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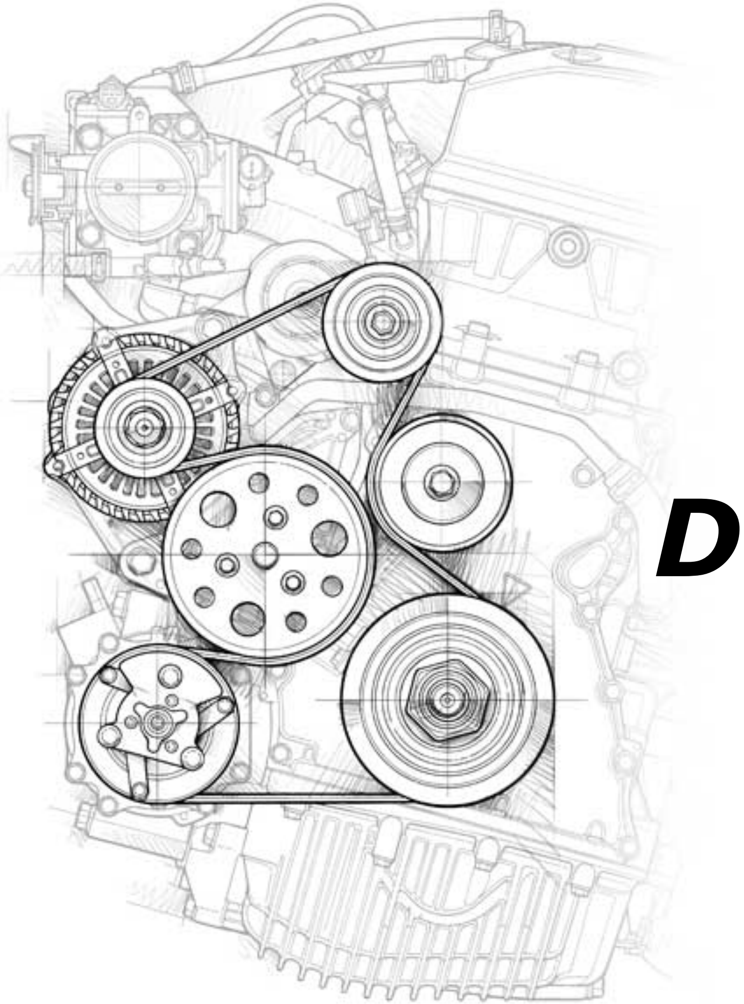

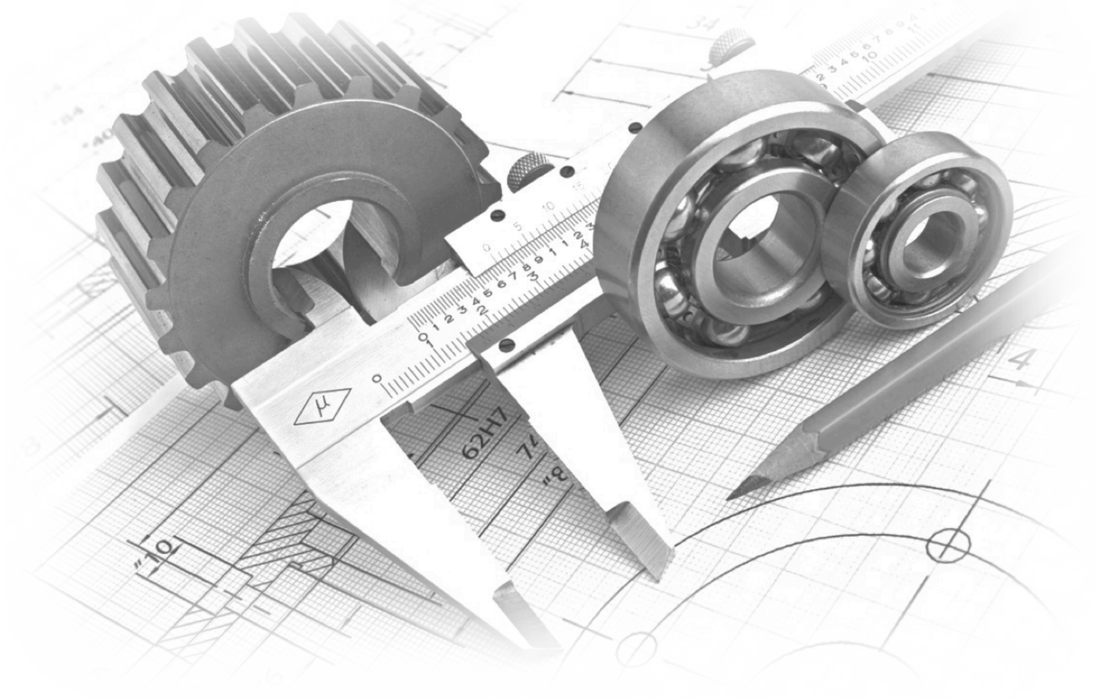

Design to Manufacture

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Contents

My lectures are about

- Learning how to think
- Changing your mindset to think in a more creative and innovative way
- Understanding the importance of design and its impact on the entire product life cycle
- Obtaining knowledge on various manufacturing methods
- Gaining an ability of thinking how to manufacture something during its design stage

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Lecture 1. Introduction to Design

Dr. ByungChul (Eric) Kim

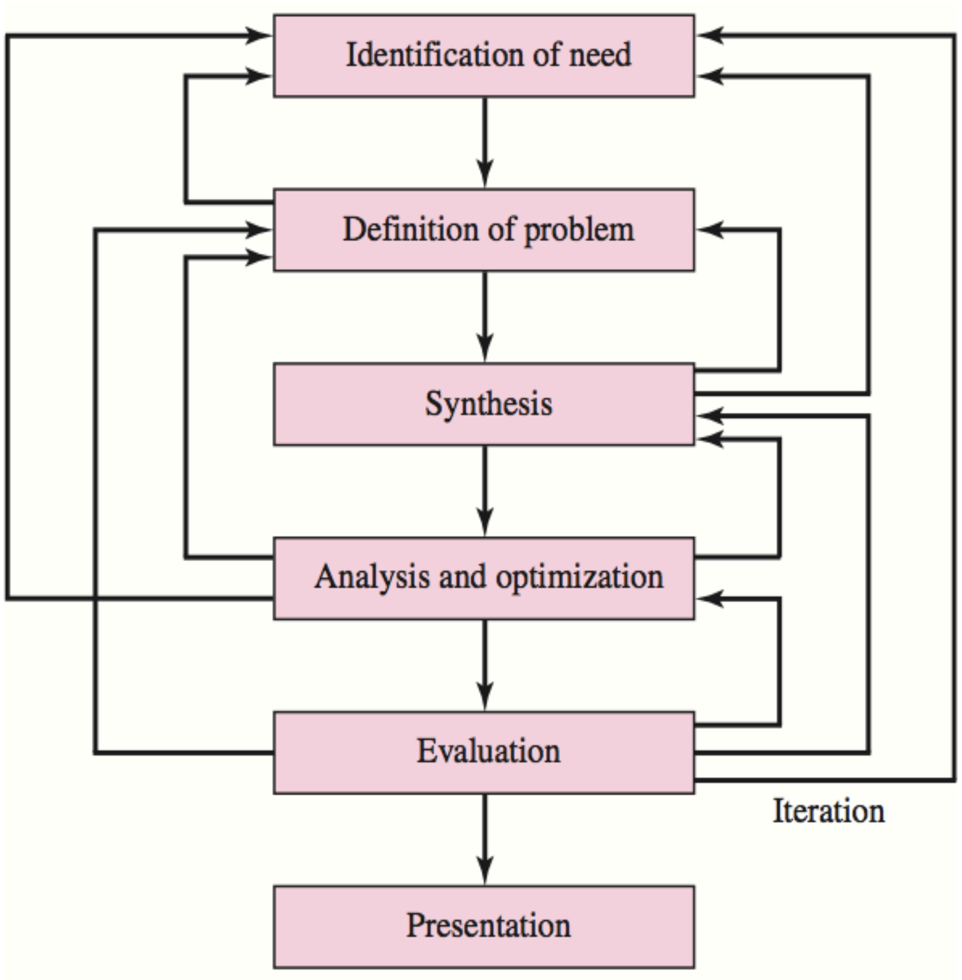
What is Design ?

- Formulating a plan for the satisfaction of a specified need or to solve a problem

- If the design results in the creation of something having a physical reality, then the product must be
  - Functional
  - Safe
  - Reliable
  - Competitive
  - Usable
  - Manufacturable
  - Marketable

What is Design ?

- Highly iterative process (for mechanical engineers, electrical engineers, mayors, CEOs, etc)



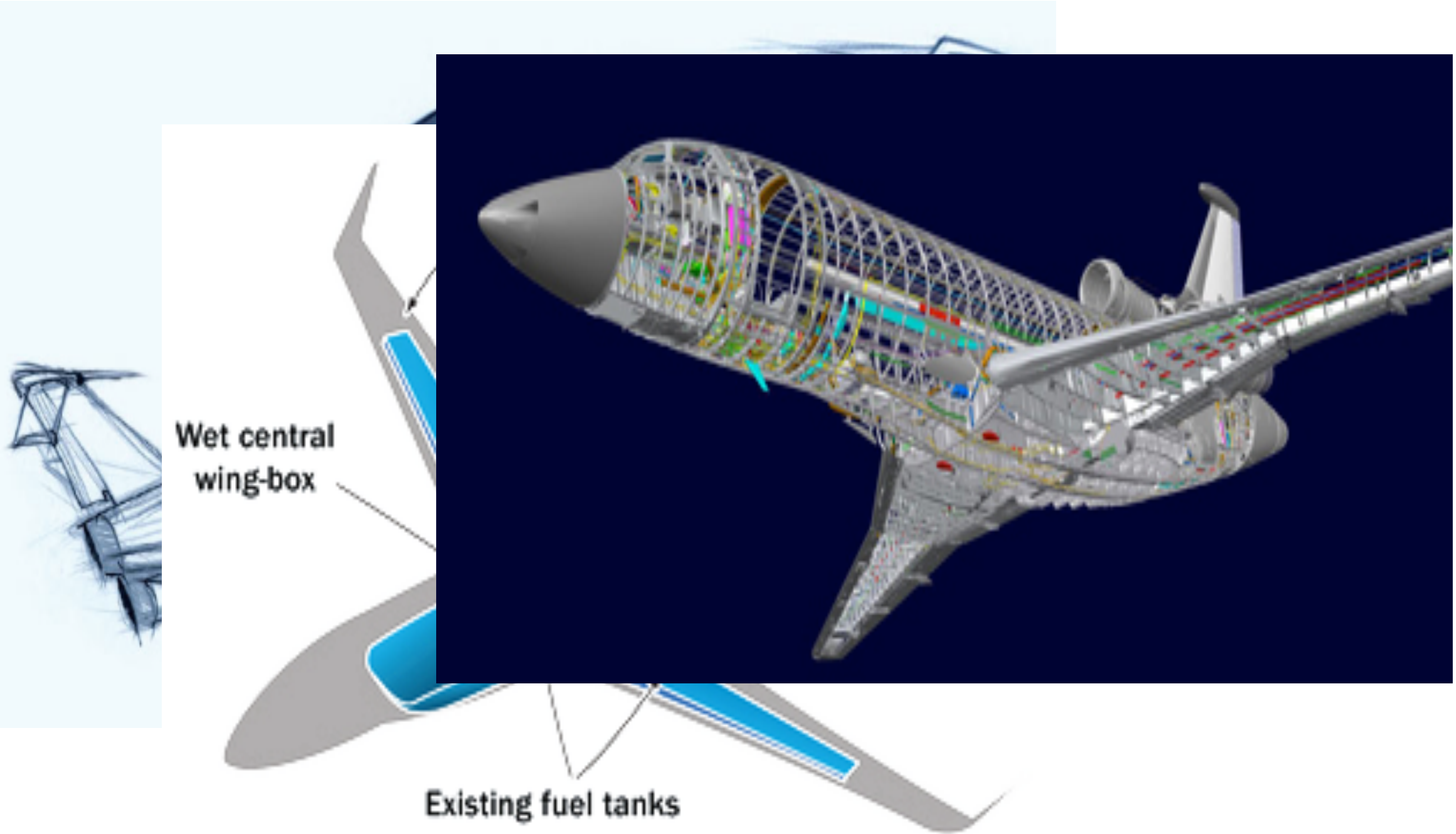
1. Know and understand their customers' needs
2. Define the problem they must solve to satisfy the needs.
3. Conceptualise the solution through synthesis.
4. Perform analysis and optimise the proposed solution
5. Check resulting design solution to see if it meets the original customers' needs.

Ref) Shigley's Mechanical Engineering Design, McGraw Hill, 2006.

What is Design ?

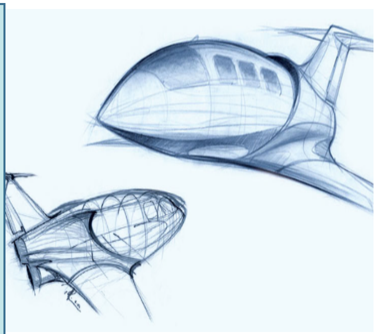
- Decision-making process
  - From too little / the right amount of / an excess of partially contradictory INFORMATION
  - The designer has to be personally comfortable with a decision making, problem solving role.
- Communication-intensive activity
  - Engineers have to communicate effectively and work with people of many disciplines. These are important skills, and an engineer's success depends on them.
  - Written / oral / visualised forms
  - In an accurate and ethical manner
  - Even with yourself
  - Even with customers who you have never met before
  - Even with previous designers who have designed similar products

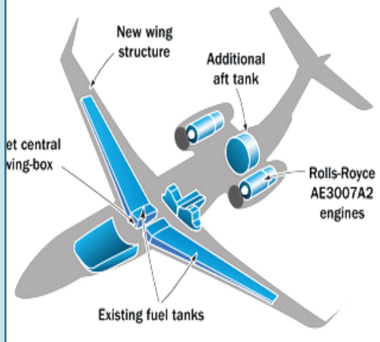
What is Design ?

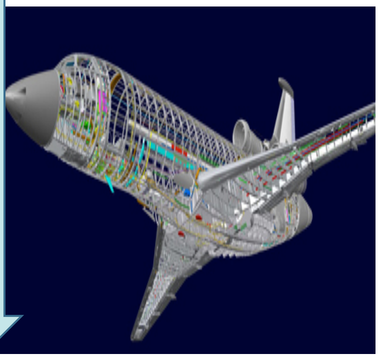


What is Engineering Design?

Abstract







Detail

Cultural stream

Politics
|
Sociology
|
Economics
|
Science - Engineering science — ***Engineering design*** — Engineering technology - Production
|
Industrial design
|
Architecture
|
Art

Technical stream

Ref) G. Pahl, et. al. Engineering Design: A systematic approach, 2007.

What is Engineering Design?

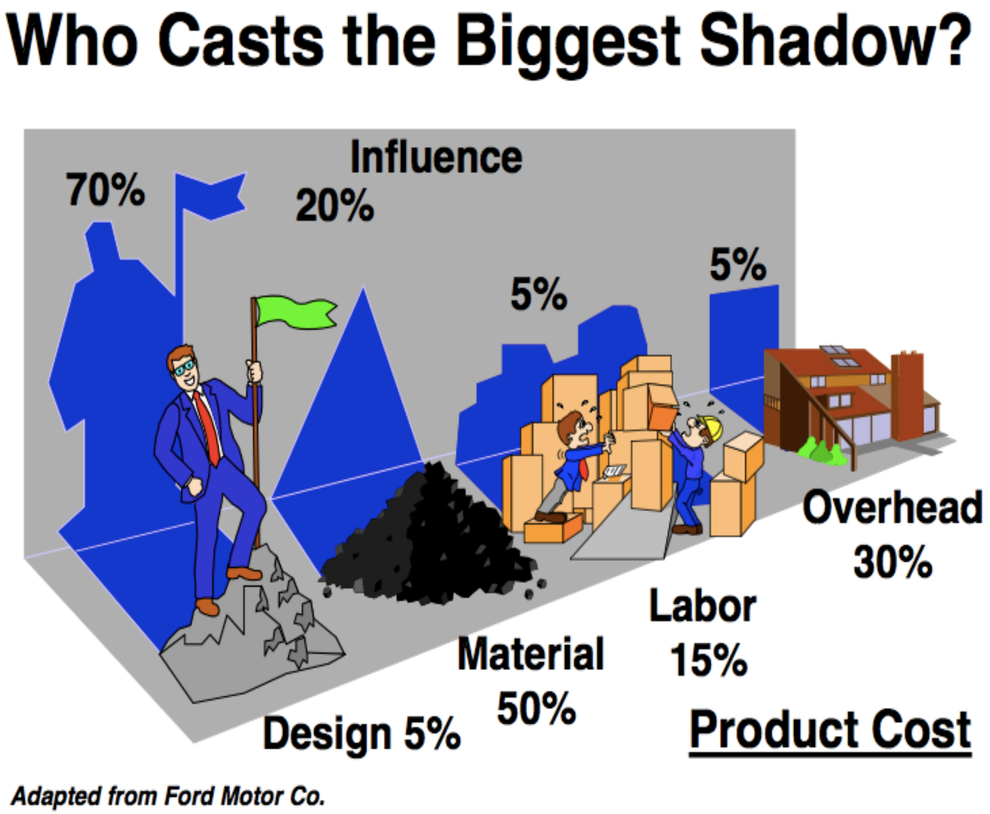
- Socio-technical decision-making process
  - Human preferences, legal, economic, environmental & social impacts are considered.
  - Laws and insights of science are contained.
  - The outcome is a technical product as an artifact. (Science vs. Technology)

- More sophisticated output than conceptual design
  - Engineering drawing/CAD model, specifications

- *This means that a good engineering designer should have multidisciplinary knowledge and experience. Studying all artifacts around you will be good learning! Watch everything carefully and think!*

Importance of Design

- Poor design leads to failure of the end products in terms of technical performance, manufacturing cost and marketing.
- It may cause disasters and threaten people's lives.



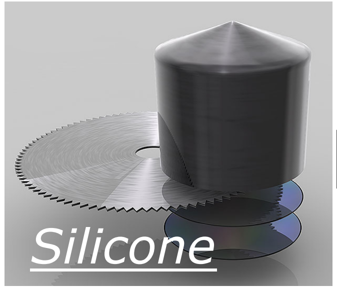
Science vs. Technology

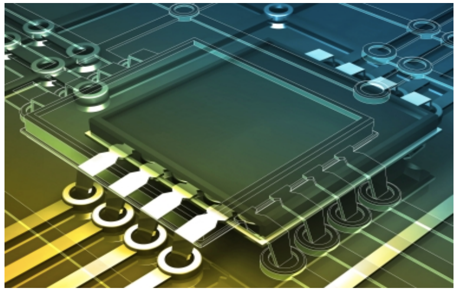
Science	Technology
Knowing	Doing
A single answer	Multiple answers
Discovery	Design, Invention, Production
Why?	Why not?
Drawing correct conclusions based on theories	Decision-making (incomplete data and approx. model)
Experiments, logical thinking	Design, planning, testing, problem solving, communication

Science vs. Technology

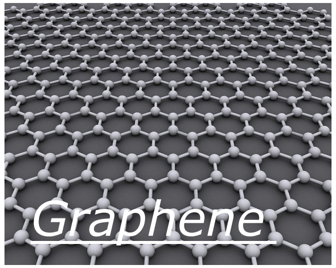
Technology is not just the practical application of Science.

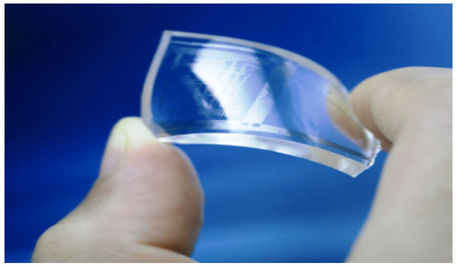
Science-driven Technology


Silicone




Plastics

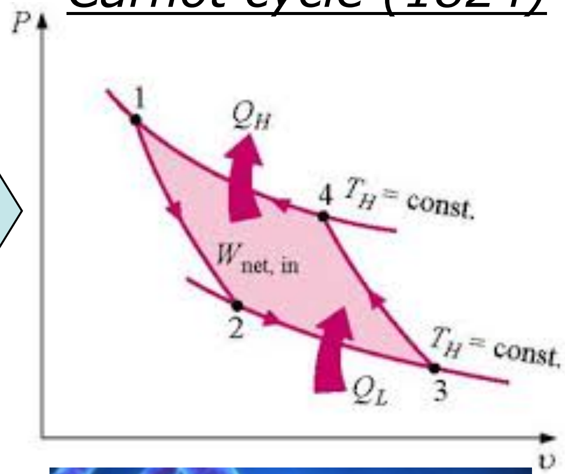

Graphene

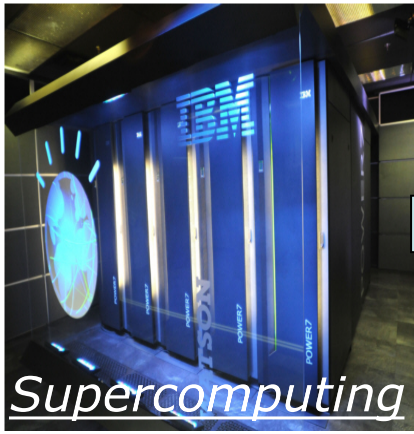


Technology-driven Science

Steam engine (1st century)

Carnot cycle (1824)





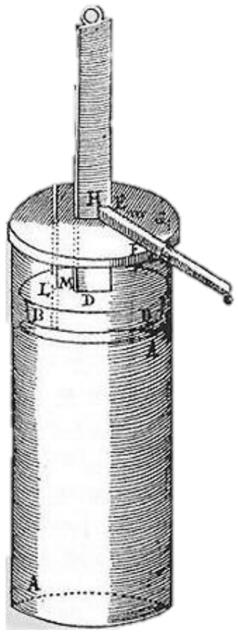
Supercomputing


Genome map

Revolution by Design

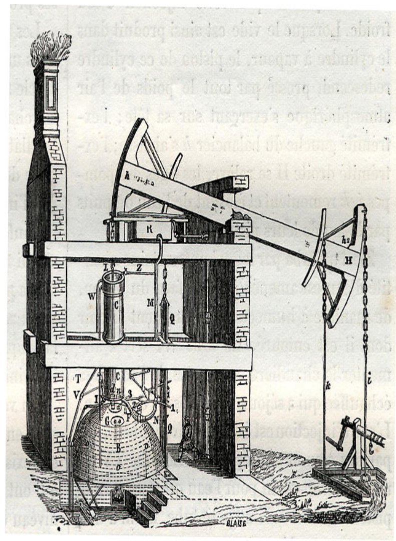
- History of the steam engine

Heron (Greek)
Roman Egypt,
1AD

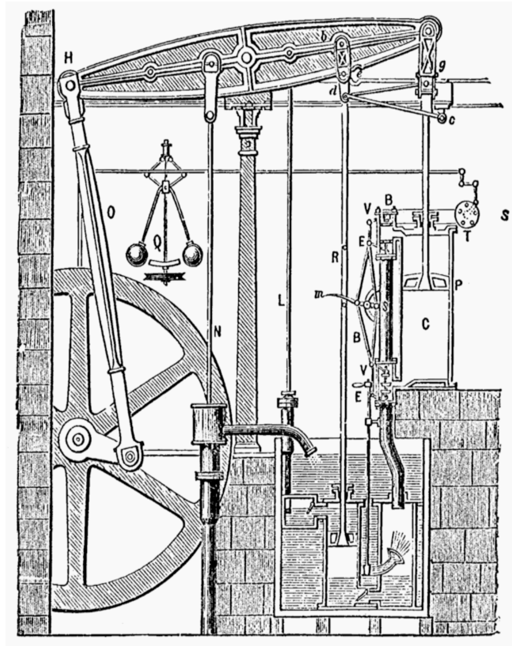


Denis Papin
(French)
England, 1680

Thomas Savery
(British)
England, 1698
: First steam engine applied industrially



Thomas Newcomen
(British)
England, 1712
: First practical steam engine



James Watt
(British)
Scottland,
1765~1774

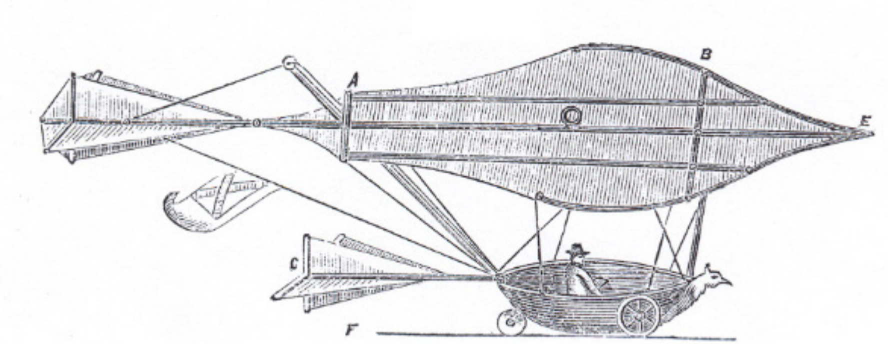
Triggered industrial revolution!!! Why?

Revolution by Design

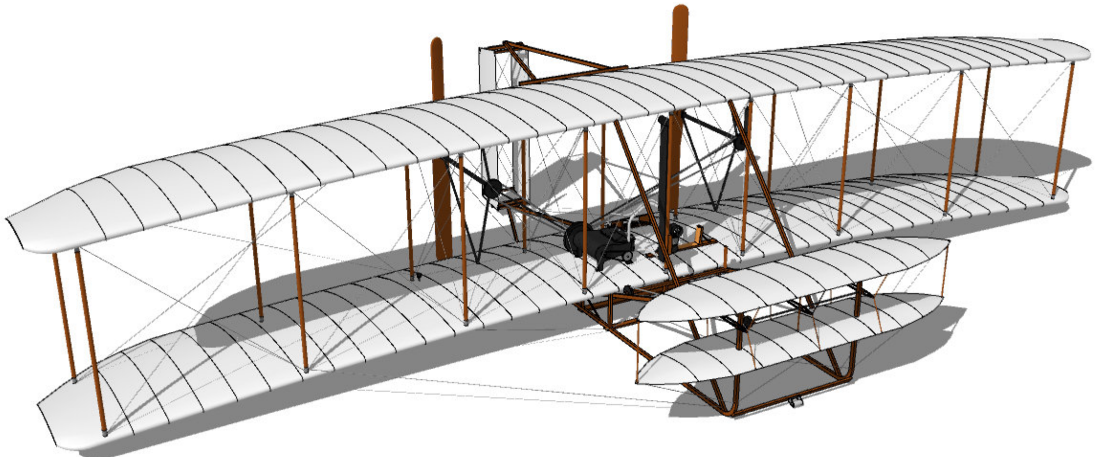
- Flying machines

Mimicking Birds

Why did people waste a lot of time to mimic birds?



George Cayley "Father of aviation" (British), England, 1799
: First "fixed wing concept"



Wright brothers (American), US, 1849
: First PRACTICAL fixed-wing aircraft

Revolution by Design

- How did they achieve the innovation?
- What made their design revolutionary?
- Did they really know the way to achieve the innovation?

AXIOMATIC DESIGN

History of Axiomatic Design

- Developed by Prof. Suh in 1970s
  - Head of the Department of Mechanical Engineering at MIT (1991~2000)
  - Founding Director of the MIT Laboratory for Manufacturing and Productivity (1977-1984)
  - Presidential appointment at US NSF (National Science Foundation) in Engineering
- The ultimate goal of Axiomatic Design
  - Establish a scientific base to improve design activities by providing the designer with a theoretical foundation based on logical and rational thought processes and tools

His Motivation

- In the past, many designers have designed their products iteratively, empirically, and intuitively, based on years of experience, cleverness, or creativity.
- Design ability was considered to be highly empirical and experience-based, and very hard to be acquired by education.
- *Can we make human designers more creative, reduce the random search process, and minimise the iterative trial-and-error process to determine the best design?*
- *What is good or bad design? How can we judge?*
- *There are many practical guides for achieving a good design based on personal experiences, but can't we find a simple and compact law for a good design?*

If there is such a principle, it could be called 'science'.

Definition of Design in AD?

Design is an interplay between

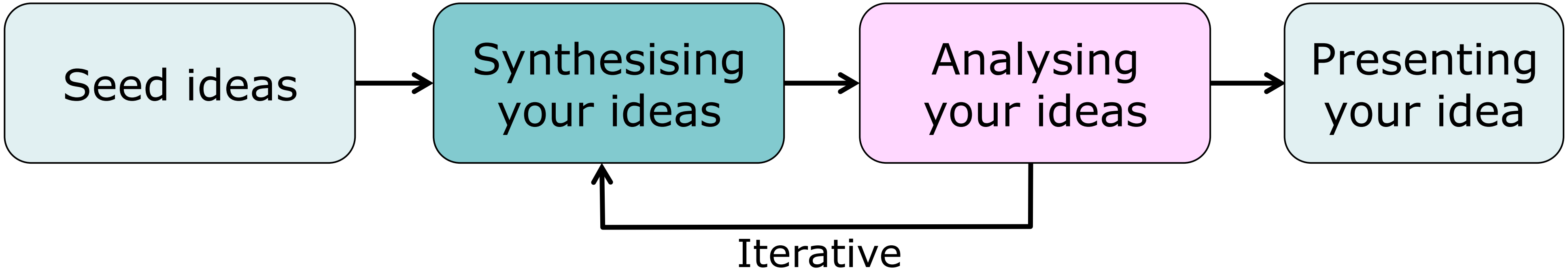
What we want to achieve

Mapping

How we achieve it

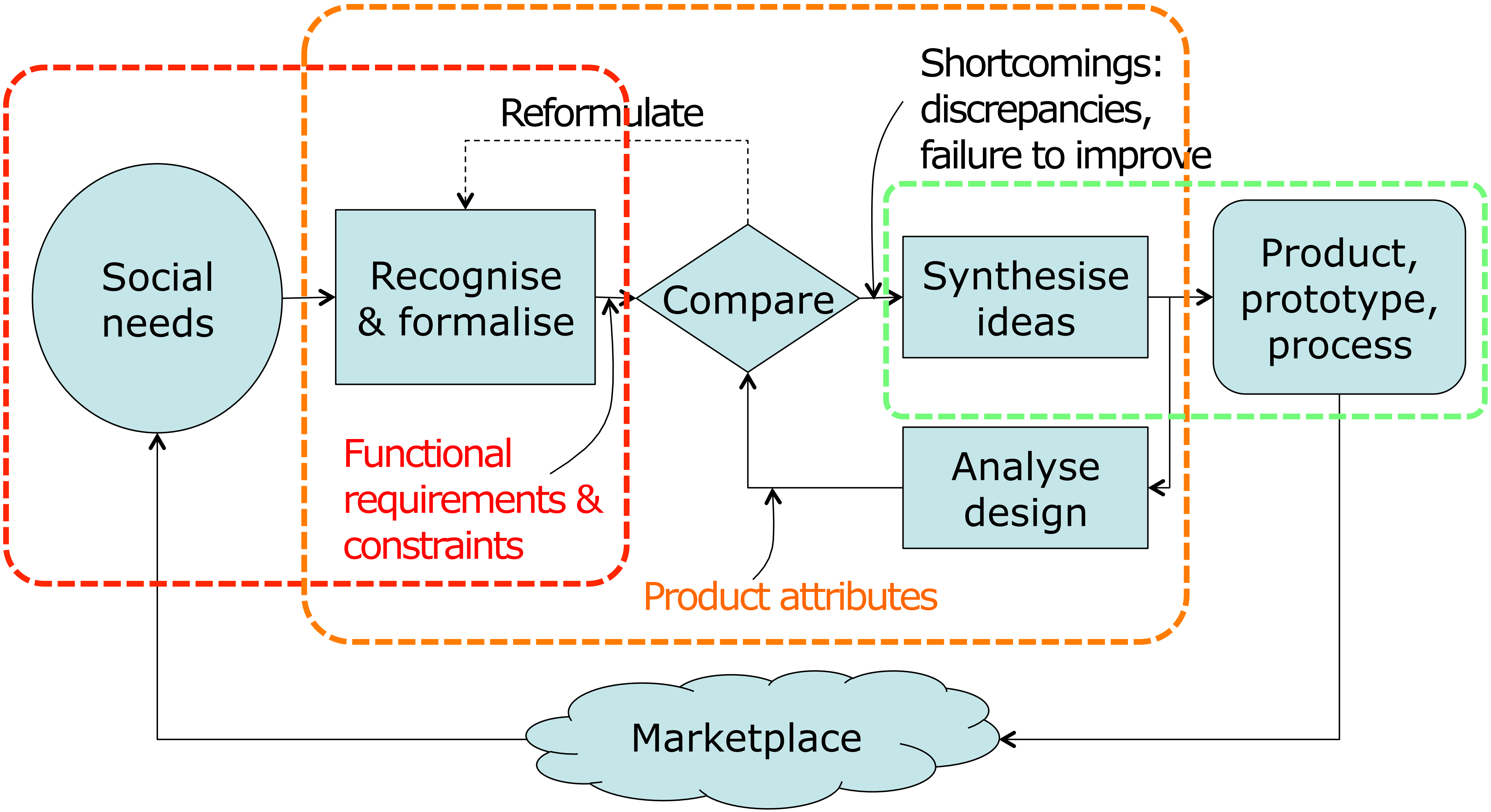
Uniqueness of Axiomatic Design

- Design: Synthesis process vs. Analysis process
- Different from other algorithmic approaches (e.g. TRIZ)



- In AD, analysing your ideas quickly and accurately is much more important than the synthesis process. It is to maximise the degree of freedom in synthesis (source of creativity) but filter bad design quickly.
- It makes your decision-making process faster and more accurate.

Design process in AD

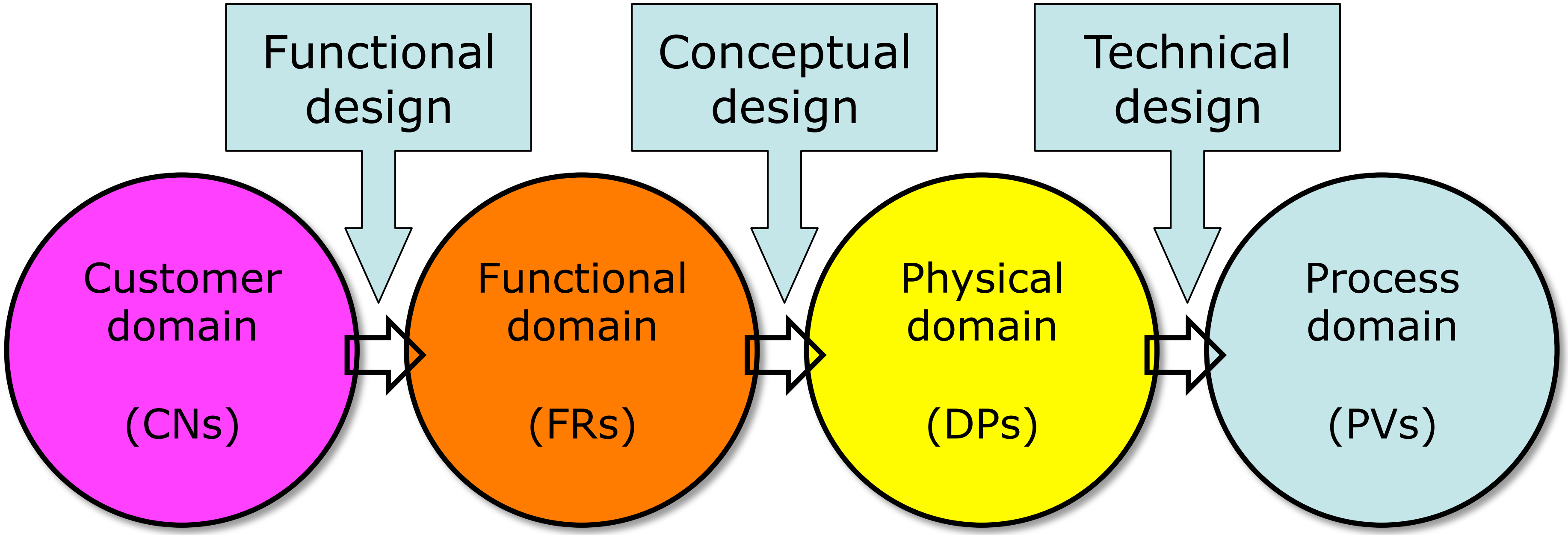


Definitions in AD

- CNs (Customer's Needs) ***What adds value***
- FRs (Functional Requirements) ***What it does***
  - A minimum set of independent requirements that completely characterises the functional needs of the product (or software, organisation, systems, etc.).
- DPs (Design Parameters) ***What it looks like***
  - Key physical means that characterise the design satisfies the specified FRs.
- PVs (Process Variables) ***How we make it***
  - Key variables that characterises the process that can generate the specified DPs.
- Cs (Constraints) ***What we need to avoid***
  - Bounds on acceptable solutions. (input constraints / system constraints)

Axiomatic design framework

- 4 generic domains help designers to distinguish "What they want to achieve" from "How they can achieve it", and to see a big picture.
- Mapping processes from "What" to "How"
- AD provides a set of laws for the best decision-making in the mapping process.



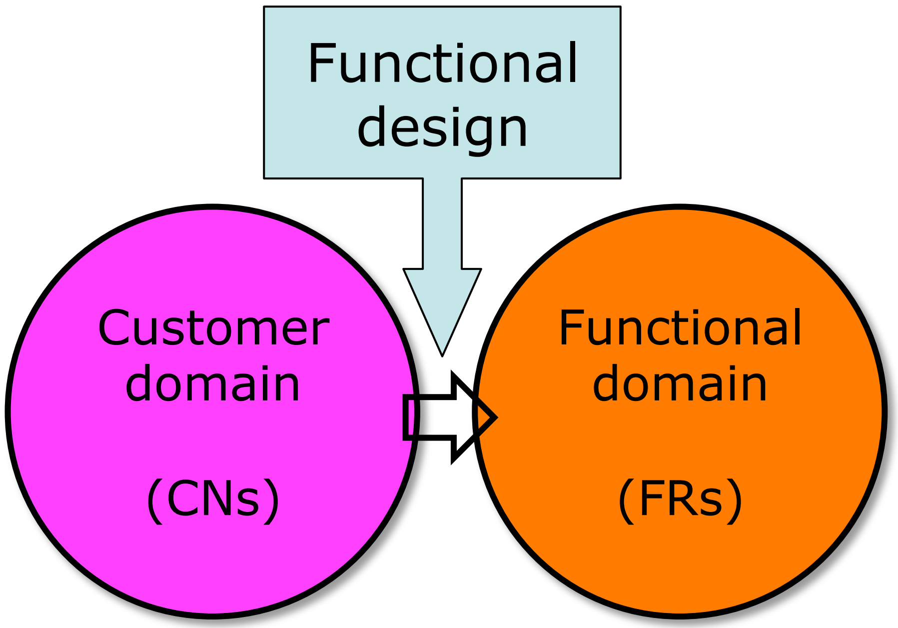
< Domains and mapping >

Examples of domains in design

Domains Character Vectors	Customer Domain {CAs}	Functional Domain {FRs}	Physical Domain {DPs}	Process Domain {PVs}
Manufacturing	Attributes which consumers desire	Functional requirements specified for the product	Physical variables which can satisfy the functional requirements	Process variables that can control design parameters (DPs)
Materials	Desired performance	Required Properties	Micro-structure	Processes
Software	Attributes desired in the software	Output Spec of Program codes	Input Variables or Algorithms Modules Program codes	Sub-routines machine codes compilers modules
Organization	Customer satisfaction	Functions of the organization	Programs or Offices or Activities	People and other resources that can support the programs
Systems	Attribute desired of the overall system	Functional requirements of the system	Machines or components, sub-components	Resources (human, financial, materials, etc.)
Business	ROI	Business goals	Business structure	Human and financial resource

Design is communication

- **CN-FR mapping**
  - translate CNs into specific FRs by using engineering terminologies.
  - and predict the potential customers' need and create new FRs to meet their potential desire.
  - and analyse the FRs of the previous product and find out what the previous designer missed.



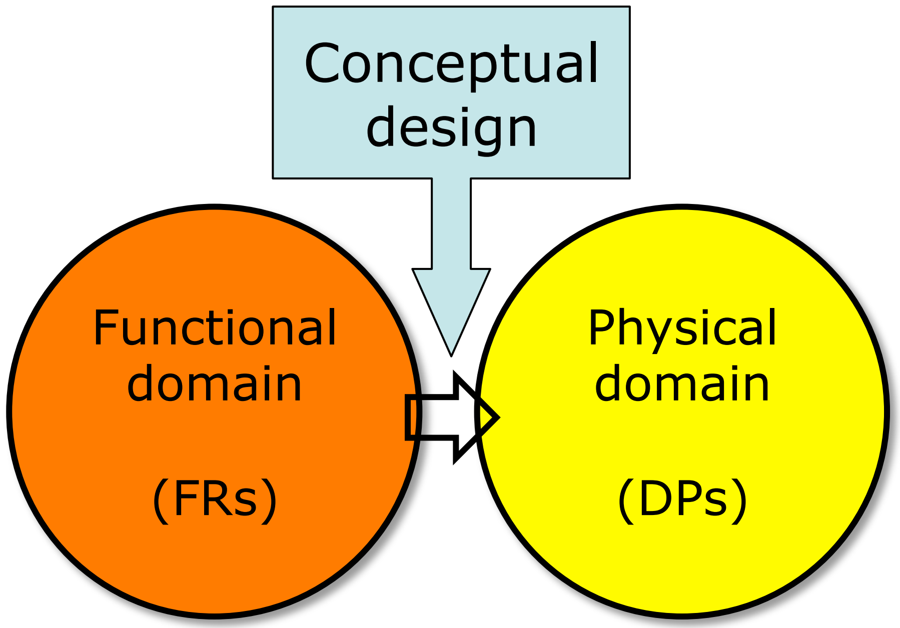
e.g.

- slippery ➔ surface friction
- difficult to rotate ➔ torque, torsion, friction
- strong ➔ stiffness, strength
- stretching ➔ elongation, strain
- force ➔ tensile, compression, bending, torsion, …
- heating ➔ conduction, convection, radiation, …

Functional Thinking

- **FR-DP mapping (most important procedure in AD)**
  - synthesis ideas using scientific knowledge, experience, analogy from other examples, laws of nature, and all possible ways in order to generate physical means to achieve the functions.
  - analyse the synthesised solution repeatedly until an optimal solution can be found. (Decision-making)

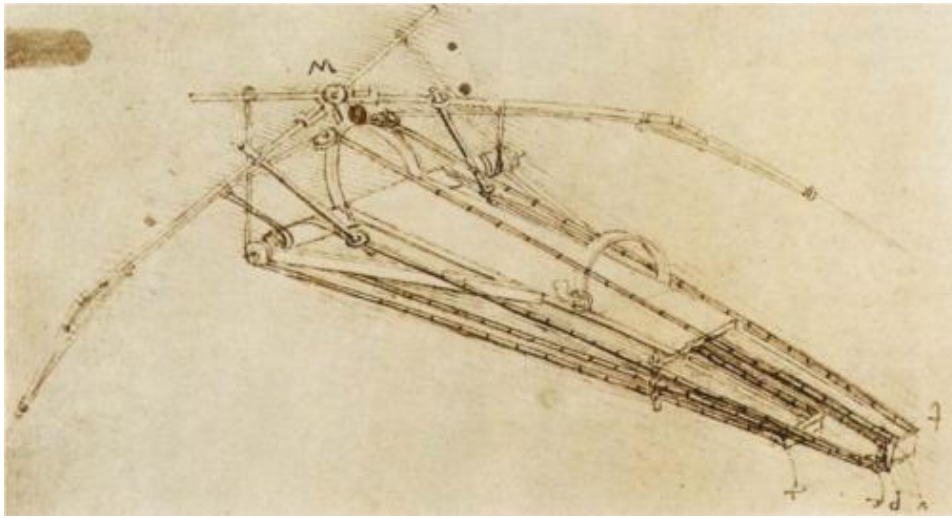
***Make correct decisions quickly by filtering out bad designs by using Axioms.* Still iterative but faster and strategic.**



Provide the underlying principles, theories and methodologies improving the designers' creativity.

Functional Thinking

Example of design failure due to lack of functional thinking



Functional Thinking

The FRs must be defined without ever thinking about something that has been already designed or what the design solution should be. ***(Solution-neutral !!!)***

Examples

CN: Transport people in the air
FR: Provide a vehicle system that has parts providing lifting and thrust forces in the air (solution-neutral)
cf. An aircraft (solution-specific)

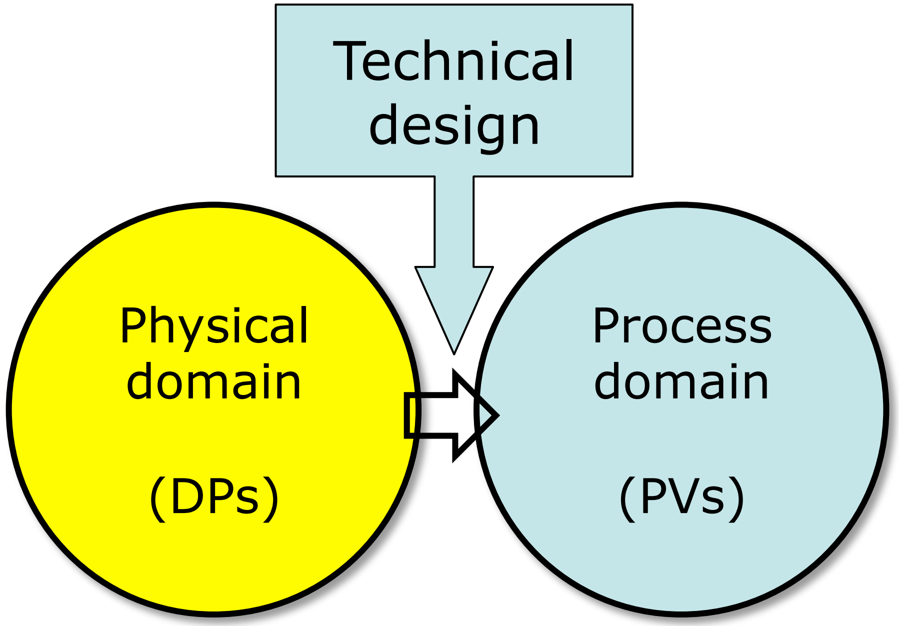
CN: Transport goods over the Pacific ocean
FR: Provide a vehicle system that produces buoyancy and thrust forces on the water (solution-neutral)
cf. A ship (solution-specific)

Design for Manufacturing

- **DP-PV mapping**
  - consider the manufacturing process of the physical means (DPs) that can achieve the FRs in the conceptual design stage.

    "Concurrent engineering" or "Simultaneous engineering"
  - When existing processes are used to minimise capital investment, the existing process variables may acts as constraints in choosing DPs.

When you design a new manufacturing process, DP-PV mapping is exactly like FR-DP mapping.
This is why the AD mainly focuses on FR-DP mapping.



Importance of effective communication

'The Expert' written & directed by Lauris Beinerts (https://youtu.be/BKorP55Aqvg)

An extra skill you need is to translate the engineering description for your design reversely into common language.

Next Lecture

How can we design a good product?

Axiomatic Design Principle