MODULARITY

Modularity

Introduction

Why modularity?

✓ modularity is a topic that includes several fields: from «thinking mechanisms» to economics and organization till scientific methodologies and engineering.

✓ following contexts of increasing complexity, in engineering modularity is taken into account as useful reference aimed to the generation of higher efficiency and effectiveness solutions.

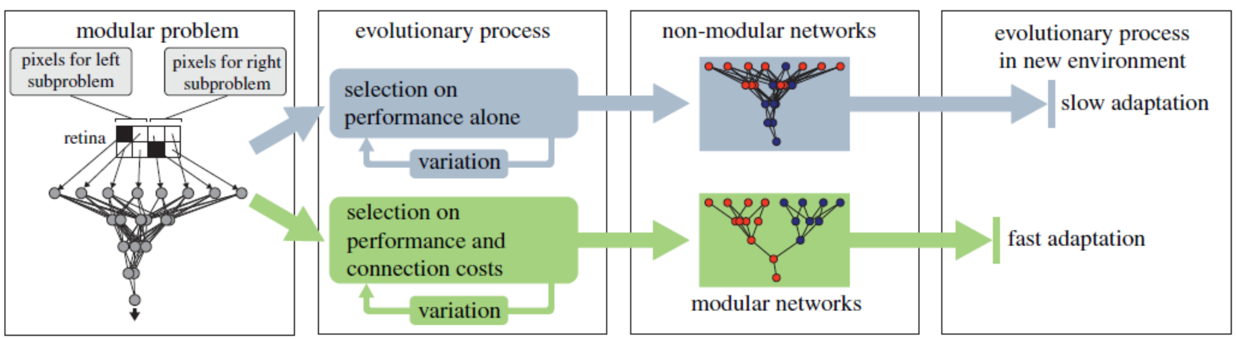


Figure 1. Main hypothesis. Evolving networks with selection for performance alone produces non-modular networks that are slow to adapt to new environments. Adding a selective pressure to minimize connection costs leads to the evolution of modular networks that quickly adapt to new environments.
J. Clune, J.B. Mouret, H. Lipson- The evolutionary origins of modularity– Royal Society Publishing, 2013]

example of modularity showed by organisms

Modularity

Introduction

A peculiarity of modularity …

«After lifting through additional industrial and academic literature on modularity, it became clear that, while the term "modular" is used often, there has been little effort made to come to a consensus on the definition of this term and its appropriate use. […] Much of the work on product modularity is done in isolation. Most of the effort is put into proposing new ideas as opposed to testing existing or proposed hypothesis» [Gershenson, Prasad e Zhang, 2003, 296 e 308].

[M. Bordignon – La modularità e il suo potenziale ruolo nelle imprese - Aracne, 2009]

… it's a relative peculiarity, that's not so far by what we said on technology definition.

Modularity

Introduction

«Now, we've just seen that complexity must be considered in technology management. Indeed, **complexity can arise when technololy characteristics don't fit with management ones (generally speaking with company's skills and culture)** Then, what would you do in such case?»
«I think you could've guessed because sometimes, may be when you were a child, you played Lego! Actually, when you have something (a system), whose mechanisms you're not able to catch, first thing you'd do is to deploy the system, that's to disassemble it. Modularity is just what you need: you can decompose a system in modules, that's parts whose interfacing's ways you're able to find out.

… so, a preliminary definition of modularity is

modularity is a general set of design principles for managing the complexity of large-scale interdependent systems (products, organizations …)

[A. Langlois - Modularity in technology and organization – Journal of Econom. Behavior Organ. 2002, 49-137]

Just a note: it's to take into account that modularity is for systems (in its wide meaning), then it isn't limited to technologies or organizations must be meant in a wide meaning (see next page).

Modularity

Introduction

As you can see by the below tables, modularity concept can be effectively applied not only in manufacturing, but in design and in the field as well. Besides in designing supply chain each supplier/supply chain's actor would be a module etc.

On the other hand, technology isn't a manufacturing's prerogative. Indeed you have design, maintenance etc. technologies.

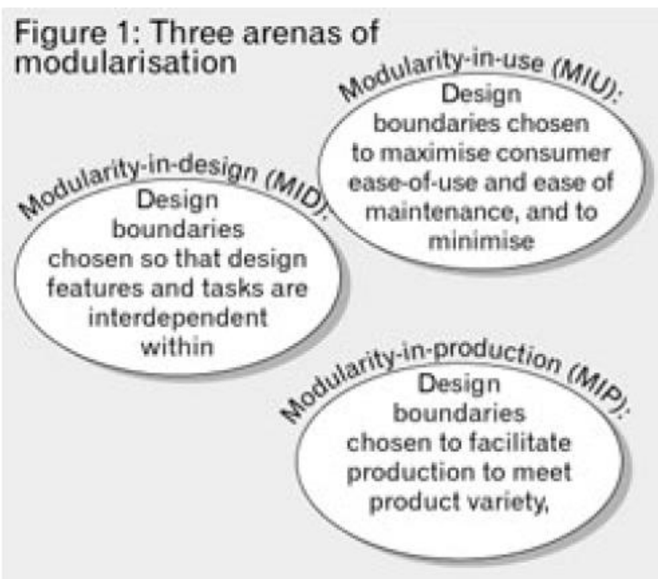


Figure 1: Three arenas of modularisation

[M. Sako, F. Murray – 1999]

Table 3-1. Module Drivers™

Product development and design	Carryover
	Technology evolution
	Planned product changes
Variance	Different specification
	Styling
Production	Common unit
	Process and/or organization
Quality	Separate testing
Purchase	Supplier available
After sales	Service and maintenance
	Upgrading
	Recycling

(*) carryover is a part or a subsystem of a product that most likely will be not exposed to any design change during the life of the product platform.

[A. Ericsson, G. Erixon – Controlling Design Variants (Modular Product Platforms]

Modularity

Introduction

Examples of modularity's applications (prodcuts and services)

- ✓ **automotive**
- ✓ **consumer electronics**
- ✓ **household appliances**
- ✓ **software applications**
- ✓ **financial applications**
- ✓ **…**

- Automobile makers define product architectures for car models, using 'hard points' that define the interface between the car body and its mechanical components, as well as interfaces between the major mechanical components themselves. Several product model variations are then leveraged by mixing and matching body styles and major mechanical components. General Motors, for example, has established a modular product architecture for all its global automobile design projects. Future GM products must be designed using combinations of components from about 70 different body modules (hard point arrangements) and about 100 major mechanical components like engines, power trains, and suspensions (Kacher, 1994). Modular design is also being applied to major components of automobiles as well. Ford now designs families of modular engines in which different parts can be used in different combinations to give engines of different displacements, different numbers of cylinders, single or twin overhead cams, and other variations.
- Japanese consumer electronics companies often base entire product lines of stereo receivers, CD players, televisions, and other products on different mix-and-match combinations of components in a modular platform design. Sony, for example, leveraged more than 160 Walkman models for the US market in the 1980s from five modular platform designs (Sanderson and Uzumeri, 1990).
- General Electric's appliance unit creates several models of dishwashers and stoves that are differentiated primarily by offering different combinations of key components. Dishwashers are distinguished primarily by the controls contained in door panel modules, and kitchen stoves are distinguished by different cooktop modules and control panels.
- Object-oriented programming is a modular design process for software that creates applications software composed of modules of routines and data that can be mixed and matched to create new program variations to suit the needs of different users.
- The electronic funds transfer (EFT) industry has established a modular architecture for the messages that communicate various transaction requests from automated cash machines to financial institutions and back. The 128 fields available for describing transactions in the EFT standard message allow a nearly inexhaustible number of new kinds of transactions (i.e., financial service products) to be added by changing transaction codes in any of the available message fields.

Leveraging a new product variation by introducing new combinations of components also costs much less and takes much less time than creating another *de novo* product model by the conventional design process. The ability to leverage product variations from a modular product architecture relatively cheaply and quickly improves the responsiveness of a firm in differentiating products for the growing number of market segments characteristic of dynamic product markets. A firm may also use a superior ability to leverage large numbers of product variations to probe a product space to improve its knowledge of customer preferences and to proliferate product models to saturate product space in the region of most profitable demand. Sony's pattern of product introductions of its Walkman models, for example, suggests that Sony used introductions of product variations to discover customer preferences for the new product concept – and then intensified its offerings of related product models discovered to be most appreciated by consumers.

Modularity

Key concepts

«Let's go on modulairity concept: we said that in order to investigate on a complexed item you'd disassemble it, but when you'd stop disassembling?»
«The question is easy: indeed you'd stop disassembling when you'll be able to understand the working mechanisms of the investigated item, that's when you understand what are the features of any single part and how they interact. That means that you'd not be interested to go on, and this implies the following main issues:

- **information hiding** → as a matter of fact when you've got the above working mechanisms you wouldn't take any interest in further internal mechanisms of the single parts, so you abstract from them.

- **visible information** (or visible desing rules) which, in contraposition with the upmentioned abstraction are just the information you need. Such information include:
    - **architecture,**
    - **interfaces,**
    - **standard**

✓ a complex system can be managed by dividing it into small pieces and looking at each one separately. Once the complexity of one of the elements crosses a certain threshold, that complexity can be isolated by defining a separate *abstraction* that has a simple *interface*. The abstraction *hides* the complexity of the element; the *interface* indicates how the element interacts with the larger system.
[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

✓ in a decomposable system, by contrast, the proper working of a given part will depend with high probability on the characteristics of other parts within its subassembly — but will depend with relatively lower probability on the characteristics of parts outside of that subassembly.
[R.N. Langlois – Modularity in technology, organization and society]

Modularity

Key concepts

What just showed about information’s hiding and visible rules gives the opportunity of a further and more exhausistive definition of modularity, that’s

Modularity is a special form of design that intentionaly creates a high degree of independence or “loose coupling” between components design by standardizing component interface specifications.

[R. Sanchez, J.T. Mahoney – Modularity flexibility, and knowledge managent in production and organization design]

… and

A module is a unit whose elements are powerfully connected among themselves and relatively weakly connected to elements in other units. Clearly there are degrees of connection, thus there are gradations of modularity.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Such definitions let us introduce some patterns for modularity:

- Baldwin & Clark
- Ulrich
- Schilling

Modularity

Patterns

Baldwin & Clark pattern

Baldwin & Clark pattern is related to the «visible design rules» and states three items which must be defined for a modular system, that's

- **architecture** → specifies what modules will be part of the system and what their functions will be.
- **interfaces** → describe in detail how the modules will interact, including how they fit together and communicate.
- **standards** → test a module's conformity to design rules and measure the module's performance relative to other modules.

... which let's a further defintion of modules: **modules are units in a larger system that are structurally independent of one another, but work together.**

Modularity

Patterns

Ülrich pattern

Ülrich pattern **underlines modules' features** (functions). It states:

- **A system is modular when:**
  - ✓ **any part of it** (so any module) **implements one or few functions,**
  - ✓ **the interactions of such parts are well defined and implement primary functions of the system** (product or service).

One can distinguish three types of functions for a product or a service, that's:

- Primary → intrinsic function of a product (for instance: for a cup the ability to hold a liquid)
- Subsidiary → they enrich to the primary (a cap or a thermos suitable for the upmentioned cup).
- Additional → they complement th the whole (aesthetic characteristic of the cup holder).

- It's interesting the definition of architecture given by Ülrich, that's **architecture as "the scheme by which the function of a product is allocated to physical component"** (see Att. 1 as well)**.**

Modularity

Patterns

Schilling pattern

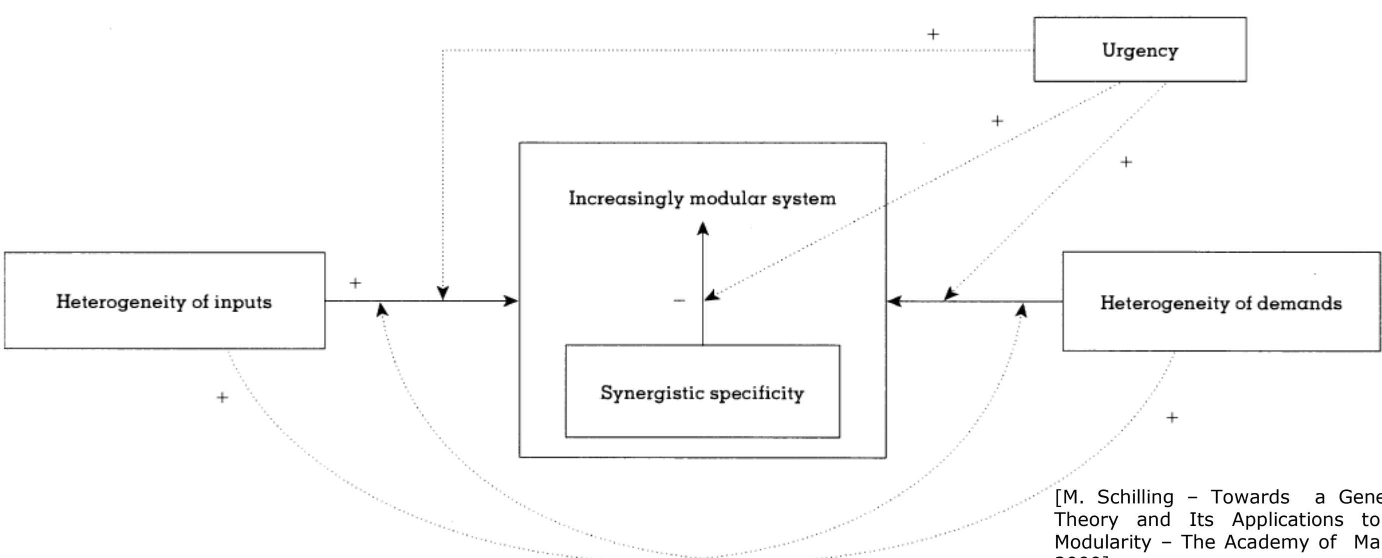
Schilling pattern is about the context's condtions (determinats) whose arising lead to a modular development:

✓ **inputs' heterogeneity** → the accessibility to different technological options, that's to different modules with the related different functions.

✓ **outputs' heterogeneity** → the possibility to customize/differentiate the system (product or service) functions (accordingly to the choice of suitable modules).

✓ **urgency** → the definition of an architecture composed by apt modules requires shorter development time than an integral architecture.

Modular Systems[a]



[a] Solid lines represent direct effects; dashed lines represent indirect effects.

[M. Schilling – Towards a General Model System Theory and Its Applications to Intrfirm Product Modularity – The Academy of Management review , 2000]

Modularity

Summary on key concepts

Summing up (i)

Summing up, **how to apply modularity in the technology management?** Here-below some hints.

- **first, what are your expectations? What's your vision on the investigated technology? Such vision would correspond to the architecture, at which some primary functions will be allocated and whose deployment will help in order to define the composing parts and the related standards. That said, may be you should define some priorities, which could depend by the accessible inputs (ref. to Schilling pattern) you have.**

- **that said and coming back to the complexity level of the system, one should suitably identify if the organization fits** (that's if it's mechanistic or organic at the right level) **and how the organizational units would face both the technology you're going to implement and themselves** (that's the organizational units interfacing)**.** Just on this it's to remember that modularity is a tool fully applicable to organization's design.

The above considerations mean a design development, which is tipically iterative (… three steps forward and two backwards).

Modularity

Summary on key concepts

Summing up (ii)

"That's all, is what mentioned in the previous page immediately applicable?"
"So and so! The criteria are those but some tools could be useful. In other words:

- **specifically about the system's development one should consider some particular development methods:**
  - **Design Structure Matrix** - DSM (Steward, 1981)
  - **Function Structure Heuristic** - FSH (Stone, 1997)
  - **Modular Function Deployment**- MFD (Erixon, 1996)
  - **Design Effort Complexity** - DEC (Hölttä, Otto 2005)

  On next pages you can find some notes about such methods.

- **About work's completion - that's the definition on interfaces and modules' typologies – one can choose some standard solutions** (see Att. 2).

Modularity

Design methods – difference between modular and integral design (i/ii)

In order to better understand the characteristcs of modular design, some few words of the difference bewtween it and the conventional/»traditional» design are useful.

Just a key note: **modular designs start from the architecture definition**.

Table 2 Differences in Product Definition, Design, and Development in Conventional Versus Modular Product Design

	Definition	*Design*	*Development*
Conventional Product Design	Attributes of 'optimal' product are determined by marketing research.	Product functionality is decomposed into components, but component interfaces are determined during component development processes.	Component designs and product architecture co-evolve in a reiterative process. Product architecture is defined in the final design for the product – i.e., as the output of the development process.
Modular Product Design	Product is conceived as a platform for leveraging product variations and improved models to serve a range of market preferences.	Modular product architecture fully specifies component interfaces at beginning of development and constrains component development.	Modular product architecture allows component development processes to be concurrent, autonomous, and distributed. Product architecture defined at outset does not change during development.

[R. Sanchez – Managing product creation, European Management Journal Vol. 14 1996]

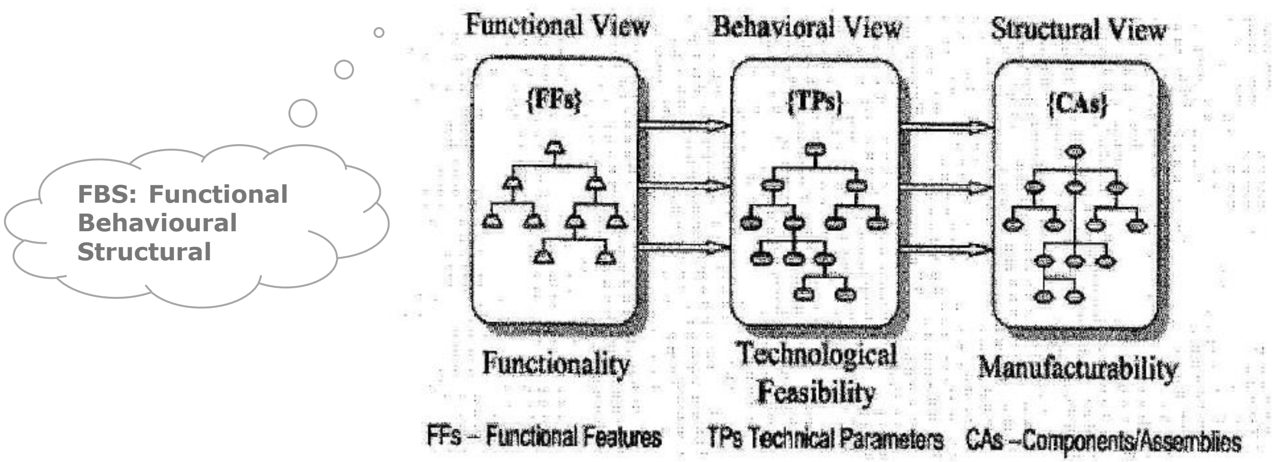
A suitable definition of platform is «platform as totality of shared assets» [Robertson e Ulrich 1998] . See Att. 3 for example.

Modularity

Design methods – difference between modular and integral design (ii/ii)

Anyway, just in order to better qualify modular design, it’s useful to take into account the three different «architectures» which a product (or a service) can have passing from the expecations (ref. Functional) to the technical choices (ref. Technological Features) till the operations (ref. Manufacturing).

FBS model for product’s design



[*abstract form* S. Gallinaro – LA modularità nello sviluppo dei prodotti e dei servizi, Impresa Progetto n. 1 2009]

The above sketch reminds three mdularity’s different areas of application, which can be summed up as:

- ✓ **Functional Structure**, which is about the product’s performances (Functional Features FFs), that’s to the end users’ expecations.
- ✓ **Technical Structure,** which, meant as otuput pf the development process, is in practice related to the modules and to to their interactions characteristics ai moduli e alle loro interazioni in termini di parametri tecnici (Technical Parameters TPs).
- ✓ **Physical Structure**, that’s the configuration of the components and sub-assemblies which accomplish the design solutions coming by the technical structure and which is strongly linked with manufacturing and logistic topics. In other words: the allotment of the design outputsto the physical compomenents (Components and Assemblies Cas) comes from evaluations both on the company’s production processes (capacities, technologies, costs, economies of scale etc.) and of the ones belongiing to the companies involved in the supply-chain. [Gallinaro, 2009]”.

Modularity

Design methods - DSM

Key of **Design Structure Matrix (DSM)**

… the definition of modules comes from the relationships among the product or service parameters. The organization of design’s groups will be a consequence.

That said, DSM is built on some sequenced steps:

- Hierarchy of Design Parameters
- Design Structure Matrix
- Tasks Structure Matrix
- Integration and Testing Rules

Modularity

Design methods - DSM

... elementi/terminologia **propedeutica** (ii)

- **Hierarchical Design Parameters** (HDP)
  - it's about **existance of dependance conditions of some parameters by some others.**
  - ... by setting a series of switches early on, designers can bound their immediate problems (the design at hand) to one that is manageable given their knowledge and resources. Modular designs are the result of a purposeful, consistent and rigorous application of this boundary.

the sketch is referred, as example, to a cup with its possible cap. Naturally the defintion of the cap's diameter will depend by the choice of having or not to having the cap itself, however it'll be related to the cup's diameter.

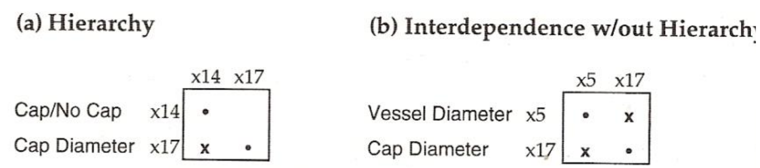


Figure 2.2 Design structure: hierarchical and interdependent design parameters.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

it's important to focus the sentence **"modular designs are the result of a purposeful, consistent and rigorous application of this boundary"**

... so, boundary has the meaning of conditions to comply with.

Modularity

Design methods - DSM

el

… so, applying HDP (… enlarging previous page’s example) one would get a matrix like the below one, that is named **Design Structure Matrix (DSM)**. Indeed it shows hierarchy and dependency conditions among parameters.

Design Parameter

		1	2	3	4	5	6	7	8	9	10
Material	1	•	x	x			x	x	x		x
Tolerance	2	x	•	x			x	x	x	x	x
Mfr. Process	3	x	x	•			x	x	x	x	x
Height	4			x	•	x			x		x
Vessel Diameter	5		x	x	x	•	x	x	x		
Width of Walls	6	x	x	x	x	x	•	x	x		
Type of Walls	7	x	x	x		x	x	•	x	x	
Weight	8	x		x	x	x	x	x	•	x	
Handle Material	9	x	x	x				x	x	•	x
Handle Shape	10	x	x	x	x					x	•

Figure 2.3 Design structure matrix: a map of a portion of the design structure of a mug.

… hierarchical relationship and interdependencies among design parameters can be formally mapped using a tool called *Design Structure Matrix* (DSM).

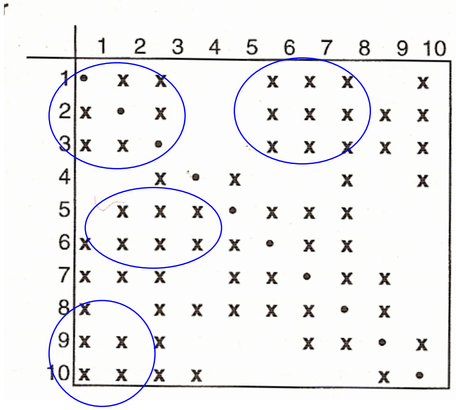
[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Modularity

Design methods - DSM

… a nice tale !!

«And now a question: does the disposition of the x remind you on something?» the professor asked.
«Yes», said the diligent student. «the concentration of some x in defined areas seems to …»
«To …?» the professor pressed the student.
«It seems to limit some areas … Yes, here I am! It defines the boundaries you mentioned».
«Very good», the professor smiled. «And so …» he wasn't fully satisfied … and the student wrongly thought he was fussy.



The student's expression revealed his effort. «Yes», he shouted rising his arts. «you said that modules are units whose elements are powerfully connected among themselves and relatively weakly connected to elements in other units, then the concentration of x shows the possible modules».
"My compliments and … you've deserved the best mark."

Modularity

Design methods - DSM

The drive system, the main board etc. could be meant like macro-modules. In other words very likely one could apply the same exercize of «x grouping» inside the areas defining such macro-modules. In other words some other «smaller» modules could be identified.

… so, let's see a real case related to a laptop, about which modules are the drive system, the main board, the LCD screen and the packaging. Such modules are identified by the concentration of the interdipendence signs (the «x»), **but there are some other ones external to the shown boundaries**.

How could they be managed? Let's see next pages that will lead us to the:

- Tasks Structure Matrix
- Integration and Testing Rules.

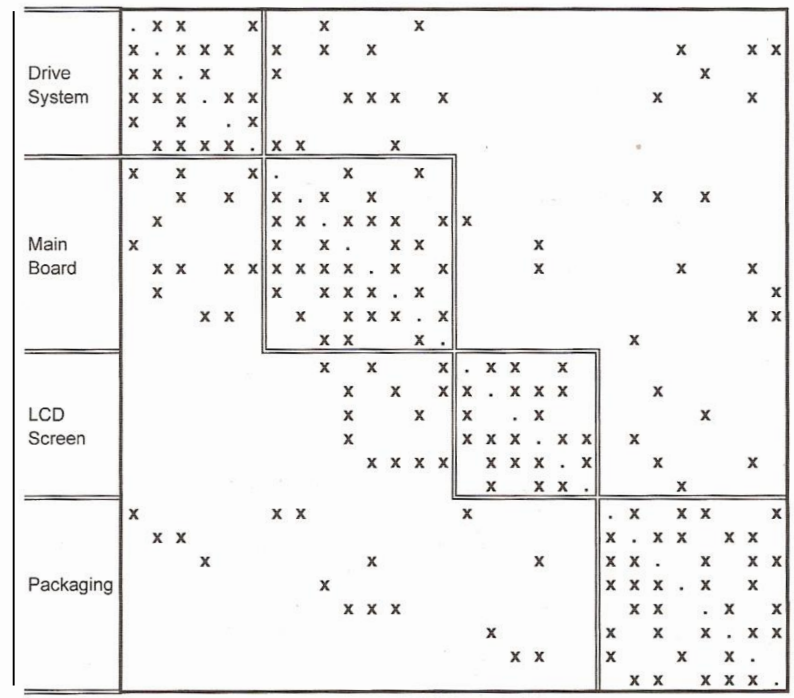


Figure 2.5 An interconnected, ordered task structure matrix: design of a laptop computer after reordering tasks.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Modularity

Design methods - DSM

about Tasks Structure Matrix

By the way, thinking that in the end design parameters, and the related DSM, are in order to achieve the implementaton of specific functions (ref. to Ülrich pattern), it's quite spontaneous grouping technicians accordiingly to their skills on such functions themselves.

Task Structure Matrix (TSM) logically comes comes from Design Structure Matrix and depicts the link between the product design and the design process.

Indeed, through the interdependence among variables DSM represents the design structure, towards which the organization of design teams can't be not isomorphous.

… identification of design tasks … it is a powerful analytic device because by using it we can see with clarity how the physical and logical structure of an artefact gets transmitted to its design process, and from there to the organization of individuals who carry the process forward.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Structures, Context, and Operators

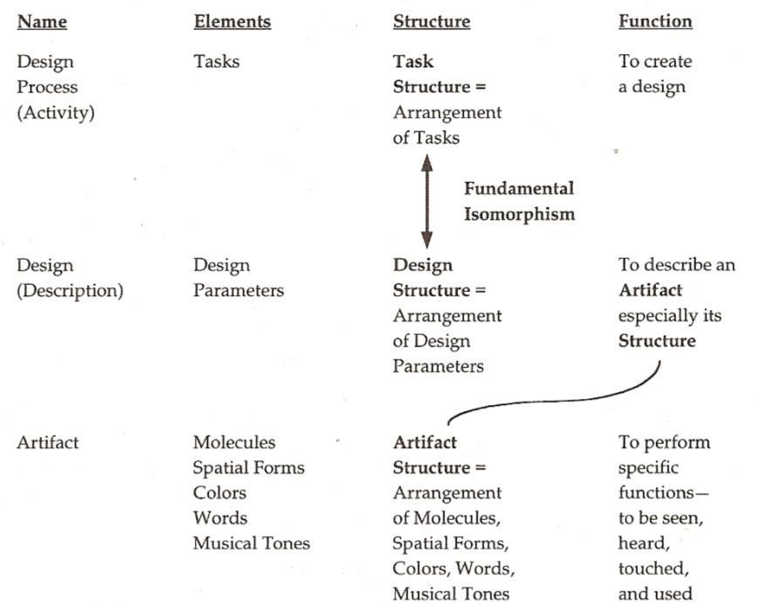


Figure 2.4 The "layers of structure" in an artifact's design.

Modularity

Design methods - DSM

about Integration and Testing Rules

As a further remarks one can see that both the tasks and the integration rules come from the product architecture (ref. to Baldwin & Clarck pattern). Infact a typical role of a modular design is the «desing's architect», who's in charge for the rules issuing.

And what about the x not included in single taks? The answer is easy: one will have to define rules finalized to manage them. They'll be the **Integration and Testing Rules.**

Indeed, through the interdependence among variables DSM represents the design structure, towards which the organization of design teams can't be not isomorphous.

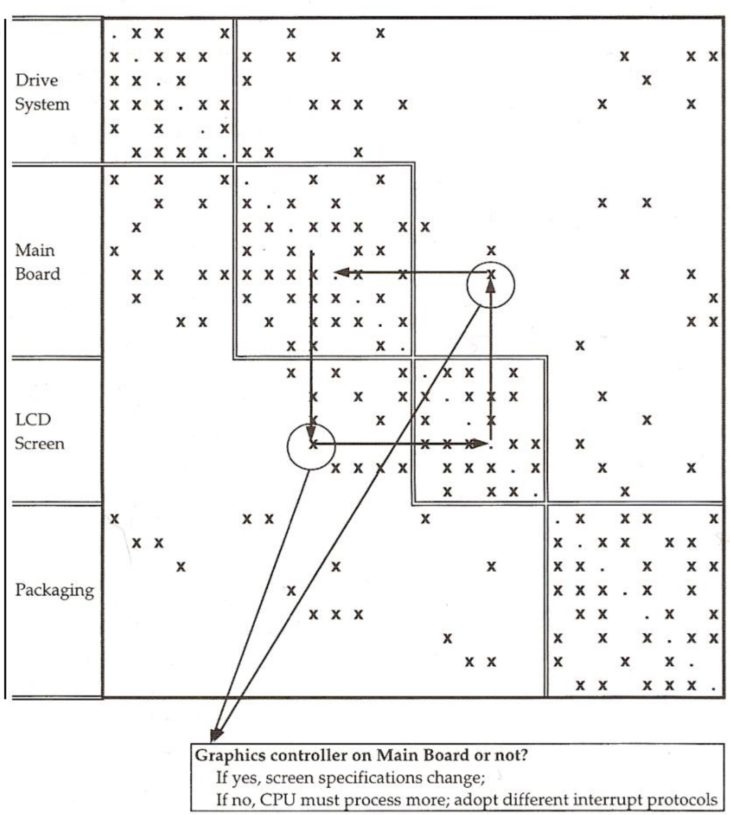


Figure 3.1 Design rationalization: cycling around the graphics controller issue.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

Modularity

Design methods - DSM

Integration and Testing Rules can be interpreted ad an example of modularity application in the organization's design.

As a matter of fact, the information flow (that's the single tasks' interfacing) mirrors the above rules.

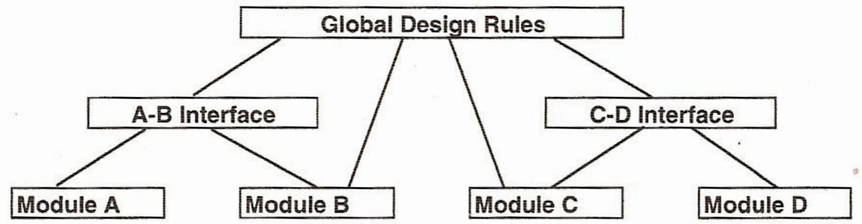


Figure 3.5 A design hierarchy with four hidden modules and three levels of visibility. There are three levels of visibility/invisibility. The global design rules are directly visible to modules B and C and indirectly visible to modules A and D. This means that designers of hidden modules B and C must know the global design rules as well as their local interface specifications, while designers of modules A and D need only know their local interface. However, the interfaces are based on the global design rules; if these change, the interfaces must change as well.

[C. Y. Baldwin, K. B. Clark – Design rules: the power of Modularity]

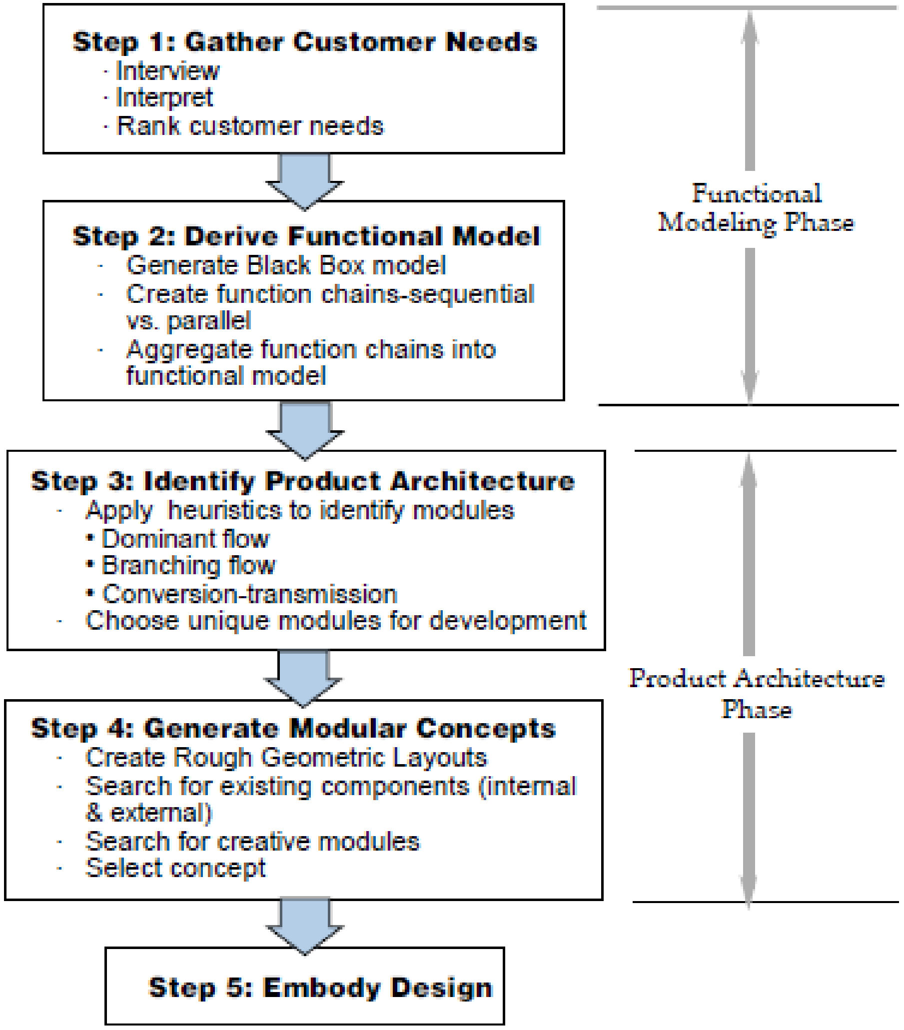
Modularity

Design methods - FSH

Function Heuristic Method (FSH) starts from the functional structure of the product in order to identify some possible sub-functions (which can be meant as what coming by the parts whose linking generates the main function and, may be, to the subsidiary ones mentioned in Ulrich pattern page) **and "flows" of energy, material, information etc.**

Summing up in a very preliminary way:

- ✓ the characteristic of FSH is related to such flows whose (well- reasoned) whole can be meant as a module (indeed a macro-module) and which implies the conversion among different flows' contents (for instance from energy to material or viceversa etc.)
- ✓ in the end: one could identify:
  - **modules related to specific flows achievement,**
  - **some other related to the interfacing of such modules** (that's "conversion and transfer modules")



[Stone, Wood, Crawford – A Heuristic method for identifyinhg modules for product architecture – Design Studies, Elsevier, 2000]

Modularity

Design methods - MFD

In a very summarized way: Modular Functions Deployment (MFD) can just be meant as an application in modularity of QFD (Quality Function Deployment).

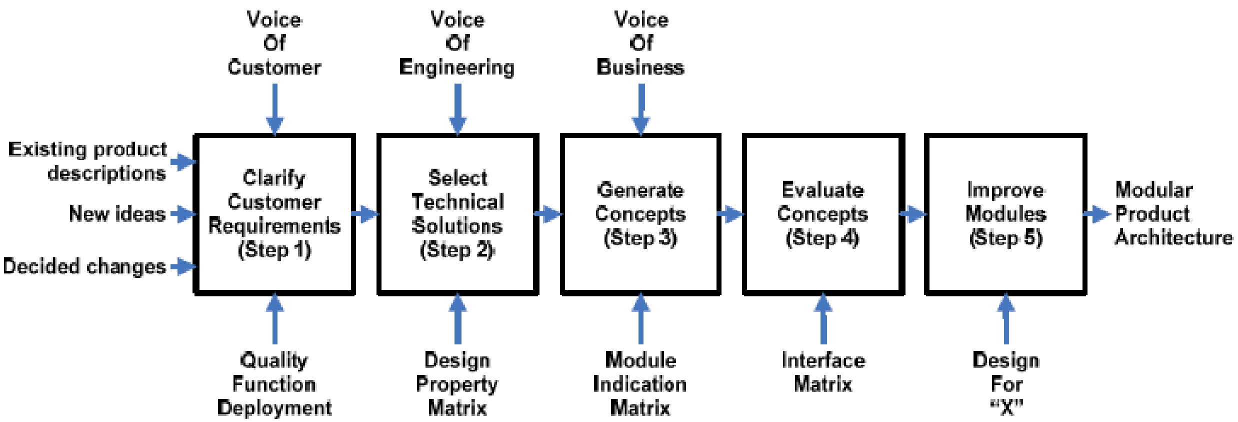
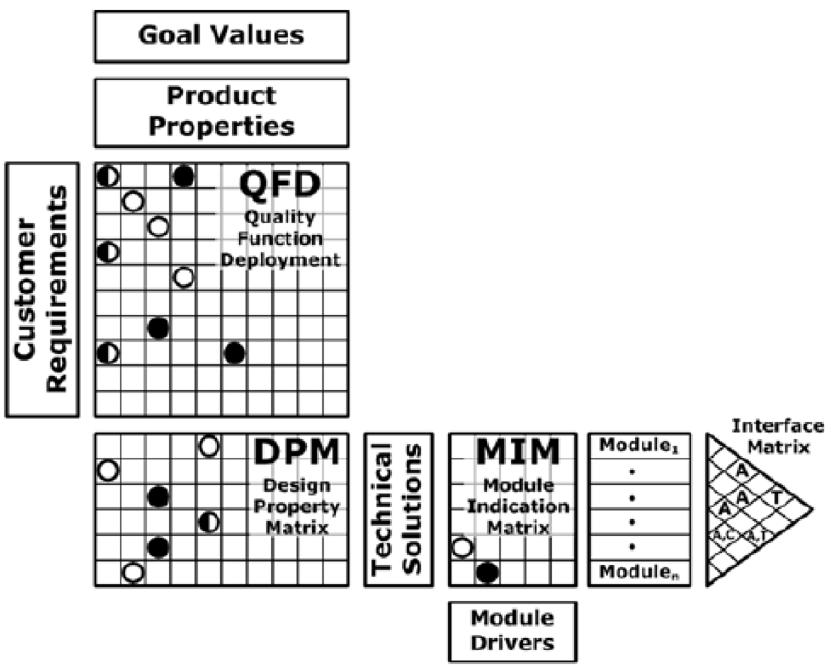


Fig. 4.3 Modular Function Deployment, adapted from (Erixon 1998).

In other words:

- first step will be to get the correlation of the design's solutions to the modules' drivers.
- second one will be identification of the interfaces (that generally will mean assembling on a base module or in series/sequence to it.



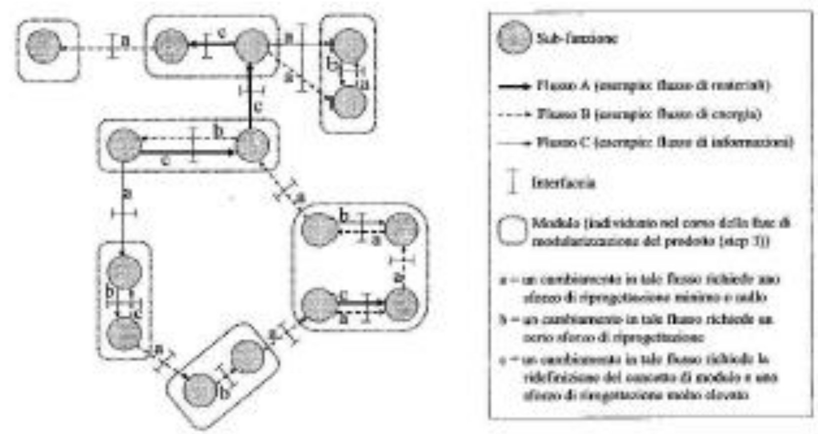
Modularity

Design methods - DEC

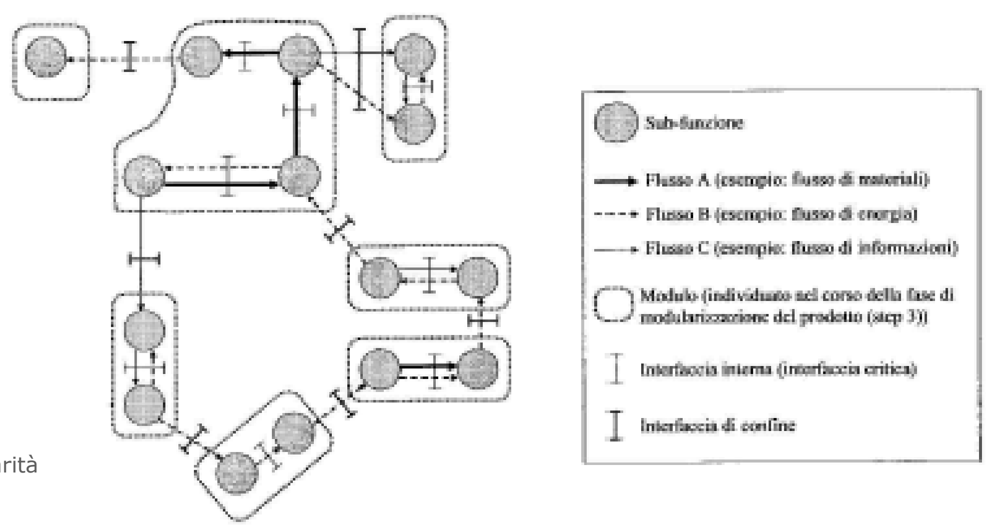
Design Effort Complaxity (DEC) method is aimed at the optimization both of modules' independence and of interfaces' stability.

It starts from the carrying out of a functional analysis and of the flows (so not dissimilar by FSC), then some anysis related to the flows' variation and to their effects are carried out.

Analysis of interfaces's complexity



Final configuration of the modules



[*abstract from* M. Bordignon – La modularità e il suo potenziale ruolo nelle imprese - Aracne, 2009]

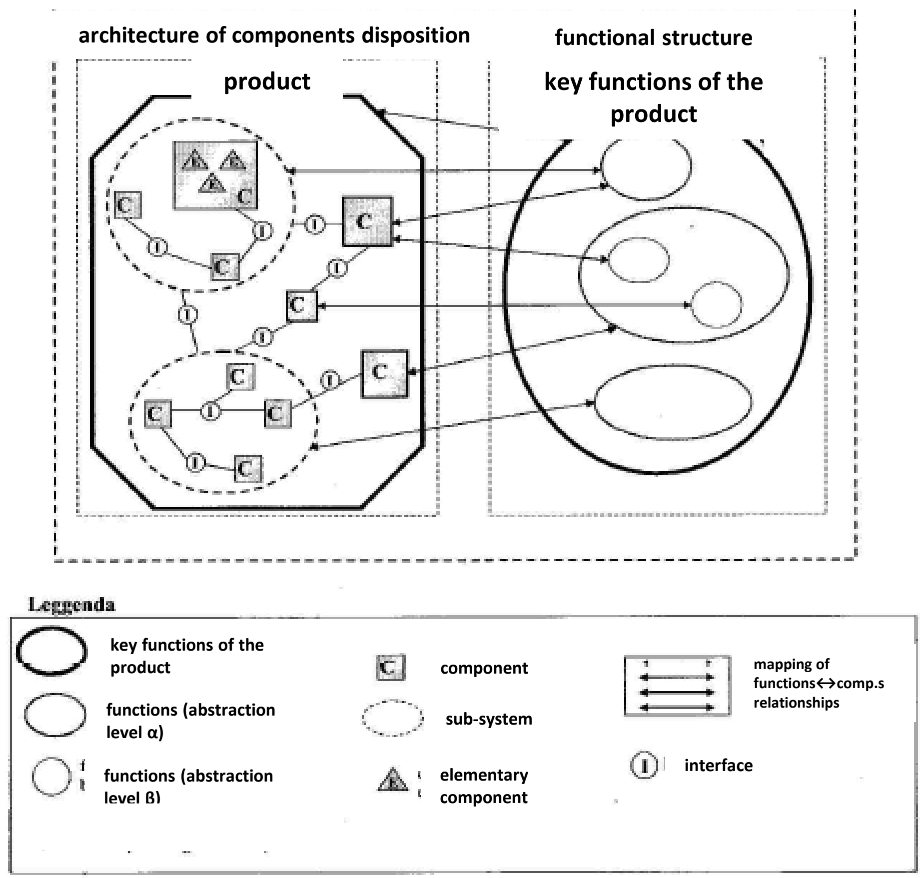
Modularity

Att. 1

Graphic description of the concept of product’s architecture.

Graphic description of the concept of product’s architecture.

Product’s architecture.



[*abstract from* M. Bordignon – La modularità e il suo potenziale ruolo nelle impese]

Modularity

Att. 2

Types of interfaces

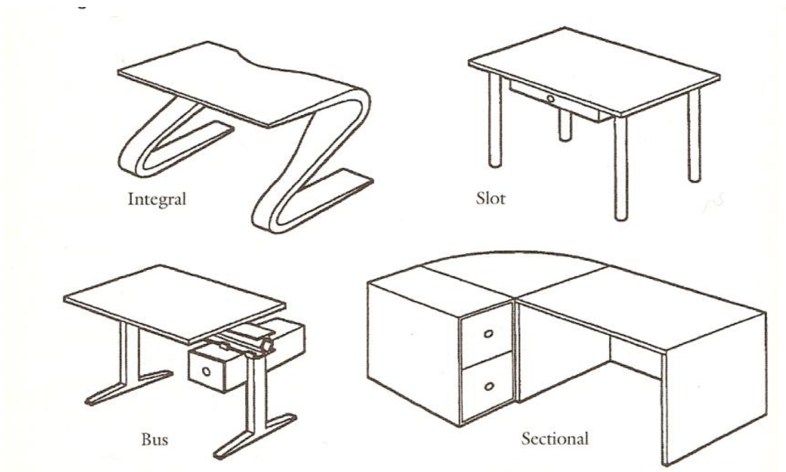


Figure 4.6 Four desk architectures.

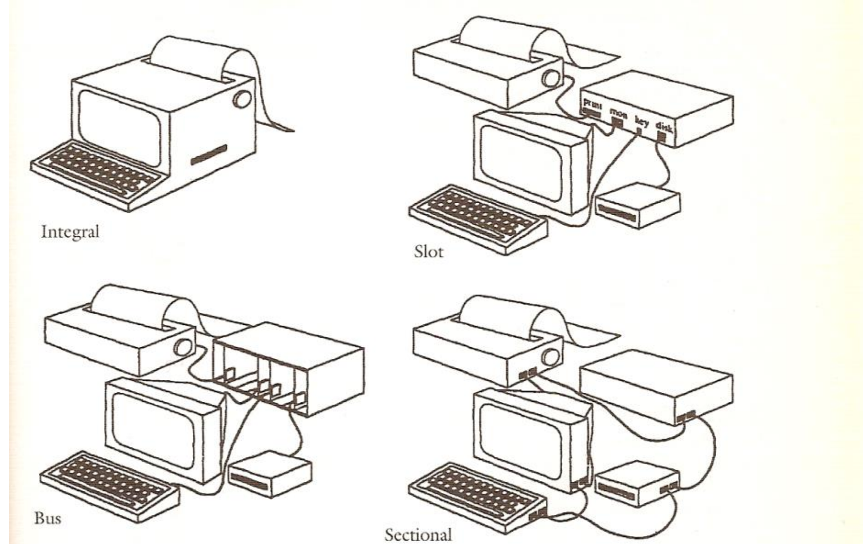


Figure 4.7 Four personal computer architectures.

- **slot** → each of the interfaces between components in a slot architecture is of a different type from the others, so that the various components in the product cannot be interchanged.
- **bus** → in a bus architecture, there is a common bus to which the other physical components connect via the same type of interface.
- **sectional** → in a sectional architecture, all interfaces are of the same type and there is no single element which all the other components attach. The assembly is built up by connecting the components to each other via identical interfaces.

[R. Garud, A. Kumaraswami, R.N. Langlois – Managing in the modular age]

Modularity

Att. 3

Platform’s example

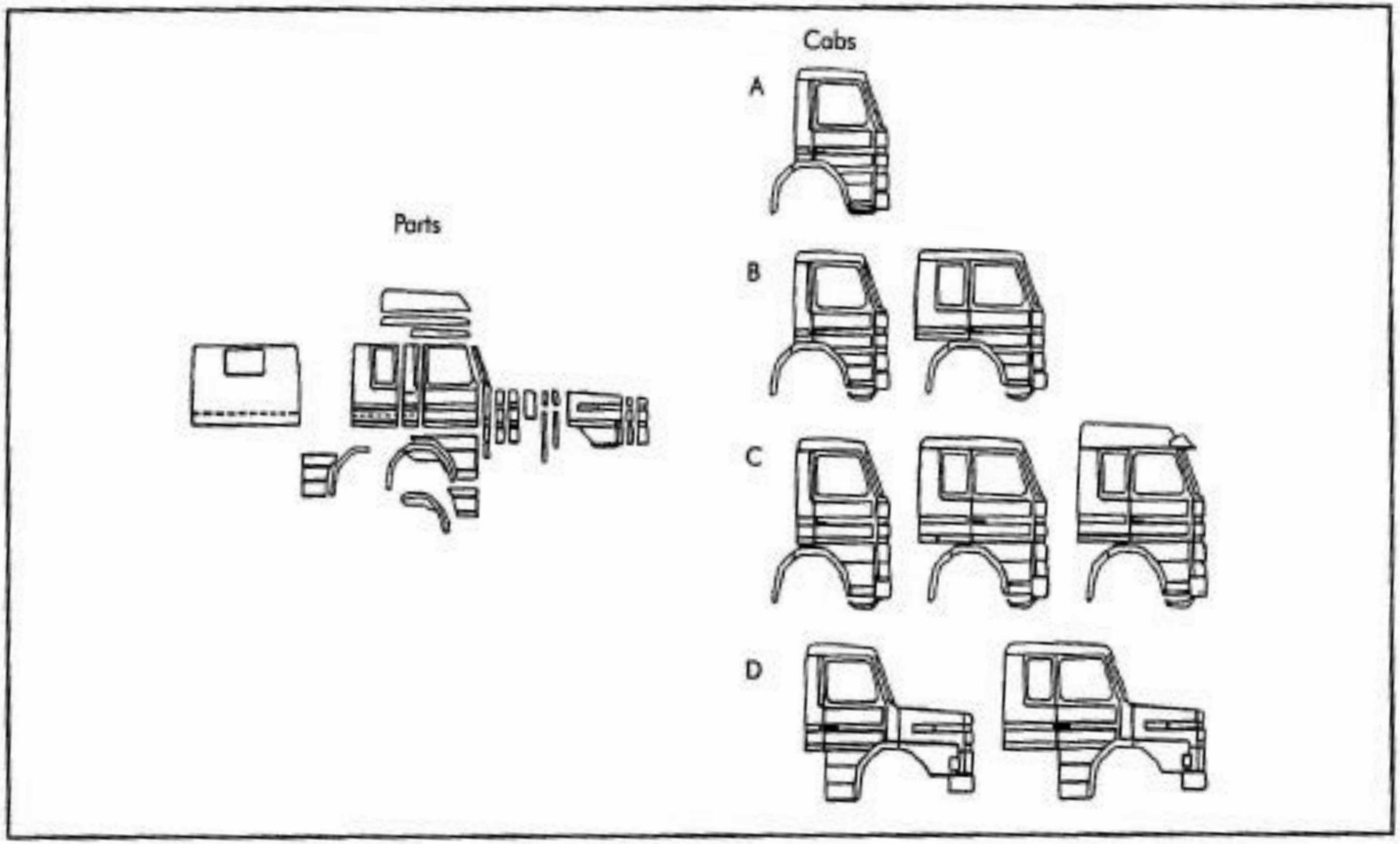


Figure 1-2. Scania's modular truck cab. With the modularized cab, Scania can offer their customers a wider range of products than previously and they now have fewer parts, fewer pressing tools, and shorter assembly time.

[A. Ericssson, G. Erixon – Controlling Design Variants (Modular Product Platforms]