Object-Oriented (OO) Modeling Approach

- Start with a problem statement
  - High-level requirements
- Define domain model (high-level class diagram)
  - Identify key elements in the system
  - Prepare data dictionary
  - Identify associations and aggregations
  - Identify attributes of objects and links
  - Organize and simplify using inheritance
  - Iterate and refine the model
  - Group classes into modules
The purpose of the software for the Home Heating System is to control the heating system that heats the rooms of a house. The software shall maintain the temperature of each room within a specified range by controlling the heat flow to individual rooms.

1. The software shall control the heat in each room.
2. The room shall be heated when the temperature is 2°F below desired temp.
3. The room shall no longer be heated when the temperature is 2°F above desired temp.
4. The flow of heat to each room shall be individually controlled by opening and closing its water valve.
5. The valve shall be open when the room needs heat and closed otherwise.
6. The user shall set the desired temperature on the thermostat.
7. The operator shall be able to turn the heating system on and off.
8. The furnace must not run when the system is off.
9. When the furnace is not running and a room needs heat, the software shall turn the furnace on.
10. To turn the furnace on the software shall follow these steps:
    a. open the fuel valve
    b. turn the burner on
11. The software shall turn the furnace off when heat is no longer needed in any room.
12. To turn the furnace off the software shall follow these steps:
    a. close fuel valve
    b. turn burner off
Identify High-Level Classes

- Requirements Statements
- Extract Nouns
- Tentative Object Classes
- Eliminate Spurious Classes
- Object Classes

Candidate Classes

- Water Pump
- Hot Water
- Burner
- Fuel Valve
- Fuel
- Operator
- Furnace
- Thermostat
- Heating system
- Desired temp
- On-off switch
- Temp Sensor
- Control Panel

Eliminate Bad Classes

- Redundant classes
  - Classes that represent the same thing with different words
- Irrelevant classes
  - Classes we simply do not care about
- Vague classes
  - Classes with ill-defined boundaries
- Attributes
  - Things that describe individual objects
- Operations
  - Sequences of actions are often mistaken for classes
- Roles
  - The name of a class should reflect what it is, not the role it plays
- Implementation details
  - Save that for implementation
Eliminate Classes

- **Redundant Attributes**
  - heating system
  - user

- **Irrelevant Operations**
  - Fuel
  - software

- **Vague Roles**
  - Hot Water

- **Attributes Implementation**
  - heat
  - house
  - heat flow
  - range
  - temperature
  - desired temp

Classes After Elimination

- **Burner**
- **Home Heating System**
- **Water Valve**
- **Temp Sensor**
- **Control Panel**
- **Controller**
- **on-off switch**
- **Operator**
- **Room**
- **Furnace**
- **Thermostat**
- **Water Pump**
- **Fuel Valve**
Prepare Data Dictionary

- **Water Tank**
  - The storage tank containing the water that circulates in the system.

- **Pump-1**
  - The pump pumping water from the Water Tank to the radiators in the rooms

Possible Associations

- Not much information from the prose requirements
- A lot of information from the system design

1. A room consists of a thermometer and a radiator
2. A radiator consists of a valve and a radiator element
3. The home heating system consists of a furnace, rooms, a water pump, a control panel, and a controller
4. The furnace consists of a fuel pump and a burner
5. The control panel consists of an on-off switch and a thermostat
6. The controller controls the fuel pump
7. The controller controls the burner
8. The controller controls the water pump
9. The controller monitors the temperature in each room
10. The controller opens and closes the valves in the rooms
11. The operator sets the desired temperature
12. The operator turns the system on and off
13. The controller gets notified of the new desired temperature
Attributes

Thermostat
desired-temp

On-Off switch
setting

Temp Sensor
temperature

OO Model – Modified Again

Home Heating System

Control Panel

On-Off Switch
setting

Thermostat
desired-temp

Operator

Notifies

Furnace

Burner

Fuel Valve

Water Pump

Runs

Opens/Closes

Ignites

Room

1..*

Temp Sensor
temperature

Controller

Heats

Ignites

Opens/Closes

Monitor

Runs
Iterate the Model

- Keep on doing this until you, your customer, and your engineers are happy with the model.

Operation vs Method

- **Operation**: specifies object behavior
- **Service**: represented by set of operns.
- **Message**: object requests execution of an opern. from another object by sending it mesg.
- **Method**: mesg is matched up with method defined by the class to which the receiving object belongs (or any of its superclasses)
- **Operations** of class are public **services** offered by class.
- **Methods** of its classes are the implementations of these **operations**.
**OO Using UML: Dynamic Models**

*Defining how the objects behave*

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**Overview**

- The object model describes the structure of the system (objects, attributes, and operations)

- The dynamic model describes how the objects change state (how the attributes change) and in which order the state changes can take place

- Several models used to find the appropriate dynamic behavior
  - Interaction diagrams
  - Activity diagrams
  - State Diagrams

- Uses finite state machines and expresses the changes in terms of events and states
Interaction Diagrams

We Will Cover

- Why interaction diagrams?
- Sequence diagrams
  - Capturing use-cases
  - Dealing with concurrency
- Collaboration diagrams
- When to use what
- When to use interaction diagrams
Different Types of Interaction Diagrams

• An Interaction Diagram typically captures a use-case
  ▪ A sequence of user interactions

• **Sequence diagrams**
  ▪ Highlight the sequencing of the interactions between objects

• **Collaboration diagrams**
  ▪ Highlight the structure of the components (objects) involved in the interaction

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Home Heating Use-Case

**Use case:** Power Up  
**Actors:** Home Owner (initiator)  
**Type:** Primary and essential  
**Description:** The Home Owner turns the power on. Each room is temperature checked. If a room is below the desired temperature the valve for the room is opened, the water pump started, the fuel valve opened, and the burner ignited. If the temperature in all rooms is above the desired temperature, no actions are taken.

**Cross Ref.:** Requirements XX, YY, and ZZ  
**Use-Cases:** None
Sequence Diagrams

Example from Fowler
Concurrency

Another Example
Comment the Diagram

When the owner turns the system on, the on switch notifies the controller.
The controller creates a room object for each room in the building.
The rooms sample the temperature in the room every 5s.
If a low temp is detected, the room notifies the controller.

Example from Fowler

An Entry Window: Window
An Order: Order
An Order: Order
A Stock Item: StockItem

An Entry Window: Window
An Order: Order
An Order: Order
A Stock Item: StockItem

A Delivery Item: DeliveryItem
Collaboration Diagrams

Sequence Diagrams
OO Model – Modified Again

Scenario-1

Room | Controller | Fuel Valve | Burner | Water Pump
---|---|---|---|---
Every 5s | request-temp | open-water-valve | start-burner | pump-on
Temp Low | respond-temp | | | |
Every 5s | request-temp | | | |
Temp Normal | respond-temp | close-water-valve | stop-burner | pump-off

Controller:
- Pushes
- Adjusts
- Notifies

Home Heating System:
- On-Off Switch
- Thermostat
- Operator

Furnace:
- Burner
- Fuel Valve

Water Pump:
- Water Valve
- Temp Sensor

Controller:
- Monitors
- Heats
- Opens/Closes
- Runs

Every 5s:
- Temp Low
- Temp Normal
**Scenario-1, v2a**

- **Room**
  - Every 5s request-temp
  - Temp Low respond-temp
  - Temp Normal

- **Controller**
  - Every 5s request-temp
  - Temp Low respond-temp
  - Temp Normal

- **Fuel Valve**
  - [respond-temp(s) < desired-temp-2]
  - open-valve

- **Burner**
  - start-burner
  - pump-on

- **Water Pump**
  - pumps-off

**Scenario-1, v2b**

- **Room**
  - Every 5s request-temp
  - Temp Low
  - Temp Normal

- **Controller**
  - Every 5s request-temp
  - Temp Low open-water-valve
  - Temp Normal

- **Fuel Valve**
  - open-valve
  - start-burner
  - pump-on

- **Burner**
  - pump-off

- **Water Pump**
  - stop-burner
  - close-valve
Scenario-2

Control Panel | Room | Controller | Fuel Valve | Burner | Water Pump
---|---|---|---|---|---
Every 5s | Desired temp change | desired-temp-change | open-valve | start-burner | pump-on
Every 5s | Temp Low | open-water-valve | pump-off | stop-burner | close-valve
Every 5s | Temp Normal | close-water-valve | stop-burner | close-valve

Scenario-2, v2

Control Panel | Room | Controller | Fuel Valve | Burner | Water Pump
---|---|---|---|---|---
Every 5s | Desired temp change | desired-temp-change | open-valve | start-burner | pump-on
Every 5s | Temp Low | open-water-valve | pump-off | stop-burner | close-valve
Every 5s | Temp Normal | close-water-valve | stop-burner | close-valve
Conditional Behavior

- Something you will encounter trying to capture complex use-cases
  - The user does something. If this something is X do this... If this something is Y do something else... If this something is Z...

- Split the diagram into several
  - Split the use-case also

- Use the conditional message
  - Could become messy

- *Remember, clarity is the goal!*

Comparison

- Both diagrams capture the same information
  - People just have different preferences

- We prefer sequence diagrams
  - They clearly highlight the order of things
  - Invaluable when reasoning about multi-tasking

- Others like collaboration diagrams
  - Shows the static structure
    - Very useful when organizing classes into packages

- We get the structure from the Class Diagrams
When to Use Interaction Diagrams

- When you want to clarify and explore single use-cases involving several objects
  - Quickly becomes unruly if you do not watch it
- If you are interested in one object over many use-cases -- state transition diagrams
- If you are interested in many objects over many use cases -- activity diagrams
We Will Cover

• State Machines
  ▪ An alternate way of capturing scenarios
    o Large classes of scenarios

• Syntax and Semantics

• When to use state machines

Events, Conditions, and States

• Event: something that happens at a point in time
  o Operator presses self-test button
  o The alarm goes off

• Condition: something that has a duration
  o The fuel level is high
  o The alarm is on

• State: an abstraction of the attributes and links of an object (or entire system)
  o The controller is in the state self-test after the self-test button has been pressed and the reset-button has not yet been pressed
  o The tank is in the state too-low when the fuel level has been below level-low for alarm-threshold seconds
Making a Phone Call Scenario

Context for example: (shorter version)

To make a call, the caller lifts receiver. The caller gets a dial tone and the caller dials digit (x). The dial tone ends. The caller completes dialing the number. The callee phone begins ringing at the same time a ringing begins in caller phone. When the callee answers the called phone stops ringing and ringing ends in caller phone. The phones are now connected. The caller hangs up and the phones are disconnected. The callee hangs up.

Partial Class Diagram
Event Trace

<table>
<thead>
<tr>
<th>Phone:Caller</th>
<th>Line:theLine</th>
<th>Phone:Callee</th>
</tr>
</thead>
<tbody>
<tr>
<td>caller lifts receiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial tone begins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dials digit (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial tone ends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dials digit (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dials digit (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dials digit (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dials digit (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ringing tone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phone rings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>callee answers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tone stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ringing stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phones connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phones connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>caller hangs up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phones disconnected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phones disconnected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>callee hangs up</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

State Diagram for Scenario

- **State Diagram**
- **States**: Idle, Dial tone, Dialing, Ringing, Connected, Disconnected
- **Transitions**: on-hook, off-hook, digit(s), valid-number, called-phone-answers, called-phone-hangs-up
Scenario 2

Phone:Caller
- caller lifts receiver
- dial tone begins
- dials digit (3)
- dial tone ends
- dials digit (2)
- dials digit (3)
- dials digit (4)
- dials digit (5)
- busy tone
- caller hangs up

Phone:Callee

Line:theLine

Modified State Machine

- on-hook
- idle (off-hook)
- dial tone
  - digit(s)
- dialing
  - digit(s)
- dialing
  - valid-number
  - number-busy
- busy tone
  - number-busy
  - routed
- ringing
  - called-phone-answers
  - called-phone-hangs-up
- connected
  - called-phone-hangs-up
- disconnected
Conditions

- Sometimes the state transitions are conditional

Operations (AKA Actions)

- Actions are performed when a transition is taken or performed while in a state
- Actions are terminated when leaving the state
Hierarchical State Machines

- Group states with similar characteristics
- Enables information hiding
- Simplifies the diagrams

Information Hiding
Concurrence

- Some states represent several concurrent concepts
- Concurrency is supported by the state machines
- Concurrent state machines are separated by dashed lines

State Machines - Summary

- Events
  - instances in time
- Conditions
  - conditions over time
- States
  - abstraction of the attributes and associations
- Transitions
  - Takes the state machine from one state to the next
    - Triggered by events
    - Guarded by conditions
    - Cause actions to happen
- Internal actions
  - something performed in a state
- Hierarchies
  - allows abstraction and information hiding
- Parallelism
  - models concurrent concepts
When to use State Machines

- When you want to describe the behavior of one object for all (or at least many) scenarios that affect that object
- Not good at showing the interaction between objects
  - Use interaction diagrams or activity diagrams
- Do not use them for all classes
  - Some methods prescribe this
  - Very time consuming and questionable benefit
Coming up with the State Diagrams

Modeling Approach

- Prepare scenarios
  - Work with the customer
  - Start with normal scenarios
  - Add abnormal scenarios
- Identify events (often messages)
  - Group into event classes
- Draw some sequence diagrams
  - Find objects with complex functionality you want to understand better
- Build a state diagram for the complex classes
Scenario-1

<table>
<thead>
<tr>
<th>Room</th>
<th>Controller</th>
<th>Fuel Valve</th>
<th>Burner</th>
<th>Water Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>open-valve</td>
<td>start-burner</td>
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<td></td>
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<td></td>
<td>pump-on</td>
<td></td>
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<tr>
<td></td>
<td>open-water-valve</td>
<td>request-temp</td>
<td></td>
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<td></td>
<td>respond-temp</td>
<td>request-temp</td>
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<td></td>
<td>close-water-valve</td>
<td>stop-burner</td>
<td>close-valve</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>open-water-valve</td>
<td>request-temp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scenario-1, v2

<table>
<thead>
<tr>
<th>Room</th>
<th>Controller</th>
<th>Fuel Valve</th>
<th>Burner</th>
<th>Water Pump</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td>close-water-valve</td>
<td>stop-burner</td>
<td>close-valve</td>
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<tr>
<td></td>
<td>open-water-valve</td>
<td>request-temp</td>
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<tr>
<td>69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Software Engineering (Cheng) 30
Scenario-2

<table>
<thead>
<tr>
<th>Control Panel</th>
<th>Room</th>
<th>Controller</th>
<th>Fuel Valve</th>
<th>Burner</th>
<th>Water Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired temp change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp Low</td>
<td>Every 5s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp Normal</td>
<td>Every 5s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scenario-2, v2

<table>
<thead>
<tr>
<th>Control Panel</th>
<th>Room</th>
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</tbody>
</table>

Software Engineering (Cheng)
Dynamic Model

Water Pump
- On
- Off

Fuel Valve
- Open
- Closed

Burner
- On
- Off

More Dynamic Model

Room

Temp-Sensor
- Idle

Processing Request

Water-Valve
- open-water-valve
- close-water-valve

Valve
Even More Dynamic Model

Controller

TemperatureControl

timeout(5s)/request-temp

Temp-Low

Temp-Normal

timeout(5s)/request-temp

respond-temp(x)[x<desired-temp+2]/stop-heating

HomeHeatingSystemControl

timeout(1s)/pump-on,open-water-valve

start-heating/open-water-valve

All-Running

Burner-On

Fuel-Open

All-Off

Water-Off

Fuel-Off

timeout(1s)/stop-burner

timeout(1s)/close-water-valve

Even More Dynamic Model, v2

Controller

TemperatureControl

timeout(5s)/request-temp

Temp-Low

Temp-Normal

timeout(5s)/request-temp

respond-temp(x)[x<desired-temp+2]/stop-heating

HomeHeatingSystemControl

timeout(1s)/pump-on,open-water-valve

start-heating/open-water-valve

All-Running

Burner-On

Fuel-Open

All-Off

Water-Off

Fuel-Off

timeout(1s)/stop-burner

timeout(1s)/close-water-valve, close-water-valve
Identify Key Operations

- Operations from the object model
  - Accessing and setting attributes and associations (often not shown)

- Operations from events
  - All events represent some operation

- Operations from actions and activities
  - Actions and activities represent some processing activity within some object

- Operations from functions
  - Each function typically represent one or more operations

- Shopping list operations
  - Inherent operations (what should be there)

Complete OO Model
Iterate the Model

- Keep on doing this until you, your customer, and your engineers are happy with the model.
We Will Cover

- History of activity diagrams in UML
  - A highly personal perspective
- Activity diagrams
- Swimlanes
- When to use activity diagrams
  - When not to

Activity Diagrams

- Shows how activities are connected together
  - Shows the order of processing
  - Captures parallelism
- Mechanisms to express
  - Processing
  - Synchronization
  - Conditional selection of processing
Why Activity Diagrams

- Very good question
  - Not part of any previous (UML related) method
  - To make UML more inclusive of business modeling needs

- Suitable for modeling of business activities
  - UML and OO is becoming more prevalent in business applications
  - Object frameworks are making an inroad
  - Stay within one development approach and notation
  - Notation similar to process modeling languages

Coffee Example
HACS Use-Cases

Use case: Distribute Assignments
Actors: Instructor (initiator), Student
Type: Primary and essential
Description: The Instructor completes an assignment and submits it to the system. The instructor will also submit the delivery date, due date, and the class the assignment is assigned for. The system will at the due date mail the assignment to the student.

Cross Ref.: Requirements XX, YY, and ZZ
Use-Cases: Configure HACS must be done before any user (Instructor or Student) can use HACS

Activity Diagrams for Use Cases
Swimlanes (Who Does What?)

When to Use Activity Diagrams

- Useful when
  - Analyzing a use case (or collection of use cases)
  - Understanding workflow in an organization
  - Working with multi-threaded applications
    - For instance, process control applications
  - Do not use activity diagrams
    - To figure out how objects collaborate
    - See how objects behave over time
Approaching a Problem

Where do we start?
How do we proceed?

Where Do We Start?
(Early Requirements)

- Start with the requirements
  - Capture your goals and possible constraints
  - Environmental assumptions
- Use-case analysis to better understand your requirements
  - Find actors and a first round of use-cases
- Start conceptual modeling
  - Conceptual class diagram
  - Interaction diagrams to clarify use-cases
  - State diagrams to understand major processing
How Do We Continue?
(Late Requirements)

- Refine use-cases
  - Possibly some “real” use-cases
    - Using interface mockups
- Refine (or restructure) your class diagram
  - Based on your hardware architecture
    - For instance, client server
- Refine and expand your dynamic model
  - Until you are comfortable that you understand the required behavior
- Identify most operations and attributes

How Do We Wrap Up?
(Design into Implementation)

- Refine the class diagram based on platform and language properties
  - Navigability, public, private, etc
  - Class libraries
- Identify all operations
  - Not the trivial get, set, etc.
- Write a contract for each operation
- Define a collection of invariants for each class
- Implement
Requirements Products

- Specification document
  - Agreement between customer and developer
  - Validation criteria for software
- Preliminary users manual
- Prototype
  - If user interaction is important
  - If resources are available
- Review by customer and developer
  - Iteration is almost always required

Analysis: Steps to follow

- Obtain a problem statement
- Develop use cases (depict scenarios of use)
- Build an object model and data dictionary
- Develop a dynamic model
  - state and sequence diagrams
- Verify, iterate, and refine the models
- Produce analysis document (e.g., SRS)
Use Cases

- High-level overview of system use
- Identify scenarios of usage
- Identify actors of the system:
  - External entities (e.g., users, systems, etc.)
- Identify system activities
- Draw connections between actors and activities
- Identify dependencies between activities (i.e., extends, includes)

Analysis: Object Model

- Organization of system into classes connected by associations
  - Shows the static structure
  - Organizes and decomposes system into more manageable subsystems
  - Describes real world classes and relationships
Analysis: Object Model

- Object model precedes the dynamic model because
  - static structure is usually better defined
  - less dependent on details
  - more stable as the system evolves

Analysis: Object Model

- Information comes from
  - The problem statement and use cases
  - Expert knowledge of the application domain
    - Interviews with customer
    - Consultation with experts
    - Outside research performed by analyst
  - General knowledge of the real world
Object Model: Steps to follow

- Identify classes and associations
  - nouns and verbs in a problem description
- Create data dictionary entry for each
- Add attributes
- Combine and organize classes using inheritance

Analysis: Dynamic model

- Shows the time dependent behavior of the system and the objects in it
- Expressed in terms of
  - states of objects and activities in states
  - events and actions
- State diagram summarizes permissible event sequences for objects with important dynamic behavior
Dynamic Model: Steps to follow

- Use cases provide scenarios of typical interaction sequences
- Identify events between objects (Sequence Diagram)
- Prepare an event trace for each scenario
- Build state diagrams
- Match events between objects to verify consistency

Analysis: Iteration

- Analysis model will require multiple passes to complete
- Look for inconsistencies and revise
- Look for omissions/vagueness and revise
- Validate the final model with the customer