Engineering Design w/Embedded Systems

Lecture 14—Engineering Design Process

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Definition

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. You'd like to solve it.
  $\Rightarrow$ Use engineering design!

Engineering design is an open-ended process which applies technical knowledge in a creative way for some useful purpose.

Quotes on 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

Creativity

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.

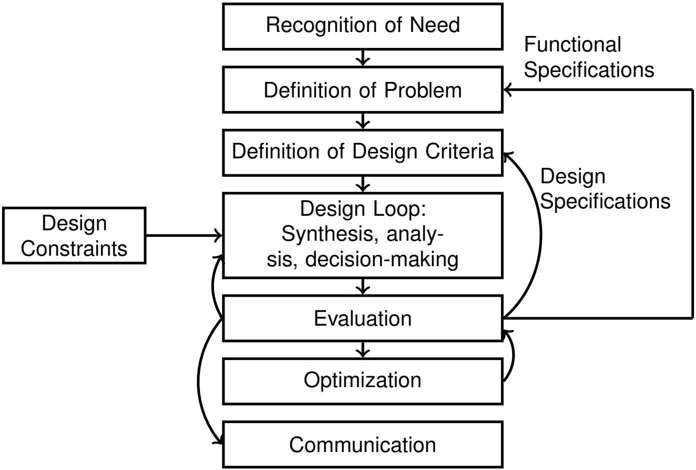
Engineering Design

"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 Engineering Design Process



Software is Different

Previous slide: a model for classical engineering disciplines—ends with the transfer of blueprints to manufacturing and construction firms.

Software is different.

Customer Requirements

In this phase:

- trying to figure out what the customer is looking for.
- note: customers might not know what they want;
- can always give 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 (but consider input).

Design Criteria

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

Examples of design criteria?

Design Constraints

Constraints are what make things interesting (as long as they're satisfiable).

- Your task: 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;
- 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 and guidelines

Four related terms:

- *design heuristic*: 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.

- *design guideline*: general rule based on experience and specific knowledge of the design problem that may be applied to a design solution.

  More specific than heuristics.

Standards and Specifications

- *standard*: provides more direction about the acceptable solution space by stating technical requirements that must be satisfied by candidate designs.

  Do not provide a complete solution, but do dictate a set of requirements.

- *specification*: in this class, 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.

Synthesis, Analysis and Decision-Making.

You've got 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.

Iteration

Expect to iterate:

- Even after you get a “best” alternative, maybe your criteria were wrong, or you didn’t satisfy all of the design constraints or meet the desired design criteria.
- When iterating, bring back less-favoured alternatives, and reconsider and revise all of the alternatives. You’ll get a better set of alternatives.

Once you have a sufficiently-good best design, exit the design loop. This design should satisfy all constraints and achieve the desired criteria.

Choose the winning design, optimize, and implement.

Innovation versus evoluation

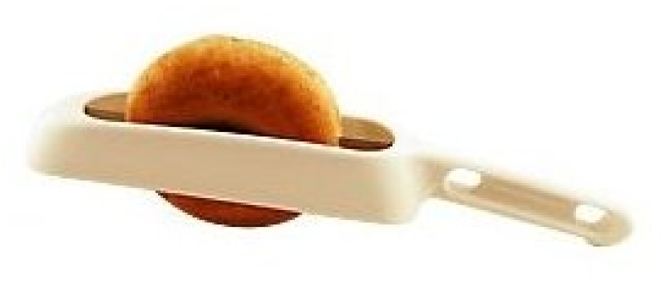
Solutions tend to have some innovation and some evolution. It's a continuum.

- 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).

Example: Brooklyn Bagel Slider



Goal: Avoid Bagel-Related Injuries.

What is innovative about this design? What is evolutionary?

Creativity

Popular misconception: engineering is not creative.

- Good engineering uses creativity when necessary.

Know when to innovate and when to build on others' designs.

Avoid the high-risk, low-reward category: make sure there is a payoff, and analyze your proposed solution carefully to ensure that it meets all requirements and constraints.

Risks of creativity

- adds to time required to complete a design;
- adds to cost for prototyping the design;
- might not lead to a solution at all; and
- might lead to an unsatisfactory solution.