ECE155: Engineering Design with Embedded Systems Winter 2013

Lecture 14 — February 4, 2013

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Engineering Design and Analysis

Here's the Canadian Engineering Accreditation Board definition of engineering design:

> Engineering design integrates mathematics, basic sciences, engineering sciences, and complementary studies in developing elements, systems, and processes to meet specific needs. It is a creative, iterative, and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social, or other pertinent factors.

In other words, you have a technical problem and you'd like to solve it. Use engineering design. It's an open-ended process which applies technical knowledge in a creative way for some useful purpose.

Creativity.

> A good scientist is a person with original ideas. A good engineer is a person who makes a design that works with as few original ideas as possible.

Freeman Dyson, physicist with mastery of mechanical engineering

> I believe that engineering is a highly creative profession. Research tells us that creativity does not spring from nothing; it is grounded in our life experiences, and hence limited by those experiences. Lacking diversity on an engineering team, we limit the set of solutions that will be considered and we may not find the best, the *elegant* solution.

William W. Wulf, former president of National Academy of Engineering

In creativity, we explore a search space for interesting points, perhaps solutions to a problem.

- Creativity is required for innovation.
- Creativity introduces the possibility of failure.
- A great engineer leverages existing design knowledge as much as possible and uses creativity only when necessary to solve a problem.

Progress.

> . . . (that) any general system of conveying passengers would . . . go at a velocity exceeding ten miles an hour; or thereabouts, is extremely improbable.

Thomas Treadgold, railway engineer, 1835

Progress has been inevitable in the past few hundred years. Engineering implements technological progress, enabling people to do the improbable.

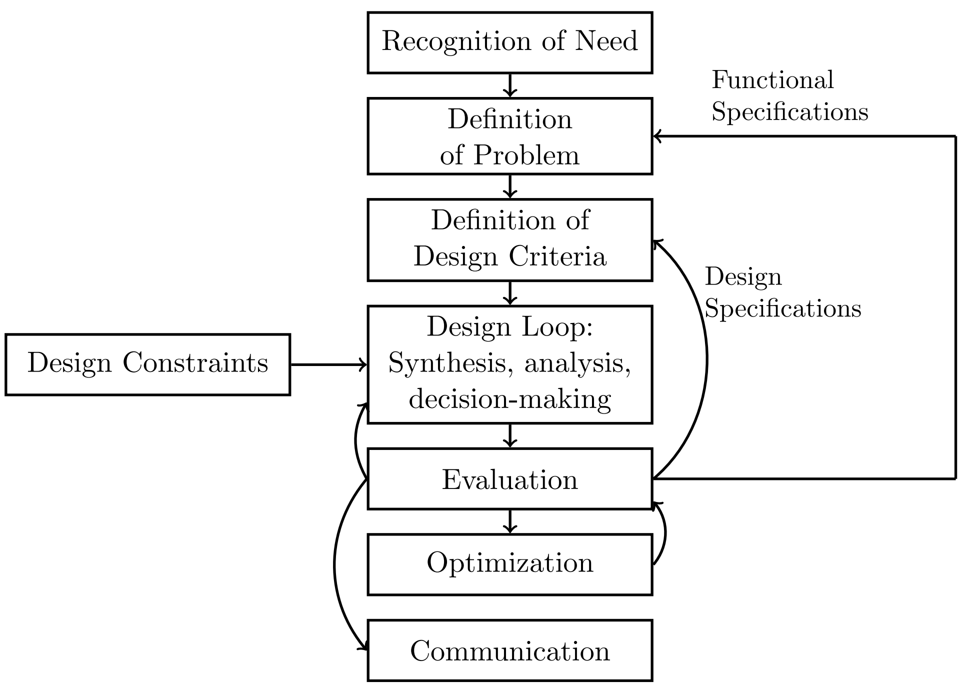
Engineering Design.

> "All parts should go together without forcing. You must remember that the parts you are reassembling were disassembled by you. Therefore, if you can't get them together again, there must be a reason. By all means, do not use a hammer."

IBM Maintenance Manual, 1925

One way of getting a design is by using a (metaphorical) hammer. This is not going to be a win. Good engineering design is hard.

Overview of the Engineering Design Process. (i.e. why people with engineer envy love the waterfall model):



Note. This is a model for classical engineering disciplines, which ends with the transfer of blueprints to manufacturing/construction firms. Software is different.

Customer Requirements. In this phase, you're trying to figure out the properties that the customer is looking for in your solution. Especially when it comes to software, customers might not know what they want. They can give you platitudes, e.g. convenient, easy-to-use, lightweight, simple. By digging deeper, you can find a design problem among what they're saying.

Avoid getting pigeonholed by "helpful" customers giving you advice on how to solve the problem.

Design Criteria. Given a problem, you need to know *specifically* what constitutes a solution. The solution should, to the extent possible, meet the design criteria. A project that fails to meet one criterion isn't necessarily a failure.

What are some examples?

Design Constraints. Constraints are what make things interesting (as long as they're satisfiable). The idea is to find a constraint-satisfying solution.

Design constraints may apply to the design process (that is, the designer or the final design) or the manufacturing process; they may be imposed by management, the environment, or physical laws involved in the design.

What are some examples of design constraints?

We usually consider design constraints non-negotiable; solutions must satisfy all design constraints.

Heuristics, Guidelines, Standards and Specifications. Here are four related terms.

A *design heuristic* is a general (and not necessarily actionable) rule-of-thumb based on experience. Heuristics lead to quick design solutions that often work well but may fail in some situations. No substitute for understanding.

A *design guideline* is a general rule based on experience and specific knowledge of the design problem that may be applied to a design solution. When we talk about guidelines, we mean something more specific than heuristics.

A *standard* provides more direction about the acceptable solution space by stating technical requirements that must be satisfied by candidate designs. Standards do not provide a complete solution, but do dictate a set of requirements that must be satisfied by a solution.

Our definition of *specification* refers to a description of a solution which provides all of the details. Using a specification, an engineer should be able to reproduce a design exactly.

What are examples of all of these terms?

Synthesis, Analysis and Decision-Making. Now you know about your constraints and requirements. Time to come up with a solution. You will use the *design loop*.

- Synthesis: gather information, combine (synthesize) it, and come up with ideas or methods to solve a problem.
- Analysis: estimate the expected result from each idea or method.
- Decision-making: compare the expected results and their uncertainties; pick the best alternative.

You'll find that you often have to iterate the design loop. Even after you get a "best" alternative, you might have found that your criteria were wrong, or that you didn't satisfy all of the design constraints or meet the desired design criteria.

When iterating, you bring the less-favoured alternatives back on the table, and reconsider and revise all of the alternatives. You'll get a better set of alternatives out of the process.

Once you have a sufficiently-good best design, you can finish the design loop. This design should satisfy all constraints and achieve the desired criteria. Choose the winning design, optimize, and implement it.

Innovation versus evolution. Solutions tend to have some innovation and some evolution. It's a continuum.

- Evolutionary design solutions *build on top of* existing solutions, improving them in some way.
- Innovative design solutions invent *something new*, a completely original idea or a novel way of solving the design problem.

Modern engineering design solutions combine innovation and evolution. (You don't want to innovate on all fronts simultaneously). Consider, for instance, the Brooklyn Bagel Slicer:

`http://online.wsj.com/article/SB125952152870368561.html`

`http://www.amazon.com/Brooklyn-Bagel-Slicer-Knife-Stainless/dp/B001PN0GBE`

It is a knife embedded in plastic to enable you to safely cut bagels, while avoiding Bagel-Related Injuries.

What is innovative about this design? What is evolutionary?

Creativity. One of the popular misconceptions about engineering is that it's not creative. Good engineering uses creativity when necessary.

The best engineers know when to be innovative and when to simply build upon the designs of others. Creativity should be avoided when it doesn't pay off, and non-standard (creative) solutions need to be carefully analyzed to ensure that they meet all requirements and constraints, potentially add to the time required to complete a design and to the cost required to prototype a design.

The risks of creativity, then, are that you might not find anything, and that you might get something unsatisfactory.