System Engineering and Testing Strategies

RSS Lecture 4

Tuesday, 17 February 2009

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My Goals Today

- Discuss system engineering from an intellectual and practical standpoint
- Introduce a "toolkit" of ideas and techniques that you can adopt in your own engineering endeavors
- Get you thinking about your own useful engineering practices

Caveat Auscultator (Listener beware)

- Some of this material will be new to you; some will be familiar
  - It doesn't hurt to hear things twice.
- Some things you will probably agree with; some things you probably won't
  - But surely you're used to this by now.

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: artifact with desired *behavior*

Human View

- Engineers are people who:
  - *Conceive of* and *execute* ways to optimize an underspecified tradeoff between possibly conflicting goals
- ... subject to physical constraints:
  - Natural: Laws of physics, i.e., reality
- ... and 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 env't assumptions are justified)

Essence of Engineering ...

- ... Process is the (typically iterative)
  - Formation of a mental model
  - Implementation of a prototype artifact
  - 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 *has to be* correct!
- Can boil these ideas down to an aphorism:
  - "Don't sweep anomalies under the rug."
  - In other words, anomalous behavior presents a great opportunity to learn something!

Documentation: JavaDocs

- JavaDocs comprise:
  - Declarations
  - Comments

  } for some code corpus
- Can help match mental models, but...
- ... teammates' agreement to make the code implement the *intent* stated in the comments essentially amounts to a *social contract*

Strategy

- Predict and test
- Rather than "Hmm, now that I have edited the code, let's see what happens"
- Predict outcome of well-defined test
- Perform the test, evaluate outcome
- Simple, systematic 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 input!
  - Postconditions (A) == Preconditions (B)

Teammate-Checking Code

- Twist: for each module you write, ask a *teammate* to write checker
- 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*)

Caution

- Make sure your checking, reporting, witness etc. code has no side effects that enable correct algorithm function
- Otherwise, when you remove or suppress self-test, bugs may emerge
- Examples?

Adversary

- Someone/something that tries to
  - Find holes in your correctness proof (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 person, program, or a carefully-designed environment

Adversary's Strategies

- Generate challenging *inputs* …
  - Exhaustively
  - Randomly
  - Qualitatively
  - Deviously (e.g., provoke a teammate to do it)
- … and environmental *conditions*:
  - 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.
- Aphorism: "Make each module prove itself before you trust it."

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!

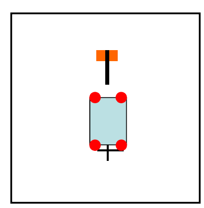
- Robots are subject to "hard state" fundamentally not under s/w control
- Consider dependence of proprioceptive (e.g., odometry, IMU) and extero-ceptive (e.g., sonar) sensors – fallible?
- Actuators pose analogous problems
- Simulation can be useful, but …
- Real world is the only way to enforce absolute consistency of env't, state

Example

- Bot commands forward motion, but wall ahead of us 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

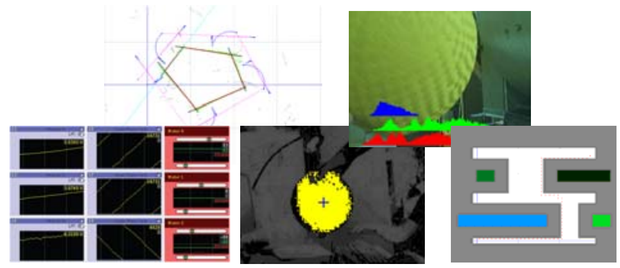


Self-Checking Summary (cont.)

- Pit system against known environment.
- Aphorism (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 (for matching 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 "good" conditions/inputs
- Course challenge requires repeated runs of 10-15 minutes (good practice!)

Consider Pair Programming

- Treat programming as an actual *collaborative* activity among peers
- One person types, the other person constructively comments, questions
- Trade roles with some frequency
- Prompts useful design discussions
- Shortens design iteration dramatically
- Try it!

General Comments

- You've heard it all before
  - "Think before you code"
- 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**