Formal Specification

• Techniques for the unambiguous specification of software

Objectives

• To explain why formal specification techniques help discover problems in system requirements
• To describe the use of algebraic techniques for interface specification
• To describe the use of model-based techniques for behavioural specification

Topics covered

• Formal specification in the software process
• Interface specification
• Behavioural specification

Formal methods

• Formal specification is part of a more general collection of techniques that are known as ‘formal methods’
• These are all based on mathematical representation and analysis of software
• Formal methods include
  - Formal specification
  - Specification analysis and proof
  - Transformational development
  - Program verification
Acceptance of formal methods

- Formal methods have not become mainstream software development techniques as was once predicted
  - Other software engineering techniques have been successful at increasing system quality.
  - Market changes have made time-to-market rather than software with a low error count the key factor. Formal methods do not reduce time to market
  - Formal methods are hard to scale up to large systems

Use of formal methods

- Their principal benefits are in reducing the number of errors in systems so their main area of applicability is critical systems
- In this area, the use of formal methods is most likely to be cost-effective

Specification in the software process

- Specification and design are intermingled.
- Architectural design is essential to structure a specification.
- Formal specifications are expressed in a mathematical notation with precisely defined vocabulary, syntax and semantics.
Specification in the software process

- Requirements Specification
- Formal Specification
- System Modeling
- Architectural Design
- High-level Design

Specification techniques

- Algebraic approach
  - The system is specified in terms of its operations and their relationships
- Model-based approach
  - The system is specified in terms of a state model that is constructed using mathematical constructs such as sets and sequences. Operations are defined by modifications to the system's state

Formal specification languages

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<tr>
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<th>Sequential</th>
<th>Concurrent</th>
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<tbody>
<tr>
<td>Algebraic</td>
<td>Larch</td>
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Use of formal specification

- Formal specification involves investing more effort in the early phases of software development
- This reduces requirements errors as it forces a detailed analysis of the requirements
- Incompleteness and inconsistencies can be discovered and resolved
- Hence, savings as made as the amount of rework due to requirements problems is reduced
Development costs with formal specification

- Large systems are decomposed into subsystems with well-defined interfaces between these subsystems.
- Specification of subsystem interfaces allows independent development of the different subsystems.
- Interfaces may be defined as abstract data types or object classes.
- The algebraic approach to formal specification is particularly well-suited to interface specification.

Interface specification

Sub-system interfaces

The structure of an algebraic specification

<table>
<thead>
<tr>
<th>Sort</th>
<th>&lt;name&gt;</th>
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<tr>
<td>Imports</td>
<td>&lt;list of specification names&gt;</td>
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<tr>
<td>Informal description of the sort and its operations</td>
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<tr>
<td>Operation signatures setting out the names and the types of the parameters to the operations defined over the sort</td>
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<tr>
<td>Axioms defining the operations over the sort</td>
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**Specification components**

- **Introduction**
  - Defines the sort (the type name) and declares other specifications that are used
- **Description**
  - Informally describes the operations on the type
- **Signature**
  - Defines the syntax of the operations in the interface and their parameters
- **Axioms**
  - Defines the operation semantics by defining axioms which characterise behaviour

**Systematic algebraic specification**

- Algebraic specifications of a system may be developed in a systematic way
  - Specification structuring.
  - Specification naming.
  - Operation selection.
  - Informal operation specification
  - Syntax definition
  - Axiom definition

**Specification operations**

- **Constructor operations.** Operations which create entities of the type being specified
- **Inspection operations.** Operations which evaluate entities of the type being specified
- To specify behaviour, define the inspector operations for each constructor operation

**Interface specification in critical systems**

- Consider an air traffic control system where aircraft fly through managed sectors of airspace
- Each sector may include a number of aircraft, but, for safety reasons, these must be separated
- In this example, a simple vertical separation of 300m is proposed
- The system should warn the controller if aircraft are instructed to move so that the separation rule is breached
A sector object

• Critical operations on an object representing a controlled sector are
  - Enter. Add an aircraft to the controlled airspace
  - Leave. Remove an aircraft from the controlled airspace
  - Move. Move an aircraft from one height to another
  - Lookup. Given an aircraft identifier, return its current height

Primitive operations

• It is sometimes necessary to introduce additional operations to simplify the specification
• The other operations can then be defined using these more primitive operations
• Primitive operations
  - Create. Bring an instance of a sector into existence
  - Put. Add an aircraft without safety checks
  - In-space. Determine if a given aircraft is in the sector
  - Occupied. Given a height, determine if there is an aircraft within 300m of that height

Specification commentary

• Use the basic constructors Create and Put to specify other operations
• Define Occupied and In-space using Create and Put and use them to make checks in other operation definitions
• All operations that result in changes to the sector must check that the safety criterion holds