ECE155: Engineering Design with Embedded Systems Winter 2015

Lecture 10 — Engineering Design & Analysis

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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.

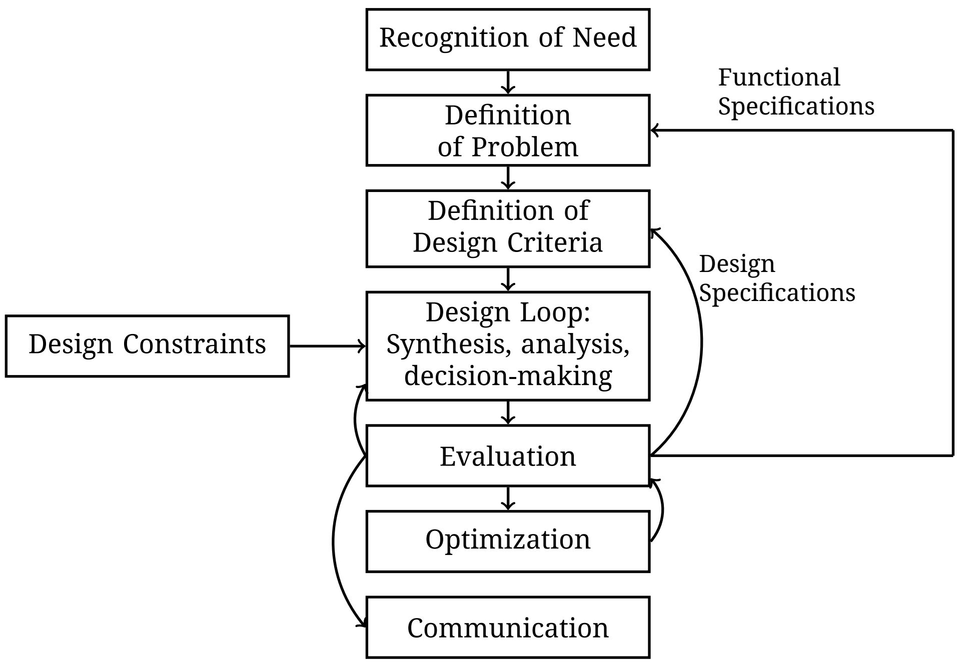
Engineering Design.

> *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. See: https://www.youtube.com/watch?v=BKorP55Aqvg

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.

Here are five steps in a typical creative process:

1. Gather information.
2. Make a concentrated mental effort to understand the problem.
3. Take a break (sleep, do something else, take a shower, etc.)
4. Discover the solution to the problem (often subconscious).
5. Write down the solution and refine it.

There is reason to believe that generating lots of alternatives (or, on a related topic, getting lots of practice developing skills [Rit07, Rit06]) is better than trying to come up with the one ideal solution.

Brainstorming and Brainwriting. Here are two techniques for generating ideas; you've probably heard of brainstorming.

The usual part of brainstorming is the synthesis part, where you write down all ideas. But there's also an analysis part, where you go over the ideas.

- Synthesis: come up with new ideas synthesizing the information; don't discount any ideas, just write them down.
- Analysis: look at all of the ideas (to some extent) and analyze them. Determine the most promising solutions.

Because unusual ideas show up, and aren't immediately discounted, they can help you come up with a variety of creative solutions, some of which might turn out to be practical.

Brainwriting is similar to brainstorming, but involves more paper.

- Write down tentative solutions on *solution sheets*.
- Each team member picks a solution sheet to refine.
- Exchange solution sheets until members run out of ideas.

Because you're writing things down, you can avoid dropping things on the floor.

Avoiding getting stuck. Roger von Oech [vO12] produces a lot of output about creativity. According to him, here are some mistaken beliefs that people often have.

- There is only one right answer.
- The creative process must be logical.
- They must "follow the rules" even if the rules are unwritten.
- They must be practical and therefore inhibit their fantasies.
- They must avoid ambiguity and therefore stifle their imagination.
- They avoid new ideas for fear of making mistakes.
- Play is frivolous, and new ideas are hard work.
- They narrow their focus and miss ideas in nearby areas.
- They are afraid to look foolish by suggesting an unworkable idea.
- They are not creative.

Evaluation

Moving on, let's talk about the evaluation phase of the design process. Now you have one or more candidate designs (design alternatives) and want to see how good it is.

A *design review* is an independent evaluation of a design alternative:

- act as a “sanity check” on the design; and
- are often conducted by evaluation teams consisting of clients and/or managers.

If all alternatives are bad (failed design reviews), the client might terminate the project.

Evaluation teams will consider the following questions:

- Does the design team have a thorough understanding of the purpose and goals of the design?
- Have all of the relevant requirements, criteria, and constraints been identified?
- Is the overall design plausible for meeting the design objectives?
- Does the overall design appear to meet the criteria specified?
- Is the (anticipated) performance of the design adequate?
- Are there any flaws in the analysis of the design?

Design Alternatives Consider presenting more than one alternative at a design review. In the presence of unclear requirements or in a large search space, having alternatives can help the customer pick the best alternative, rather than just saying “I don’t like your solution”. Also, trying to push bad designs forward can help you understand why those designs are bad.

Communication

The last phase of the engineering design process (and many other creative endeavours) is communication. You haven’t done anything if you don’t (successfully) tell anyone about it. But communication is also important en-route.

Communication between stakeholders The designers/implementers, managers, and clients need to communicate. Without communication, people tend to assume that things are going well, which can lead to unmet expectations and unpleasant surprises.

Intra-team communication. You also need communication within the design team. For a small team, communication helps with continuity and allows you continue the project even if an engineer leaves the company. (This is a key reason that extreme programming, which we’ll see later, plays up communication so much). For a large team, communication is mandatory for making sure that all of the parts integrate and for tracking the schedule.

Design Team Organization

Here are some considerations to keep in mind when organizing and managing design teams.

- Keep team sizes small; Amazon uses the “two-pizza” team concept, splitting large projects into smaller ones. Their team size is at most 8–10. Larger teams have too much coordination overhead.
- Consider how you want to divide responsibility. Extreme programming advocates collective code ownership; traditional models allocate responsibility for specific parts of the project to specific people.

- Ensure that each team member's contribution is important and that each team member understands how their part of the design contributes to the overall goal.
- Set up open communication, so that all members understand relevant schedules, deadlines, and intermediate objectives, and proactively track team members' progress. (Don't pester!)
- Encourage creativity when necessary, but make sure team members aren't going overboard.

Potential dysfunctions. Per Steve McConnell, *Rapid Development*, pp. 156–168, Microsoft Press, 1996.

- Lack of common vision
- Lack of identity
- Lack of recognition
- Productivity roadblocks
- Ineffective communication
- Lack of trust
- Problem personnel

Typical Set of Design Groups. Here are some design groups that a large organization might use.

- Development Group: tests the feasibility of new technologies and ideas.
- Design Group: refines a design to ensure manufacturability, reliability, safety, and efficient operation.
- Manufacturing Group: refines a design based on the results of the manufacturing process and the performance of test batches.
- Quality Control Group: monitors the quality of products in wide use.
- Customer Service Group: tracks the performance of products and ongoing maintenance performed for customers.

In reality, design groups work concurrently and must sometimes synchronize their work.

Development, design, manufacturing, quality control, and customer service tasks often require many groups to work together. Since these groups may have different goals and deadlines, consensus and cooperation may be difficult to achieve. (In fact, organizational inertia generally makes inter-group cooperation difficult, even without different goals and deadlines.)

Project management attempts to ensure that all groups work together as a cohesive unit. Time management is particularly important for any project with many cooperating teams; this includes scheduling meetings and deadlines.

References

[Rit06] Chanpory Rith. Talent isn't everything: 7 habits of highly effective junior designers, 2006. Online; accessed 7-December-2013.

[Rit07] Chanpory Rith. What 50 pounds of clay can teach you about design, 2007. Online; accessed 7-December-2013.

[vO12] Roger von Oech. Creative Think, 2012. Online; accessed 7-December-2013.