Outline

Model-Driven Architecture

Overview of UML

Class Diagrams

Object Diagrams

Use Case Diagrams

Activity Diagrams

State Machine Diagrams

Sequence Diagrams
Model-Driven Architecture (MDA)

Key idea:

1. Build high-level model for the software system
2. Gradually refine into actual program while maintaining a layered architecture

MDA is forward engineering: the specification comes before the implementation
Technology Independence

Requirement: Preserve investment in an application

- as platforms proliferate
- while the existing platforms change

Solution: Isolate information and processing logic from technology specifics

- Build platform-independent models
- Refine these models to specific platforms
- Maintain this separation
Raising the Level of Abstraction

- Not new. Has been done before.
  - Programming Languages
    (hardwired circuitry, punch cards, assembler, PASCAL/C, OO, ...)
  - Operating systems, data bases, ...

- Interesting: well-established for two sides of the problem
  - WYSIWYG GUI builders
  - Data modeling
    → hand coding no longer predominates

- Goal: higher productivity
MDA Models

Business Model (computation-independent)

Analysis Model (platform-independent)

Design Model (platform-dependent)

Code

Business Analyst

Architect/Designer

Developer/Tester
What is UML?

- The Unified Modeling Language (UML) is a standardized language for describing software

- **graphical notation** for all constructs

- Focus on object-oriented systems

- Dominating language for modelling application software (2nd only to English)
History

- Grady Booch, Ivar Jacobson, and James Rumbaugh, at the time employed at Rational Software:
  
  1990s: UML 1.x

- November 1997: UML became a standard, defined by the *Object Management Group* (OMG)

- September 2004: UML 2.0
Why?

1. You are very likely to see this on the job!

2. It’s the standard for OO design

3. (Some) formalization possible, enables tool-support
UML Diagram Types

Diagram

Structure

- Class
- Composite Structure
- Object
- Component
- Deployment
- Package

Behavior

- Interaction
- Use Case
- State Machine
- Activity

THIS COURSE

Sequence

Communication

Overview

Timing

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Disadvantages of UML

- Semantics is vague: meaning of diagrams is not always well-defined

- Some historical, inherited complexity

- Huge (main standard document has 732 pages), and not very accessible

- Tools assign different meanings to the same diagram
A Class Diagram...

describes the **types** of the objects, and **relationships** among objects

<table>
<thead>
<tr>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>➡️ name: String</td>
</tr>
<tr>
<td>➡️ college: College</td>
</tr>
<tr>
<td>➡️ friends: Person[0..*]</td>
</tr>
<tr>
<td>➡️ courses: Course[0..*]</td>
</tr>
<tr>
<td>➡️ supervisor: Academic</td>
</tr>
<tr>
<td>➡️ enroll(Course c): void</td>
</tr>
<tr>
<td>➡️ drop_out(Course c): void</td>
</tr>
</tbody>
</table>

- Classes have a **name** and two more compartments
- 1st compartment: fields
- 2nd compartment: methods
- Classes belong to a **package**.
These form a namespace.

The arrow denotes “contained in”
Class Fields

- These are variables, and hold the state of the object.

<table>
<thead>
<tr>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>name: String</td>
</tr>
<tr>
<td>college: College</td>
</tr>
<tr>
<td>friends: Person[0..*]</td>
</tr>
<tr>
<td>courses: Course[0..*]</td>
</tr>
<tr>
<td>supervisor: Academic</td>
</tr>
</tbody>
</table>

- Fields have a
  - name, and a
  - type.

- The type may be
  - a class,
  - or something “predefined”.
  - Arrays are also possible using *multiplicities* – we will discuss the syntax later.

- Static fields are underlined.
Initial Values

<table>
<thead>
<tr>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI: Real = 3.14159265 {readOnly}</td>
</tr>
<tr>
<td>e: Real = 2.71828183 {readOnly}</td>
</tr>
<tr>
<td>speed_of_light: Real = 299792458</td>
</tr>
<tr>
<td>Plancks_constant: Real = 6.62606896E-34</td>
</tr>
</tbody>
</table>

- Fields may have an initial value
- Syntax:
  
  ```
  field_name : field_type = value
  ```
- These are assigned upon creation of the object
  
  → constructor
Methods

<table>
<thead>
<tr>
<th>String</th>
</tr>
</thead>
<tbody>
<tr>
<td>_size: Integer</td>
</tr>
<tr>
<td>size(): Integer</td>
</tr>
<tr>
<td>concat(s: String): String</td>
</tr>
<tr>
<td>substring(lower: Integer, upper: Integer): String</td>
</tr>
<tr>
<td>toInteger(): Integer</td>
</tr>
<tr>
<td>toReal(): Real</td>
</tr>
</tbody>
</table>

- Operations that have read/write access to the fields
- Defined by
  - name,
  - parameter list,
  - return type.
- It is possible to define operators as well.
# Modifiers: Example

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-</code></td>
<td>public</td>
</tr>
<tr>
<td><code>+</code></td>
<td>private</td>
</tr>
<tr>
<td><code>#</code></td>
<td>protected</td>
</tr>
<tr>
<td><code>~</code></td>
<td>package</td>
</tr>
</tbody>
</table>

## Patient

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Property/Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-</code></td>
<td>dateOfBirth</td>
</tr>
<tr>
<td><code>+</code></td>
<td>treatment</td>
</tr>
<tr>
<td><code>#</code></td>
<td>illness</td>
</tr>
<tr>
<td><code>+</code></td>
<td>name</td>
</tr>
<tr>
<td><code>~</code></td>
<td>GP</td>
</tr>
<tr>
<td><code>-</code></td>
<td>updateCondition</td>
</tr>
<tr>
<td><code>+</code></td>
<td>changeName</td>
</tr>
<tr>
<td><code>#</code></td>
<td>printPrescription</td>
</tr>
<tr>
<td><code>+</code></td>
<td>notifyGP</td>
</tr>
</tbody>
</table>

- `dateOfBirth` : Date
- `treatment` : String
- `illness` : String
- `name` : String
- `GP` : Number
- `updateCondition(condition : ConditionCode, Notes : String) : void`
- `changeName(newName : String) : boolean`
- `printPrescription() : boolean`
- `notifyGP() : void`
Relationships between Classes

- Generalization
- Association
- Aggregation
- Composition
Generalization

- Taxonomic relationship between a more general description and a more specific one that extends it

- OO: this is inheritance

- denoted by an arrow line with an empty arrowhead from subclass to superclass

- Often: read as “is a”
Generalization: Example I

- Person
  - dateOfBirth : Date
  - name : String
  - changeName(...) : boolean

- Patient
  - treatment : String
  - illness : String
  - GP : Number
  - updateCondition(...) : void

- Doctor
  - specialities: Speciality[0..*]
This is multiple inheritance!\footnote{Read Bertrand Meyer, “Harnessing multiple inheritance”, for more on this.}
Association

▶ “Connection” between classes (may involve more than two)

▶ Class X uses/references class Y

▶ This connection may have several properties:
  ▶ Name
  ▶ Navigability
  ▶ Multiplicity
  ▶ Role names, visibility

▶ Denoted with a solid line
Properties of Associations

- **Name**
  - Typically a verb
  - Describes nature of connection

- **Navigability**
  - Establishes the direction of the relation
  - Denoted with an arrow head
  - May be bidirectional or unspecified

- **Multiplicity**
  - Establishes how many objects participate in the relation
  - Typical: 0, 1, 0..1, 1..*, 0..* (same as *)
  - Default: 1

- **Role names, visibility**
  - Think of these as extra members
Association: Example 1

Customer

0..* subscribes 0..*

+subscriber +subscribed magazine

Magazine
Association: Example II

Professor \(\text{supervises}\) 1..2 Student

\(+\text{supervisor}\) \(0..*\) \(+\text{student}\)
Association: Example III (Navigability)

```
Student
    name: String
    college: College

Mark
```
Some cases associations involve *more than two* classes

- A student takes zero or more courses, and possibly has grades
- A course has at least one student, and possibly has grades (for the students)
- A grade may have been obtained by at least one student, and may be assigned to some courses
n-Ary Relations: Another Example

Diagram:

- **Team**
  - name: String
  - Two instances of Team connected to Score

- **Score**
  - One instance of Score connected to Match

- **Match**
  - stadium: String
  - One instance of Match connected to Team

- Edges:
  - Two instances of Team connected to Score.
  - One instance of Score connected to Match.
  - One instance of Match connected to Team.

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Aggregation

- Special case of association
- Read as “has a”
- Must not involve more than two classes
- *Not* a container relationship – no implications on lifetime
- Drawn with empty diamond
Aggregation: Example

Professor teaches 0..* Course
+teacher +course
Composition

- Special case of aggregation

- This is a container relationship: once the “owner” is destroyed, so is the object contained therein

- “Owner” must have multiplicity 0..1 or 1
- Drawn with a filled diamond
Composition: Example

![Diagram showing composition example]

- Triangle
  - Point

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Templates

- Classes may have *template parameters*

- Corresponds to C++ templates or Java generics

- Build an instance with `Vector⟨int, 3⟩`
Object Diagrams

- These are instances of classes
- Look like class diagrams, but the name is underlined
- The second compartment contains initializations

<table>
<thead>
<tr>
<th>S1: Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>name='John Smith'</td>
</tr>
</tbody>
</table>
So far, we only saw Structure Diagrams

No behavior on those defined so far – even the methods are somewhat mysterious

We will now look at Behavior Diagrams:
- Use Case Diagrams
- Activity Diagrams
- State Machine Diagrams
- Sequence Diagrams
## Use Case Diagrams

A Use Case Diagram... is a description of system behavior with respect to **external entities** such as human users or other systems.
Use Case Diagrams

There are

- use cases (ovals): these correspond to behavior.
- actors (stick figures)

These diagrams are really informal.
Use Case Diagrams: Use Case Extension

- Use cases can be specialized/extended
- This is like inheritance – same notation
Use Case Diagrams: Actor Extension

- Actors can be specialized/extended
- This is also like inheritance
Activity Diagrams

- There is a notion of an active control location (the nodes)
- Change in semantics from UML 1.x to 2.x!
- UML 2.0: Rounded boxes are activities, semantics similar to Petri Nets
Activity Diagrams: Building Blocks

- Initial node
- Activity final node
- Flow final node
- Conditional branch (somewhat redundant)
- Merge (also redundant)
- Fork: concurrency!
- Join: process synchronization
Semantics of Activity Diagrams

百强

study
eat watch TV
still interested
had enough

▶ Idea: pass tokens around
▶ Forks replicate tokens, join nodes generate tokens if there are enough incoming tokens.
▶ Formalization: class assignment
Activity Diagrams: Branches and Guards

- Guards should not overlap – the ordering of evaluation is not defined
- The guards should be complete
- One of the edges may have a guard else
State Machine Diagrams

A State Machine Diagram...

is a graphical representation of a finite state machine.

▸ These are a variant of Harel’s statecharts (1987)

▸ Very popular in control engineering (automotive, aerospace, ...)

▸ Also see Martha’s Executable Biology course
State Machine Diagrams: Building Blocks

- Initial / Junction
- Terminate
- Entry Point / Exit Point / History (hierarchy)
- Choice (somewhat redundant)
- Fork
- Join

Transition with trigger, guard, and action
State Machine Diagrams: Warmup Example

Twiddle thumbs

\[
i = 0
\]

\[
[i < 10] \rightarrow i++
\]

\[
[i \geq 10]
\]
Transitions in State Machine Diagrams

Trigger, ... [ Guard ] / Action

► Each part is optional

► A Trigger is typically an event identifier with arguments:
  
  Event ( Recv-Arguments . . . )

  If there is more than one trigger: OR-semantics

► The Guard is a Boolean expression

► An Action can be
  
  ► some assignment, function call,
  
  ► a send-event command. Typical syntax:
  
  Event ( Send-Arguments )
Branches and Guards in State Machine Diagrams

- Guards should not overlap – the ordering of evaluation is not defined by the standard

- The guards need not be complete: you just stay in the current state until a transition becomes enabled
Events in State Machine Diagrams

- Idea: there is a finite set of events; events may be parameterized, e.g., \texttt{button(1)}

- Events may be external or internal

- There is a queue of events that have occurred
- The ordering of dequeuing is not defined

- The processing of an event must be finished before any other event is processed (run-to-completion)
Events in State Machine Diagrams: Example

- Those plentiful “Hang up” edges are annoying
- What about dialing more than one digit?
Internal Transitions in State Machine Diagrams

- **Internal transitions** are triggered only if the state containing them is active.

- May have triggers, guard, action.

- They fire without leaving/re-entering the state.
Internal Actions

States may have special internal transitions defined using the following prefixes:

- **entry**: executed when a state is entered
- **exit**: executed when a state is left
- **do**: ongoing activity while in the state
Hierarchy in State Machine Diagrams

- State machines may be nested, which yields hierarchy
- Transitions may cross hierarchy boundaries
- Advantage: May avoid many transitions
- Hierarchy may be used to model concurrency
Hierarchy in State Machine Diagrams: Example
Hierarchy in State Machine Diagrams: Example

Phone off the hook

Dialtone

Dialing

Ringing

Busy

Wrong Number

Connected

Dial(d)

RecBusy

Timeout

GoodNr

WrongNr

Hang up

Pick up

RecPickup

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We have seen that hierarchy is useful to model exceptions.

But how about recovery?

Sometimes it is helpful to resume what you interrupted.

This is modelled by means of a history node.
State Machine Diagrams: History

- A transition to a history state restores the state that the chart was in when it was left.

- This is meant to be used as means to resume an activity after an exception or the like.

- There may be one transition outgoing from a history state – this goes to the default state.

- There is also a deep history state:
  - Denoted by $H^*$
  - Also restores the state of any sub-charts, e.g., within “Sleep” or “Eat”.
Precedence Rules for Transitions

- What if multiple transitions are enabled? Which one is taken?

- There is only one rule:

  **UML Transition Precedence Rule**

  A transition out of a composite state \( s \) has a lower precedence than any transition out of any sub-state of \( s \).

- This applies to UML State Machine Diagrams – Statechart dialects have all sort of additional rules.
Concurrency in State Machine Diagrams

- You can use to obtain concurrent threads of execution

- There is an alternative, which is easier to manage

- There are both and-states and or-states in state charts

- or-states are what you are used to:
  you either “Eat” OR “Sleep” OR “Play” . . .

- and-states allow you to “Eat” AND “Play”
Concurrent threads denoted by means of “swimlanes”

Composite activity ends once all composed activities end
Sequence Diagrams

A Sequence Diagram...

defines the behavior of objects by describing the messages they pass.

Mike

How are you doing?

Good, and you?

John

Horizontal axis: the objects or actors

Vertical axis: time
Sequence Diagrams: Building Blocks

- **Object with type and lifeline**
- **Synchronous message**
- **Asynchronous message**
- **Return from method**
- **Control**

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Notation for Messages

1: hello
2: buy("tuna sandwich")

Messages can be numbered
Messages can have parameters
Messages can be self-referential
Synchronous vs. Asynchronous Messages

**Synchronous:** The caller *waits* for the completion of the execution of the operation

**Asynchronous:** The caller *does not wait* for the completion of the execution of the operation, but instead continues immediately
Lifetime vs. Control

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Sequence Diagrams: Webshop Example

Client

Webshop

Mastercard

```
"BUY(card, product)"

"AUTHORIZE(card, amount)"

"RESULT(status)"

"BUILD_PAGE(status)"
```
Semantics of Sequence Diagrams

- A sequence diagram defines a **partial ordering** on the time an event (send/receive) occurs.

- **Rules (causal order):**
  1. Send before matching receive
  2. Receive or send before send of same process
  3. Two receives on the same process sent from the same process

**WARNING:**

No other guarantees provided, even if suggested by diagram!
Races in Sequence Diagrams

Let $\prec_v$ be the visual ordering, and $\prec_c$ the causal ordering.

A diagram has a race iff there exists a trace $M_1, \ldots, M_n$ with

$$M_1 \prec_c M_2 \ldots \prec_c M_n$$

but not

$$M_1 \prec_v M_2 \ldots \prec_v M_n$$
Sequence Diagrams: Webshop Example Again

Client

Webshop

Mastercard

“BUY(card, product)”

“PLEASE_WAIT”

“BUILD_PAGE(status)”

“RESULT(status)”

“AUTHORIZE(card, amount)”
Combining Sequence Diagrams

Sequence diagrams can be combined or integrated into other diagrams by adding a frame.
Combining Sequence Diagrams

These are called High-level Message Sequence Charts (HMSCs)

Does this one have a race?