Engineering Part IIB

Paper 4C4 - Design Methods

SUMMARY NOTES

Product Architectures

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Version 1.0: July 2009

Product architectures

Many organisations produce a variety of products rather than just a single product. This variety is required to suit specific tasks and also to suit specific users. Different tasks require different tools, and therefore a range of different products might be produced for different purposes (e.g. to distinguish between road bikes and mountain bikes). Even for a single task, a range of products might be necessary for the purposes of market differentiation (e.g. to distinguish amateur products from professional ones).

Whilst there is benefit in producing different products to suit specific tasks and also to suit specific users, this variety brings with it a number of disadvantages. We might expect attendant increases in complexity, cost and development time, whilst also expecting a decrease in reliability and interoperability. The purpose of considering product architectures is to try to maximise the advantages of product variety whilst decreasing the disadvantages.

1. *Modular vs. integral*

Products can be thought of in both functional and physical terms. The *functional roles* of a product relate to what that product usefully does. This can include operative functions that transform an input to an output (e.g. transmit torque, reduce voltage) and structural functions that simply establish or maintain the relationship between components in a product or the relationship between the product and the outside world (e.g. support roof, attach housing). The *physical elements* of a product relate to the material form that the product takes. This includes the parts, components and subassemblies from which the product is composed. These parts, components and subassemblies can be thought of as modules.

If products can be described in terms of the functions they fulfil and the modules from which they are composed, then the degree to which a product exhibits a modular architecture depends on the relationships between those functions and those modules. With a highly modular architecture, any given module completely performs one or more functions.

For a highly integral architecture, any given function may be performed by more than one module. In addition, with a highly modular architecture, the interactions between modules may be relatively de-coupled, whereas with a highly modular architecture the interactions between modules may be highly coupled. A highly coupled interface is one in which a change to one component is likely to require a change to the other. A de-coupled interface is one in which a change to one component is less likely to require a change to the other.

Modularity is a relative term (as is interface coupling), and therefore rather than describing a product as being modular or integral, we would normally describe the *extent* to which it is modular or the *extent* to which it is integral. In products with a highly modular architecture, we might expect to see a one-to-one (1:1) mapping between functions and modules. With such an architecture, the following benefits might be realised:

- The design of each module can be assigned to a different team in the knowledge that that team are entirely responsible for a particular function
- Modifications made to any particular module need not influence the design of the other module
- If a product is failing to perform a particular function it is clear what module requires replacement or redesign
- Product ranges cost less to manufacture because of commonality between components and interfaces.

In products with a highly integral architecture, we might expect to see any one function shared across a number of modules, and also to see any one module contributing to the performance of a number of functions. With such an architecture the following penalties might be expected:

- Assigning modules to teams is difficult because a close coordination between different teams will be essential.
- Changing the design of any one module may necessitate the redesign (or at least the review) of other modules.
- Products that are failing to perform a particular function may necessitate the servicing or redesign of many different modules
- Product ranges cost more to manufacture because many of their components are unique.

Despite the drawbacks of integral product architectures, they are still widespread. This is because one of the benefits of an integral architecture is that the performance of the product can often be optimised. For example, by exploiting the contributions that each module can make to each function, the overall size and weight of the product might be minimised, and its rigidity and strength might be maximised. The cost of any single product can also be reduced, especially with high production volumes.

Note: The various modules from which large, complex products are composed may be large enough and complex enough in their own right to have their own architecture.

2. Types of modularity

Three different types of modularity can be defined according to how the interfaces between the modules are organised:

- *Slot modularity* requires that each module has a different interface type. This is popular because modules may have unique interface requirements and therefore designing unique interfaces for each module allows their interactions to be perfectly accommodated.

- *Bus modularity* requires that there is a common interface type for all modules. This common interface is called the bus, and it permits a wide range of configurations in which modules interact with the product in standard ways. Bus modularity is appropriate where there is a standard form of interaction that is suitable to each kind of module (e.g. where each module has the same power and signal requirements).

- *Sectional modularity* requires that all the interfaces between the modules are of the same kind, but there is no common bus for the modules to interface with. The modules all attach to each other or to independent sub-assemblies. Sectional modularity is appropriate for simple expandable systems where future developments are difficult to predict.

3. The influence of product architecture

A product's architecture has a strong impact on the extent to which an organisation is able to offer a useful variety of products at a reasonable cost, and on the extent to which those products can be changed during their life. To better consider this, we can examine the influence of product architecture at different stages during the development project.

During the *design of the product* the architecture influences the realisation of functions, the division of design tasks and the extent to which existing design elements can be can re-used. During the *design of the production system* the architecture influences the assembly sequences that are viable and the extent to which tooling, equipment and resources can be reused and redeployed. During *production*, the architecture influences the unit cost, the viability of late customisation and the ability to offer product variety. During *usage*, the architecture influences performance, adaptability, maintenance and obsolescence. During *post-production*, the architecture influences the cost and effectiveness of servicing, and the ability to change the product.

As described above, the product architecture that is chosen influences the ability to offer *product variety* (during production) and the ability to offer *product change* (in post production). We will now consider each of these in turn.

3.1. Product variety

'Product variety' refers to the range of models that the organisation can provide in response to market demand. This might include products that vary according to the following criteria:

- *Performance* – products with varying levels of performance. For example, car models with different engines
- *Features* – products with different feature levels. For example, audio headsets that do and don't include noise cancelling technology
- *Dimensions* – products with different geometric dimensions. For example, luggage that is available in different sizes
- *Localisation* – products tailored to specific territories. For example, computer keyboards suited to different languages.

An organisation's capability to offer product variety effectively and efficiently is often compromised if each product is developed in isolation. Where there is no collaboration between development teams, there can be a proliferation of different components throughout the range and limited re-use of processes between products. This can lead to a poor range of product offerings and demands efficient manufacturing processes to compensate. As a result, the design goal is to achieve maximum product variety with minimum complexity. This leads to a tension between the desire to uniquely tailor each product to its specific market, and a desire to maintain commonality across the range and between product generations. This trade-off is not fixed however; through effective product architecting it is possible to improve both variety *and* commonality.

3.2. Product change

'Product change' refers to the way in which products are modified or altered during their life whether by the user, the manufacturer or some other party. Product change may be motivated by the following kinds of functional change:

- *Upgrades* - due to a change in technology, competition or user needs, it may be necessary to swap one component for an upgraded component. For example upgrading memory in a computer.

- *Add-ons* – organisations may choose to offer a basic unit to which users can add components later. These components may be offered by third parties. For example, consider the proliferation of add-ons available for mobile phones.

- *Adaptation* – products expected to have a long life in the market or that must perform in different environments may need to be adapted to new uses. For an example of the first, consider buildings that are often subsequently put to uses that their designers did not anticipate. For an example the second, consider the adaptations made to electronic devices so that they can operate in different geographic regions with different voltages.

- *Wear/maintenance* – over time, different components of a product may need to be replaced because they wear out through use or because they simply degrade over time. For example, consider rubber o-rings and tyres.

- *Consumption* – certain products require the supply of consumables. These are materials that are consumed during use rather than wearing out. For example consider products that use batteries, film, paper, ink, etc.

- *Flexibility* – certain products are required to regularly adapt to different usage scenarios and therefore offer flexibility through the use of interchangeable components. For example, consider cameras that have interchangeable lenses so that they are useful for a range of different photographic tasks.

The ability to make products that can be effectively and efficiently changed can increase the useful life of products, extend their range of application and increase customer satisfaction. Products with some modularity can more easily be changed without adding complexity to the products' design, manufacture and maintenance.

4. Making architectural decisions

Much of what we have discussed above relates to the different factors that are *influenced by* product architecture; we will now consider those factors *that influence* product architecture. That is, we will consider the factors that must be considered when deciding what architecture is most appropriate. Such decisions about product architecture often involve cross-functional teams that include representatives from marketing, strategy, manufacturing, service, etc. These representatives must collectively consider (i) whether, and how often, a product may need to be changed during its life, (ii) what variety of products might be offered at any one time, and (iii) the degree to which components can be standardised (within and between products).

Architectural decisions will often be made during the conceptual design phase of the project where the processes of mapping functions, sketching form and defining production processes all have an influence on the extent to which an architecture is modular or integral. For any given product, there are a range of ways in which the design can be 'moduled' (the process by which components are divided or grouped into modules) and in which functions can be assigned to those modules. Some things to consider when making such decisions are:

- *Geometric integration* – elements that require precise alignment relative to each other should be moduled together. For example in a computer printer the paper handling components would be moduled together and the ink/toner handling components would be moduled together.

- *Function sharing* – identify those physical elements that are well suited to performing more than one function. For example, on a consumer electronics product the heat sink may perform both thermal and structural functions.

- *Supplier/partner capabilities* – products should be moduled so that those who will be responsible for each module can exploit their capabilities or specialities. For example, components that are predominantly electrical should not require extensive aerodynamic analysis and *vice versa*.

- *Localisation* – products should be moduled so that the modifications necessary for different regions are restricted to the minimum number of modules. For example, if a different transformer and plug is required for different territories, then those components should be moduled together and preferably towards the end of the assembly process.

- *Interfaces* – products should be moduled according to the demands of the different kinds of interface. For example, mechanical components often need a geometric connection that demands adjacency whilst electrical components often need only be connected by relatively flexible wires.

5. A note on 'platforms'

An increasingly common approach to product architecture is the platform-based product. The platform is a foundation of core technology that underpins product variants. It is a set of subsystems and interfaces that form the common structure upon which product variants can be based. Using platforms reduces manufacturing costs (by increasing commonality across a range), reduces assembly costs (by deferring differentiation) and reduces inventory costs (through standardisation). Platforms also improve an organisation's ability to respond to market forces by permitting the rapid and efficient integration of new technologies. A highly effective platform has been Volkswagen's 'A-Platform', which allows Volkswagen to establish component commonality by sharing between its four major brands (VW, Audi, Skoda, and Seat). Cars from these different brands share front axles, rear axles, front ends, rear ends, exhaust systems, brake systems, etc. This permits commonality of parts and processes whilst maximising differentiation in the eyes of consumers.

6. Further reading

Ulrich, K. T. and Eppinger, S. D. (2003), *Product design and development*, 3rd edition, New York, NY: McGraw-Hill. [Includes a good chapter on modular and integral architectures]

Meyer, M. H. and Lehnerd, A. P. (1997), *The power of product platforms: building value and cost leadership*, New York; London: Free Press. [Extensive case studies relating to the management of platforms]