Lecture 12: Requirements Analysis

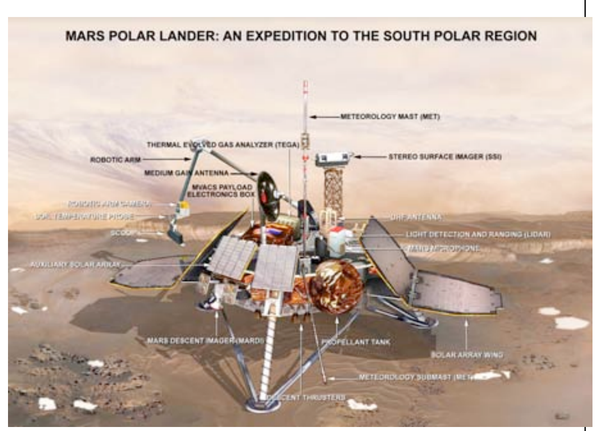
Mars Polar Lander

Launched
- 3 Jan 1999

Mission
- Land near South Pole
- Dig for water ice with a robotic arm

Fate:
- Arrived 3 Dec 1999
- No signal received after initial phase of descent

Cause:
- Several candidate causes
- Most likely is premature engine shutdown due to noise on leg sensors



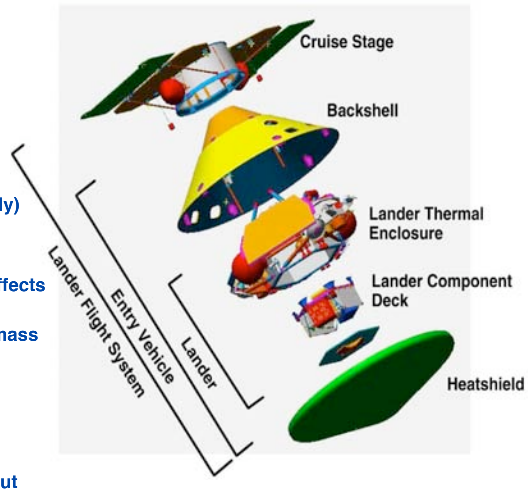
What happened?

We don't know for sure:

- spacecraft not designed to send telemetry during descent
- This decision severely criticized by review boards

Possible causes:

1. Lander failed to separate from cruise stage (plausible but unlikely)
2. Landing site too steep (plausible)
3. Heatshield failed (plausible)
4. Loss of control due to dynamic effects (plausible)
5. Loss of control due to center-of-mass shift (plausible)
6. Premature Shutdown of Descent Engines (most likely!)
7. Parachute drapes over lander (plausible)
8. Backshell hits lander (plausible but unlikely)



Premature Shutdown Scenario

Cause of error

- Magnetic sensor on each leg senses touchdown
- Legs unfold at 1500m above surface
- software accepts transient signals on touchdown sensors during unfolding

Factors

- System requirement to ignore the transient signals
- But the software requirements did not describe the effect
- Engineers present at code inspection didn't understand the effect
- Not caught in testing because:
  - Unit testing didn't include the transients
  - Sensors improperly wired during integration tests (no touchdown detected!)

Result of error

- Engines shut down before spacecraft has landed
- estimated at 40m above surface, travelling at 13 m/s
- estimated impact velocity 22m/s (spacecraft would not survive this)
- nominal touchdown velocity 2.4m/s

SYSTEM REQUIREMENTS

1) The touchdown sensors shall be sampled at 100-Hz rate.

The sampling process shall be initiated prior to lander entry to keep processor demand constant.

However, the use of the touchdown sensor data shall not begin until 12 meters above the surface.

2) Each of the 3 touchdown sensors shall be tested automatically and independently prior to use of the touchdown sensor data in the onboard logic.

The test shall consist of two (2) sequential sensor readings showing the expected sensor status.

If a sensor appears failed, it shall not be considered in the descent engine termination decision.

3) Touchdown determination shall be based on two sequential reads of a single sensor indicating touchdown.

FLIGHT SOFTWARE REQUIREMENTS

3.7.2.2.4.2 Processing

a. The lander flight software shall cyclically check the state of each of the three touchdown sensors (one at 100 Hz during EDL.

b. The lander flight software shall be able to cyclically check the touchdown event state with or without touchdown event generation enabled.

c. Upon enabling touchdown event generation, the lan flight software shall attempt to detect failed sens marking the sensor as bad when the sensor indicat "touchdown state" on two consecutive reads.

d. The lander flight software shall generate the landin event based on two consecutive reads indicating touchdown from any one of the "good" touchdown sensors.

Adapted from the "Report of the Loss of the Mars Polar Lander and Deep Space 2 Missions -- JPL Special Review Board (Casani Report) - March 2000".
See http://www.nasa.gov/newsinfo/marsreports.html

Quality = Fitness for purpose

Software technology is everywhere

- Affects nearly all aspects of our lives
- But our experience of software technology is often frustrating/disappointing

Software is designed for a purpose

- If it doesn't work well then either:
  - …the designer didn't have an adequate understanding of the purpose
  - …or we are using the software for a purpose different from the intended one
- Requirements analysis is about identifying this purpose
- Inadequate understanding of the purpose leads to poor quality software

The purpose is found in human activities

- E.g. Purpose of a banking system comes from the business activities of banks and the needs of their customers
- The purpose is often complex:
  - Many different kinds of people and activities
  - Conflicting interests among them

Designing for people

What is the real goal of software design?

- Creating new programs, components, algorithms, user interfaces,…?
- Making human activities more effective, efficient, safe, enjoyable,…?

How rational is the design process?

- Hard systems view:
  - Software problems can be decomposed systematically
  - The requirements can be represented formally in a specification
  - This specification can be validated to ensure it is correct
  - A correct program is one that satisfies such a specification
- Soft systems view:
  - Software development is embedded in a complex organizational context
  - There are multiple stakeholders with different values and goals
  - Software design is part of an ongoing learning process by the organization
  - Requirements can never be adequately captured in a specification
  - Participation of users and others throughout development is essential
- Reconciliation:
  - Hard systems view okay if there is local consensus on the nature of the problem

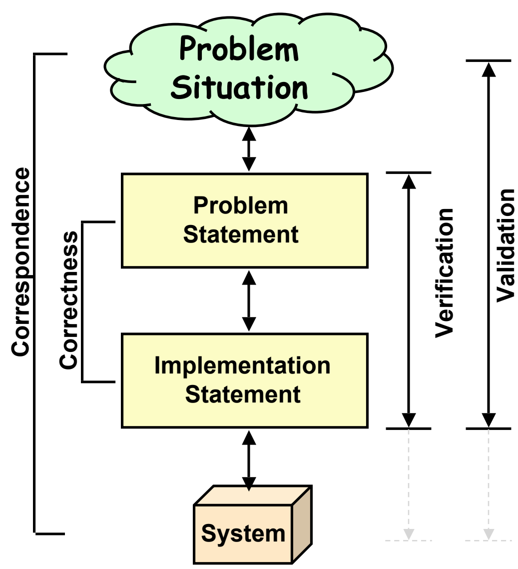
Separate the problem from the solution

A separate problem description is useful:

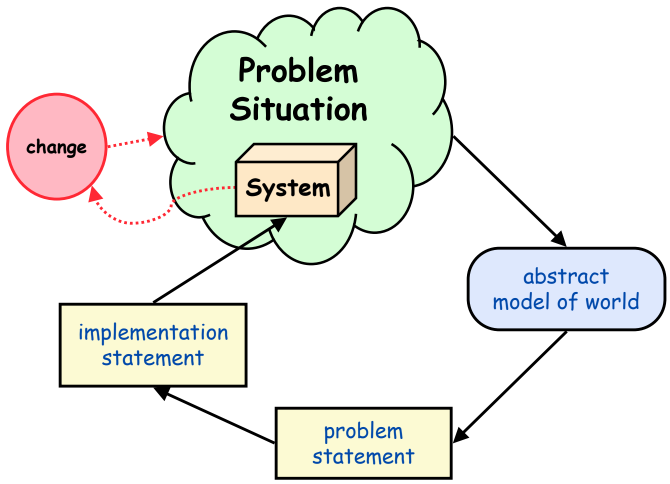
- Most obvious problem might not the right one to solve
- Problem statement can be discussed with stakeholders
- Problem statement can be used to evaluate design choices
- Problem statement is a source of good test cases

Still need to check:

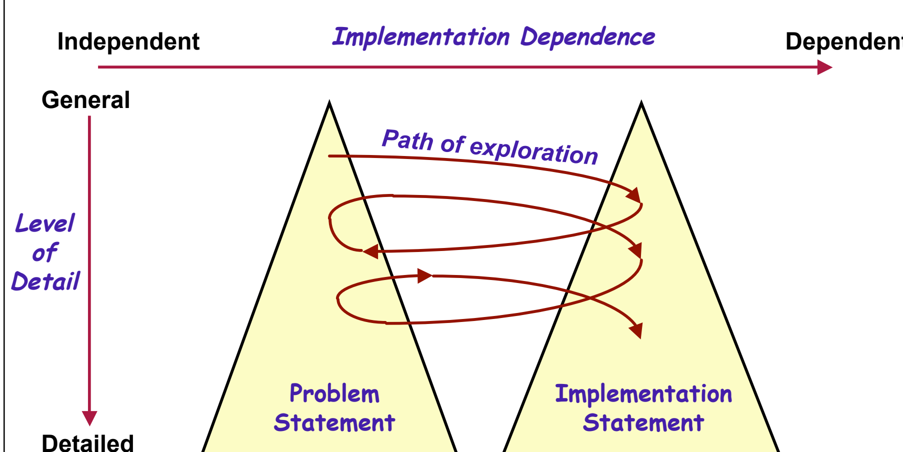
- Solution correctly solves the stated problem
- Problem statement corresponds to the needs of the stakeholders



But design changes the world…

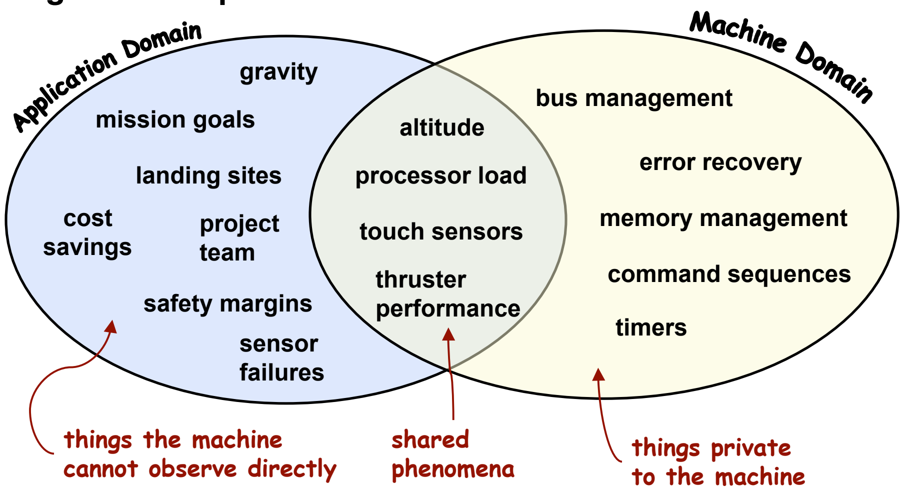


Intertwining of problems and solutions

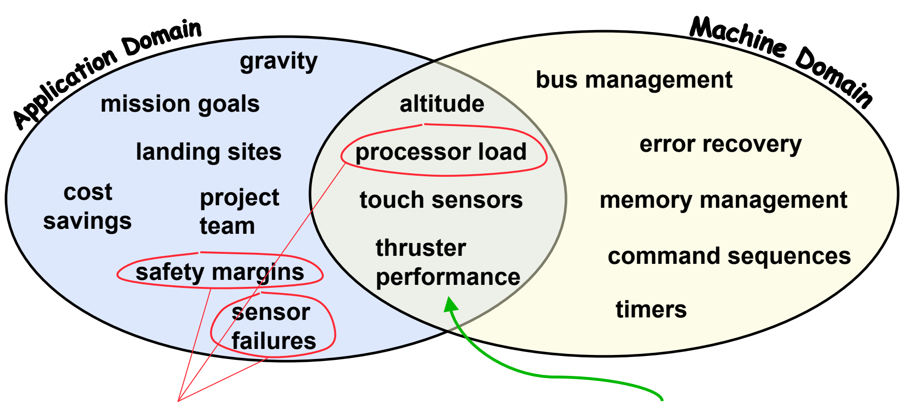


A problem to describe…

E.g. "land a spacecraft on Mars"



A problem to describe…



"Don't overload the processors…
Don't use data from failed sensors…
Ignore noise on sensors when legs unfold…"

"Poll multiple sensors continually and compare results to test sensor function.
Start using touchdown sensors at 12m above the surface
(Assumes legs have finished unfolding by then…)"

Thinking about Software Requirements

Domain Properties (assumptions):

- things in the application domain that are true, whether or not we ever build the proposed system

(System) Requirements:

- things in the application domain that we wish to be made true, by delivering the proposed system
  - May involve phenomena to which the machine has no access

A (Software) Specification:

- a description of the behaviours that the program must have, in order to meet the requirements
  - Can only be written in terms of shared phenomena!

Fitness for purpose?

Two correctness (verification) criteria:

- The Program running on a particular Computer satisfies the Specification
- The Specification, in the context of the given domain properties, satisfies the requirements

Two appropriateness (validation) criteria:

- We discovered all the important requirements
- We properly understood the relevant domain properties

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: S, D $\Rightarrow$ R

Another Example

Requirement R:

"The database shall only be accessible by authorized personnel"

Domain Properties D:

Authorized personnel have passwords

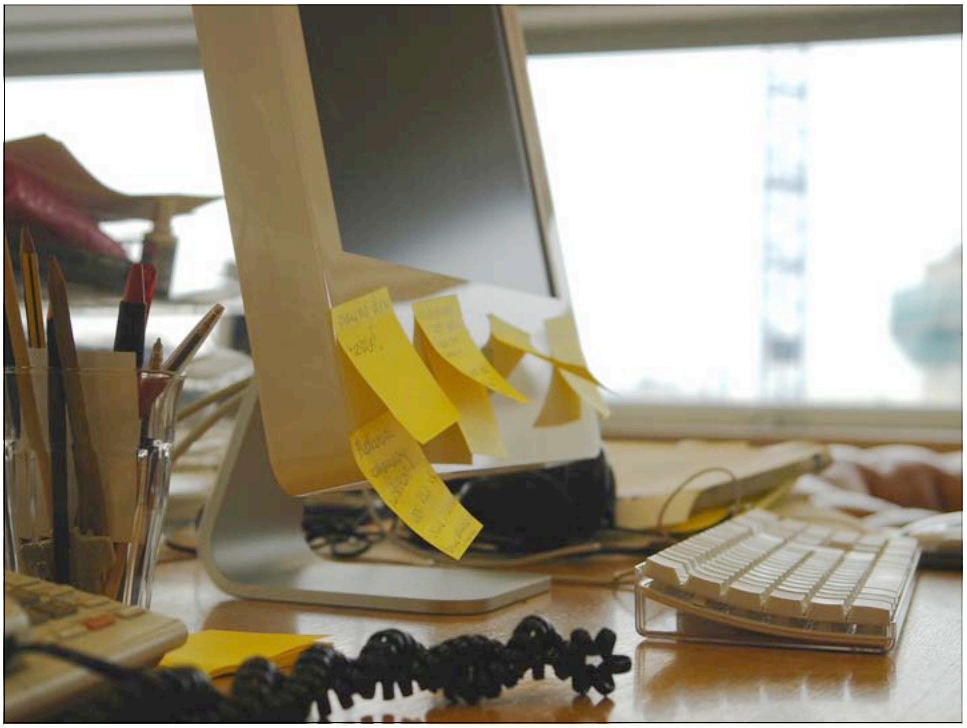
Passwords are never shared with non-authorized personnel

Specification S:

Access to the database shall only be granted after the user types an authorized password

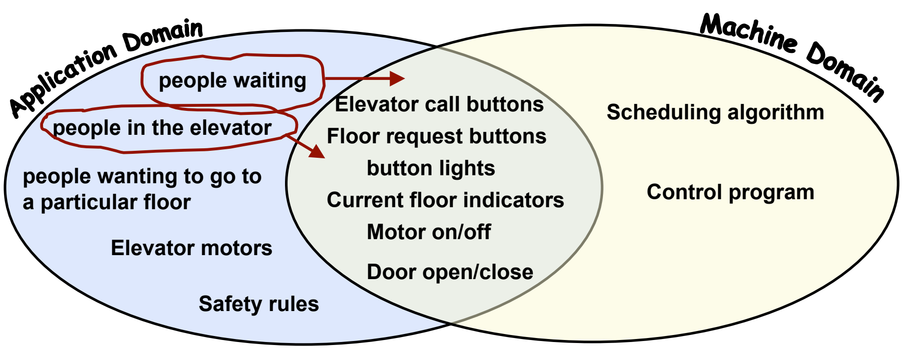
S, D $\Rightarrow$ R

But what if the domain assumptions are wrong?



But we can also move the boundaries…

E.g. Elevator control system:



➜We can shift things around:
- E.g. Add some sensors to detect when people are waiting
- This changes the nature of the problem to be solved

Observations

Analysis is not necessarily a sequential process:

- Don't have to write the problem statement before the solution statement
  - (Re-)writing a problem statement can be useful at any stage of development
- RE activities continue throughout the development process

The problem statement will be imperfect

- RE models are approximations of the world
  - will contain inaccuracies and inconsistencies
  - will omit some information.
  - assess the risk that these will cause serious problems!

Perfecting a specification may not be cost-effective

- Requirements analysis has a cost
- For different projects, the cost-benefit balance will be different
- Depends on the consequences of getting it wrong!

Problem statement should never be treated as fixed

- Change is inevitable, and therefore must be planned for
- There should be a way of incorporating changes periodically