Designing Mechatronic Product Families

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22 June, 1995

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Introduction

- Design research should consider the relationships between product structuring and design processes

> O body swayed to music, O brightening glance,
> How can we know the dancer from the dance?
>
> W.B. Yeats

- An increasing number of products use a variety of technologies to realise user functions.

- Product families are designed to improve the ratio of commercial variety and internal manufacturing efforts

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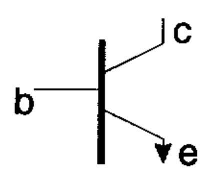
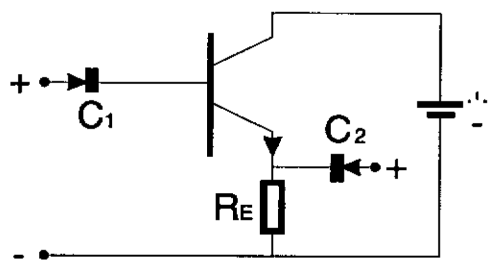
  - definitions and examples
  - consequences for product structuring and design processes
- Non-compositional systems
  - different domains and modelling languages
  - functional domain
  - technology domain
  - physical domain
- Productive reasoning model
- Developing product families
  - generic product structuring concept
  - extending the productive reasoning model
  - design considerations (modularity, integration, concurrency, etc.)

Compositional systems - 1

- Product models which are based on mathematical principles or theories from natural science are able to predict the behaviour of the system within the context of the theory.



Transistor



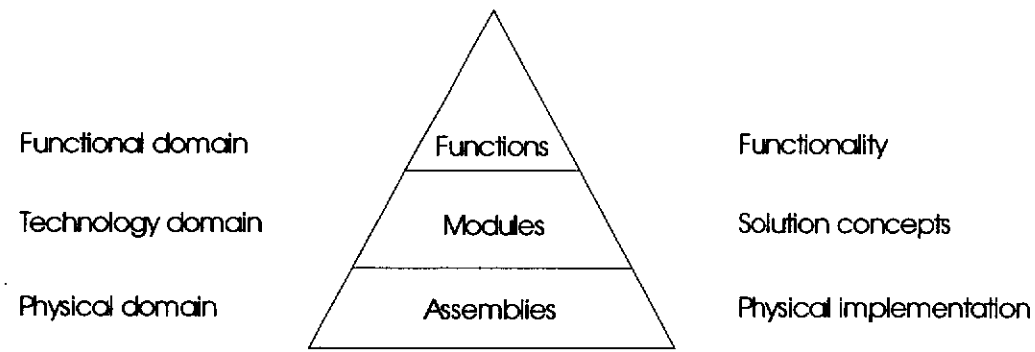
Emitter follower

Example

- The behaviour can be expressed if the behaviour of its components and the components' relationships are understood [Alberts, 1993].

Compositional systems - 2

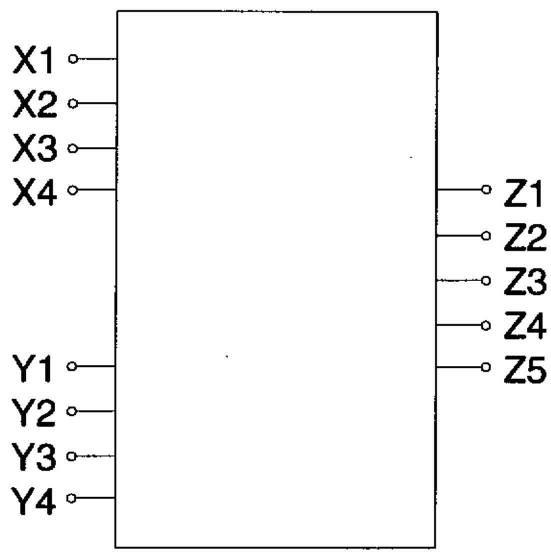
- Design process is supported by a product modelling language which integrates functionality and realisation on different abstraction levels of the product.

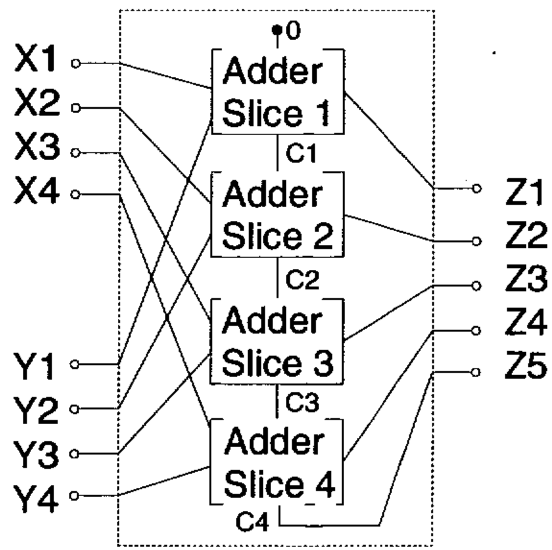


- Much research focuses on an automated derivation of implementation from functionality:
  - software: predicate calculus, constructive programming [Dijkstra, 1976]
  - electrical engineering [Alberts, 1993]
  - hydraulic engineering [Lee, 1992]
  - mechanical engineering [Pahl & Beitz, 1984] [Johnson, 1991] [Aylmer, 1988]

Compositional systems - 3

- Step-wise refinement of functionality (expressed as interfaces) and logical realisation.

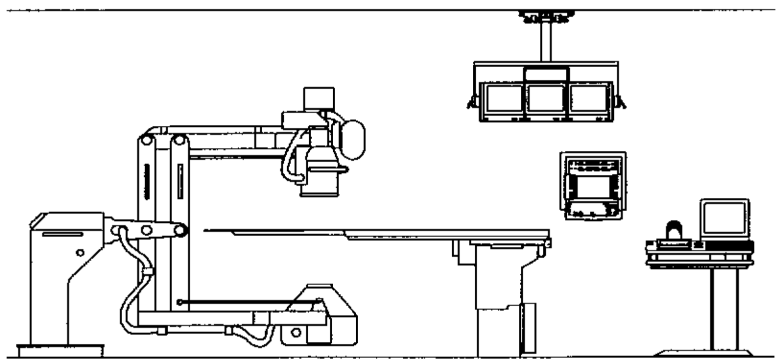




- Physical implementation is closely related to the manufacturing technologies applied.

Non-compositional systems - 1

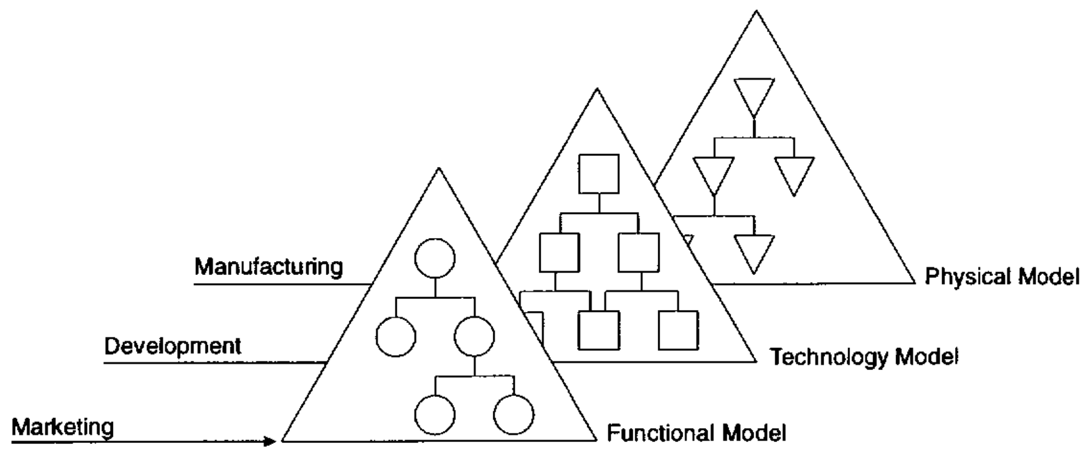
- For mechatronic products, there is no grand theory which links different theories into one uniform and predictive theory so as to predict the overall behaviour [Buur, 1989].



- User functions:
  - can be realised with different solution principles (e.g. prevent collision of patient and the medical x-ray equipment)
  - are realised with different solution principles (e.g. move patient).

Non-compositional systems - 2

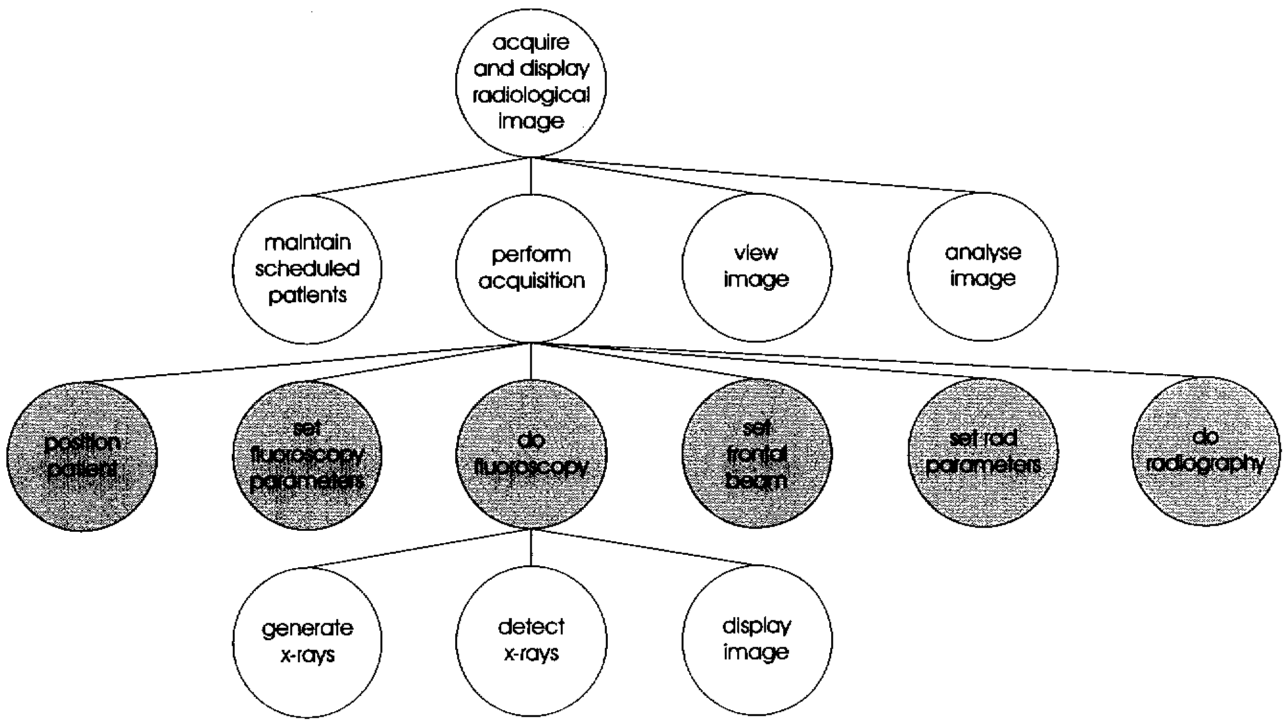
- There is a need to distinguish different domains in which the product is developed.



- Each domain has dedicated modelling languages.
- Each domain has a product model which structures the product in that domain.

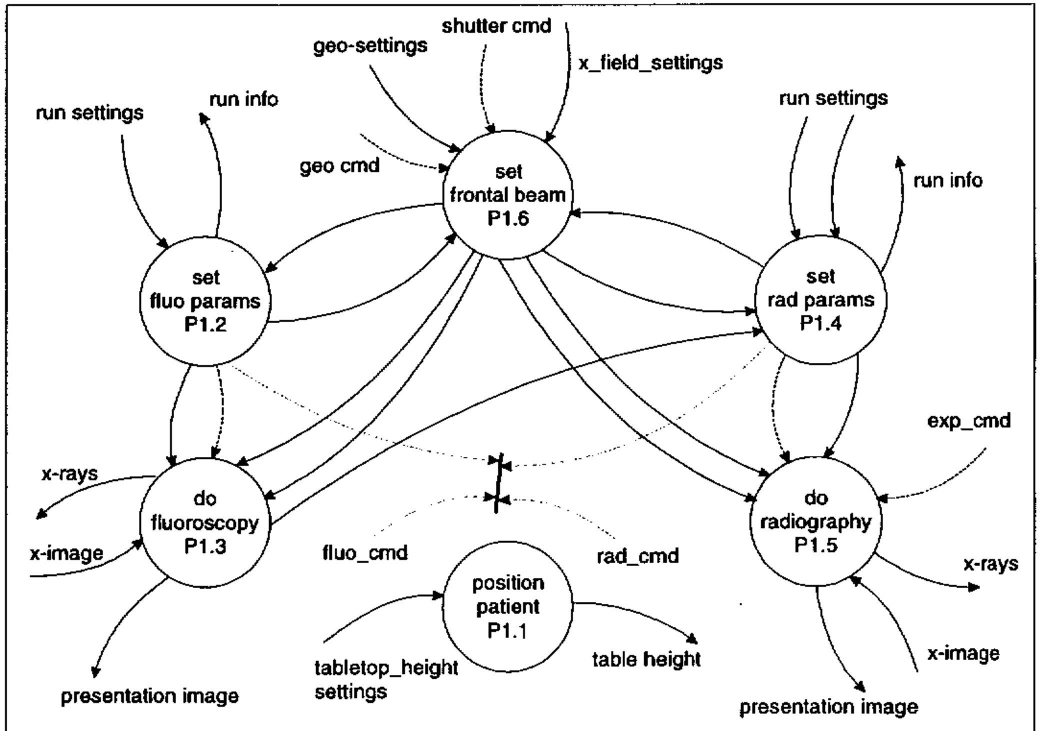
Functional domain - 1

- The *functional model* is a consistent description of the functionality of a product. It is strongly related to the use of the product.



Functional domain - 2

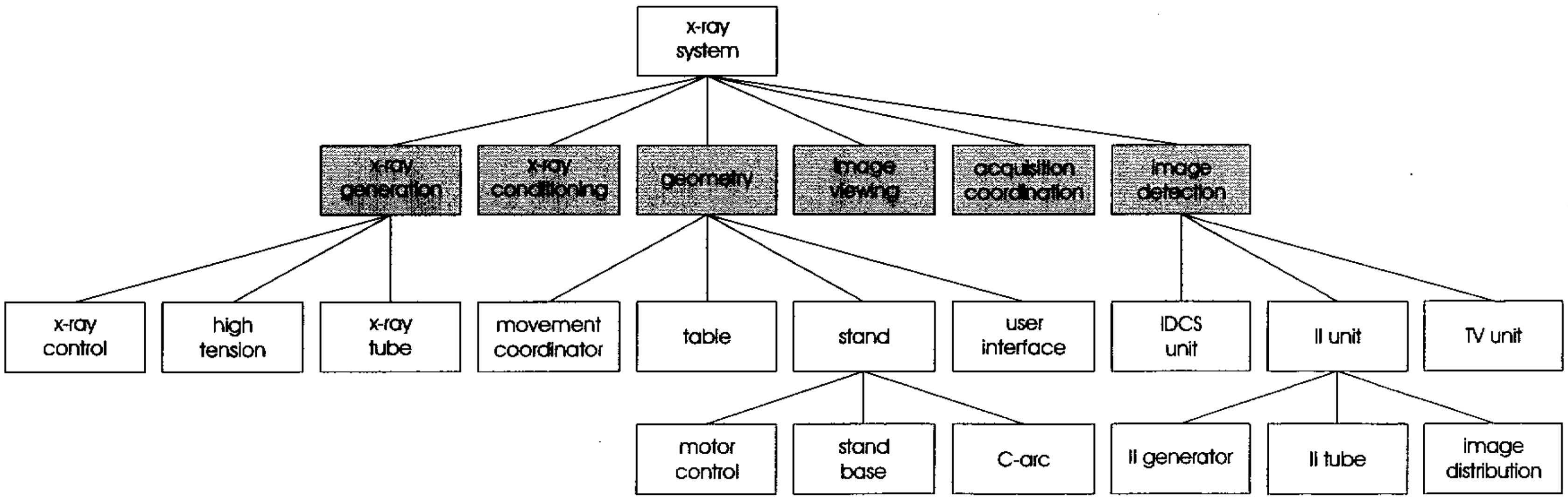
- The functional architecture defines the relationships between functions on one level of abstraction.



P1: perform acquisition

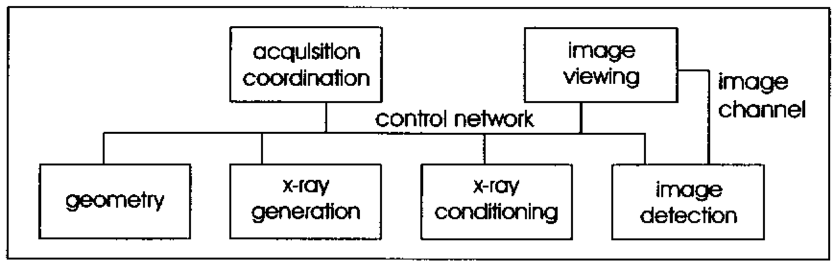
Technology domain - 1

- The *Technology Model* is a consistent description of the application of technologies to ensure the operation of the product. Development creates most of the information structured in this model.



Technology domain - 2

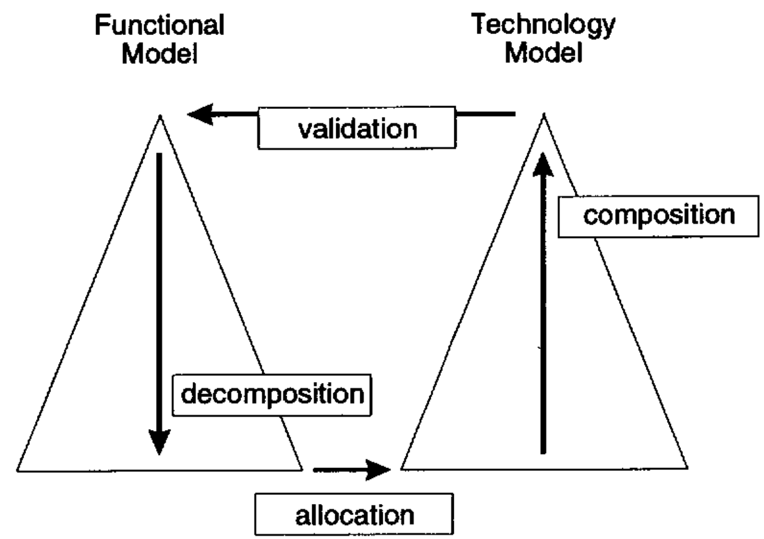
- The technology architecture defines the relationships between modules on one level of abstraction.



- In a similar way, there is a physical model and a physical architecture.
- The *Physical Model* is a consistent description of the physical realisation of a system. It is strongly related to the construction of the product.

Productive reasoning model - 1

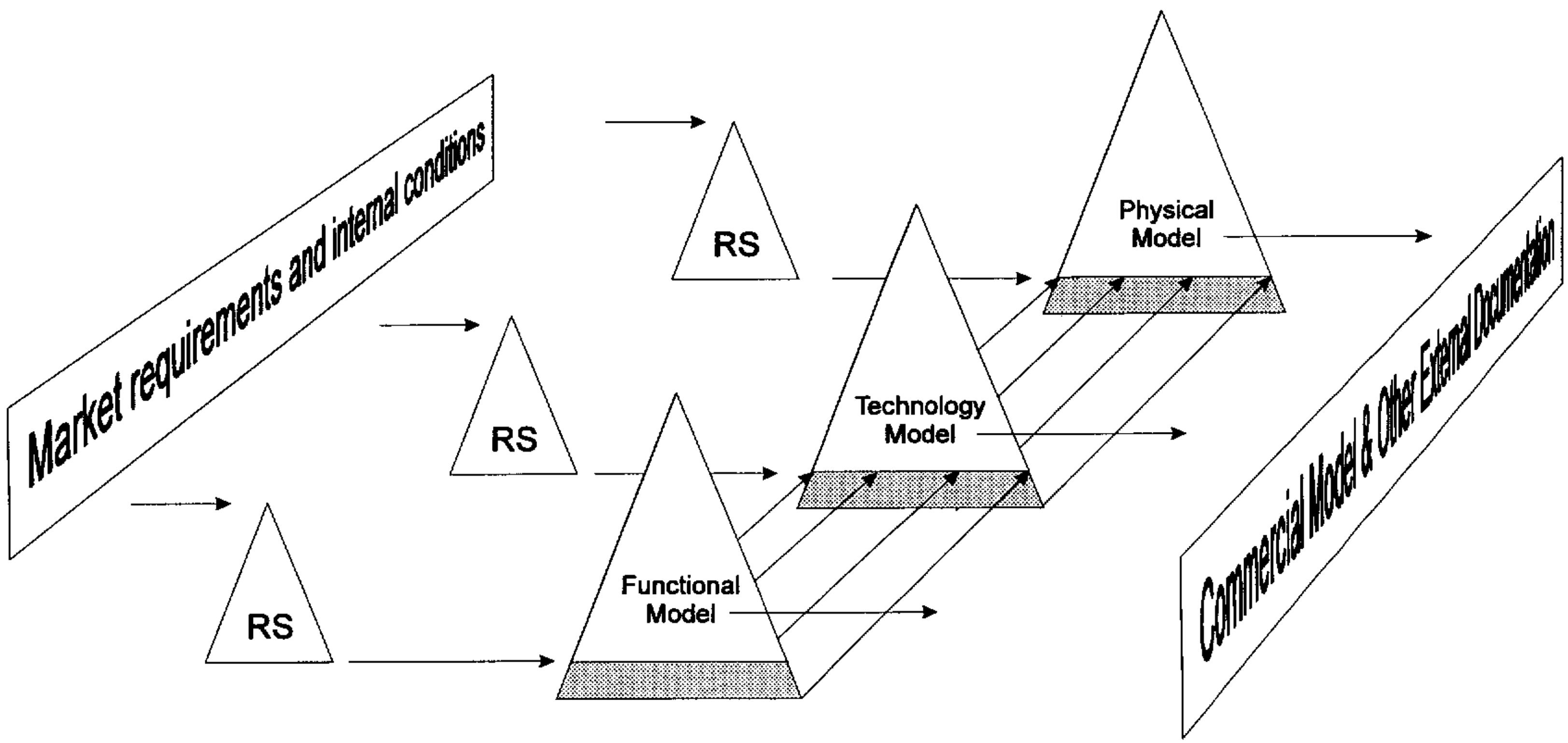
- The productive reasoning model [March, 1984] [Cross, 1989] stresses the symmetrical relationships between problems, sub-problems, solutions and sub-solutions.



- It can be used between different domains and on different levels of the product hierarchy.

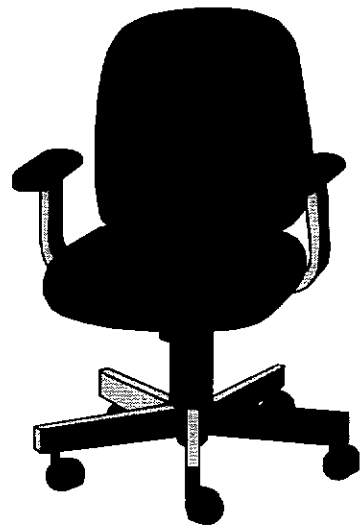
Productive reasoning model - 2

- Specifications are formalised in product models
- Function are allocated to technology modules
- Technology modules are realised in physical assemblies



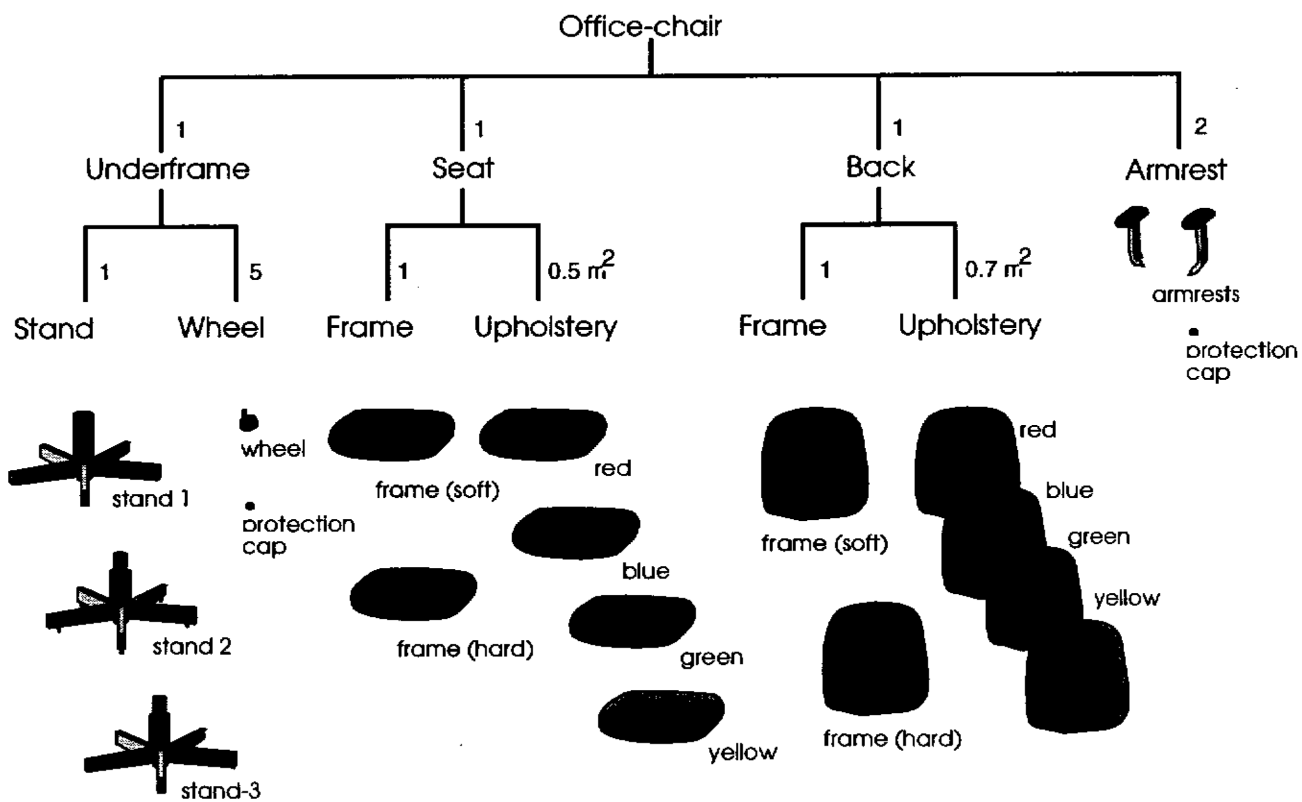
Developing product families - 1

- Model product families with the generic structuring concept.
- Office-chair
  - colour: red, blue, yellow, green
  - turnable: yes, no
  - driveable: yes, no
  - frame: soft, hard
  - elbowrests: with, without
  - Constraints:
    - colour=blue ==> driveable=yes
    - driveable=yes ==> turnable=yes



Developing product families - 2

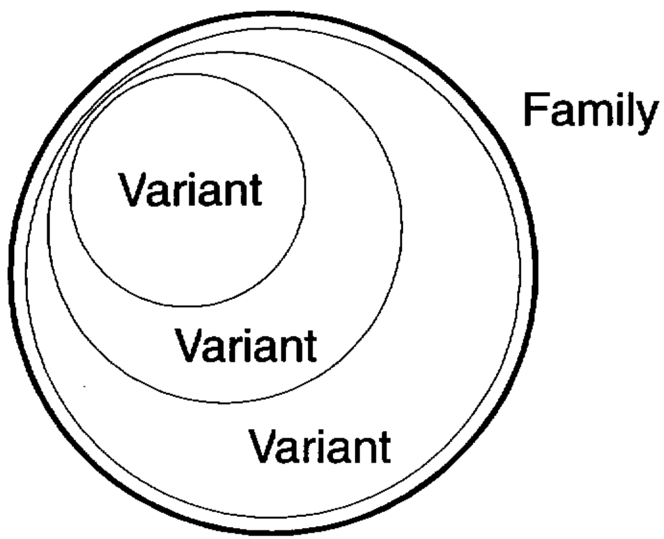
- Decompose families till the level of primitive variants.



- Boolean conditions select the right primitive variants.

Developing product families - 3

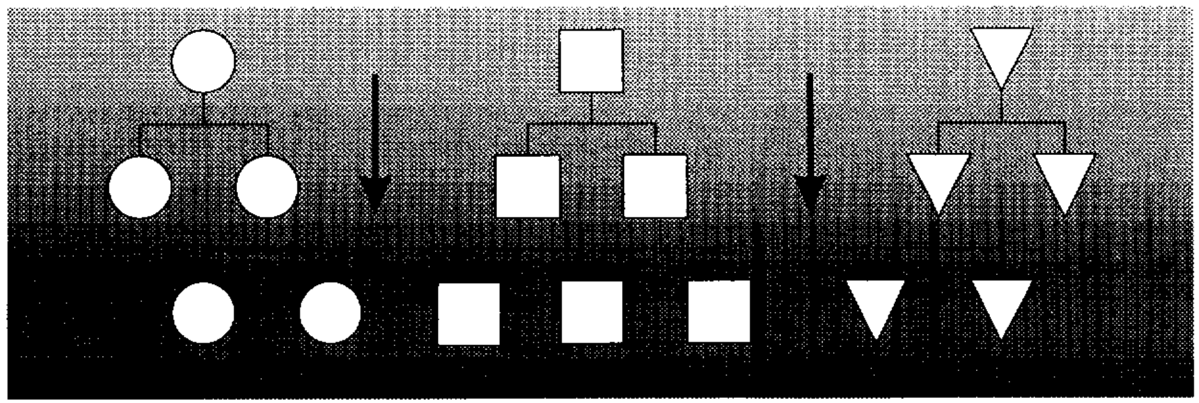
- Mechatronic product families are structured in three domains.
- Product architecture should be chosen such that different options fit into it.
- Create scaleable architectures.



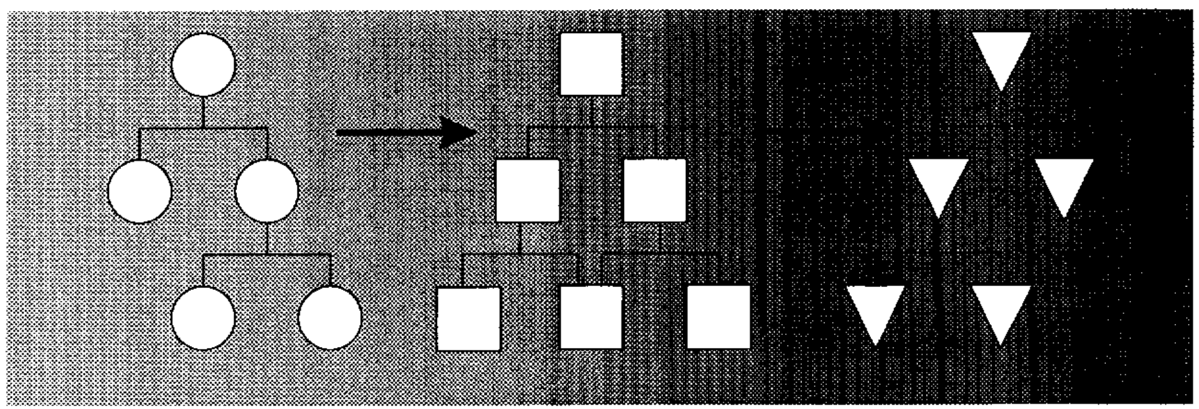
Observations - 1

Concurrent versus sequential design

- Concurrency

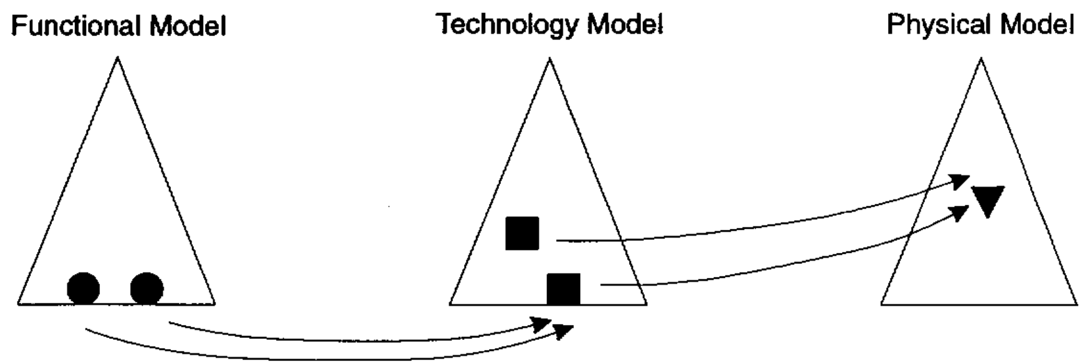


- Sequential



Observations - 2

Modularity versus integration



- Integration: - several functions are realised in a module
  - fine-grained design with many modules
- Integration requires product maturity, product families require modularity: balancing problem

Conclusions

- The design process cannot be described independent from the product descriptions.
- Non-compositional systems require dedicated modelling languages for the functional, technology and physical domain.
- The architecture of a product family should be such that different modules fit in this architecture to cater for customer variety.
- Mature products become more integrated, however also require more variety, which asks for modular designs.