CSE584: Software Engineering

Lecture 3: Requirements & Specification (B)

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Last week & this week

- Last week
  - Overview
  - Program correctness
  - Model-based specifications (Z)
  - Intro to state machines
- This week
  - Analysis of state machine based specifications (model checking)
  - Michael Jackson on video: "The World and the Machine"
  - Some wrap up

Before that…

- Last week I was at a workshop on highly dependable computing systems
  - At NASA Ames Research Center
- Academia, government, industry
  - IBM, Sun, Oracle, Sybase, Microsoft, Boeing, Honeywell, …
- Keynotes, case studies, breakout sessions, etc.
- Dependability is different things to different people
- Over all, I think that there were two camps
  - Use technology to improve dependability
  - Build a "culture of dependability"

Two NASA failures: each over $100 million

http://www.nasa.gov/newsinfo/marsreports.html

- Mars Climate Orbiter
  - A confusion in metric/English units caused an engine to fire too strongly, bringing the spacecraft too close to Mars and causing it to crash instead of orbiting
- Polar lander (very probable cause)
  - At 40m above Mars, a parachute and spring-loaded legs were deployed and a new control regime was used as planned
  - The spring-loaded legs bounced, causing the regime to think that the pads had hit the surface
  - The engine was turned off and the spacecraft crashed

Specification errors?

- Not the units
  - The specification was completely clear about this
  - A new programmer didn't know or check, and used the wrong units
  - Not caught by testing, inspections, etc.
    - Tricky to catch by testing, since it was a second order effect
  - What can be done about errors like these?
- Polar lander? Unclear
  - Each module (regime) worked as specified
  - The < 40m module assumed that a variable would be in a particular state upon entry, but it wasn't due to the leg bounce
  - What this a problem in the inter-module specification? In the implementation of the <40m module? Testing? Something else?

Specifications thread

- I found it interesting to come back from this workshop and see the thread on the mailing list about "spec avoidance"
- Specs would surely help solve some — perhaps many — of your problems
  - But not all
  - And the cost is not clear
  - I'll note that most of you wanted specs, but didn't necessarily want the responsibility of writing them
- See the paper that Cordell Green mentioned, which I posted on the mailing list

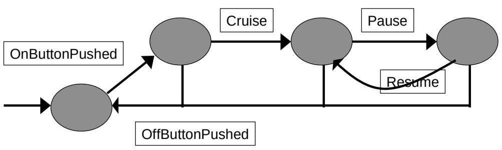
State machines

- Good for specifying reactive systems, protocols, etc.
- Event-driven
  – External events (actions in the external environment, such as “button pushed”, “door opened”, “nuclear core above safe temperature”, etc.)
  – Internal events (actions defined in the internal system to cause needed actions)
  – Can generate external events that may drive actuators in the environment (valves may be opened, alarms may be rung, etc.)
  – Transitions can have guards and conditions that control whether or not they are taken
- “Flat” (non-hierarchical) state machines tend to explode in size relatively quickly

Classic examples

- Specifying a cruise control
- Specifying the traffic lights at an intersection
- Specifying trains on shared tracks
  – Could be managing the bus tunnel in Seattle
- Etc.

A snippet of cruise control



- Completely incomplete
  - There should be guards and conditions on transitions
  - Lots of information left out

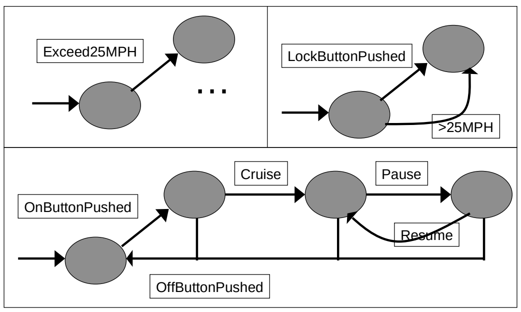
More cruise control

- What if your state machine also tracked speed?
  – Maybe the cruise control doesn't work at low speeds
  – Anyway, it needs to remember a speed so it can resume properly
- What if it also interacted with the door locking system?
- You might have to modify almost every state to track not only the state on the previous slide, but the speed, too
  – Essentially, you need to build a cross product of all combinations of states
- This is the kind of issue that can cause the machine to blowup in size
  – It's not the best example, but it's adequate

Statecharts: “review”

- The idea of statecharts [Harel] is to provide a rich, visual representation for defining finite state machines that capture the essence of complex, reactive systems
  – Specifically addresses description explosion problem
- Sorry, there isn't a simple, easy-to-get, reference
  – “The” statecharts paper, but long and a bit hard to find. D. Harel, "Statecharts: A Visual Formalism for Complex Systems, " *Science of Computer Programming* (1987).
  – A general paper on statechart-like formalisms: D. Harel. "On Visual Formalisms," *Comm. of the ACM* (1988).
- The i-Logix web site (http://www.ilogix.com/fs_papers.htm) has a set of papers, (you have to register your name, but it looks like it doesn't check anything)
  – The following looks reasonable at a glance: B.P. Douglass. State Machines and Statecharts: A White Paper. Embedded Systems Conference West (1999).

Key idea: hierarchy



Parallel AND-machines

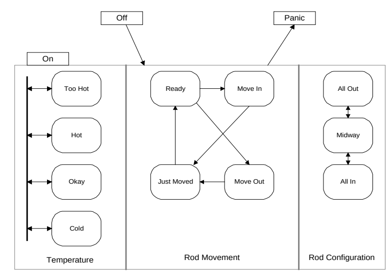
- The state of the overall machine is represented by one state from each of the parallel AND machines
  - In a cruise control state AND in a speed state AND in a door lock state
- Transitions can take place in all substates in parallel
  - Events in one substate can cause transitions in another substate

A few statechart features

- Default entry states for each substate
  - Indicated by an arrow with no initial state
- When any of the parallel machines is exited, the entire machine is exited
- You can have “history” states, which remember where you were the last time you were in a machine
- The “STATEMATE semantics” are the standard semantics
  - This is largely a question of which enabled transitions are taken, and when
  - At this level, you surely don’t care

Variants on statecharts

- There are many variants on statecharts
- One is RSML (Leveson et al.), which allows states to be connected through a bus as well as pairwise
- RSML also represents transitions differently, through explicit AND-OR tables instead of through guards and conditions on transitions



Events

Temp_Reading	External	Temperature
Initiate_Move	Rod_Move	Rod_Config
Move_Finished	External	Rod_Config
Rod_Updated	Rod_Config	Rod_Move
Clock_Event	External	Rod_Move
Temp_Update	Temperature	Rod_Move

Sample transitions

On → Panic

```
Trigger_Event: Temp_Update
Condition: Temperature in Too Hot
Output Action: Panic_Event
```

Ready → Move In

```
Trigger_Event: Temp_Update
Condition: Rod_Movement in Ready and Temperature in Hot
Output Action: Initiate_Move
```

Just Moved → Ready

```
Trigger_Event: Clock_Event
Condition: Rod_Movement in Just_Moved and
           t > t(entered(Just_Moved))+ Move_Delay
```

Leap of faith

- Statecharts (and variants) can be used to specify important, complex systems

Question

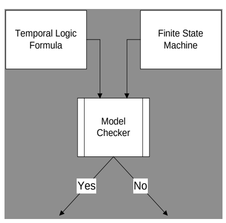
- So we have a big statecharts-like specification
- How do we know it has properties we want it to have?
  - Ex: is it deterministic?
  - Ex: can you ever have the doors unlock by themselves while the car is moving?
  - Ex: can you ever cause an emergency descent when you are under 500 feet above ground level?

Standard answers include

- Human inspection
- Simulation
- Analysis

An alternative: model checking

- Evaluate temporal properties of finite state systems
  - Guarantee a property is true or return a counterexample
  - Ex: Is it true that we can never enter an error state?
  - Ex: Are we able to handle a reset from any state?
- Extremely successfully for hardware verification
  - Intel got into the game after the FDIV error
- Open question: applicable to software specifications?

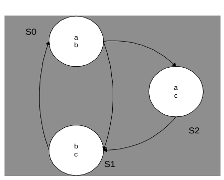


State Transition Graph

- One way to represent a finite state machine is as a state transition graph
  - S is a finite set of states
  - R is a binary relation that defines the possible transitions between states in S
  - P is a function that assigns atomic propositions to each state in S
    - e.g., that a specific process holds a lock
- Other representations include regular expressions, etc.

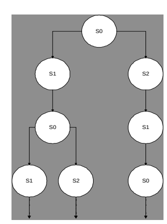
Example

- Three states
- Transitions as shown
- Atomic properties a, b and c
- Given a start state, you can consider legal paths through the state machine



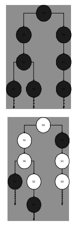
A computation tree

- From a given start state, you can represent all possible paths with an infinite computation tree
- Model checking allows us to answer questions about this tree structure



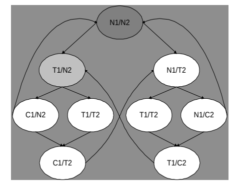
Temporal formulae

- Temporal logics allow us to say things like
  - Does some property hold true globally?
    - Top figure
  - Does some property inevitably hold true?
    - Bottom figure
  - Does some property potentially hold true?



Mutual exclusion example

- N1 & N2, non-critical regions of Process 1 and 2
- T1 & T2, trying regions
- C1 and C2, critical regions
- AF(C1) in lightly shaded state?
  - C1 always inevitably true?
- EF(C1 $\wedge$ C2) in dark shaded state?
  - C1 and C2 eventually true?



How does model checking work? (*in brief!*)

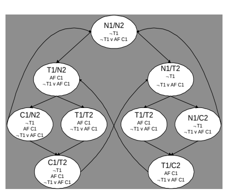
- An iterative algorithm that labels states in the transition graph with formulae known to be true
- For a query Q
  - the first iteration marks all subformulae of Q of length 1
  - the second iteration marks them of length 2
  - this terminates since the formula is finite
- The details of the logic indeed matter
  - But not at this level of description

Example

- Q = T1 $\Rightarrow$ AF C1
  - If Process 1 is trying to acquire the mutex, then it is inevitably true it will get it sometime
- Q = $\neg$T1 $\vee$ AF C1
  - Rewriting with DeMorgan's Laws
- First, label all the states where T1, $\neg$T1, and C1 are true
  - These are atomic properties

Example

- Next mark all the states in which AF C1 is true, etc.
  - The algorithm tracks states visited using depth-first search
  - Slight variations for AF, AG, EF, EG, etc.
- At termination, $\neg$T1 $\vee$ AF C1 is true everywhere
  - Hence the temporal property is true for the state machine

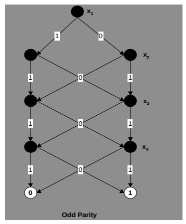


Symbolic model checking

- State space can be huge ($>2^{1000}$) for many systems
- Key idea: use implicit representation of state space
  - Data structure to represent transition relation as a boolean formula
- Algorithmically manipulate the data structure to explore the state space
- Key: efficiency of the data structure

Binary decision diagrams (BDDs)

- "Folded decision tree"
- Fixed variable order
- Many functions have small BDDs
  - Multiplication is a notable exception
- Can represent
  - State machines (transition functions) *and*
  - Temporal queries



Due to Randy Bryant

BDD-based model checking

- Iterative, fixed-point algorithms that are quite similar to those in explicit model checking
- Applying boolean functions to BDDs is efficient, which makes the underlying algorithms efficient
  - $\wedge$ becomes set intersection, $\vee$ becomes set union, etc.
- When the BDDs remain small, that is
  - Variable ordering is a key issue

BDD-based successes in HW

- IEEE Futurebus+ cache coherence protocol
- Control protocol for Philips stereo components
- ISDN User Part Protocol
- ...

Software model checking

- Finite state software specifications
  - Reactive systems (avionics, automotive, etc.)
  - Hierarchical state machine specifications
- Not intended to help with proving consistency of specification and implementation
  - Rather, checking properties of the specification itself

Why might it fail?

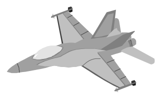
- Software is often specified with infinite state descriptions
- Software specifications may be structured differently from hardware specifications
  - Hierarchy
  - Representations and algorithms for model checking may not scale

Our approach at UW—try it!

- Applied model checking to the specification of TCAS II
  - Traffic Alert and Collision Avoidance System
    - In use on U.S. commercial aircraft
    - http://www.faa.gov/and/and600/and620/newtcas.htm
  - FAA adopted specification
  - Initial design and development by Leveson et al.
- Later applied it to a statecharts description of an electrical power distribution system model of the B777
  - I can provide examples and papers

TCAS

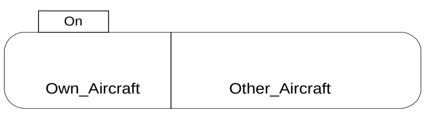
- Warn pilots of traffic
  - Plane to plane, not through ground controller
  - On essentially all commercial aircraft
- Issue resolution advisories only
  - Vertical resolution only
  - Relies on transponder data



TCAS specification

- Irvine Safety Group (Leveson et al.)
  - Specified in RSML as a research project
    - RSML is in the Statecharts family of hierarchical state machine description languages
  - FAA adopted RSML version as official
- Specification is about 400 pages long
- This study uses: Version 6.00, March 1993
  - Not the current FAA version

TCAS—high-level structure



Own_Aircraft

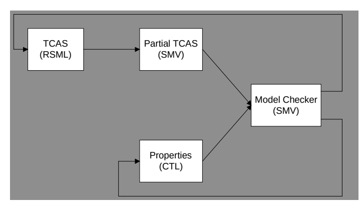
Sensitivity levels, Alt_Layer, Advisory_Status

Other_Aircraft

Tracked, Intruder_State, Range_Test, Crossing, Sense Descend/Climb

Using SMV

- SMV is a BDD-based model checker
- It checks CTL formulas
  - A specific temporal logic



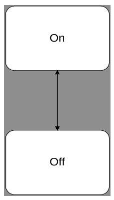
Iterative process

- Iterate SMV version of specification
- Clarify and refine temporal formula
- Model environment more precisely
- Refine specification

Use of non-determinism

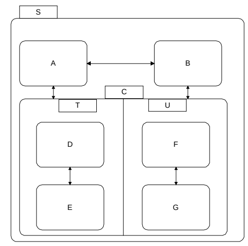
- Inputs from environment
  - `Altitude := {1000…8000}`
- Simplification of functions
  - `Alt_Rate := 0.25*(Alt_Baro-ZP)/Delta_t`
  - `Alt_Rate := {-2000…2000}`
- Unmodelled parts of specification
  - States of `Other_Aircraft` treated as non-deterministic input variables

Translating RSML to SMV




```
MODULE main
VAR
   state:{ON,OFF};
   on_event: boolean;
   off_event: boolean;
ASSIGN
   init(state) := OFF;
   next(state) := case
      state = ON &
          off_event: OFF;
      state = OFF &
          on_event: ON;
      1 : state;
   esac;
```

State encoding



- **Flatten nested AND and nested OR states**
- **One variable for each OR state**
  - **An enumerated type of the alternatives**

```
VAR
       S: {A,B,C};
       T: {D,E};
       U: {F,G};
```

Events

- **External—interactions with environment**
- **Internal—micro steps**
- **Synchrony hypothesis**
  - **External event arrives**
  - **Triggers cascade of internal events (micro steps)**
  - **Stability reached before next external event**
- **Technical issues with micro steps**

Non-deterministic transitions

- **A machine is deterministic if at most one of `T_A_B`, `T_A_C`, etc. can be true**
  - **`T_A_B` represents the conditions under which a transition is taken from state `A` to state `B`**
  - **Else non-deterministic**

Checking properties

- **Initial attempts to check any property generated BDDs of over 200MB**
- **First successful check took 13 hours**
  - **Was reduced to a few minutes**
- **Partitioned BDDs**
- **Reordered variables**
- **Implemented better search for counterexamples**

Property checking

- **Domain independent properties**
  - **Deterministic state transitions**
  - **Function consistency**
- **Domain dependent**
  - **Output agreement**
  - **Safety properties**
- **We used SMV to investigate some of these properties on TCAS' `Own_Aircraft` module**

Disclaimer

The intent of this work was to evaluate symbolic model checking of state-based specifications, not to evaluate the TCAS II specification. Our study used a preliminary version of the specification, version 6.00, dated March, 1993. We did not have access to later versions, so we do not know if the issues identified here are present in later versions.

Deterministic transitions

- **Do the same conditions allow for non-deterministic transitions?**
- **Inconsistencies were found earlier by other methods [Heimdahl and Leveson]**
  - **Identical conditions allowed transitions from Sensitivity Level 4 to SL 2 or to SL 5**
- **Our formulae checked for all possible non-determinism; we found this case, too**

Note: Earlier version of TCAS spec

```
V_254a := MS = TA_RA | MS = TA_only | MS =3 | MS = 4 |
          MS = 5 | MS = 6 | MS = 7;
V_254b := ASL = 2 | ASL = 3 | ASL = 4 | ASL = 5 |
          ASL = 6 | ASL = 7;
T_254  := (ASL = 2 & V_254a) | (ASL = 2 & MS = TA_only) |
          (V_254b & LG = 2 & V524a);
V_257a := LG = 5 | LG = 6 | LG = 7 | LG = none;
V_257b := MS = TA_RA | MS = 5 || MS = 6 | MS = 7;
V_257c := MS = TA_RA | MS = TA_only | MS = 3 | MS = 4 |
          MS = 5 | MS = 6 | MS = 7;
V_257d := ASL = 5 | ASL = 6 | ASL = 7;
T_257  := (ASL = 5 | V_257a | V_257b) |
          (ASL = 5 & MS = TA_only) |
          (ASL = 5& LG = 2 & V_257c) |
          (V_257d & LG = 5 & V_257b) |
          (V_257d & V_257a & MS = 5);
```

Function consistency

- **Many functions are defined in terms of cases**
- **A function is inconsistent if two different conditions C_i and C_j and be true simultaneously**

$$F = \begin{cases} V_1 \text{ if } C_1 \\ V_2 \text{ if } C_2 \\ V_3 \text{ if } C_3 \end{cases}$$

```
AG !((C1 & C2) |
     (C1 & C2) |
     (C2 & C3))
```

Displayed_Model_Goal =

0	**if** Composite_RA **not in state** Positive
Max(Own_Track_Alt_Rate, PREV(Displayed_Model_Goal), 1500 ft/min)	**if** (New_Climb **or** New_Threat) **and** **not** New_Increase_Climb **and** **not** (Increase_Climb_Cancelled **or** Increase_Descend_Cancelled) **and** Composite_RA **in state** Climb
Min(Own_Track_Alt_Rate, PREV(Displayed_Model_Goal), −1500 ft/min)	**if** (New_Descend **or** New_Threat) **and** **not** New_Increase_Descend **and** **not** (Increase_Climb_Cancelled **or** Increase_Descend_Cancelled) **and** Composite_RA **in state** Descend
2500 ft/min	**if** New_Increase_Climb
−2500 ft/min	**if** New_Increase_Descend
Max(Own_Track_Alt_Rate, 1500 ft/min)	**if** Increase_Climb_Cancelled **and** **not** New_Increase_Climb **and** Composite_RA **in state** Positive
Min(Own_Track_Alt_Rate, −1500 ft/min)	**if** Increase_Descend_Cancelled **and** **not** New_Increase_Descend **and** Composite_RA **in state** Positive
PREV(Displayed_Model_Goal)	Otherwise

Display_Model_Goal

- **Tells pilot desired rate of altitude change**
- **Checking for consistency gave a counterexample**
  - `Other_Aircraft` **reverse from an** `Increase-Climb` **to an** `Increase-Descend` **advisory**
  - **After study, this is only permitted in our non-deterministic modeling of** `Other_Aircraft`
  - **Modeling a piece of** `Other_Aircraft`**'s logic precludes this counterexample**

Output agreement

- Related outputs should be consistent
  - Resolution advisory
    - `Increase-Climb, Climb, Descend, Increase-Descend`
  - `Display_Model_Goal`
    - Desired rate of altitude change
    - Between -3000 ft/min and 3000 ft/min
  - Presumably, on a climb advisory, `Display_Model_Goal` should be positive

Output agreement check

- `AG (RA = Climb -> DMG > 0)`
  - If Resolution Advisory is `Climb`, then `Display_Model_Goal` is positive
- Counterexample was found
  - t_0 `: RA = Descend, DMG = -1500`
  - t_1 `: RA = Increase-Descend, DMG = -2500`
  - t_2 `: RA = Climb, DMG = -1500`

Limitations

- Can't model all of TCAS
  - Pushing limits of SMV (more than 200 bit variables is problematic)
  - Need some non-linear arithmetic to model parts of `Other_Aircraft`
    - New result that represents constraints as BDD variables and uses a constraint solver
- How to pick appropriate formulae to check?

Whence formulae?

"There have been two pilot reports received which indicated that TCAS had issued Descend RA's at approximately 500 feet AGL even though TCAS is designed to inhibit Descent RAs at 1,000 feet AGL. All available data from these encounters are being reviewed to determine the reason for these RAs." –TCAS web

Whence formulae?

- Jaffe, Leveson et al. developed criteria that specifications of embedded real-time systems should satisfy, including:
  - All information from sensors should be used
  - Behavior before startup, after shutdown and during off-line processing should be specified
  - Every state must have a transition defined for every possible input (including timeouts)
    - Predicates on the transitions must yield deterministic behavior
- Essentially a check-list, but a very useful one

What about infinite state?

- Model checking does not apply to infinite state specifications
  - The iterative algorithm will not reach a fixpoint
- Theorem proving applies well to infinite state specifications, but has generally proved to be unsatisfactory in practice
- One approach is to abstract infinite state specifications into finite state ones
  - Doing this while preserving properties is hard
- D. Jackson et al.'s Nitpick approach
  - Find counterexamples (errors), but don't "prove" anything

Model checking wrap up

- The goal of model checking is to allow finite state descriptions to be analyzed and shown to have particular desirable properties
  - Won't help when you don't want or need finite state descriptions
  - Definitely added value when you do, but it's not turnkey yet
    - There's still a real art in managing model checking
  - Definitely feasible on modest sized systems

I know this was quick

- My goal isn't to make you into model checking experts
  - But it might titillate one or two of you to learn more
- But rather to understand the sketches of what model checking is and why it is so promising for checking some classes of specifications

It's show time!

- Michael Jackson's keynote address at the 17th International Conference on Software Engineering (ICSE 17)
  - 1000 researchers, educators, and practitioners
  - Other keynoters: Fred Brooks, Michael Cusamano
- Discussion on the mailing list…

The World

and

The Machine

Michael Jackson

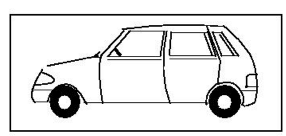
MAJ Consulting Ltd and AT&T Bell Laboratories
ICSE-17 Seattle 28th April 1995

Ways of Looking at Software

- 'Programming should be *literate*'
- ' … they regarded my programs as *logical poems* …'
- 'The goal of any system is *organisational change*'
- 'Software development is *engineering*'
  - Because we make *machines* to serve useful purposes in the *world*
    - The *problem* is in the World
    - The Machine is the *solution*

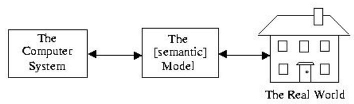
WHAT and HOW

- WHAT does an automobile do?



  - It carries *people* and their *baggage*, travelling over *roads* where its *driver* directs it to go
- WHAT is in the *world*, HOW is in the *machine*

The Machine, the Model, and the World



- *Formal Methods* concern the *left* arrow
- We have no theory for the *right* arrow

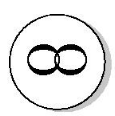
Brian Cantwell Smith; *The Limits of Correctness*

Talking about the World and the Machine

- To develop software we must talk both about the World and about the Machine
- But it's hard to maintain the right balance between these two universes of discourse
  - The relationship between them is varied and often subtle
  - Often we have personal preferences to exploit or resist

Three Topics and a Button

- 4 Facets of the Relationship
- 4 Kinds of Denial of the World
- 4 Principles for Accepting the World
- a Button:



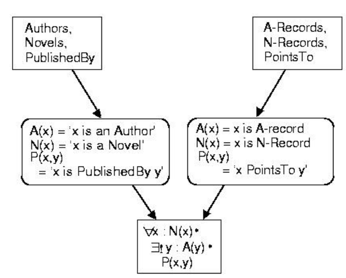
4 Facets of the Relationship

- Modelling:
  the Machine as a *model* of the World
- Interface:
  what the Machine *shares* with the World
- Engineering:
  how the Machine *changes* the World
- Problem:
  the *structure* the Machine must have to fit the problem in the World

Modelling a Reality

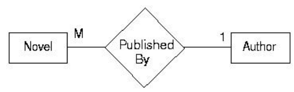
- 'An SADT system *description* is called a "model" ...'
- R L Ackoff (*Scientific Method,* 1962):
  - *Iconic* models — pictures, 3-D representations, eg a child's model farm
  - *Analytic* models — manipulable formal descriptions, eg differential equations forming an economic model
  - *Analogic* models — an analogous reality, eg an electrical network modelling the flow of water in pipes
- Software models are analogic: eg, a database, an assemblage of objects, a process network

The Machine As a Model of the World

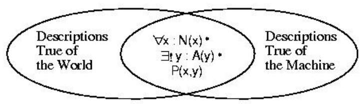


Modelling and OO

- A data model fragment:

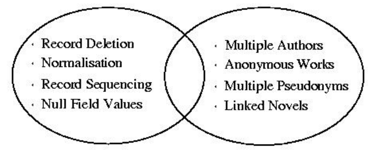


- Three sets of descriptions:



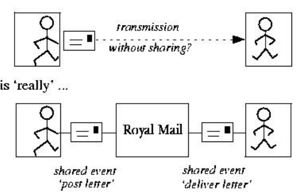
Non-Modelling and OO

- Both the World and the Machine have properties that are private and not shared

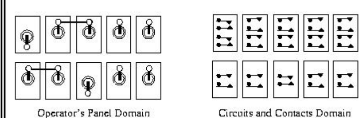


The Machine – World Interface

- Shared phenomena: *events*, other *shared individuals*, *facts* visible in both domains
- No communication without sharing:



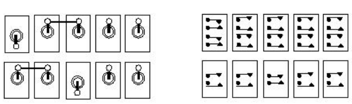
Shared Phenomena



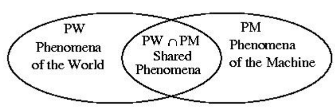
- Shared phenomena:
  - Levers ——— Switches
  - FlipUp events ——— TurnOff events
  - FlipDown events ——— TurnOn events
- Private phenomena:

• Links	• Contacts
• LinkedBy (x:Lever, y:Link)	• LocatedOn (x:Contact, y:Switch)

Shared Phenomena and OO



- The shared phenomena are in the (small) intersection between two sets of phenomena:



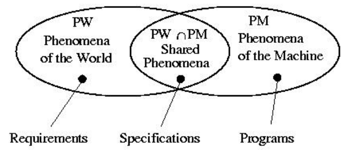
Modelling and Shared Phenomena

- *Sharing phenomena* and *modelling* are different relationships between the Machine and the World
  - Shared phenomena → modelling
    - Any description that is true of the shared phenomena is a shared descriptions
  - But ...
  - ... ¬ (modelling → shared phenomena)
    - The database shares no phenomena with the reality it models

Engineering: Requirements, Specifications, and Programs

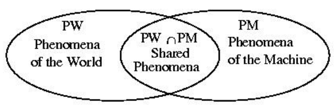
- The purpose of the Machine is to *change* the World: this is the *requirement*
- The required changes are expressible entirely in terms of phenomena of the World ...
- ... but not usually entirely in terms of phenomena shared with the Machine
- The final engineering product:
  - Machine behaving according to the *program* ...
  - ... thus satisfying the *specification* and ...
  - ... thus ensuring achievement of the *requirement*

Requirements, Specifications, Programs



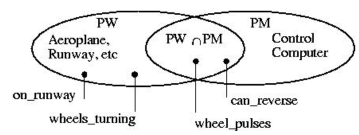
- A specification is also a requirement
- A specification is also a program

Engineering and OO



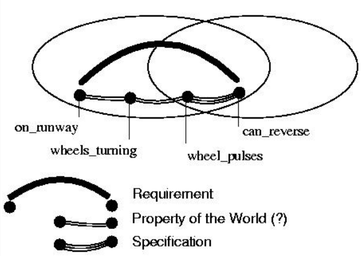
- Programs can satisfy specifications only by virtue of *properties of the machine* (p/l semantics)
- Specifications can satisfy requirements only by virtue of *properties of the world*
- The engineering is in determining, describing and exploiting the properties of the world

A Little Engineering Example



- *R*: on_runway $\leftrightarrow$ can_reverse
- *D1*: wheel_pulses $\leftrightarrow$ wheels_turning
  D2: wheels_turning $\leftrightarrow$ on_runway
- *S*: can_reverse $\leftrightarrow$ wheel_pulses
- We have: S, D1, D2 $\vdash$ R — is it enough?

Properties of the World



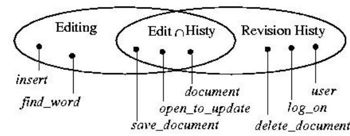
The Problem Facet of the Relationship

- Solution structure should reflect problem structure
  - There's less need for invention
  - It's easier to validate the solution
- Traditional solution structures are often *hierarchical* and *homogeneous* ...
  - Procedure hierarchies, class hierarchies, layered abstract machines, process/dataflow structures
- ... but the World rarely exhibits such structures

A Simple Editing Tool

- Three requirements:
  - *Editing* allows users to create and edit texts
  - *GUI* provides convenient and efficient operation
  - *Revision History* provides progress reporting by users and texts
- The requirements are related by conjunction:
  - *Editing* $\wedge$ *GUI* $\wedge$ *Revision History*
- The requirements *share phenomena*

Two Requirements Sharing Phenomena



Problem Structures

- Problems are usually structured as subproblems that are:
  - heterogeneous
  - related by superimposition
  - pinned together at shared phenomena
- The appropriate metaphor is ...
  - ... not assemblies and sub-assemblies
  - ... but CYMK separations in colour printing

The World and Us (1)

"The world is too much with us ..."
— *William Wordsworth*

4 Kinds of Denial

- How we may deny our involvement
  - Denial by Prior Knowledge
  - Denial by Hacking
  - Denial by Abstraction
  - Denial by Vagueness

Denial by Prior Knowledge

"We don't need a requirements capture phase. The problem is already well-defined; our task is merely to solve it."

- Automobile designers don't have a requirements capture phase ...
  - The car shall be able to travel over snowdrifts and under water
  - The car shall be able to lift a load of 5 tons
  - The car shall accommodate 10 passengers each of weight up to 500 pounds
- ... it would be called 'Rethinking the Motor-car'

Denial by Prior Knowledge

- Legitimate only in applications that are both *specialised* and *standardised*
- Both bridge-design and automobile design are *specialised*
- But only automobile design is *standardised* (human beings, roads and baggage don't vary much)
- Bridge design is not *standardised* (each location has unique characteristics)

Denial by Hacking

- Computers are beautiful and fascinating

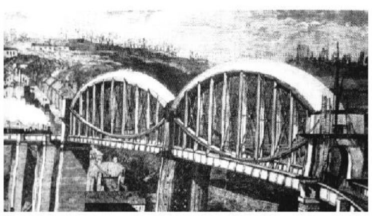
" ... Miss Byron, young as she was, understood its working and saw the great beauty of the invention."
Mrs De Morgan, on Ada's visit to Babbage, 1828

- Applications are often much less interesting

"I came into this job to work with computers, not to be an amateur stockbroker."
Member of failed development team, 1993

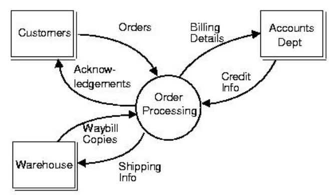
- The Machine is the developers' own creation; the World is not

The Royal Albert Bridge, Saltash



I K Brunel, Engineer, 1849

Looking at the Problem Context



- Which is the World? Which is the Machine?
- Which do you describe at the next level of DFDs?

Denial by Abstraction

"We come now to the decisive step of mathematical abstraction: we forget what the symbols stand for."
Hermann Weyl, quoted by Abelson & Sussman

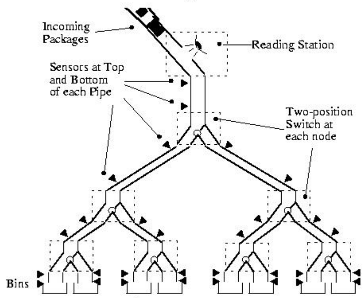
- Abstraction is a valuable intellectual tool ...
- ... but it must not be a rule of life for software developers
- Too much abstraction blinds you to the nature of many problems

Doing Justice to the Problem

"One tribe always tells the truth and the other always lies. A traveller meets two men, and asks the first: 'Are you a truth teller?'. The reply is 'Goom'. The second says: 'He said Yes, but he is lying'.
Martin Gardener, 2nd Book of Puzzles

- Abstract answer:
  "The reply must always be Yes; so the second man is a truth-teller, and the first is a liar"
- *Lucy Jonelis*' answer:
  "The first man clearly can't speak English: 'Goom' must mean 'What?' or 'Welcome to our land'. So the second man is a liar, and the first is a truth-teller."

The Package Router



Denial by Vagueness

- Central technique:
  - Describe the Machine, but imply that you're describing the World
- Prerequisite:
  - Avoid saying explicitly what is being described
- Facilitators:
  - The modelling relationship (the same description is true of both)
  - The shared phenomena at the interface (two sides of the same penny, isn't it?)

The System and the Real World

" ... the Z approach is to construct a specification document which consists of a judicious mix of informal prose with precise mathematical statements. ... the informal text can be consulted to find out what aspects of the *real world* are being described.... The formal text in the other hand provides the precise definition of the *system* and hence can be used to resolve any ambiguities present in the informal text."

- Machine = *system*? World = *real world*?
- Which is being described?

Talking About the World: 4 Principles

von Neumann's principle

- *Knowing what you're talking about*

The principle of reductionism

- *Finding the solid ground*

The Shanley principle

- *Recognising versatility*

Montaigne's principle

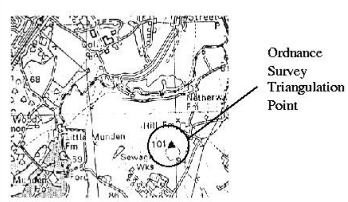
- *Minding your language*

von Neumann's Principle

"There is no point in using exact methods where there is no clarity in the concepts and issues to which they are to be applied."
von Neumann & Morganstern: Theory of Games

- Designations
  - Mother(x,y) ≈ 'x is the genetic mother of y'
  - Formal term ≈ recognition rule
  - Anticipate interventions of the form: "It all depends on what you mean by *mother*"

Aligning a Description

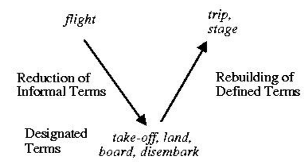


- Designated terms and phenomena are like triangulation points on the map and on the ground

The Principle of Reductionism

- In any informal world many terms — often nouns in English — are obviously important …
  - in telephony: *calls*
  - in a meeting-scheduling system: *meetings*
  - in an airline system: *flights*
- … but difficult or even impossible to designate
- They must be reduced to elementary designated phenomena — often *events*

Reducing Domain Concepts



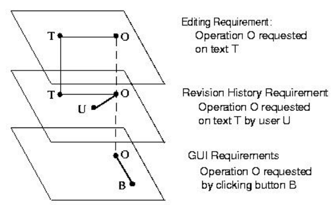
- The rebuilt defined terms are not the original informal terms
- Definition is not designation

The Shanley Principle

"In civil engineering design it is presently a mandatory concept known as the Shanley Design Criterion to collect several functions into one part."
Pierre Arnoul de Marneffe, cited by D Knuth, 1974

  - 1940-1945 rockets had separate components for fuel tank, outer skin, body frame
  - Saturn-B had a tubular body that was at once its fuel tank, outer skin, and body frame
- It may (or may not) be good to engineer Machines in this way, but the World is certainly like this!
  - No class hierarchy, no strong typing!

Shanley and Many Descriptions



- One description is not enough

Montaigne's Principle

"The greater part of this world's troubles are due to questions of grammar."

- Demanded for some Government contracts:

  "Absolute tense 'shall': a binding, measurable requirement ….
  "Future tense 'will': a reference to the future, … not under control of the system being specified.
  "Present tense: for all other verbs …."
- The distinction is not of *tenses*, but of *moods*
  - Optative: *desired* in the World
  - Indicative: true *regardless* of the Machine

Indicative and Optative

- Natural language distinctions are impractical:
  - "I shall drown, no-one will save me!"
  - "I will drown, no-one shall save me!"
- Mood of a sentence in development changes with its context:
  - In handling the *Revision History* requirement, the *Editing* requirement should be treated as satisfied — not optative but indicative
- So indicative and optative sentences should be kept apart in separate descriptions

Three Topics and a Button

- 4 Facets of the Relationship
  - The Machine as a *model* of the World
  - The interface of *shared phenomena*
  - *Engineering* the World and the Machine
  - Problem and solution *structures*
- 4 Kinds of Denial of the World
- 4 Principles for Accepting the World

The World and Us (2)

"I accept the universe"
— *Margaret Fuller*

"By Gad! she'd better!"
— *Thomas Carlyle*

Good night

- Hope you enjoyed your night at the movies with Michael Jackson
- Let's leave discussion to the mailing list