Chapter 4 Objectives

- Eliciting requirements from the customers
- Modeling requirements
- Reviewing requirements to ensure their quality
- Documenting requirements for use by the design and test teams
4.1 The Requirements Process

- A **requirement** is an expression of desired behavior.
- A requirement deals with:
  - objects or entities
  - the state they can be in
  - functions that are performed to change states or object characteristics
- Requirements focus on the customer needs, not on the solution or implementation:
  - designate what behavior, without saying how that behavior will be realized
Sidebar 4.1 Why Are Requirements Important?

- Top factors that caused project to fail
  - Incomplete requirements
  - Lack of user involvement
  - Unrealistic expectations
  - Lack of executive support
  - Changing requirements and specifications
  - Lack of planning
  - System no longer needed

- Some part of the requirements process is involved in almost all of these causes

- Requirements error can be expensive if not detected early
4.1 The Requirements Process
Process for Capturing Requirements

- Performed by the req. analyst or system analyst
- The final outcome is a Software Requirements Specification (SRS) document
4.2 Requirements Elicitation

• Customers do not always understand what their needs and problems are
• It is important to discuss the requirements with everyone who has a stake in the system
• Come up with agreement on what the requirements are
  – If we cannot agree on what the requirements are, then the project is doomed to fail
4.2 Requirements Elicitation

Stakeholders

- **Clients**: pay for the software to be developed
- **Customers**: buy the software after it is developed
- **Users**: use the system
- **Domain experts**: familiar with the problem that the software must automate
- **Market Researchers**: conduct surveys to determine future trends and potential customers
- **Lawyers or auditors**: familiar with government, safety, or legal requirements
- **Software engineers** or other technology experts
4.2 Requirements Elicitation
Means of Eliciting Requirements

- Interviewing stakeholders
- Reviewing available documentations
- Observing the current system (if one exists)
- Apprenticing with users to learn about user's task in more details
- Interviewing user or stakeholders in groups
- Using domain specific strategies, such as Joint Application Design, or PIECES
- Brainstorming with current and potential users
4.3 Types of Requirements

- **Functional requirement**: describes required behavior in terms of required activities
- **Quality requirement** or **nonfunctional requirement**: describes some quality characteristic that the software must posses
- **Design constraint**: a design decision such as choice of platform or interface components
- **Process constraint**: a restriction on the techniques or resources that can be used to build the system
4.3 Types of Requirements
Resolving Conflicts

• Different stakeholder has different set of requirements
  – potential conflicting ideas
• Need to prioritize requirements
• Prioritization might separate requirements into three categories
  – essential: absolutely must be met
  – desirable: highly desirable but not necessary
  – optional: possible but could be eliminated
4.3 Types of Requirements
Two Kinds of Requirements Documents

- **Requirements definition**: a complete listing of everything the customer wants to achieve
  - Describing the entities in the environment where the system will be installed
- **Requirements specification**: restates the requirements as a specification of how the proposed system shall behave
4.4 Characteristics of Requirements

- Correct
- Consistent
- Unambiguous
- Complete
- Feasible
- Relevant
- Testable
- Traceable
4.5 Modeling Notations

- It is important to have standard notations for Modeling, documenting, and communicating decisions.
- Modeling helps us to understand requirements thoroughly.
  - Holes in the models reveal unknown or ambiguous behavior.
  - Multiple, conflicting outputs to the same input reveal inconsistencies in the requirements.
4.5 Modeling Notations
ER Diagrams Example: UML Class Diagram

- **UML (Unified Modeling Language)** is a collection of notations used to document software specifications and designs.
- It represents a system in terms of:
  - objects: akin to entities, organized in classes that have an inheritance hierarchy
  - methods: actions on the object's variables
- The **class diagram** is the flagship model in any UML specification,
  - A sophisticated ER diagram relating the classes (entities) in the specification
4.5 Modeling Notations
UML Class Diagram of Library Problem
4.5 Modeling Notations
UML Class Diagram (continued)

• Attributes and operations are associated with the class rather than instances of the class

• A **class-scope attribute** represented as an underlined attribute, is a data value that is shared by all instances of the class

• A **class-scope operation** written as underlined operation, is an operation performed by the abstract class rather than by class instances

• An **association**, marked as a line between two classes, indicates a relationship between classes' entities
4.5 Modeling Notations
UML Class Diagram (continued)

- **Aggregate association** is an association that represents interaction, or events that involve objects in the associated (marked with white diamond)
  - “has-a” relationship
- **Composition association** is a special type of aggregation, in which instances of the compound class are physically constructed from instances of component classes (marked with black diamond)
4.5 Modeling Notations
Event Traces

• A graphical description of a sequence of events that are exchanged between real-world entities
  – Vertical line: the timeline of distinct entity, whose name appear at the top of the line
  – Horizontal line: an event or interaction between the two entities bounding the line
  – Time progresses from top to bottom

• Each graph depicts a single trace, representing one of several possible behaviors

• Traces have a semantic that is relatively precise, simple and easy to understand
4.5 Modeling Notations

Event Traces (continued)

• Graphical representation of two traces for the turnstile problem
  – trace on the left represents typical behavior
  – trace on the right shows exceptional behavior

![Diagram showing two traces for the turnstile problem](image-url)
4.5 Modeling Notations

Event Traces Example: Message Sequence Chart

• An enhanced event-trace notation, with facilities for creating and destroying entities, specifying actions and timers, and composing traces
  – Vertical line represents a participating entity
  – A message is depicted as an arrow from the sending entity to the receiving entity
  – Actions are specified as labeled rectangles positioned on an entity's execution line
  – Conditions are important states in an entity's evolution, represented as labeled hexagon
4.5 Modeling Notations
Message Sequence Chart (continued)

- Message sequence chart for library loan transaction
4.5 Modeling Notations
State Machines

• A graphical description of all dialog between the system and its environment
  – Node (state) represents a stable set of conditions that exists between event occurrences
  – Edge (transition) represents a change in behavior or condition due to the occurrence of an event

• Useful both for specifying dynamic behavior and for describing how behavior should change in response to the history of events that have already occurred
4.5 Modeling Notations
State Machines (continued)

- Finite state machine model of the turnstile problem
4.5 Modeling Notations
State Machines (continued)

- **A path**: starting from the machine's initial state and following transitions from state to state
  - A trace of observable events in the environment

- **Deterministic state machine**: for every state and event there is a unique response
4.5 Modeling Notations
State Machines Example: UML Statechart Diagrams

• A UML statechart diagram depicts the dynamic behavior of the objects in a UML class
  – UML class diagram has no information about how the entities behave, how the behaviors change

• A UML model is a collection of concurrently executing statecharts

• UML statechart diagram have a rich syntax, including state hierarchy, concurrency, and intermachine communication
4.5 Modeling Notations
UML Statechart Diagrams (continued)

• **State hierarchy** is used to unclutter diagrams by collecting into superstate those states with common transitions

• A **superstate** can actually comprise multiple concurrent submachines, separated by dashed line
  – The submachines are said to operate concurrently
4.5 Modeling Notations
UML Statechart Diagrams (continued)

- The UML statechart diagram for the Publication class from the Library class model
4.5 Modeling Notations
UML Statechart Diagrams (continued)

- An equivalent statechart for Publication class that does not make use of state hierarchy or concurrency
  - comparatively messy and repetitive
4.5 Modeling Notations
UML Statechart Diagrams (continued)

- The UML statechart diagram for Loan association class illustrates how states can be annotated with local variables, actions and activities.
4.5 Modeling Notations
State Machines: Ways of Thinking about State

- Equivalence classes of possible future behavior
- Periods of time between consecutive event
- Named control points in an object's evolution
- Partition of an object's behavior
4.5 Modeling Notations
State Machines Example: Petri Nets

• A form or state-transition notation that is used to model concurrent activities and their interaction
  – Circles (places) represent activities or conditions
  – Bars represents transitions
  – Arcs connect a transition with its input places and its output places
  – The places are populated with tokens, which act as enabling conditions for the transitions
  – Each arc can be assigned a weight that specifies how many tokens are removed from arc's input place, when the transition fires
4.5 Modeling Notations
Petri Nets (continued)

- Petri net of book loan
4.5 Modeling Notations
Petri Nets (continued)

- A high level Petri net specification for the library problem
4.5 Modeling Notations
Data-Flow Diagrams

- ER diagram, event trace, state machines depict only lower-level behaviors
- A data-flow diagram (DFD) models functionality and the flow of data from one function to another
  - A bubble represents a process
  - An arrow represents data flow
  - A data store: a formal repository or database of information
  - Rectangles represent actors: entities that provide input data or receive the output result
4.5 Modeling Notations
Data-Flow Diagrams (continued)

- A high-level data-flow diagram for the library problem
4.5 Modeling Notations
Data-Flow Diagrams (continued)

• Advantage:
  – Provides an intuitive model of a proposed system's high-level functionality and of the data dependencies among various processes

• Disadvantage:
  – Can be aggravatingly ambiguous to a software developer who is less familiar with the problem being modeled
4.5 Modeling Notations

Data-Flow Diagrams Example: Use Cases

• Components
  – A large box: system boundary
  – Stick figures outside the box: actors, both human and systems
  – Each oval inside the box: a use case that represents some major required functionality and its variant
  – A line between an actor and use case: the actor participates in the use case

• Use cases do not model all the tasks, instead they are used to specify user views of essential system behavior
4.5 Modeling Notations
Use Cases (continued)

- Library use cases including borrowing a book, returning a borrowed book, and paying a library fine
4.5 Modeling Notations
Functions and Relations

- **Formal methods or approach:** mathematically based specification and design techniques
- **Formal methods** model requirements or software behavior as a collection of mathematical **functions** or **relations**
  - Functions specify the state of the system's execution, and output
  - A relation is used whenever an input value maps more than one output value
- **Functional method** is consistent and complete
4.5 Modeling Notations
Functions and Relations (continued)

- Example: representing turnstile problem using two functions
  - One function to keep track of the state
  - One function to specify the turnstile output

\[
NetState(s,e) = \begin{cases} 
  \text{unlocked} & s=\text{locked} \text{ AND } e=\text{coin} \\
  \text{rotating} & s=\text{unlocked} \text{ AND } e=\text{push} \\
  \text{locked} & (s=\text{rotating} \text{ AND } e=\text{rotated}) \\
  & \text{OR } (s=\text{locked} \text{ AND } e=\text{slug}) 
\end{cases}
\]

\[
Output(s,e) = \begin{cases} 
  \text{buzz} & s=\text{locked} \text{ AND } e=\text{slug} \\
  \text{<none>} & \text{Otherwise} 
\end{cases}
\]
4.5 Modeling Notations
Functions and Relations Example: Decision Tables

- It is a tabular representation of a functional specification that maps events and conditions to appropriate responses or action.
- The specification is formal because the inputs (events and conditions) and outputs (actions) may be expressed in natural language.
- If there are n input conditions, there are $2^n$ possible combination of input conditions.
- Combinations map to the same set of results can be combined into a single column.
### Decision Tables (continued)

- **Decision table for library functions** `borrow`, `return`, `reserve`, and `unreserve`

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<th>Possible Input events</th>
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<tr>
<td>item out on loan</td>
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<tr>
<td>item on reserve</td>
</tr>
<tr>
<td>patron.fines &gt; $0.00</td>
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<th>X</th>
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<tbody>
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<td>Put item in stacks</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Put item on reserve shelf</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Send recall notice</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Reject event</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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</table>

**Possible responses**
4.5 Modeling Notations

Logic

• An **operational notation** is a notation used to describe a problem or a proposed software solution in terms of situational behavior
  – Model of case-based behavior
  – Examples: state machine, event traces, data-flow diagram, functional method

• A **descriptive notation** is a notation that describes a problem or a proposed solution in terms of its properties or its variant
  – Example: logic
A logic consists of a language for expressing properties and a set of inference rules for deriving new, consequent properties from the stated properties.

In logic, a property specification represents only those values of the property's variables for which the property's expression evaluates to true.

It is first-order logic, comprising typed variables, constants, functions, and predicates.
4.5 Modeling Notations
Logic (continued)

- Consider the following variables of turnstile problem, with their initial value

```plaintext
num_coins : integer := 0;  /* number of coins inserted */
num_entries : integer := 0; /* number of half-rotations of turnstile */
barrier : {locked, unlocked} := locked; /* whether barrier is locked */
may_enter : boolean := false; /* event of coin being inserted */
push : boolean := false;     /* turnstile is pushed sufficiently hard to rotate it one-half rotation */
```

- The first-order logic expressions

```plaintext
num_coins ≥ num_entries
(num_coins ≥ num_entries ⇔ (barrier = unlocked))
(barrier = locked) ⇔ ¬may_enter
```
4.5 Modeling Notations
Logic (continued)

• Temporal logic introduces additional logical connectives for constraining how variables can change value over time.

• The following connectives constrain future variable values, over a single execution:
  - □f \Leftrightarrow f is true now and throughout the rest of execution.
  - ◊f \Leftrightarrow f is true now or at some point in the execution.
  - ○f \Leftrightarrow f is true in the next point in the execution.
  - f W g = f is true until a point where g is true, but g may never be true.

• Turnstile properties expressed in temporal logic:
  - □(insert_coin => ◊(may_enter \ W push))
  - □(\forall n(insert_coin \land num_coins=n) => ◊(num_coins=n+1))
4.5 Modeling Notations
Logic Example: Object Constrain Language (OCL)

- A constraint language that is both mathematically precise and easy for non-mathematicians to read, write, and understand
- Designed for expressing constraints on object models, and expressing queries on object type
4.5 Modeling Notations

Library classes annotated with OCL properties
4.5 Modeling Notations
Logic Example: Z

• A formal requirements-specification language that
  – structures set-theoretic definitions of variables into a complete abstract-data-type model of problem
  – uses logic to express the pre- and post-conditions for each operation

• Method of abstractions are used to decompose a specification into manageable sized modules, called schemas
4.5 Modeling Notations

Partial Z specification for the library problem

Opern is modified or queried; (?) input/(!) output vars

Pre (input Item i? not already in Catalogue) and postconditions (‘) indicates after operation
4.5 Modeling Notations

Algebraic Specifications

- To specify the behavior of operations by specifying interactions between pairs of operations rather than modeling individual operations.
- It is hard to define a set of axioms that is complete and consistent and that reflects the desired behavior.
4.5 Modeling Notations
Algebraic Specifications Example: SDL Data

- Partial SDL data specification for the library problem
4.6 Requirements and Specification Languages
Unified Modeling Language (UML)

- Combines multiple notation paradigms
- Eight graphical modeling notations, and the OCL constrain language, including
  - Use-case diagram (a high-level DFD)
  - Class diagram (an ER diagram)
  - Sequence diagram (an event trace)
  - Collaboration diagram (an event trace)
  - Statechart diagram (a state-machine model)
  - OCL properties (logic)
4.6 Requirements and Specification Languages

Specification and Description Language (SDL)

- Standardized by the International Telecommunication Union
- Specifies the behavior of real-time, concurrent, distributed processes that communicate with each other via unbounded message queues
- Comprises
  - SDL system diagram (a DFD)
  - SDL block diagram (a DFD)
  - SDL process diagram (a state-machine model)
  - SDL data type (algebraic specification)
- Often accompanied by a set of Message Sequence Chart (MSC)
4.6 Requirements and Specification Languages
SDL System Diagram

- The top-level blocks of the specification and communication channels that connect the blocks
- Channels are directional and are labelled with the type of signals
- Message is asynchronous
4.6 Requirements and Specification Languages

Other Features of Requirement Notations

• Some techniques include notations
  – for the degree of uncertainty or risk with each requirement
  – for tracing requirements to other system documents such as design or code, or to other systems, such as when requirements are reused

• Most specification techniques have been automated to some degree
4.7 Prototyping Requirements

Building a Prototype

- To elicit the details of proposed system
- To solicit feedback from potential users about
  - what aspects they would like to see improve
  - which features are not so useful
  - what functionality is missing
- Determine whether the customer's problem has a feasible solution
- Assist in exploring options for optimizing quality requirements
4.7 Prototyping Requirements
Prototyping Example

• Prototype for building a tool to track how much a user exercises each day
• Graphical representation of first prototype, in which the user must type the day, month and year

![Prototype example](image)
4.7 Prototyping Requirements
Prototyping Example (continued)

- Second prototype shows a more interesting and sophisticated interface involving a calendar
  - User uses a mouse to select the month and year
  - The system displays the chart for that month, and the user selects the appropriate date in the chart
4.7 Prototyping Requirements
Prototyping Example (continued)

- Third prototype shows that instead of calendar, the user is presented with three slide bars
  - User uses the mouse to slide each bar left or right
  - The box at the bottom of the screen changes to show the selected day, month, and year
4.7 Prototyping Requirements
Approaches to Prototyping

• **Throwaway approach**
  – Developed to learn more about a problem or a proposed solution, and that is never intended to be part of the delivered software
  – Allow us to write “quick-and-dirty”

• **Evolutionary approach**
  – Developed not only to help us answer questions but also to be incorporated into the final product
  – Prototype has to eventually exhibit the quality requirements of the final product, and these qualities cannot be retrofitted

• Both techniques are sometimes called rapid prototyping
4.7 Prototyping Requirements

Prototyping vs. Modeling

- **Prototyping**
  - Good for answering questions about the user interfaces

- **Modeling**
  - Quickly answer questions about constraints on the order in which events should occur, or about the synchronization of activities
4.8 Requirements Documentation

Requirement Definition: Steps Documenting Process

- Outline the general purpose and scope of the system, including relevant benefits, objectives, and goals
- Describe the background and the rationale behind proposal for new system
- Describe the essential characteristics of an acceptable solution
- Describe the environment in which the system will operate
- Outline a description of the proposal, if the customer has a proposal for solving the problem
- List any assumptions we make about how the environment behaves
4.8 Requirements Documentation

Requirements Specification: Steps Documenting Process

- Describe all inputs and outputs in detail, including:
  - the sources of inputs
  - the destinations of outputs,
  - the value ranges
  - data format of inputs and output data
  - data protocols
  - window formats and organizations
  - timing constraint

- Restate the required functionality in terms of the interfaces' inputs and outputs

- Devise fit criteria for each of the customer's quality requirements
4.8 Requirements Documentation
Sidebar 4.6 Level of Specification

• Survey shows that one of the problems with requirement specifications was the uneven level of specification
  – Different writing styles
  – Difference in experience
  – Different formats
  – Overspecifying requirements
  – Underspecifying requirements

• Recommendations to reduce unevenness
  – Write each clause so that it contains only one requirement
  – Avoid having one requirement refer to another requirement
  – Collect similar requirements together
Sidebar 4.7 Hidden Assumptions

- Two types of environmental behavior of interest
  - desired behavior to be realized by the proposed system
  - existing behavior that is unchanged by the proposed system
    - often called assumptions or domain knowledge
- Most requirements writers consider assumptions to be simply the conditions under which the system is guaranteed to operate correctly
4.8 Requirements Documentation
IEEE Standard for SRS Organized by Objects

1. Introduction to the Document
1.1 Purpose of the Product
1.2 Scope of the Product
1.3 Acronyms, Abbreviations, Definitions
1.4 References
1.5 Outline of the rest of the SRS
2. General Description of Product
2.1 Context of Product
2.2 Product Functions
2.3 User Characteristics
2.4 Constraints
2.5 Assumptions and Dependencies
3. Specific Requirements
3.1 External Interface Requirements
3.1.1 User Interfaces
3.1.2 Hardware Interfaces
3.1.3 Software Interfaces
3.1.4 Communications Interfaces
3.2 Functional Requirements
3.2.1 Class 1
3.2.2 Class 2
...
3.3 Performance Requirements
3.4 Design Constraints
3.5 Quality Requirements
3.6 Other Requirements
4. Appendices
4.8 Requirements Documentation
Process Management and Requirements Traceability

• Process management is a set of procedures that track
  – the requirements that define what the system should do
  – the design modules that are generated from the requirement
  – the program code that implements the design
  – the tests that verify the functionality of the system
  – the documents that describe the system

• It provides the threads that tie the system parts together
4.8 Requirements Documentation

Development Activities

- Horizontal threads show the coordination between development activities
4.9 Validation and Verification

- In requirements validation, we check that our requirements definition accurately reflects the customer's needs.
- In verification, we check that one document or artifact conforms to another.
- Verification ensures that we build the system right, whereas validation ensures that we build the right system.
### 4.9 Validation and Verification

List of techniques to validate requirements

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<td>Models to check functions and relationships</td>
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<td>Check for unreachable states of transitions</td>
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<td>Mathematical proofs</td>
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4.9 Validation and Verification
Requirements Review

• Review the stated goals and objectives of the system
• Compare the requirements with the goals and objectives
• Review the environment in which the system is to operate
• Review the information flow and proposed functions
• Assess and document the risk, discuss and compare alternatives
• Testing the system: how the requirements will be revalidated as the requirements grow and change
4.9 Validation and Verification
Sidebar 4.8 Number of Requirements Faults

• Jone and Thayes's studies show that
  – 35% of the faults to design activities for project of 30,000-35,000 delivered source instructions
  – 10% of the faults to requirements activities and 55% of the faults to design activities for projects of 40,000-80,000 delivered source instructions
  – 8% to 10% of the faults to requirements activities and 40% to 55% of the faults to design activities for project of 65,000-85,000 delivered source instructions

• Basili and Perricone report
  – 48% of the faults observed in a medium-scale software project were attribute to “incorrect or misinterpreted functional specification or requirements”

• Beizer attributes 8.12% of the faults in his samples to problems in functional requirements
4.9 Validation and Verification

Verification

- Check that the requirements-specification document corresponds to the requirements-definition
- Make sure that if we implement a system that meets the specification, then the system will satisfy the customer's requirements
- Ensure that each requirement in the definition document is traceable to the specification
4.9 Validation and Verification
Sidebar 4.9 Computer-Aided Verification

• **Model checking** is an exhaustive search for a specification's execution space, to determine whether some temporal-logic property holds of the execution
  – Atlee (1996) used the SMV model checker to verify five properties of an SCR specification of the A-7 naval aircraft

• **A theorem prover** uses a collection of built-in theories, inference rules, and decision procedures for determining whether a set of asserted facts logically entails some unasserted fact
  – Dutertre and Stavridou (1997) used theorem prover PVS to verify some of the functional and safety requirements of an avionic system
4.10 Measuring Requirements

• Measurements focus on three areas
  – product
  – process
  – resources
• Number of requirements can give us a sense of the size of the developed system
• Number of changes to requirements
  – Many changes indicate some instability or uncertainty in our understanding of the system
• Requirement-size and change measurements should be recorded by requirements type
4.10 Measuring Requirements
Rating Scheme on Scale from 1 to 5

1. You understand this requirement completely, have designed systems from similar requirements, and have no trouble developing a design from this requirement.
2. Some elements of this requirement are new, but they are not radically different from requirements that have been successfully designed in the past.
3. Some elements of this requirement are very different from requirements in the past, but you understand the requirement and can develop a good design from it.
4. You cannot understand some parts of this requirement, and are not sure that you can develop a good design.
5. You do not understand this requirement at all, and cannot develop a design.
4.10 Measuring Requirements
Testers/Designers Profiles

- Figure (a) shows profiles with mostly 1s and 2s
  - The requirements are in good shape
- Figure (b) shows profiles with mostly 4s and 5s
  - The requirements should be revised
4.11 Choosing a Specification Technique
Criteria for Evaluating Specification Methods

- Applicability
- Implementability
- Testability/Simulation
- Checkability
- Maintainability
- Modularity
- Level of abstraction
- Soundness
- Veriability
- Run time safety
- Tools maturity
- Looseness
- Learning curve
- Technique maturity
- Data modeling
- Discipline
4.11 Choosing a Specification Technique

Steps

• Determine which of the criteria are especially important
• Evaluate each of the candidate techniques with respect to the criteria
• Choose a specification technique that best supports the criteria that are most important to the problem
## Important of Specification Criteria During Reactive-System Life Cycle

- **R**=Requirements, **D**=Design, **I**=Implementation, **T**=Testing, **M**=Maintenance, **O**=Other

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4.14 What This Chapter Means for You

• It is essential that the requirements definition and specification documents describe the problem, leaving solution selection to designer
• There are variety of sources and means for eliciting requirements
• There are many different types of definition and specification techniques
• The specification techniques also differ in terms of their tool support, maturity, understandability, ease of use, and mathematical formality
• Requirements questions can be answered using models or prototypes
• Requirements must be validated to ensure that they accurately reflect the customer's expectations