Chapter 4

Requirements Specification

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Version 1.0

Topics

- State Specifications
- Behavior Specifications
- State Change Specifications

Principles of requirements specification

- Specification models are concerned with
  - State
  - Behavior
  - State change
- State and behavior modeling are conducted in parallel
- The world cannot be understood from a single view
- Visual Modeling Language - UML
State specifications

- **Object state** is determined by the values of its attributes and associations
- **State specification:**
  - Model of data structures
  - Static view on the system
  - Class operations left out in initial specs
  - Emphasis on entity classes (“business objects”)

Modeling classes

- Cornerstone of OO development – a system is a set of collaborating (and classified) objects
- Iterative and incremental process
- CASE tool
  - For collaborative development
  - For personal productivity otherwise

Discovering classes

- No two analysts will come up with the identical class models for the same application domain
- Discovering classes
  - Noun phrase
  - Common class patterns
  - Use case driven
  - CRC
  - Mixed
**Noun phrase approach**
- Nouns considered candidate classes
- Three kinds of candidate classes
  - Irrelevant (can be skipped)
  - Relevant
  - Fuzzy
- Assumes that the Requirements Document is complete and correct

**Common class pattern approach**
- Derives candidate classes from the classification theory of objects
- One possible classification pattern:
  - Concept (e.g. Reservation)
  - Events (e.g. Arrival)
  - Organization (e.g. Department)
  - People (e.g. Passenger)
  - Places (e.g. TravelOffice)
- Just a guidance
- Only loosely bound to user requirements
- Possible naming misinterpretations

**Use case driven approach**
- Assumes that:
  - Use Case Diagrams (and possibly some high-level Sequence Diagrams) have been developed
  - Narrative descriptions for each use case exist
- Similar to the noun phrase approach
- Function-driven (problem-driven)
- Relies on the completeness of use case models
CRC approach

- CRC – classes, responsibilities, collaborators
- More than a technique for class discovery
- Animated brainstorming sessions
- Identifies classes from the analysis of how objects collaborate to perform business functions (use cases)
  - Suitable also for:
    - Verification of classes discovered with other methods
    - Determination of class properties

Mixed approach

- Perhaps with elements of all four previous approaches
- Middle-out rather than top-down or bottom-up
- One possible scenario:
  - Initial classes – domain knowledge
  - Common class patterns approach to guide
  - Noun phrase approach to add more classes
  - Use case approach to verify
  - CRC to brainstorm

Guidelines for class discovery

- Statement of purpose
- Description for a set of objects
  - Singleton classes
- Houses a set of attributes
  - Identifying attributes - keys
  - OID
- Class or attribute?
- Houses a set of operations (what does the class do?)
Example 4.1 – University Enrolment

Consider the following requirements for the University Enrolment system and identify the candidate classes:

- Each university degree has a number of compulsory courses and a number of elective courses.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Course</th>
<th>Relevant</th>
<th>Fuzzy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 4.1 – University Enrolment

More requirements:

- Each course is at a given level and has a credit-point value
- A course can be part of any number of degrees
- Each degree specifies minimum total credit points value required for degree completion
- Students may combine course offerings into programs of study suited to their individual needs and leading to the degree in which enrolled

<table>
<thead>
<tr>
<th>CourseOffering</th>
<th>StudyProgram</th>
<th>Student</th>
<th>ElectiveCourse</th>
<th>CompulsoryCourse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 4.1– University Enrolment (solution)

<table>
<thead>
<tr>
<th>Relevant classes</th>
<th>Fuzzy classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course</td>
<td>CompulsoryCourse</td>
</tr>
<tr>
<td>Degree</td>
<td>ElectiveCourse</td>
</tr>
<tr>
<td>Student</td>
<td>StudyProgram</td>
</tr>
<tr>
<td>CourseOffering</td>
<td></td>
</tr>
</tbody>
</table>
Example 4.2 – Video Store

Consider the following requirements for the Video Store system and identify the candidate classes:

- The video store keeps in stock an extensive library of current and popular movie titles. A particular movie may be held on video tapes or disks.

MovieTitle
VideoTape
VideoDisk
VideoStore
Stock
Library

Relevant

Example 4.2 – Video Store

More requirements:

- Video tapes are in either "Beta" or "VHS" format
- Video disks are in DVD format
- Each movie has a particular rental period (expressed in days), with a rental charge to that period
- The video store must be able to immediately answer any inquires about a movie’s stock availability and how many tapes and/or disks are available for rental
- The current condition of each tape and disk must be known and recorded

Example 4.2 – Video Store (solution)

<table>
<thead>
<tr>
<th>Relevant classes</th>
<th>Fuzzy classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MovieTitle</td>
<td>RentalConditions</td>
</tr>
<tr>
<td>VideoMedium</td>
<td></td>
</tr>
<tr>
<td>VideoTape</td>
<td></td>
</tr>
<tr>
<td>VideoDisk</td>
<td></td>
</tr>
<tr>
<td>BetaTape</td>
<td></td>
</tr>
<tr>
<td>VHSTape</td>
<td></td>
</tr>
</tbody>
</table>
Example 4.3 – Contact Management

Consider the following requirements for the Contact Management system and identify the candidate classes:

- To “keep in touch” with current and prospective customer base
- To win new contracts
- To store the names, phone numbers, postal and courier addresses, etc. of organizations and contact persons in these organizations
- To schedule tasks and events for the employees with regard to relevant contact persons
- Employees can schedule tasks and events for other employees or for themselves
- A task is a group of events that take place to achieve a result (e.g. to solve customer’s problem)
- Typical types of events are: phone call, visit, sending a fax, arranging for training, etc.

Example 4.3 – Contact Management (solution)

<table>
<thead>
<tr>
<th>Relevant classes</th>
<th>Fuzzy classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
<td>CurrentOrg</td>
</tr>
<tr>
<td>Contact</td>
<td>ProspectiveOrg</td>
</tr>
<tr>
<td>Employee</td>
<td>PostalAddress</td>
</tr>
<tr>
<td>Task</td>
<td>CourierAddress</td>
</tr>
<tr>
<td>Event</td>
<td></td>
</tr>
</tbody>
</table>

Specifying classes

- In Class Diagram
  - Each class given a name (and possibly a code)
  - Singular noun
    - Recommendation – multiple words joined; each word starting with a capital letter (e.g. PostalAddress)
  - Meaningful
  - Short (less than 30 characters)

- Class properties to be defined
  - Attributes (initially those that capture interesting object states)
    - Recommendation – small letters; underscore to separate words (e.g. street_name)
  - Operations (can be delayed till later analysis stages or even till design)
Example 4.4 – University Enrolment

Refer to Example 4.1
Consider the following additional requirements from the Requirements Document:
- A student’s choice of courses may be restricted by timetable clashes and by limitations on the number of students who can be enrolled in the current course offering.

Example 4.4 – University Enrolment

More requirements:
- A student’s proposed program of study is entered on on-line enrolment system T
- The system checks the program’s consistency and reports any problems
- The problems need to be resolved with the help of an academic adviser
- The final program of study is subject to academic approval by the delegate of the Head of Division and it is then forwarded to the Registrar

Example 4.4 – University Enrolment (solution)

```java
class Degree {
    String degree_name;
    int total_credit_points;
}

class Course {
    String course_code;
    String course_name;
    int credit_points;
}

class Student {
    String student_id;
    String student_name;
}

class CourseOffering {
    Date year;
    int semester;
    int enrolment_quota;
}
```

MACIASZEK (2001): Req Analysis & Syst Design
Example 4.5 – Video Store

- Refer to Example 4.2
- The additional requirements are:
  - The rental charge differs depending on video medium: tape or disk (but it is the same for the two categories of tapes: Beta and VHS).

Example 4.5 – Video Store

- More requirements:
  - The system should accommodate future video storage formats in addition to VHS tapes, Beta tapes and DVD disks
  - The employees frequently use a movie code, instead of movie title, to identify the movie
  - The same movie title may have more than one release by different directors

Example 4.5 – Video Store (solution)

```sql
MovieTitle
- movie_code : String
- movie_title : String
- director : String
- is_in_stock : Boolean

VideoTape
- video_condition : Byte
- number_currently_available : Integer

VideoDisk

RentalConditions
- rental_period_in_days : Integer
- rental_charge_per_period : Currency

BetaTape

VHSTape

DVDDisk
```
Example 4.6 – Contact Management

- Refer to Example 4.3 and consider the following additional information
  - A customer is considered current if there exists a contract with that customer for delivery of our products or services. Contract management, however, outside the scope of our system.

More requirements:
- Reports on contacts based on postal and courier addresses (e.g., find all customers by post code)
- Date and time of the task creation are recorded
- The "money value" of a task can be stored
- Events for the employee are displayed on the employee’s screen in the calendar-like pages (one day per page)
  - The priority of each event (low, medium or high) is visually distinguished on the screen
- Not all events have a "due time" - some are "untimed"
- Event creation time cannot be changed, but the due time can.
- Event completion date and time are recorded
- The system stores identifications of employees who created tasks and events, who are scheduled to do the event ("due employee"), and who completed the event.

Example 4.6 – Contact Management (solution)
Example 4.7 - Telemarketing

Consider the following additional information:

- Each campaign
  - Has a title that is generally used for referring to it
  - Has also a unique code for internal reference
  - Runs over a fixed period of time
- Soon after the campaign is closed, the prizes are drawn and the holders of winning tickets are advised.

Example 4.7 - Telemarketing

More requirements:

- Tickets are uniquely numbered within each campaign
- The total number of tickets in a campaign, number of tickets sold so far, and the current status of each ticket are known (e.g. available, ordered, paid for, prize winner)
- To determine the performance of the society’s telemarketers, the duration of calls and the successful call outcomes (i.e. resulting in ordered tickets) are recorded
- Extensive information about supporters is maintained
  - Contact details (address, phone number, etc.)
  - Historical details such as the first and most recent dates when a supporter had participated in a campaign
  - Any known supporter’s preferences and constraints (e.g. times not to call, usual credit card number)

Example 4.7 - Telemarketing

More requirements:

- Telemarketing calls are made according to their priorities
- Calls which are unanswered or where an answering machine was found, are rescheduled
  - Times of repeat calls are alternated
  - Number of repeat calls is limited
  - Limits may be different for different call types (e.g. a normal “solicitation” call may have different limits than a call to remind a supporter of an outstanding payment)
- Call outcomes are categorized - success (i.e. tickets ordered), no success, call back later, no answer, engaged, answering machine, fax machine, wrong number, disconnected.
Example 4.7 – Telemarketing (solution)

Campaign
- ticket_number : String
- ticket_value : Currency
- ticket_status : String

Supporter
- supporter_id : String
- supporter_name : String
- phone_number : String
- mailing_address : String
- date_first : Date
- date_last : Date
- campaign_count : Integer
- preferred_hours : String
- credit_card_number : String

CallOutcome
- start_time : Date
- end_time : Date

CallScheduled
- phone_number : String
- priority : String
- attempt_number : Integer

Telemarketer
- telemarketer_id : String
- telemarketer_name : String
- average_per_hour : Double
- success_per_hour : Double

Prize
- prize_description : String
- prize_value : Currency
- prize_ranking : Integer

CallType
- type_description : String
- call_attempt_limit : Integer
- alternate_hours : String

OutcomeType
- outcome_type_description : String
- follow_up_action : String

Discovering associations

- Side effect of discovering classes
- Some attributes are associations
- "Dry-run" of use cases to discover more associations
- Avoid ternary associations
- Cycles of associations that do not commute

Specifying associations

- Naming associations
  - Recommendation – small letters; underscore to separate words (e.g. emp_task)
- Naming association roles
- Determining multiplicity
  - Lower and/or upper multiplicity bounds can be omitted initially
- Rolenames for recursive associations
Example 4.8 – Contact Management

Refer to Examples 4.3 and 4.6 - specify associations

Consider, for example, the requirement:

- The system allows producing various reports on our contacts based on postal and courier addresses.

PostalAddress
- street : String
- po_box : String
- city : String
- state : String
- post_code : String
- country : String

CourierAddress
- street_and_directions : String
- city : String
- state : String
- country : String

Contact
- <<PK>> contact_id : Integer
- family_name : String
- first_name : String
- phone : String
- fax : String
- email : String

Example 4.8 – Contact Management (solution – 1)

Example 4.8 – Contact Management (solution – 2)
Modeling aggregation

Four semantics for aggregation possible

- ExclusiveOwns (e.g. Book has Chapter)
  - Existence-dependency
  - Transitivity
  - Asymmetry
  - Fixed property
- Owns (e.g. Car has Tire)
  - No fixed property
- Has (e.g. Division has Department)
  - No existence dependency
  - No fixed property
- Member (e.g. Meeting has Chairperson)
  - No special properties except membership

Discovering aggregation

Discovered in parallel with discovery of associations

The litmus test phrases

- “has”
- “is-part-of”

Can relate more than two classes

Specifying aggregation

UML supports

- Aggregation
  - By-reference semantics
  - Hollow diamond
  - Corresponds to Has and Member aggregations
-Composition
  - By-value semantics
  - Solid diamond
  - Corresponds to ExclusiveOwns and Owns aggregations
Example 4.9 – University Enrolment

Refer to Examples 4.1 and 4.5

Consider the following additional requirements:

- The student's academic record to be available on demand
- The record to include information about the student’s grades in each course that the student enrolled in (and has not withdrawn without penalty)
- Each course has one academic in charge of a course, but additional academics may also teach in it
  - There may be a different academic in charge of a course each semester
  - There may be different academics for each course each semester

Example 4.9 – University Enrolment (solution)

AcademicRecord
course_code : String
cyear : Date
semester : Integer
grade : String

Course
<<PK>> course_code : String
<<CK>> course_name : String
credit_points : Integer

AcademicInCharge

Student
<<PK>> student_id : String
student_name : String
current_fees : Money

0..*
takes

0..*
takes_crs

has_stud

CourseOffering

eyear : Date
semester : Integer
enrolment_quota : Integer

0..*
takes

0..1
takes_crs

0..*
has_crs

Modeling generalization

- Common features abstracted into a more generic class
- Subclasses inherit (reuse) superclass features
- Substitutability – subclass object is a legal value for a superclass variable (e.g., a variable holding Fruit objects can have an Apple object as its value)
- Polymorphism – the same operation can have different implementations in different classes
- Abstract operation – implementation provided in subclasses
- Abstract class – class with no direct instance objects
  - A class with an abstract operation is abstract
Discovering and specifying generalization

- Some discovered in parallel with discovery of associations
- The litmus test phrases
  - “can-be”
  - “is-a-kind-of”
- Multiple inheritance possible
- Solid line with an arrowhead pointing to the superclass

Example 4.10 – Video Store

- Refer to Examples 4.2 and 4.5.
- The classes identified in Example 4.5 imply a generalization hierarchy rooted at the class VideoMedium
- Extend the model to include relationships between classes, and specify generalization relationships
- Assume that the Video Store needs to know if a VideoTape is a brand new tape or it was already taped over (this can be captured by an attribute is_taped_over)
- Assume also that the storage capacity of a VideoDisk allows holding multiple versions of the same movie, each in a different language or with different endings

Example 4.10 – Video Store (solution)
Modeling and specifying objects

- Only to exemplify
  - To illustrate complex relationships between objects
  - To demonstrate changes to objects over time
  - To illustrate object collaboration

Example 4.11 – University Enrollment

- Show few objects representing the classes in Example 4.9

Don Donaldson - Student
COMP224 - AcademicRecord
COMP326 - AcademicRecord

Rick Richards - AcademicInCharge
2000 Sem2 - CourseOffering

Behavior specification

- Depicted in use cases
  - Determines which classes are involved in execution of use cases
    - Main class operations identified
    - Message passing between objects captured
    - Control classes and boundary classes considered
- Computations modeled in Activity Diagrams
- Interactions modeled in Sequence Diagrams or Collaboration Diagrams
Modeling use cases
- Complete piece of functionality
  - Main flow
  - Subflows
  - Alternate flows
- Piece of externally visible functionality
- Orthogonal piece of functionality
- Piece of functionality initiated by an actor
- Piece of functionality that delivers an identifiable value to an actor

Discovering use cases
- Discovered from
  - Requirements identified in the Requirements Document
  - Actors and their purpose in the system
- Questions to ask
  - What are the main tasks performed by each actor?
  - Will an actor access or modify information in the system?
  - Will an actor inform the system about any changes in other systems?
  - Should an actor be informed about unexpected changes in the system?

Specifying use cases
- Actors
- Use cases
- Four kinds of relationships
  - Association (between actor and use case)
  - Include (stereotyped with the word: «include»)
    - Included use case is always necessary for the completion of the activating use case
  - Extend (stereotyped with the word: «extend»)
    - Another use is activated occasionally at specific extension point
  - Generalization
- Relationships to be used with restrain
Example 4.12 – University Enrolment

Example 4.13 – Contact Management

Example 4.14 – Video Store
Example 4.14 – Video Store (Rent Video)

**Brief Description**
A customer wishes to rent a video tape or disk that is picked from the store's shelves or that has been previously reserved by the customer. Provided the customer has a non-delinquent account, the tape is rented out once the payment has been received. If the tape is not returned in a timely fashion, an overdue notice is mailed to the customer.

**Actors**
Employee, Scanning Device

**Preconditions**
Video tape or disk is available to be hired. Customer has a membership card. Scanner devices work correctly. Employee at the front desk knows how to use the system.

**Main Flow**
A customer may inquire an employee about video availability (including a reserved video) or may pick a tape or disk from the shelves. The video and membership card are scanned and any delinquent or overdue details are brought up for the employee attention. If the customer does not have a delinquent rating, then he/she can hire up to a maximum of eight videos. However, if the rating of the customer is "unreliable" then a deposit of one rental period for each tape or disk is requested. Once the amount payable is received, the stock is updated and the tapes and disks are handed out to the customer together with the rental receipt. The customer pays by cash, credit card or electronic transfer. Each rental record stores the check-out and due-in dates together with the identification of the employee. A separate rental record is created for each video hired. The use case will generate an overdue notice to the customer if a video has not been returned within two days of the due date, and a second notice after another two days (and at that time the customer is noted as "delinquent").

**Alternative Flows**
A customer does not have a membership card. In this case, the Maintain Customer use case may be activated to issue a new card. An attempt to rent too many videos. No videos can be rented because of the customer’s delinquent rating. The video medium or membership card cannot be scanned because they are damaged. The electronic transfer or credit card payment is refused.

**Postconditions**
Videos are rented out and the database is updated accordingly.
Example 4.15 – Telemarketing (solution)

Modeling activities

- Activity Diagrams
- Flow of logic
  - Sequential control
  - Concurrent control
- Can be used at different levels of abstraction
  - To define execution of a use case
  - To define execution of an operation

Discovering and specifying activities

- The execution proceeds from one activity state to the next
- An activity state completes when its computation is completed
- Activities can be discovered from the narrative specifications of use cases
- Activities are connected by transition lines
- Synchronization bars (fork and re-join)
- Branch diamonds (branch and merge)
- External events not normally modeled on activity graphs
Example 4.16 – Video Store (solution)

Modeling interactions

- **Sequence Diagrams**
  - Show an exchange of messages between objects arranged in a time sequence
  - More useful in analysis

- **Collaboration Diagrams**
  - Emphasize the relationships between objects along which the messages are exchanged
  - More useful in design

- Can be used to determine operations in classes

Message sequences

- Activities in Activity Diagrams are mapped to messages to Sequence Diagrams

- **Message can be a:**
  - **Signal**
    - Denotes asynchronous inter-object communication
    - The sender continues executing after sending the signal message
  - **Call**
    - Denotes synchronous invocation of an operation
    - The return message can return some values to the caller or it can just acknowledge that the operation completed
Example 4.17 – University Enrolment

Modeling public interfaces
- Determined by the set of operations that the class offers as its service
- In analysis
  - Signature of each operation is defined
    - Operation name
    - List of formal arguments
    - Return type
- In design
  - Algorithm of a method that implements the operation is defined
- Operation can have
  - Instance scope
  - Class (static) scope ($ in front of operation name)

Discovering class operations
- From Sequence Diagrams
  - Message to an object must be serviced by an operation in that object
- From expected object responsibilities, including the CRUD operations
  - Create – a new object instance
  - Read – the state of an object
  - Update – the state of an object
  - Delete – i.e. destroy itself
Example 4.18 – UE (solution)

- Refer to Examples 4.9 and 4.17 and to the classes Course and CourseOffering
- Derive operations from the Sequence Diagram and add them to the classes Course and CourseOffering

<table>
<thead>
<tr>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>- course_code : String</td>
</tr>
<tr>
<td>- course_name : String</td>
</tr>
<tr>
<td>- credit_points : Integer</td>
</tr>
<tr>
<td>- crs_off : set&lt;CourseOffering&gt;</td>
</tr>
<tr>
<td>- areYouOpen(out c_check)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CourseOffering</th>
</tr>
</thead>
<tbody>
<tr>
<td>- year : Date</td>
</tr>
<tr>
<td>- semester : Integer</td>
</tr>
<tr>
<td>- enrolment_quota : Integer</td>
</tr>
<tr>
<td>- std : list&lt;Student&gt;</td>
</tr>
<tr>
<td>- crs : Course</td>
</tr>
<tr>
<td>- areYouOpen(out c_check)</td>
</tr>
<tr>
<td>- addStudent(stdOID)</td>
</tr>
</tbody>
</table>

**State change specifications**

- Statechart Diagrams
- For each class that exhibits an interesting dynamic behavior
- Changes to some attributes signify state changes

**Specifying object states**

- State transition fires when a certain event occurs or a certain condition is satisfied
  - transition line does not have to be labeled with an event name
  - condition itself (written in square brackets) can fire the transition
- Transition can be triggered by
  - Signal event
  - Call event
  - Change event
  - Time event
### Example 4.19 – Video Store

<table>
<thead>
<tr>
<th>Movie Title</th>
<th>Status</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Available</td>
<td>rent out(quantity)/return item [last item]</td>
</tr>
<tr>
<td></td>
<td>Available</td>
<td>put on shelf(quantity)</td>
</tr>
<tr>
<td></td>
<td>Not in Stock</td>
<td>rent out(quantity)/return item [last item]</td>
</tr>
<tr>
<td></td>
<td>Not in Stock</td>
<td>order item(quantity)</td>
</tr>
<tr>
<td></td>
<td>In Stock</td>
<td>order item(quantity)</td>
</tr>
<tr>
<td></td>
<td>In Stock</td>
<td>replenish stock(quantity)</td>
</tr>
<tr>
<td></td>
<td>Ordered</td>
<td>order item(quantity)</td>
</tr>
<tr>
<td></td>
<td>Ordered</td>
<td>(insufficient stock)</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>order item(quantity)</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>(insufficient stock)</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>reserve(medium type)/update number reserved</td>
</tr>
<tr>
<td></td>
<td>Not Reserved</td>
<td>[no more reserved]</td>
</tr>
</tbody>
</table>

### Summary

- **State specifications** describe the IS world from the static perspective of classes, their attribute content and their relationships
  - There are many methods of class discovery
  - Class diagrams visualize classes and relationships: associations, aggregations, and generalizations
- **Behavioral specifications** describe the IS world from the operational (functional) perspective
  - Use case diagrams provide simple visualization – each use case is given a narrative specification
  - Other behavioral diagrams include activity diagrams, interactions diagrams, and addition of operations to classes.
- **State change specifications** describe the IS world from the dynamic perspective
  - Statechart diagrams allow modeling of state changes