Object Modeling Approach

- Start with a problem statement
  - High-level requirements
- Define object model
  - Identify objects and classes
  - 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 Home Heating System

Home Heating Requirements

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.

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

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

Candidate Classes
- Water Pump
- Hot Water
- Burner
- furnace
- Fuel Valve
- desired temp
- on-off switch
- Fuel

Controller
- operator
- house
- room
- Water Valve
- temperature
- Home
- range
- heating system
- heat
- software
- 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
- heating system
- user

Irrelevant
- Fuel
- software
- Hot Water

Vague
- heat
- house
- heat flow
- home
- range

Attributes
- desired temp
- temperature

Operations
- None

Roles
- None

Implementation
- None

Classes After Elimination

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

- A room consists of a thermometer and a radiator
- A radiator consists of a valve and a radiator element
- The home heating system consists of a furnace, rooms, a water pump, a control panel, and a controller
- The furnace consists of a fuel pump and a burner
- The control panel consists of an on-off switch and a thermostat
- The controller controls the fuel pump
- The controller controls the burner
- The controller controls the water pump
- The controller monitors the temperature in each room
- The controller opens and closes the valves in the rooms
- The operator sets the desired temperature
- The operator turns the system on and off
- The controller gets notified of the new desired temperature
The Home Heating System

Object Model
Object Model - Modified

Attributes

Thermostat
- desired-temp

On-Off switch
- setting

Temp Sensor
- temperature
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 operations.
- **Message**: object requests execution of an operation from another object by sending it a message.
- **Method**: message is matched up with a method defined by the class to which the receiving object belongs (or any of its superclasses).
- **Operations** of class are public **services** offered by the class.
- **Methods** of its classes are the implementations of these operations.

OO Using UML: Dynamic Models

Defining how the objects behave
### 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.

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### 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
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 5 s. When a low temp is detected the room notifies the controller.
Collaboration Diagrams

- 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
State Diagrams

We Will Cover

- State Machines
  - An alternate way of capturing scenarios
    - 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
  - Operator presses self-test button
  - The alarm goes off
- Condition: something that has a duration
  - The fuel level is high
  - The alarm is on
- State: an abstraction of the attributes and links of an object (or entire system)
  - 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
  - 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

To make a call, the caller lifts receiver. The caller gets a dial 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>Caller</th>
<th>Line</th>
<th>Callee</th>
</tr>
</thead>
<tbody>
<tr>
<td>caller lifts receiver</td>
<td>dial tone begins</td>
<td>callee answers</td>
</tr>
<tr>
<td></td>
<td>dials digit (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dial tone ends</td>
<td>tone stops</td>
</tr>
<tr>
<td></td>
<td>dials digit (2)</td>
<td>ringing stops</td>
</tr>
<tr>
<td></td>
<td>dials digit (3)</td>
<td>phones connected</td>
</tr>
<tr>
<td></td>
<td>dials digit (4)</td>
<td>phones connected</td>
</tr>
<tr>
<td></td>
<td>dials digit (5)</td>
<td>caller hangs up</td>
</tr>
<tr>
<td></td>
<td>ringing tone</td>
<td>phones disconnected</td>
</tr>
<tr>
<td></td>
<td>phone rings</td>
<td>callee hangs up</td>
</tr>
<tr>
<td></td>
<td>phones connected</td>
<td></td>
</tr>
<tr>
<td></td>
<td>phones disconnected</td>
<td></td>
</tr>
</tbody>
</table>
State Diagram for Scenario from System Point of View

Scenario 2

<table>
<thead>
<tr>
<th>Caller</th>
<th>Line</th>
<th>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>dial digit (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial tone ends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial digit (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial digit (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial digit (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dial digit (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>busy tone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>caller hangs up</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Modified State Machine

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

- Idle
- Dial tone
- Do sound dial tone
- Dial(x) [x is a digit]
- Dial(x) [x = *]
- Connect line
- Disconnect line
- Busy tone
- Do find connection
- Ringing
- Do/ ring bell
- Make Call
- Establish call
- Voice Mail
- Connected
- Disconnected
- Dial(x)
- Number-busy
- Establish call
- Called
- Phone
- Answer
- Connect line
- Called
- Phone
- Hangs up
- Disconnect line
- On
- Hook
- Disconnect line
- Off
- Hook
- Reset
- Alarms Enabled
- Alarms Disabled
- Visual Alarm
- Aural Alarm

Concurrency

- 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>Every 5s request-temp</td>
<td>respond-temp</td>
<td>open-valve</td>
<td>start-burner</td>
<td>pump-on</td>
</tr>
<tr>
<td>Temp Low</td>
<td>request-temp</td>
<td>open-water-valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every 5s respond-temp</td>
<td></td>
<td>pump-off</td>
<td>stop-burner</td>
<td></td>
</tr>
<tr>
<td>Temp Normal</td>
<td>close-water-valve</td>
<td></td>
<td>close-water-valve</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>
</tr>
</thead>
<tbody>
<tr>
<td>Every 5s request-temp</td>
<td>respond-temp(x)</td>
<td>[x&lt;desired-temp-2] open-water-valve</td>
<td>start-burner</td>
<td>pump-on</td>
</tr>
<tr>
<td>Temp Low</td>
<td>request-temp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every 5s respond-temp(x)</td>
<td></td>
<td>[x&gt;=desired-temp+2] pump-off</td>
<td>stop-burner</td>
<td></td>
</tr>
<tr>
<td>Temp Normal</td>
<td>close-water-valve</td>
<td></td>
<td>close-water-valve</td>
<td></td>
</tr>
</tbody>
</table>
### 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>Every 5s</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>request-temp</td>
<td>open-valve</td>
<td>start-burner</td>
</tr>
<tr>
<td>Desired temp change</td>
<td>desired-temp</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>open-water-valve</td>
<td>pump-on</td>
</tr>
<tr>
<td>Every 5s</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>request-temp</td>
<td>open-valve</td>
<td>start-burner</td>
</tr>
<tr>
<td>Temp Low</td>
<td>[x &lt; desired-temp - 2]</td>
<td>open-water-valve</td>
<td>respond-temp</td>
<td>close-water-valve</td>
<td>stop-burner</td>
</tr>
<tr>
<td>Temp Normal</td>
<td>[x &gt;= desired-temp + 2]</td>
<td>close-water-valve</td>
<td>respond-temp</td>
<td>close-valve</td>
<td></td>
</tr>
</tbody>
</table>

### Scenario-2, v2

<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>Every 5s</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>request-temp</td>
<td>open-valve</td>
<td>start-burner</td>
</tr>
<tr>
<td>Desired temp change</td>
<td>desired-temp</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>open-water-valve</td>
<td>pump-on</td>
</tr>
<tr>
<td>Every 5s</td>
<td>request-temp</td>
<td>respond-temp</td>
<td>request-temp</td>
<td>open-valve</td>
<td>start-burner</td>
</tr>
<tr>
<td>Temp Low</td>
<td>[x &lt; desired-temp - 2]</td>
<td>open-water-valve</td>
<td>respond-temp</td>
<td>close-water-valve</td>
<td>stop-burner</td>
</tr>
<tr>
<td>Temp Normal</td>
<td>[x &gt;= desired-temp + 2]</td>
<td>close-water-valve</td>
<td>respond-temp</td>
<td>close-valve</td>
<td></td>
</tr>
</tbody>
</table>
Dynamic Model

Water Pump

- On
  \[ x > \text{desired-temp} + 2 \] \( \Rightarrow \) pump-on
  \[ x < \text{desired-temp} + 2 \] \( \Rightarrow \) pump-off
- Off

Fuel Valve

- Open
  \( \Rightarrow \) open-valve
  \( \Rightarrow \) close-valve
- Closed

Burner

- On
  \( \Rightarrow \) start-burner
  \( \Rightarrow \) stop-burner
- Off

More Dynamic Model

Water-Valve

- [x < desired-temp - 2]
- open-water-valve \( \Rightarrow \) wv-open
- close-water-valve \( \Rightarrow \) wv-close

Temp-Sensor

- Idle
  \( \Rightarrow \) temp-report(x)
  \( \Rightarrow \) respond-temp(x)
- Processing Request
  \( \Rightarrow \) request-temp

Room
Even More Dynamic Model

**Controller**

TemperatureControl
- \( \text{responD-temp}(x | x \leq \text{desired-temp} - 2) \) \text{stop-heating}
- \( \text{timeout}(5s) / \text{req u est-temp} \)
  - \( \text{Temp-Low} \) \( \text{Temp-Normal} \)

HomeHeatingSystemControl
- \( \text{timeout}(1s) / \text{pump-on,open-water-valve} \)
  - \( \text{Burner-On} \) \( \text{Fuel-Open} \)
  - \( \text{All-Running} \)
  - \( \text{Water-Off} \) \( \text{Fuel-Off} \)
- \( \text{timeout}(1s) / \text{stop-burner} \)

Even More Dynamic Model, v2

**Controller**

TemperatureControl
- \( \text{responD-temp}(x | x \geq \text{desired-temp} + 2) \) \text{stop-heating}
- \( \text{timeout}(5s) / \text{req u est-temp} \)
  - \( \text{Temp-Low} \) \( \text{Temp-Normal} \)

HomeHeatingSystemControl
- \( \text{timeout}(1s) / \text{pump-on,open-water-valve} \)
  - \( \text{Burner-On} \) \( \text{Fuel-Open} \)
  - \( \text{All-Running} \)
  - \( \text{Water-Off} \) \( \text{Fuel-Off} \)
- \( \text{timeout}(1s) / \text{stop-burner} \)
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)

OO Model – Modified Again
Iterate the Model

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

Activity Diagrams
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
- A glorified flowchart
Why Activity Diagrams

- Very good question
  - Not part of any previous (UML related) method
  - Introduced to sell products
- 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
- Generally a flowchart and I do not really see the need in OO modeling
  - Probably because I do not do business systems

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](image-url)
Swimlanes (Who Does What?)

Problems with Activity Diagrams

- They are glorified flowcharts
  - Very easy to make a traditional data-flow oriented design
- Switching to the OO paradigm is hard enough as it is
  - Extensive use of activity charts can make this shift even harder
- However...
  - Very powerful when you know how to use them correctly