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Structured workflow approach to support evolvability

Thom J. van Beek *, Tetsuo Tomiyama

Department of Mechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands

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ABSTRACT

This work aims at explicitly modelling key concepts of the evolution process to support the product development process of complex multi-disciplinary systems such as Magnetic Resonance Imaging (MRI) systems. The key concepts span over different domains of the product development process: product use (workflow models), system functionality (Function–Behaviour–State modelling), component interfaces (Design Structure Matrix and Interface model) and the organisational view (stakeholder analysis). By having an explicit view on these domains, effectiveness of change management is improved by showing how changes in one domain propagate to other domains. The focus on simplicity of the models and human understandable language is essential to ensure understanding by all (non-engineering) stakeholders such as nurses and physicians from the start of the evolution process. From these models a modularisation of the system can be extracted. The modularisation separates closely connected elements and thereby reduces the risk of unknown future changes having a high impact. The method is illustrated using a real industrial example, namely, the development of a product that facilitates intra-operative MRI.

1. Introduction

The complexity of systems has been discussed extensively in literature [1–5] and can be split up into the complexity of the system and the complexity of the design process. Not only are systems increasing in size (i.e. number of parts, lines of code, integrated functionalities), but the developing organisations are becoming larger, geographically scattered and more multi-disciplinary. Both the system and the design process sides of complexity should be properly addressed in attempting to create a complex system that needs to adapt to changing requirements.

A new generation of contemporary complex systems (such as Magnetic Resonance Imaging (MRI) systems) cannot be designed from scratch. The time and investment required for a completely new design would exceed the available time to market and expected profits [6]. The design process for complex systems usually begins with existing systems and can be characterised as a re-design process. There is a paradox in choosing a re-design over a completely new design in order to reduce complexity, because by doing so a different kind of complexity is introduced in the form of managing changes.

This work looks at the MRI patient handling system as an example of a complex system re-design. The complexity of the MRI system can be characterised by the eight million lines of code, three Tesla helium cooled superconductive magnet, and a geographically distributed multi-disciplinary development team. Additionally its applications are all in the medical domain where the end-users are physicians, nurses and other medical experts with limited time for non-medical activities and can only be exposed to a basic form of technical information while communicating about the design. Conversely product development engineers have difficulties in accessing real experiences during MRI operations. These stakeholder aspects increase the complexity of the MRI development process.

One of the key features of complexity management is change management [7]. Changes to the MRI system design are driven by amended medical domain user requirements, technological advancements resulting from research and development activities, and the new (medical) devices that have to be connected. Rowe et al. [8,9] recognised that changes in these three aspects are the key concepts driving system evolvability which they define as the ability of a system to adapt to, or cope with change in requirements, environment and implementation technologies [8]. Rowe et al. do not explicitly discuss what is regarded as part of the 'system' in their definition. However in this work, system evolution explicitly covers the combination of the system design and designers. Here the task of the MRI design team is to translate the changes currently requested into a new system with minimal impact and costs, while safeguarding the long term system evolvability. The strategy followed by designers to implement any changes should therefore be one of 'least regret'. When evolvability is not safeguarded during

* Corresponding author. Tel.: +31 648254856.
E-mail addresses: thomvanbeek@gmail.com (T.J. van Beek), t.tomiyama@tudelft.nl (T. Tomiyama).

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the design process, incorporating unknown future changes could be troublesome or even impossible.

The most difficult future changes to accommodate for and to minimise the impact of are the unknown future changes. These changes cannot be fully predicted; what can be predicted for unknown future changes are the aspects or domains of the design that they will affect. Rowe et al. [9] show that the changes driving evolution affect four aspects; stakeholder needs, environment, implementation technologies, and requirements. Changes in these four aspects result in changes in system such as; user workflow, functions, behaviour, entities, and involved stakeholders. Although complete preparation for unknown future changes is impossible, designers can prepare by modelling the aspects of systems in which changes typically occur.

A system is defined as a set of interrelated, interdependent elements that form a complex whole. Typically, changes in an element have the highest impact on the element itself and the immediate surrounding interrelated elements. This is how changes propagate through a system [7] similar to an attenuating ring-wave travelling on water. The further elements are positioned from the source element that is changed, the lower the 'amplitude' of the impact. To minimise the impact of changes their propagation should be restricted as much as possible. A 'least regret strategy' therefore boils down to ensuring the impact of unknown future changes on the system remain local.

A least regret strategy is believed to benefit from a modular system in which closely interrelated elements are grouped together in such a way that unknown future changes in any of these elements will only have a local effect with minimal impact. Therefore, in order to implement a 'least regret strategy', this work follows two thoughts. First emphasis should be placed on the modelling of different system aspects that are likely to be subject to unknown future changes and the interrelationships amongst these aspects. This modelling is done to create a common stakeholder understanding and the alignment of stakeholder expectations. Secondly, loosely connected sub-systems should be separated to reduce the risk of future changes having a costly global impact on the whole system.

This paper hypothesizes that a common stakeholder understanding and an explicit relationship between requirement changes and system aspect changes can be articulated by an interlinked set of simple, easy to produce, domain-independent models.

The proposed set of models in this work focus on the early phases of development and can be used without prior training by all relevant stakeholders. The proposed set of modelling aspects are:

1. User workflow flowchart models.
2. A system functionality tree graph.
3. A graph of system entities and behaviours.
4. A system matrix representation of entity are interrelation ships.
5. A graph representation of the impact of the proposed changed system design compared to the existing system design.

The method presented here to capture the high level of abstraction user needs and system functionality uses workflow models connected to function models. Connecting the function models to interface models is necessary in order to relate the high level models to the implementation level models.

Following this introduction, a brief overview of the related work and background from literature is presented. Section 3 will explain the structured workflow approach in more detail and Section 4 presents a real industrial example where the method was applied in the development of an intra-operative magnetic resonance imaging system. Sections 5 and 6 discuss the results and conclude this paper respectively.

2. Related work and background

2.1. Understanding evolution

The evolution of an engineered system is defined here as: changes to a system at design time as a result of changed requirements. In literature evolution and evolvability of engineered systems is often defined as a system property. An engineered system however rarely evolves by itself as Kauffman points out [10]. Therefore the ability to evolve a system and to adapt it to changing requirements from one release of the system to the next is a skill of the system designers. This system development is based on the existing system, the design team experience, and the analysis performed by the system designers regarding other phases of the system's lifecycle. It is during design time that the real changes are incorporated, a new generation of the system is created, and the behaviour of the system during its entire life is determined. Therefore the method presented in this work specifically targets the design process during design time even though this may cause confusion when design- and run-time coincide (e.g. regular software updates during the life of a product).

Run-time changes to systems do exist. In some cases systems adapt to a changing environment at run time automatically. This ability is defined by Chmarra et al. as adaptability [11]. Compared to evolution however, adaptability can be seen as deterministic. The designers and developers have determined how the system will react to inputs beforehand at design time. Therefore adaptability itself is not regarded here as evolvability, but rather as a system property.

2.1.1. Biological evolution

The term evolution is well-known in the field of biology and was proposed by Wallace and Darwin [12,13]. An analogy of engineered systems with biological evolution is useful when trying to understand the evolution process. Probably the most famous catch phrase from biological evolution is 'survival of the fittest'. Biological systems display a need to survive. Whether or not a biological system survives over time is not a local optimum (e.g. the life of one man), but seems to be a global optimum of survival of the species (e.g. a parent sacrificing his/her own life to save the life of his/her child). Therefore evolution should be regarded as a long term, cyclic process across generations. The same holds for engineered systems.

Long term system survival is determined by how well the system adapts to its changing environment. If one species can cope better with threats and opportunities from its surrounding environment, then that species is more likely to survive. It will be the fittest. Examples of environmental influences in engineered systems are: the market, user needs, connected systems, competitors and technological advancements. The combination of system design and system designer that copes best to these adapting environmental influences is most likely to survive. For the system designers a rigorous understanding of the environment is therefore crucial in the evolution process. To improve the understanding of the system and environment this work addresses the modelling of the intended workflow of a newly evolved system in combination with its environment.

In biological evolution the terms nature and nurture are distinguished. Taking a human life as an example, when it is conceived (comparable with design time of a system), the genes of the new life are formed by a combination of the genes of both parents. This is referred to as nature or acquired character and is a discrete process in the lifecycle as the DNA will not change during the lifetime (run-time of a system) of the human. However, the environmental influences that this person encounters do cause changes to the