Lecture 7: Requirements Modeling III

Last Week:
Modeling and Analysis (II)
Modeling Functionality
Structured Analysis
Object Oriented Analysis

This Week:
Modeling and Analysis (III)
Formal Modeling Techniques
Program Specification vs. Reqts Modeling
Egs: RSML, SCR, RML, Telos, Albert II
Tips on formal modeling

Next Week:
Communicating Reqts
Specification Languages
Documentation Standards
Traceability

Formal Methods in RE

→ What to formalize in RE?

- models of requirements knowledge (so we can reason about them)
- specifications of requirements (so we can document them precisely)

Why formalize in RE?

- To remove ambiguity and improve precision
- Provides a basis for verification that the requirements have been met
- Allows us to reason about the requirements
  - Properties of formal requirements models can be checked automatically
  - Can test for consistency, explore the consequences, etc.
- Allows us to animate/execute the requirements
  - Helps with visualization and validation
- Will have to formalize eventually anyway
  - RE is all about bridging from the informal world to a formal machine domain

Why people don't formalize in RE

- Formal Methods tend to be lower level than other analysis techniques
  - They force you to include too much detail
- Formal Methods tend to concentrate on consistent, correct models
  - …but most of the time your models are inconsistent, incorrect, incomplete…
- People get confused about which tools are appropriate:
  - E.g. modeling program behaviour vs. modeling the requirements
  - formal methods advocates get too attached to one tool!
- Formal methods require more effort
  - ...and the payoff is deferred

What are Formal Methods?

→ Broad View (Leveson)

- application of discrete mathematics to software engineering
- …involves modeling and analysis
- …with an underlying mathematically-precise notation

→ Narrow View (Wing)

- Use of a formal language
  - a set of strings over some well-defined alphabet, with rules for distinguishing which strings belong to the language
- Formal reasoning about formulae in the language
  - E.g. formal proofs: use axioms and proof rules to demonstrate that some formula is in the language

→ For requirements modeling…

- A notation is formal if:
  - …it comes with a formal set of rules which define its syntax and semantics.
  - …the rules can be used to analyse expressions to determine if they are syntactically well-formed or to prove properties about them.

Varieties of formal analysis

→ Consistency analysis and typechecking

- "Is the formal model well-formed?"
  - [assuming that we only use modeling languages where "well-formedness" is a useful thing to check]

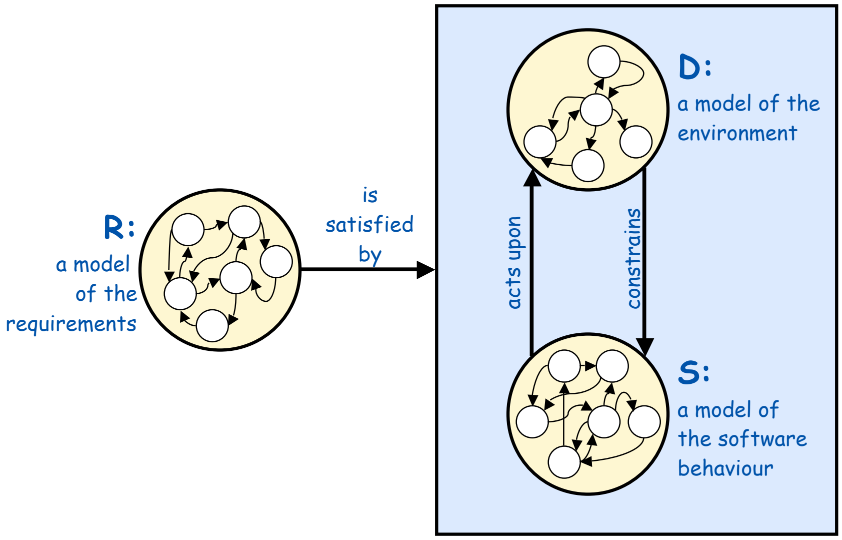
→ Validation:

- Animation of the model on small examples
- Formal challenges:
  - "if the model is correct then the following property should hold..."
- 'What if' questions:
  - reasoning about the consequences of particular requirements;
  - reasoning about the effect of possible changes
- State exploration
  - E.g. use a model checking to find traces that satisfy some property
- Checking application properties:
  - "will the system ever do the following..."

→ Verifying design refinement

- "does the design meet the requirements?"

Three different models??



R:
a model
of the
requirements

is
satisfied
by

D:
a model of the
environment

acts upon

constrains

S:
a model of
the software
behaviour

FM in practice

- From Shuttle Study [Crow & DiVito 1996]
  - More errors found in the process of formalizing the requirements than were found in the formal analysis
    - Formalization forces you to be precise and explicit, hence reveals problems
    - Formal analysis then finds fewer, but more subtle problems
  - Typical errors found include:
    - inconsistent interfaces
    - incorrect requirements (system does the wrong thing in response to an input)
    - clarity/maintainability problems

Issue Severity	*With FM*	*Existing*
High Major	2	0
Low Major	5	1
High Minor	17	3
Low Minor	6	0
Totals	30	4

How do FMs differ?

- **Mathematical Foundation**
  - Logic
    - first order predicate logic - e.g. RML
    - temporal logic - e.g. Albert II, SCR, KAOS
    - multi-valued logic – e.g. Xchek
  - Other
    - algebraic languages - e.g. Larch
    - set theory - e.g. Z
- **Ontology**
  - fixed
    - states, events, actions - e.g. SCR
    - entities, activities, assertions - e.g. RML
  - extensible
    - meta language for defining new concepts - e.g. Telos
- **Treatment of Time**
  - State/event models
    - time as a discrete sequence of events - e.g. SCR
    - time as quantified intervals - e.g. KAOS
  - Time as a first class object
    - meta-level class to represent time - e.g. Telos

Three traditions …

Formal Specification Languages

- Grew out of work on program verification
- Spawned many general purpose specification languages
  - Suitable for specifying the behaviour of program units
- Key technologies: Type checking, Theorem proving

Applicability to RE is poor
- No abstraction or structuring
- closely tied to program semantics

Examples: Larch, Z, VDM, …

Reactive System Modeling

- Grew out of a need to capture dynamic models of system behaviour
- Focus is on reactive systems (e.g. real-time, embedded control systems)
  - support reasoning about safety, liveness, performance(?)
  - provide a precise requirements specification language
- Key technologies: Consistency checking, Model checking

Applicability to RE is good
- modeling languages were developed specifically for RE

Examples: Statecharts, RSML, Parnas-tables, SCR, …

Formal Conceptual Modeling

- Grew out of a concern for capturing real-world knowledge in RE
- Focus is on modeling domain entities, activities, agents, assertions
  - provide a formal ontology for domain modeling
  - use first order predicate logic as the underlying formalism
- Key technologies: inference engines, default reasoning, KBS-shells

Applicability to RE is excellent
- modeling schemes capture key requirements concepts

Examples: Reqts Apprentice, RML, Telos, Albert II, …

(1) Formal *Specification* Languages

- Three basic flavours:
  - **Operational** - specification is executable abstraction of the implementation
    - good for rapid prototyping
    - e.g., Lisp, Prolog, Smalltalk
  - **State-based** - views a program as a (large) data structures whose state can be altered by procedure calls…
    - … using pre/post-conditions to specify the effect of procedures
    - e.g., VDM, Z
  - **Algebraic** - views a program as a set of abstract data structures with a set of operations…
    - … operations are defined declaratively by giving a set of axioms
    - e.g., Larch, CLEAR, OBJ
- Developed for specifying *programs*
  - Programs are formal, man-made objects
    - … and can be modeled precisely in terms of input-output behaviour
  - But in RE we're more concerned with:
    - real-world concepts, stakeholders, goals, loosely define problems, environments
  - So these languages are NOT appropriate for RE
    - but people fail to realise that requirements specification ≠ program specification

(2) Reactive System *Modeling*

- modeling how a system should behave
  - General approach:
    - Model the environment as a state machine
    - Model the system as a state machine
    - Model safety, liveness properties of the machine as temporal logic assertions
    - Check whether the properties hold of the system interacting with its environment
- Examples:
  - Statecharts
    - Harel's notation for modeling large systems
    - Adds parallelism, decomposition and conditional transitions to STDs
  - RSML
    - Heimdahl & Leveson's Requirements State Machine Language
    - Adds tabular specification of complex conditions to Statecharts
  - A7e approach
    - Major project led by Parnas to formalize A7e aircraft requirements spec
    - Uses tables to specify transition relations & outputs
  - SCR
    - Heitmeyer et. al. "Software Cost Reduction"
    - Extends the A7e approach to include dictionaries & support tables

(3) Formal Conceptual *Modeling*

→ General approach

- model the world beyond functional specifications
  - a specification is prescriptive, concentrating on desired properties of the machine
  - but we also need to capture an understanding of the application domain
  - hence build models of humans' knowledge/beliefs about the world
- make use of abstraction & refinement as structuring primitives

→ Examples:

- RML - Requirements Modeling Language
  - Developed by Greenspan & Mylopoulos in mid-1980s
  - First major attempt to use knowledge representation techniques in RE
  - Essentially an object oriented language, with classes for activities, entities and assertions
  - Uses First Order Predicate Language as an underlying reasoning engine
- Telos
  - Extends RML by creating a fully extensible ontology
  - meta-level classes define the ontology (the basic set is built in)
- Albert II
  - developed by Dubois & du Bois in the mid-1990s
  - Models a set of interacting **agents** that perform **actions** that change their **state**
  - uses an object-oriented real-time temporal logic for reasoning

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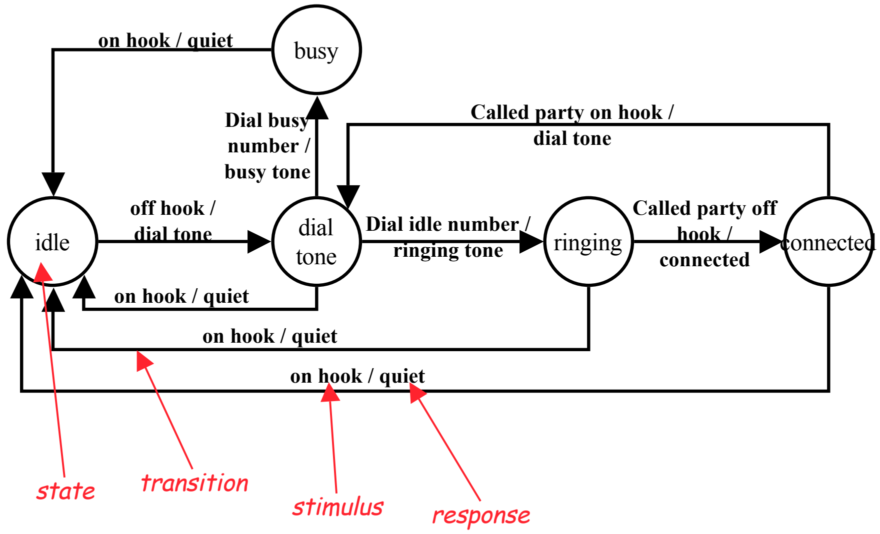
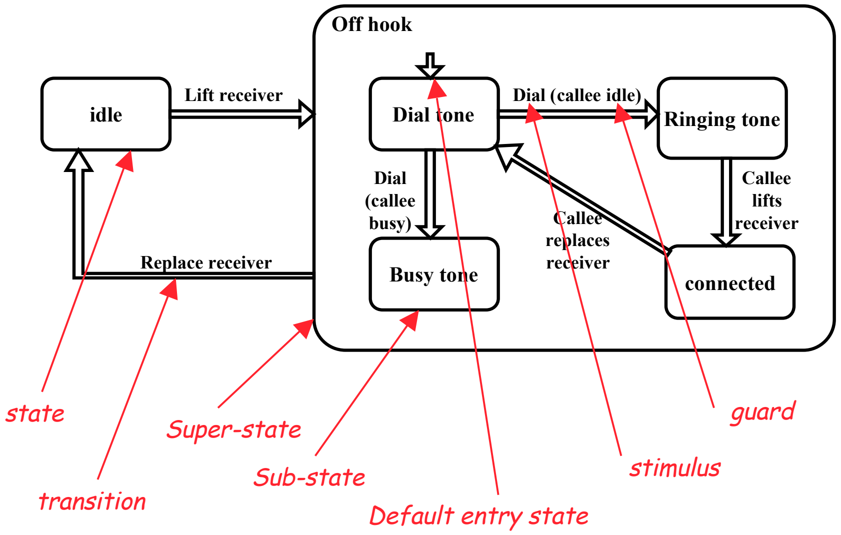
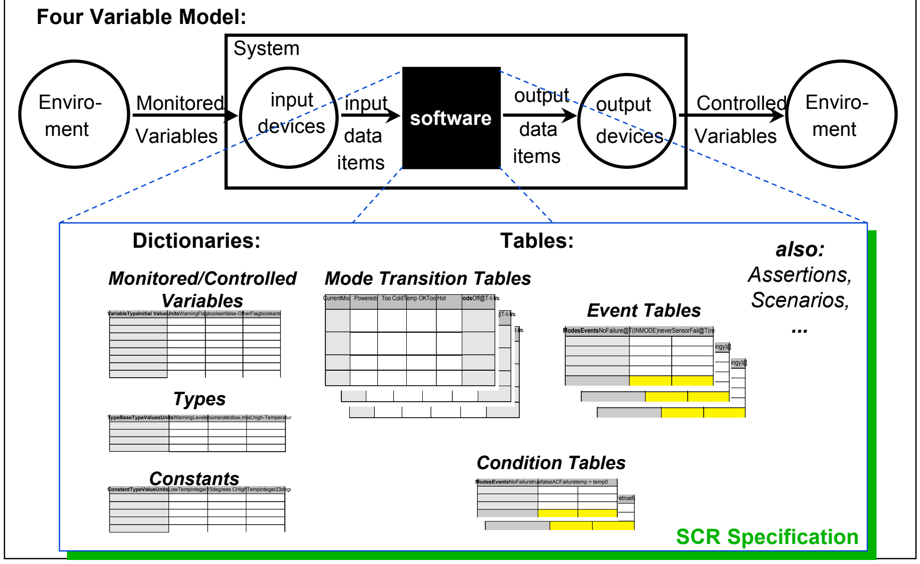
Example: State Transition Diagram



Example: Statecharts



Example: SCR



SCR basics

- Modes and Mode classes
  - A mode class is a finite state machine, with states called *system modes*
    - Transitions in each mode class are triggered by *events*
  - Complex systems are described using a number of mode classes operating in parallel
- System State
  - A (system) state is defined as:
    - the system is in exactly one mode from each mode class…
    - …and each variable has a unique value
- Events
  - An event occurs when any system entity changes value
    - An *input event* occurs when an *input* variable changes value
    - Single input assumption - only one input event can occur at once
    - Notation: **@T(c)** means "c changed from false to true"
  - A conditioned event is an event with a predicate
    - **@T(c) WHEN d** means: "c became true when c *was* false and d *was* true"

Source: *Adapted from Heitmeyer et. al. 1996.*

SCR Tables

- Mode Class Tables
  - Define the set of *modes* (states) that the software can be in.
  - A complex system will have many different modes classes
    - Each mode class has a mode table showing the conditions that cause transitions between modes
  - A mode table defines a *partial function* from modes and events to modes
- Event Tables
  - An event table defines how a term or controlled variable changes in response to input events
  - Defines a *partial function* from modes and events to variable values
- Condition Tables
  - A condition table defines the value of a term or controlled variable under every possible condition
  - Defines a *total function* from modes and conditions to variable values

Source: *Adapted from Heitmeyer et. al. 1996.*

Example: Temp Control System

Mode transition table:

Current Mode	Powered on	Too Cold	Temp OK	Too Hot	**New Mode**
Off	@T	-	t	-	**Inactive**
	@T	t	-	-	**Heat**
	@T	-	-	t	**AC**
Inactive	@F	-	-	-	**Off**
	-	@T	-	-	**Heat**
	-	-	-	@T	**AC**
Heat	@F	-	-	-	**Off**
	-	-	@T	-	**Inactive**
AC	@F	-	-	-	**Off**
	-	-	@T	-	**Inactive**

Source: *Adapted from Heitmeyer et. al. 1996.*

Failure modes

Mode transition table:

Current Mode	Powered on	Cold Heater	Too Cold	Warm AC	Too Hot	**New Mode**
NoFailure	t	@T	t	-	-	**HeatFailure**
	t	-	-	@T	t	**ACFailure**
HeatFailure	t	@F	t	-	-	**NoFailure**
ACFailure	t	-	-	@F	t	**NoFailure**

Event table:

Modes		
NoFailure	@T(INMODE)	never
ACFailure, HeatFailure	never	@T(INMODE)
Warning light =	**Off**	**On**

Source: *Adapted from Heitmeyer et. al. 1996.*

Consistency Checks in SCR

- Syntax
  - did we use the notation correctly?
- Type Checks
  - do we use each variable correctly?
- Disjointness
  - is there any overlap between rows of the mode tables?
    - ensures we have a deterministic state machine
- Coverage
  - does each condition table define a value for all possible conditions?
- Mode Reachability
  - is there any mode that cannot ever happen?
- Cycle Detection
  - have we defined any variable in terms of itself?

Using Formal Methods

- Selective use of Formal Methods
  - Amount of formality can vary
  - Need not build complete formal models
    - Apply to the most critical pieces
    - Apply where existing analysis techniques are weak
  - Need not formally analyze every system property
    - E.g. check safety properties only
  - Need not apply FM in every phase of development
    - E.g. use for modeling requirements, but don't formalize the system design
  - Can choose what level of abstraction (amount of detail) to model
- Lightweight Formal Methods
  - Have become popular as a means of getting the technology transferred
  - Two approaches
    - Lightweight *use of* FMs - selectively apply FMs for partial modeling
    - *Lightweight FMs* - new methods that allow unevaluated predicates