GRENOBLE INP UGA Génie industriel

École nationale supérieure de génie industriel

Introduction to the Fundamentals of Systems Engineering

1. A brief introduction to Systems Engineering (SE)

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Systems Engineer / Systems Architect

Ingénieur Système H/F

ALSTOM ★★★★☆ 2,663 avis

Postuler

Le Creusot (71)

Temps plein, CDI

40 000 € - 60 000 € par an

Vous souhaitez vous investir dans une entreprise à la pointe des dernières solutions du secteur ferroviaire ? L'esprit d'équipe, le sens de l'action et la confiance sont des valeurs que vous partagez ? N'attendez plus pour rejoindre nos 34500 collaborateurs ! Alstom place l'innovation au cœur de son modèle pour proposer des solutions de transport toujours plus propres grâce à ses systèmes intelligents. En nous rejoignant, en plus de relever les défis de la mobilité du futur, vous intégrerez une entreprise engagée dans la diversité, l'entreprenariat, la responsabilité sociale et l'éthique. Grâce à notre implantation dans 60 pays au travers de nos 130 sites, ce sont de multiples opportunités qui s'offriront à vous, en France comme à l'international !

Vos principales missions sont de :

- Piloter des activités de conception systèmes, relatives à un sous-système train associé aux bogies, comme l'accès passager, le confort passager, l'agressivité vis-à-vis de l'infrastructure ;
- Elaborer l'architecture système, les spécifications fonctionnelles et techniques en conformité avec les performances train et les requis clients ;
- Assurer la coordination des activités de conception internes et externes ;
- Diriger les activités de conception avec les différents métiers du Bureau d'Etudes (mécaniques, simulation, automatisme, validation) mais aussi avec les expertises transverses telles que la sûreté de fonctionnement ;
- Participer au suivi de la réalisation et de la qualification ;
- Spécifier les essais et participer à la mise au point, la validation et certification des sous-systèmes développés ;
- Animer et contribuer la résolution d'anomalie ;
- Assurer conseil et expertise face aux projets et aux clients

Ingénieur Architecte Système Mécatronique H/F

Safran ★★★★☆ 2,559 avis

Continuer pour postuler

société s'appuie sur 3 000 ingénieurs répartis dans 9 pays à travers le monde.

Nous vous proposons de participer au développement et à la pérennisation de notre pôle de compétence Ingénierie Système et d'accompagner la croissance des activités d'architecture système autour de produits orientés mécatroniques (contrôle moteur aéronautique, véhicule autonome, drone, systèmes de commandes de vols) :

- Vous êtes garants des processus d'Ingénierie Système sur l'ensemble du cycle en V, à savoir :
- Elicitation du besoin
- Architecture opérationnelle
- Architecture fonctionnelle
- Architecture organique
- Validation (exigences et modèles)
- Intégration et vérification
- Vous définissez ou mettez en oeuvre la méthodologie nécessaire à la bonne réalisation des activités d'ingénierie système,
- Vous orientez les choix de développement par le biais de trade off d'architecture et le pilotage des KDD,
- Vous êtes garants de l'avancement technique du projet
- Vous managez opérationnellement les ingénieurs système en place sur le projet
- Vous travaillerez en étroite collaboration avec les différents acteurs des projets (responsables métiers HW/SW/Méca, sûreté de fonctionnement, certification etc) pour comprendre et répondre à leurs besoins.

Ingénieur système à dominante mécatronique avec expérience significative en architecture de systèmes complexes (électromécanique ou mécatronique)

Minimum 5 ans d'expérience dans le domaine de l'architecture système

Vous maîtrisez :

- Ingénierie Système : Maîtrise de tous les processus Ingénierie Système Etat de l'art (CESAMES)
- Activités : Rédaction Spécifications techniques, Modélisation MBSE (SysML, BPMN), modélisation Simulink
- Outils : DOORS ou PTC Integrity, MBSE : Rhapsody/Papyrus/Capella, Simulink
- Culture technique : systèmes d'actionnements électomécaniques, calculateurs, capteurs, réseaux de communication (CAN, Ethernet, Flexray etc), sureté de fonctionnement (ARP 4754/4761 ou ISO26262)
- Gestion de projet

Entry Level Model Based Systems Engineer

BOEING ★★★★☆ 8,106 reviews

Berkeley, MO

Apply On Company Site

Job Company

Boeing Defense Space and Security is currently looking for an **Entry Level - Model Based Systems Engineer.** This position will perform a wide variety of Systems Engineering functions to support a proprietary BDS program, ensuring our products meet performance requirements and are delivered to meet market and/or customer needs. This position helps programs develop system architectures in an MBSE environment. The candidate should have experience in the Systems Engineering activities throughout the life cycle (such as requirements development, system design, verification planning and testing, etc.).

Position Responsibilities:

- Participate requirements development.
- Participate in model development.
- Participate in Functional Thread Workshops to help identify, design, and record highly complex/important design threads.

The individual will need to be a self-starter, comfortable with identifying and solving problems, able to understand the big design picture (larger than just MBSE), and have good communication skills. The successful candidate will work in a fast paced and dynamic environment and work both independently and as part of team. Strong oral and written communication skills are required.

Preferred Qualifications (Desired Skills/Experience):

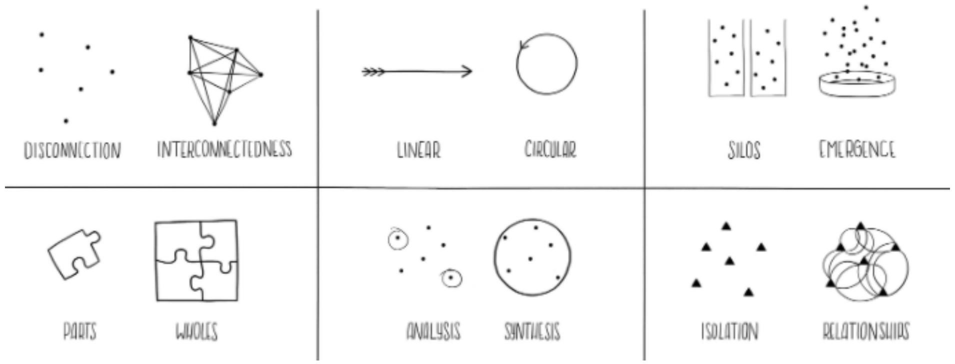
- Experience with Systems Engineering Principles
- Experience in Model Based System Engineering
- Experience with systems architecture, requirements development and test & verification
- Knowledge of MBSE tools and languages (such as SysML "Systems Modeling Language") is a strong plus
- Knowledge of SW languages and ability to write scripts and understand agile processes.

What do you know about product design?

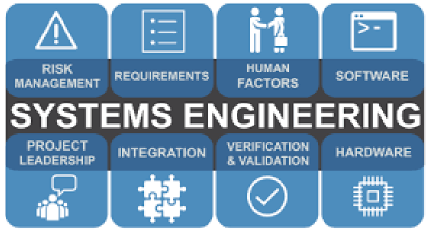
How would you develop a new wearable drug delivery system?

Learning Outcomes

- Acquire a « systems thinking » mindset



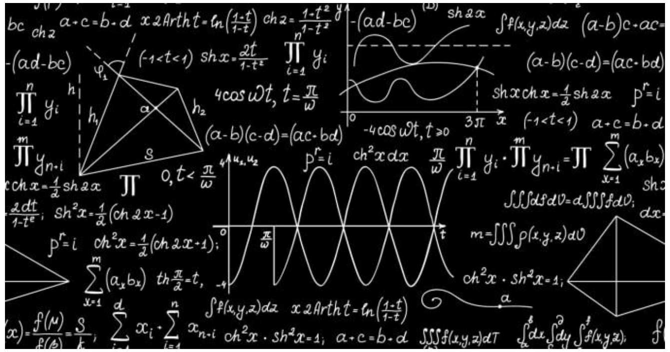
- Be aware of the systems engineering approach for new product development



- Learn the fundamental principles and their systematic application

What Students Are Used To…

Subject of interest is technical



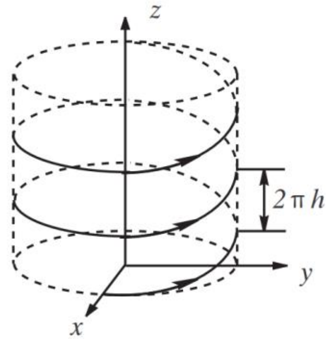
Well-defined problems

Ex-M1.16 **Mouvement hélicoïdal (*)**

Soit l'hélice droite définie en coordonnées cylindriques par les équations : $r = R$ et $z = h\theta$
et orientée dans le sens θ croissant (soit h cste>0).
L'origine de la trajectoire du point M est en $z = 0$.

1) Déterminer les équations de l'hélice en coordonnées cartésiennes.

2) Le point M parcourt l'hélice à une vitesse constante v.
a) Déterminer les vecteurs vitesse et accélération en fonction de R, h et v.
b) Montrer que l'angle $\alpha = (\overrightarrow{e_z}, \overrightarrow{v})$ est constant.
En déduire l'hodographe du mouvement.



Questions have a right answer

Corrigé du Concours Blanc (Algèbre) Sujet 1.

Problème 1 (E3A PSI 2005).
Préliminaire.

1. Puisque U n'est pas inversible, u n'est pas bijectif, donc pas injectif et son noyau n'est pas réduit à {0}. Donc : $\exists\, x \in E,\ x \neq 0,\ u(x) = 0$.
2. On sait que : $\forall\, 1 \le i \le n$, $\sum_{j=1}^{n} u_{i,j}.x_j = 0$, puisque : u(x) = 0.

   Soit alors i un indice tel que : $|x_i| = \|x\|_\infty$, alors : $|u_{i,i}|\|x\|_\infty = |u_{i,i}||x_i| = \left|-\sum_{\substack{j=1\\ j\neq i}}^{n} u_{i,j}.x_j\right| \le \sum_{\substack{j=1\\ j\neq i}}^{n} |u_{i,j}||x_j|$, à l'aide de l'inégalité triangulaire.
3. Puisque x est non nul, on a : $\|x\|_\infty \neq 0$, et si on note à nouveau i un indice tel que : $|x_i| = \|x\|_\infty$, alors :

   $|u_{i,i}| \le \sum_{\substack{j=1\\ j\neq i}}^{n} |u_{i,j}| \frac{|x_j|}{\|x\|_\infty} \le \sum_{\substack{j=1\\ j\neq i}}^{n} |u_{i,j}|$, puisque tous les quotients sont inférieurs ou égaux à 1.
4. Puisque la condition précédente n'est vérifiée sur aucune ligne de la matrice proposée, elle est donc inversible (on a toujours : $|u_{i,i}| = 4$, et : $\forall\, 1 \le i \le 5$, $\sum_{\substack{j=1\\ j\neq i}}^{5} |u_{i,j}| \le 3$).

Well-defined methods, techniques, formalisms

Comment déterminer les équations différentielles du mouvement :

Le problème est à plus d'un degré de liberté : on projette le PFD dans la base la plus adaptée (ex : tir balistique).

Le problème est à un degré de liberté (ex : pendule simple), 3 possibilités :

- On projette le PFD selon l'axe du mouvement
- On applique le théorème de la puissance cinétique $\frac{dE_C}{dt} = P_{totale}$
- On applique la forme différentielle du TEM $\frac{dE_m}{dt} = P^{nc}$

What You Should Be Aware Of…

To make students aware of…

- The impact of working in a large organisation, e.g. processes, organisations, roles, responsibilities…
- The communication challenges between various technical disciplines and less technical stakeholders
- The ill-defined and multi-dimensional nature of system problems, uncertainties, unknowns, ambiguities, dynamics, conflicting needs and goals
- The impact of external conditions on the system and its design
- System life cycle to provide insight in available methods, techniques, and concepts

Engineered Systems

A man-made integrated set of elements (hardware, software, people, procedures, facilities etc.), created, and utilized to provide services in a defined operating environment (or context) for the benefit of users and other stakeholders.

- Systems have a purpose
- All parts must be present (for a system to carry out its purpose)
- The order and arrangement of the parts affect performance
- All systems have a boundary and operate within an environment

Do you observe an evolution in the system/product?

Evolution of Engineering and Engineered Systems

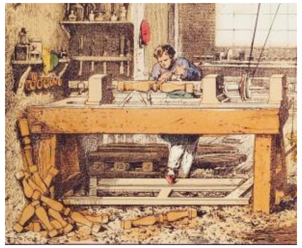
18 °

Era of craftsmen
(creativity & customisation)


Clay


Steel


Stone


Wood

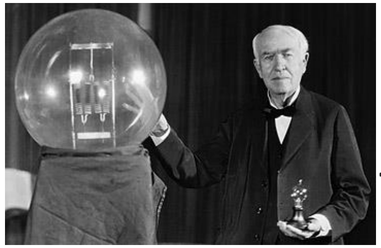
19 °

Industrial revolution
(repetability & standardisation)

Era of greatest inventions
(technical problems solving)


A. G. Bell, 1876


K. Benz, 1880


T. Edison, 1879

20 °

Era of complex technical systems
(network of great inventions)

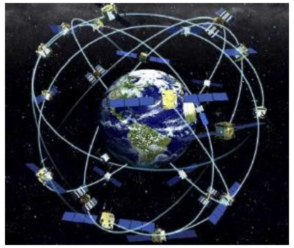

Communication network


Transportation network


Energy network

21 °

Era of socio-technical systems of systems
(contingencies of a dynamical society)


Merging of communication and transportation networks (GPS)

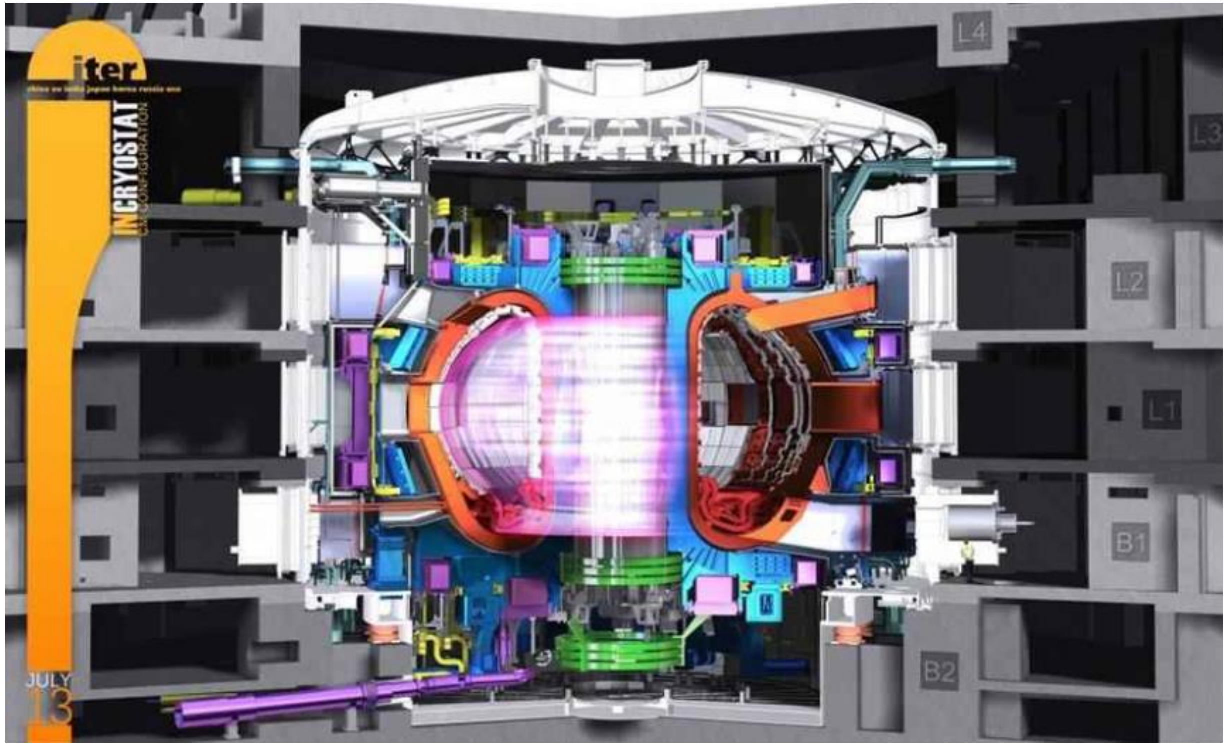

Merging of transportation and energy networks (electrical cars network)

Abstraction

- The design of the ITER reactor started well before any construction began
- It began with a concept for a reactor
- Considering all the machinery and software that goes into such a complex system, can you imagine how the concept initially developed
- Well, scientists and engineers didn't just start by making a longlist of parts to go and buy – the project is massively complex
- To handle this design complexity, they had to ABSTRACT the concept into easily manageable parts

Abstraction

- The Tokamak Reactor is the heart of the ITER
- Over 23,000 Tons
- Over 10,000,000 parts (just the reactor)
- This is a very complex design requiring many design teams from around the world coordinating their contributions to this massive effort
- When beginning to conceptualize a solution (a design), these teams had to ABSTRACT away the details in order to develop the top-level concept for how the whole system is going to work



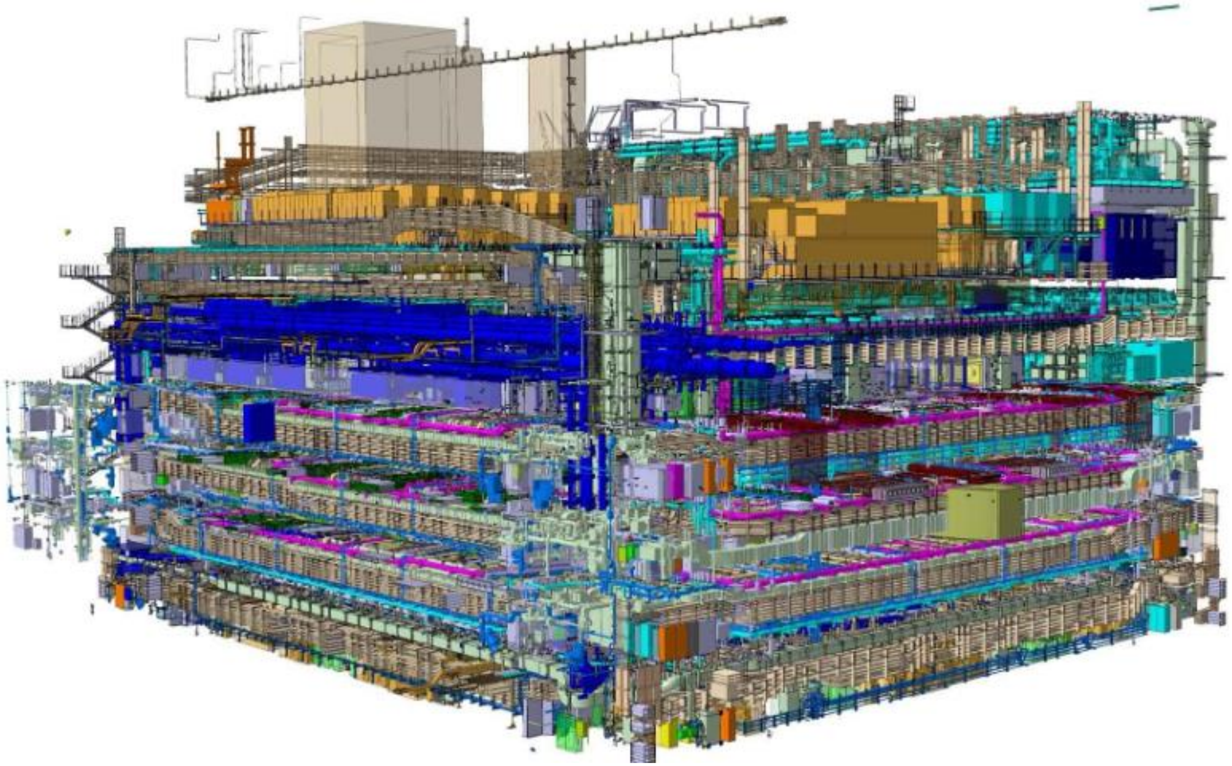
Abstraction

- In addition to the reactor itself, MAJOR supporting infrastructure has to be designed and built

- The total engineering effort on this project is absolutely staggering

- One can imagine that all this design effort does not happen all at once

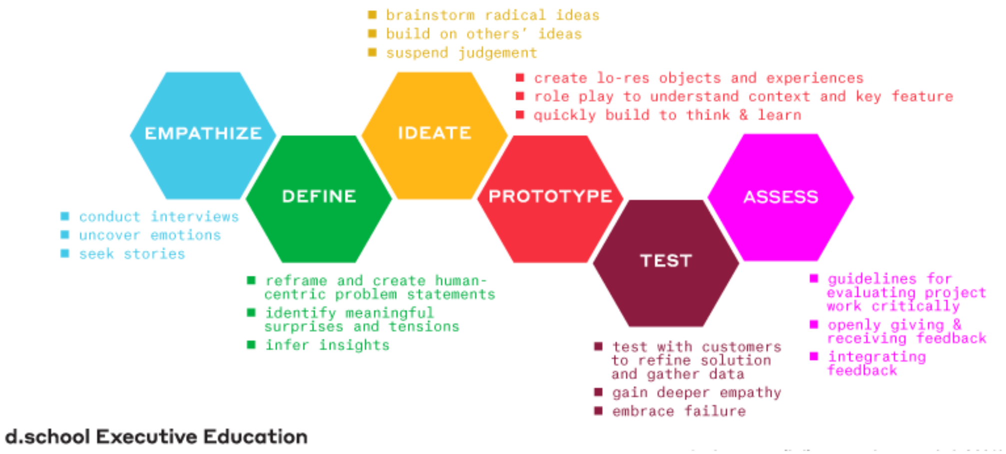
- The entire system needs to be abstracted and decomposed in an organized way to ensure the entire project comes together in the end (is integrated) as smoothly as possible



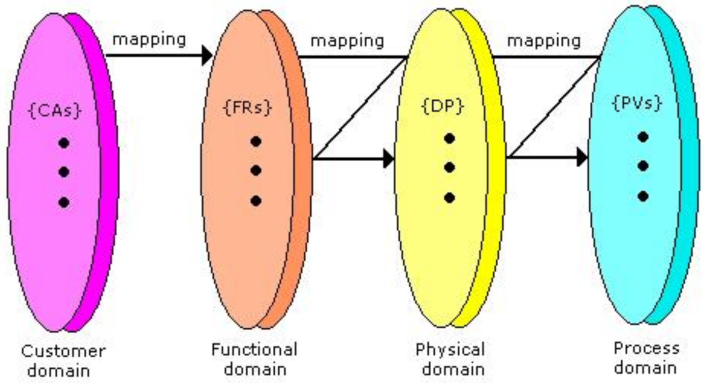
What design approach do you know?

Some examples…

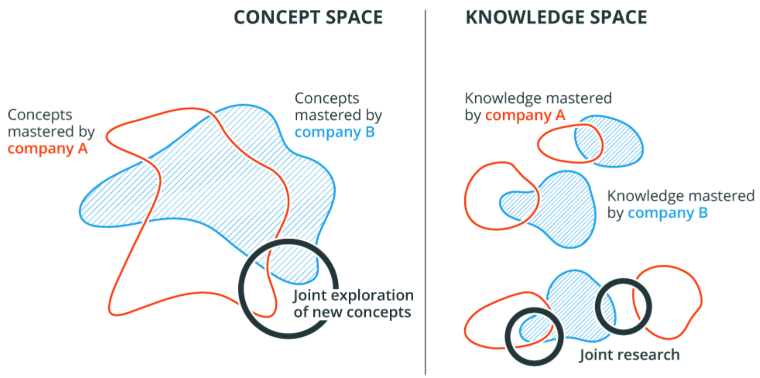
Design Thinking



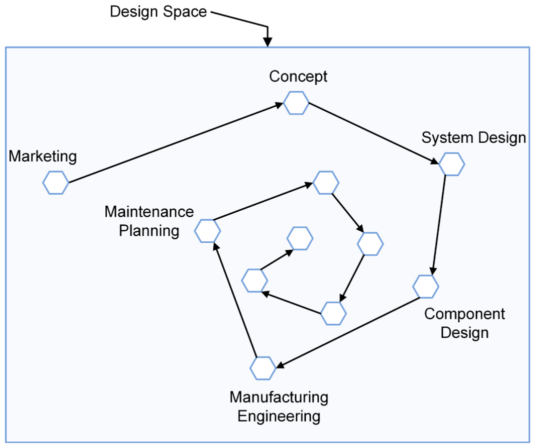
Axiomatic Design



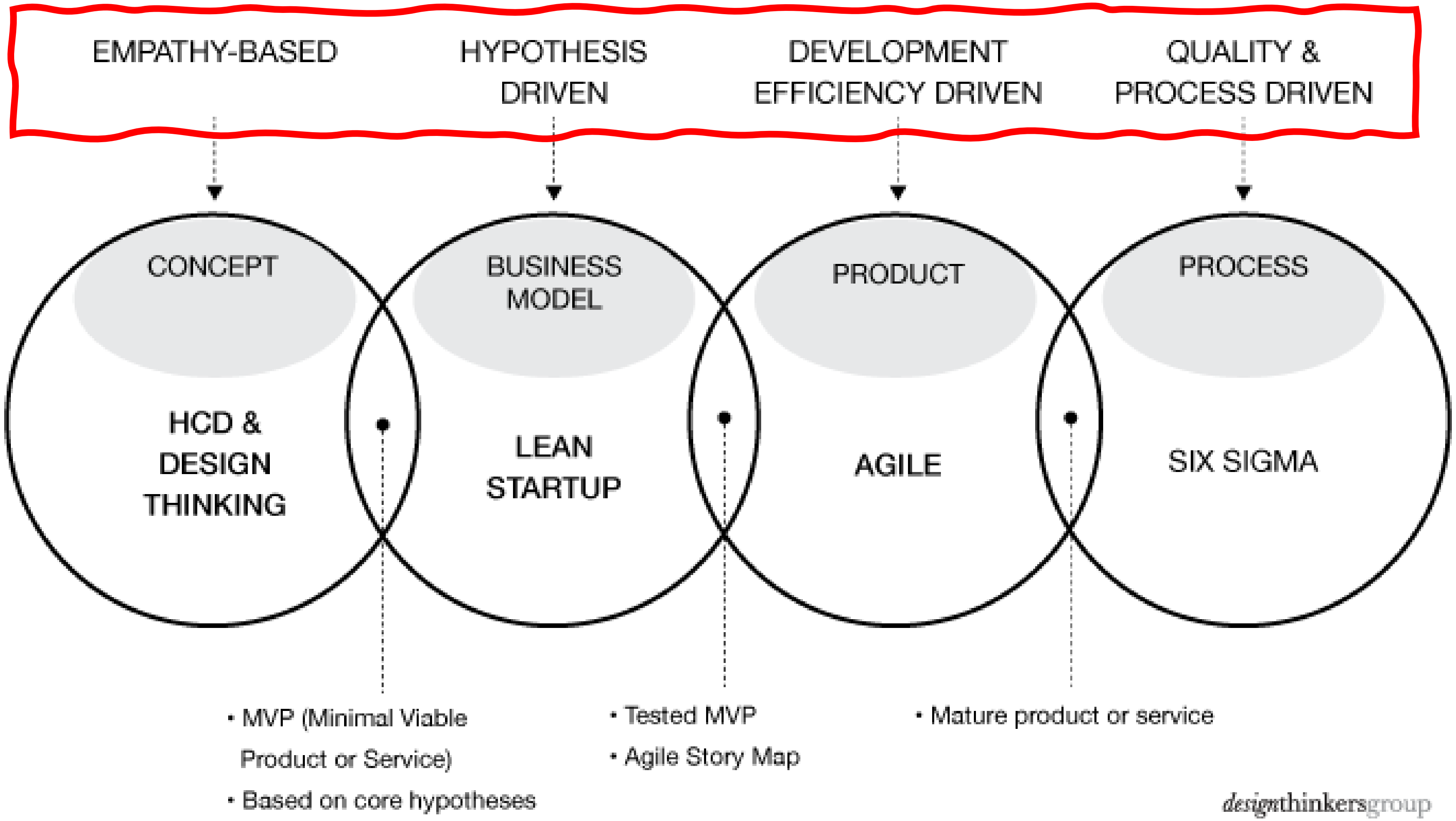
C-K Theory



Set-Based Design



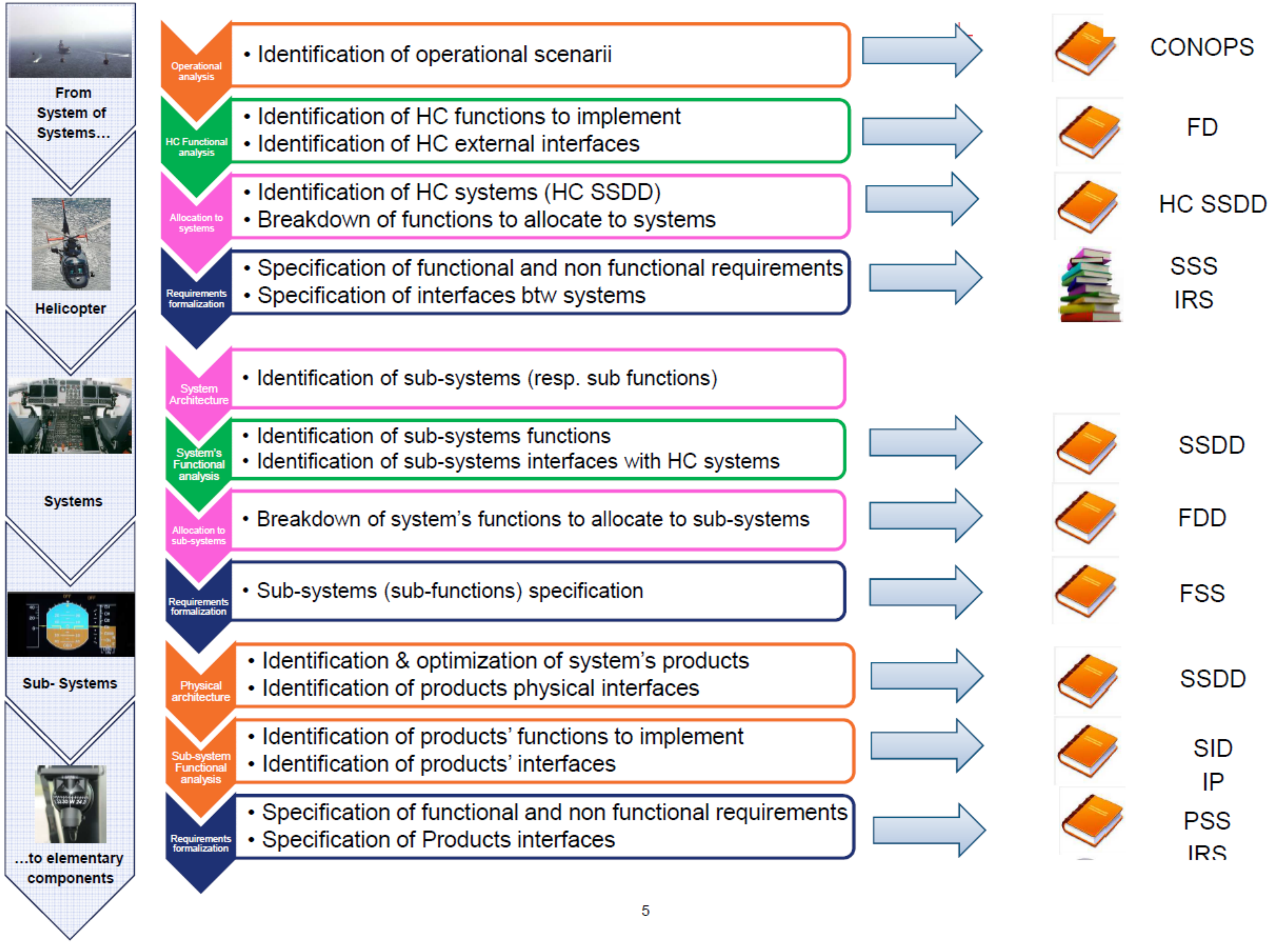
Design Philosophy



A design approach is often built on top of a design philosophy, including the axioms, postulates, assumptions, and convictions taken to be true to serve as a premise or starting point for further reasoning and arguments. For instance, the "Design Thinking" approach relies on the "Human Centered Design" philosophy.

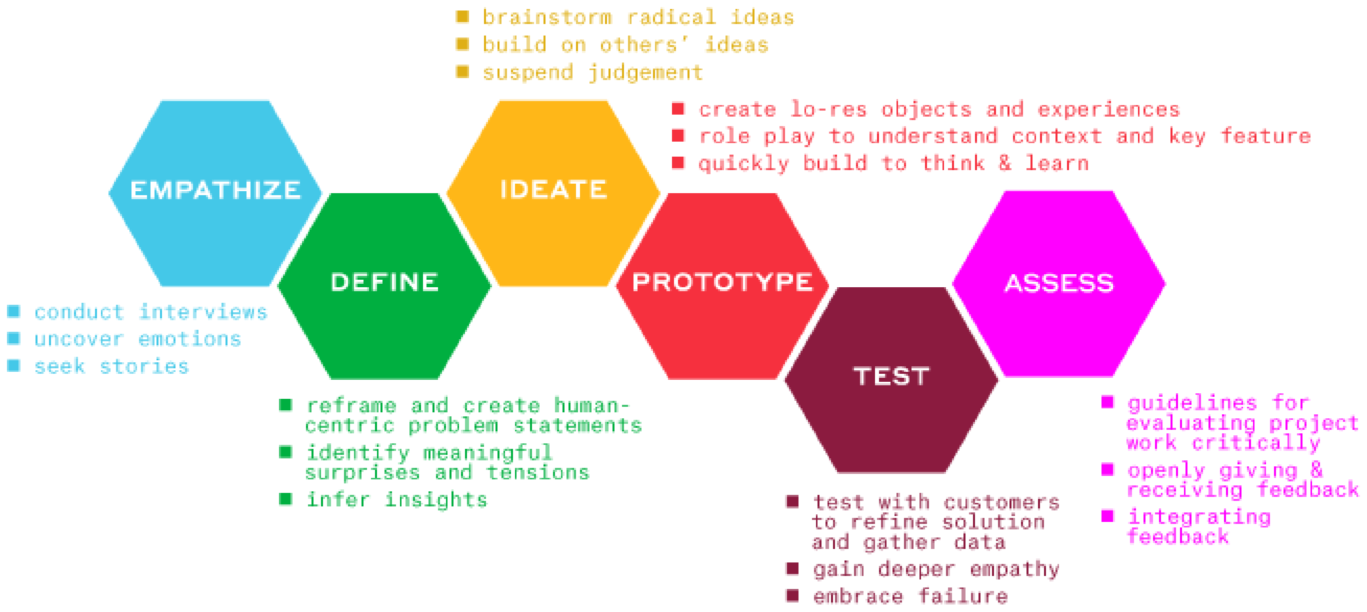
Design Approach *VS.* Process *VS.* Method

A process is a set of activities that tells you "What" to do and "When" to deliver it, and "Who is responsible for it" – e.g. new product development process:



Design Approach *VS.* Process *VS.* Method

A method tells you "How" to practically perform the activities in order to get the expected results (*e.g. How to capture needs? How to write good requirements? How to create modular architectures?*). A method often comes with its own limited "process". You will not find any method that covers all activities of your design process but someone will have to work-out methodological elements to reliably perform them. There is no clear boundary between sub-processes and methods.

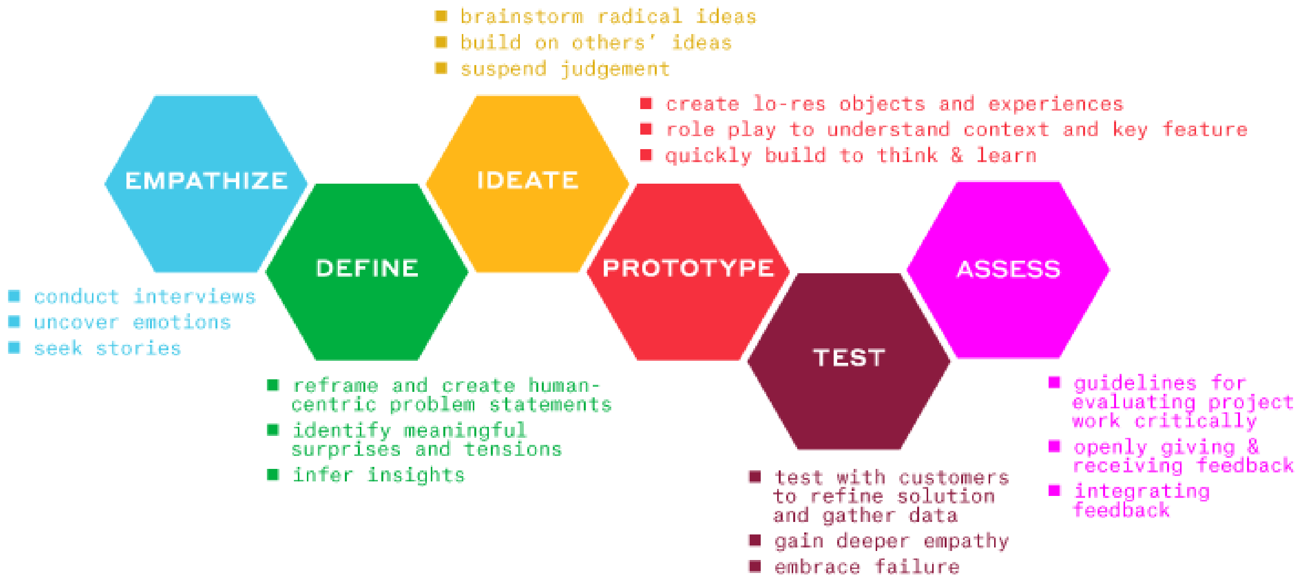


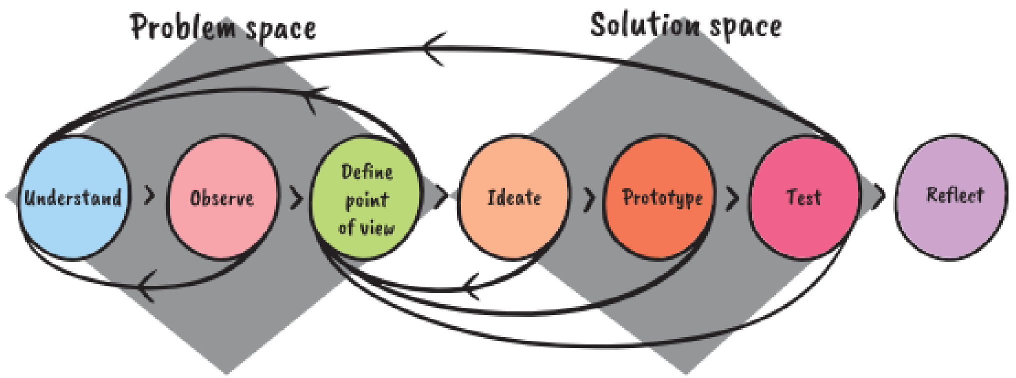
In the 6-activity Design Thinking process, the bullet points are sub-activities that tells you « How » to perform the main activities. In this course, we will consider the set of sub-activities (e.g., Conduct interviews, Uncover emotions, Seek stories) as a sub-process and not a method as there is no clear procedure to perform the activity "Empathize".

Design Approach *VS.* Process *VS.* Method

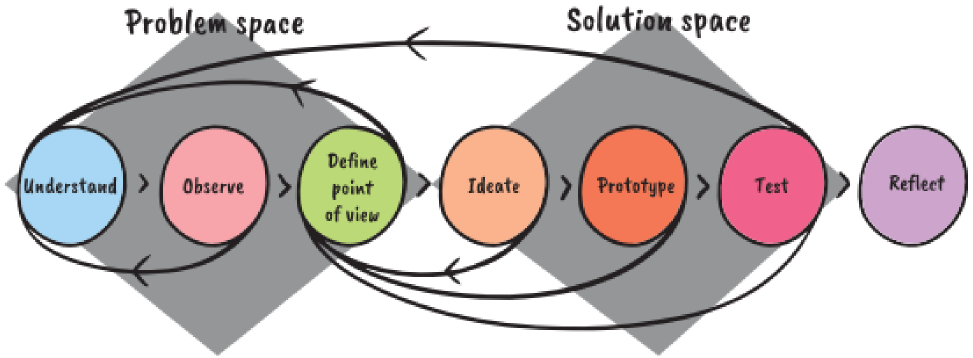
One approach “Design Thinking” and two processes (6-activity or 7-activity). We can’t talk about the Design Thinking process!

We can only discuss the 6-activity or 7-activity Design Thinking process.





Design Approach *VS.* Process *VS.* Method



Tools Quickfinder Matrix	Page	Understand	Observe	Point of view	Ideate	Prototype	Test	Reflect	Examples of tools applied over a typical design cycle of 1 day up to 14 weeks				Your favorite tools for various workshops/projects				
									1 day	2–3 days	4–7 days	14 weeks	days	days	days	days	days
Problem statement	49	●	◐	◐					✓	✓	✓	✓					
Design principles	53	●	◐	◐	◐	◐	◐	◐			✓	✓					
Interview for empathy	57	●	◐				◐		✓	✓	✓	✓					
Explorative interview	63	●	◐				◐			✓	✓	✓					
Ask 5x why	67	●	◐				◐			✓	✓	✓					
5 WH questions	71	●	◐				◐			✓	✓	✓					
Jobs to be done	75	●	◐		◐		◐			✓	✓	✓					
Extreme users/lead users	79	●	◐				◐				✓	✓					
Stakeholder map	83	●	◐				◐				✓	✓					
Emotional response cards	87	●	◐				◐					✓					
Empathy map	93	◐	●	◐			◐		✓	✓	✓	✓					
Persona/user profile	97	◐	●	◐			◐			✓	✓	✓					
Customer journey	103	◐	●	◐		◐	◐				✓	✓					
AEIOU	107	◐	●		◐						✓	✓					
Analysis question builder	111	◐	●									✓					
Peers observing peers	115	◐	●									✓					
Trend analysis	119	◐	●		◐							✓					
"How might we…" question	125			●	◐				✓	✓	✓	✓					
Storytelling	129			●		◐	◐			✓	✓	✓					
Context mapping	133	◐		●	◐			◐		✓	✓	✓					
Define success	137	◐	◐	●	◐	◐	◐	◐			✓	✓					
Vision cone	141	◐	◐	●				◐				✓					
Critical items diagram	145			●		◐	◐	◐			✓	✓					
Brainstorming	151				●	◐	◐	◐	✓	✓	✓	✓					
2x2 matrix	155	◐	◐	◐	●	◐	◐	◐	✓	✓	✓	✓					
Dot voting	159				●	◐	◐	◐		✓	✓	✓					
Brainwriting/6-3-5 method	163				●	◐				✓	✓	✓					
Special brainstorming	167				●	◐					✓	✓					
Analogies & benchmarking as an inspiration	171		◐		●	◐					✓	✓					
NABC	177		◐	◐	●	◐	◐				✓	✓					
Blue ocean tool & buyer utility map	181				●	◐	◐					✓					
Exploration map	187					●	◐				✓	✓					
Prototype to test	199					●	◐		✓	✓	✓	✓					
Service blueprint	203					●	◐				✓	✓					
MVP – minimum viable product	207					●	◐					✓					
Testing sheet	213						●			✓	✓	✓					
Feedback capture grid	217	◐	◐	◐	◐	◐	●	◐	✓	✓	✓	✓					
Powerful questions for experience testing	221	◐	◐				●			✓	✓	✓					
Solution interview	225	◐	◐				●				✓	✓					
Structured usability testing	229	◐	◐				●					✓					
A/B testing	233						●					✓					
I like / I wish / I wonder	239	◐	◐	◐	◐	◐	◐	●	✓	✓	✓	✓					
Retrospective sailboat	243						◐	●		✓	✓	✓					
Create a pitch	247			◐			◐	●		✓	✓	✓					
Lean canvas	251			◐				●			✓	✓					
Lessons learned	255							●				✓					
Road map for implementation	259							●				✓					
Problem to growth & scale innovation funnel	263							●				✓					

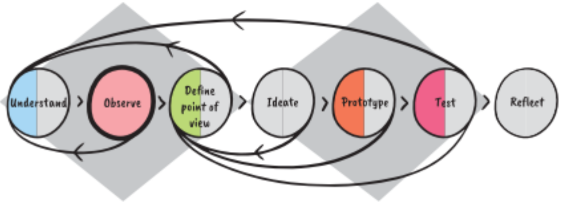
Design Approach *VS.* Process *VS.* Method

Each method contains detailed instructions (materials, procedure, template, etc.). Below is an example of the method to define a customer journey map.

Customer journey map

I would like...

to walk in the shoes of my customers to understand in great detail what they experience when they interact with our company, our products, or services.



What you can do with the tool:

- Establish a common understanding on the team about the experiences of customers with a company, product, or service.
- Identify "moments of misery" that negatively affect the customer experience.
- Achieve a solid understanding of all the customer's touch points.
- Close problematic points and gaps in the customer interaction and realize a unique experience.
- Design a new and improved customer experience.
- Develop new products and services continuously on a customer-oriented basis.

Some information on the tool:

- A customer journey map allows us to build empathy with the customer by visualizing his actions, thoughts, emotions, and feelings that emerge in an interaction.
- In contrast to a process map, which can usually only map the internal processes of a company, a customer journey map is geared to the human being and his/her needs.
- In addition, a customer journey map looks at the actions that are not directly associated with the product or service (e.g. informing, waiting, ordering, delivery, installing, customer service, disposing of).
- The customer journey map is usually developed and used in the "understand," "observe," and "prototype" phases.
- The customer journey also provides a good base for the creation of a service blueprint.

What tools might be used as an alternative?

- Service blueprint (see page 203)

Which tools support working with the customer journey map?

- Interview for empathy (see page 57)
- Persona/user profiles (see page 97)
- Jobs to be done (see page 75)

How much time and what materials do we need?

Group size

4–6

- Mixed teams of experts and people with little experience in the respective process.
- Ideally, 4-6 members in each group.

Typical duration

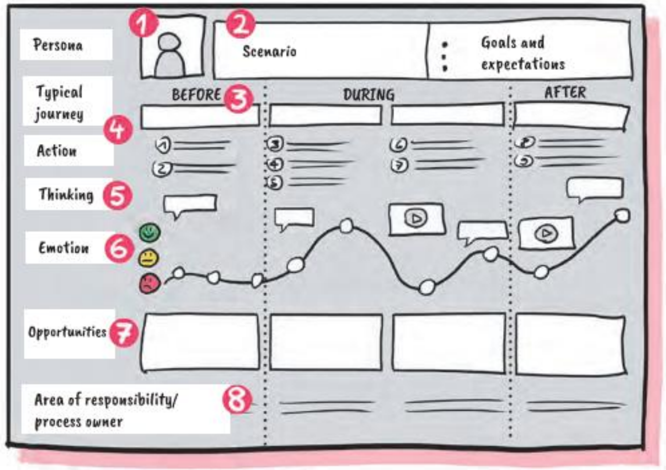
120–240 min.

- The duration depends on the complexity. An initial draft can emerge after 120 minutes.
- Often, variations are needed for specific customer groups and events on the customer journey map.

Materials needed

- Post-its, pens, markers
- Large whiteboard
- Plenty of space on the wall for hanging up pictures of customers, locations, activities, and for visualizing the journey

Procedure and template: Customer journey map



How the tool is applied...

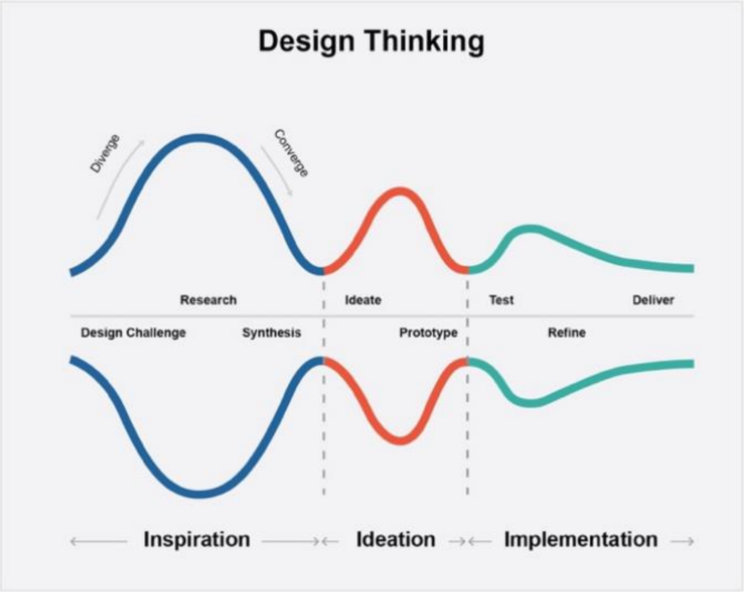
- **Step 1:** Choose a persona to be used in the customer journey map and share the story of the persona with the design team.
- **Step 2:** Then choose a scenario or job to be done. What does the persona do and what is the context? It may be an end-to-end experience or a part of it.
- **Step 3:** Define what happens BEFORE, DURING, and AFTER the actual experience to make sure that the most important steps are included. Mark all experience steps (e.g. using Post-its). It is easier to compile an overview on the meta-level before expanding and elaborating.
- **Step 4:** Decide which interactions should be assigned where and how. The template gives us space for the typical journey and the respective actions.
- **Steps 5 & 6:** Supplement what the persona thinks (Step 5) and the emotion he/she feels (Step 6). Capture the emotional status (positive and negative) of each step with colored glue dots or emoticons.
- **Steps 7 & 8:** Define potential areas of improvement (Step 7) and the people responsible for the action/ process within the organization (Step 8). Once a clear picture of the experience emerges, the design team automatically comes up with questions, new insights, and potential improvements.

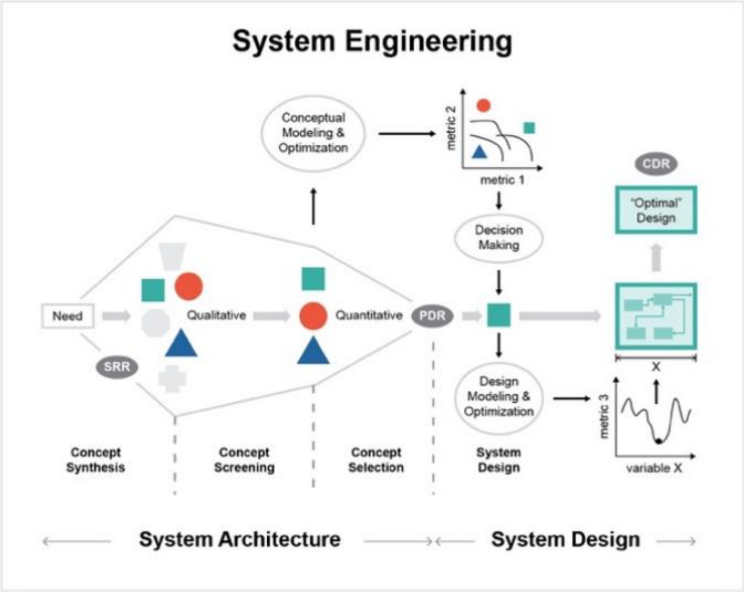
So, what is the nature of systems engineering?

Systems Engineering *VS.* Design Thinking

Methodology	Design Thinking	System Engineering
Technique	Qualitative	Quantitative
Process	Diverge & Converge	Decomposition & Integration
Mental Model	Human-centered	Function-centered
Scale	Primarily small-scale projects	Primarily large-scale projects
Key Steps	Inspiration (e.g. research, interview), ideation (e.g. brainstorm, design) and implementation (e.g. prototype, test, refinement, manufacturing) Note: It was adapted from IDEO Method Cards (2003).	Input and output; requirements analysis and loop; functional analysis/allocation; synthesis; design loop; verification and balance (System Engineering Fundamentals, 2001)

https://www.youtube.com/watch?v=M66ZU2PClcM&ab_channel=AlfonsoNeri





How would you choose between several design approaches?

The role of convictions (firmly held belief or opinion)

Agile Research - Getting beyond the Buzzword

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Abstract: *"Oh yeah, we're an Agile shop, we gave up Waterfall years ago." – product owners, managers, or could be anyone else. You will seldom have a conversation with a product or software development team member without the agile buzzword thrown at you at the drop of a hat. It would not be an oversell to say that Agile software development has been adopted at a large scale across several big and small organizations. Clearly, Agile is an ideology that is working, which made me explore more on its applicability in research. As someone who has been in the Information Technology sector for more than a decade and a half, and a new entrant in the research community, I am inclined to uplift the best practices from my IT experience and evaluate implementing them in research. The idea is to assess the provocative metaphor of "agile research" and the different research philosophies around the concept. The aim is to explore Agile research methodology, its applicability and find the scenarios where it can add value and those where it may not.*

Keywords: Agile Research; Spiral model; Cyclic research method; Grounded theory of research; Action research

Convictions play an important role in the adoption (e.g., by the top management of a company or targeted practitioners) of a design approach. Indeed, the reputation of the organisation (company or research lab) in which the approach has been pioneered serves as a proxy for justifying the choice of one design approach over another. Looking for successful applications in well-known companies published by well-known academics explains how the uptake of a design approach can behave like fashions, where many companies take up a design approach at the same time and then also discard it at the same time.

Systems Engineering

Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system. […] It is a way of looking at the "big picture" when making technical decisions. It is a way of achieving stakeholder functional, physical, and operational performance requirements in the intended use environment over the planned life of the systems. In other words, systems engineering is a logical way of thinking. (NASA, 2007)

Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE, 2004)

My Systems Engineering Definition

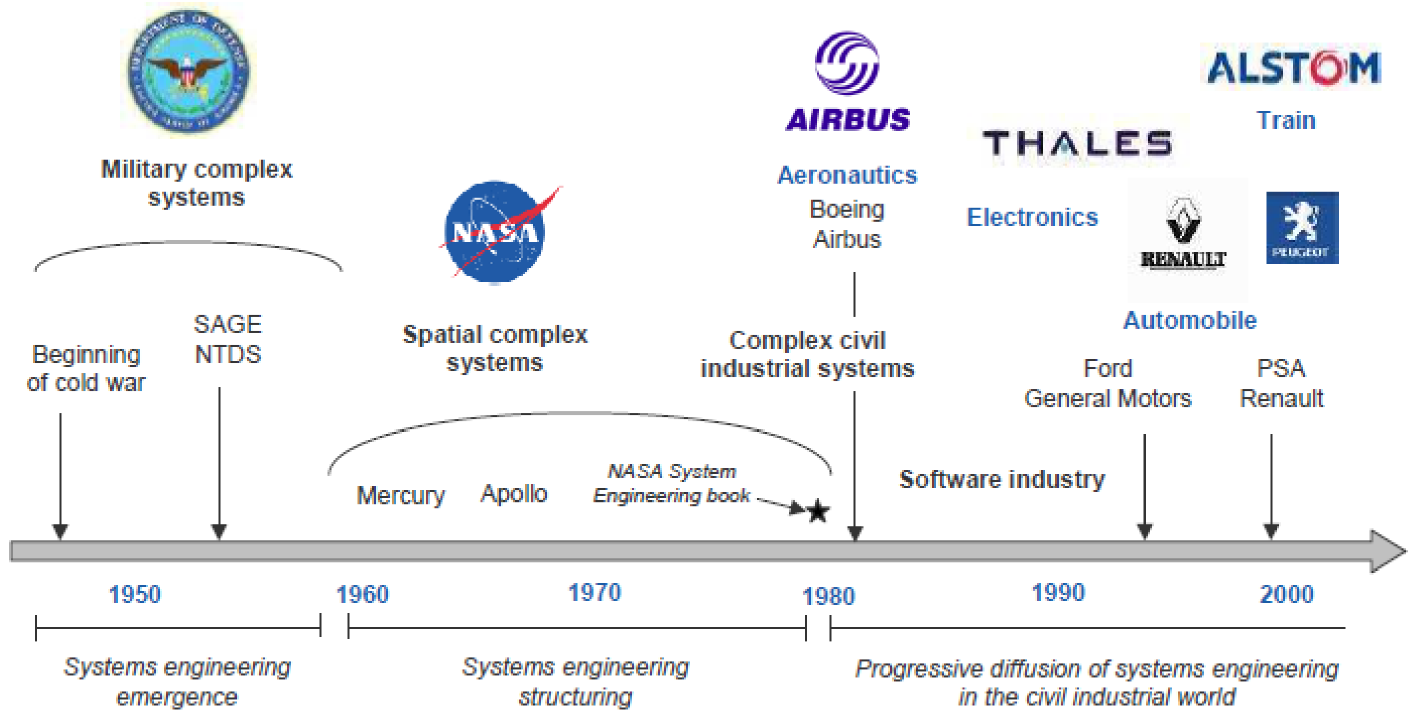
Systems Engineering cannot be a method or a process as there is no single recipe to do it. Each company has its own set of processes and methods for implementing Systems Engineering. Consequently, Systems Engineering is a design approach.

In this course, a design approach is a logical way of thinking that relies upon several elements - convictions, processes, methods, tools... - establishing a design discipline among New Product Development (NPD) team members.

Systems Engineering is a methodical and interdisciplinary design approach that mainly concentrates on five main activities: requirements definition, requirements validation and architecture design performed recursively in a top-down process, plus integration and verification of design and implementation performed recursively in a bottom-up process.

Genesis

The Systems Engineering body of knowledge started to emerge during the world war II and the cold war with the development of missiles and missile-defense systems by the Department Of Defense of the USA. The main motivation was to work out a set of best practices to better manage the quality and costs of new complex military systems. Then, the NASA continued to improve the Systems Engineering approach, especially during the Apollo program, and published the NASA Systems Engineering Handbook. In the 90's, large systems integrators adopted the systems engineering approach.

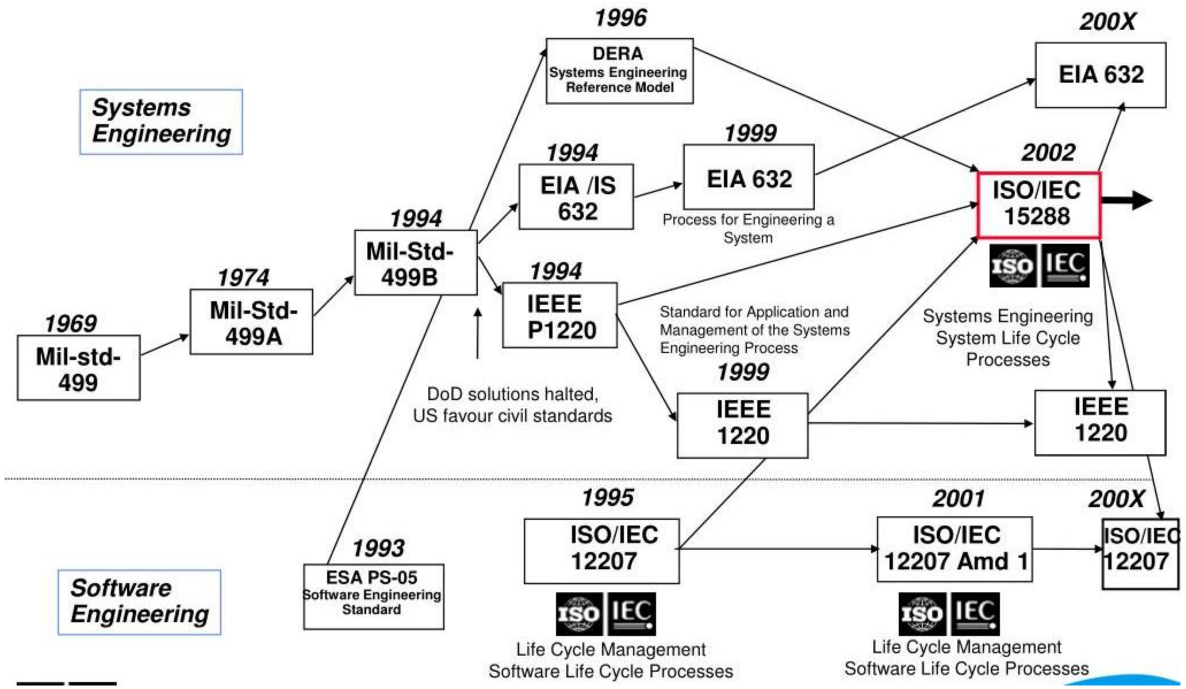


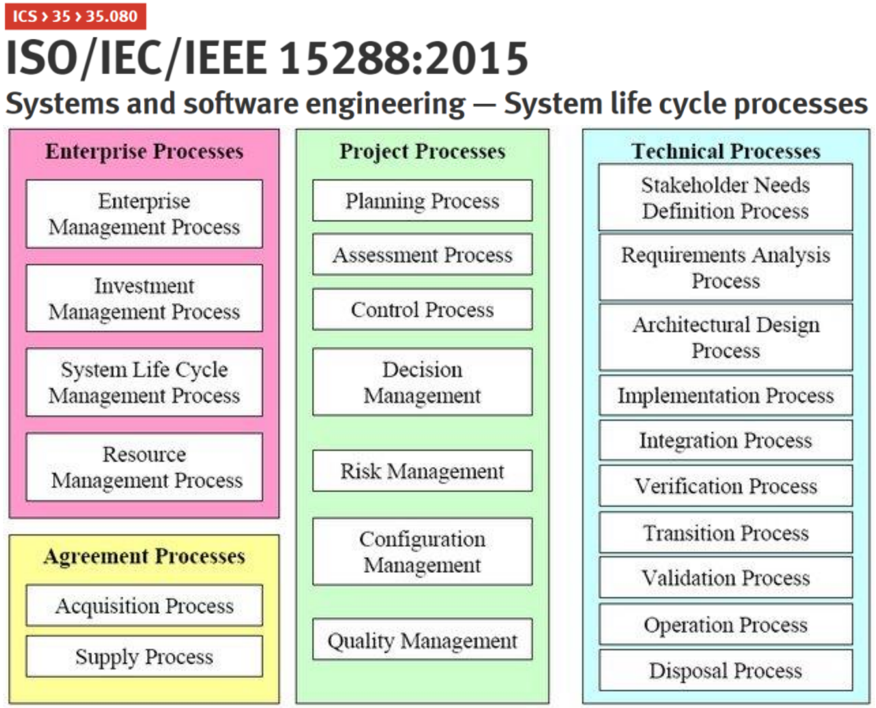
- SAGE = Semi-Automatic Ground Environment = 1st American anti-aircraft defense system
- NTDS = Navy Tactical Data System = = 1st American naval defense system

Standardised Approach – What's a standard?

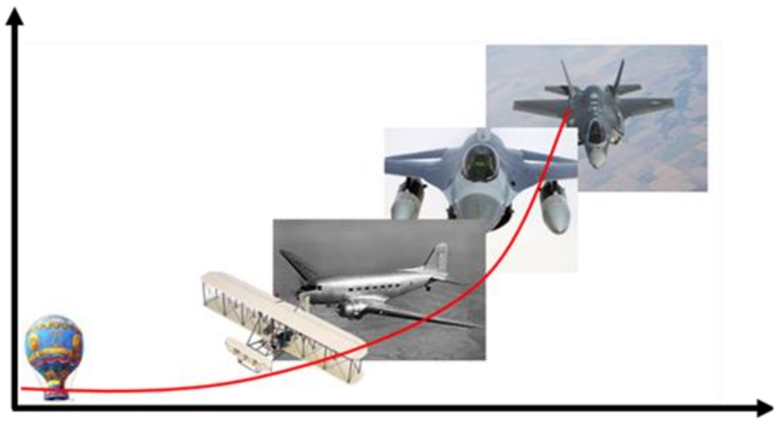
A Standardised Approach

Compared to other design approaches, SE is standardised by international standard development organisations (e.g., ISO, IEEE...) and is tailored to industries by more specific recommended practices (e.g., ARP in the aerospace industry). Systems According to ISO 15288:2015, SE is not all about technical processes but also enterprise, project, and agreement processes. Although it is relevant to consider both the product "*le système à faire*" and the project "*le système pour faire (le system à faire)*", systems engineering is not about project management. It is recommended to separate the systems engineer/architect role from the project manager role. In this course, we will concentrate on the core activities of the technical processes.





Systemic Complexity



Technical complexity

(#parts, #interfaces, multi-physics, emergent properties, etc.)

Organisational complexity

(extended enterprise, multi-site, multinational)

Diversity

(variants, options)

Prescriptive texts

(laws, standards, policies, standards, etc.)

Systems Thinking, blah blah blah

Systems Thinking

Abstraction	A focus on essential characteristics is important in problem solving because it allows problem solvers to ignore the nonessential, thus simplifying the problem. (Sci-Tech Encyclopedia 2009; SearchCIO 2012; Pearce 2012)
Boundary	A boundary or membrane separates the system from the external world. It serves to concentrate interactions inside the system while allowing exchange with external systems. (Hoagland, Dodson, and Mauck 2001) ★
Change	Change is necessary for growth and adaptation, and should be accepted and planned for as part of the natural order of things rather than something to be ignored, avoided, or prohibited (Bertalanffy 1968; Hybertson 2009).
Dualism	Recognize dualities and consider how they are, or can be, harmonized in the context of a larger whole (Hybertson 2009)
Encapsulation	Hide internal parts and their interactions from the external environment. (Klerer 1993; IEEE 1990)
Equifinality	In open systems, the same final state may be reached from different initial conditions and in different ways (Bertalanffy 1968). This principle can be exploited, especially in systems of purposeful agents.
Holism	A system should be considered as a single entity, a whole, not just as a set of parts. (Ackoff 1979; Klir 2001)
Interaction	The properties, capabilities, and behavior of a system are derived from its parts, from interactions between those parts, and from interactions with other systems. (Hitchins 2009 p. 60) ★
Layer Hierarchy	The evolution of complex systems is facilitated by their hierarchical structure (including stable intermediate forms) and the understanding of complex systems is facilitated by their hierarchical description. (Pattee 1973; Bertalanffy 1968; Simon 1996) ★
Leverage	Achieve maximum leverage (Hybertson 2009). Because of the power versus generality tradeoff, leverage can be achieved by a complete solution (power) for a narrow class of problems, or by a partial solution for a broad class of problems (generality).
Modularity	Unrelated parts of the system should be separated, and related parts of the system should be grouped together. (Griswold 1995; Wikipedia 2012a) ★

https://www.incose.org/docs/default-source/los-angeles/libraryresources/systems-thinking.pdf?sfvrsn=7a4c97c6_2

Systems Thinking

Network	The network is a fundamental topology for systems that forms the basis of togetherness, connection, and dynamic interaction of parts that yield the behavior of complex systems (Lawson 2010; Martin et al. 2004; Sillitto 2010)
Parsimony	One should choose the simplest explanation of a phenomenon, the one that requires the fewest assumptions (Cybernetics 2012). This applies not only to choosing a design, but also to operations and requirements.
Regularity	Systems science should find and capture regularities in systems, because those regularities promote systems understanding and facilitate systems practice. (Bertalanffy 1968)
Relations	A system is characterized by its relations: the interconnections between the elements. Feedback is a type of relation. The set of relations defines the network of the system. (Odum 1994)
Separation of Concerns	A larger problem is more effectively solved when decomposed into a set of smaller problems or concerns. (Erl 2012; Greer 2008)
Similarity/ Difference	Both the similarities and differences in systems should be recognized and accepted for what they are. (Bertalanffy 1975 p. 75; Hybertson 2009). Avoid forcing one size fits all, and avoid treating everything as entirely unique.
Stability/ Change	Things change at different rates, and entities or concepts at the stable end of the spectrum can and should be used to provide a guiding context for rapidly changing entities at the volatile end of the spectrum (Hybertson 2009). The study of complex adaptive systems can give guidance to system behavior and design in changing environments (Holland 1992).
Synthesis	Systems can be created by choosing (conceiving, designing, selecting) the right parts, bringing them together to interact in the right way, and in orchestrating those interactions to create requisite properties of the whole, such that it performs with optimum effectiveness in its operational environment, so solving the problem that prompted its creation (Hitchins 2008: 120).
View	Multiple views, each based on a system aspect or concern, are essential to understand a complex system or problem situation. One critical view is how concern relates to properties of the whole. (Edson 2008; Hybertson 2009)

★

https://www.incose.org/docs/default-source/los-angeles/libraryresources/systems-thinking.pdf?sfvrsn=7a4c97c6_2

SE Fundamentals for Managing this Complexity

How can the systems engineering approach (or other engineering design approaches) methodically implement those three theoretical systems thinking concepts?

Boundary	A boundary or membrane separates the system from the external world. It serves to concentrate interactions inside the system while allowing exchange with external systems. (Hoagland, Dodson, and Mauck 2001)

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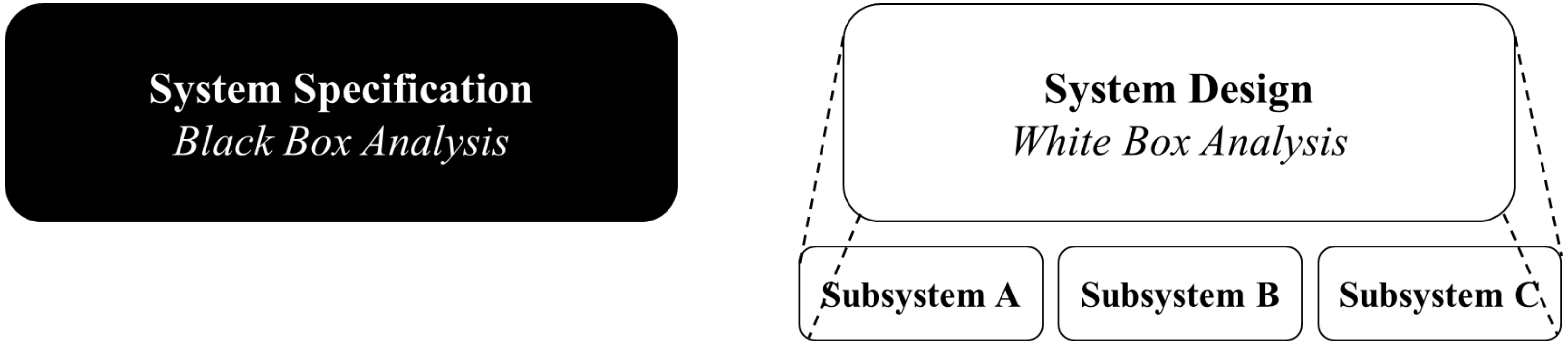
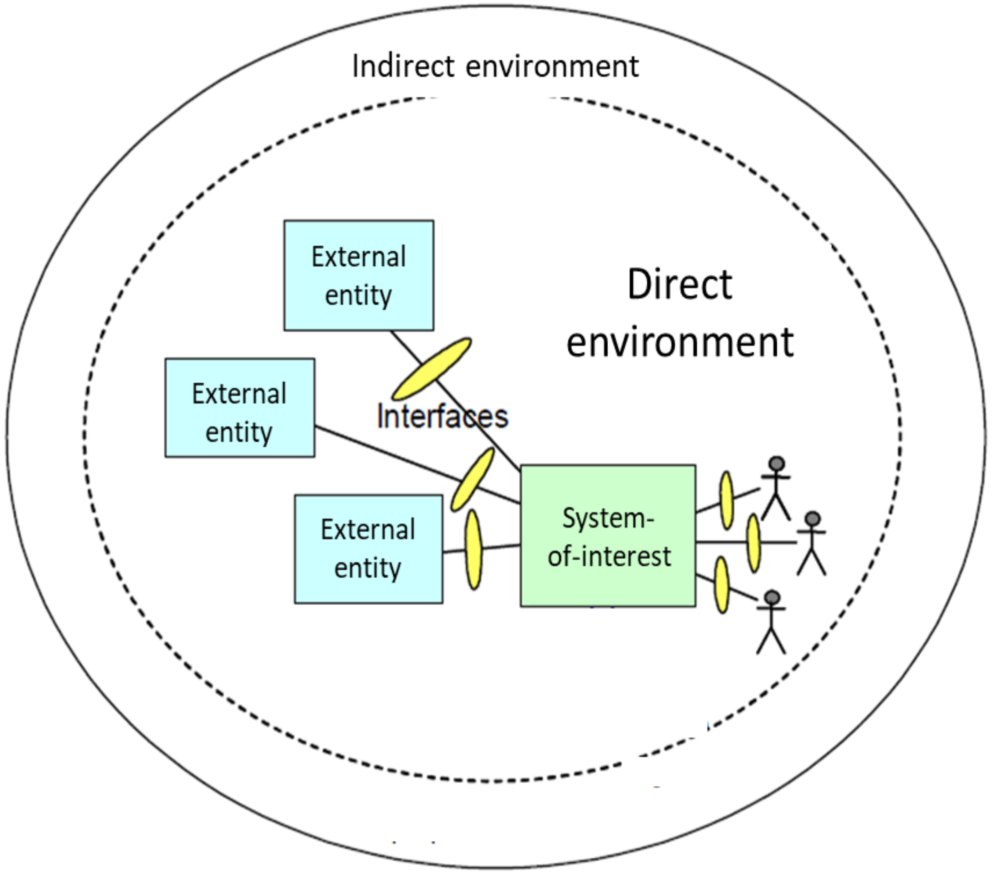
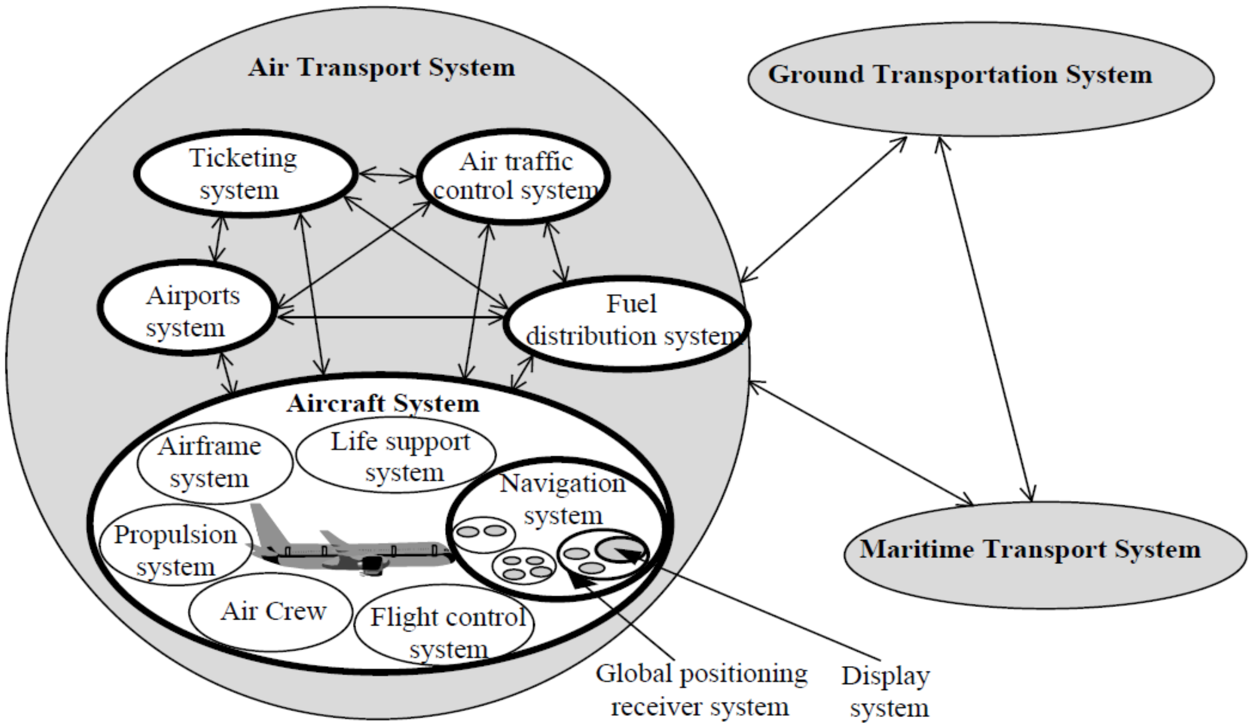
External « Black Box » *VS.* Internal « White Box »







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Top-Down

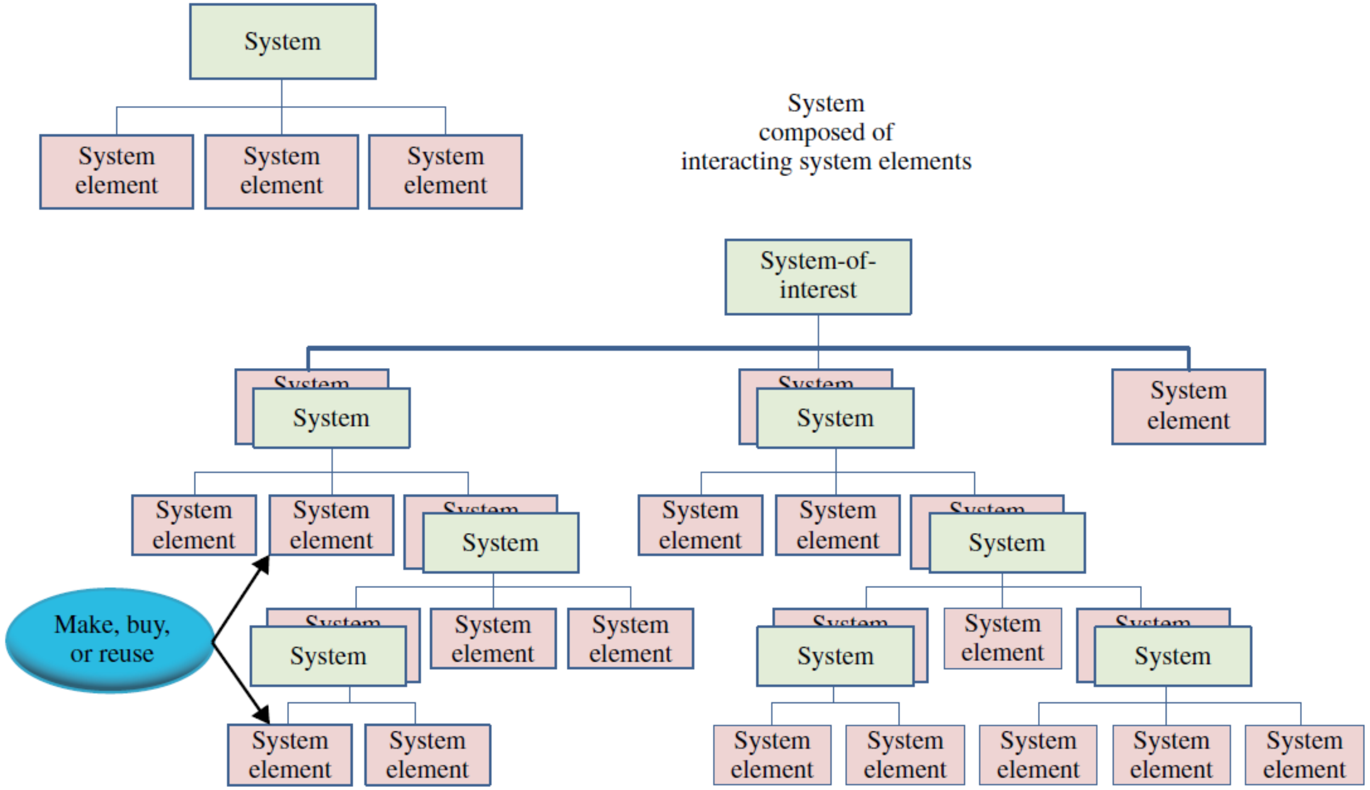

FIGURE 2.1 Hierarchy within a system. This figure is adapted from ISO/IEC/IEEE 15288:2015, Figure 1 on page 11 and Figure 2 on page 12, with permission from the ANSI on behalf of the ISO.

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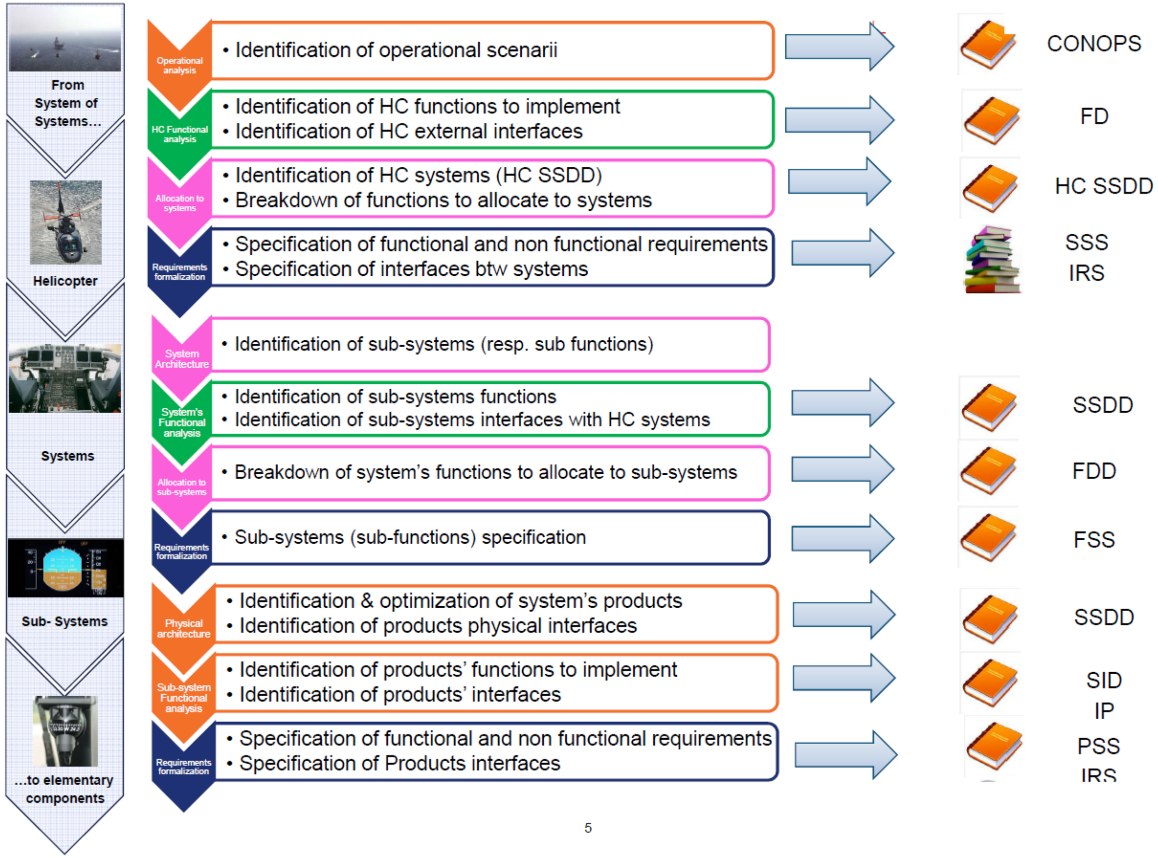
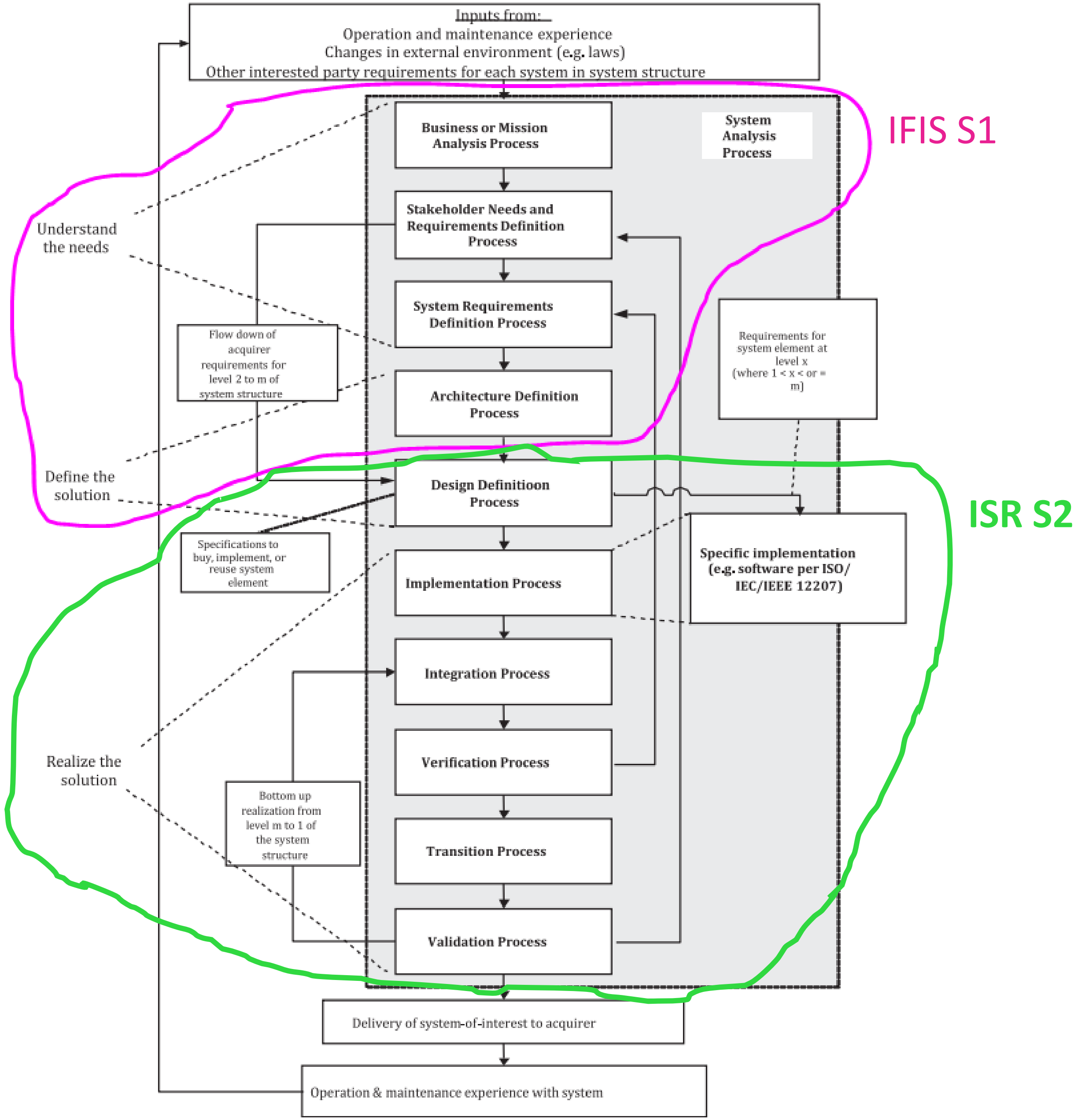


Top-Down



Inputs from:
Operation and maintenance experience
Changes in external environment (e.g. laws)
Other interested party requirements for each system in system structure
Business or Mission Analysis Process
System Analysis Process
IFIS S1
Understand the needs
Stakeholder Needs and Requirements Definition Process
System Requirements Definition Process
Flow down of acquirer requirements for level 2 to m of system structure
Requirements for system element at level x (where 1 < x < or = m)
Architecture Definition Process
Define the solution
Design Definitioon Process
ISR S2
Specifications to buy, implement, or reuse system element
Specific implementation (e.g. software per ISO/ IEC/IEEE 12207)
Implementation Process
Integration Process
Verification Process
Realize the solution
Bottom up realization from level m to 1 of the system structure
Transition Process
Validation Process
Delivery of system-of-interest to acquirer
Operation & maintenance experience with system

Top-Down

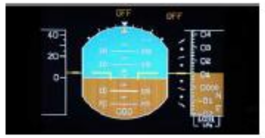
From System of Systems…

Helicopter

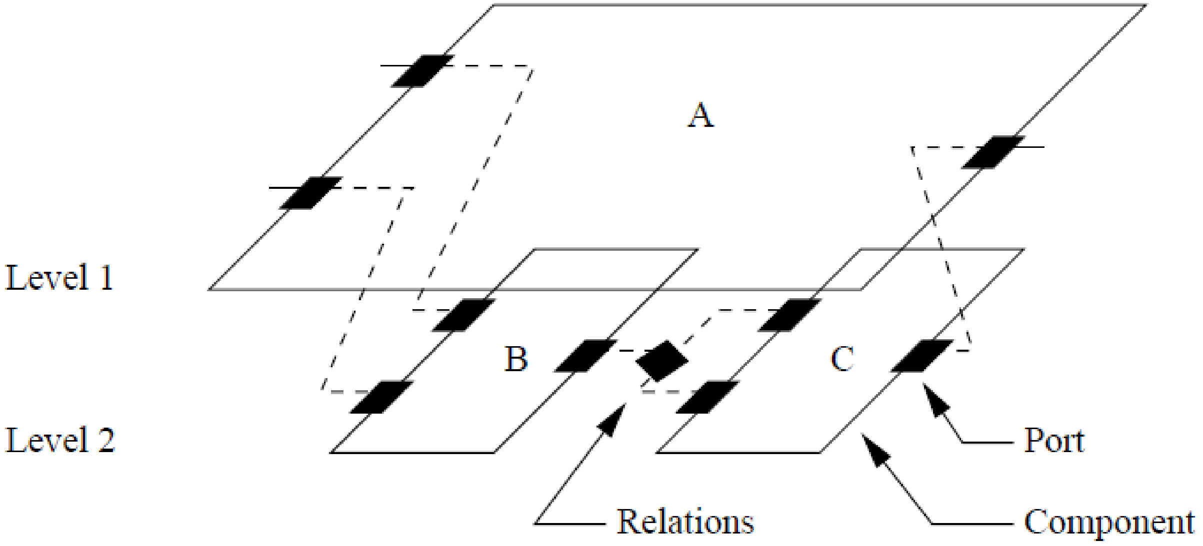
Systems

Interfaces

Sub-systems



…To elementary components



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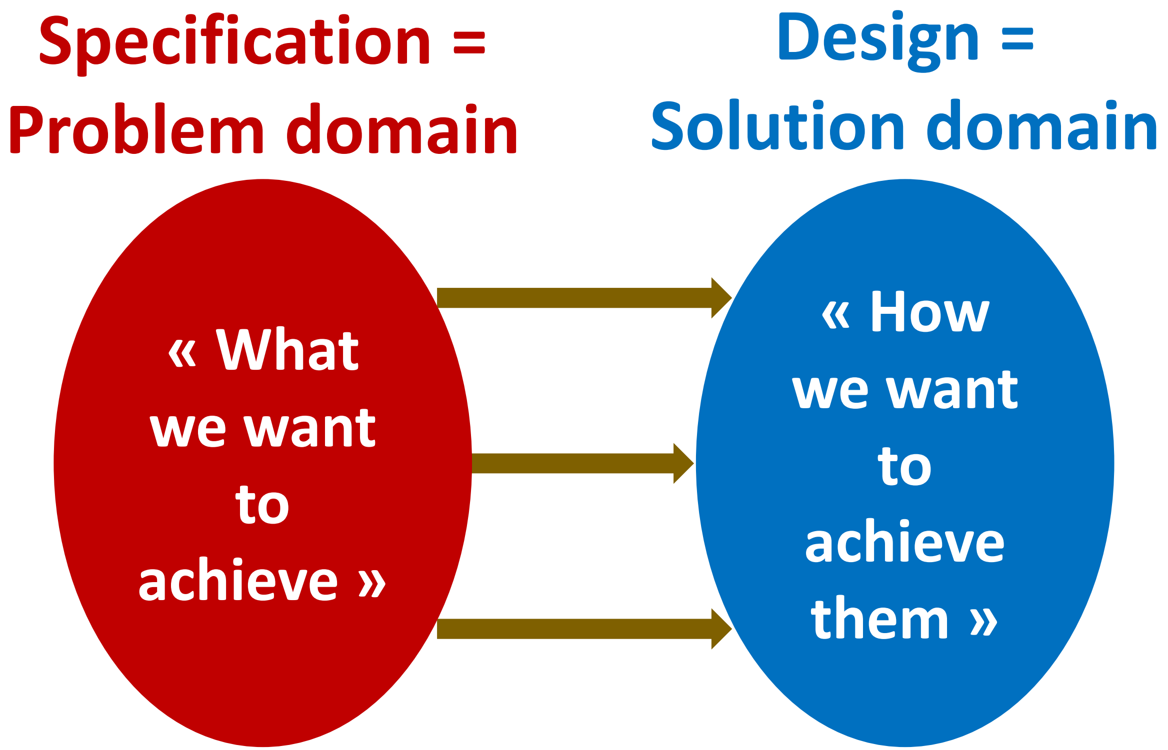
Causal Approach



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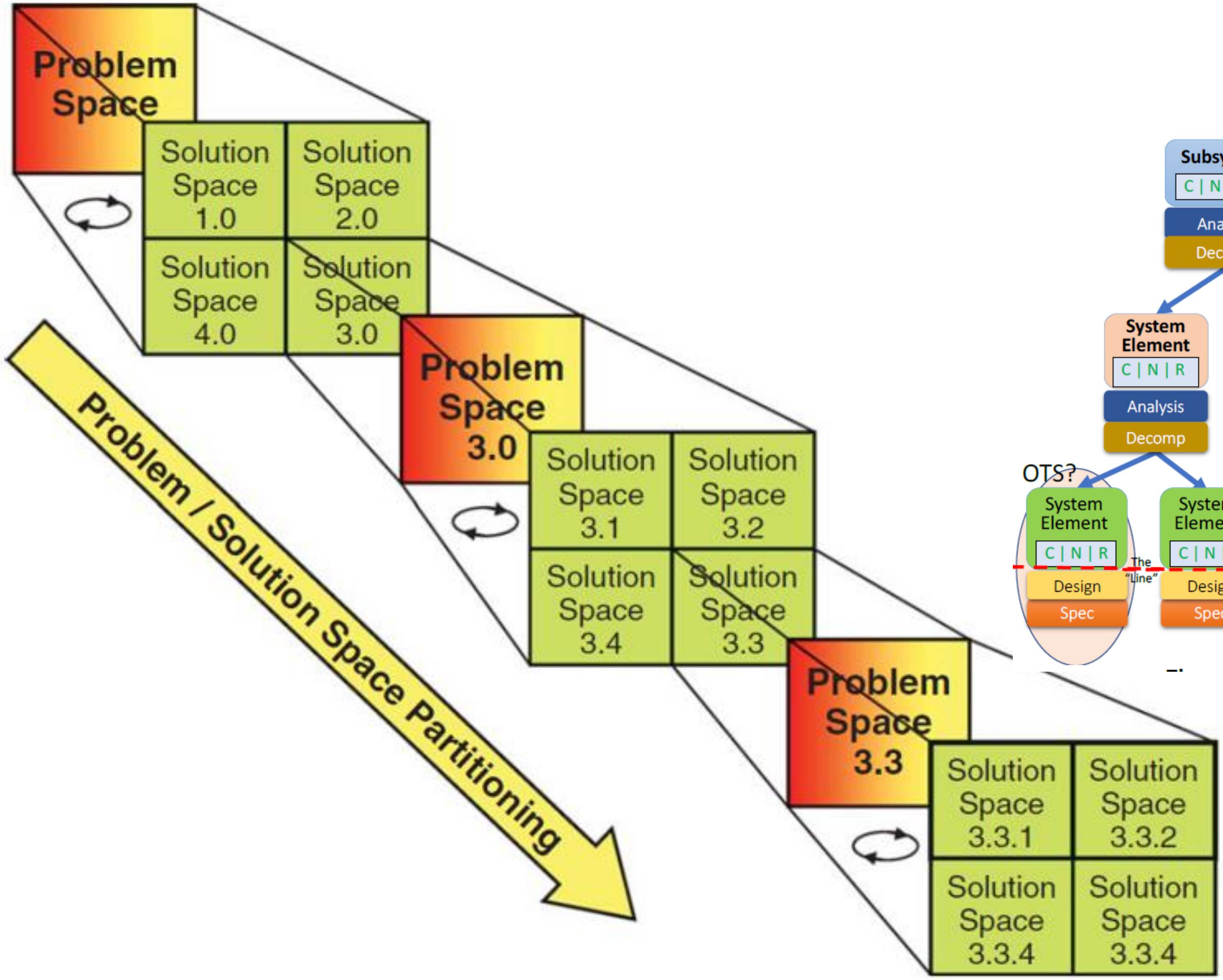
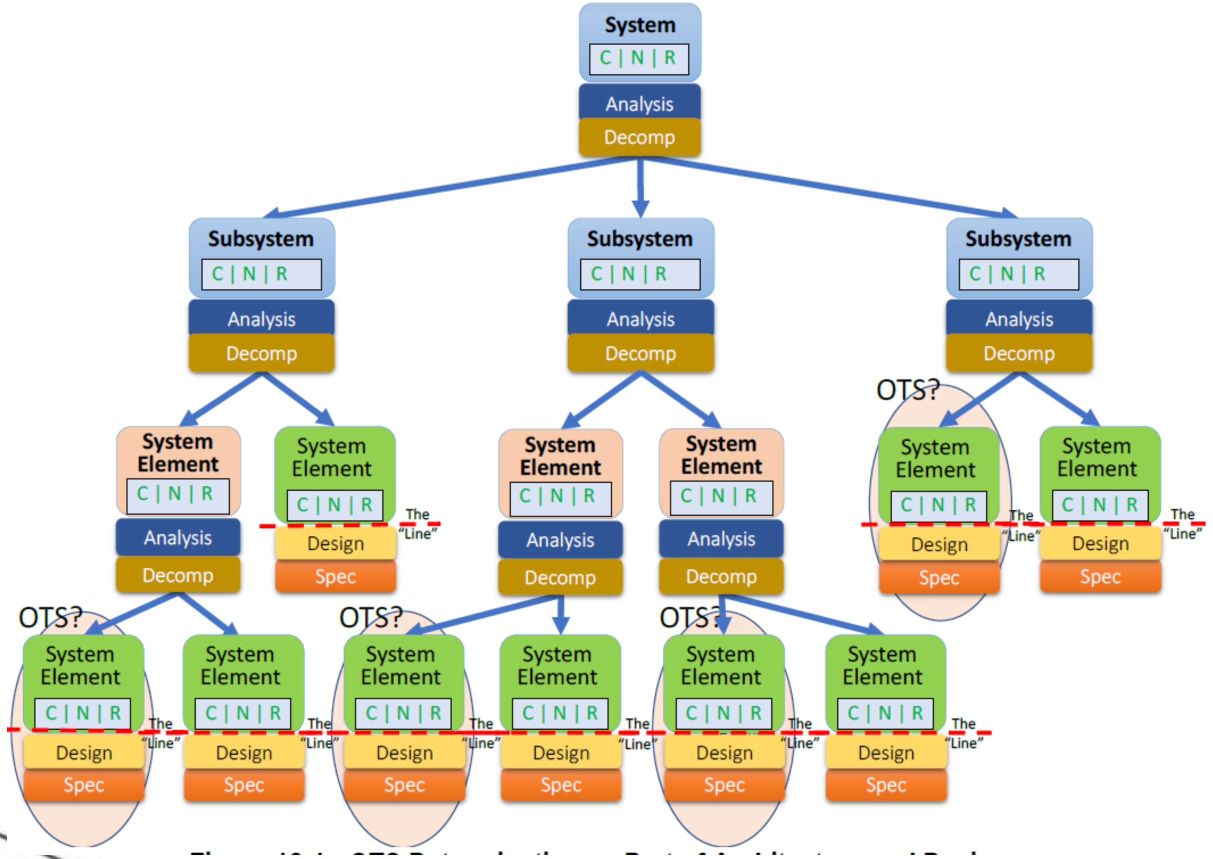
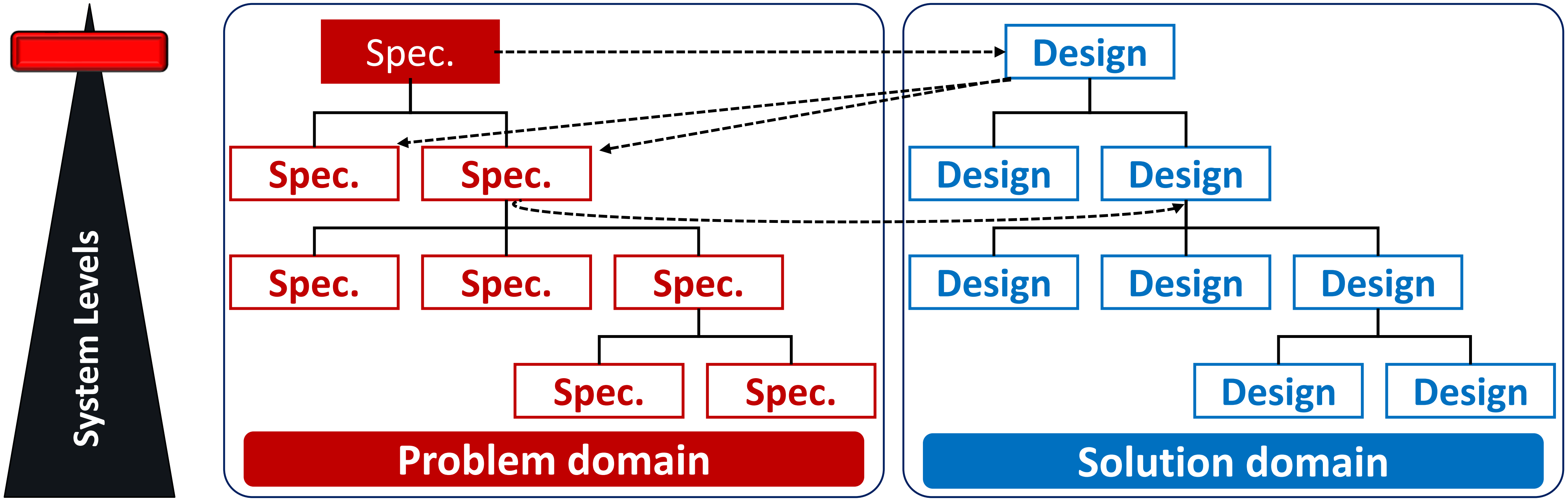


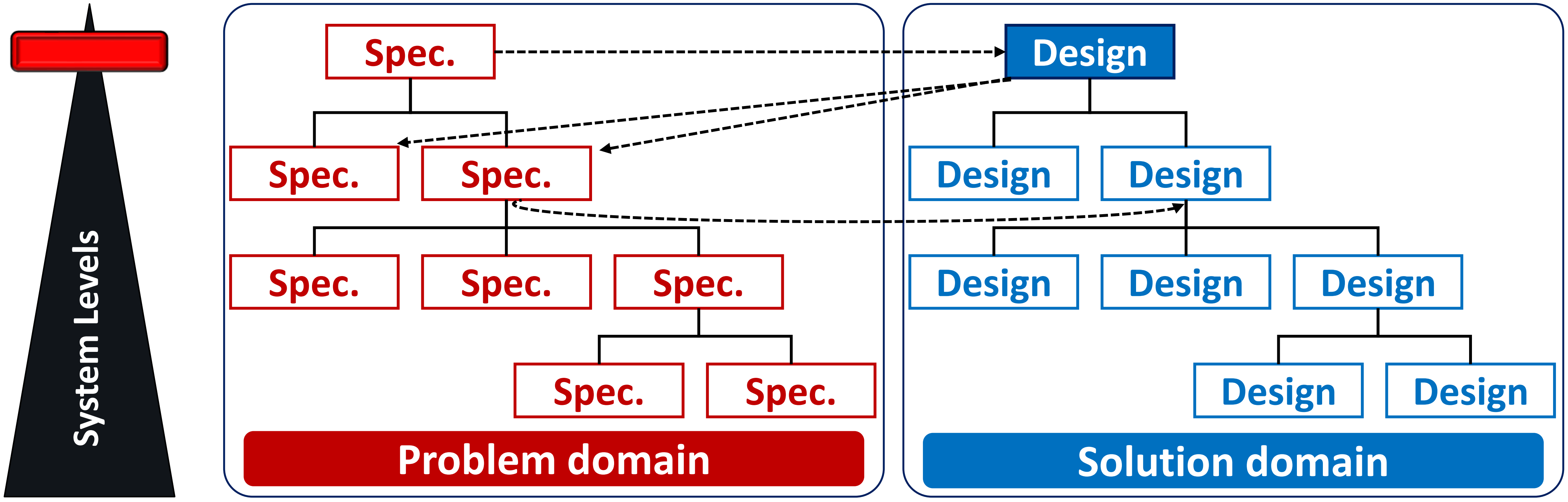


Zigzagging



Zigzagging from Axiomatic Design theory (Suh, 02)

Zigzagging



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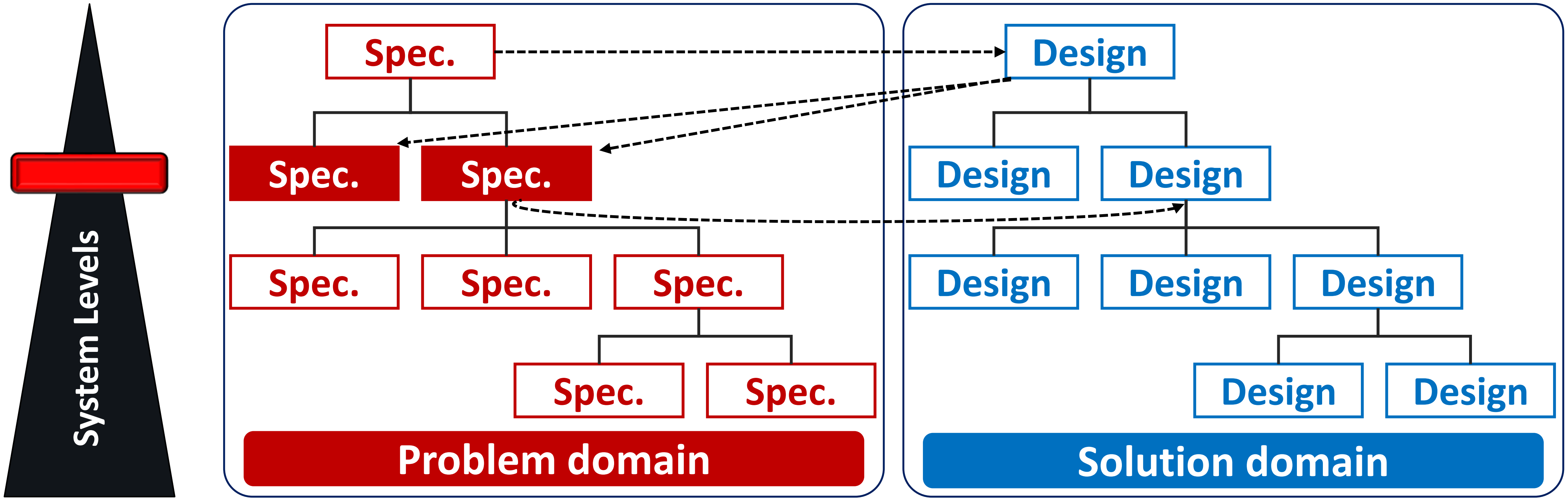
Zigzagging



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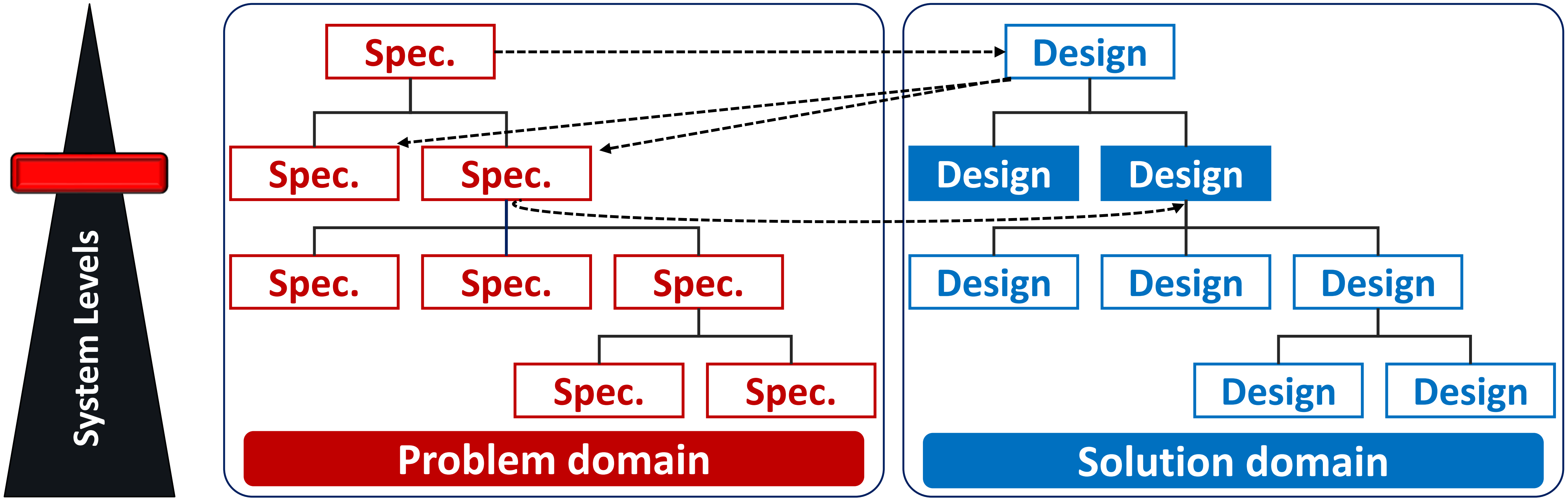

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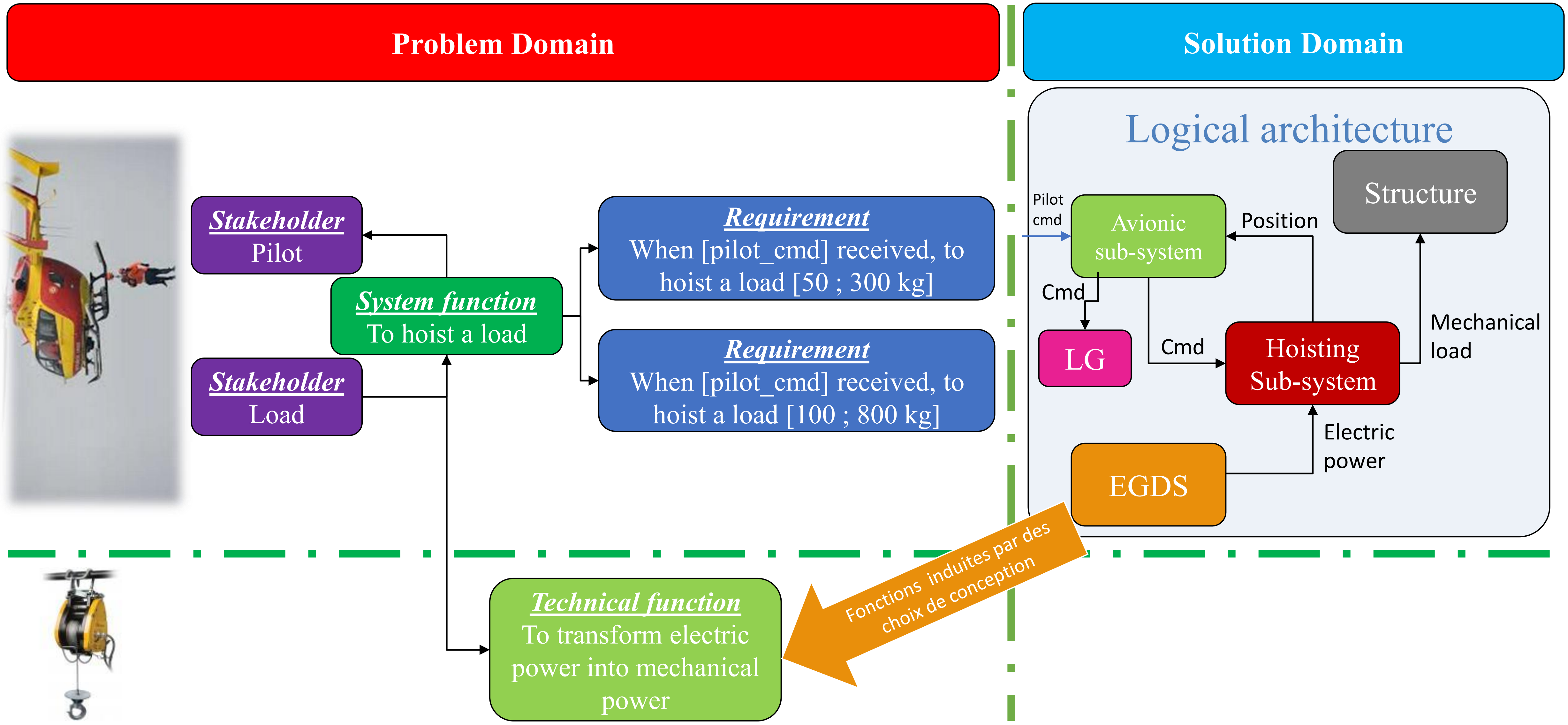
Zigzagging



Problem Domain
Solution Domain
Stakeholder
Pilot
System function
To hoist a load
Stakeholder
Load
Requirement
When [pilot_cmd] received, to hoist a load [50 ; 300 kg]
Requirement
When [pilot_cmd] received, to hoist a load [100 ; 800 kg]
Technical function
To transform electric power into mechanical power
Fonctions induites par des choix de conception
Logical architecture
Structure
Pilot cmd
Avionic sub-system
Position
Cmd
LG
Cmd
Hoisting Sub-system
Mechanical load
Electric power
EGDS

Well, what do we deliver?

GRENOBLE INP UGA Génie industriel

École nationale supérieure de génie industriel

Introduction to the Fundamentals of Systems Engineering

1. A brief introduction to Systems Engineering (SE)

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Grenoble Institute of Technology – School of Industrial Engineering – G-SCOP UMR CNRS