Lecture 19: Verification and Validation

- **Some Refreshers:**
  - Summary of Modelling Techniques seen so far
  - Recap on definitions for V&V
- **Validation Techniques**
  - Inspection (see lecture 6)
  - Model Checking (see lecture 16)
  - Prototyping
- **Verification Techniques**
  - Consistency Checking
  - Making Specifications Traceable (see lecture 21)
- **Independent V&V**

The story so far

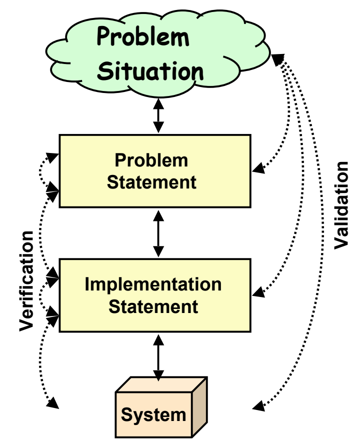
- **We've looked at the following UML diagrams:**
  - Activity diagrams
    - capture business processes involving concurrency and synchronization
    - good for analyzing dependencies between tasks
  - Class Diagrams
    - capture the structure of the information used by the system
    - good for analysing the relationships between data items used by the system
    - good for helping you identify a modular structure for the system
  - Statecharts
    - capture all possible responses of an object to all uses cases in which it is involved
    - good for modeling the dynamic behavior of a class of objects
    - good for analyzing event ordering, reachability, deadlock, etc.
  - Use Cases
    - capture the view of the system from the view of its users
    - good starting point for specification of functionality
    - good visual overview of the main functional requirements
  - Sequence Diagrams (collaboration diagrams are similar)
    - capture an individual scenario (one path through a use case)
    - good for modelling dialog structure for a user interface or a business process
    - good for identifying which objects (classes) participate in each use case
    - helps you check that you identified all the necessary classes and operations

The story so far (part 2)

- **We've looked at the following non-UML diagrams**
  - Goal Models
    - Capture strategic goals of stakeholders
    - Good for exploring 'how' and 'why' questions with stakeholders
    - Good for analysing trade-offs, especially over design choices
  - Fault Tree Models (as an example risk analysis technique)
    - Capture potential failures of a system and their root causes
    - Good for analysing risk, especially in safety-critical applications
  - Strategic Dependency Models (i*)
    - Capture relationships between actors in an organisational setting
    - Helps to relate goal models to organisational setting
    - Good for understanding how the organisation will be changed
  - Entity-Relationship Models
    - Capture the relational structure of information to be stored
    - Good for understanding constraints and assumptions about the subject domain
    - Good basis for database design
  - Mode Class Tables, Event Tables and Condition Tables (SCR)
    - Capture the dynamic behaviour of a real-time reactive system
    - Good for representing functional mapping of inputs to outputs
    - Good for making behavioural models precise, for automated reasoning

Verification and Validation

- **Validation:**
  - "Are we building the right system?"
  - Does our problem statement accurately capture the real problem?
  - Did we account for the needs of all the stakeholders?
- **Verification:**
  - "Are we building the system right?"
  - Does our design meet the spec?
  - Does our implementation meet the spec?
  - Does the delivered system do what we said it would do?
  - Are our requirements models consistent with one another?



Refresher: V&V Criteria

→ **Some distinctions:**
- Domain Properties: things in the application domain that are true anyway
- Requirements: things in the application domain that we wish to be made true
- Specification: a description of the behaviours the program must have in order to meet the requirements

→ **Two verification criteria:**
- The Program running on a particular Computer satisfies the Specification
- The Specification, given the Domain properties, satisfies the Requirements

→ **Two validation criteria:**
- Did we discover (and understand) all the important Requirements?
- Did we discover (and understand) all the relevant Domain properties?

Source: Adapted from Jackson, 1995, p170-171

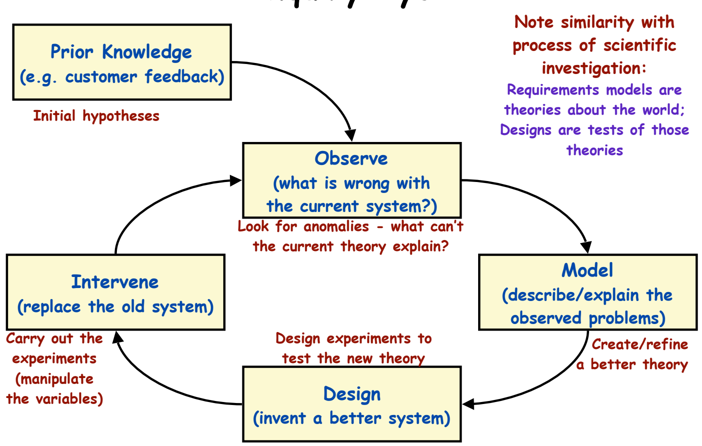
V&V Example

→ **Example:**
- Requirement R:
  - "Reverse thrust shall only be enabled when the aircraft is moving on the runway"
- Domain Properties D:
  - Wheel pulses on if and only if wheels turning
  - Wheels turning if and only if moving on runway
- Specification S:
  - Reverse thrust enabled if and only if wheel pulses on

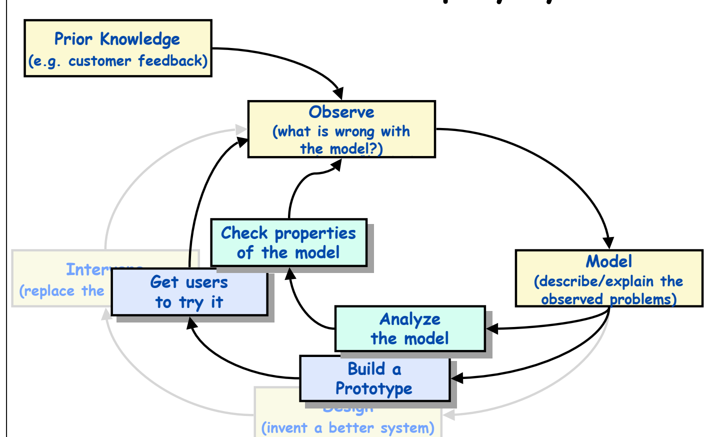
→ **Verification**
- Does the flight software, P, running on the aircraft flight computer, C, correctly implement S?
- Does S, in the context of assumptions D, satisfy R?

→ **Validation**
- Are our assumptions, D, about the domain correct? Did we miss any?
- Are the requirements, R, what is really needed? Did we miss any?

Inquiry Cycle



Shortcuts in the inquiry cycle



Prototyping

"A software prototype is a partial implementation constructed primarily to enable customers, users, or developers to learn more about a problem or its solution." [Davis 1990]

"Prototyping is the process of building a working model of the system" [Agresti 1986]

→ Approaches to prototyping

- Presentation Prototypes
  - explain, demonstrate and inform – then throw away
  - e.g. used for proof of concept; explaining design features; etc.
- Exploratory Prototypes
  - used to determine problems, elicit needs, clarify goals, compare design options
  - informal, unstructured and thrown away.
- Breadboards or Experimental Prototypes
  - explore technical feasibility; test suitability of a technology
  - Typically no user/customer involvement
- Evolutionary (e.g. "operational prototypes", "pilot systems"):
  - development seen as continuous process of adapting the system
  - "prototype" is an early deliverable, to be continually improved.

Throwaway or Evolve?

→ Throwaway Prototyping

- Purpose:
  - to learn more about the problem or its solution…
  - discard after desired knowledge is gained.
- Use:
  - early or late
- Approach:
  - horizontal - build only one layer (e.g. UI)
  - "quick and dirty"
- Advantages:
  - Learning medium for better convergence
  - Early delivery → early testing → less cost
  - Successful even if it fails!
- Disadvantages:
  - Wasted effort if reqts change rapidly
  - Often replaces proper documentation of the requirements
  - May set customers' expectations too high
  - Can get developed into final product

→ Evolutionary Prototyping

- Purpose
  - to learn more about the problem or its solution…
  - …and reduce risk by building parts early
- Use:
  - incremental; evolutionary
- Approach:
  - vertical - partial impl. of all layers;
  - designed to be extended/adapted
- Advantages:
  - Requirements not frozen
  - Return to last increment if error is found
  - Flexible(?)
- Disadvantages:
  - Can end up with complex, unstructured system which is hard to maintain
  - early architectural choice may be poor
  - Optimal solutions not guaranteed
  - Lacks control and direction

Brooks: "Plan to throw one away - you will anyway!"

Model Analysis

→ Verification

- "Is the model well-formed?"
- Are the parts of the model consistent with one another?

→ 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
  - "will the system ever do the following..."
- State exploration
  - E.g. use a model checking to find traces that satisfy some property

Basic Cross-Checks for UML

Use Case Diagrams

- Does each use case have a user?
  - Does each user have at least one use case?
- Is each use case documented?
  - Using sequence diagrams or equivalent

Class Diagrams

- Does the class diagram capture all the classes mentioned in other diagrams?
- Does every class have methods to get/set its attributes?

Sequence Diagrams

- Is each class in the class diagram?
- Can each message be sent?
  - Is there an association connecting sender and receiver classes on the class diagram?
  - Is there a method call in the sending class for each sent message?
  - Is there a method call in the receiving class for each received message?

StateChart Diagrams

- Does each statechart diagram capture (the states of) a single class?
  - Is that class in the class diagram?
- Does each transition have a trigger event?
  - Is it clear which object initiates each event?
  - Is each event listed as an operation for that object's class in the class diagram?
- Does each state represent a distinct combination of attribute values?
  - Is it clear which combination of attribute values?
  - Are all those attributes shown on the class diagram?
- Are there method calls in the class diagram for each transition?
  - …a method call that will update attribute values for the new state?
  - …method calls that will test any conditions on the transition?
  - …method calls that will carry out any actions on the transition?

Independent V&V

- **V&V performed by a separate contractor**
  - Independent V&V fulfills the need for an independent technical opinion.
  - Cost between 5% and 15% of development costs
  - Studies show up to fivefold return on investment:
    - Errors found earlier, cheaper to fix, cheaper to re-test
    - Clearer specifications
    - Developer more likely to use best practices
- **Three types of independence:**
  - Managerial Independence:
    - separate responsibility from that of developing the software
    - can decide when and where to focus the V&V effort
  - Financial Independence:
    - Costed and funded separately
    - No risk of diverting resources when the going gets tough
  - Technical Independence:
    - Different personnel, to avoid analyst bias
    - Use of different tools and techniques

Some philosophical views of validation

- **logical positivist view:**
    - "there is an objective world that can be modeled by building a consistent body of knowledge grounded in empirical observation"
  - In RE, assumes there is an objective problem that exists in the world
    - Build a consistent model; make sufficient empirical observations to check validity
    - Use tools that test consistency and completeness of the model
    - Use reviews, prototyping, etc to demonstrate the model is "valid"
- **Popper's modification to logical positivism:**
    - "theories can't be proven correct, they can only be refuted by finding exceptions"
  - In RE, design your requirements models to be refutable
    - Look for evidence that the model is wrong
    - E.g. collect scenarios and check the model supports them
- **post-modernist view:**
    - "there is no privileged viewpoint; all observation is value-laden; scientific investigation is culturally embedded"
    - E.g. Kuhn: science moves through paradigms
    - E.g. Toulmin: scientific theories are judged with respect to a *weltanschauung*
  - In RE, validation is always subjective and contextualised
    - Use stakeholder involvement so that they 'own' the requirements models
    - Use ethnographic techniques to understand the weltanschauungen