Course "Softwaretechnik"
Book Chapter 5
Analysis: Dynamic Modeling etc.

Lutz Prechelt, Bernd Bruegge, Allen H. Dutoit

Freie Universität Berlin, Institut für Informatik

- Dynamic modeling
  - Sequence diagrams
  - State machine diagrams
- Using dynamic modeling for the design of user interfaces

And then:
- Requirements analysis document template
  - esp. non-functional req's.
- Requirements analysis model validation
How do you find classes?

- In previous lectures we have already established the following sources
  - Application domain analysis: Talk to client to identify abstractions
  - Application of general world knowledge and intuition
  - Scenarios
  - Use Cases
  - Textual analysis of problem statement (Abbott)

- Today we show how to identify classes and their operations and attributes from dynamic models
  - Activity lines in sequence diagrams identify candidates for classes
  - Messages in sequence diagrams may turn up as operations in classes
  - Actions and activities in state machine or activity diagrams are candidates for public operations in classes
Dynamic Modeling with UML

- Diagrams for dynamic modeling
  - Interaction diagrams describe behavior examples
  - State machines specify a single object

- Interaction diagrams
  - Sequence diagram:
    - Dynamic behavior of a set of objects in time sequence
    - Good for real-time specifications and complex scenarios
  - Communication diagram:
    - Different but roughly equivalent diagram type, rare

- State machine diagram:
  - A state machine of the responses of an object to the receipt of outside stimuli (Events)
Dynamic Modeling

• Definition of dynamic model:
  • A collection of multiple behavior diagrams (such as state machine, activity, and sequence diagrams),
    • usually at least one regarding each important class with important dynamic behavior

• Purpose:
  • Understand behavioral requirements
  • Detect and supply methods for the object model

• How do we do this?
  • Start with use case or scenario, plus identification of classes
  • Model interaction between objects ➔ sequence diagram
  • Model dynamic behavior of a single object ➔ state machine diagram
Heuristics for sequence diagrams

• A typical layout:
  • 1st column: The *actor* who initiated the use case
  • 2nd column: A *boundary object* (perhaps missing in analysis)
  • 3rd column: Perhaps a *control object* managing the use case
  • further columns: the other participating objects

• Creation:
  • Control objects are often created at the initiation of a use case
  • Additional boundary objects may be created by control objects

• Access:
  • Entity objects are accessed by control and boundary objects
  • Entity objects should never call boundary or control objects:
    • This makes it easier to share entity objects across use cases and
    • makes entity objects resilient against technology-induced changes in boundary objects
An ARENA sequence diagram: create tournament

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>newTournament (league)</td>
<td>Create a new tournament</td>
</tr>
<tr>
<td>setName(name)</td>
<td>Set the name of the tournament</td>
</tr>
<tr>
<td>setMaxPlayers(maxp)</td>
<td>Set the maximum number of players</td>
</tr>
<tr>
<td>commit()</td>
<td>Commit the changes</td>
</tr>
<tr>
<td>createTournament(name, maxp)</td>
<td>Create a tournament with name and max players</td>
</tr>
<tr>
<td>checkMax Tournament()</td>
<td>Check the maximum number of players</td>
</tr>
<tr>
<td>:Announce Tournament Control</td>
<td>Announce the tournament control</td>
</tr>
</tbody>
</table>

ARENA is a tournament control SW on top of computer games.
ARENA’s Object Model (before)

- This is the ARENA object model before we formulated the previous sequence diagram

- The Sequence Diagram identified new classes
  - Tournament Boundary
  - Announce_Tournament_Control (see next slide)
ARENA’s Object Model (new)

**LeagueOwner**
- Attributes
- Operations

**League**
- Attributes
- Operations

**Tournament**
- Attributes
- Operations

**Announce_Tournament_Control**
- Attributes
- Operations

**Player**
- Attributes
- Operations

**Match**
- Attributes
- Operations
Impact on ARENA’s Object Model (2)

- The Sequence Diagram also supplied us several new events
  - newTournament(league)
  - setName(name)
  - setMaxPlayers(maxp)
  - commit()
  - checkMaxTournaments()
  - createTournament(name, maxp)

Who "owns" these events?
- For each object that receives an event there is a public operation in the associated class
  - The name of the operation is usually the name of the event
Example from the sequence diagram

createTournament is a (public) operation in Announce_Tournament_Control

and so:
What else can we get out of sequence diagrams?

- Sequence diagrams are derived from use cases
  - We therefore see the structure of the use cases

- The structure of the sequence diagram helps us to determine how decentralized the system should be

- We distinguish two basic structures of sequence diagrams (Ivar Jacobson):
  - Fork-style diagrams (central control)
  - Stair-style diagrams (distributed control)

(see next slides)

UML stereotype symbols:

- Actor
- Control
- Boundary
- Entity
Central control: Fork diagram

- Much of the dynamic behavior is placed in a single object, usually the control object
  - It knows all the other objects and uses them for direct questions and commands
Decentralized control: Stair diagram

- The dynamic behavior is distributed. Each object delegates some responsibility to other objects.
  - Each object knows only a few of the other objects and knows which objects can help with a specific behavior.
Fork or Stair?  
(Design thinking, not analysis thinking!)

Which of these diagram types should be chosen?

- Object-oriented fans claim the stair structure is better
  - "The more the responsibility is spread out, the better"
- However, this is not always true
  - One should usually have a "suitable" mix of both forms
  - (see also design patterns "Mediator", "Façade")

Considerations:

- Decentralized control structure is locally simple:
  - Objects do not get overly complex
  - Responsibilities are easy to understand
- Centralized control structure better supports change:
  - The operations can easily change order
  - New operations can easily be inserted for new requirements
UML state machine diagram notation

- Notation based on work by Harel ("statecharts")
  - UML adds a few object-oriented modifications
- A UML state machine diagram (statechart diagram, state chart diagram) can be mapped to a finite state machine
State machine diagrams

- Graph whose nodes are states and whose directed edges are transitions labeled by event names.
- We distinguish between two types of executable nodes in a state machine:
  - Activity: Compound operation
    - can be described by its own Activity diagram
  - Action: Elementary operation
    - May in fact have structure, too, but the present state machine ignores it.
- A state machine diagram relates events and states for one class.
  - An object model with a set of objects can have a corresponding set of state machine diagrams.
State

• An abstraction of the attribute values of a later implementation class
  • A state describes a certain set of configurations of attribute values in an object (instance)

• Basically an "appropriate" equivalence class of attribute value configurations that need not be distinguished
  • example: the state "in_active_region" may mean
    • x in 0..150 & y in 100...150 (in fact 7701 different states!)
    • What is appropriate depends on our current goal

• State has duration
Example of a state machine diagram

Idle

- coin_in(amount) / set balance
- cancel / refund coins

Collecting Money
- coin_in(amount) / add to balance
- select(item)
- [item empty]
- [change<0]

Testing item and computing change
- entry / test and charge item
- [change==0]
- [change>0]

Do/dispensing item

Making change

Note some states do not have (nor need) a name, but need further details
Nested state diagram

- Activities in states are composite items denoting other lower-level state diagrams
  - which may be spelled out or not

- A lower-level state diagram corresponds to lower-level states and events that are invisible at the higher level

- The set of substates in such a nested state diagram denotes a *composite state*
  - enclosed by a large rounded box, also called region

- Transitions from other states to the composite state enter the initial substate of the composite state
  - Much like the entry point of a subroutine

- Transitions to other states from a composite state are inherited by all the substates (state inheritance)
  - Much like a runtime exception whose occurrence can terminate a method at many points
Nested State Machine Example

'Dispense item' as an atomic activity:

'Dispense item' as a composite activity:

The little glasses indicate that there are sub-activities hidden in this composite activity.
Composite State

moving arm to row

arm ready

moving arm to column

arm ready

pushing item off shelf
Modeling concurrency

Two types of concurrency:

1. System concurrency (across objects)
   - State of overall system as the aggregation of state machines, one for each object
   - Note that one state diagram (for a class) may result in many state machines (one per instance of the class)
   - Each state machine is conceptually executing concurrently with all others

2. Object concurrency (within objects)
   - An object can be partitioned into subsets of states (attributes and links) such that each subset has its own subdiagram
   - The state of the object consists of a set of states: one state from each subdiagram
   - State diagrams or composite states may be divided into regions by dotted lines
Example of concurrency within an object

Activity diagram style

- Setting Up
- Ready
- Dispensing Cash
- Cash taken
- Ejecting Card
- Card taken
- Ready to reset

Splitting control
Synchronization
Using implicit join/split

**Splitting control**

Statechart style

**Emitting**

- Dispensing Cash
  - Cash taken
- Ejecting Card
  - Card taken

**Setting Up**

Ready

**Synchronization**

Ready to reset
Dynamic modeling of user interfaces

- Statechart diagrams can be used for the design of user interfaces
  - to represent the Navigation Path or Page Flow
- States: Name of screens
  - Graphical layout of the screens associated with the states helps when presenting the dynamic model of a user interface
- Activities/actions are shown as bullets under screen name
  - Often only the exit action is shown
- State transitions: Result of exit action
  - Button click
  - Menu selection
  - Cursor movements
- Good for web-based user interface design
Simplified navigation path example

**Diagnostics Menu**
- User moves cursor to Control Panel or Graph

**Control panel**
- User selects functionality of sensors

**Graph**
- User selects data group and type of graph

**Selection**
- User selects data group
  - Field site
  - Car
  - Sensor group
  - Time range
- User selects type of graph
  - time line
  - histogram
  - pie chart

**Visualize**
- User views graph
- User can add data groups for being viewed

**List of events**
- User selects event(s)

**Define**
- User defines a sensor event from a list of events

**List of sensor events**
- User selects sensor event(s)

**Enable**
- User can enable a sensor event from a list of sensor events

**Disable**
- User can disable a sensor event from a list of sensor events

**List of sensor events**
- User selects sensor event(s)

**Visualize**
- User views graph
- User can add data groups for being viewed

**Link**
- User makes a link (doclink)
Practical tips for state machine modeling

- Construct dynamic models only for classes with significant (complex/important) dynamic behavior
  - Avoid "analysis paralysis"
  - Exception: If state diagrams suffice for code generation
    - e.g. for control logic in telecommunications systems
- Consider only relevant attributes when defining states
  - Use abstraction heavily
- Stick to a sensible granularity of actions and activities
  - This is still analysis, not design!
- Reduce notational clutter
  - Try to put actions into state boxes (look for identical actions on events leading to the same state)
Summary: requirements analysis

1. What is the external behavior?
   - Create scenarios, use cases, use case diagrams
   - Talk to client, observe, get historical records, do thought experiments

2. What is the structure of the system?
   - Create class diagrams
   - Identify objects, associations, attributes, operations

3. What is its behavior?
   - Create sequence diagrams
     - Identify senders and receivers
     - Show sequence of messages exchanged between objects
   - Create state machine diagrams
     - Only for the dynamically interesting objects

Functional Modeling
Object Modeling
Dynamic Modeling
Analysis: UML activity diagram

Note that this diagram is rather vague, as the meaning of the arrows is not explained.
When is a model dominant?

• We call a model dominant if it contains a much larger fraction of the *interesting* information than the others

Examples:

• Simple database system:
  • Situation: The operations are straightforward (load, store), but there are complex data structures
  • Consequence: The static object model is dominant

• Telephone switching system:
  • Data structures do not tell us much and behavior is too complex to be fully described by use cases
  • The dynamic model (in particular using statecharts) is dominant
Requirements analysis
document template

1. Introduction
2. Current system
3. Proposed system
   3.1 Overview
   3.2 Functional requirements
   3.3 Nonfunctional requirements
   3.4 Constraints ("Pseudo requirements")
3.5 Analysis Model
   3.5.1 Scenarios
   3.5.2 Use case model
   3.5.3 Object model
      3.5.3.1 Data dictionary
      3.5.3.2 Class diagrams
   3.5.4 Dynamic model
   3.5.5 User interface
4. Glossary

Remember this is only conceptually a single document.
It may actually be a variety of separate things, some not even written up at all.

[keep this short! → 3.5.2]

see the following slides on 3.5 (short), 3.3, 3.4
Section 3.5: system models

- 3.5.1 Scenarios
  - As-is scenarios, visionary scenarios

- 3.5.2 Use case model
  - Actors and use cases

- 3.5.3 Object model (this is still analysis!)
  - Data dictionary
  - Class diagrams (classes, associations, attributes and operations)

- 3.5.4 Dynamic model
  - State diagrams for classes with significant dynamic behavior
  - Sequence diagrams for collaborating objects (protocol)

- 3.5.5 User Interface
  - Navigational Paths, Screen mockups
Section 3.3: nonfunctional requirements

- 3.3.1 User interface and human factors
- 3.3.2 Documentation
- 3.3.3 Hardware considerations
- 3.3.4 Performance characteristics
- 3.3.5 Error handling and extreme conditions
- 3.3.6 System interfacing
- 3.3.7 Quality issues
- 3.3.8 System modifications
- 3.3.9 Physical environment
- 3.3.10 Security issues
- 3.3.11 Resources and management issues

see the following slides
Nonfunctional requirements: trigger questions

• 3.3.1 User interface and human factors
  • What type of user will be using the system?
  • Will more than one type of user be using the system?
  • What sort of training will be required for each type of user?
  • Is it particularly important that the system be easy to learn?
  • Must users be particularly well protected from making errors?
  • What sort of UI input/output devices will be used?

• 3.3.2 Documentation
  • What kind of documentation is required?
  • What audience is to be addressed by each document?

• 3.3.3 Hardware considerations
  • What hardware is the proposed system to be used on?
  • What are the characteristics of the target hardware, including memory size and auxiliary storage space?
Nonfunctional requirements (2)

- **3.3.4 Performance characteristics**
  - Are there any speed, throughput, or response time constraints on the system?
  - Are there size or capacity constraints on the data to be processed by the system?

- **3.3.5 Error handling and extreme conditions**
  - How should the system respond to input errors?
  - How should the system respond to extreme conditions?

- **3.3.6 System interfacing**
  - What input is coming from systems outside the proposed system?
  - What output is going to systems outside the proposed system?
Nonfunctional requirements (3)

• 3.3.7 Quality issues
  • What are the requirements for reliability?
  • Must the system trap faults?
  • How fast must the system restart after a failure?
  • What is the acceptable system downtime per day/month/year?
  • Is it important that the system be portable (able to move to different hardware or operating system environments)?

• 3.3.8 System Modifications
  • What parts of the system are likely candidates for later modification?
  • What sorts of modifications are expected?

• 3.3.9 Physical Environment
  • For example, unusual temperatures, humidity, vibrations, magnetic fields, ...
Nonfunctional requirements (4)

- **3.3.10 Security Issues**
  - Must access to any data or the system itself be controlled?
  - Is physical security an issue?

- **3.3.11 Resources and Management Issues**
  - How often will the system be backed up?
  - Who will be responsible for
    - system installation?
    - daily operation and configuration?
    - back up? When? How often?
    - maintenance?
  - What is the desaster recovery plan?
Section 3.4
Constraints (pseudo requirements)

• Constraint:
  • Any client restriction on the solution domain

• Examples:
  • The target platform must be an IBM iSeries
  • The implementation language must be COBOL
  • The documentation standard X must be used
  • A dataglove must be used
  • ActiveX must not be used
  • The system must interface to a papertape reader
Verification and validation of models

Analysis

System Design

Object Design

Implementation

Validation (acceptance test)

M = Model
R = Reality
f = Behavior/relationships
A = abstraction/modelling
Correctness, completeness and consistency

• Verification is an equivalence check between two related models:
  • The second was derived from the first by transformation. Is the transformation correct?

• Validation is different. We don’t have two models, we need to compare one model with reality
  • "Reality" can also be an artificial system, like a legacy system

• Requirements and implementations should be validated with the client and the user
  • Techniques for requirements: Formal and informal reviews (Meetings, requirements review)
  • Techniques for implementations: Acceptance testing, system use

• Requirements validation involves the checks for
  • Correctness, Completeness, Ambiguity, Realism
Modeling checklist for the review

- **Is the model correct?**
  - A model is correct if it represents the client’s view of the system: Everything in the model represents an aspect of reality

- **Is the model complete?**
  - Every relevant scenario, including exceptions, is described

- **Is the model consistent?**
  - The model does not have components that contradict each other (for example, deliver contradicting results)

- **Is the model unambiguous?**
  - The model describes one target reality, not many

- **Is the model realistic?**
  - The model can be implemented with acceptable effort
At the end of analysis:
Project agreement

- The project agreement represents the acceptance of (parts of) the analysis model (as documented by the requirements analysis document) by the client.

- The client and the developers converge on a single idea and agree about the functions and features that the system will have. In addition, they agree on:
  - a list of prioritized requirements
  - a revision process
  - a list of criteria that will be used to accept or reject the system
  - a schedule, and probably a budget

- In a phased development model, this is a single event, in modern iterative development, it will be several
  - and can even be a continuous process
Prioritizing requirements

• High priority ("Core requirements")
  • Must be addressed during *analysis, design, and implementation*
  • A high-priority feature must be demonstrated successfully during client acceptance

• Medium priority ("Optional requirements")
  • Must be addressed during *analysis and design*
  • Often implemented and demonstrated in a later iteration of the system development

• Low priority ("Fancy requirements")
  • Must be addressed during *analysis* ("very visionary scenarios")
  • Illustrates how the system may be going to be used in the future
    • e.g. once not-yet-available technology becomes available
Summary

• In this lecture, we reviewed the construction of the dynamic model from use case and object models.
  • In particular: Sequence and State Machine diagrams for identifying new classes and operations

• In addition, we described the requirements analysis document and its components
Thank you!