System Engineering and Testing Strategies

RSS Lecture 7

Wednesday, 27 March 2013

Prof. Seth Teller

What is Engineering?

- Engineering (n.) (Merriam-Webster Online)
  - a: the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people
  - b: the design and manufacture of complex products
- Does science + math + usefulness + complexity capture all of engineering?

What is Engineering?

- Engineering (n.)

  The process of specifying, designing, implementing, and validating physical artifacts with a *desired set of properties*

  (With "properties" construed broadly to mean material attributes, rigid and articulated DOFS, appearance, *behavior*, ...)

Process View

- Engineering is a *Means* ...
  - Specifying: describing *what* to make
  - Designing: describing *how* to make it
  - Implementing: *realizing* actual artifact
  - Validating: convincing yourself (and others) that artifact *works* as specified
- ... to an *End*
  - Namely: an artifact with desired *behavior*

Human View

- Engineers are people who:
  - *Conceive of* and *execute* ways to optimize an underspecified tradeoff between usually conflicting goals (e.g. performance, size, cost, etc.) …
- … subject to *physical* constraints:
  - Natural: Laws of physics, i.e., reality
- … and to *social* constraints:
  - Cultural: Law, morality, ethics …

Conception & Execution

- Conception:
  - A *mental model* of artifact, constraints, and assumptions about environment
- Execution:
  - Putting the mental model into *practice*
  - Observing whether it *predicts* behavior under real-world conditions (and whether environmental assumptions are justified)

Essence of Engineering ...

- ... Process is the (typically iterative)
  - *Formation* of a mental model;
  - *Implementation* of prototype artifact; and
  - *Observation* of its behavior, leading to:
    - Revision of designer's operative mental model
    - Revision of current design or implementation
    - (Or both)
- ... Until desired behavior is achieved

Consequences of Anomalies

- If it "looks wrong" to you, two possibilities:

- If things "look wrong," it's an opportunity to

... And if it looks correct?

- Is it correct?
- Sure, it often is correct. But that doesn't mean that it *always* is or *must be* correct!
- Can boil these ideas down to an aphorism:
  - "Don't sweep anomalies under the rug."
  - In other words, anomalous behavior presents a well-defined opportunity to *learn something*!

Documentation: JavaDocs

- JavaDocs comprise:
  - Declarations
  - Comments

  } for some code corpus
- Can help match mental models, but...
- ... teammates' agreement to *write* the code so that it implements the stated *intent* essentially amounts to a *social contract* (not a technical one)

A Concrete Strategy

- Iterative Prediction, Test, Evaluation
- Not:
  - “Hmm, now that I have modified this element, let’s see what happens…”
- Instead:
  - *Predict* outcome of some well-defined test
  - *Perform* the test
  - *Evaluate* actual outcome; form conclusions
  - Simple, systematic, *constructive* approach

Team Mental Models

- This strategy can be pursued by an individual, or by an entire team
- Also useful for resolving discrepancies in mental models *within* a team
- How?
- Inexhaustible source of experiments

Self-Checking Code

- Idea: make machine work for you
- For each algorithm/module, write a “checker” that inspects its *output* for the properties that it should have
- ... same idea applies to module *input*!
  - Postconditions (A) == Preconditions (B)

Pre/Postconditions, Invariants

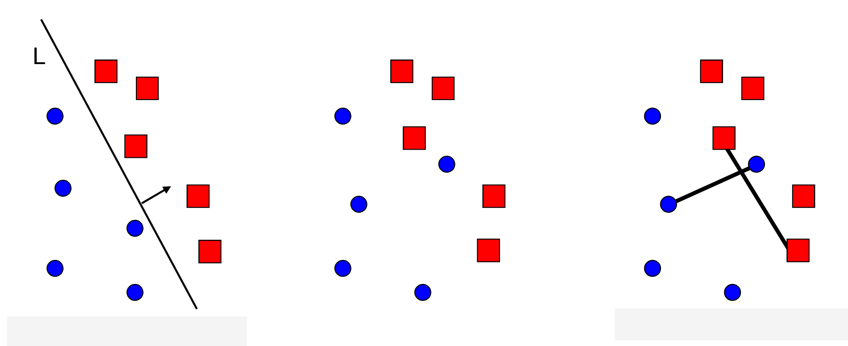
- Preconditions, postconditions and invariants are commonly used in “design-by-contract” engineering.
- Precondition - what must be true when a method is invoked. When a precondition fails, the fault lies ____.
- Postcondition - what must be true after a method completes successfully. Provided that the precondition was met, when a postcondition fails, the fault lies ____.
- Class Invariant - what must be true about each instance of a class after every method call (including construction!). When a class invariant fails, fault could lie in the ____, in the ____ or ____.
- Another common kind of invariant is *internal* – any condition(s) in the implementation which we know must always hold. (Ex.?)

Teammate-Checking Code

- Twist: for each module you write, ask a *teammate* to write the checker (could be as fine as function grain)
- Multiple benefits:
  - Validates your solution (as before)
  - Decreases chance that checker succeeds due to an invalid *assumption* (why?)
  - Facilitates agreement of your mental model with your teammate's model
  - Exploits a natural human characteristic: *competitiveness* (s/he acts as *adversary*)

Witnesses: "Prove it!"

- Example: linear separability (LP)
  - Given point sets $\{A_i\}$, $\{B_i\}$, i in [1..N]
  - Identify line L s.t. all A_i lie above L & all B_i lie below L, or show that no such L exists



Caution: A Practical Issue

- Make sure your checking, reporting, witness etc. code has no *side effects* that enable correct algorithm function
- Otherwise, *disabling* your self-testing code may introduce bugs into system
- Examples?

Adversary

- Someone/something that tries to
  - Find holes in your correctness argument (e.g. as A did for R & S of RSA security)
  - Produce *inputs* that break your code (e.g., by violating your assumptions)
  - Produce *conditions* that break system (more than just program's *formal input*)
- Adversary can be a , , or even a

Some Adversarial Strategies

- Generate challenging *inputs* ...
  - Exhaustively
  - Randomly
  - Qualitatively
  - Deviously (e.g., provoke a teammate to do it)
- ... and nominal or anomalous *conditions*:
  - Notional environment, arranged to expectations
  - Missing or mis-wired connectors
  - Misbehaving sensors
  - Depressed all-stop buttons
  - Undefined environment variables
  - Misconfigured networks, remote hosts, etc.

Self-Checking Summary

- Pit each module against *itself*.
  - Make each module prove itself before you trust it.
- Pit each module against a *checker*
  - Preferably one written independently
- Modules should *catch & correct errors*
  - Listen liberally, speak strictly

Test Harness

- Battery of test cases applied to a system to validate its responses
- We've seen these in "software only" systems, with "soft-copy only" inputs
- But what about robotics? How can we validate sensors and actuators using only software?

Robotics is Different!

- Robots are subject to "hard state," fundamentally not under s/w control
- Consider relation of proprioceptive (e.g., odometry, IMU) and exteroceptive (e.g., vision, ranging) sensor data for motion
- Actuators pose analogous problems
- Simulation can be useful*, but ...
- Real world is the *only way* to enforce absolute consistency of env't, state

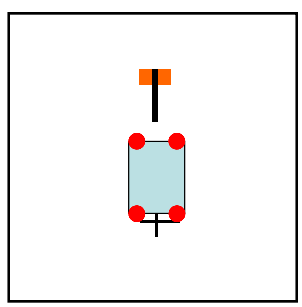
*Rod Brooks: "Simulation is doomed to succeed." What does that mean?

Example

- Bot commands forward motion, but sensed wall ahead isn't getting closer!
- Many possible explanations:

Robotics Test Harness

- Place robot in a *known* environment
  … thus actions have known outcomes
- For concreteness, imagine harness for:
  - Odometry
  - Motor drivers
  - Bump sensors
  - Visual servoing
  - Arm driver
  - Gripper sense

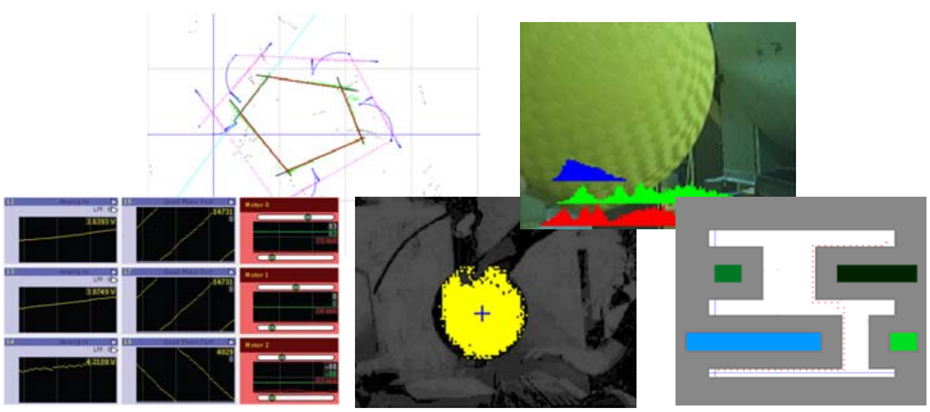


Self-Checking Summary (cont.)

- Pit system against known environment.
- Aphorism (attributed to Feynman): “You can’t fool Mother Nature.”

Transparency of Live State

- Make live system state graphically *visible* (at least while debugging)
  - Generalizes print statements (& more fun)



Benefits of State Visualization

- Exposes otherwise hidden system state
- Exploits high-bandwidth visual system
- Speeds iterative development cycle
- Increases achievable complexity
- Useful for communicating results
  - To teammates (to match mental models)
  - To others (for demos, presentations...)

Hierarchical Testing

- Idea underlying all CS:
- This suggests a *recursive* test strategy:

Longitudinal Testing

- Running over long time scales & spatial excursions may expose *vulnerabilities*:
  - Memory leaks, desynchronization, insufficient buffering, drift, decalibration…
- Longer runs increase the likelihood of encountering useful conditions/inputs
- Course challenge requires repeated runs of 10-15 minutes (good practice!)

Consider Pair Development

- Treat development as a concrete, *collaborative* activity among peers
- One person develops (sw,hw), the other constructively comments, questions
- Trade roles at agreed-upon intervals
- Prompts useful design discussions
- Shortens design iteration dramatically
- *Try it*!

General Comments

- You've heard it all before
  - "Think before you implement"
- My variation on this:
  - "Validate *as* you design and implement"
- Tangible benefits in rapidity of proto-typing & achievable complexity while retaining confidence in correctness

Summary

- Engineering is about **predictive power**
- Primacy of **mental models** in testing
  - Both individual and shared
- Importance of **transparent state**
- Strategies for **iterative design & test**
- Potential of **adversarial self-checking**