Some Useful Engineering Strategies

Seth Teller

RSS II

16 November 2005

My Goals Today

- Discuss engineering from an intellectual and practical standpoint
- Introduce a "toolkit" of ideas and techniques that you can use in your own engineering endeavors
- Solicit your own ideas about 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
- Do science, math, usefulness, and complexity "capture" 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 properties

Human View

- Engineers are people who:
  - *Conceive of* and *execute* ways to optimize an underspecified tradeoff between possibly conflicting goals
- Subject to severe *constraints*:
  - Natural: Laws of physics, i.e., reality
  - Cultural: Legal system, mores, ethics …

Conception & Execution

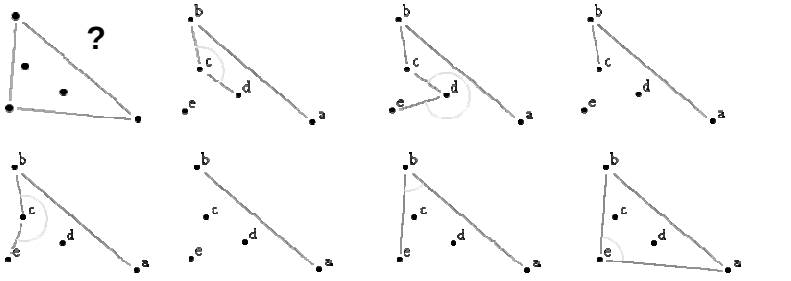
- Conception:
  - A *mental model* of artifact & constraints
- Execution:
  - Putting the mental model into practice
  - Observing whether it *predicts* behavior under real-world conditions

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 operative design or implementation
    - (Or both)
- … Until desired behavior is achieved

Visualization & Inspection

- Idea: graphical analogue of printf
  - Visually expose artifact's *internal state*



(CSE Ohio State; CIS 680)

- Distinct from "algorithm animation"
  - Rendering *output* of batch computation

Consequences

- If it "looks wrong" to you, two possibilities:
  - A) Artifact state really *is* wrong, in which case:
    - Artifact has deviated from your mental model
    - You can find first place of deviation, and fix it
  - B) Artifact state is *correct*, in which case:
    - Your mental model made it "look wrong" to you
    - Thus your mental model must be revised!

A C M K C E a b d a b C d E

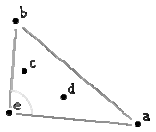
- If it "looks wrong," it's an opportunity to
  - Improve the system's behavior, or
  - Learn something, i.e., improve mental model!

… And if it looks correct?

- Is it correct?
- Sure, it often is. But that doesn't mean that it always is!
- Can boil these ideas down to an aphorism:
  - "Don't sweep anomalies under the rug."

Self-Checking Code

- Idea: make machine work for you
- For each algorithm/module, write a "checker" that inspects output for the properties that it should have
- Convex hull example:
  - Traverse output vertices in order; check orientation of each triplet



- Same idea applies to input
  - Postconditions (A) == Preconditions (B)

Distinction: JavaDocs

- JavaDocs comprise:
  - Declarations
  - Comments

  } for some code corpus

- But teammates' agreement to make the code implement the *intent* stated in the comments essentially amounts to a *social contract*

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*)

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 even a contrived environment

Adversary's Strategies

- Generate challenging *inputs* …
  - Exhaustively
  - Randomly
  - Qualitatively
  - Deviously (e.g., provoke your 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.

Benefiting from Adversary

- Implement a "state capture" facility
  - Ensure that it is very easy to invoke
  - … And that state can be reconstituted
- This makes misbehavior repeatable
- Gives rise to "defensive coding"

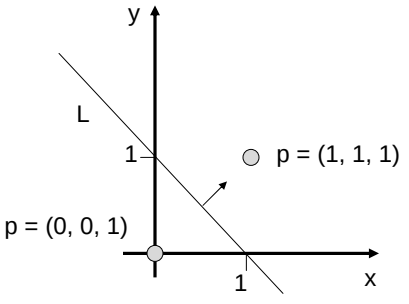
- Aphorism: "Chance favors the prepared program"

Self-Reporting Code

- Useful when a subroutine might legitimately succeed or fail
  - Example: path planning among obstacles
- Notion of a "witness" from CS theory community: consists of either a
  - Checkably correct output solution, or an
  - Input subset that "proves" infeasibility of the specific input instance provided

Digression: Line Equations

- Points represented as p = (x, y, 1)
- Lines represented as L = (A, B, C)
  - Defines "positive halfspace" L · P > 0
  - Defines "negative halfspace" L · P < 0



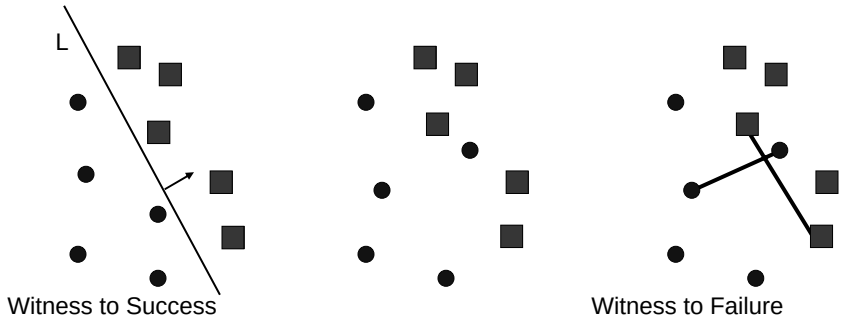
Example:

Line equation x + y = 1
x + y – 1 = 0
(1, 1, -1) · (x, y, 1) = 0

Thus L = (1, 1, -1)

Linear Separability

- 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 no such L exists



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 will emerge
- Examples?

Self-Test Summary

- Pit code against itself.
- Aphorism: "Make function prove itself before you trust it."

Test Harness

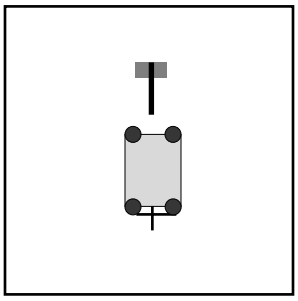
- Battery of test cases applied to a system to validate its responses
- We've seen these in "software only" systems, with "softcopy only" inputs
- But what about robotics? How can we validate sensors and actuators using only software? … We can't!

Robotics is Different!

- Robots are subject to “hard state” fundamentally not under s/w control
- Consider e.g. all-stop button sense question that arose last week
- Or, even harder: sensors. How to force them to behave as you want?
- Actuators have same problem
- Real world is the only way to enforce absolute consistency of env’t, state

Robotics Test Harness

- Place robot in a known environment … so actions have known outcomes
- For concreteness, imagine harness for:
  - Odometry
  - Motor drivers
  - Bump sensors
  - Visual servoing
  - Arm driver
  - Brick storage



Self-Test Summary (2)

- Pit machine against environment.
- Aphorism (Feynman):
  "You can't fool Mother Nature."

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

Your Ideas for Next RSS II

- How to promote rapid prototyping, validation?
- More or better tools?
- In-class or in-lab exercises?

Your Ideas for Next RSS II

- How to prompt students to address integration, end-to-end issues earlier?
  - Example: systems group; great idea
  - Move first integration even earlier?
    - I.e., as soon as message formats published?

Summary

- Discussed engineering as an endeavor
- Described several tools/methods for validation and rapid prototyping
- Argued that “robotics is different”