ECSE-211
Design Principles and Methods

Lecture 2D: The Engineering Design Process

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From the Last Lecture

What is design ?

Why do we need design ?

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Requirements and Specifications

- A specification is essentially a more detailed, or implied, requirement
- It may put values on some requirements
  - E.g. the requirement says "motor must fit in the space provided in the chassis" – the specification says max motor dimensions are 0.3m x 0.3m x 0.5m
  - The requirement says that the maximum torque must accelerate the vehicle to 100 kph in 5 seconds – the specification says that this needs to be 70Nm
- In a sense, requirements and specifications are the same
  - The requirements are what the customer (either end user or systems engineer) needs.
  - The specifications describe the performance of the system – and a production device must meet them to be acceptable
- A specification could come from an international standard related to a device designed for a particular need

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A Basic Engineering Design Process

- Engineering Design is a formal Process
  - The goal of the process is to construct a system to meet the requirements subject to:
    - The current state of technology
    - The capabilities of the design team
    - The manufacturing processes that exist within the company
    - The budget that is available for the design process
    - The final cost requirement of the manufactured product
    - The time available to complete the project
    - …

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A Basic Engineering Design Process

- So how does the Engineering Design Process allow an engineering team to move from a requirement

"Create an affordable electric autonomous vehicle capable of carrying four adults with a maximum range of 400km"

- To an operating system:

?

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A Basic Engineering Design Process

- This involves gradually increasing complexity and verifying each decision
- The final solution is then validated against the component or system requirements
- The concept of a "Verification and Validation Cycle"

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Contents

- Where does the Engineering Design Process start?
- The concept of a "Design Space"
- What is a Model?
- The System Model
- Increasing the Detail – Component Design
- The V-Cycle

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The Client or Stakeholder

- The client has a requirement or a need for a system
  - Could be an autonomous electric vehicle
  - Could be a system to place a satellite in orbit
  - Could be a need to increase the bandwidth of wireless transmissions (5G)
  - Could be a renewable energy power system
  - Could be an electric toothbrush or a dish washer
  - Could be a robot design for ECSE-211
  - …

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Where does the Engineering Design Process Start?

- With the client, who has a need – often expressed through a brief document or in a conversation
- The need can be expanded into a set of Requirements
  - A reasonably detailed list of what the final product must do
  - These Requirements could be related to:
    - Performance – e.g. for an EV achieve 400 km on a single battery charge
    - Physical constraints – weight, size, …
    - Environmental – emissions, recycling, …
    - Legal – standards, safety, …
    - Costs – manufacturing, price, running…
    - …

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The Generation of a Requirements List

- The more that is known about the needs, and the implied needs and constraints, the easier it is to find a solution
- For example, a requirement may say that an electric vehicle must achieve 300km on a battery charge
  - This raises questions – which MUST be answered
    - How big is the battery?
    - How heavy is the vehicle?
    - What power is needed from the motor?
    - What is the motor efficiency?
    - What are the other losses in the system that the motor has to overcome?
    - …
- Until these are answered, you do not have a complete set of requirements.. *If you do not answer them at the start, you will have to answer them during the design process and this can increase the costs of the design.*

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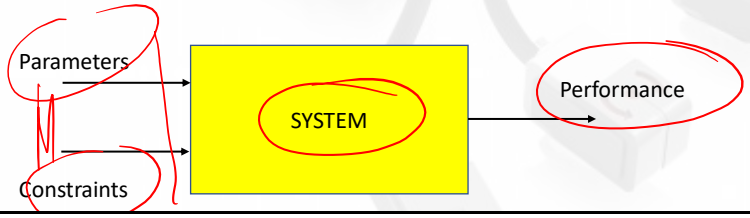
Concept of a Design Space

- The requirements define the space in which the solution is to be found
- They can be split into two components
  - Performance values, i.e. what the system MUST achieve
  - Inputs (or Parameters)
    - Parameters – values which can be altered
    - Constraints – limits on certain inputs



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Concept of a Design Space

- In general, the requirements put values (or ranges) on the performance but not necessarily all the outputs
- The requirements may also specify some of the inputs – in effect constraining them
- Time, budget, technology, legislation, … may also constrain both inputs and some of the outputs
- So – we need a SYSTEM which generates particular outputs (and others we don't care about) and has several inputs – some of which may be specified…
- BUT – how are these all linked?

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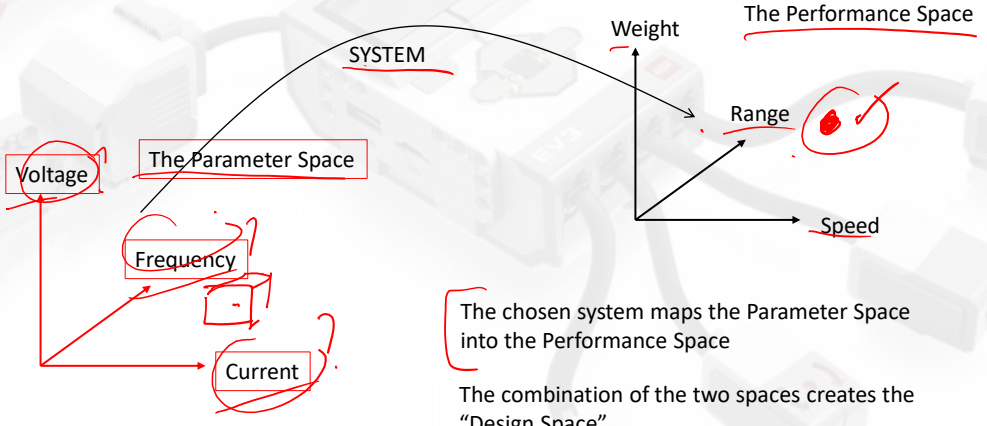
Concept of a Design Space



The chosen system maps the Parameter Space into the Performance Space

The combination of the two spaces creates the "Design Space"

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Concept of a Design Space

- Design is a process of
  - Specifying the Design Space
  - Efficiently searching the Design Space for a Solution
- So – there are 2 stages…
  - First – create the design space (i.e. think of a solution to the problem)
  - Second – once the design space is created (with bounds on values) – search it for an "optimal" solution
- These two steps are the basis of the Engineering Design Process

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Where does the Engineering Design Process Start?

- The Requirements provide a view of what the Product should do BUT they do not say HOW to do it…
  - But they are the Starting Point
- A translation of the Requirements is needed to achieve the HOW
- The HOW is implemented through a proposal for a System by an Engineering Designer
- The Engineering Designer uses experience and knowledge to perform the translation
  - We will discuss this process further in later lectures, but the first step is to construct a *MODEL*
  - Some will say that this is a natural process for humans
    - *"Humans are model-builders"*

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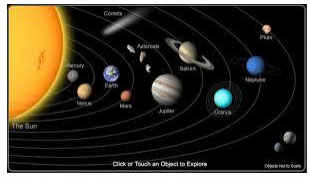
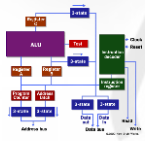
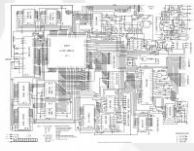
What is a Model?

- We need a definition for this course
- A Model is
  - A representation of a physical system or process
    - The structure of a planetary system
    - A map
    - The Engineering Design Process
    - A circuit







- What do all these have in common?

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What is a Model?

- It is a Representation of a System, Device or Process which
  - Provides an understanding or description of the physical structure at a level which is appropriate for the user's purpose
  - It could provide information in a graphical form
    - "A picture, or sketch, is worth a thousand words"
  - It could be a written description, or based on mathematics describing the physics
  - It allows a prediction of the output response of a physical structure to a particular set of inputs
    - At some level of detail

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Why is a Model Needed?

- Obviously, the ultimate Model is the Physical System itself
- So – why use anything else? Just build the physical device..
- Physical Devices are:
  - Expensive
  - Take a long time to construct
  - May need specialized equipment for manufacture
  - Difficult to test
  - Contain too many variables
  - Maybe too large or complex (e.g. an aircraft carrier, a processor chip)
  - …..
- Engineers need fast response during the early design phases
  - So – simple models…

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Why is a Model Needed?

- So – a Model is a structure that allows:
  - The physical structure (system, device, process) to be represented
  - The checking of Product ideas against the Client Requirements
  - A prediction of output performance in response to particular inputs
  - Is appropriate to the level of detail needed at the current point in the design process
- A model allows Validation and Verification of the current system design against Requirements..
- But
  - What is Validation and Verification?

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Validation and Verification

- According to the IEEE:
  - *Validation* is an exercise largely conducted with external clients and stakeholders to provide assurance that a product meets (or will meet) the needs
  - *Verification* is an internal operation which evaluates whether a product, service or system complies with a requirement (which may be a regulation, a specification, etc.)
- In this course, we will merge these two terms and refer to "Validation and Verification" as an exercise which is repeated to ensure that the final product meets requirements
- The method by which these are implemented is "*Testing*"

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The System Model

- The Engineering Design Process starts with a set of client needs
- This is translated into a set of Requirements for the final system
  - Includes the needs but also adds in other information such as the capability of the design team, etc.
- The Requirements lead to the development of a System Model
- What is a System?
  - *A collection of interdependent functional elements that, when brought together as a single unit combine to meet a set of common objectives.*
- The System Model is the highest level model in the Design Process

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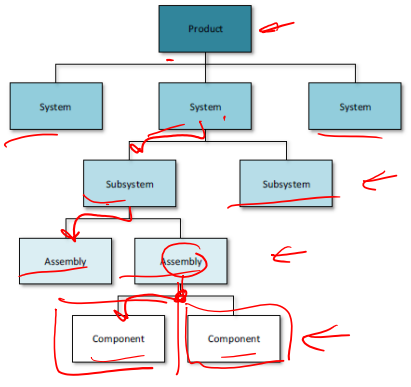
The System Model

- A Product (Final Design) is a combination of one or more systems
- Each System is composed of parts – subsystems, etc.
- For a Lego Robot, the "Product" is the robot
  - The System is the Hardware and Software structures and their interconnections that implement the Requirements
  - The subsystems are the sensors, the motor drives, the Lego structures, the software components, etc.



Example of System Hierarchy

Image courtesy of Morgan Jenkins, Siemens DISW

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The System Model

- Requirement:
  "I want the highest electric range for a car in this class"

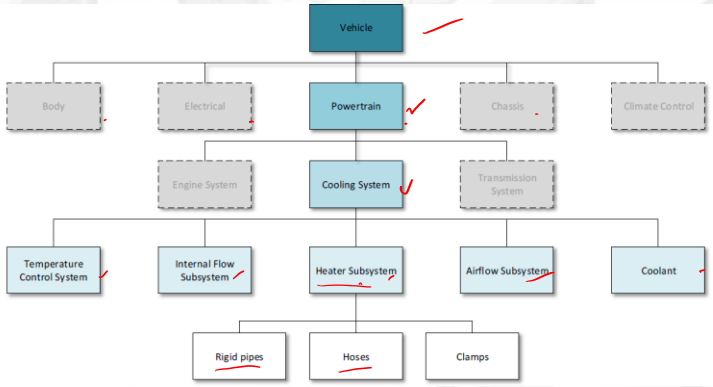

Image courtesy of Morgan Jenkins, Siemens DISW

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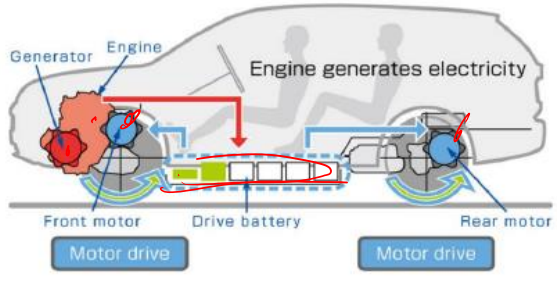
The System Model

- A sketch showing how the subsystems address the requirements
- Combined with the previous diagram, we now have a System Model



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The Increasing the Detail

- The System Model provides an overview of the proposed solution to meet the Requirements
- Once it has been verified*, the subsystems can be defined
- The requirements of each subsystem can be specified
- Each subsystem can be implemented as a set of components
- The requirements for each component can be specified
- *Now – and only NOW – each component can be designed and verified (tested)*

* Verified in the sense that it has the potential to meet all the requirements..

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The Development of the System

- The System Design (as discussed in the first lecture) is based on
  - The current state of knowledge
    - Physics
    - Mechanics
    - Control
    - Software
    - Manufacturing
    - …
  - The tools available to
    - Implement models – could be virtual or physical
    - Test the models

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The Development of the System

- The Solution (Product) which satisfies the Customer Requirements is non-unique
- Each design team will have different skill levels and capabilities
  - Background knowledge
  - Previous Experience
  - Access to, and ability to use, the various tools to support the design process
- Hence the Laboratories in DPM
- They are intended to
  - Expand your knowledge/understanding of the capabilities of the various components
  - Train you in the use, capabilities and limitations of the simulation tools and software environment
  - Develop an understanding of what is possible
- This is Research and Development

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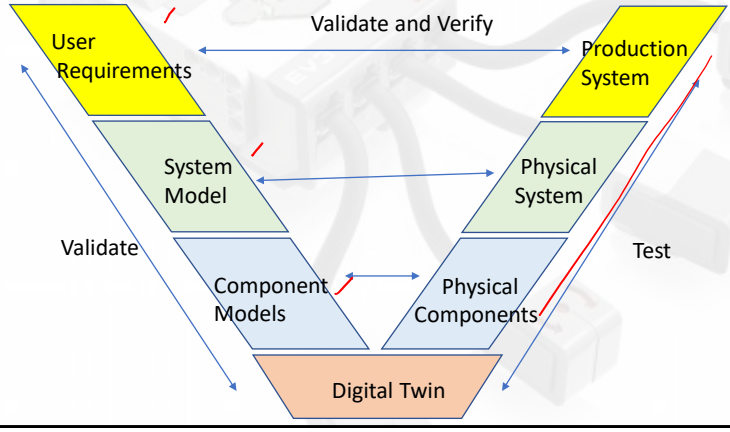
The V-Cycle

- One of several ways of managing the Engineering Design Process
- Illustrates the gradual increase in detail as the process moves forwards



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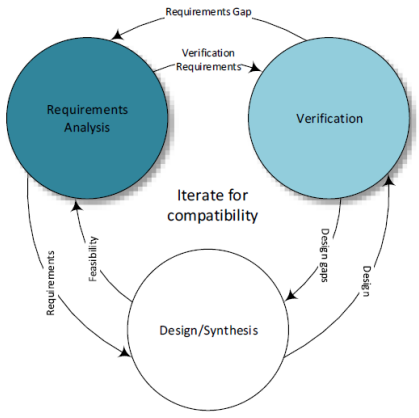
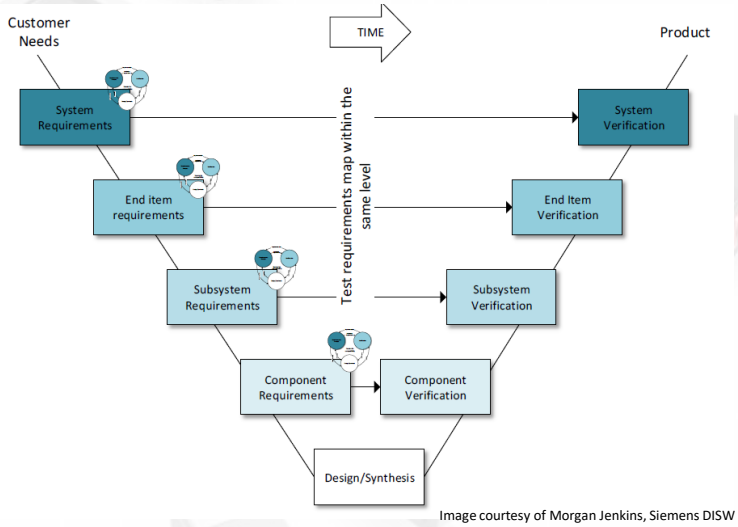
The V-Cycle – Starting with Customer Requirements





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Summary

- We have
  - Examined at the Role of the Client in the Process
  - Discussed the translation of Needs into Requirements
  - Defined the concept of a “Design Space”
  - Considered the use of Models in the Engineering Design Process and the role that tools play in both developing virtual models and testing the

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Summary

- We have
  - Described the role played by a System Model as the start of the real design process
  - Seen how the V-Cycle can be used to implement and control the EDP
  - Specified and justified the objectives of the laboratories which are part of the DPM course
    - All design teams need to learn how to use the tools available
    - All design teams need to understand the capabilities and limitations of the components to be used to implement the Design Solution

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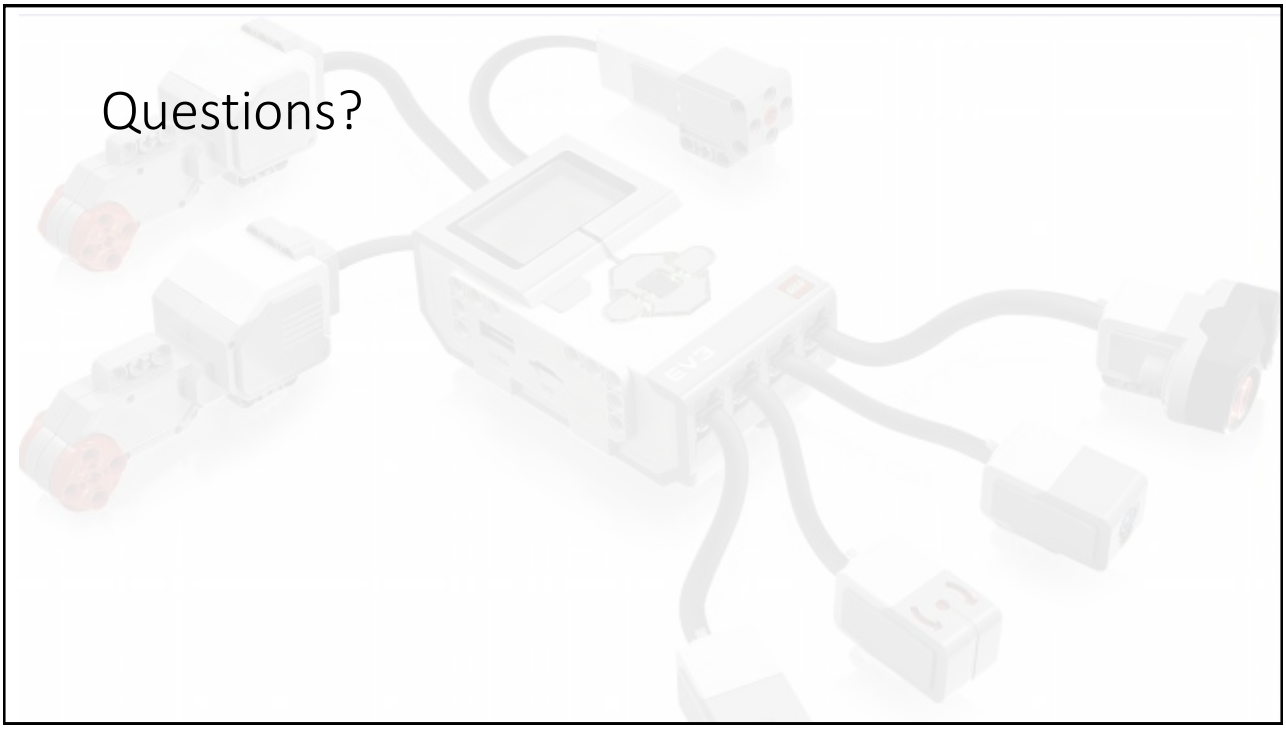
Questions?



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