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EBU5608 Product Development and Management

Topic 9 – System Level Design

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Agenda

- Aim of Phase 2 System-level Design
- Product architecture – what is it?
- Modular and integral architecture
- Implications of product architecture
- Role of the product architecture team
- **4-step method** for establishing the product architecture
- Key outcomes

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The product development process

- Product development **starts** with planning and **concludes** with product launch
- A generic product development process can be used as an example
- The process has six distinct phases
  - 0. **Planning**
  - 1. **Concept development**
  - 2. **System-level design**
  - 3. **Detail design**
  - 4. **Testing and refinement**
  - 5. **Production ramp-up**

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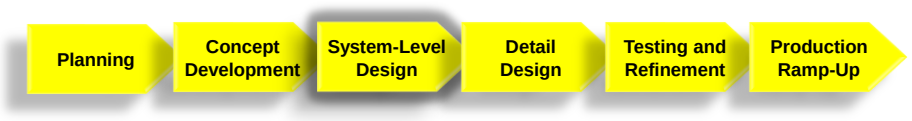
Phase 2 – System-level design

- During phase 2, the development of the **architecture** of the product continues from phase 1 - concept development
  - i.e. the **product specifications** identified in the Contract Book continue to become more **defined**
- Phase 2 includes the definition of the **product architecture** and the **decomposition** into functional & physical **elements**



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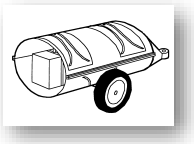
Phase 2 – System-level design

- This definition and decomposition can be clearer for **physical** products, but still relevant for **software** etc
  - Think about the use of classes, subsystems and interfaces in **Java** program development, for example



Java

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Product Architecture

- **Product Architecture** can be described as:
  - "the **scheme** by which the **functional elements** of the product are **arranged** into **physical chunks** and by which the **chunks interact**"
  - **Functional** – individual **operations** and **transformations** that contribute to its **overall** performance
  - **Physical** – **parts**, **components** and **subassemblies** that implement the product's functions

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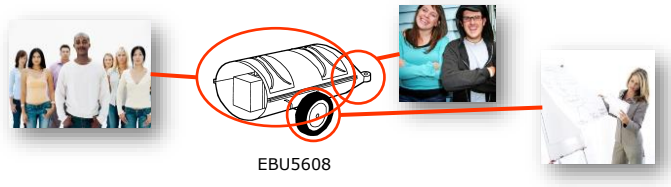
Product Architecture's Aim

- Architectural decisions allow the **detailed design** and **testing** of these physical blocks to be assigned to **teams**, individuals, and/or suppliers, so that the development of different portions can be carried out **simultaneously**



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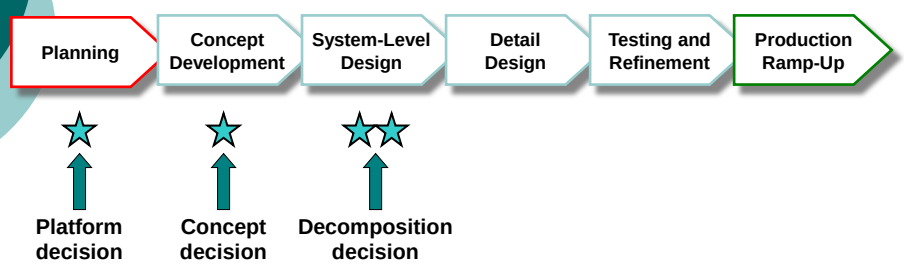
…in a Product Development Process



Product architecture is determined early in the development process.

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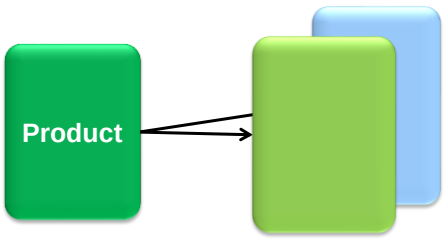
Product Architecture - Chunks

- The physical elements of a product are typically organised into several major building blocks – called **chunks**
- These chunks become the building blocks for the product or **family** of products



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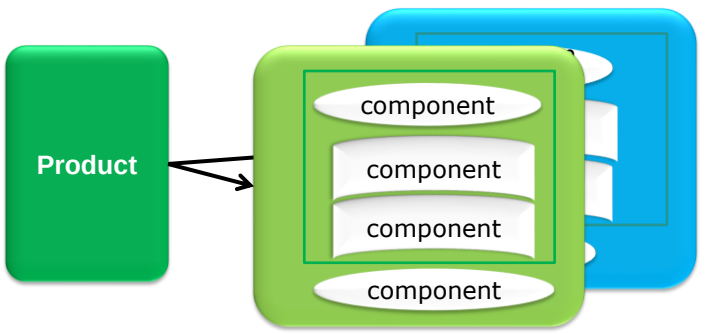
Product Architecture - Chunks

- Each chunk is then made up of a collection of **components** which implement the **functions** of the product



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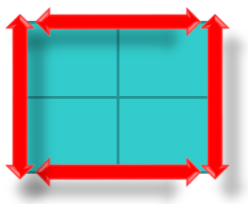
Product Architecture - Chunks

- The **architecture** of a product is therefore the **scheme** by which the **functional elements of the product are**
  - **arranged** into **physical chunks** and
  - by which the **chunks interact**



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Modular or Integral Architecture?

iPhone

Rollerblade In-Line Skates

Tesla car

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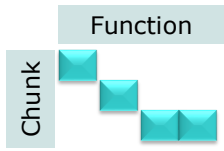
Modular & integral architecture

- A **key characteristic** of product architecture is the degree to which it is either:
  - **Modular**, in which
    - Each chunk implements **one** or a **few functions entirely.**
    - The **interactions** between chunks are **well defined.**
    - Modular architecture has **simplicity** and **reusability** for a product family or platform.



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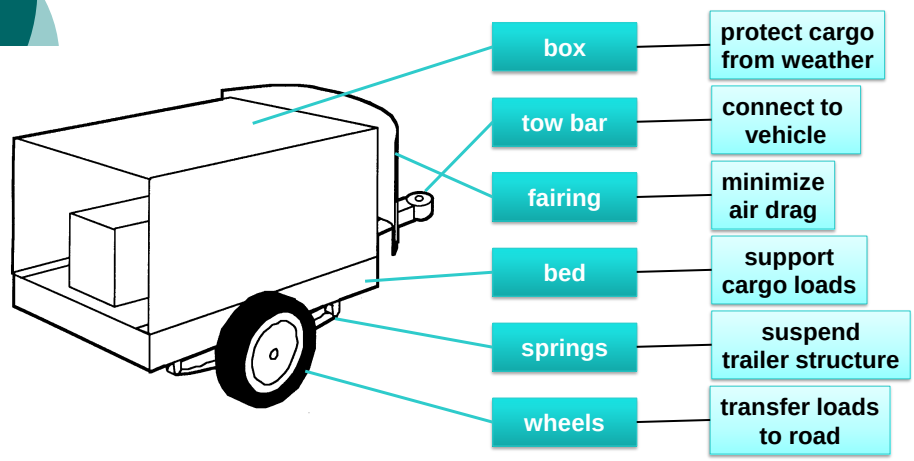
Trailer example: Modular Architecture



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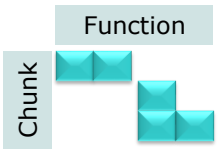
Modular & integral architecture

- **Integral**
  - **Functional elements** are implemented by **multiple** chunks, or a chunk may implement many functions
  - The **interactions** between chunks are **poorly defined**
  - Integral architecture generally increases performance and reduces costs for any specific product model.



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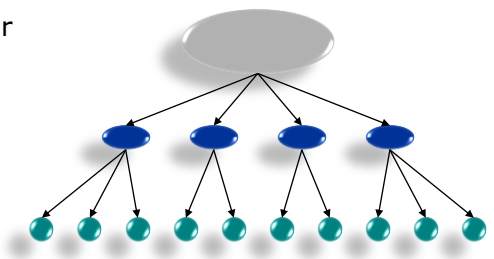
Concepts and levels

- The concepts of integral and modular apply at several levels:
  - System
  - Sub-system
  - Component



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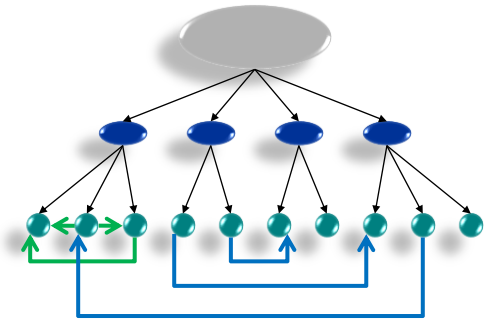
Decomposition & interactions

- Product Architecture is decomposition + interactions
- Decomposition
- Interactions
  - within chunks
  - across chunks



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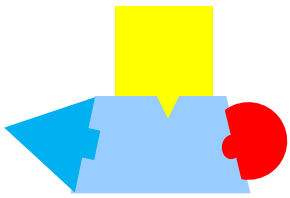
Modular architecture

- There are three main types of modular architecture:
  1. **Slot-modular** (the most common type)
     - Each of the **interfaces** between chunks in a slot-modular architecture is of a **different type** from the others – therefore the various **chunks** in the product **cannot** be interchanged



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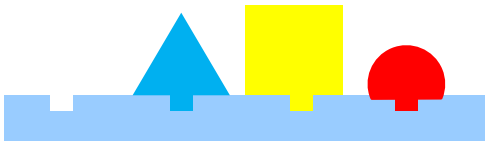
Modular architecture

- There are three types of modular architecture:
  2. **Bus-modular**
     - There is a **common bus** to which the other chunks connect via the **same type** of interface



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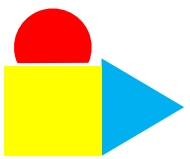
Modular architecture

- There are three types of modular architecture:
  3. **Sectional-modular**
     - All **interfaces** are of the **same type**, there is **no single element** to which all the other chunks **attach**
     - The assembly is built up by connecting the chunks to **each other** via identical interfaces



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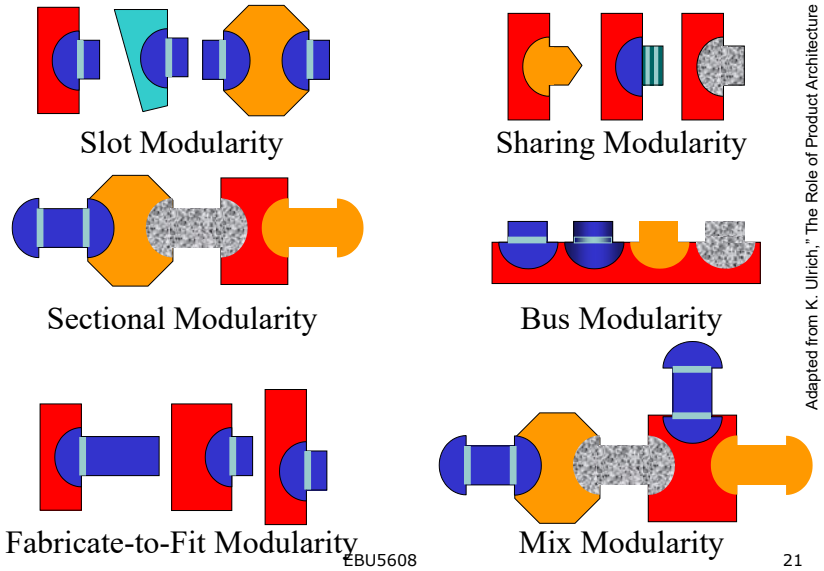
Other Types of Modularity



Adapted from K. Ulrich, "The Role of Product Architecture in the Manufacturing Firm", *Research Policy*, 1995.

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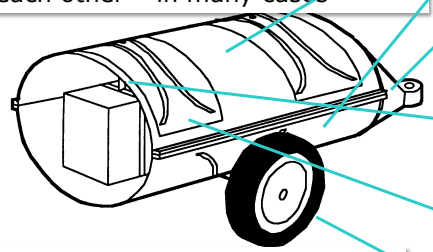
Trailer example: Integral Architecture

Here we show a similar example to the modular architecture trailer, but the parts are now integral to each other – in many cases



One chunk can perform **many functions** – and **one function** can need **many chunks**

- upper half
- lower half
- nose piece
- cargo hanging straps
- strap slot covers
- wheels

- protect cargo from weather
- connect to vehicle
- minimize air drag
- support cargo loads
- provide trailer structure
- transfer loads to road

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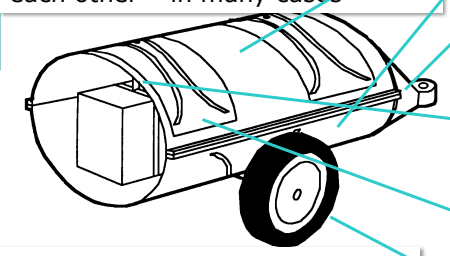

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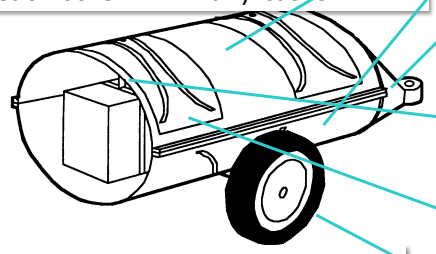

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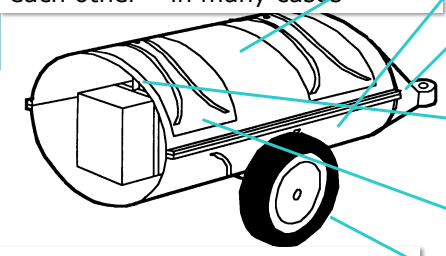

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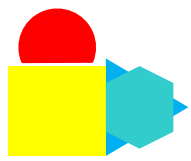
Implications of product architecture

- There are **implications** to the decisions you make about product architecture
- **Product change**
  - **Modular** chunks allow **changes** to be made to a **few isolated** functional elements of the product without necessarily affecting the design of **other chunks**
  - **Motives** for change include – upgrades, add-ons, adaptation, wear, consumption, flexibility in use, reuse



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Implications of product architecture (cont.)




- **Product variety**
  - Variety refers to the **range** of product models the firm can produce within a particular **time** period in response to market **demand**
  - Products built around **modular** product architectures can be **more easily varied** without adding tremendous complexity to the **manufacturing** system
    - e.g. mobile phone handset design, portable audio

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Implications of product architecture – product variety example

- Sony is a major consumer and commercial electronics manufacturer
- Sony sells **54 models** of portable audio equipment in the UK, including
  - MP3
  - Personal CD, minidisc & tape
  - Portable CD+radio
  - Portable radio
- Uses **modular architecture** and **flexible manufacturing** techniques to
  - Introduce new **models**
  - Meet changes in **demand**




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Implications of product architecture (cont.)

- **Component standardisation**
  - The use of the **same** component or chunk in **multiple** products
  - If a chunk implements only one or a few **widely useful** functional elements, then the chunk can be **standardised** and used in several **different** products
  - Example – standard batteries

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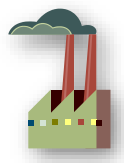
Implications of product architecture (cont.)

- **Product performance**
  - How **well** a product implements its intended **functions**
  - Product performance **characteristics** include speed, efficiency, life, accuracy and noise
- **Manufacturability**
  - The product architecture also directly affects the ability of the team to design each chunk to be **produced** at **low cost**



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Implications of product architecture (cont.)

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- **Product development management**

Responsibility for the detail design of each chunk is usually assigned to a relatively **small group** within the **firm** or to an outside **supplier**

Chunks are assigned to a single individual or group because their design requires careful resolution of **interactions** among components within the chunk

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Role of Product Architecture Team

- The architecture should be established by a **cross-functional** effort by the development team as it will have implications for
  - subsequent product **development** activities, and
  - the **manufacturing** and **marketing** of the completed product

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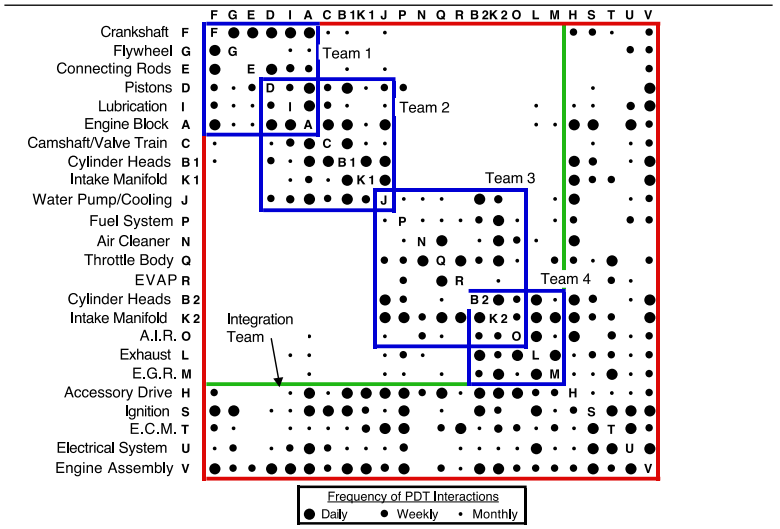
System Team Assignment Based on Product Architecture



From "Innovation at the Speed of Information", S. Eppinger, *HBR*, January 2001.

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Summary

- The **architecture** of a product is therefore the **scheme** by which the **functional elements of the product** are arranged into **physical chunks** and by which the **chunks interact.**
- Two main types of architecture
  - **Modular** (slot, bus, sectional) in which each chunk implements **one** or a **few functions entirely** and the **interactions** between chunks are **well defined.**
  - **Integral**, in which **functional elements** are implemented by **multiple** chunks, or a chunk may implement many functions, and the **interactions** between chunks are **poorly defined.**
- Implications of product architecture: product **change**, **variety**, **performance**, **manufacturability**, **components standardisation**, **product development management**

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The 4 step method

- Ulrich and Eppinger recommend a **4-step method** for establishing the product architecture
  - Step 1 – Create a **schematic** of the product
  - Step 2 – **Cluster** the elements of the schematic
  - Step 3 - Create a rough **geometric layout**
  - Step 4 – Identify the fundamental and incidental **interactions**

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Product Architecture Example: Hewlett-Packard DeskJet Printer

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Step 1 – Create a schematic of the product

- A schematic is a diagram representing the team's understanding of the **component elements** of the product
  - An example can be seen in a later slide
- At the **end** of **Phase 1** – Concept Development
  - some of the **elements** in the schematic are **physical** concepts
  - some correspond to **critical components**
  - but some are still only described **functionally**

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Step 1 – Create a schematic of the product

- The schematic should reflect the **best understanding** of the state of the product, it does not have to contain every detail
- More **detailed** functional elements are finalised **later** in Phase 2
- A good **guideline** is for there to be **no more than 30 elements** in the schematic
- Usually **more than one** alternative schematic is developed and the team spend time **selecting** the most appropriate

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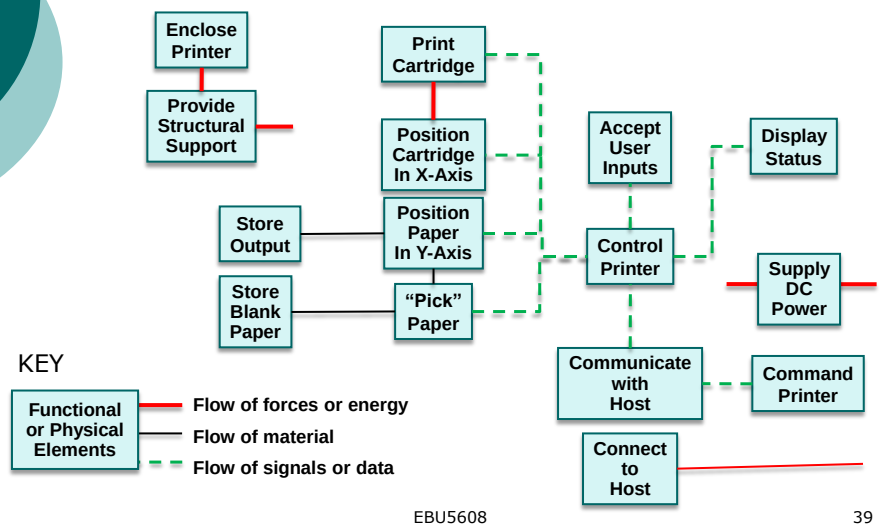
Architecture example - DeskJet Printer Schematic



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Step 2 – Cluster the elements of the schematic

- This step requires **assigning** and/or **clustering** each of the **elements** of the schematic to a **chunk**
- An **example** of this clustering can be seen in the next slide

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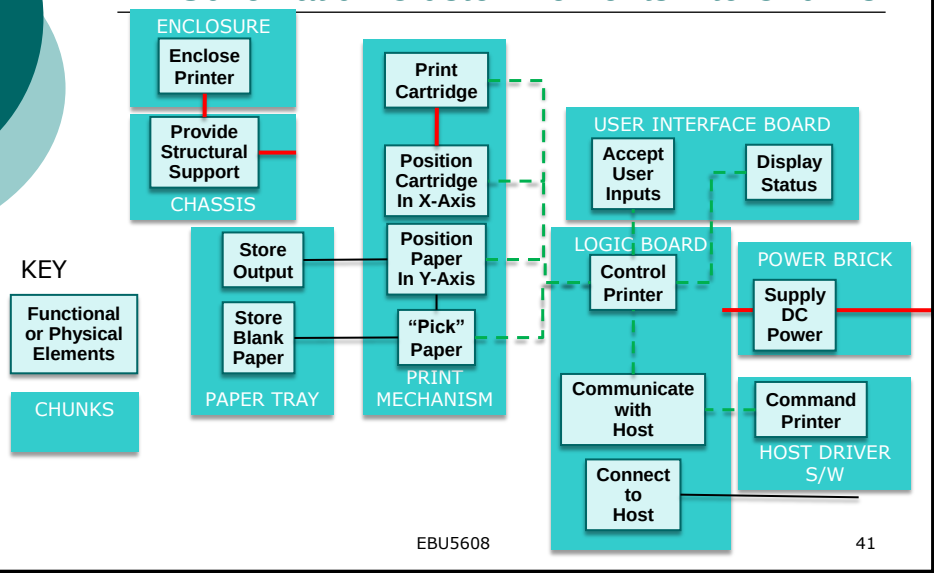
Architecture example - DeskJet Printer Schematic - Cluster Elements into Chunks



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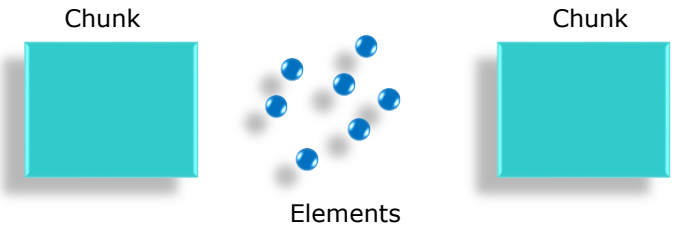
Setting the clusters

- The clustering role is undertaken by the **team** to ensure that the right decisions are taken in terms of **functionality split**



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Setting the clusters

- When deciding where to set the clusters, the following factors should be considered:
- **Geometric integration and precision**
  - Assigning elements to the **same** chunk allows a **single** individual or group to control the physical **relationships** among the elements
  - Elements requiring **precise location** or **close geometric integration** can often be best designed if they are part of the **same** chunk
    - e.g. paper handling in a printer

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Setting the clusters

- **Function sharing**
  - When a **single** physical **component** can implement **several functional** elements of the product, these functional elements are best clustered **together**
  - For example, an integrated control panel on a car

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Setting the clusters

- **Capabilities of vendors**
  - A **trusted vendor** may have specific capabilities related to a project
  - To best take advantage of such capabilities a team may choose to cluster those elements about which the vendor has **expertise** into **one chunk**

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Setting the clusters

- **Similarity of design or production technology**
  - When **two or more** functional elements are likely to be implemented using the **same design** and/or **production technology**, then incorporating these elements into the **same chunk** may allow for more economical design and/or production
  - A common strategy, for example, is to **combine** all functions that are likely to involve **electronics** in the **same chunk**. This allows the possibility of implementing all of these functions within a **single circuit board**

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Setting the clusters

- **Localisation of change**
  - When a team expects there to be a **great deal of change** in an element, it makes sense to **isolate** that element into its own modular chunk
  - In that way, any necessary changes to the element can be carried out without **disrupting** any of the other chunks

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Setting the clusters

- **Accommodating variety**
  - Elements should be clustered together to enable the firm to **vary** the product in ways that will have value for **customers**
  - Example – a power supply needs to handle different mains supplies in different countries

230V 50Hz

120V 60Hz

100V 60Hz

120V 50Hz

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Setting the clusters

- **Enabling standardisation**
  - If a set of elements will be useful in **other products**, they should be clustered together into a single chunk
  - This allows the **physical elements** of the chunk to be produced in **higher quantities**
  - Example – cartridge in ink jet printer

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Step 3 - Create a rough geometric layout

- A geometric layout can be created in **2 or 3 dimensions** or as **physical** models
  - an example can be found on a later slide
- Creating a geometric layout forces the team to consider
  - whether the **geometric interfaces** among the chunks are **feasible** and
  - to work out the basic **dimensional relationships** among the chunks

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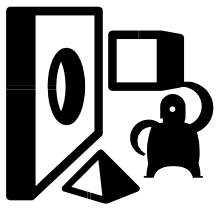
Step 3 - Create a rough geometric layout

- In some cases, the team may discover that the clustering derived in step 2 is **not** geometrically feasible
- If this happens, some of the elements have to be **reassigned** to other chunks



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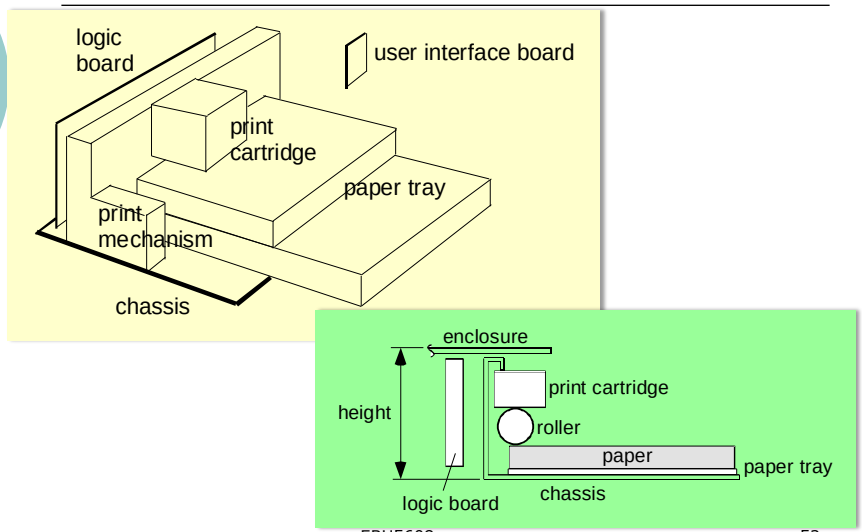
Geometric Layout Example



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Step 4 - Identify the fundamental and incidental interactions

- It is most likely that a **different** person or group will be assigned to design **each chunk**
- Because the chunks interact with one another in both **planned** and **unintended** ways, these different groups will have to **coordinate** their activities and exchange information
- To **manage** this coordination process better, the team should **identify** the known **interactions** between chunks during the system-level design phase

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Step 4 - Identify the fundamental and incidental interactions

- There are two categories of interaction
  - **Fundamental**
    - Those which correspond to the lines on the **schematic** that **connect** the chunks to one another
    - These are the **fundamental** interactions of the systems operation

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Step 4 - Identify the fundamental and incidental interactions

- **Incidental**
  - Those that arise because of
    - the particular physical implementation of functional elements, or
    - because of the geometric arrangement of the chunks
  - An **incidental interaction graph** is used to document this type of interaction, see next slide

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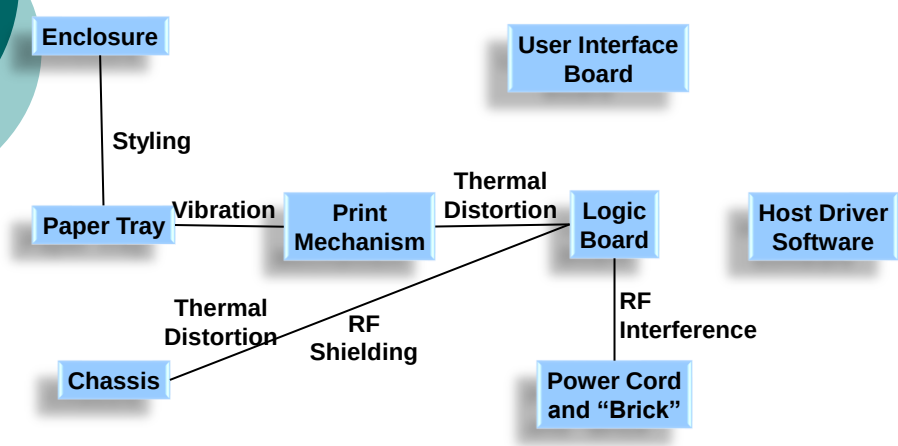
Incidental interactions example



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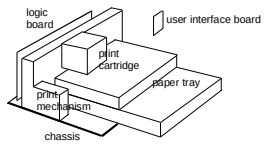
Key Outcomes

- The **end results** of this 4-step method for establishing the product architecture are:
  - an approximate **geometric layout** of the product
  - **descriptions** of the major chunks
  - documentation of the key **interactions** among the chunks



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Summary

- **4-step method** <u>for establishing the product architecture</u>
  - Step 1 – Create a **schematic** of the product
  - Step 2 – **Cluster** the elements of the schematic
  - Step 3 - Create a rough **geometric layout**
  - Step 4 – Identify the fundamental and incidental **interactions**

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In-class Exercise (15 mins):

1. Name 3 different types of modular design in a PC.
2. From system-level design perspective, explain the 3 major differences between Apple keyboard design 1983 and that of 2024.

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Reading

- **Core Textbook** (Ulrich & Eppinger, 7th Edition)
  - Chapter 10. Product Architecture.

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References

1. Product Design and Development, Karl T Ulrich and Steven D Eppinger, 7th Edition, 2020, McGraw-Hill, chapter 10.