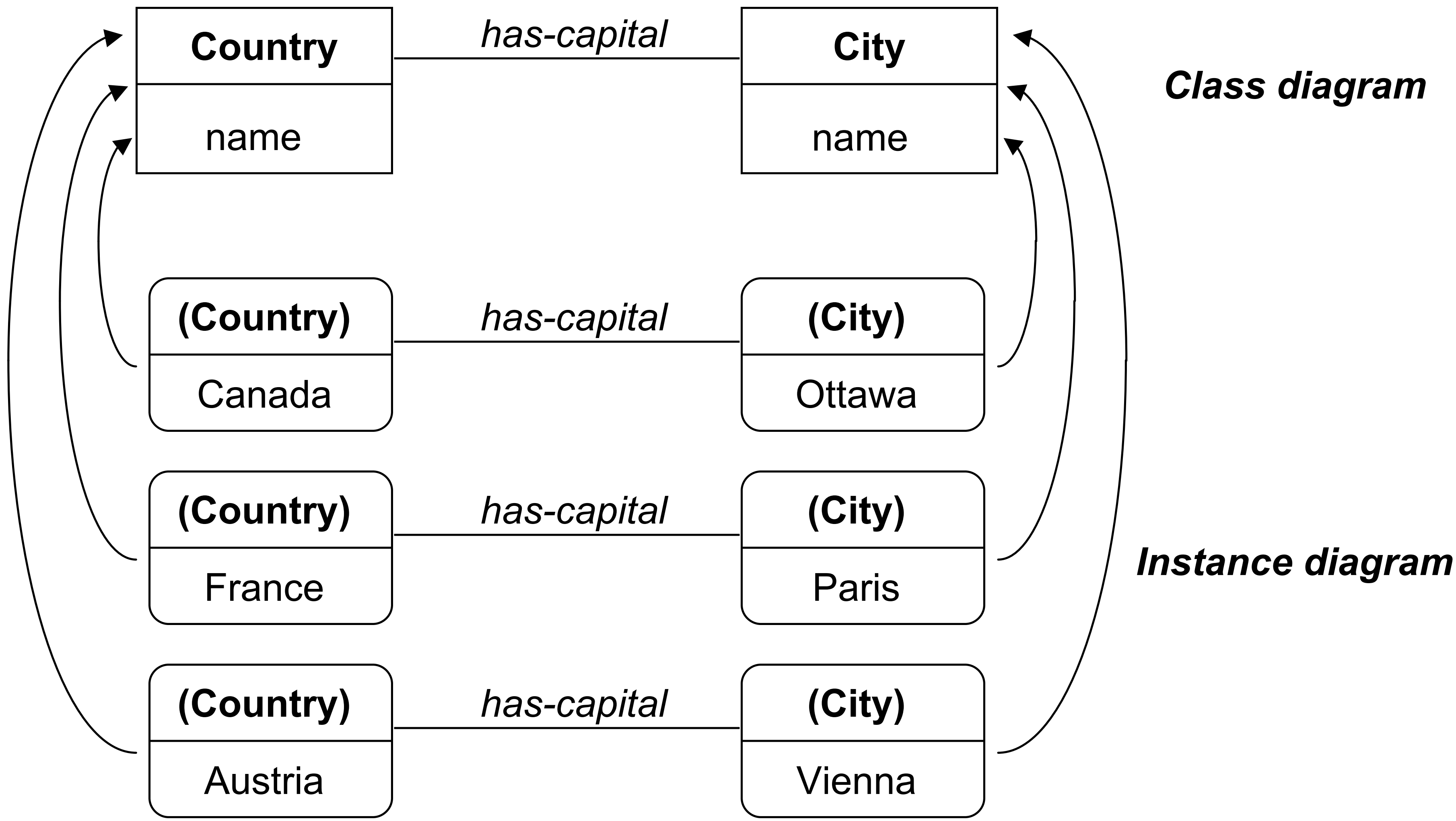
- An association is a relation among two or more classes describing a group of links, with common structure and semantics
- A link is a relationship or connection between objects and is an instance of an association
- A link or association is inherently bi-directional
  - the name may imply a direction, but it can usually be inverted
  - the diagram is usually drawn to read the link or association from left to right or top to bottom
- A role is one end of an association
  - roles may have names

OMT Association Notation

Class, Association, and Roles



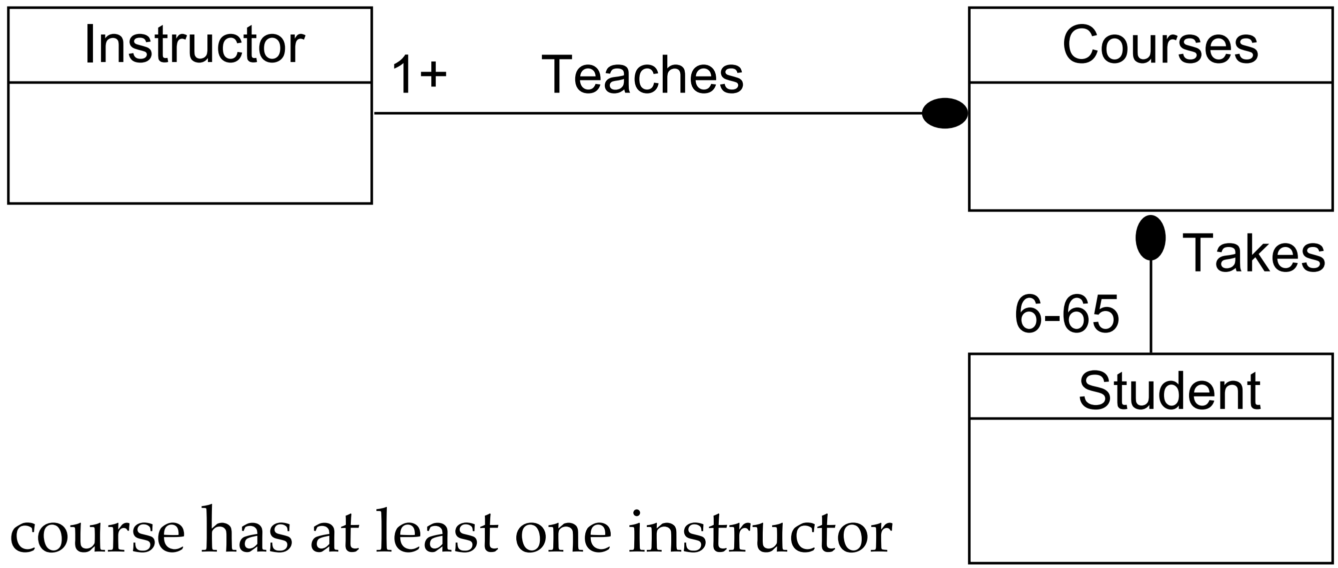
Association and Links



Multiplicity of Associations

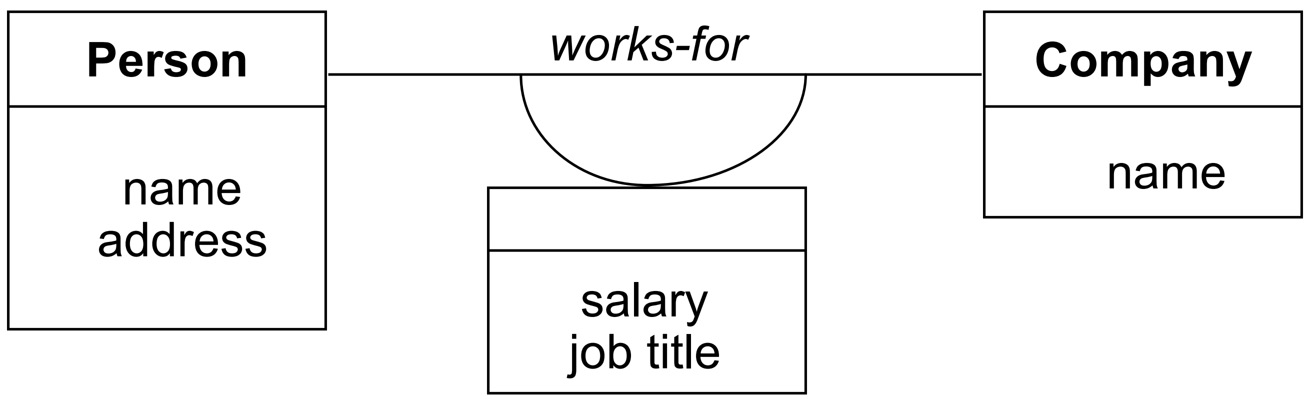
- Multiplicity is the number of instances of one class that may relate to a single instance of an associated class
  - 1-to-1
  - 1-to-many (0 or more)
  - 1-to-(zero-or-one) ‘optional’
  - 1-to-(one-or-more) ‘required’
  - 1-to-n

OMT Multiplicity Notation



Each course has at least one instructor and between 6 and 65 students
A student may take many courses
An instructor may teach many courses

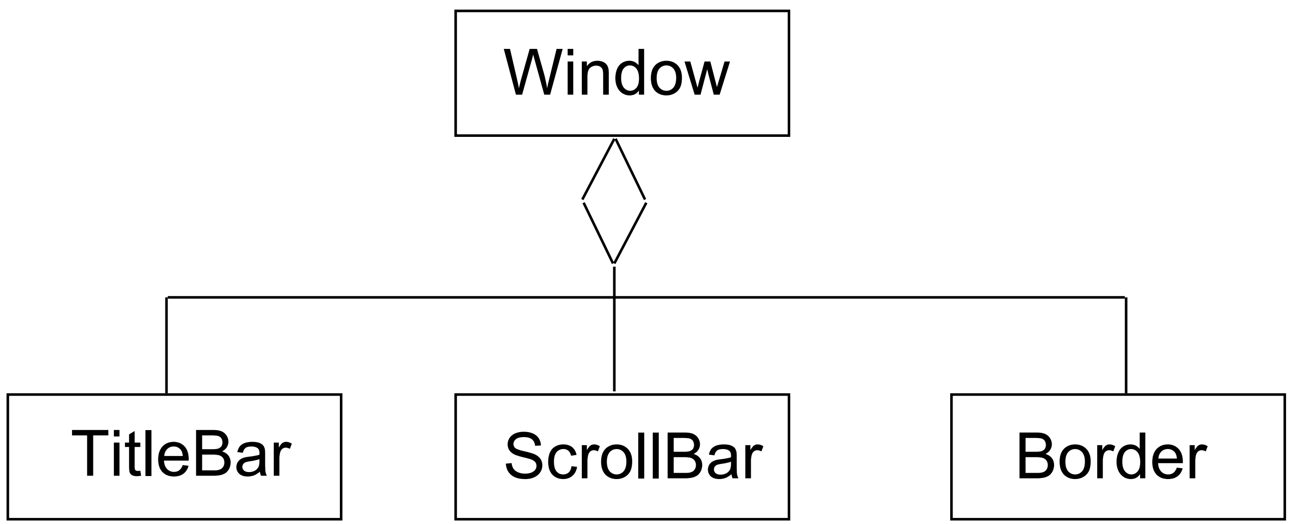
Link attributes for associations



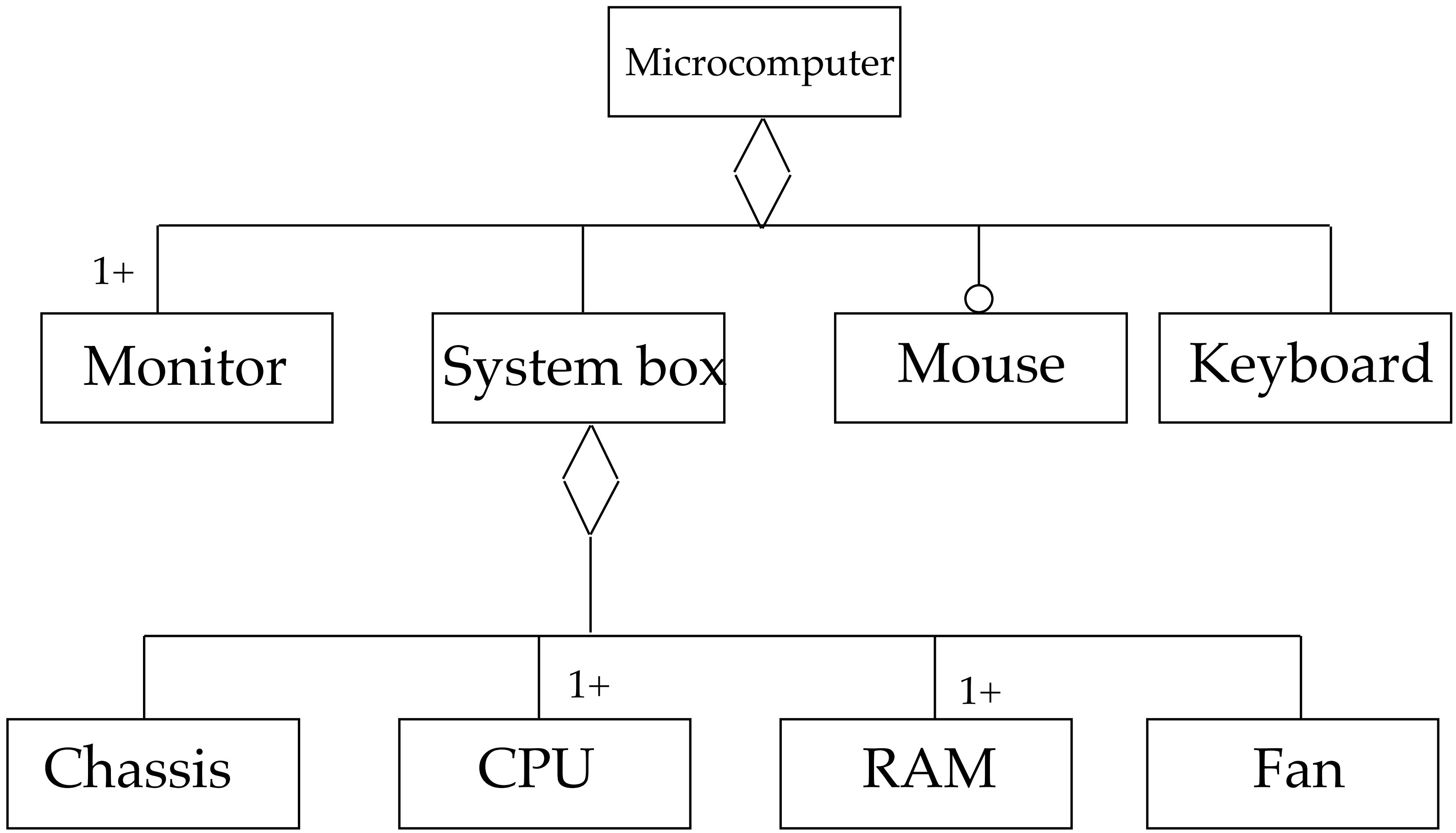
Aggregation

- Aggregation is a special form of association that indicates a “part-of” relationship between a whole and its parts
- Useful when the parts do not have independent existence
  - A part is subordinate to the whole
- In an aggregation, properties and operations may be propagated from the whole to its parts

OMT Aggregation Notation



Multilevel aggregation



An Example

FastData Inc. wants a subsystem to process office supply orders via the Web. The user will supply via a form their name, password, account number, and a list of supplies along with an indication of the quantities desired. The subsystem will validate the input, enter the order into a database, and generate a receipt with the order number, expected ship date, and the total cost of the order. If the validation step fails, the subsystem will generate an error message describing the cause of the failure.

Purpose of Example

- We will demonstrate the UML /OMT using this example
  - Class modeling will be done first
  - Dynamic and Functional modeling will occur next
  - Detailed design after that
- Things to remember
  - This example does not demonstrate how the technique is applied to ALL problems. Be sure to distinguish between the details of the example and the details of the technique!

Concise Problem Definition

- Define the problem concisely
  - Use only a single sentence

"FastData, Inc. employees may order office supplies via the Web and receive a receipt confirming the order"

- This is the first step towards identifying the classes of the subsystem

Informal Strategy

- Identify the constraints governing the system
  - Use only a single paragraph

"FastData, Inc. employees may order office supplies via the Internal Web and receive a receipt confirming the order. The order must include the user name, user password, account number, and the list of supplies. A receipt must be generated containing an order number, ship date, and total cost. If the order is valid, it must be entered into an order database. If the order is invalid, an error message must be generated."

- We now have more information to be used in identifying classes for the subsystem

Formalize the Strategy

- Identify the nouns of the description, which serve as the basis for identifying the subsystem's classes.
  - Look for out-of-domain nouns (and throw them out!)
  - Look for abstract nouns (use these for attributes)
  - The remaining nouns are good candidates!

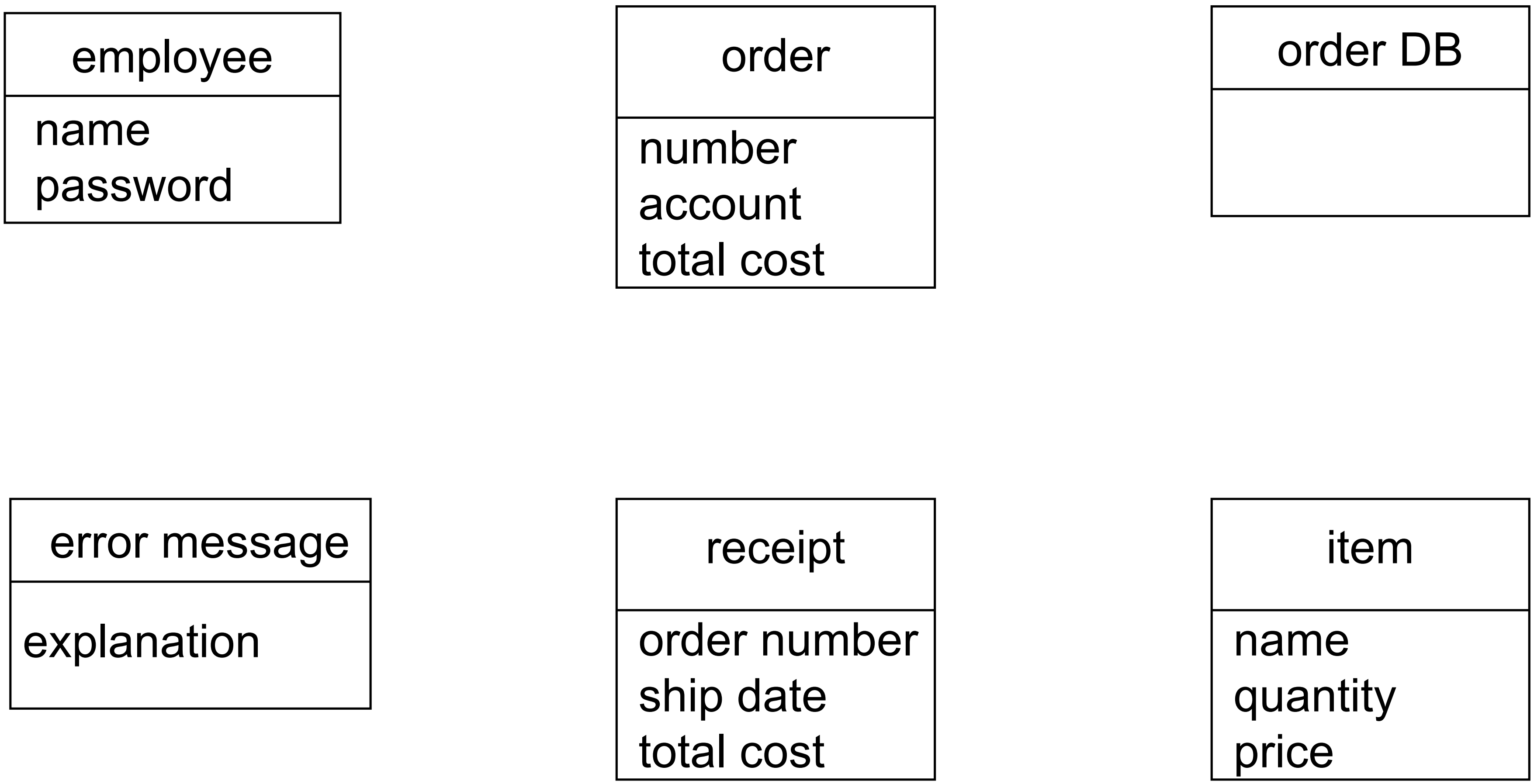
"FastData, Inc. ***employees*** may order ***office supplies*** via the ***Internal Web*** and receive a ***receipt*** confirming the ***order***. The ***order*** must include the ***user name, user password, account number,*** and the ***list of supplies***. A ***receipt*** must be generated containing an ***order number, ship date,*** and ***total cost***. If the ***order*** is valid, it must be entered into an ***order database***. If the ***order*** is invalid, an ***error message*** must be generated."

Nouns

- Out-of-Domain
  - Internal Web
- Abstract
  - user name
  - user password
  - account number
  - order number
  - ship date
  - total cost
  - list of supplies
  - office supplies -> item
- Good Candidates
  - employee
  - item (was office supplies)
  - receipt
  - order
  - order database
  - error message
- Notes

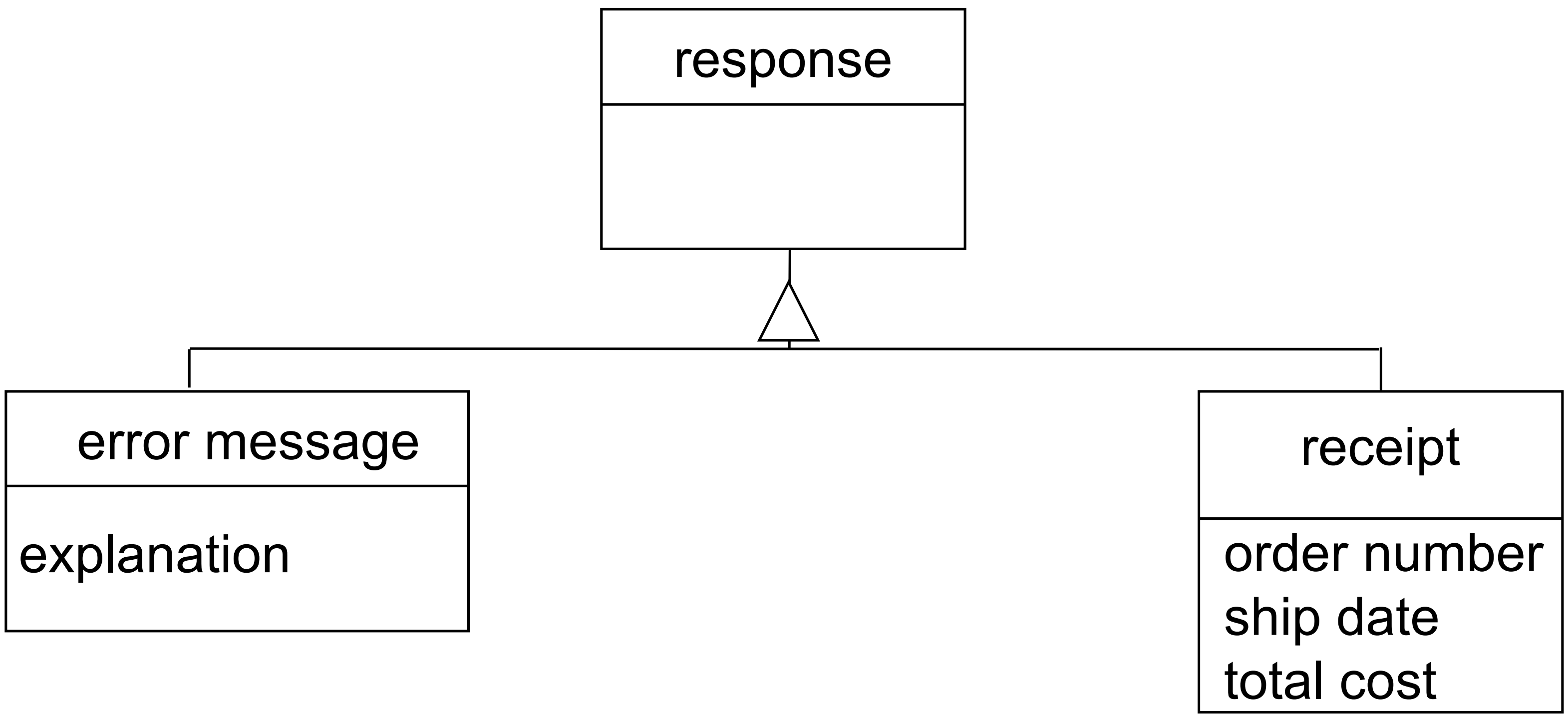
  We have decided not to worry about the Web in this design. Instead we focus on the inputs and outputs and defer the Web details until later.

Class Model

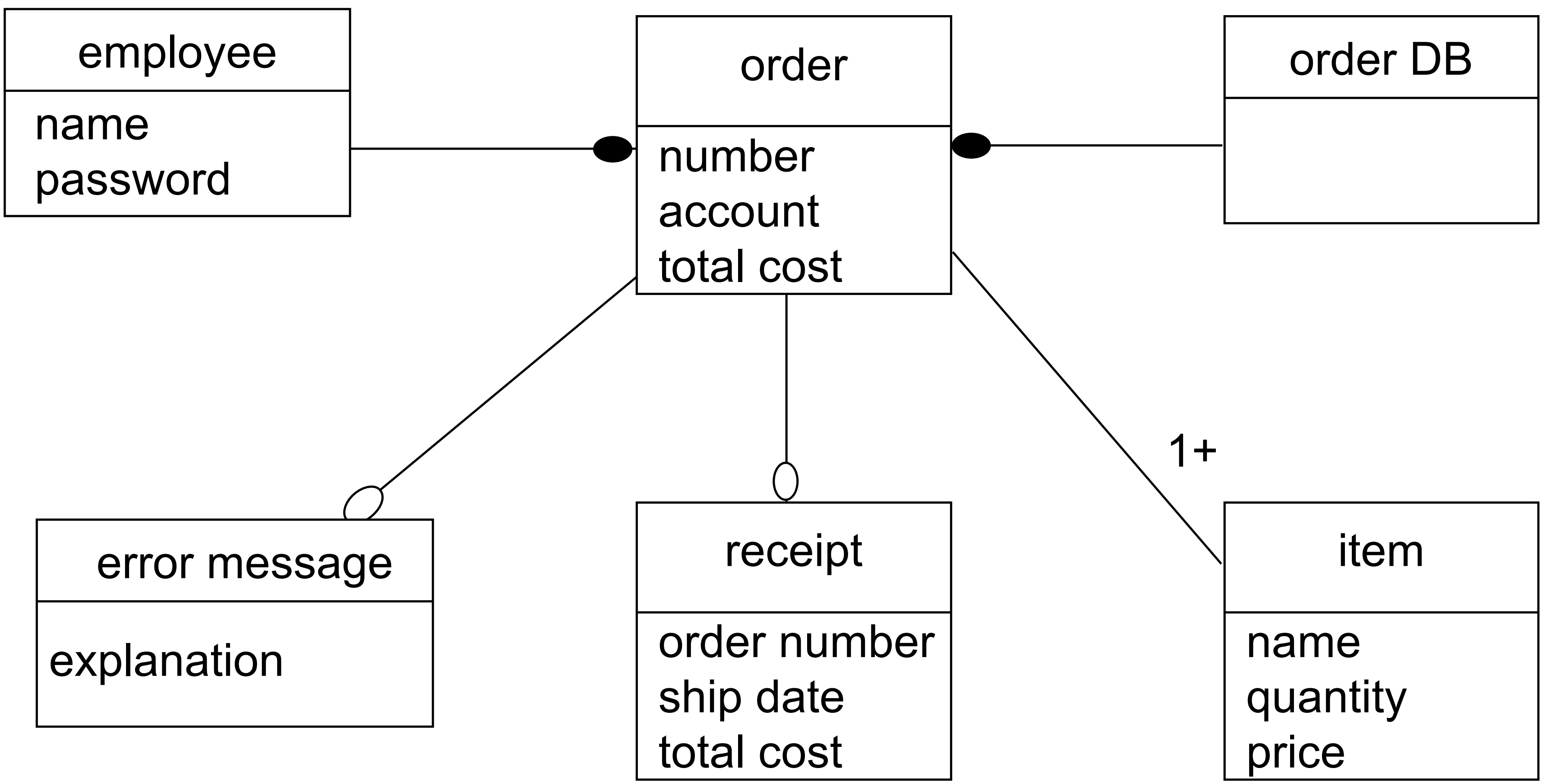

employee
name
password
order
number
account
total cost
order DB
error message
explanation
receipt
order number
ship date
total cost
item
name
quantity
price

Class Model, continued

Since both receipts and error messages will be generated as output it might make sense to have them as subclasses of a more general class. We do not know enough yet to assign it attributes however.



Class Model, relationships



Overview - Object-Oriented Analysis and Design

- Three models
  - Object model
  - Dynamic model
  - Functional model
- Four phases
  - object-oriented analysis
  - system design
  - object design
  - Implementation
- Detailed Design
- Integration Testing

OMT Analysis and Design: Steps

- Class Modeling
- Dynamic Modeling
- Functional Modeling
- Add Operations to the Class Model
- Iterate and refine the models
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Dynamic Modeling

- Prepare scenarios
- Identify events between objects
- Prepare an event trace for each scenario
- Build a state diagram
- Match events between objects to verify consistency

Dynamic Model Diagrams

- The dynamic model tracks behavior over time
  - described in terms of change in objects or event sequences between objects
- Event Trace Diagrams
  - show typical dialog or usage scenarios as well as exceptional and/or special cases
- State Diagrams
  - relates events, states, and state transitions
  - a scenario is a path through the state diagram

Events and Scenarios

- An event is [an ‘instantaneous’ change of state in the application domain] that triggers a change to an object’s object state (?)
  - events have attributes, which are the information transferred from one object to another
- A scenario is a specific sequence of events representing a path through a system’s state space
- Legitimate scenarios
  - common paths (e.g. frequently used functionality)
  - Error conditions and known exceptions
- An event trace extends the scenario to clarify events between objects

Event classes and attributes

- Event Classes
  - airplane departs (airline, flight number, city)
  - mouse button pushed (button, location)
  - phone receiver lifted
  - digit dialed (digit)

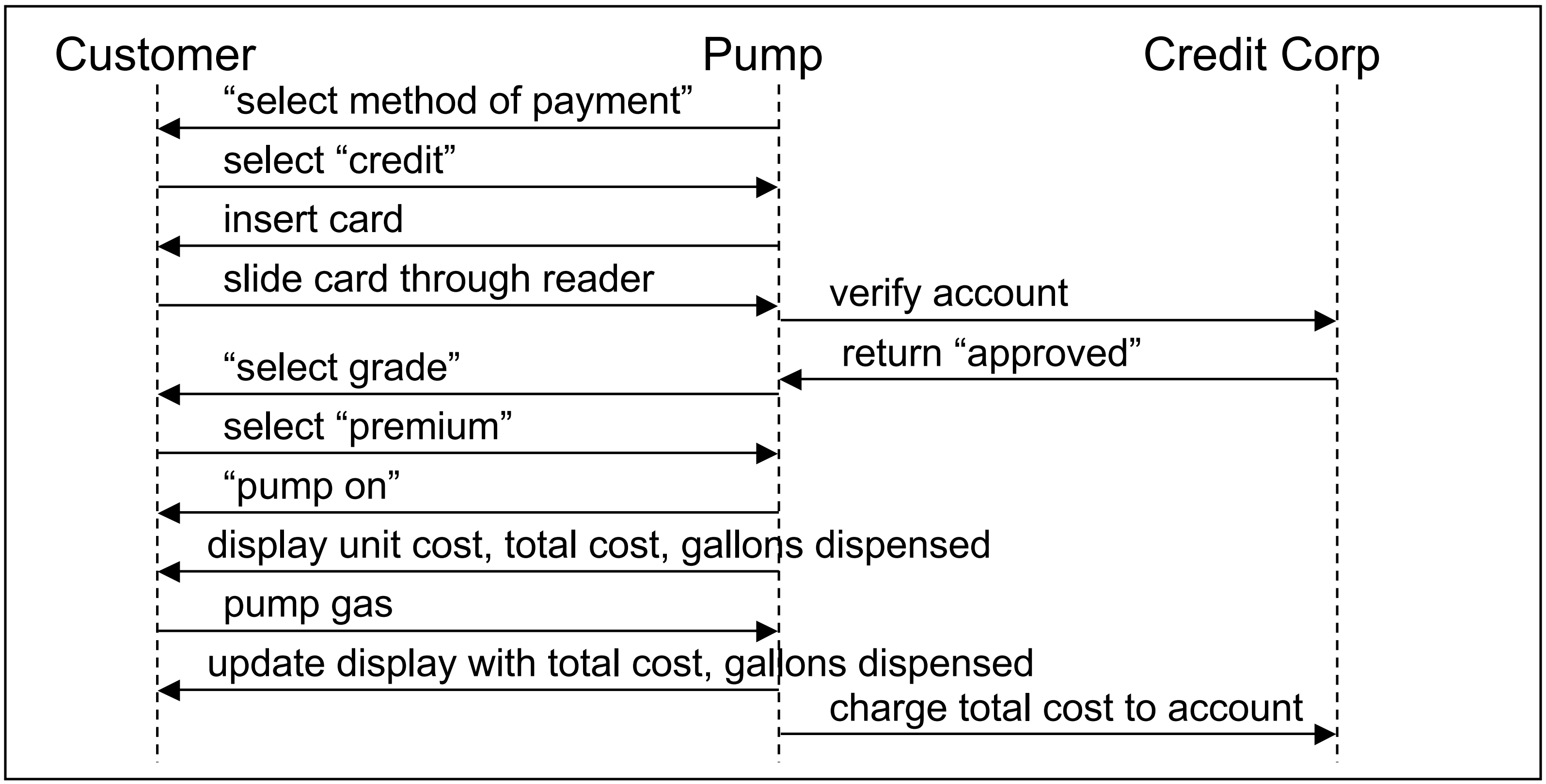
- Events
  - United Flight 23 departs from Rome
  - right mouse button pushed at (29, 30)
  - phone receiver lifted
  - digit dialed (2)

An example scenario

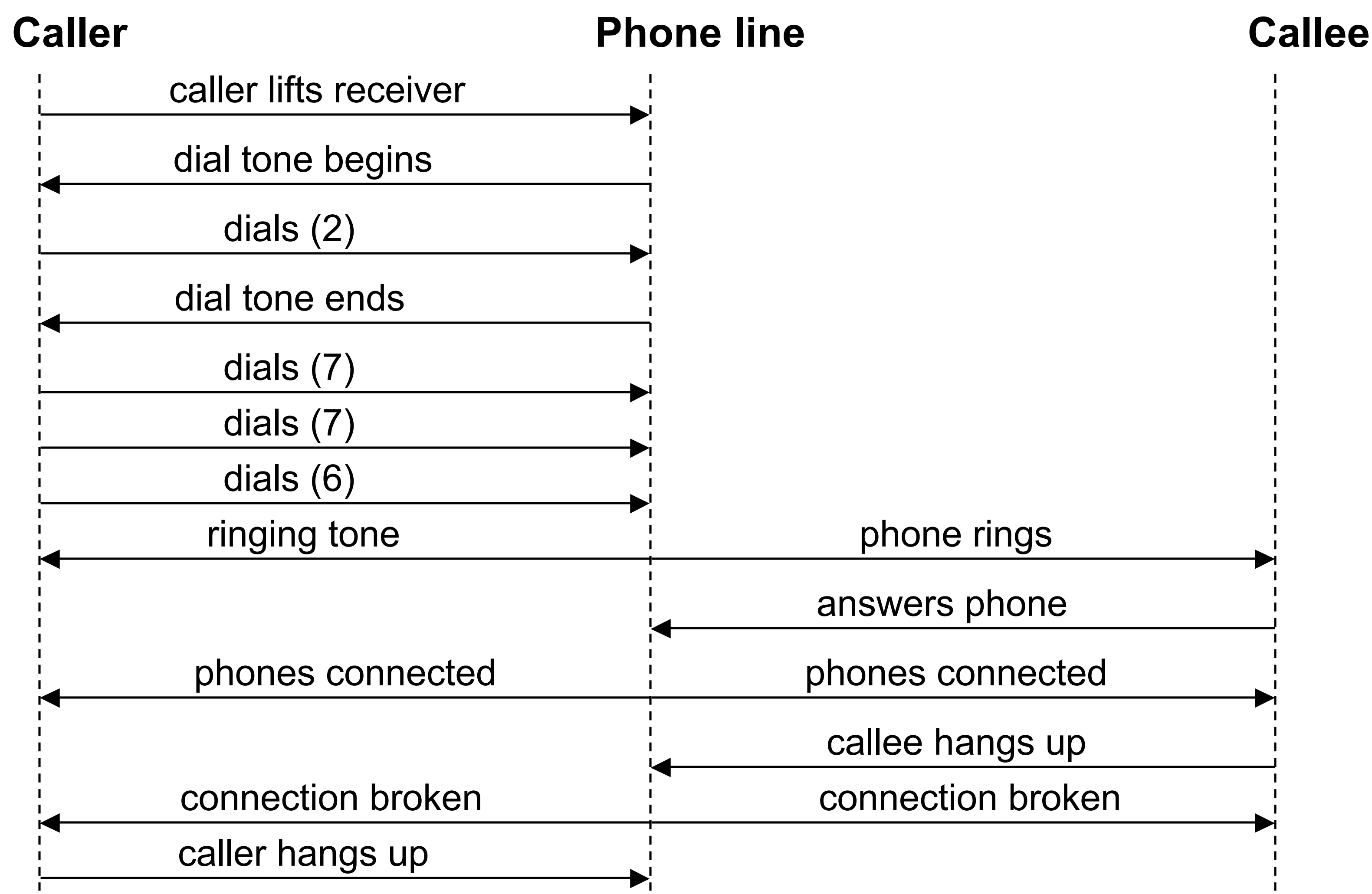
- Scenario for a phone call
  - caller lifts receiver
  - dial tone begins
  - caller dials digit (2)
  - caller dials digit (7)
  - caller dials digit (7)
  - caller dials digit (6)
  - specified phone rings
  - etc.

OMT Event Trace Notation

- objects are vertical lines
- events are horizontal lines
- arrows indicate sender and receiver
- time passes from top to bottom



Event Trace: example

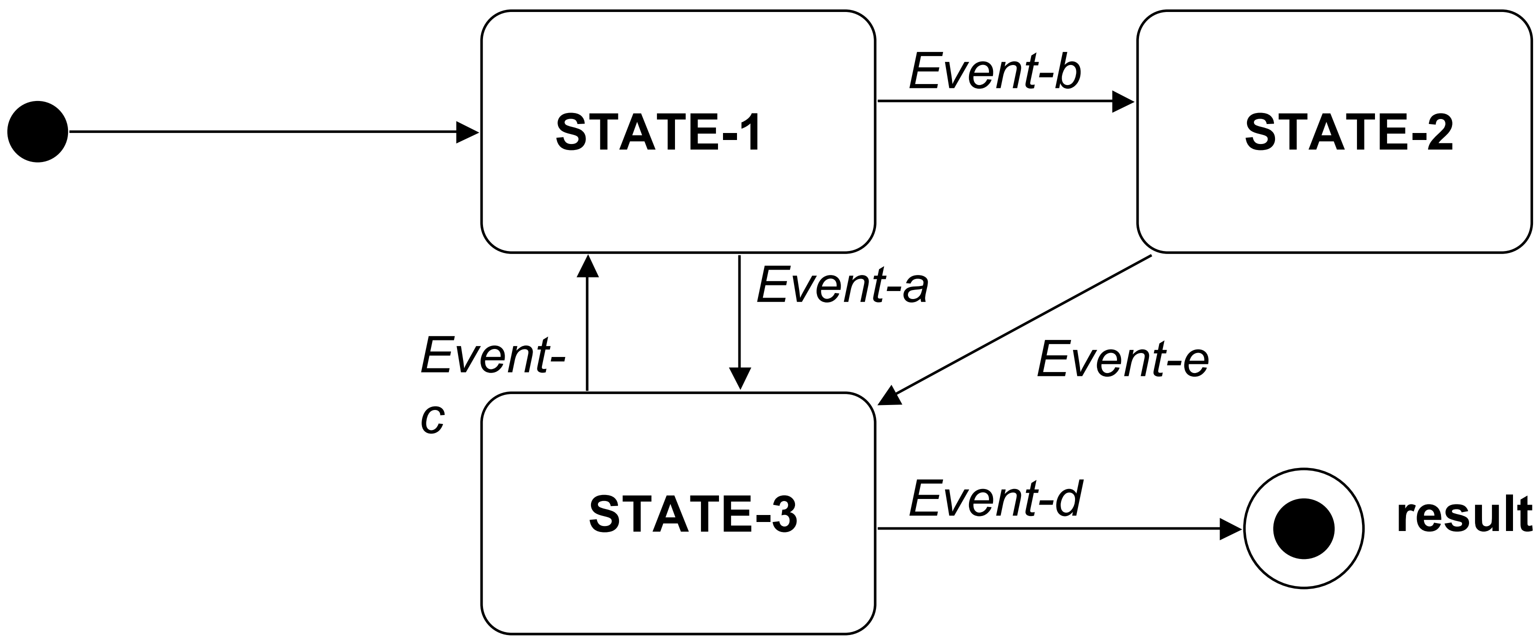


States and Transitions

- A *state* is an interval between events (values of relevant variables to the problem…)
  - it may have an activity that can trigger starting, intermediate and ending events
  - defined in terms of a subset of object attributes and links
- A state *transition* is a change in an object's attributes and links
  - it is the response of an object to an event
  - all transitions leaving a state must correspond to distinct events

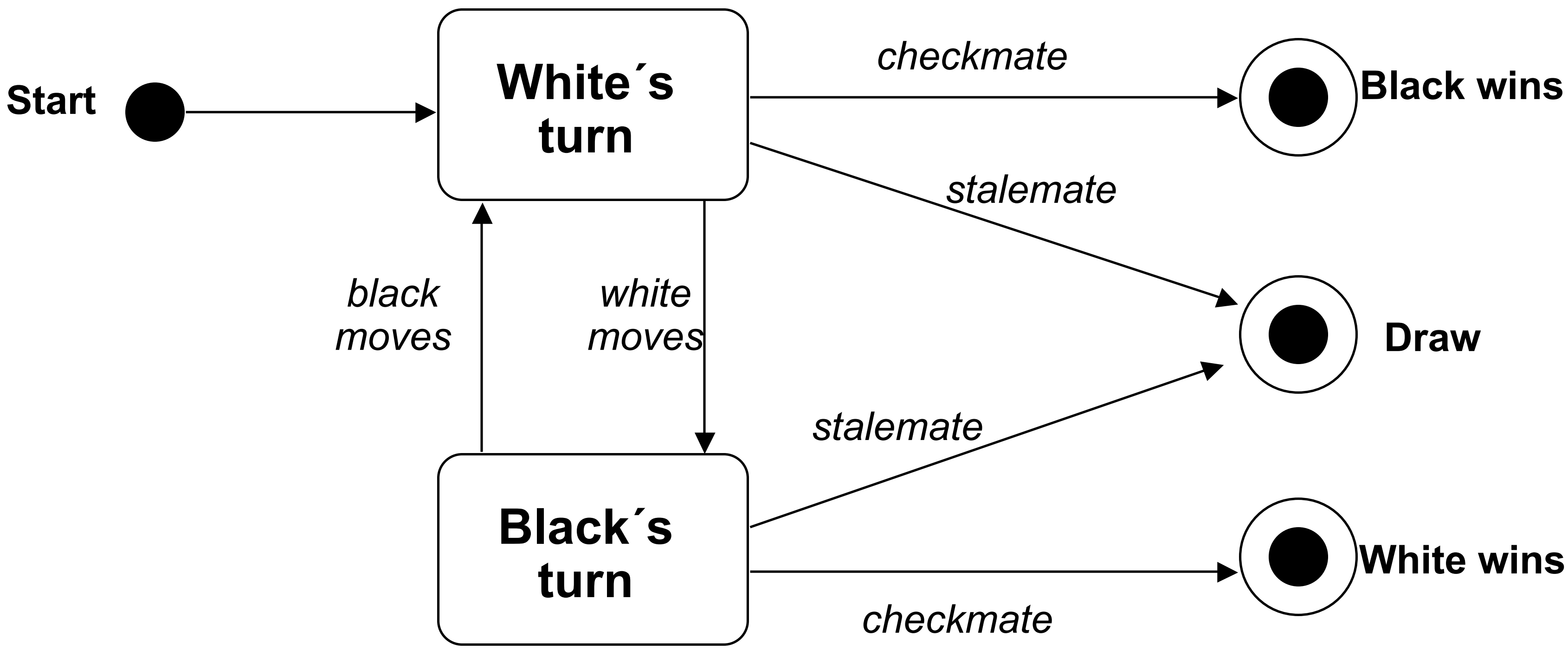
OMT State Notation

- states represented as nodes: **rounded rectangles with state name**
  - initial state represented as solid circle
  - final state represented as bull's eye
- transitions represented as edges between nodes and labeled with an *event name*



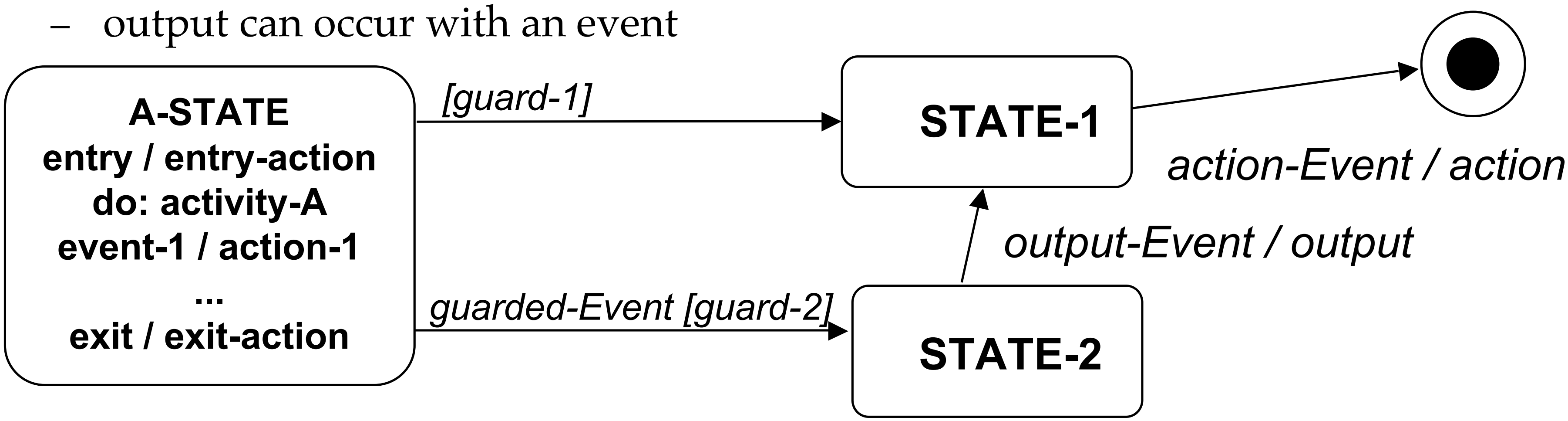
OMT State Diagram - Example

Chess game



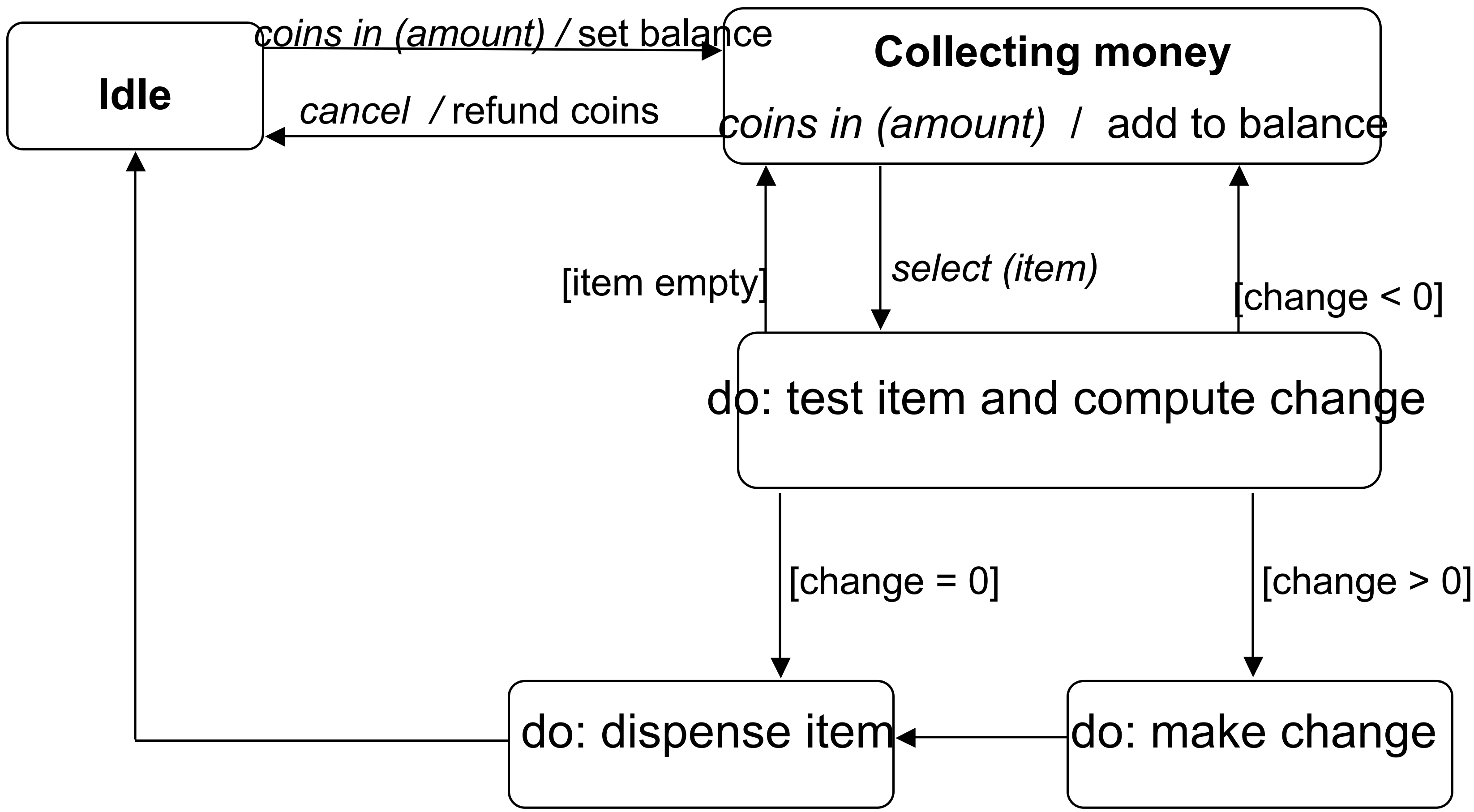
Guards, Activities and Actions

- *Guards* are boolean conditions on attribute values
  - transition can only happen when guard evaluates to “true”
  - automatic transitions occur as soon as an activity is complete (check guard!)
- *Activities* take time to complete
  - activities take place within a ‘state’
- *Actions* are relatively instantaneous
  - actions take place on a transition or within a state (entry, exit, event actions)
  - output can occur with an event



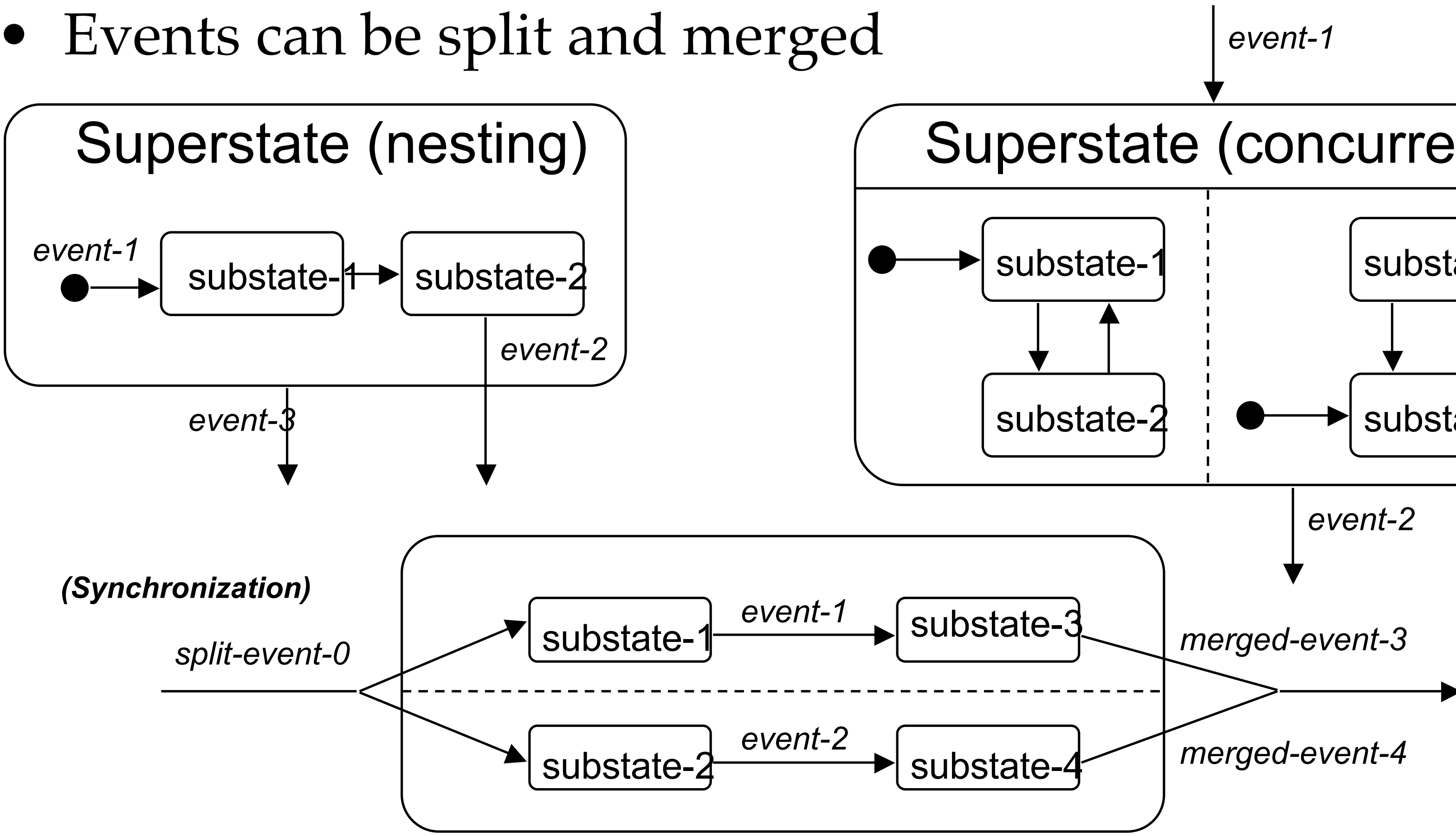
Guards, Activities and Actions - Example

Vending machine model

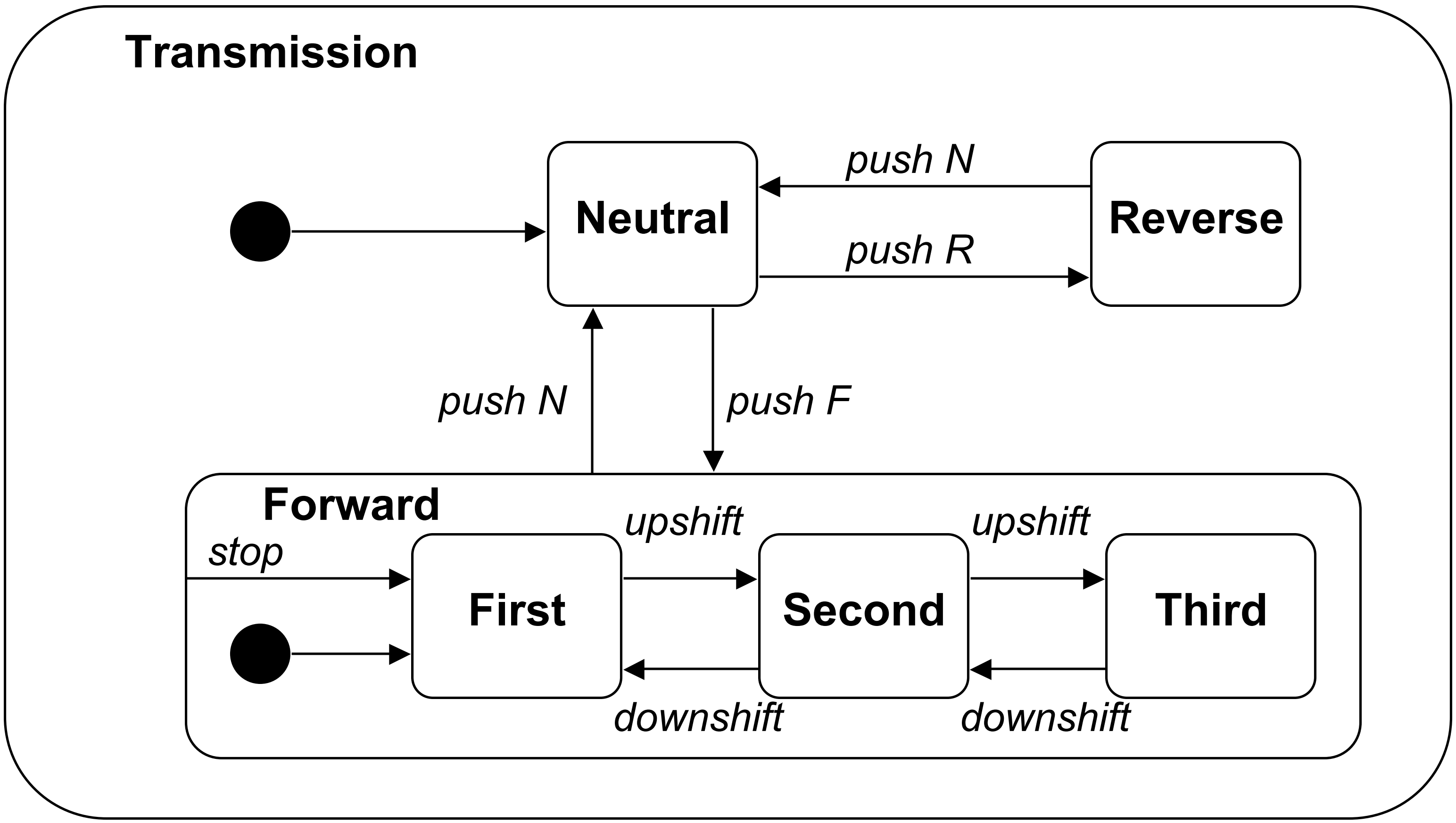


OMT State Relationships

- States can be nested or concurrent
- Events can be split and merged



State Generalization: example



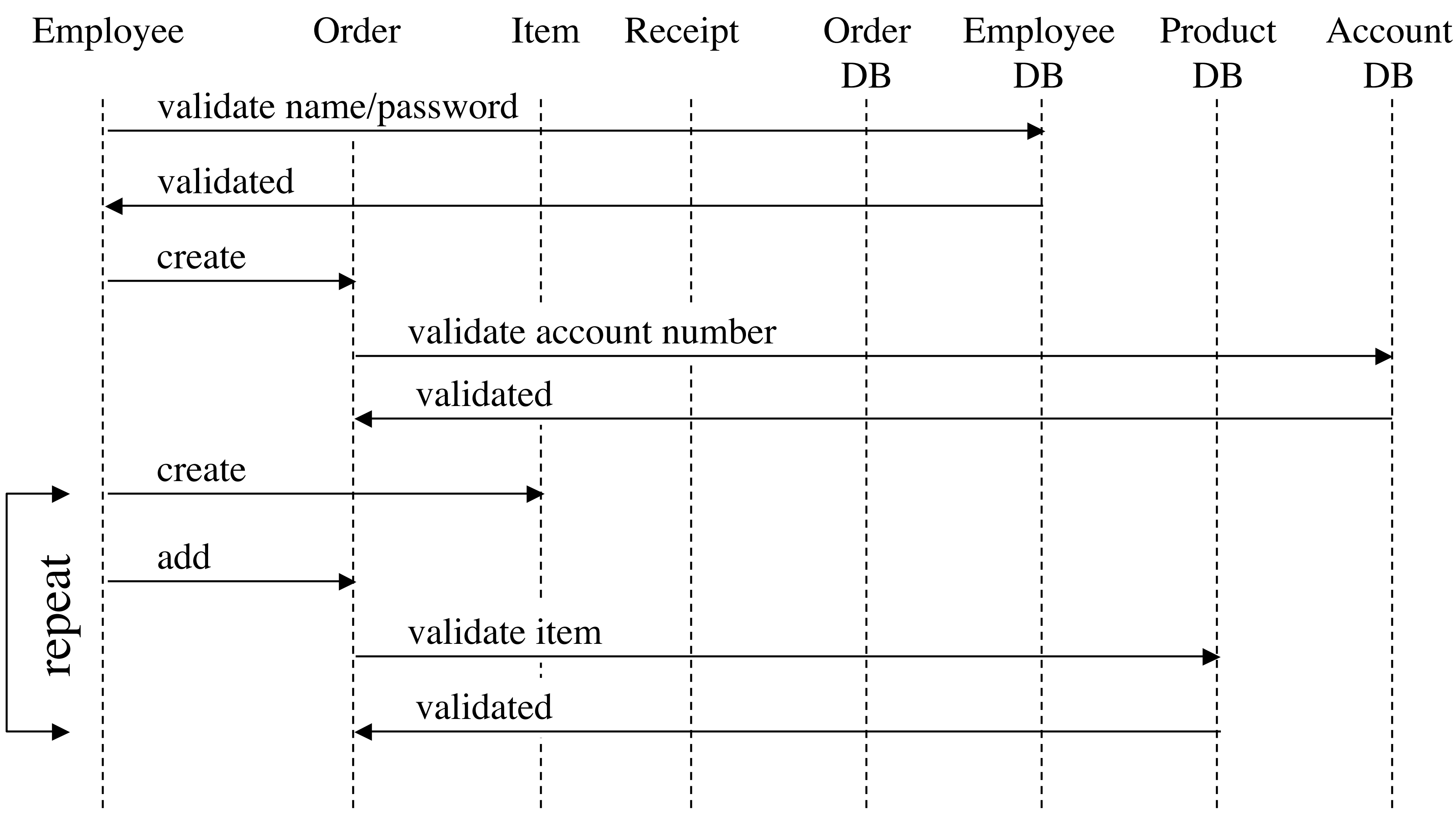
Returning to the FastData example

- Lets define a scenario for an office supply order processor: a successful order
  - Alternatively we could describe a scenario for an unsuccessful order
- Assumptions
  - We are not going to consider how the order form is transmitted to our system nor how our receipt is transmitted back
  - The employee object is responsible for validating the input to the system

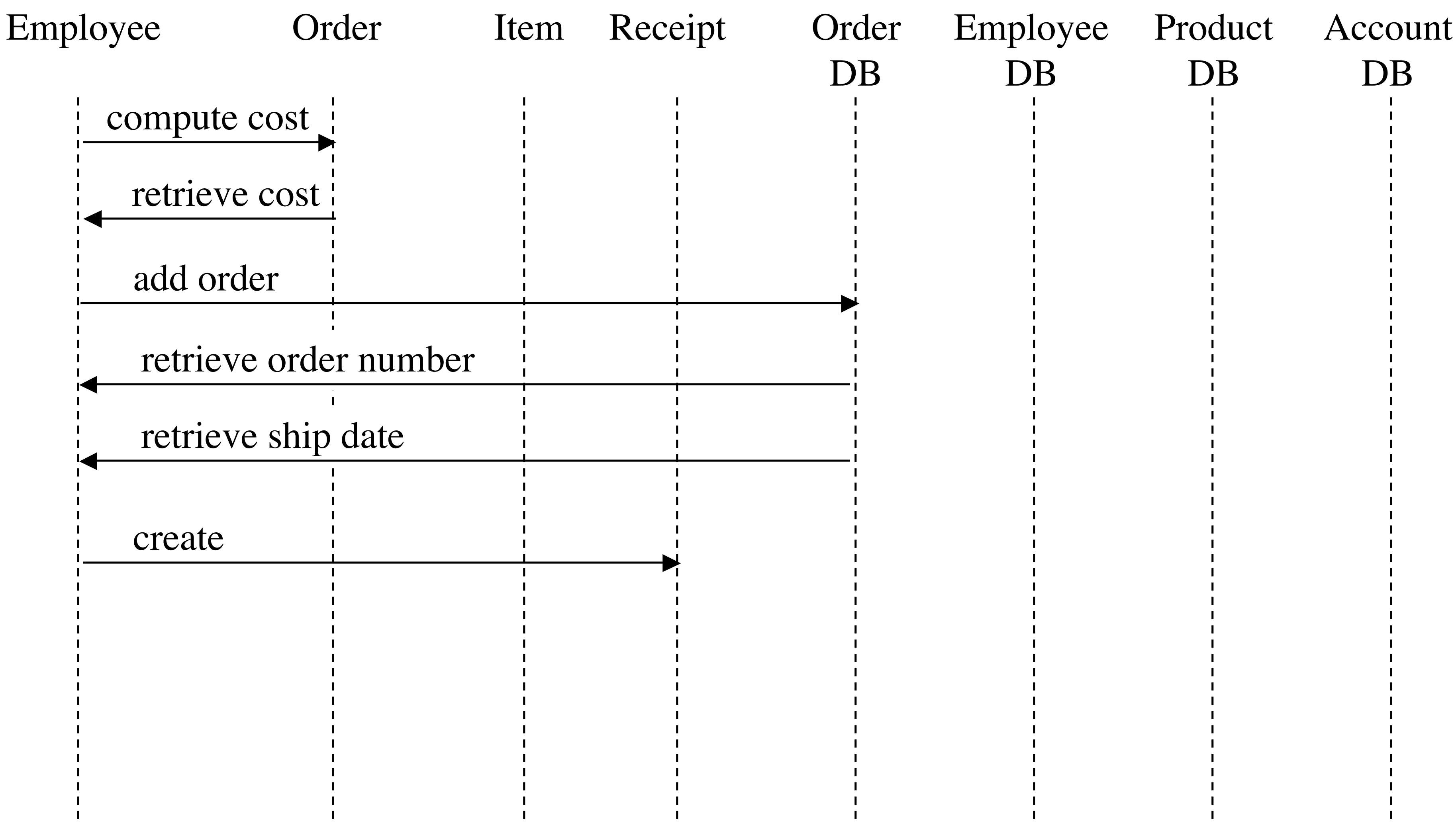
A successful order

- input received (we don’t care how)
- create employee object
- pass input to employee
- validate name and password
- create order object
- validate account number
- for each item
  - create item
  - add item to order and validate item
- compute total cost
- add order to order DB and retrieve order number and ship date
- generate receipt
- return receipt (we don’t care how)

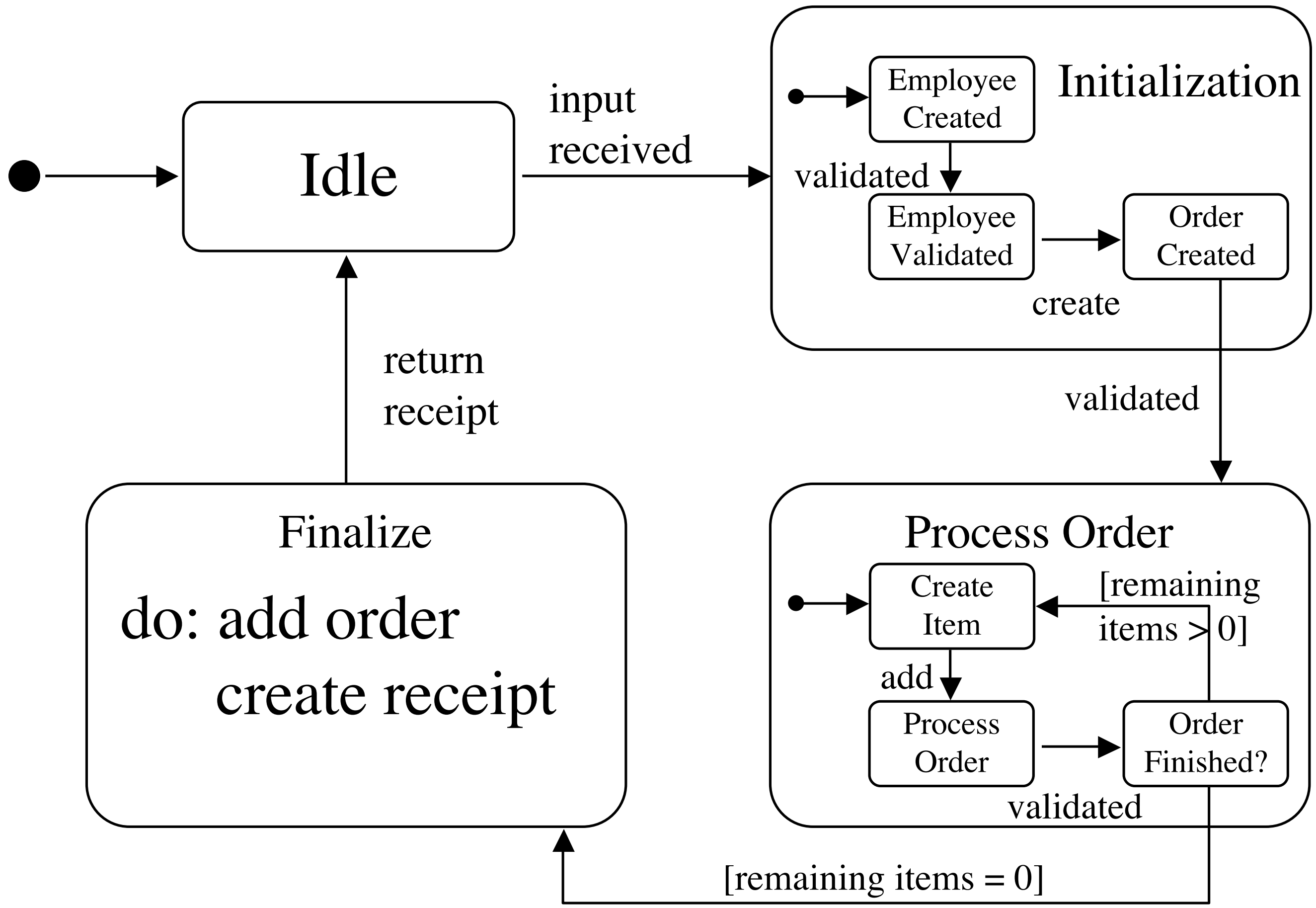
Event Trace


Employee
Order
Item
Receipt
Order DB
Employee DB
Product DB
Account DB
validate name/password
validated
create
validate account number
validated
create
add
validate item
validated
repeat

Event Trace, continued



(One Possible) State Transition Diagram



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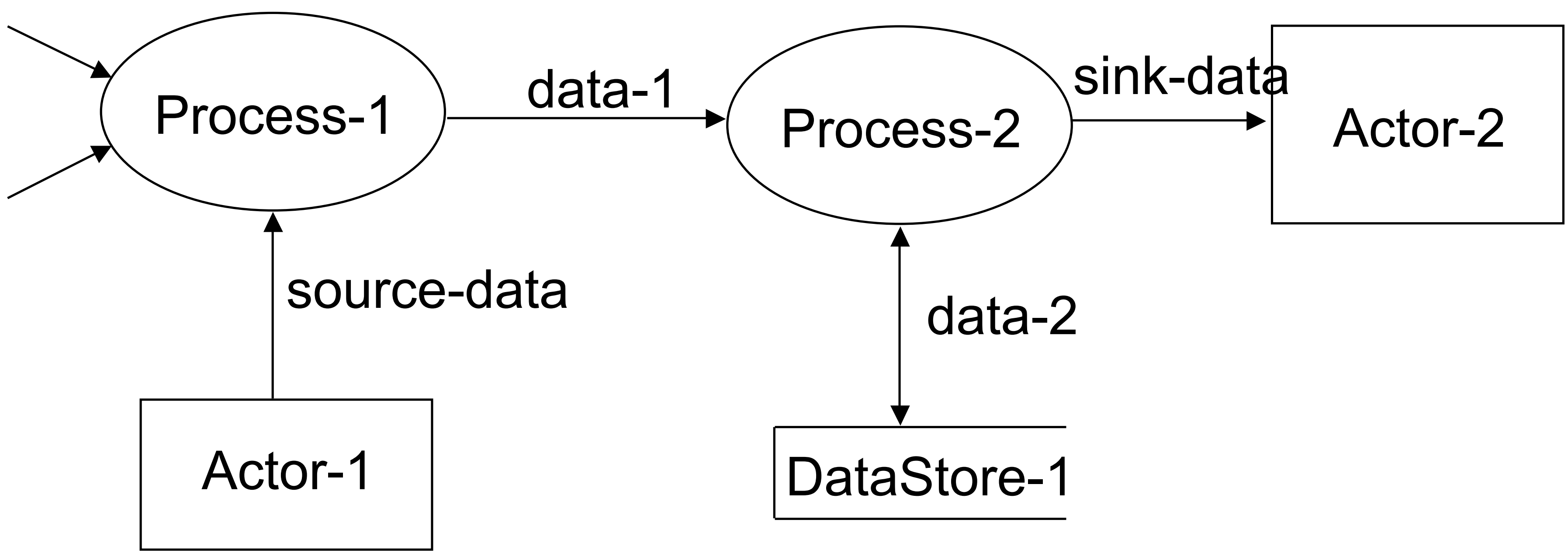
Functional Modeling

- Identify input and output values
- Build data flow diagrams showing transformation and functional dependencies (expanding non-trivial processes)
- Describe functions (in some language)
- Identify constraints between objects (add to DM and FM)

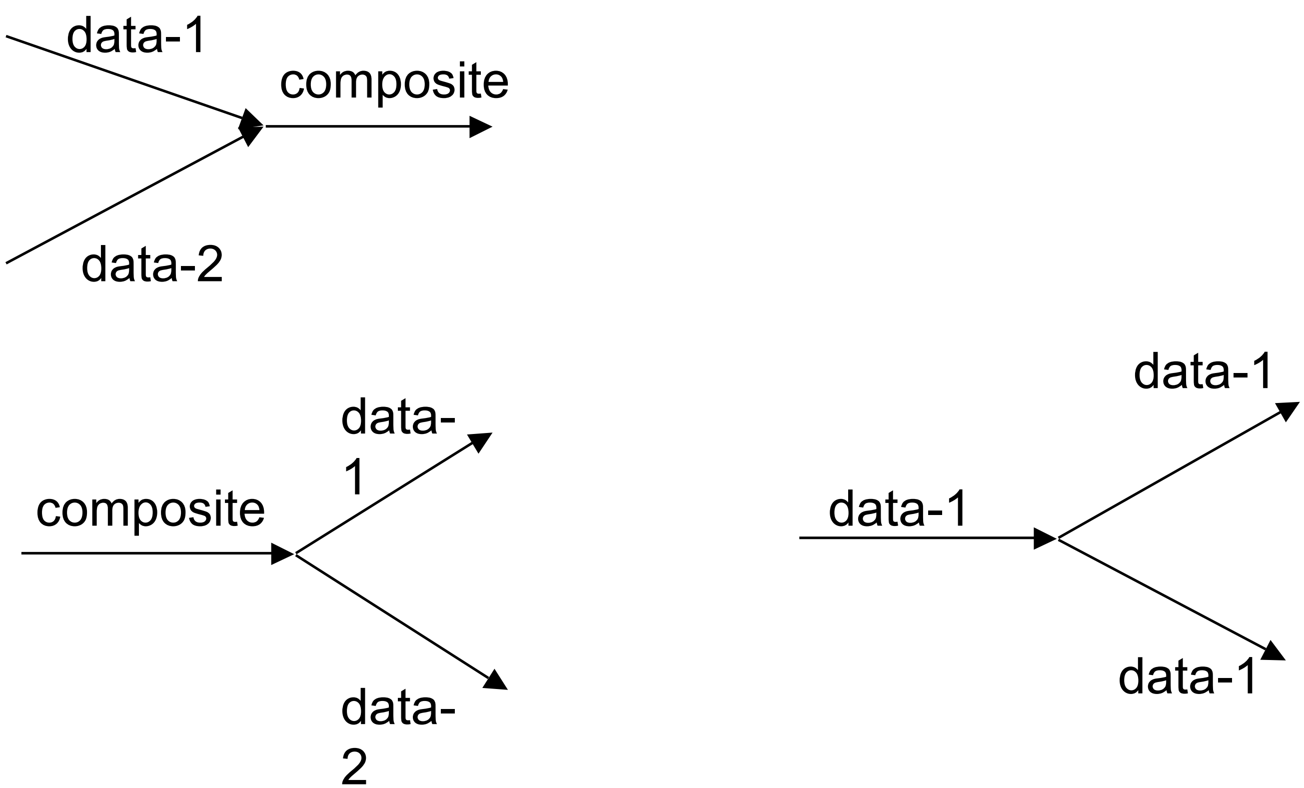
OMT DFD Notation

- Processes transform data
- Actors are sources or sinks of data (= Active Objects)
- Data stores are persistent repositories of data, which may be accessed or updated (= Passive Objects)
- Data flows between processes, actors, and data stores

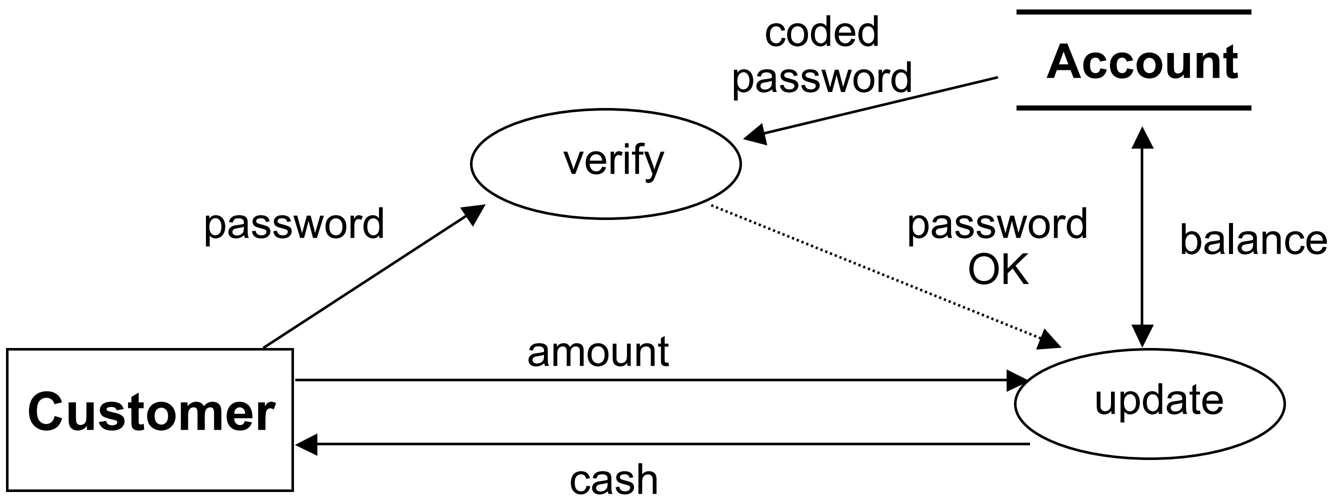


Data Value Notation

- Data may be a composed, decomposed, or duplicated



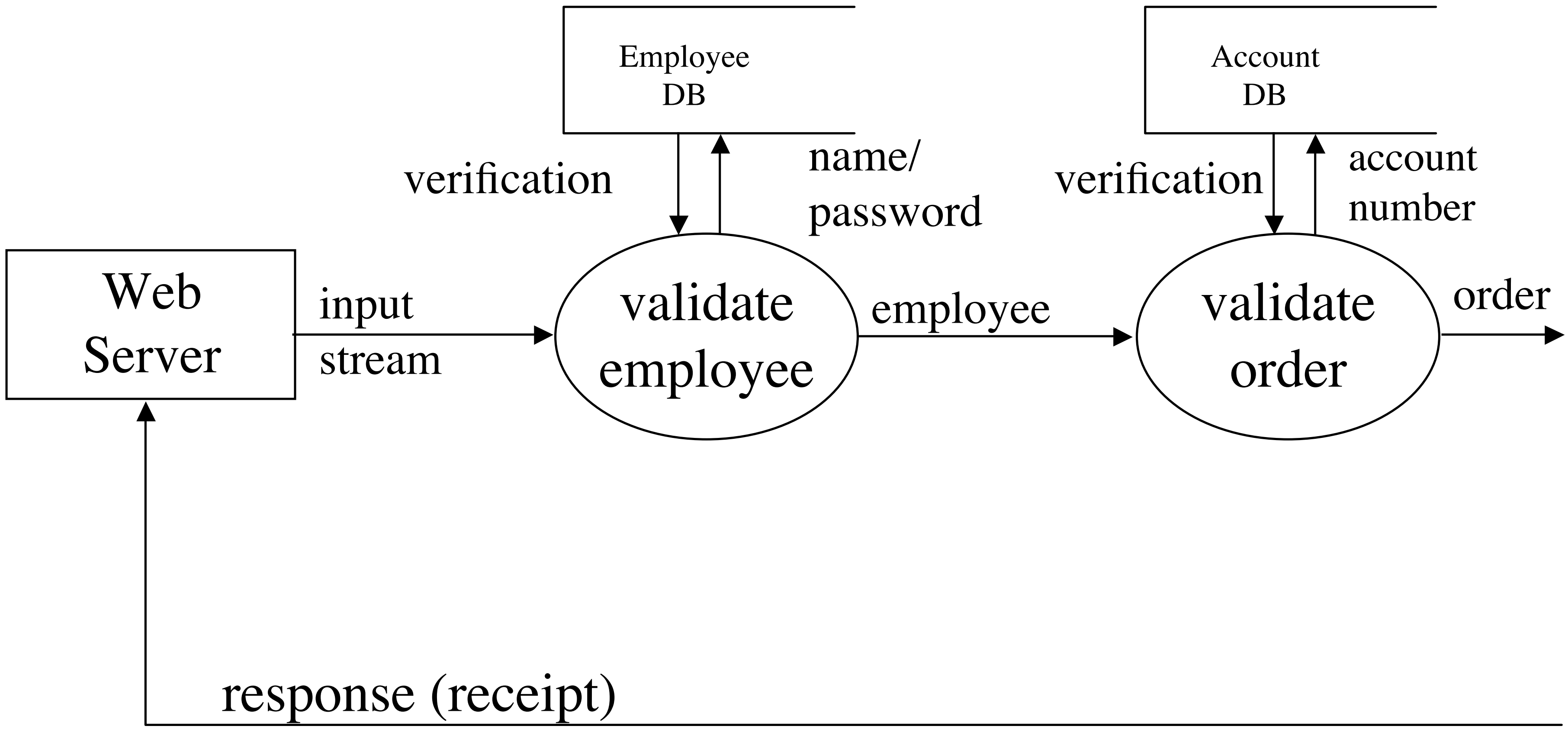
Control Flow in the DFD



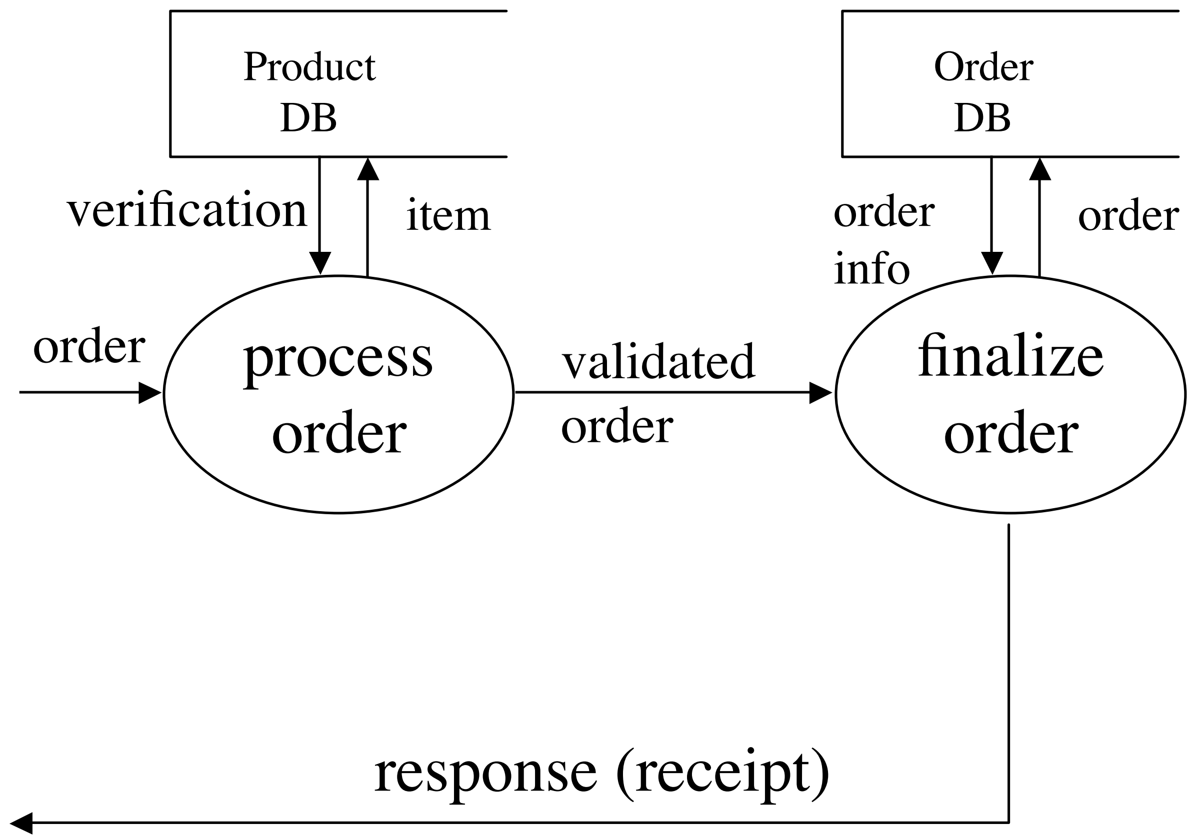
Hierarchical DFD

- High-level functionality iteratively refined into smaller functional units
  - each high-level process may be expanded into a separate DFD
  - top-level processes correspond to operations on complex objects, while lower-level processes are operations on basic objects
- Nesting depth is dependent on application
  - terminates with simple functions
  - each level must be coherent
- Hierarchical DFD corresponds to the following
  - context diagram shows boundaries of system
  - mid-level DFDs show context decomposition
  - primitive DFDs are simple functions that need not be expanded

Data Flow Diagram: Office Supply example



Data Flow Diagram: Office Supply example



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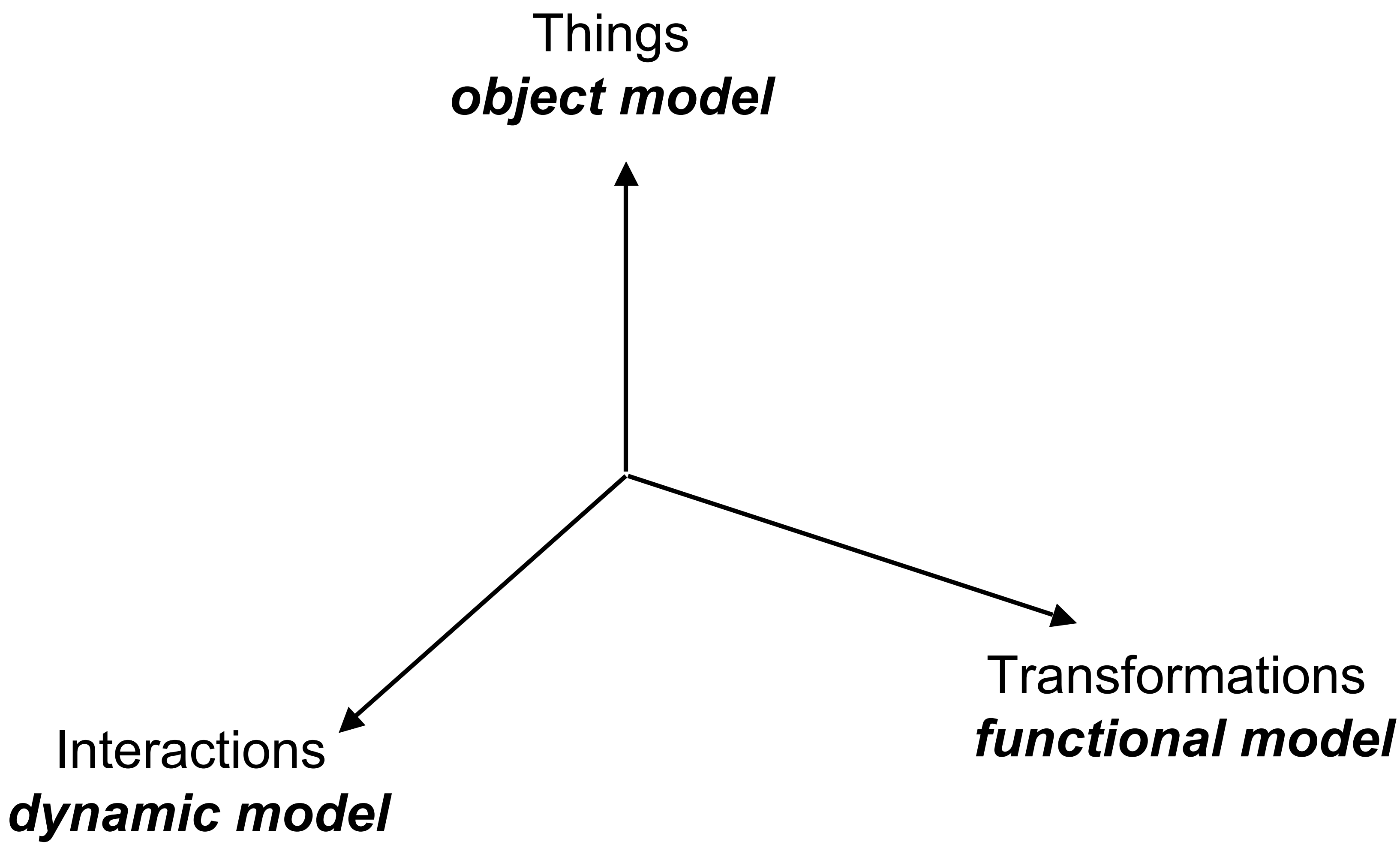
Add Operations to the Object Model

- From the Object Model:
  - Reading/writing object attributes (e.g., get_width, get_height of Rectangle)
- From Events, State Actions, and Activities in the Dynamic Model:
  - Each event sent to an object => operation (e.g., Vending machine: set_balance)
  - Actions/activities may be operations (e.g., Vending machine: do: test item and compute change)
- From Functions in the Functional Model:
  - Each function in the DFD corresponds to an operation (e.g., bank example: subtract withdrawal from Account)

Relation of the three models



Relation of Dynamic Model to Class Model

- Dynamic model provides a second dimension - time - to objects and classes
- Dynamic model builds upon and is derived from object model
  - states in dynamic model represent sets of attribute and link values in object model
  - events in dynamic model yield operations in object model
- Relation between organization
  - inherent differences in objects are distinguished in object model as distinct classes
  - temporal differences in object attributes are distinguished in dynamic model as distinct states

Relation of Functional Model to Class and Dynamic Model

- Functional model describes the actions (what), the dynamic model describes the timing (when), and the class model describes what takes action (who)
- Functional model builds on / derived from class model
  - processes in the functional model correspond to operations on objects
  - The input streams of processes in the functional model identify objects that are related by function
  - data flows in the functional model correspond to objects or attribute values in the class model
- Functional model may capture actions not part of any scenario

OMT: Four phases

- Object-oriented analysis
  - builds a real-world model
- System design and Architecture
  - determines overall architecture of system
- Object design
  - decides upon data structures and algorithms
- Implementation
  - translates design into programming language

System Design and Architecture

- *Devises high-level strategy* for solving problem
  - Set trade-off priorities
- *Construct system architecture* by organizing into subsystems (system structuring)
  - Choose an approach for persistent data management (repository model)
  - Allocate components to processors and tasks (distribution model)
- Choose the implementation of control in software system (control modeling)
  - Identify concurrency inherent in the problem
  - Define access to global resources
- Divide problem into implementable components (modular decomposition)

Object Design

- *Full definition* of all the classes in the system
- *Implementation alternatives* evaluated and chosen
- Combine three models to obtain class operations
- Design algorithms to implement operations
- Optimize access paths to data
- Implement control for external interactions
- Adjust class structure to increase inheritance
- Design associations
- Determine object representation
- Package classes and associations into implementable modules

Detailed Design

- Detailed design is the process of completely specifying an architectural design such that module implementation can proceed (independently)
- Interface specifications
  - brief description of each module
  - attributes
    - ¤ brief description and specify types
  - operations
    - ¤ brief description
    - ¤ list of parameters and parameter types
    - ¤ return type (if applicable)

Detailed Design, continued

- Algorithm and data structure specification
  - the designer can give hints as to what algorithms or data structures might be most useful for a particular module
  - also, the client may have specified a particular algorithm or data structure that must be used
  - in addition, constraints in the requirements may require one approach over another
    - for instance, implementing a data structure so that it uses the minimum amount of memory possible vs. keeping everything in memory for speed

Mapping design into code

- Most programming languages provide very similar sets of features
  - user-defined types
  - control structures
    - ¤ if…then…else…
    - ¤ while x do y
    - ¤ for i = 1 to x
    - ¤ etc
  - etc.
- This means that, in general, operations can be expressed in many different languages

Mapping design into code, continued

- Major differences between languages usually fall into these categories
  - compiled vs. interpreted
  - procedural vs. object-oriented
  - general purpose vs. application/domain specific
    - ¤ e.g. C++ vs. FileMaker Pro's scripting language
- If a design takes advantage of, or depends on, one or more of these features then certain programming languages have to be excluded from implementation

Modularity Mechanisms

- One important feature of any programming language is how it can represent modules directly
  - C and C++ have separate header and body files
  - Java has package names and class files
  - Ada has a construct called a package with a specification and body (implementation)
  - etc.
- These features are important since it makes it easier to map the design into code and to trace a code module back to its design counterpart