A holistic view of design for manufacture

Dr James Moultrie

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Agenda …

- A brief history lesson !
- Design for manufacture
- Design for assembly
- Product architecture
- Product platforms

A brief history lesson …

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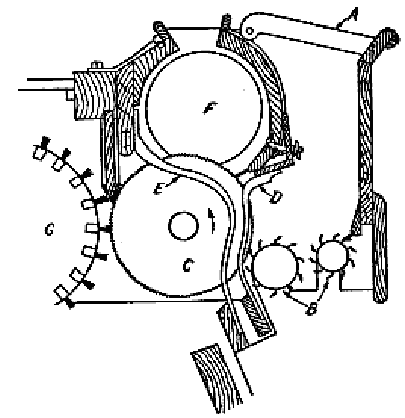
Eli Whitney …

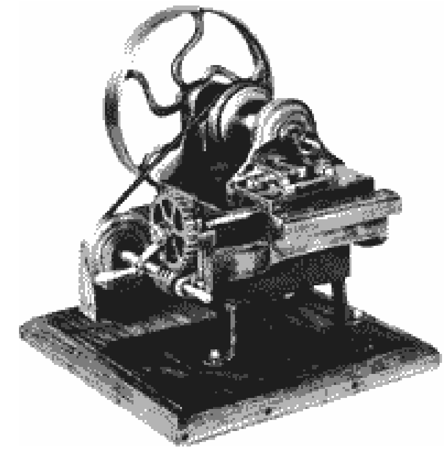
- Originally a blacksmith: nails and hatpins
- Attended Yale in mid 20s
- Taught
- Worked on a plantation
  - Designed a machine to clean cotton
  - Did work of several people
  - But machine copied
  - Nearly ruined in court cases
- Penniless at 39

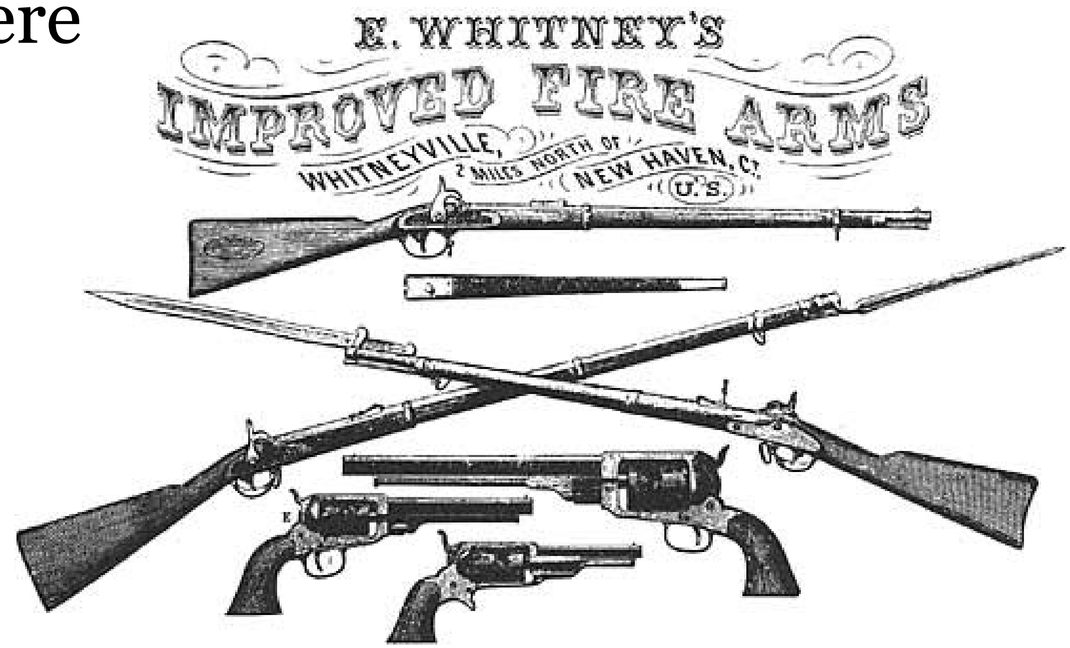


Source: www.eliwhitney.org/

Eli Whitney …

- Took an impossible order to make 10,000 muskets at $13.40 each
- Up to then, all rifles were handmade
- Invented the milling machine
- He created (arguably) standardised and interchangeable components
- Tolerances!





Source: www.eliwhitney.org/

Henry Ford …

- 1907: assembly line
- divided manual assembly operations into short cycle repetitive steps
- Model T ford - standardised parts, simplification
- Serviceability - easy access for repair

“We start with the consumer, work back through the design and finally arrive at manufacturing”

Value analysis …

- General Electric 1940
- Systematic review of product costs
- Initially applied to existing products

- Value engineering: applied during design phase

Source: http://dismuke.net/howimages/gerefrig1940large.jpg

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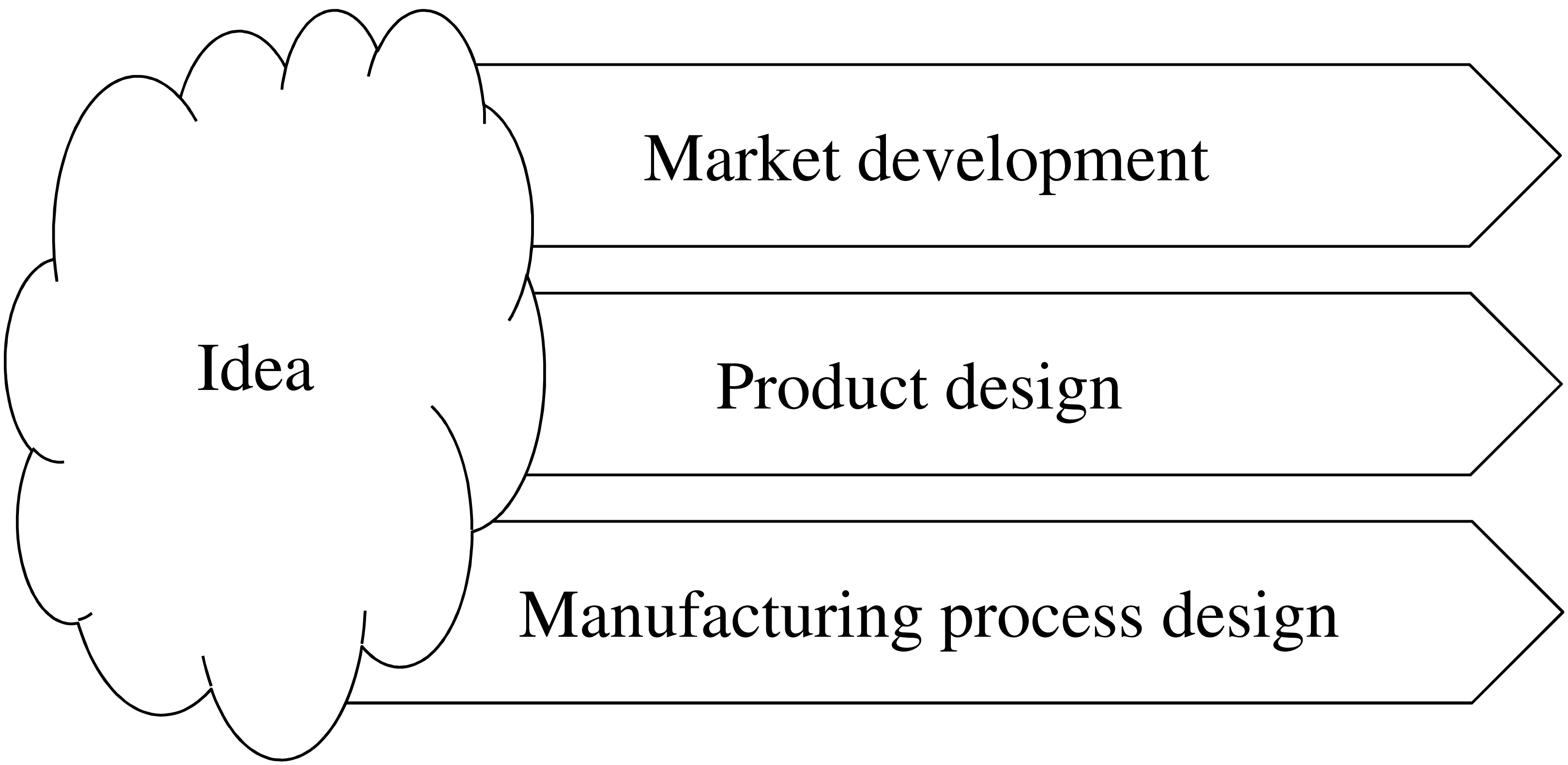
1960 onwards …

- 1960s: Producibility & manufacturability
  - GE developed internal guide - *“manufacturing producibility handbook”*
  - c. 1985 DfM came into wider use
- 1968: Systematic methods for Design for Assembly
  - Boothroyd & Redford: studied automatic assembly
  - Later Boothroyd & Dewhurst
  - Lucas Engineering Systems

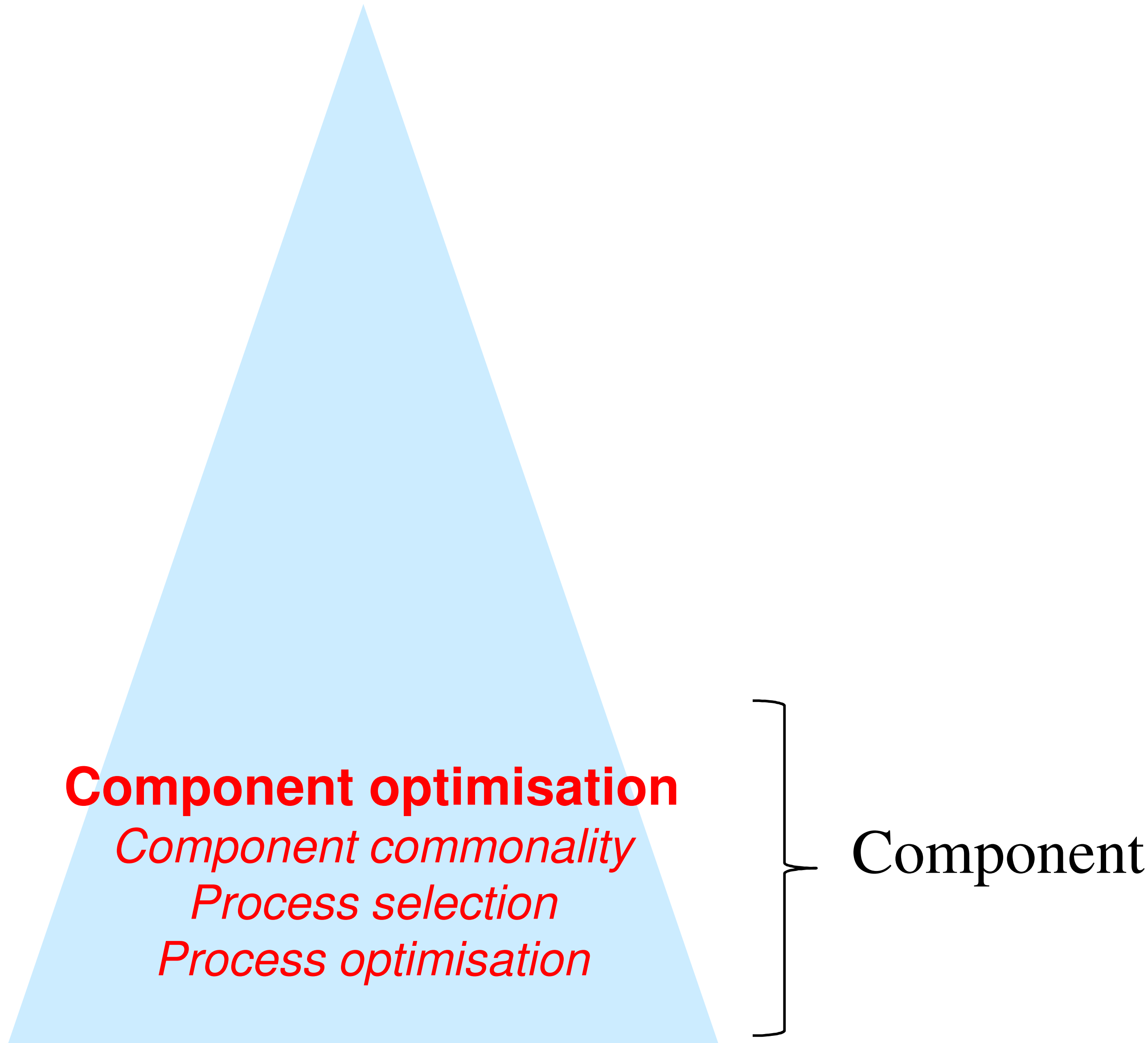
1980's: Concurrent engineering …



1990s DfX and Product architecture

- Df … environment, safety, etc
- Product platforms
- Product architecture
- Modularity
- Reuse

Design for manufacture


Component optimisation
Component commonality
Process selection
Process optimisation
Component

DFM elements …

- Appropriate process selection
  - material, volume
  - tolerances, complexity
  - set up costs
  - expertise (internal / external)
- Reduce the number of process stages
  - eliminate and combining processes
  - reducing set up requirements
- Optimise for the process
  - recognise the process limitations
  - exploit benefits of the process
  - DFM process specific guidelines

Process guidelines ...

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DESIGN FOR MANUFACTURABILITY / ASSEMBLY GUIDELINES
INJECTION MOLDING

Raw Materials

	Yes	No	Exception/Explanation
Use standard material types, colors, and fills.			
Consider recyclability of the material when selecting.			
Substitute a material that is more economical			
Substitute a material that is easier to process.			
Mark the part with the material to be used.			

General

	Yes	No	Exception/Explanation
Avoid unnecessary part features & complex shapes - they involve more complex tooling			
Avoid unnecessary tolerances & finishes			
Use lowest cost equipment that provides needed capability			

Part Ejection:

	Yes	No	Exception/Explanation
Place gate & ejector pin locations on underside of part where blemishes are least critical			
Use draft angles to facilitate part removal. The draft angles should typically be > .5" minimum; typically 1° to 2° for 5" depth. Use a greater angle with texture.			
Minimize surface area perpendicular to part line since greater surface area of walls & projections perpendicular to part line requires increased ejection force. Higher ejection forces require longer cooling times. Since cooling is 70%-80% of mold cycle, ejection force is an important DFM factor.			
Reduce ejection force requirement by: considering rib & projection height & surface area; use gussets instead of ribs; use larger draft angles, and polish the mold surface.			

Wall thickness:

	Yes	No	Exception/Explanation
Keep uniform - less than 15% variation			
Make transitions gradual			
Thicker walls require more cooling time; consider ribs as a structural alternative			

Corners:

	Yes	No	Exception/Explanation
Avoid sharp corners			
Maintain inner radii > .5 x wall thickness			
Maintain outer radii >1.5 x wall thickness			
Maintain inner & outer radii around common center point			

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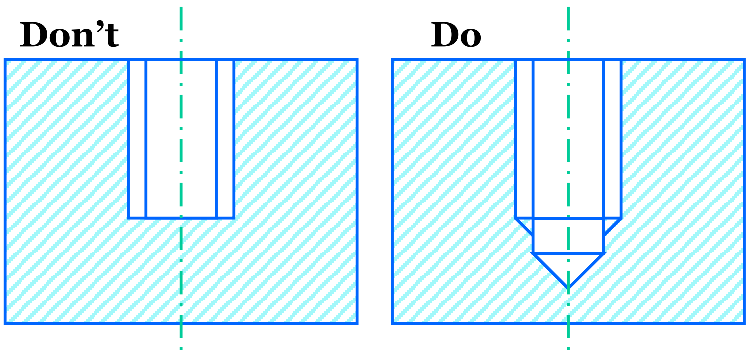
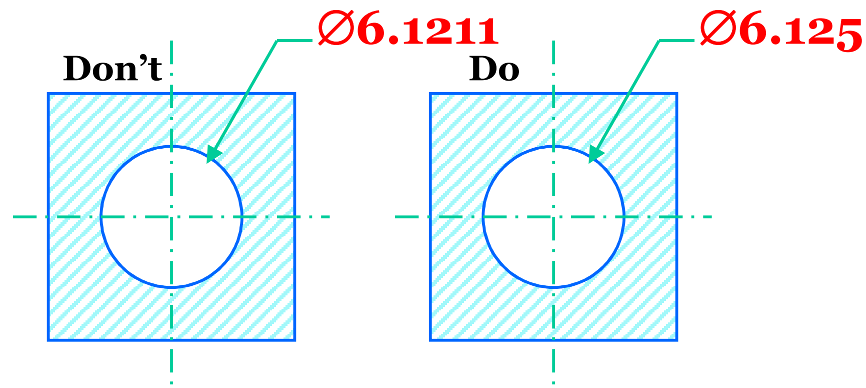
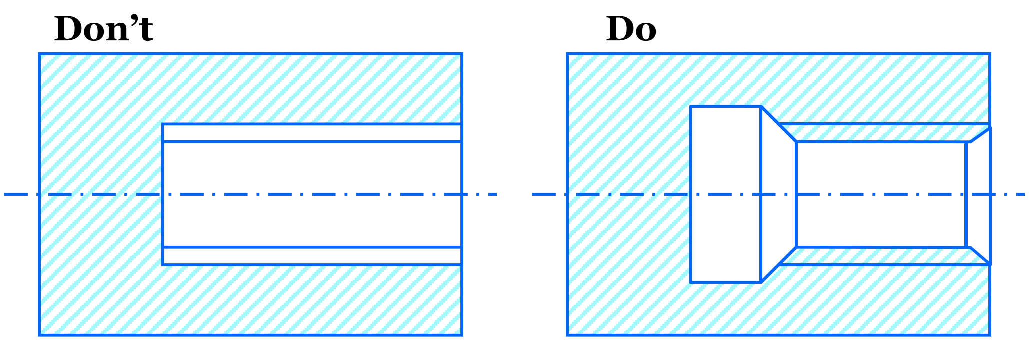
Examples … machined part guidelines …



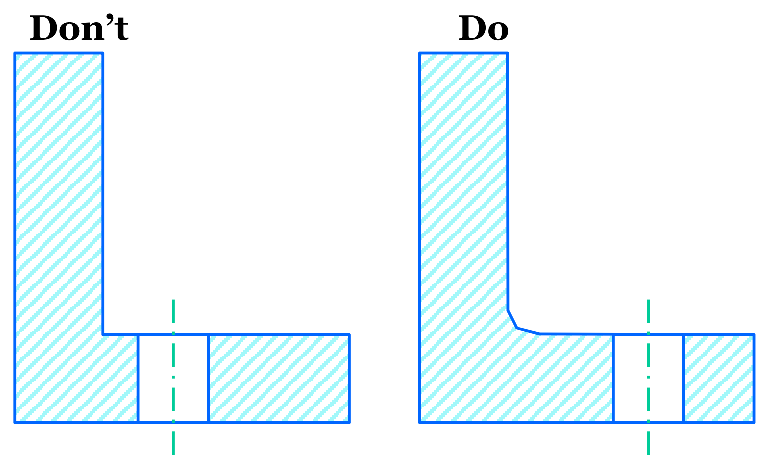
DO - Design holes to the shape of the tool. If a hole is to be tapped, provide space for it.



DO - Use standard dimensions wherever possible (NB - these may vary depending on the tooling available)

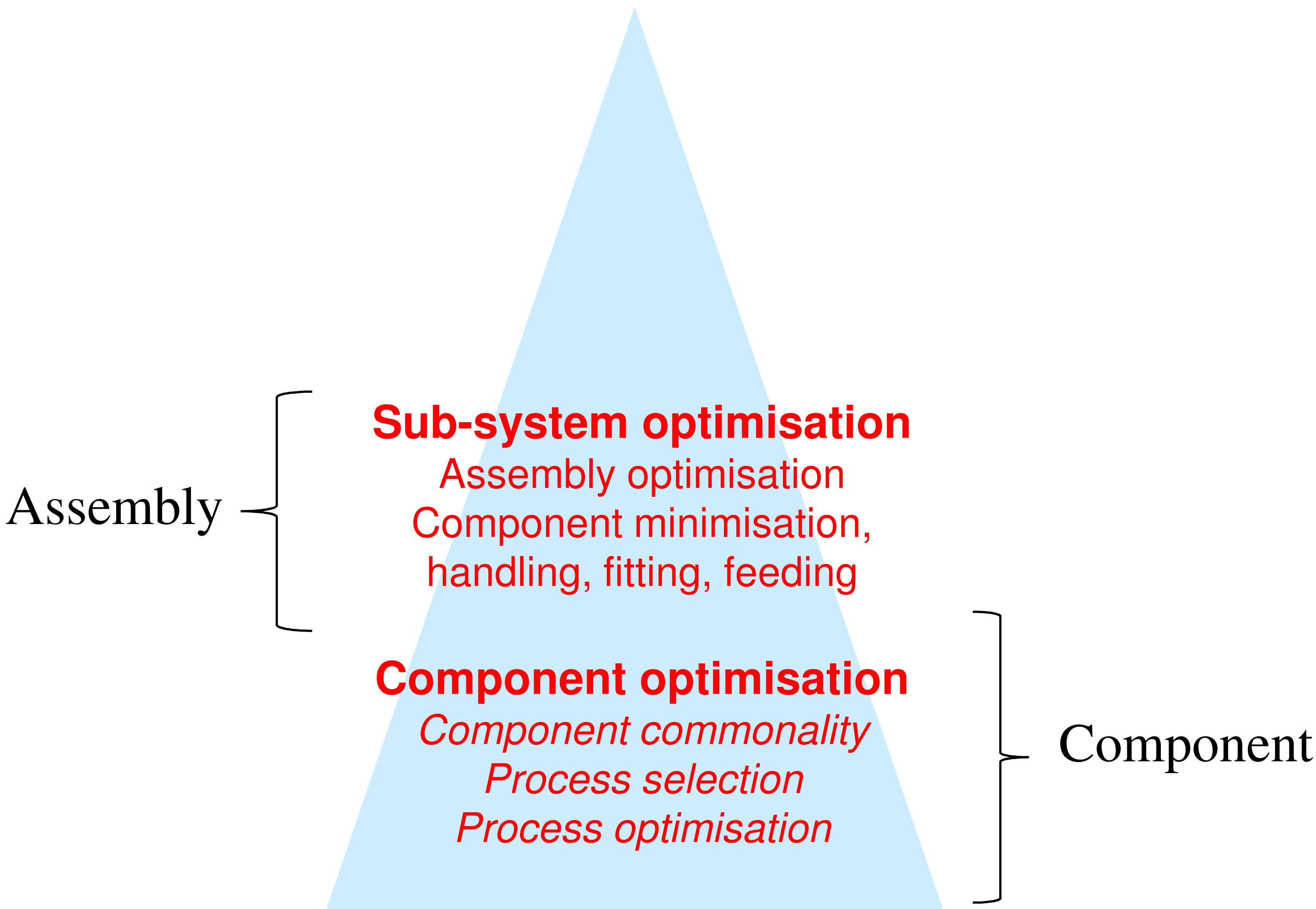


DO - Provide an undercut for threads in turned components



DO - Provide appropriate fillet radii (matched to tool tips)
DO - Place holes away from edges - allow room for tool

Design for assembly


Sub-system optimisation
Assembly optimisation
Component minimisation,
handling, fitting, feeding
Component optimisation
Component commonality
Process selection
Process optimisation
Assembly
Component

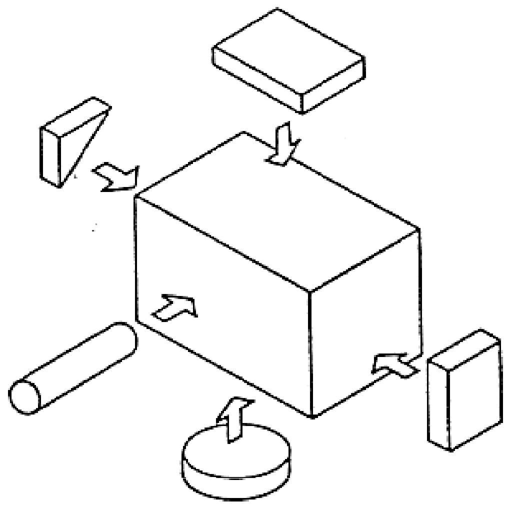
DFA - Design for Assembly …

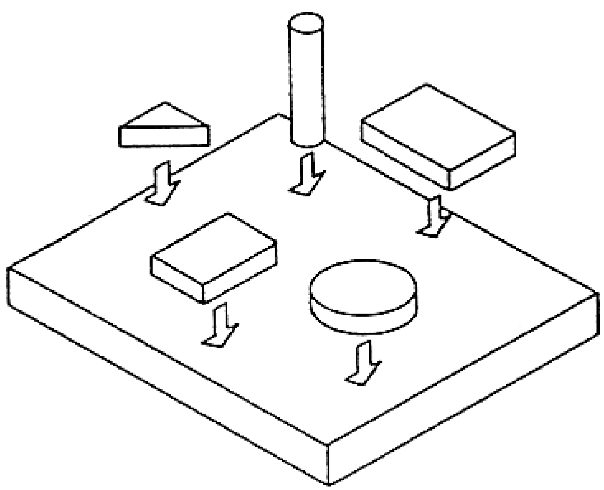
- Design guidelines or design rules
  - System level
  - Issue specific - handling, fixing etc

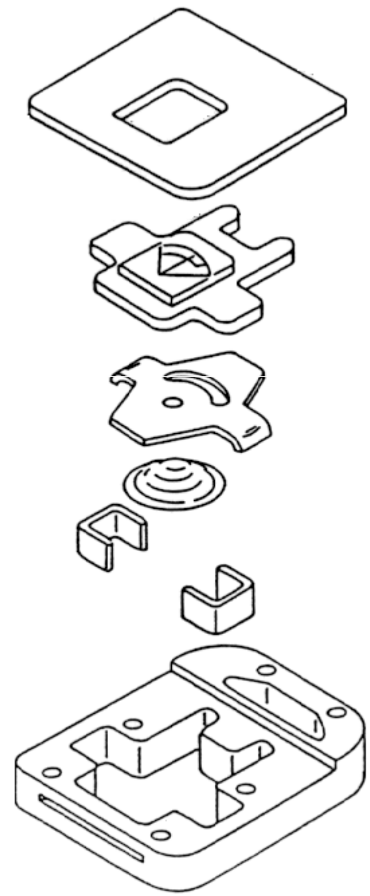
- Systematic methods to analyse an assembly
  - Lucas Engineering & Systems
  - Boothroyd & Dewhurst

- Basic philosophy of all approaches
  - minimise the number of components
  - maximise ease of locating & joining

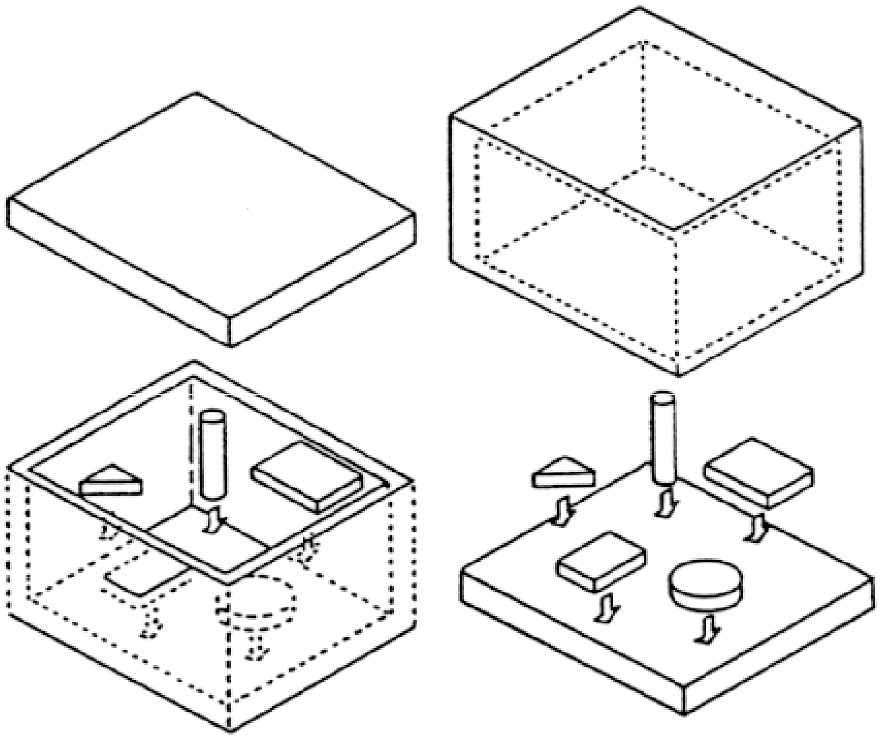
Don’t fight gravity







Open enclosures



Avoid confined spaces
Don’t ‘hide’ key components

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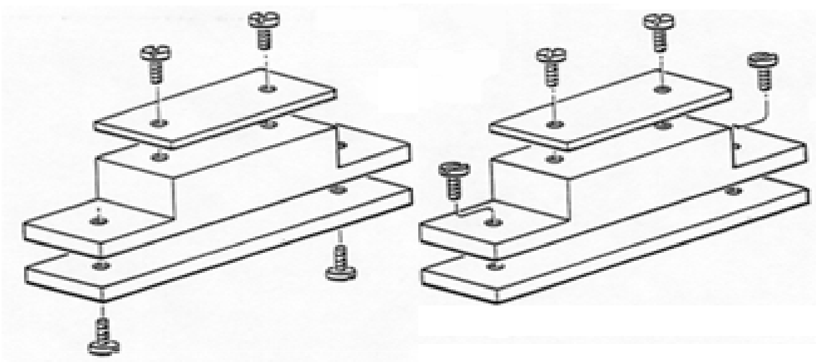
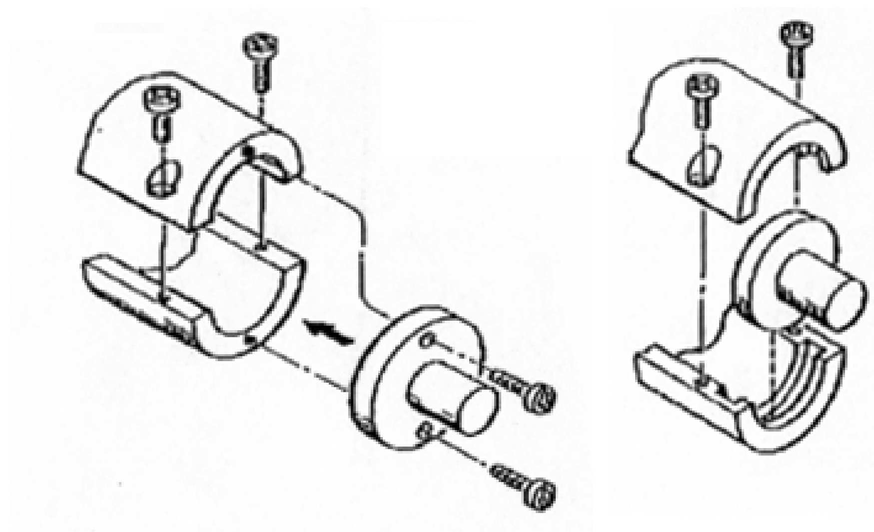
Assemble from a single direction





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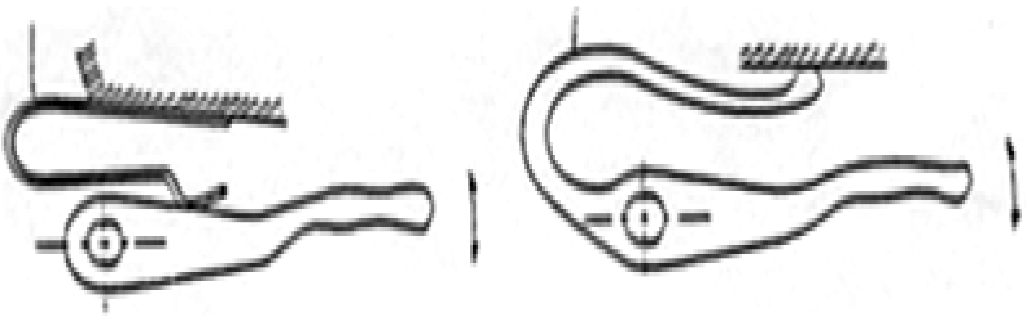
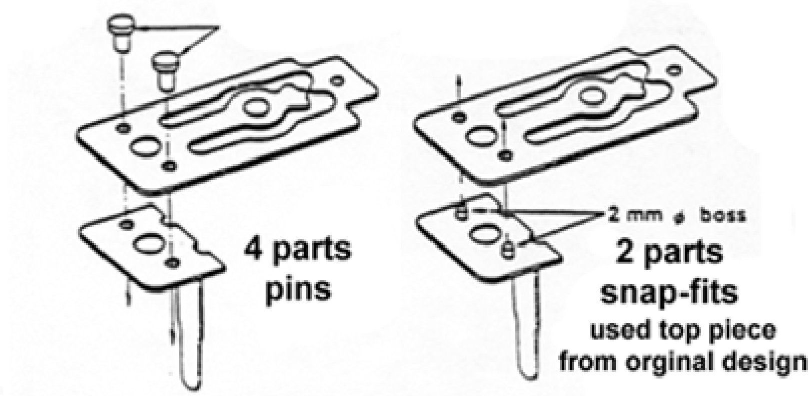
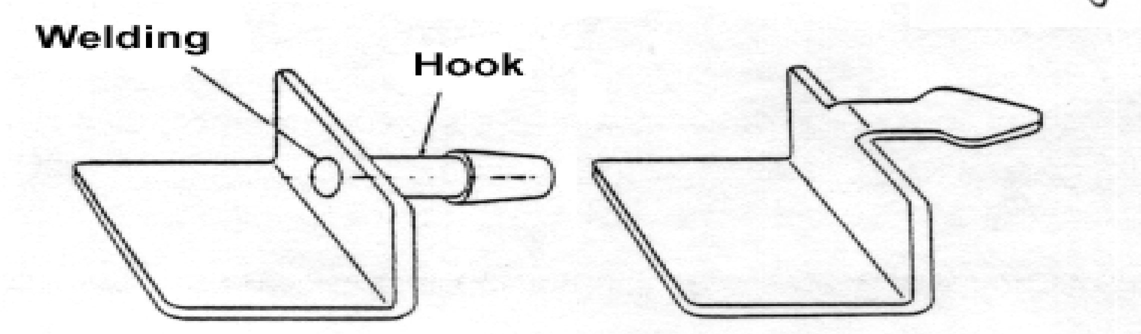
Integrate components ...



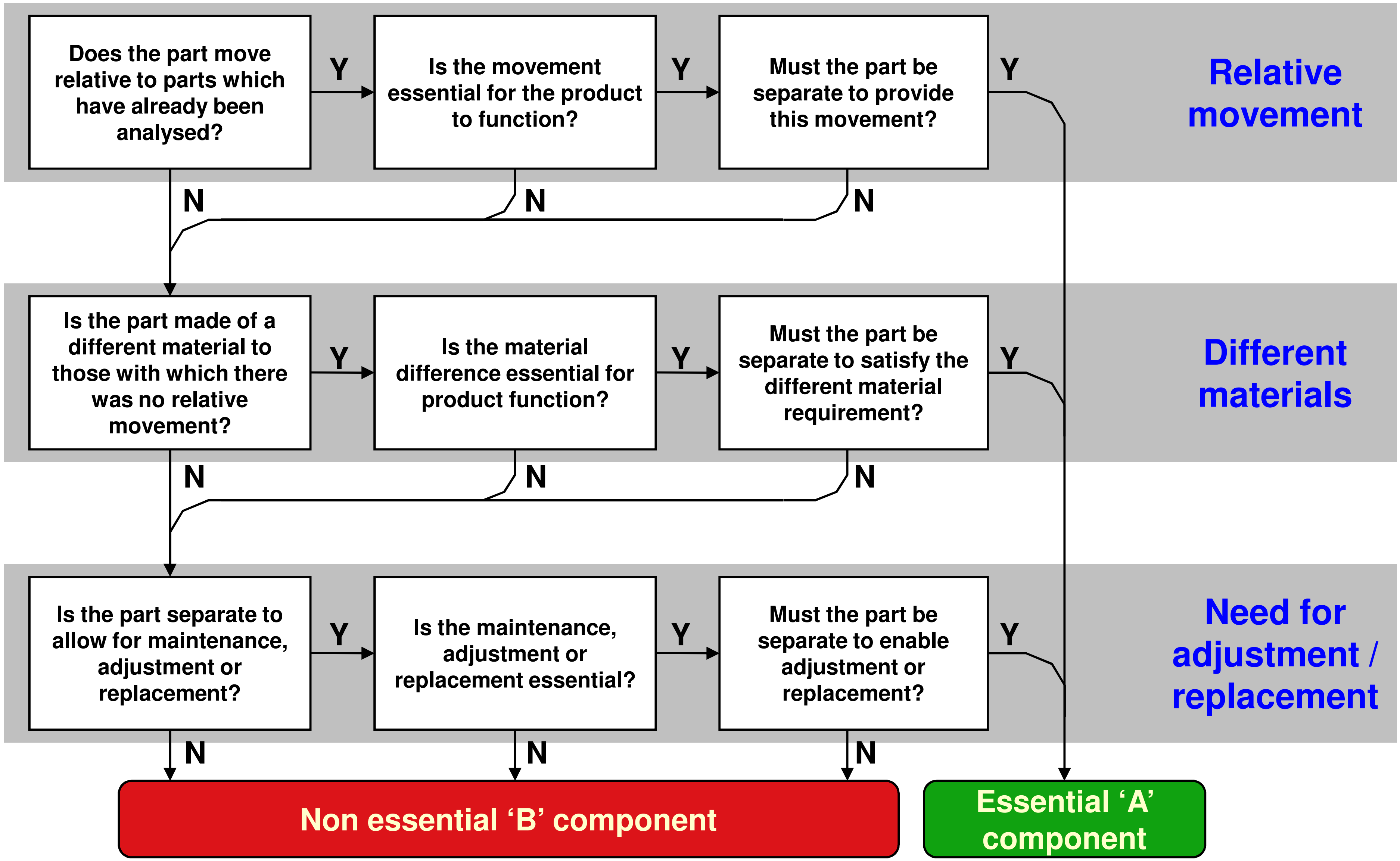




Systematic methods …

- Functional analysis
  - Is each component needed?
- Handling analysis
  - Are the components simple to handle?
- Fixing analysis: Mapping assembly sequence:
  - *Insertion / holding process*
  - *Securing / fixing processes*
  - *Additional (non-assembly) processes*

Component functional analysis …



Component handling & feeding …

- Handling
  - Presentation of parts in manual assembly

- Feeding
  - presentation of parts in automated assembly

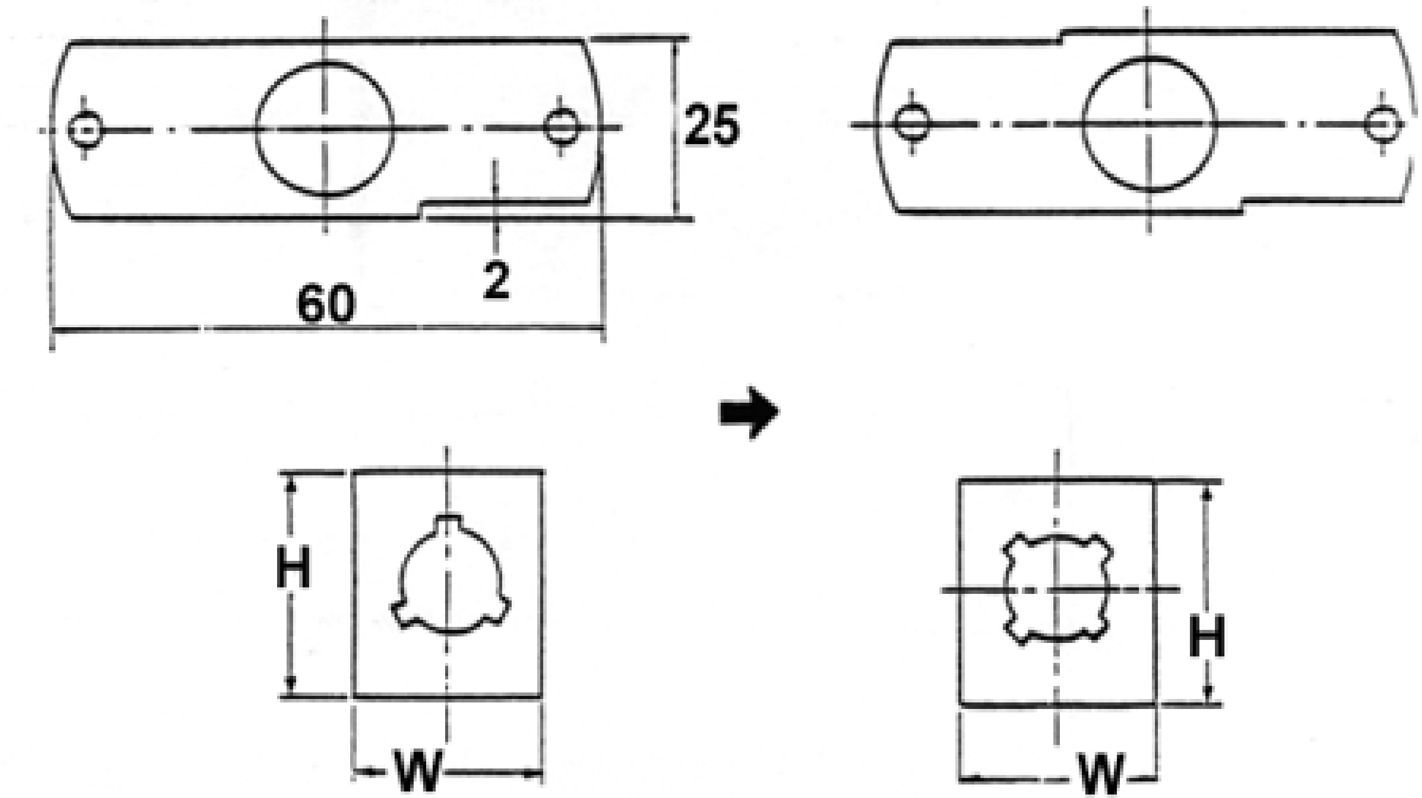
- Scores based on:
  - size and weight
  - specific handling difficulties
  - part orientation - symmetry

Component handling …

Ease of delivering, handling and orienting each component in preparation for assembly

	0	1	3	5	Score
Component size & weight	**Convenient size** *One hand only*	**Small** *Fiddly or requires tools*	**Large / heavy** *2 hands or tools*	**Very large / heavy** *2 people or hoist*	
Handling difficulties	**No handling difficulties**	**Need care to grip** *Adherence, delicate, sharp / abrasive*	**Difficult to grip** *Flexible, untouchable, awkward*	**Tangling & severe nesting**	
Beta (rotational) symmetry: about axis of insertion	**Any orientation**	**Easy to orient:** *orientation easy to see and mistake proof*	**Tricky to orient:** *Orientation difficult to see but mistake proof*	**Difficult to orient:** *Orientation difficult to see – mistakes possible*	
Alpha (end-to end) symmetry: perpendicular to axis of insertion	**Any orientation**	**Easy to orient:** *orientation easy to see and mistake proof*	**Tricky to orient:** *Orientation difficult to see but mistake proof*	**Difficult to orient:** *Orientation difficult to see – mistakes possible*	
				TOTAL HANDLING SCORE	/20

Maximise symmetry …



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Fitting & fixing …

- *Insertion / holding process*
- *Securing / fixing processes*
- *Additional (non-assembly) processes*

- Scores based on:
  - does it need a fixture?
  - The assembly direction
  - Alignment difficulties
  - Restricted vision or access
  - Insertion force
  - Etc.

5

Component insertion / holding process …

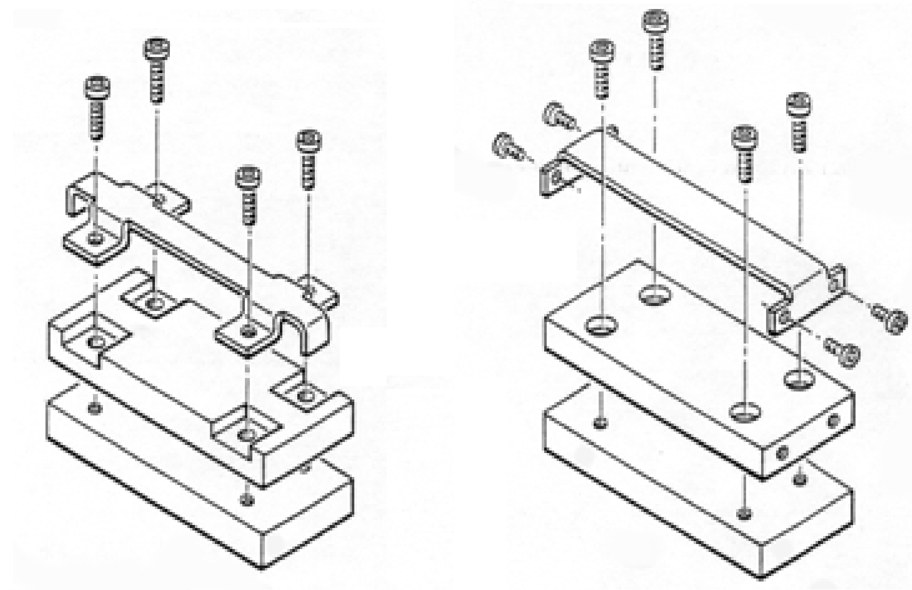
	0	1	3	5	Score
Gripping / holding during insertion	Holding simple during insertion - no tools needed	Need tools to grip during insertion - but simple	Difficult to hold securely during insertion	No suitable / easy to access gripping surfaces during insertion	
Holding down	*Self sustaining - stays in place without holding down*			Needs holding in place – secured later	
View during insertion	Clear view during insertion	View partly obscured during insertion	View badly obscured during insertion	No view during insertion – feel only	
Access	Clear access during insertion	Partly obscured access during insertion	Badly obscured access during insertion	No access to insert	
Insertion direction	Straight line from above	Straight line, from side	Straight line from below	Not in a straight line	
Insertion resistance	No resistance	Light resistance	Significant resistance	Large resistance – need leverage	
				TOTAL INSERTION SCORE	25

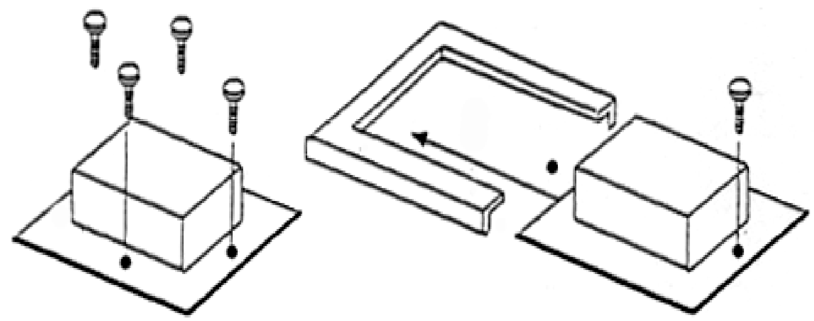
Fixing / securing processes …

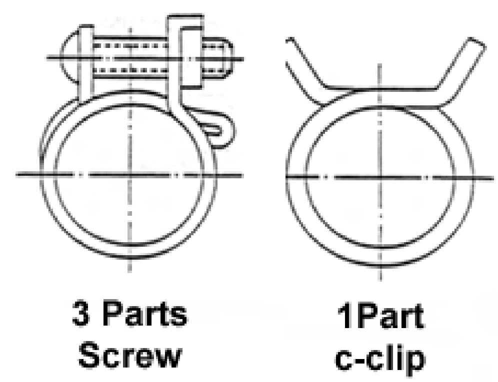
	0	1	3	5
Threaded fasteners	*No threaded fasteners*	**Self drilling / tapping screws**	**Stud / bolt & nut Screw**	**Nut, bolt & washer (separate loose parts)**
Non-threaded fasteners	**Snap fit or light push fit**	**Rivet**	**Simple crimping or bending**	**Difficult crimping or bending**
Soldered / Welded joints	*No welded joints*		**Simple solder / weld**	**Difficult weld**
Glued joints	*No glued joints*		**Simple glued joint**	**Difficult glued joint**

Fixing & joining …

- Eliminate / minimise fasteners
  - Separate fasteners of same type
  - Different types fasteners
  - Avoid threaded fasteners
- Carefully position fasteners
  - Away from obstructions
  - Provide flat surfaces
  - Provide proper spacing between fasteners
- Simple fastening
  - Self fastening features
  - One handed assembly
  - Parts secured on insertion
  - Single linear motion
- Minimise assembly tools
- Parts should easily indicate orientation direction
  - Self alignment
  - Self orienting / no orientation needed





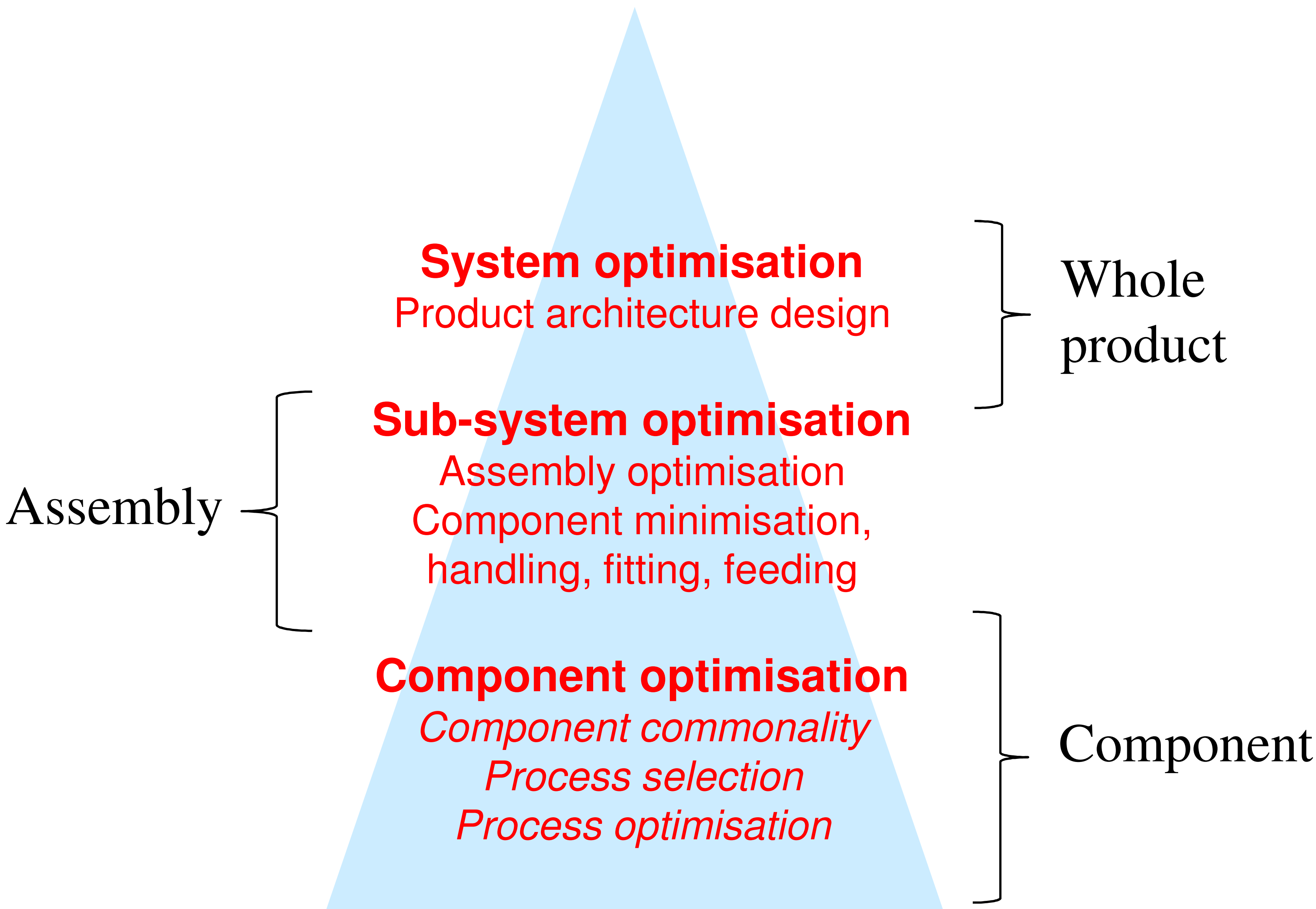


Additional (non-assembly) processes …

3

	0	1	3	5
Additional screwing	*No threaded fasteners*		**Some additional screwing**	**Significant additional screwing**
Setting	*No setting required*		**Simple / quick setting**	**Complex / slow setting**
Test & measure	*No testing & measuring*		**Easy / quick testing**	**Difficult / slow testing**
Fill / empty	*No filling / emptying*		**Simple / quick fill / empty liquid / gas**	**Complex / slow fill / empty gas**
Re-orientation	*No reorientation*		**Small reorientation**	**Significant reorientation**

Product architecture


System optimisation
Product architecture design
Sub-system optimisation
Assembly optimisation
Component minimisation,
handling, fitting, feeding
Component optimisation
Component commonality
Process selection
Process optimisation
Whole product
Assembly
Component

Functional elements → physical elements …

Function 1

Function 2

Function 3

Function 4

Function … n

A product’s **architecture** is the way in which the **functional elements** are assigned to the **physical elements** and the way in which these **elements interact**

Part 1

Part 2

Part 3

Part 4

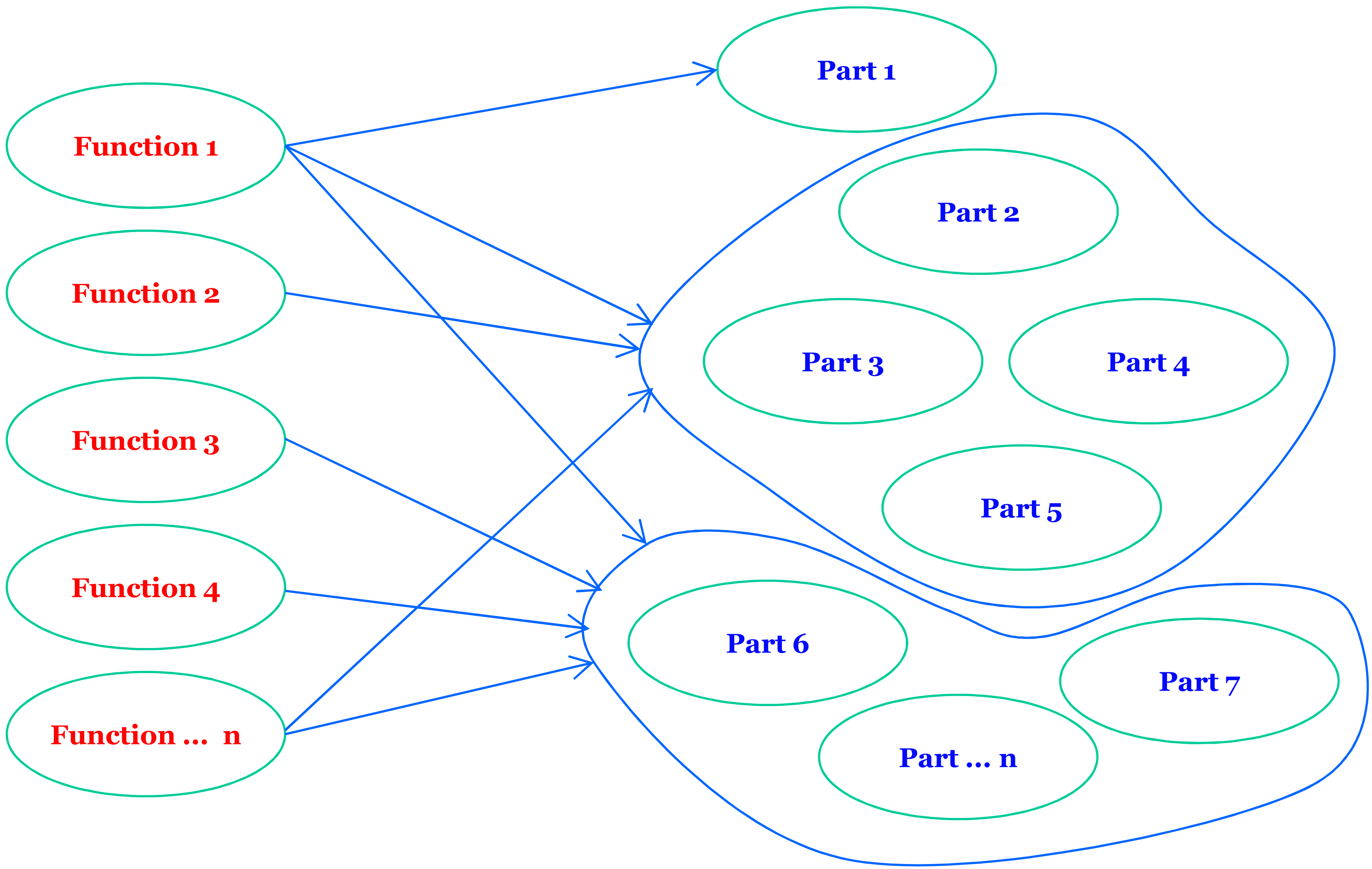
Part 5

Part 6

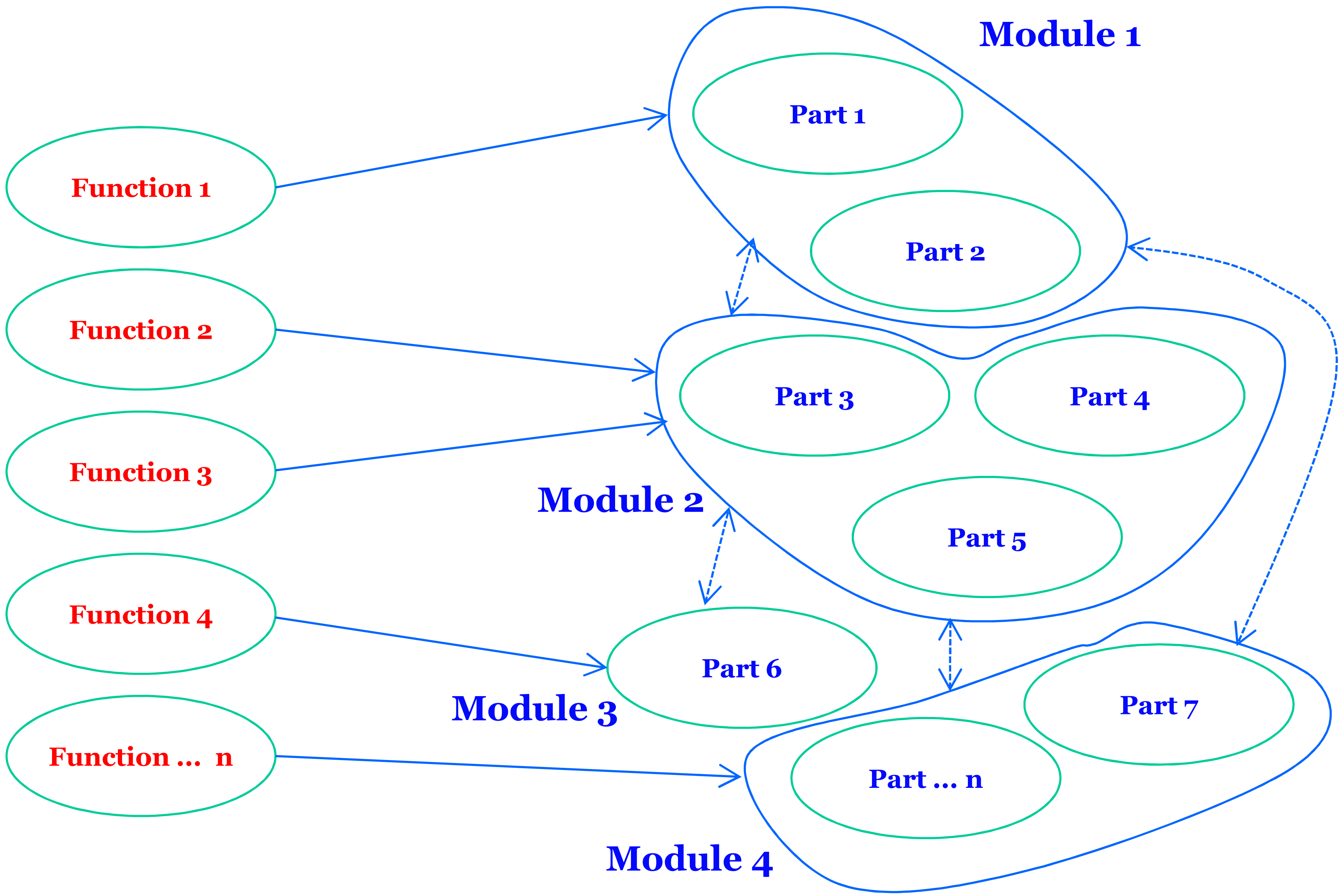
Part 7

Part … n

Integrated product structures …



Modular product structures …



Product change …

- Integral products
  - Changes to one element can result in changes to many others
  - A functional change demands physical change

- Modular products
  - changes can be made to isolated elements independently

- Design goal …
  - Minimise **physical changes** to enable **functional changes**

Types of functional change …

- **Upgrade**: more memory in a PC
- **Add-ons**: a new flash gun for a camera
- **Adaptation**: different power supplies for different markets
- **Wear / maintenance**: replacement razor blades
- **Consumption**: replacement film, or printer ink
- **Flexibility in use**: changeable lenses

Example: Cooke movie lenses ...

- Lots of commonality in production:
  - Common external mechanics, different lens and iris assemblies
  - Common parts
  - Common features on parts: different lengths, reuse of CAM
  - Common tool set: radii, thread forms, holes etc
  - Common processes: designed for single M/C tool
- Modularity: optical elements, lens to camera interface, Iris assembly

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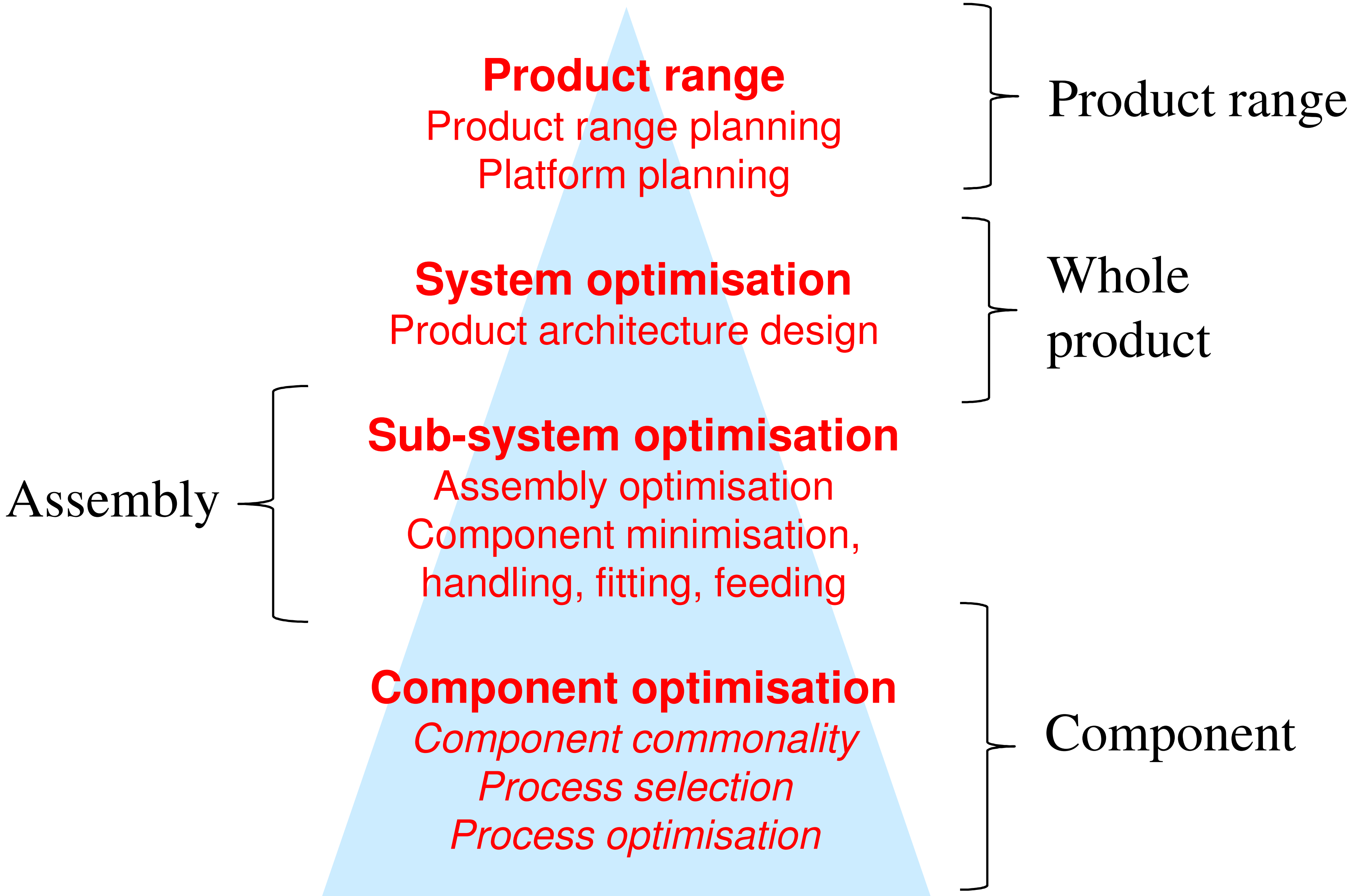
14
18
25
32
50
75
100


14
16
18
21
25
27
32
35
40
50
65
75
100
135


12
180

Product platforms


Product range
Product range planning
Platform planning
System optimisation
Product architecture design
Sub-system optimisation
Assembly optimisation
Component minimisation,
handling, fitting, feeding
Component optimisation
Component commonality
Process selection
Process optimisation
Product range
Whole product
Assembly
Component

Volkswagen A-Platform

Plattform	VW	Audi	Skoda	Seat	Rolls-Royce/ Bentley	Lamborghini	Bugatti?
Sportwagen*	W12 Coupé/ Roadster					Diablo SV/ Diablo VT Roadster	EB 110
D	Luxuslimousine	A8 (Nachfolger)			Silver Seraph/ Arnage*		EB 112*
B/C	Passat Plus Passat	A4/A6					
A	Golf, Bora, Beetle	A3 TT Coupe/ Roadster	Octavia	Toledo (Nachfolger)			
A 00/ A 0	Polo, Lupo	Al,	Felicia (Nachfolger)	Ibiza/ Cordoba, Arosa			

Audi A3

Audi TT coupe

Audi TT roadster

VW Golf IV

VW Beetle & convertible

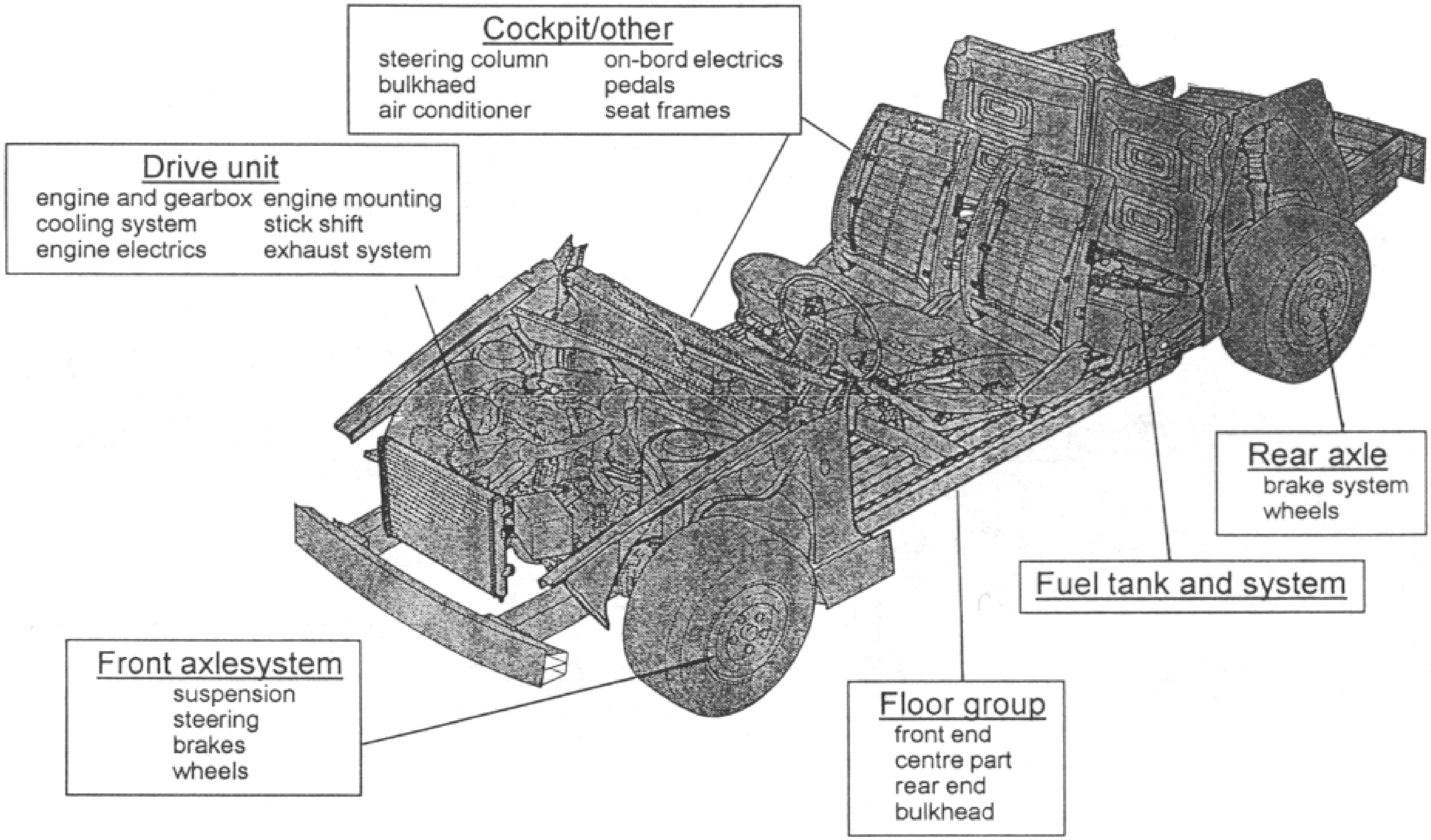
Skoda Octavia

Seat Toledo Successor (Coupe, Saloon, Convertible)

VW Bora

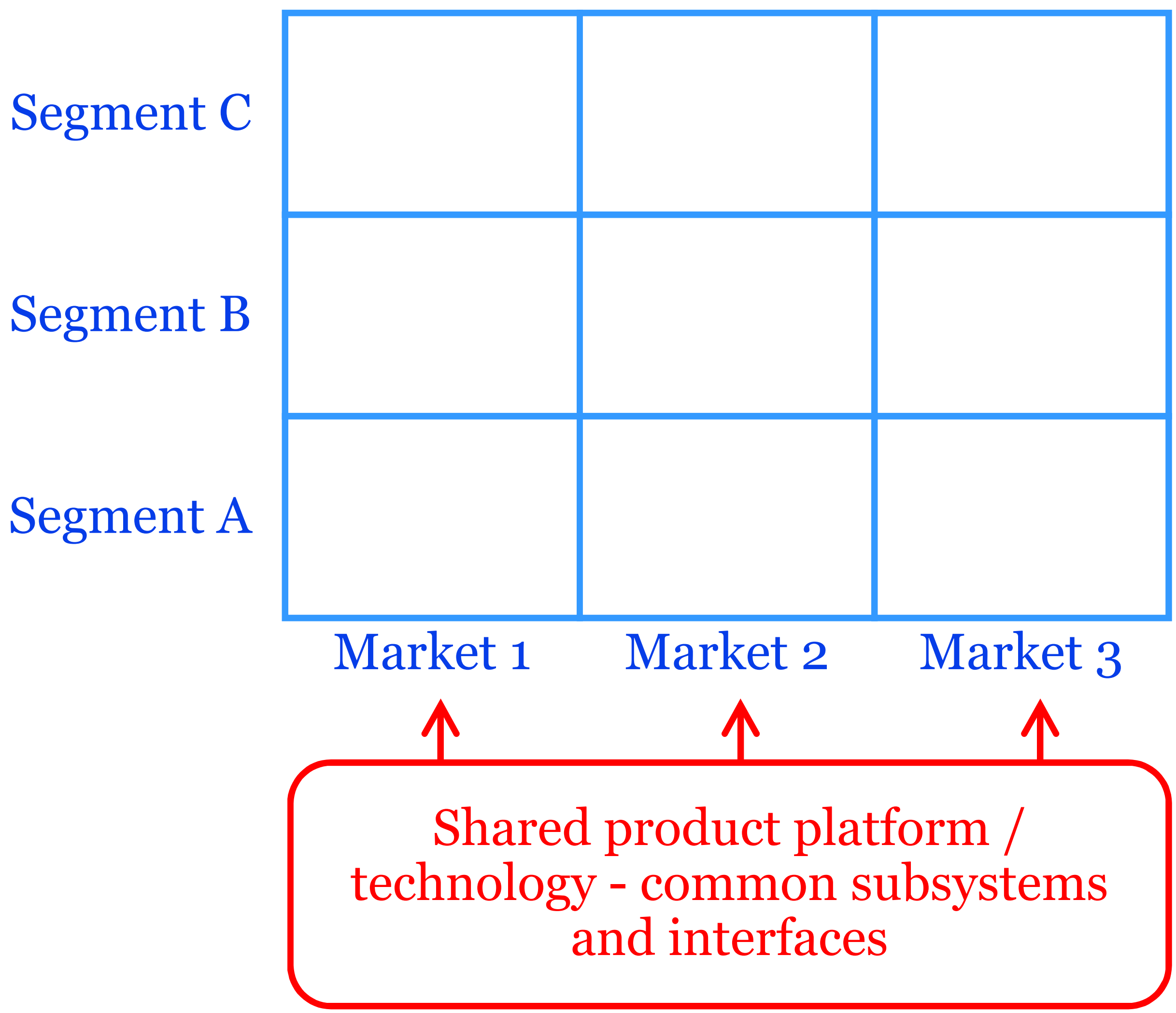
- Aprox 19 vehicles based on A-platform
- VW estimates development and investment cost savings of $1.5 billion/yr using platforms

VW Platform: common components …



Source: Shimokawa, K., Jurgens, U., and Fujimoto, T. (Eds.), 1997, Transforming Automobile Assembly, Springer, New York.

Market segmentation grid …



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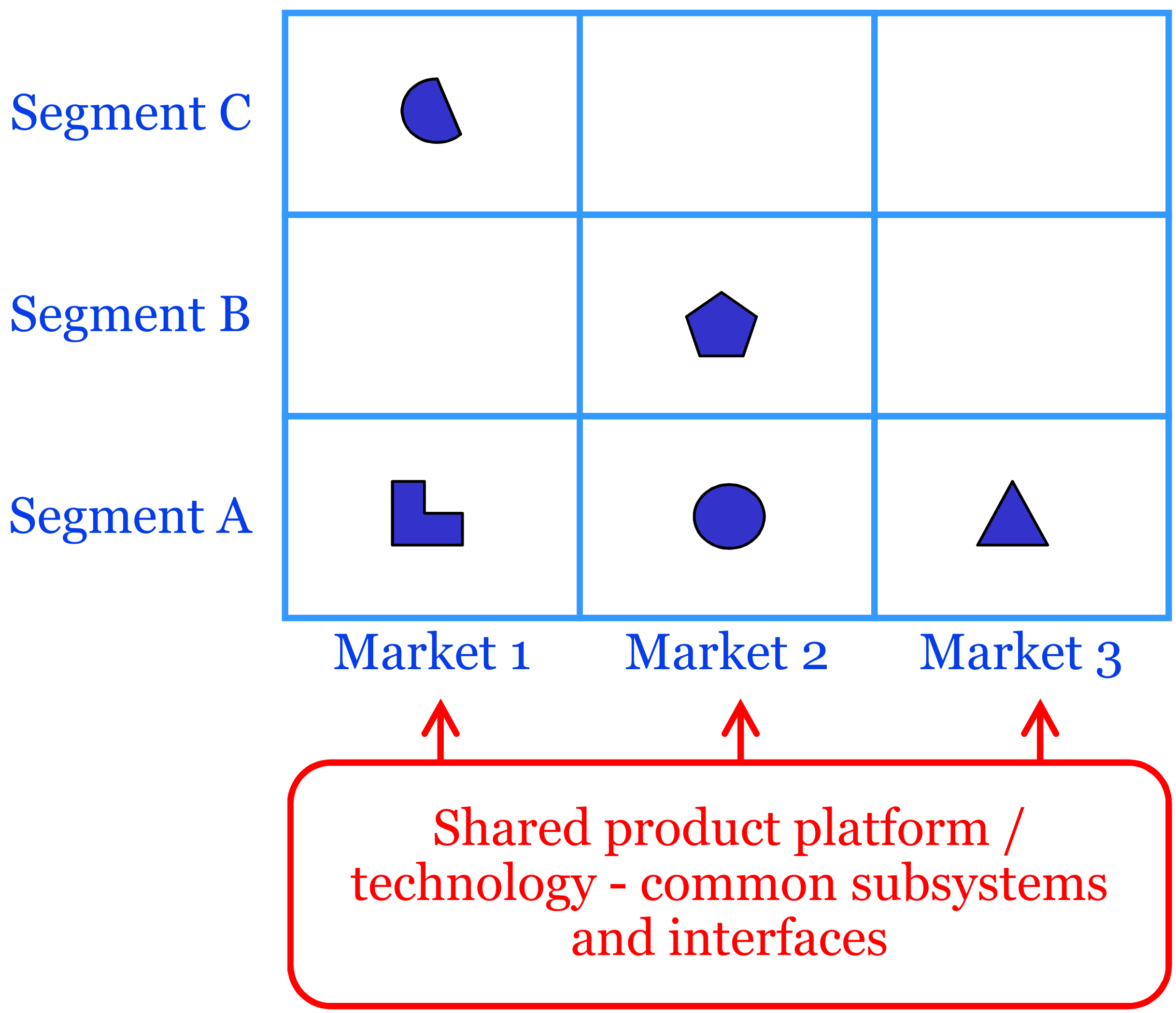
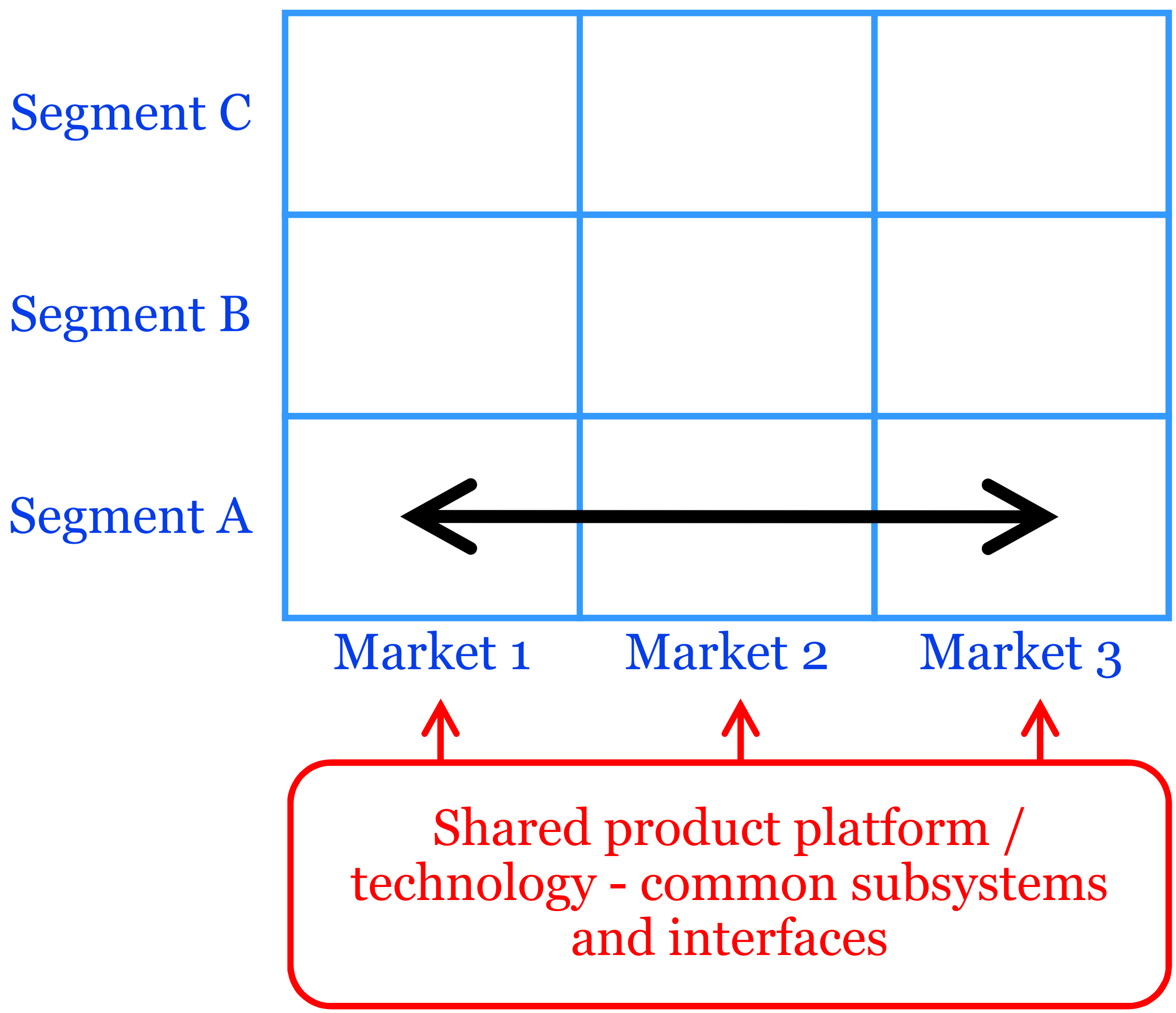
No leveraging ...



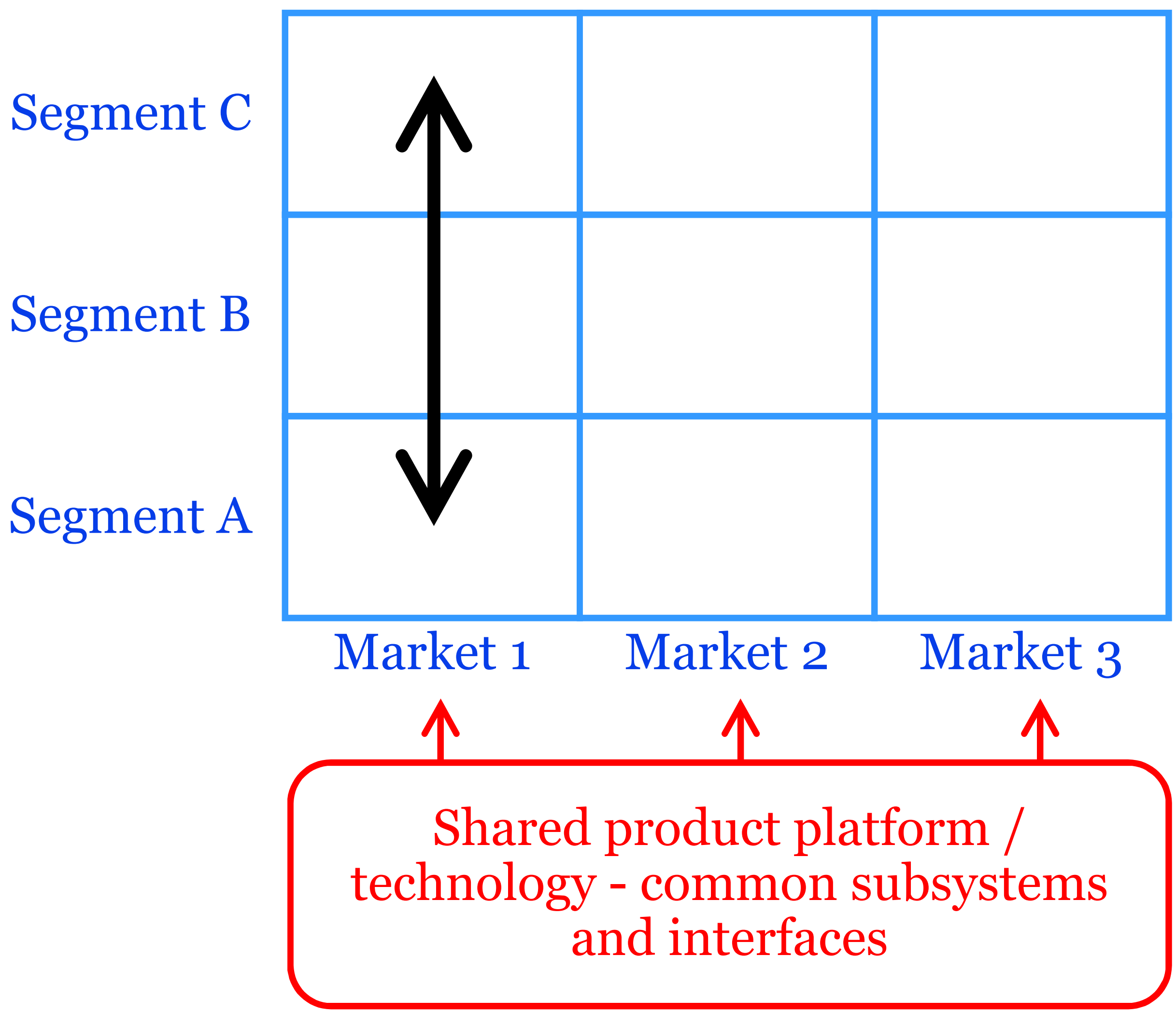
Unique products targeted at individual segments

Horizontal leveraging ...



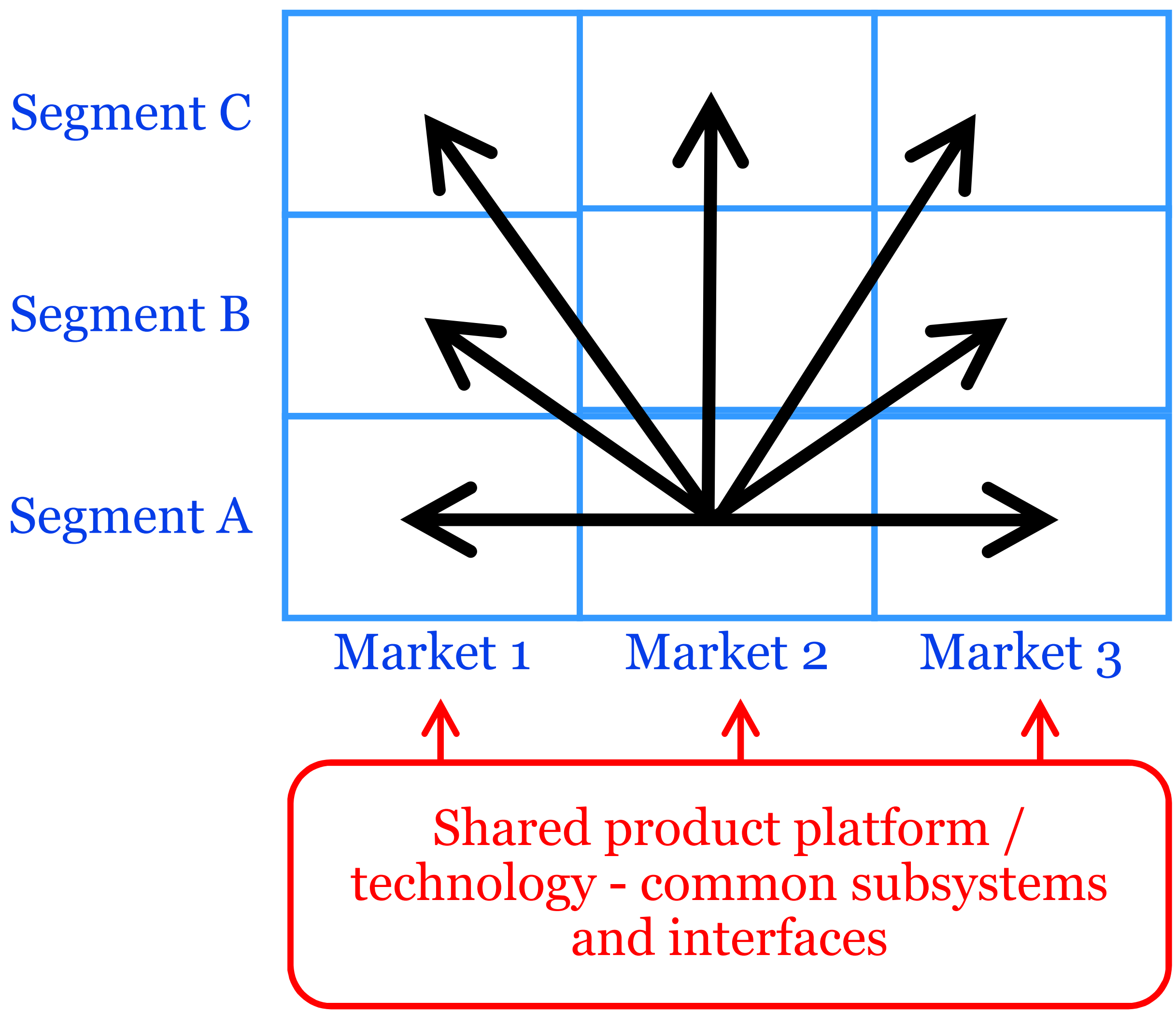
Reuse of platform elements **across** markets, and within a segment

Vertical leveraging ...



Reuse of platform elements **within** a market and across segment

Beach-head leveraging ...



Horizontal and vertical reuse of platform elements across markets and across segments

Example: Cooke lenses …

Telephoto

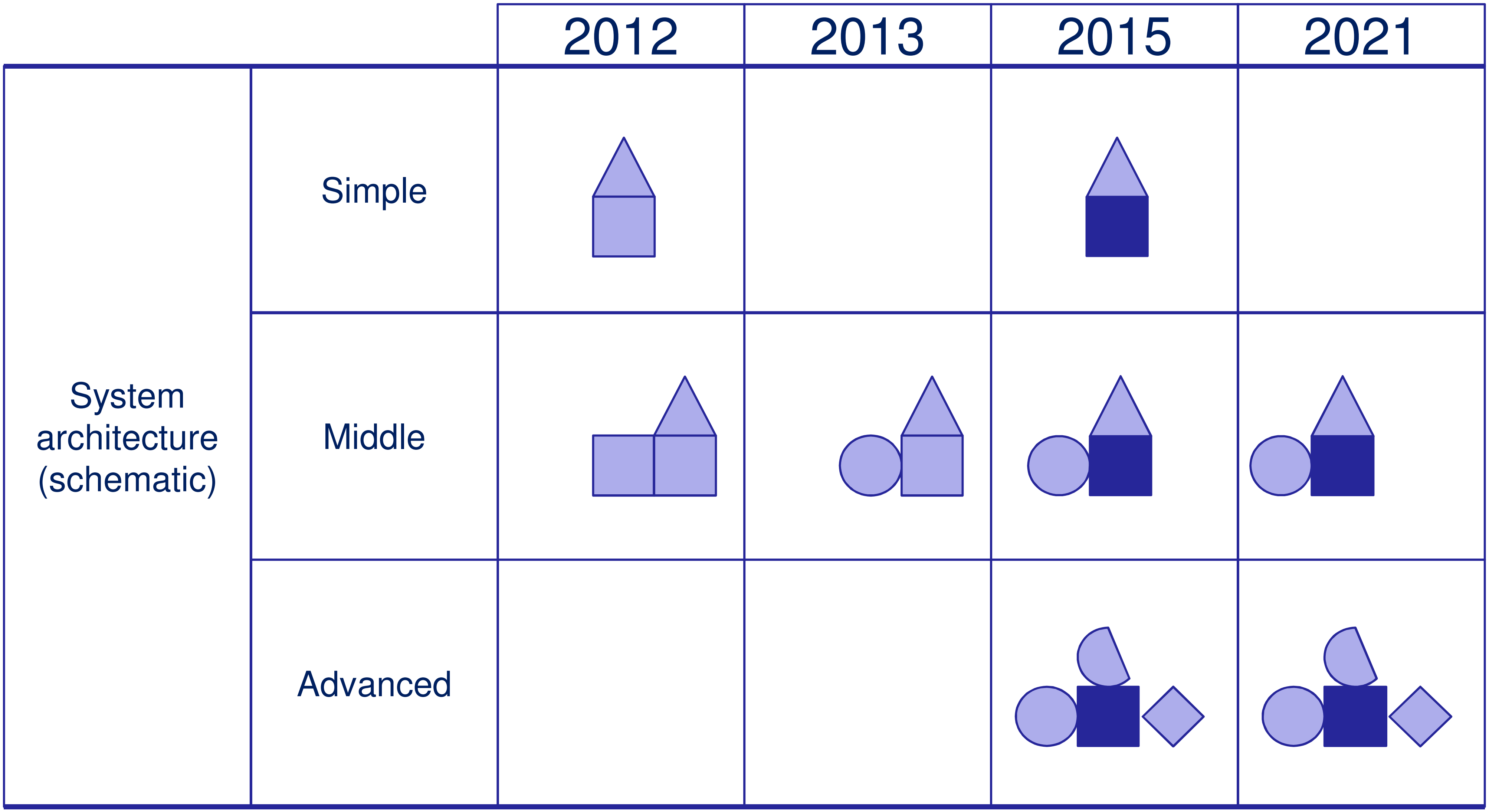
Normal

Wide angle

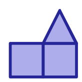
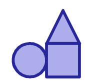
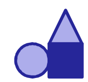
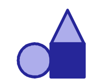
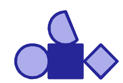
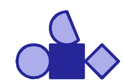
35mm film | 16mm film | Digital | Zoom lenses

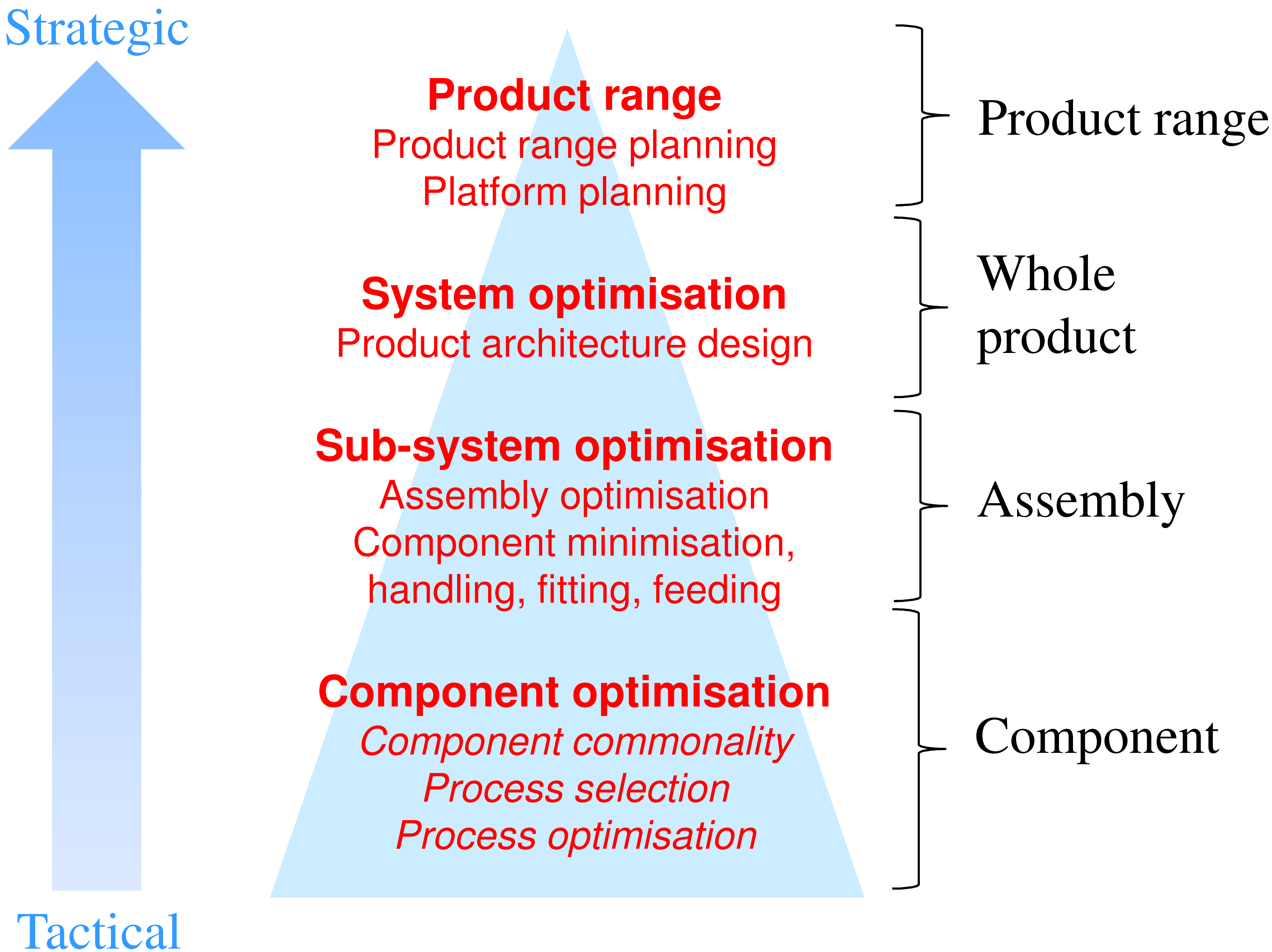
Production methods, housings, irises, optics

System architecture map



System roadmap …

		2012	2013	2015	2021
Functionality	Simple	• A • B • C	• D • E		• F • G
	Middle	• P • Q • R	• S • T	• U • V	• W
	Advanced			• X • Y • Z	• X • Y • Z
System architecture (schematic)	Simple				
	Middle				
	Advanced				
Core technologies	Simple	• New materials	• New sensors		
	Middle	• Existing sensor	• New materials	• Communications • RFID	
	Advanced			• GPS	• Data logging • Data management



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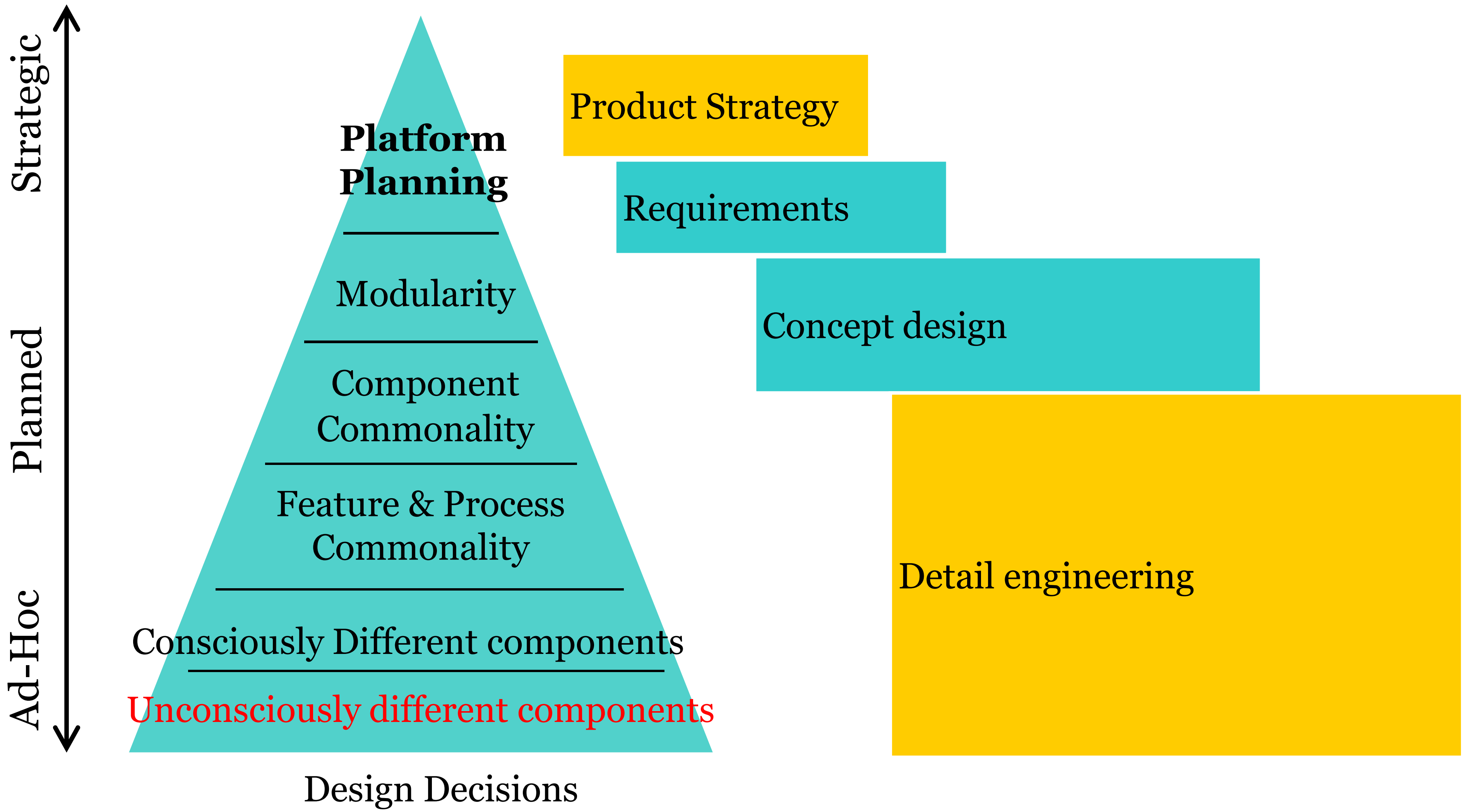
When to consider platforms etc …



Thank you …