

System and Context Modeling; Visualizations of Where, When, and How¹

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Abstract. Modeling of systems and their context is done to support communication with stakeholders, to facilitate reasoning about system requirements and design, to support decision making, and in general to create and maintain understanding, insight, and overview. One of the challenges in modeling is to find appropriate representations that are understandable for relevant stakeholders and that contain sufficient information.

In this paper, we discuss how to visualize space, time and process flow of systems, both internal as well as in their context. We argue that visualizations must connect to the stakeholders' world. We observe that architects tend to create abstract diagrams, alienating their stakeholders by abstraction, the use of jargon, and the presence of lots of (irrelevant) details.

We will illustrate the visualization techniques with some models made as part of the Darwin project. The Darwin project researches evolvability of systems and architectures, using Magnetic Resonance Imaging scanners at Philips Healthcare as case.

Introduction

The IEEE 1471 standard [IEEE1471 2000, Hilliard 2001] introduces the notion that architecture descriptions consists of models. Models capture one or more specific views. A viewpoint is the combination of stakeholder and a specific concern. Following this line of reasoning many models are needed to create an architecture description. Standards such as DoDAF [DoDAF 2003] provide many predefined views.

Currently the term model is also fashionable as means to streamline the engineering process. *Model-Based Design* [MathWorks 2009], *Model Driven Architecture* [OMG 2009], or *Model Driven Engineering* are approaches where models are used to specify, but also to design and engineer. These approaches are propagated by commercial tool vendors, such as MathWorks and IBM. The tools support the creation and management of models. These models are also used to generate the final realization details, without further human intervention.

In this paper we discuss the use of models as a means of communication and discussion between stakeholders and as a means to reach design decisions that fit in the context and life cycle of the system-of-interest. These models follow the idea behind IEEE1471, where models relate to stakeholders and concerns. These models serve mostly to help human stakeholders to understand problem and solution space and to reason about choices.

The emphasis of this paper is on three basic visualizations: space (where), time (when), and process flow (how). Cernosek and Naiburg explain in [Cernosek 2004] that the value of modeling is to *better understand the situation*, to *craft a better system*, to *build and design a system architecture*, and to *create visualizations of the implementation*. We agree with these value propositions. However, we consider these value propositions too limited. Visualizations of system context, life cycle context, system characteristics, and architectural concepts are all powerful means to achieve the mentioned values. These same visualizations are also means to communicate with stakeholders, to share vision and direction, to reach decisions, to convince decision makers, to defuse politics, et cetera.

For all of these benefits the understandability and accessibility to a wide range of stakeholders is essential. Many formalized representations tend to fit the narrow group of stakeholders familiar with such formalism, but at the same time stakeholders with different backgrounds feel left out and ignore the, incomprehensible formalized diagrams. This effect occurs with any formalism, but today's fashion of UML and SysML [OMG 2008] is a typical example of representation loved by one group of experts and disliked by stakeholders from other disciplines. See also the brief section about SysML at the end of this paper.

We observed in a usability study of Systems Engineering techniques in the processing industry [Drotninghaug 2008] that simple spatial diagrams, time diagrams and process flows triggered most interaction, while more formal representation, such as IDEF0 [SofTech 1981] (see also <www.idef.com>), were much less appreciated. We have applied this insight in parts of the architecture description of Magnetic Resonance Imaging (MRI) scanners.

Research Methodology

The modeling and analysis methods and techniques are researched by applying the methods in the class room and in workshops in industrial practice. The students or industrial employees are guided through the modeling approach in 3 to 5 days. The author of this paper is the teacher or facilitator. The author also is observer and data collector, simultaneously with the facilitation in workshop or course. The main purpose in this phase of research is to collect case material and anecdotes about successes and failures.

This paper is using techniques based on the course *Modeling and Analysis*. The course *Modeling and Analysis*, taught at Buskerud University College [SEMA6201 2008], is a one week course followed by a ten week project. The master students have to model an actual system in its usage and life cycle contexts, in a group of 2 to 4 students. This actual system is preferably the system that they are working on in daily practice, with some actual challenging problem.

This paper is based on the 2007, 2008, and 2009 editions of this course and on workshops derived from this course in companies in healthcare systems, semiconductor equipment, food preparation systems, and in defense systems. From the more than 10 different cases and domains we use the MRI scanner case, used in the Darwin project [van de Laar 2007], as illustration for this paper on visualizing space, time and processing. So far about 30 students participated in the courses and about 70 industrial employees participated in workshops.

Case

This paper illustrates the modeling approach and especially the visualization of space, time and process flow by showing some project results of the Darwin project [Darwin 2009].

We research *evolvability* by means of the industry-as-laboratory [Potts 1993] approach in the Darwin project. Our laboratory is the development department of MRI scanners. Since 1981 Philips Healthcare develops and sells MRI scanners. In these decades a broad successful family of products has grown with many clinical applications.

The clinical market of MRI scanners is still evolving fast. Trends in healthcare require more integration in the hospital work flow. Technical innovations enable new applications: changes in base technology, such as computing and communication, are pushed forward by telecommunication and PC industry and are forced upon the MRI scanner engineers. Mergers and -acquisitions have grown the development into a large multi-site organization.



Figure 1. Achieva MRI scanner. (Photo courtesy Philips Healthcare)

The historic growth of the development organization has resulted in many specialized teams, covering many technologies. The integral understanding of the entire system is mostly embedded in the heads of a limited set of employees with a long history in the development of MRI scanners. The consequence is that most of the architectural rationale is implicit. One of the assertions of the Darwin project is that evolvability is supported by making the architectural rationale explicit, see [Muller 2008a].

Cost effectiveness is a big issue in Healthcare. For MRI scanners this translates to decreased examination times, while diagnostic quality should be high. Patient Handling is a significant contributor to examination time, as well as to diagnostic quality. For example, the operator has to place an receive coil at the right position on the patient. Positioning the receive coil takes significant time, while poor positioning degrades image quality and hence diagnostic quality.

Part of the Darwin project looked at patient handling and modeled patient handling related issues during a set of workshops We customized the above mentioned Modeling and Analysis course into three workshops with 10 participants from industry and 5 researchers. During the workshop four different cases were modeled. We use patient handling as case in this paper, based on work of two of the workshop teams.

Modeling approach.

Figure 2 shows the objectives of modeling as taught in the course and the principles underlying the course(for all course material see [SEMA 2009]). The main objectives of modeling a system and its context are:

- to support communication with stakeholders
- to facilitate reasoning about choices in problem space and solution space
- to support decision making
- to create and to maintain understanding, insight and overview

All of these objectives belong to the core of systems architecting and address problems occurring everywhere in engineering projects of complex systems. We apply a number of principles throughout the course:

- use feedback (a very common principle in many engineered systems, but also very common in biological systems!)
- incremental and evolutionary way of working (see the book by Gilb about incremental and evolutionary methods [Gilb 2005])
- be explicit, and make issues tangible

In complex projects stakeholders and engineers sometimes use the complexity as an argument to stay vague and to ignore potential problems too long. This tendency camouflages problems and limits the insight. The principles *be explicit* and *make issues tangible* are countermeasures for this behavior. The modeling approach offers means to be more explicit and to make issues more tangible.

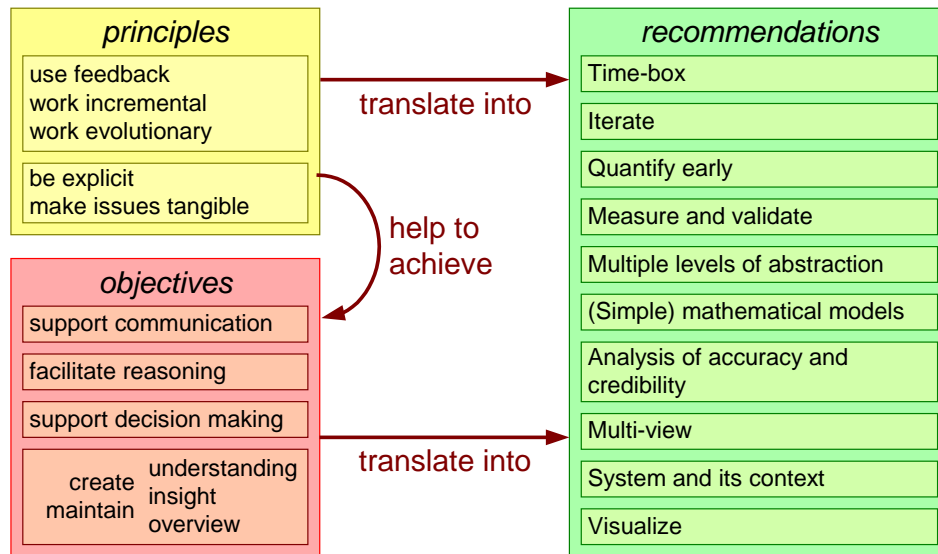


Figure 2. Guidelines from the course System Modeling and Analysis, showing the objectives, the underlying principles, and the derived recommendations for the modeling approach.

The objectives of modeling and the underlying principles are translated into 10 recommendations at the right hand side of Figure 2. In this paper we zoom in on *visualization* of space, time and processing. However, the success of the approach itself requires the combined application of all recommendations. In [Muller 2008b] the approach is described in detail, including the other recommendations.

Space, Time, and Process flow

Space and *time* are dimensions that all stakeholders use in their daily life. We are quite used to look at spatial representations, for example maps, blueprints of buildings, or 2D and 3D Computer Aided Design (CAD) drawings. All of these representations are very intuitive and every stakeholder can point to them when discussing issues, e.g. the operator has to be at these seven different locations to perform one examination.

The *time* dimension is also quite natural to us. Although the visualization is somewhat more diverse, for example timing diagrams in electronics, graphs showing properties as function of time, schedules as PERT-plan or MS project-like, et cetera. Most time representation use the horizontal axis for time: left is past, right is future. Normally, the horizontal axis is linear, 1cm on paper represents a fixed amount of time, e.g. 1 hour. Some of the vertical time-related diagrams, such as activity diagrams, miss the absolute time dimension: these diagrams show the order and relations without duration.

The third representation that we discuss is the process flow: *how* does it work? This aspect is quite natural for humans, but at the same time the terms and representations we use show a very wide variation. Terms like *function*, *process*, *task*, *transaction*, or *sequence*, appear to be highly context sensitive. Nevertheless, most people start to draw and explain, when they are challenged to tell *how* it works. Note that *it* can be the clinical examination, as well as the generation of, for example, magnetic gradient fields. In general we are looking for a description with mainly verbs and some subjects, e.g. “fetch the patient” or “calculate set points”.

We have observed in the courses and workshops that visualizations of *space*, *time*, and *process flow* are shared by many stakeholders. At the same time these visualizations provide a first insight in the problem and solution space. Note that we need many more visualizations to describe and discuss actual architectures. Our assertion is that these three types of visualizations form a good foundation for communication and for other representations.

These three representations are related. Many steps in the process flow happen somewhere, sometime. When stakeholders explain the process flow they tend to point at space or time diagrams and vice versa.

Scale

The space and time diagrams are meaningful at many different scales. When we zoom in we can make diagrams at milli, micro or nano scale, while zooming out we can make diagrams at kilo or mega scale. At specific scale levels we have to highlight specific facts. We can compare this with geographic maps. Detailed maps of 1:25000, as used by hikers, show details of foot path and terrain, while maps of countries or continents show main cities, and large structures as rivers and motorways.

The process flow also looks different at different scales, but we cannot relate a unit like second or meter to the scale. Nevertheless we can zoom in and zoom out orders of magnitude at the process flow. If we zoom out quite far, then we discuss the macroscopic healthcare flow in society, while we can zoom in to small details and discuss how the spins of protons are precessing in the magnetic field of an MRI scanner.

The understanding of a system in its contexts requires many space, time, and process flow diagrams at different scales. The system designer has to zoom in and to zoom out to get an understanding of the system.

Scenario

It is often difficult to make generic drawings at an absolute scale. The exact sizes (or times) depend on the actual instance in an actual situation. We recommend to make drawings for one specific instance of the system in one specific situation, a so-called scenario. The scenario can be fictional. In this paper we use the MRI examination of patient George with constant headache as scenario. Our experience is that real systems in real situations are quite similar to the chosen scenario; real systems and situations are variations on a theme.

Case results

MRI introduction

The core of Magnetic Resonance Imaging is the physics of imaging. The spins of Hydrogen nuclei, protons, in the human body precess with the so-called resonance frequency, which is

proportional to the magnetic field strength. Typical field strengths today are 1.5 or 3Tesla. The spatial information needed for imaging is introduced by generating gradient fields: magnetic fields that are proportional to the position in x, y, and z-directions. The spins can be “excited” by Radio Frequency (RF) fields at the resonance frequency. Once excited the spins align themselves again with the magnetic field. During this alignment small RF pulses are emitted, at the same resonance frequency, and received by RF receive coils.

Figure 3 shows at the right hand-side the core elements, as discussed above, of MRI scanners: Magnet, Gradient coils, RF transmit coils and RF receive coils. These core components are connected to a chain of electronic circuits to generate and receive the magnetic and RF fields. A typical chain starts with software generating set points for the electronics, digital electronics to communicate and synchronize, analog electronics to actually generate and shape the desired current or voltage with the appropriate frequency and phase, and amplifiers to achieve the desired power level. This entire chain is represented in Figure 3 as the block “generate B_0 , G_x , G_y , G_z , B_1 ” and the block “receive RF”.

There is a significant number of transformations happening to get from the clinical user interface to the set point generation described before. Clinical users have to determine the region of interest and the required contrast. In several steps an extensive software system converts these clinical needs into controls that make sense for the hardware.

The signals as received by the RF receive coils also go through extensive software functions where spatial images are reconstructed. These images are viewed by human operators to use them for navigation, diagnosis, or treatment.

Figure 3 has been created to explain MRI scanners in a nutshell, this is not a diagram that has been made for use in the architecture description.

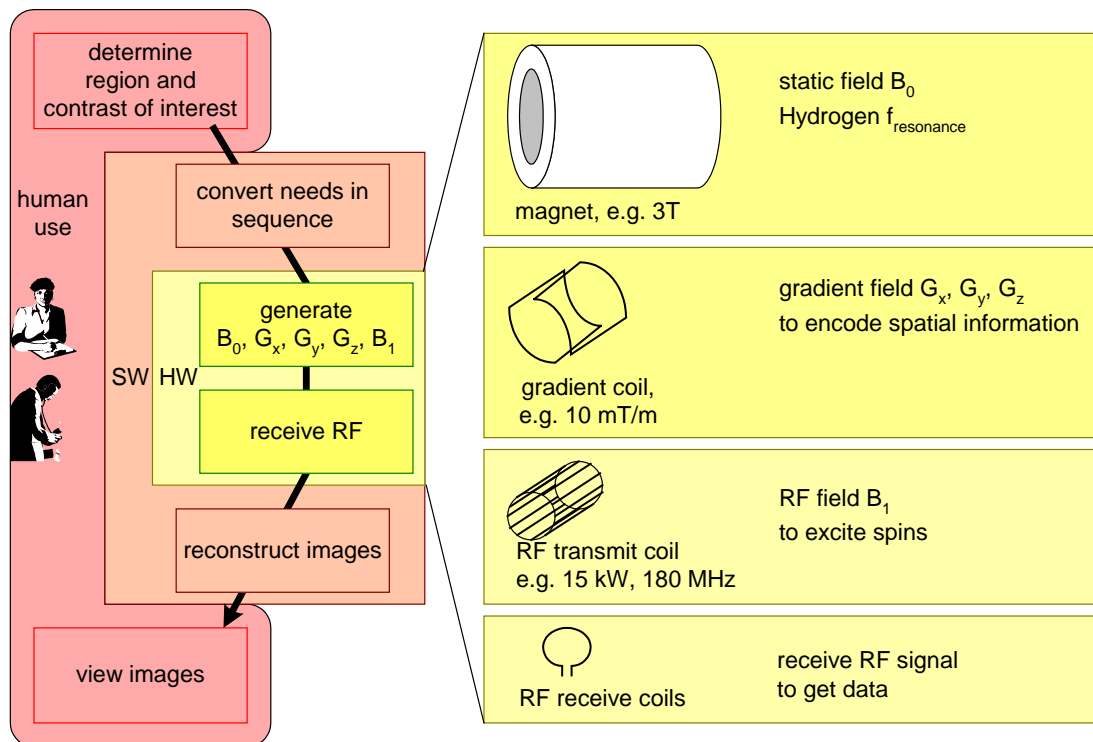


Figure 3. Basic MR process flow and the related core components.

The actual imaging process consists of repeating a basic sequence many times. Every sequence is slightly varied to encode different spatial information. Figure 4 shows the repetition of such sequence at the top of the figure; in this particular example the sequence is repeated with 128 different values for the y-gradient. Figure 4 also enlarges one instance of the basic sequence. This instance shows the waveforms for the RF generation, the gradient generation and the typical received RF signal, the so-called echo.

Note that Figure 4 shows one example of a basic sequence, a so-called Field Echo. MRI scanners offer many variants of such basic sequence, which all give specific types of imaging information. The benefit of MRI as imaging modality is that many different clinical interesting aspects can be imaged: density and contrast dependent on the chemical composition and context, and physiological data, such as flow, and temperature. The type of imaging information depends amongst others on the echo time (TE), the repetition time (TR), and the strength of the transmit pulse.

Both Figure 3 and 4 provide some typical numbers for MRI scanners, such as gradient field strength, RF transmission power, magnetic field strength which relates directly to the RF frequency, and TE and TR times.

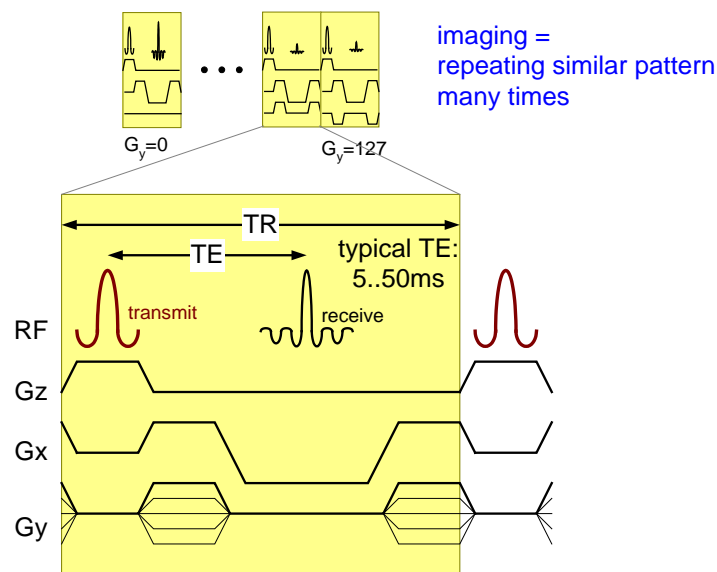


Figure 4. Elementary MR sequence that is repeated a few hundred times with minor variations of the gradient fields.

Neuro Scenario

We have selected a very common situation for MRI examinations: a patient with persistent headache. MRI is quite often used in a wide variation of neurology problems, because of its diagnostic capabilities.

The scenario of our fictional patient George is:

- Patient George has continuous headaches.
- His family doctor has sent him to a referring physician, in this case the neurologist.
- The neurologist wants to exclude the possibility of a tumor and requests an MRI

examination.

- George's head is imaged at the MRI scanner.
- The radiologists does not see any indication of a tumor.
- The radiologist sends his report to the Neurologist.
- The neurologist discusses his findings with patient George and sends a report to the family doctor.

This scenario is visualized in Figure 5. Note that it is quite common that the patient never sees the radiologist who actually does the diagnosis from the MRI images. Note also that this figure gives a reasonable insight in the stakeholders that are involved in MRI examinations.

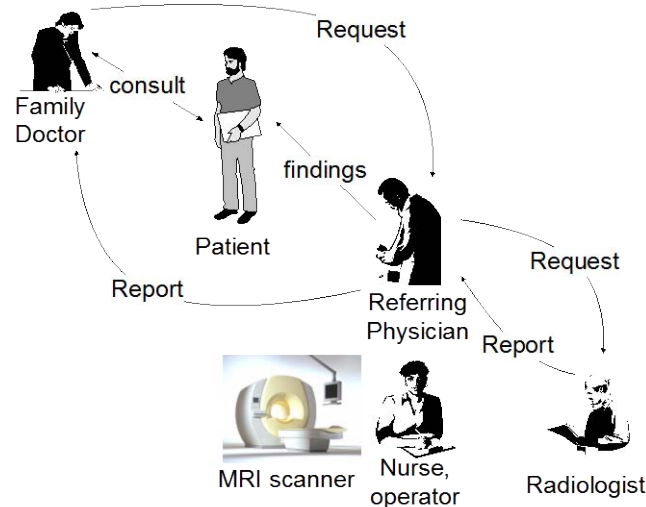


Figure 5. Visualization of the neuro scenario and the involved stakeholders.

Space, Time, and Flow Diagrams

The scenario of patient George can be visualized on a time-line. Figure 6 shows the time-line on scale of days. This figure also shows a functional or process flow. At this scale process steps tend to cluster in groups, with typical waiting times between the cluster. In this example we see a typical waiting time before a patient can see the specialist, a typical waiting time before a MRI examination can take place, and a typical waiting time before the results are told to the patient.

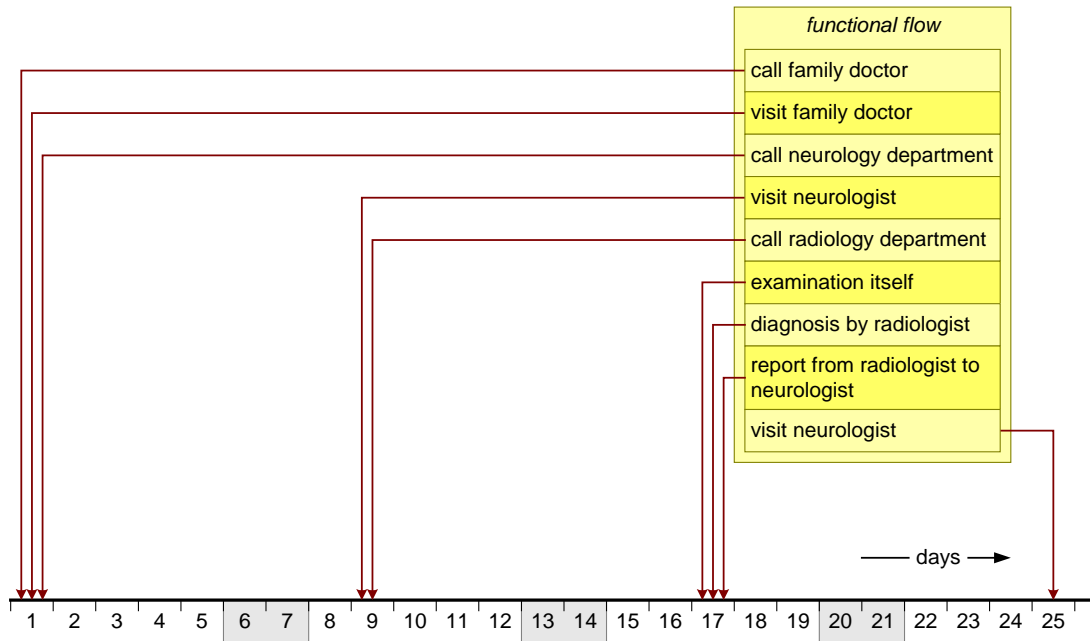


Figure 6. The neuro scenario of patient George shown as functional flow and mapped on a time-line.

Figure 7 shows a typical layout around a MRI scanner. This is a spatial diagram at meter scale. The figure also shows the preparation work flow. The layout of the MRI scanner is overlaid with the positions where the work flow steps take place. These types of overlay often create discussion and insight.

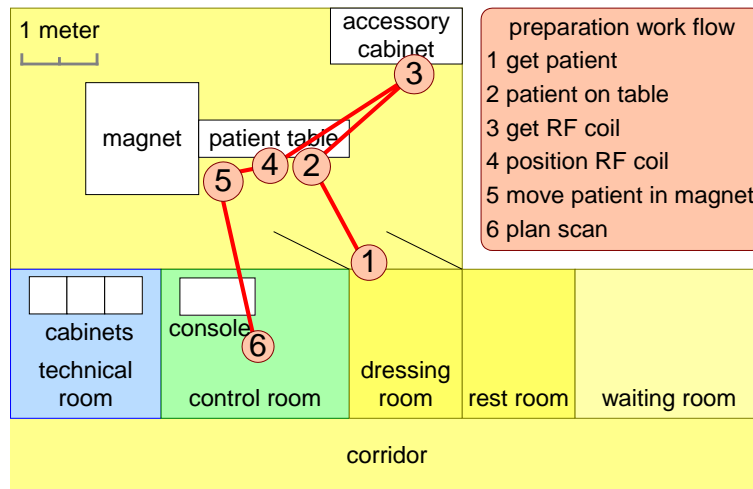


Figure 7. Layout of rooms related to MRI scanner, related to the preparation work flow.

We can zoom in further on the time-line at examination level, see Figure 8, where about half an hour is the time scale. This figure shows that from George's perspective the examination takes half an hour. About 15 minutes are actually spent in the examination room. The actual imaging time is again half of that, about 7 minutes.

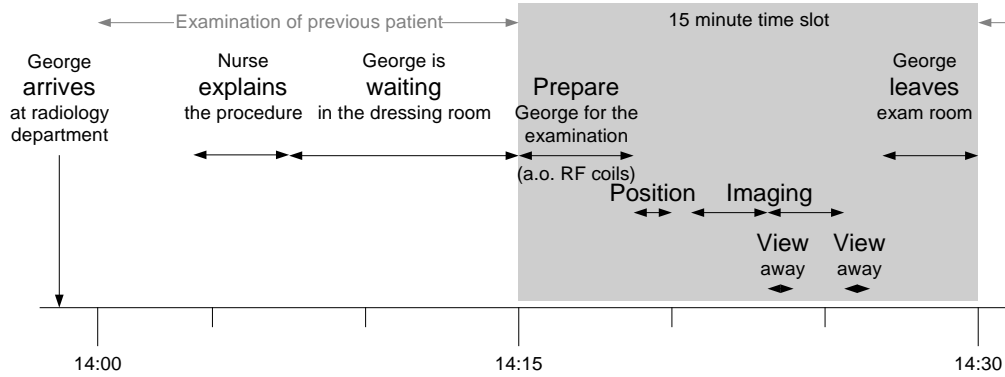


Figure 8. Time-line of the examination of a single patient

The tendency in specification discussions is to focus on the imaging functionality and performance. However, the time-line of the examination shows that patient handling and preparation are significant contributors to the time that the examination room is occupied. In Figure 9 we again zoom in further on the functional procedure of the patient preparation. The time scale here is about 5 minutes. Note that in the time-line few activities appear that were not yet part of the procedure, but that can be observed in the examination room in practice: talking and walking. Talking is essential to keep the patient well-informed and comfortable. Walking is simply required due to the geographical layout.

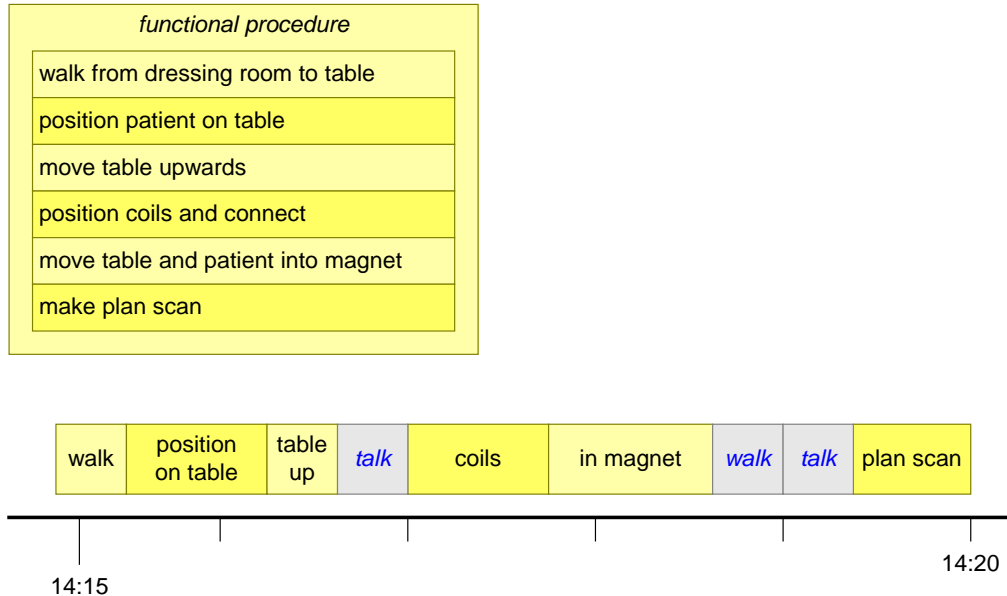


Figure 9. Functional procedure and time-line of the patient handling preparation phase of an MRI examination.

We can search for ways to decrease the preparation time, once we have the more detailed time-line of the preparation. Figure 10 is an annotated version of Figure 9, where potential throughput improvements are shown.

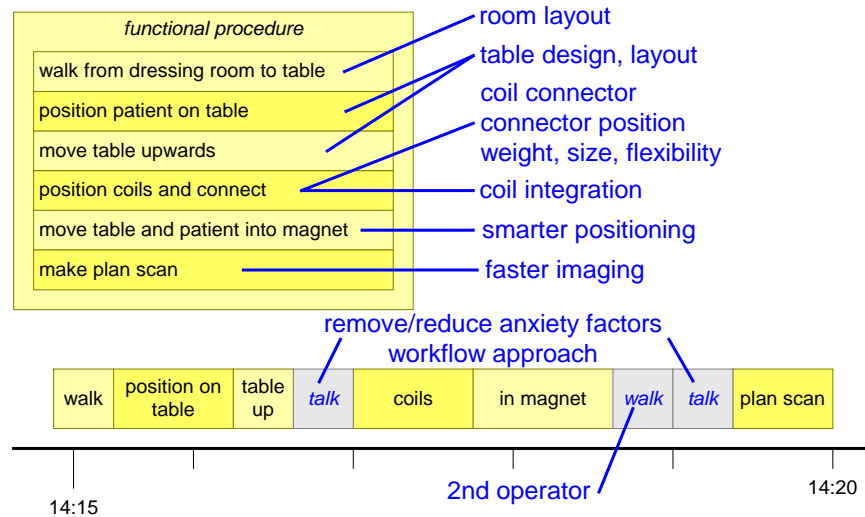


Figure 10. Annotation of procedure and time-line with possibilities to speed up the patient handling preparation phase of an MRI examination.

One of the improvements is faster imaging. Faster imaging will not only improve the plan scan as part of the preparation, but it will also shorten the actual imaging time. For illustration purposes we zoom in further on the imaging sequence. Figure 11 shows the tens of millisecond time scale of the sequence annotated with performance improvements that would help to make imaging faster. Note that in practice these particular relations are so essential to MRI designers that drawing this figure does not bring much value to them.

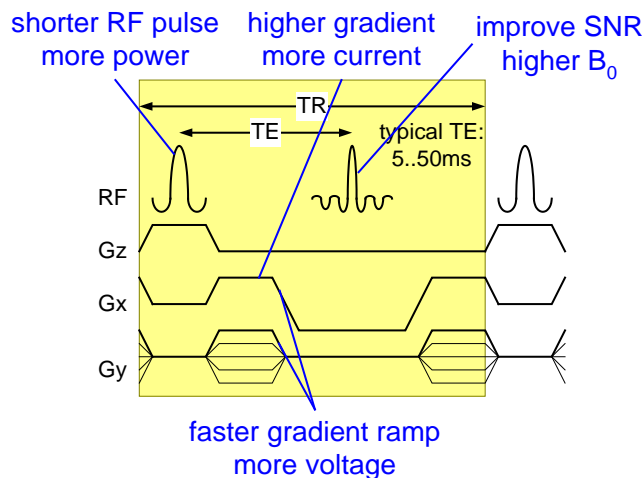


Figure 11. Decreasing imaging time can be achieved in many ways. Annotation of the scan sequence with characteristics of MRI core components that impact scan time.

SysML

The immediate question posed by systems engineers when showing these kinds of visual models is: Why not use SysML? SysML offers a number of representations to capture structure, behavior, and more system aspects. The weakness of the SysML representations is that the more abstract representations do not connect well with the mental models of many stakeholders. For example, in the defining standard of SysML [OMG 2008, Figures 7.3 and 8.8 at pages 28, and 52] two examples are given: car driving performance and a block diagram of a wheel of a car (see Figure 12). Imagine that you discuss these figures with a car mechanic, a car salesman or industrial designer to see how these kind of figures connect with stakeholders from other disciplines. If an annotated 3D model of a wheel would be used, these stakeholders would immediately connect.

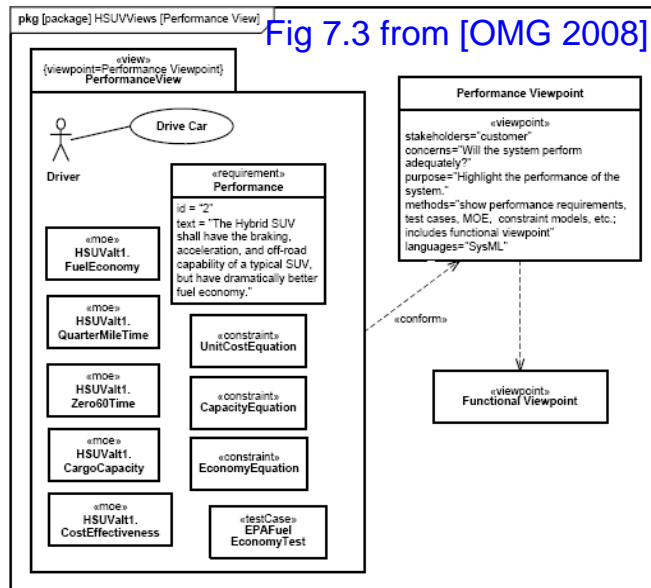


Figure 7.3 - View/Viewpoint example

NOTE: moe refers to Measure of Effectiveness (see Annex C.3.2)

Car performance diagram

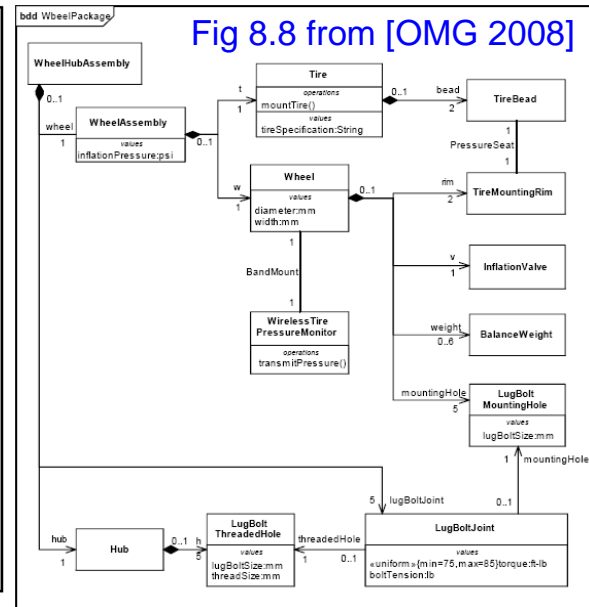


Figure 8.8 - Block diagram for the Wheel Package

Wheel Package

Figure 12. Examples from SysML documentation [OMG 2008].

Future Work

In this paper we provided one case study and we focused on time, space, and flow. We are working on the consolidation of other case studies and we will use these to report on the other recommendations for modeling and analysis, such as the use of other views, visualization, time-boxing, iterations et cetera.

In the longer term the challenge is to move from observational research to a more theoretical foundation: what are modeling prerequisites, what are (well-founded) guidelines for modeling, what is the value of modeling? Especially challenging is the validation, since many soft factors impact the modeling outcome. A separate branch of research has to address methodological

issues in researching and validating this combination of hard engineering and soft sciences.

Summary and Conclusion

Figure 13 shows how some of the MRI specific key drivers relate to design choices. The space visualizations, the time-lines and the process flows at the different scales help to understand these relationships.

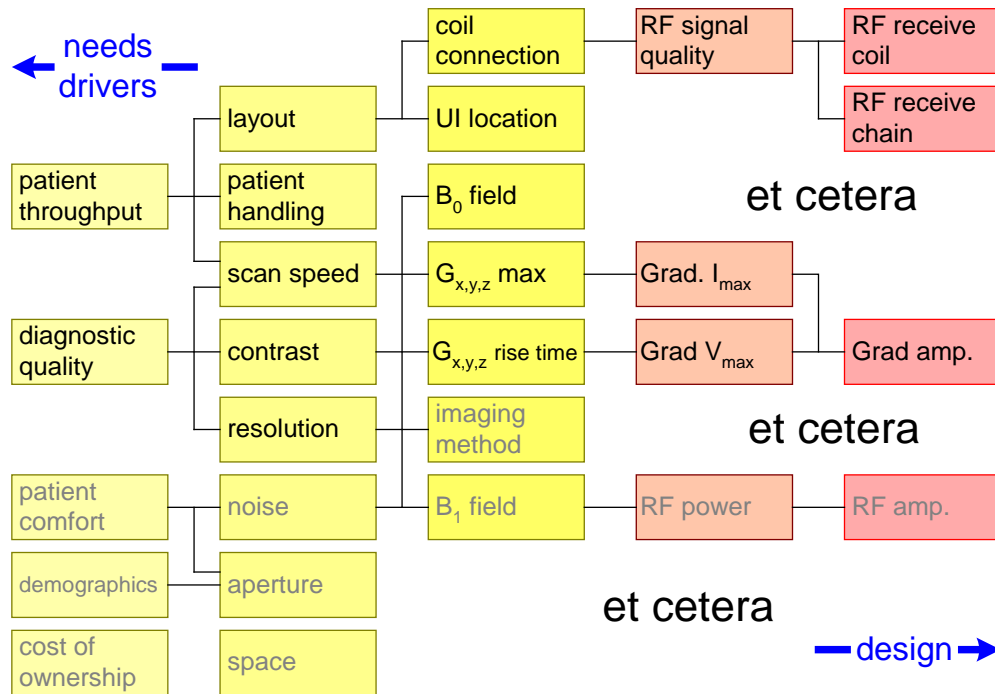


Figure 13. Part of the key driver graph of MRI scanners, showing relations between customer needs and design options.

We conclude that time, space, and flow diagrams, are complementary, close to human (stakeholder) experience, and insightful, as shown by Figures 7 and 9. Figures 4, 6, 8, and 9 show timing examples at different time scales, from days down to milliseconds, illustrating that meaningful time diagrams can be made on a broad range of scales. Similarly useful spatial diagrams can be made at many different scales. Finally, the use of the neuro scenario, Figure 5, helped us to make time and place sequences specific.

Acknowledgements

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Author Biography



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Gerrit Muller received his Master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as a manager of systems engineering, returning to Philips (Research) in 1999. Since 2003 he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008 he became a full professor of systems engineering at Buskerud University College in Kongsberg, Norway.

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