

'Living' Architecture Overviews - Supporting the Design of Complex Systems

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Abstract

When dealing with complex systems, it is essential that designers and system architects have a clear understanding of the system as a whole. The main 'tool' for this is the so-called 'system architecture description' or 'reference architecture'. Although the concept of system architecture description and what should it include is still open for discussion, its utility and potential benefits have largely been proved and supported by manifold papers and experts. Overviews of the system and its environment are the core of this system architecture description. However, HOW to create those overviews of complex systems is uncertain. Even more difficult is to keep those overviews up-to-date to be continually used. The purpose of this paper is to propose an approach to create a 'living' overview of a complex system in order to support system designers and architects in the creation of products. An example based on previous work conducted at Philips Medical Systems with a real complex system (MRI scanner) will be described.

Keywords:

1 INTRODUCTION

Good System Architecting and Design is vital in the industry for the survival of complex systems. The effort and resources required to adapt complex systems to changing requirements or different environments can be significant. Even minor top-level functional changes can have lengthy, costly and difficult to predict development cycles. To cope with these trends, present systems need to acquire new properties such as evolvability (Isaac and McConaughy 1994; Steiner 1998). This paper is the result from the research and many interactions and discussions with systems architects from Philips Medical Systems.

Current trends in the industrial sector cause new system properties to be required at different levels. Among these trends and consequences, it is worth to mention:

- Complexity increase: solutions in response to demands for new features to add value to the system have been increasing rapidly in recent years and are driving an increase in system complexity.
- Time to market pressure: the innovation cycle of products is decreasing. Product manufacturers are under severe pressure to reduce product and development costs and yet remain technologically one step ahead of the competition.
- Open system demands: customer's expectations are that their products can connect to a variety of products and systems from different manufacturers.
- Product families: customers demand personalized products. The final system is not just one product but a family of products. This leads to an increase in the effort required during the life-cycle design, as product families are derived from a common platform in order to enable re-use of current knowledge and infrastructures.

Industrial sectors such as aerospace, automotive, naval and DoD, have already identified the necessity of adopting new approaches to design their systems and have placed it as a primary requirement (Steiner 1998; Schulz and Fricke 1999).

In contrast with the current way of working, tools and methods are largely identical to years ago. Although some changes has taken place such as the introduction of computer aided design (CAD), this change has not worked for the better (Ottoson 1998). The author of that reference contends that in the "drawing board environment", the workflow was from "big picture" -in the form of the large overview drawings- to detail, with the big picture always present. Nowadays the notion of the big picture is largely absent so the overview over the system and the design has decreased. In addition, system architects and system designers face new challenges, such as:

- Function integration has increased, both on the product scale (products are able to perform more functions) as on the part scale (a part performs several functions);
- Products contain mechanics, electronics and software that have to cooperate intensively (multidisciplinary systems);
- The team of designers is large and maybe at different locations around the world;
- The expectations and requirements on quality, reliability and maintainability have increased;

When dealing with complex systems, we are confronted with the fact that humans can only handle a limited number of inputs; *the magical number seven plus or minus two* (Miller 1956). It is to say, there is a limit to the amount of information that can be easily handled by humans. Overview means a broad, comprehensive view of the system as a whole.

2 ARCHITECTURE OVERVIEW OF COMPLEX SYSTEMS

Almost every system is inherently complex. In a complex system, knowledge of the elementary building blocks does not give a glimpse of the behavior of the global system. We accept that processes that can occur simultaneously on different scales or levels are important, and the intricate behaviour of the whole system depends on its units in a non-trivial way. It is to say, systems are complex when they are in practical sense unpredictable, uncertain, etc. Complexity has been widely studied by several authors and is out of the scope of this paper.

2.1 System Architecture in Complex Systems

When dealing with complex systems, it is essential that designers and system architects have a clear understanding of the system as a whole. The main ‘tool’ for this is the so-called ‘system architecture’ or ‘reference architecture’. Although the concept of system architecture and what should it include is still open for discussion, its utility and potential benefits have largely been proved and supported by manifold papers and experts.

The level of abstraction of a system architecture makes it difficult to understand their role. System architecture is used to design and engineer the system, resulting in engineering documentation that describes how the system can actually be ordered, assembled and tested. Field feedback from actual systems results in updates of the engineering documentation.

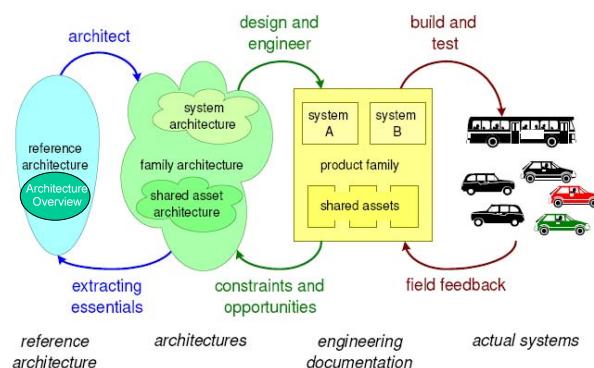


Figure 1 Role of the architecture in the product creation process (courtesy of Gerrit Muller)

Many frameworks and standards exist to create architecture descriptions, such as IEEE 1471, although all other frameworks and standards can provide inspiration for creating architecture overviews. On top of providing the framework, IEEE 1471 also recognizes the fact that complete consistency in the entire architectural description is an illusion. This notion of incomplete consistency is not an excuse for sloppy design; quite the opposite: recognizing the existence of inconsistencies is a much better starting point for dealing with them. In the end, no important inconsistencies may be left in the architecture description.

2.2 The Need for Overview

Literature regarding system architectures and on how the design process should be conducted is abundant. Also literature on how the design process is performed in practice can be found. An issue that has received less

attention is how to create and keep the overview during the life-cycle of the system.

As stated before, we are confronted with the fact that humans can only handle a limited number of inputs. With this limitation in mind, leads to the conclusion that it is impossible for one man or a small group to handle all detailed information of the system at hand. The problem needs to be subdivided in order to come to pieces that can be handled by one or a few tightly cooperating persons. The fact that more than one person is required to design complex systems is even part of the definition of a complex system (Axelsson 2002).

A short specific architecture overview is a powerful means during product creation [Gerrit]. An overview provides:

- Focus on customer and business.
- Direction and guidance to the project team.
- Insight in important choices and risks.
- Attention for issues that go beyond organizational entities.

When designing a system, communication between disciplines is crucial. There are organizational means that reduce the barriers, like collocation, project meetings etc. However, they do not eliminate the different jargons and do not create a synergistic way of working. There is a difference in thinking between engineers of different fields. As mentioned by (Eising 2007) even different mechanical engineers have a different view on their object of interest. These different views, and the absence of a common view, result in different optimizations (and thus different designs). An overview provides a common framework that facilitates communication across the multiple dimensions. The common (architectural) vision focuses and aligns efforts of multiple peoples and teams. The modularization of the system provided by the overview helps to divide the effort, where the context information ensures later integration.

By helping the designer to acquire necessary knowledge about the system and order that information, he will be able to make better decisions and use his creativity more efficiently, resulting in better products. The overview improves the effectiveness by:

- Driving and harvesting synergy
- Providing guidance, e.g. architecture principles, best practices
- Capturing and sharing (architectural) patterns
- Providing an architecture baseline and an architecture blueprint

3 CREATING THE ARCHITECTURE OVERVIEW

As shown in Figure 2, when creating the overview of the system architecture, the goal should be that only the relevant information that needs to be handled by the system engineers is present in it.

To create the overview it is necessary to acquire knowledge both from experts and available sources of information such as internal documents, books, articles, etc. A stated before, complete knowledge of the architecture is an illusion, there always be some degree of uncertainty that will impact the architecture overview. Thus, to allow for future improvement, the overview should provide means to adapt new knowledge when available; it is to say, the overview should be ‘alive’.

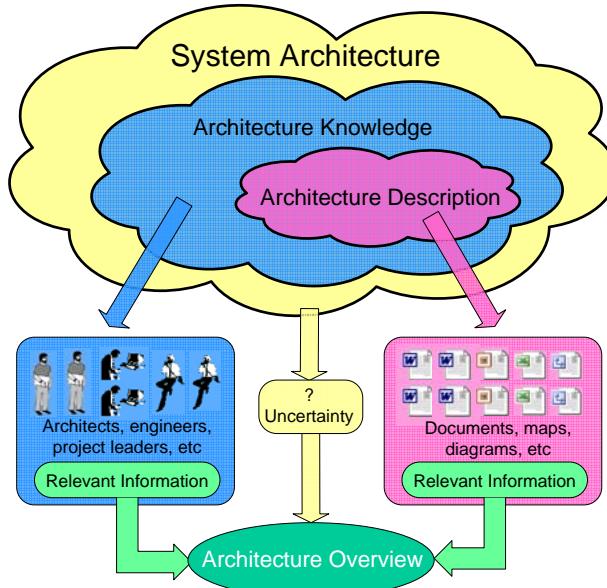


Figure 2 Creating the Architecture Overview

Then, the challenge to create the architecture overview is how to acquire the necessary knowledge and how to visualize that knowledge.

3.1 Proposed Approach

We believe that the best approach to acquire the necessary knowledge to create an overview is through case study research. Case study research is a qualitative research method depending on sources such as observation, interviews, documents and the researcher's impression. It is particularly applicable in an industrial context [39] Previous research has been conducted using this approach and have proven to be successful. In this fashion, to create an overview first a case study should be conducted to collect, analyze and interpret large amounts of data in an exploratory manner.

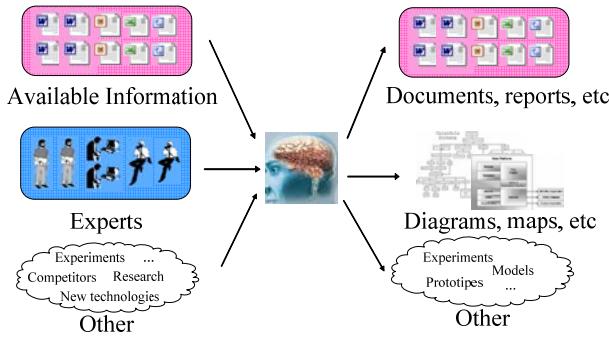


Figure 3 Overview Creation Process

As shown in Figure 3, the process to obtain first-hand information on the system is mainly by collecting company documents covering topics such as system requirements and specification, building block architecture, and system architecture. In addition, it is necessary to collect information through interviews with key personnel in the organization. The interviewees should be selected according to their experience and track record.

The first step is to define the scope of the architecture overview. The next step is bottom-up by exploring facts. We strongly recommend to quantify facts as much as possible, to ensure that this exploration is sufficiently specific. Next step is to work top-down, where IEEE 1471

can be applied. The result of this exploration is a broad set of still disconnected data-points.

The architecture overview does not have to be a conventional document. We recommend to provide both visual as well as textual information. The core of the architecture information should be partially visual, as diagrams, tables and lists, and partially textual. The text should explain the visual information and glue the information into a coherent set of information. There are many possible dimensions that can be used to structure the overview. Unfortunately no single dimension is ideal to structure. The structure of the architecture overview must serve its communication purpose. In other words the structure itself is less important than clarity and understandability of the content.

In order to get the desired output from the experts, the interviews should be conducted in a specific fashion to maximize its efficiency. Based on our previous experience, we propose the following approach:

1. Prior to the interview; send an introductory text to the interviewees explaining the reason and topic of the interview. It also wise to briefly explain the architecture overview concept in general terms to provide a context, to avoid misunderstandings regarding the many connotations of the 'architecture overview' concept, which may otherwise result in an unfocused interview. The introductory text also allows the interviewees to prepare themselves.
2. Prepare the interview: To really take advantage of the expert's knowledge, it is important to previously become familiar with the topic under discussion. For that, relevant documentation should be reviewed and analyzed. In addition, an architecture overview should be created according to the researcher's impression and knowledge, to be used as a discussion tool at the interview; it is much easier for the expert to modify a wrong architecture overview than creating a new one from scratch.
3. Perform the interview: Minimally guiding the interviewee often resulted in less biased information. It is for this reason that we think the interviewee should elaborate as much as possible by asking them open questions instead of closed ones. Key questions should be prepared in advance. Finally, asking for additional output such as relevant documentation or further contacts.
4. Review the overview and incorporate changes; after the interview, all new information and proposed changes should be incorporated in the current overview for future discussions.
5. Ask for feedback in order to validate the new information.
6. Repeat the process until the overview seems complete enough. Check with the system architects the validity of the overview.

Common pitfalls:

- Information overload: When dealing with complex systems, is easy to become overloaded with information. In order to prevent it, no matter how interesting may the findings look like it is important to keep focus. On top, it is important not to be side-tracked or diverted from the goal: the architecture overview.

- Audience of the overview: The target audience of an architecture overview is a broad set of stakeholders; despite these differences the overview must be clear and easily accessible for the entire target audience. Therefore, the overview should be created with the cooperation at least of the system architects and chief engineers.
 - Scope and size: The overview should not be too simple or too specific; it needs to capture the essence of the system. The overview of a complex system cannot be done in just a single map or document. It should not be however so complex that only people whom made it (not even them) can understand it.
 - Expert's behaviour: IT should be noticed that when performing interviews: Experts do not really know what you want from them. They want to share present problems. They can easily talk about present implementation, but functions and architecture issues require deeper thinking. They may feel threatened by the purpose of the research.

3.2 Criteria for a Good Architecture Overview

The overview should provide insight of the system and its behaviour, enabling the architect to have a quick answer to questions like: "*what happens if component / function changes?*"

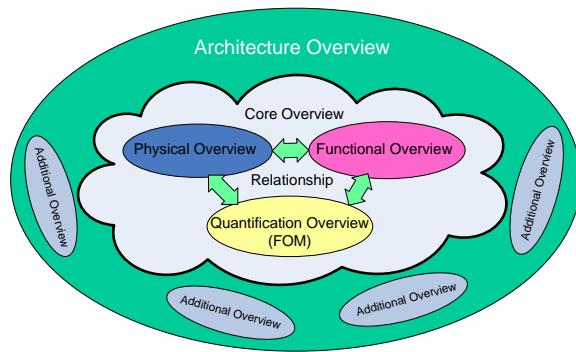


Figure 4 Architecture Overview Compositions

The physical overview of the system (*how is the component / subsystem accomplishing its function?*) is probably the easiest to create, as humans can easily deal with it, as is something tangible. The functional overview of the system (*what function must the subsystem / component perform to accomplish the goal?*) is more difficult to get, as people are not used to think in functions. The most difficult part to acquire is probably the quantification overview. The reason is that collecting all the precise numbers of the system is often an impossible task which would require huge amounts of time and resources. However, this is usually not necessary, as just approximations or rough estimations of the important parameters in form of figures of merit (FOM) are required for a good overview. These figures of merit could be provided for example by experts.

The overviews should not be isolated from each other, therefore, clear relationship among the overviews should be provided.

Additional overviews may be added to the architecture overview, to broaden the accuracy and utility of the overview, such as the environment, market, business and so on.

We recommend the following list as criteria for a good overview:

- Understandable for a broad set of heterogeneous stakeholders (customers, product managers, project managers, engineers et cetera).
 - accessible and actually read/seen by majority of the organization
 - addresses the key issues of the specific domain
 - satisfactory quality
 - acceptable
 - up-to-date and maintainable

The understandability is crucial; the challenge is to make it understandable for the wide variety of stakeholders. Note that security concerns sometimes conflict with the necessity for information sharing and open communication. The quality level is assessed by the stakeholders and by historical evaluation. One of the threats to quality is the acceptance. Also, an outdated architecture overview may become useless as it no longer represents the system. To be up-to-date and maintainable is mandatory for a good architecture overview.

4 GIVING ‘LIFE’ TO THE OVERVIEW

At this point we should be able to create good architectural overviews of complex systems. However, as stated before, is important to keep the overview up-to-date and maintainable. In addition, maybe the views are not appropriate or the preferences of the architects change over time. Each time a new visualization is required or a change is introduced, great work has to be conducted in order to create the new overview.

4.1 Approach to give ‘Life’ to the Overview

How to efficiently collect and store data for future use?

Creating tables

Step 1: Store the information collected in a database

Build tables: Components, Functions, Attributes, Dependencies, View, etc.

ID		SW	HW	Comm	...
1	Magnet		X	X	...
2	Field				...
3	Rf Signal	X		X	...
...

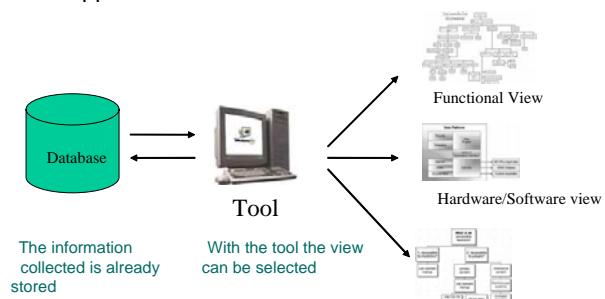
ID	ID1	Attribute	Value	SW	HW	Comm	...
1	1	Bo	1.5T		X		...
2	3	Bandwidth	1Mb	X	X	X	...
3							...
...

Storing data efficiently

Step 2: Building views/diagrams

Depending on the need, one view or another will be generated.

Tool support



- The tool should allow to visualize different views with the information available.
- The information will be available for future use (e.g. model the MR network)

Advantages:

- Automatic process to generate diagrams
- Easy to modify, add new data.

Disadvantages:

- Scope: Not too deep nor too high
- Time consuming:
 - **Filling the database**
 - **Learn to use the tool**
- The information may not be complete, can the tool still work with uncertain?

We recommend to get feedback on visualization and text from different potential readers. Not only listen to their immediate feedback, but also observe the impact on them:

- Did the reader understand the essence?
- Did text or visualizations suggest unexpected interpretations?

5 STUDY CASE: PHILIPS MRI SYSTEM ARCHITECTURE OVERVIEW

The present paper emerges from the Darwin project (Laar, America et al. 2007). This applied research project is currently conducted at Philips Medical Systems and focuses on the evolvability of software-intensive systems, with as use case Magnetic Resonance Imaging (MRI) systems.

Koninklijke Philips Electronics N.V. (Royal Philips Electronics N.V.), usually known as Philips, is one of the largest electronics companies in the world, founded and headquartered in the Netherlands. In 2006, its sales were €27 billion and it employed 121,700 people in more than 60 countries (Medical 2007).

Philips Medical Systems is a global leader in diagnostic imaging systems, healthcare information technology solutions, patient monitoring and cardiac devices. Philips also provides customer services such as financing, consultancy and maintenance & repair. Their product line includes technologies in X-ray, ultrasound, magnetic resonance, computed tomography, nuclear medicine, positron emission tomography, radiation oncology systems, patient monitoring, information management and resuscitation products.

Magnetic resonance imaging (MRI)

MRI is an imaging technique used primarily in medical settings to produce high-quality images of the inside of the human body. MRI is based on the principles of nuclear magnetic resonance (NMR).

An MRI scanner has a large electromagnet around a human-sized tube (bore) in which the patient or test subject lies. The electromagnet consists of coiled wires made of super-conductive material. The gradient coils are used to vary the strength of the main magnetic field. Radio frequency coils that transmit and receive radio signals are used in combination with the magnetic field to induce and measure a resonant field within the patient or test subject. The patient's protons align themselves in the same direction as the magnetic field applied by the scanner. Under the control of the operator, the radio frequency coils in the scanner emit short bursts of radio waves that cause the protons to re-align. When the radio waves and the protons vibrate at the same frequency, the protons absorb some of the radio wave energy. This is called resonance, and it is from this phenomenon that the term magnetic resonance is derived. Each time that the radio frequency coils are turned off, the protons go through a process of returning to their initial orientation. As the protons do so, they emit energy. This energy generates a voltage in a receiving wire antenna and is then converted into a digital signal that serves as the basis for MR images. Different tissues give off signals of different strength depending on their chemical composition and location (Hornak 2003).

MRI Architecture Overview

The MRI is based on several building blocks termed chains. A chain is a hierarchically organized, functional unit of the MRI system. It may consist of a number of hierarchically lower building blocks and has a unique name and description with a tree structure. The MRI system consists of the following building blocks (chains);

- Magnet: Provides a constant homogeneous electromagnetic field.
- Radio frequency system (RF): Induces and measures a resonant field in the patient's body in combination with the main magnetic field.
- Gradient (GRAD): Varies the strength of the main magnetic field at specific locations.
- Control Data and Acquisition System (DAS): Acquisition and control of scan data in cooperation with the reconstructor.
- Patient support (handling & administration): Patient positioning, observation, monitoring and data collection.

Applying the case study research approach, we have conducted a case study to collect, analyze and interpret large amounts of data in an exploratory manner. The study has been conducted in cooperation with the Product Group MR of Philips Medical Systems Nederland B.V. We have obtained first-hand information on the system architecture by collecting company documents

covering topics such as system requirements and specification, supported configurations, building block architecture, system architecture and so on. In addition, we collected information through interviews with key personnel in the organization. We have conducted a number of interviews with system architects, system designers and engineers. The interviewees were selected according to their experience and field of work. Information collection took approximately four months and the interviews were held at Philips Medical Systems. Prior to the interviews, an introductory text was sent to the interviewees to explain the reason and topic of the interview. The introductory text also allowed the interviewees to prepare themselves (e.g. to collect the architectural overviews to be shown during the interviews). Only individuals were interviewed to increase the possibility for having in-depth discussions and ensuring that the interviewee could speak freely. Minimally guiding the interviewee often resulted in less biased information. It is for this reason that we think the interviewee should elaborate as much as possible by asking him (the study included only men) open instead of closed questions. To complete the study, we have surveyed the document archive. This was especially useful to verify if the general structure of the system concurs with the documentation hierarchy and vice versa. In addition, comparing the collected documents with the results of the interviews provided insight into the quality and consistency of the information obtained. The final outcome was validated by the system architect.

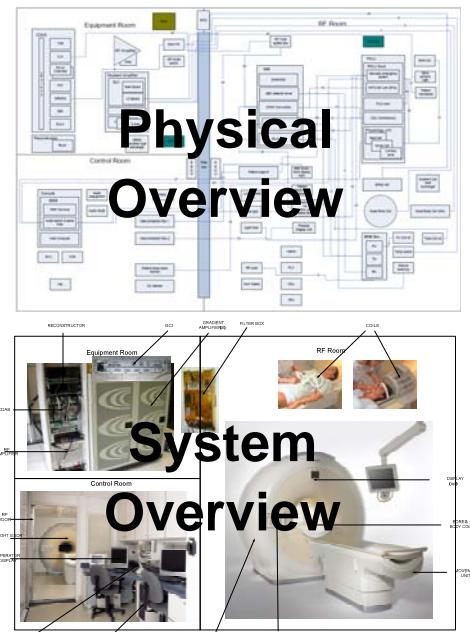
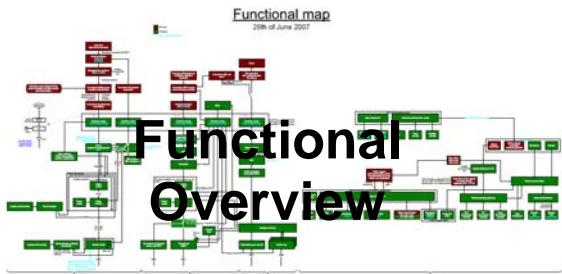


Figure 5 MRI overviews examples

As shown in Figure 5, we have created several overviews and several documents describing the MRI system architecture. This architecture overview has proven to be useful as a tool for communication and discussion among different people with different backgrounds and further research. We aim that the architecture overview will support the designers and system architects in their work, and to enable better communication among experts and decision-makers.

6 CONCLUSIONS

7 SUMMARY

8 ACKNOWLEDGMENTS

9 REFERENCES