Abstracting Complexity for Design Planning

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Abstract: This short paper is based on research carried out during an eight month case study at a large UK aerospace company. The focus of the study was to develop a more effective technique for planning the complex design processes found in the company, in order to support the development of more detailed and more accurate schedules. The paper outlines some key findings of this research, concluding with an important challenge for future work: once an appropriate level of abstraction has been identified for modelling complex design plans, how can the distributed, subjective planning knowledge be synthesized to form a coherent perspective?

Keywords: complexity, planning.

Introduction

The design of complex products such as jet engines or helicopters requires the co-ordination of hundreds or even thousands of individuals performing tasks which span disciplines, companies, and locations. These tasks form an evolving network of interrelated activities; a network which companies strive to understand in their efforts to meet the increasingly tight time, budget and quality constraints placed on their design processes. Planning methods currently available to industry are ill-equipped to cope with the complexity and unpredictability of engineering design; as a result, design managers are forced to make decisions based on a limited overview of the development process. Additionally, although increasing pressure is placed on design managers to assess process risk in addition to product risk, this can be a difficult task without a coherent understanding of the plan of work.

This paper describes design planning as a complex process and outlines the author's approach to supporting industrial practice through plan modelling. Iteration is briefly described as the key driver of uncertainty in these models.

Complexity in planning

A plan may be viewed as a framework for reaching process goals, usually displaying both descriptive and prescriptive aspects: descriptive, due its use in predicting such quantities as programme cost, delivery dates or resourcing requirements; and prescriptive, due to its use in setting and communicating deadlines and deliverables. The ideal plan, as sometimes envisaged by design managers, would take the form of a simple model which determined the company's collective behaviour with regards to the context of the design process. As the process unfolded, the plan would be continuously modified to remain effective and up-to-date.

A more realistic picture of planning in industry is provided by Eckert *et al* [1], who carried out empirical studies in a number of design companies. They describe how many planning documents were used in parallel, and how these representations took on a variety of forms - including individuals' activity checklists, the ubiquitous Gantt charts, and even bills of materials. The information content of these documents was found to exhibit high overlap and a low degree of coherence. Eckert concluded that global consistency in planning is achieved through an ongoing process in which many individuals reason about and maintain overlapping sets of representations, and that the corresponding lack of overview led to avoidable mistakes and inefficiencies. In reality, then, the information captured in a document such as a Gantt chart is a model or abstraction of the planning knowledge which is in turn distributed amongst the individuals who use and maintain it. Such knowledge is often subjective, partly tacit and thus difficult to elicit. In summary, the planning process exhibits substantial complexity in its own right; complexity which builds on that of the design process it aims to describe and control. To be useful in industry, supporting techniques should provide an appropriate abstraction of the design process in order to provide the overview required for effective planning, while remaining simple and flexible enough for application in a broad range of situations.

Improving planning practice

A number of approaches have been proposed to improve design planning, most of which have had limited industrial impact. Several of these approaches use simulation techniques to derive plans from models which capture possible routes through the design process; such plans may then be optimized with respect to variables captured within the underlying process model. These results can be difficult to verify as they depend, among other factors, on the simulation achieving an accurate reflection of the possible population of processes.

An alternative approach, taken by this work, is to model plans directly - in other words, to provide a representation which allows engineers to describe their existing plans in a more coherent and accessible form than is currently possible. A variation on the 'Signposting' framework [2] has been developed, using a simple graphical format to capture plans which are valid only within a certain, well-defined range of scenarios. Plans are described in terms of tasks and their input/output data, together with resource requirements and uncertainty information. The method makes use of a novel approach to modelling iteration and uses simulation to resolve the resulting networks into the familiar, linear Gantt chart format. In the example case study, this planning methodology allowed schedules of previously unattainable detail to be developed through an iterative process of critique and refinement.

The framework recognizes the conflict between utility and robustness of plans in cases such as engineering design, where processes can be seen to exhibit a high degree of unpredictability. To illustrate this concept, it is useful to consider two types of framework which may be used for modelling plans. Firstly, some models attempt to capture emergent properties through understanding the behaviour of and interactions between individual tasks; an approach taken by O'Donovan [3]. A key benefit of this 'bottom up' approach is the ability to construct models from disjoint fragments of process knowledge; however, the main challenges lie in effectively characterizing task behaviour and in verifying the emergent properties revealed through simulation. Secondly, widely used network representations such as Gantt charts or Design Structure Matrices may be used to model plans or processes as static networks of tasks. These 'top down' models have proven pragmatically valuable in representing the structural overview required for planning; however, they are less robust to the types of uncertainty found in the design process. Models developed using such representations can require frequent modification to remain useful in the dynamic context of the design process.

The new method described in this paper allows hierarchical plans to be constructed which contain both 'top down' and 'bottom up' descriptions. At any level in the hierarchy, the user may choose the description which is most suitable to that part of the process. This choice must be informed by an appreciation of the situated nature of uncertainty in the design process.

Causes and effects of design iteration

Iteration is commonly seen as a major driver of uncertainty in design planning. Unfortunately, despite the concept of iteration forming a core theme across much design literature, the available insights often seem unsuitable for application to planning.

Both in literature and in industry it was found that iteration may stem from a number of causes (figure 1):

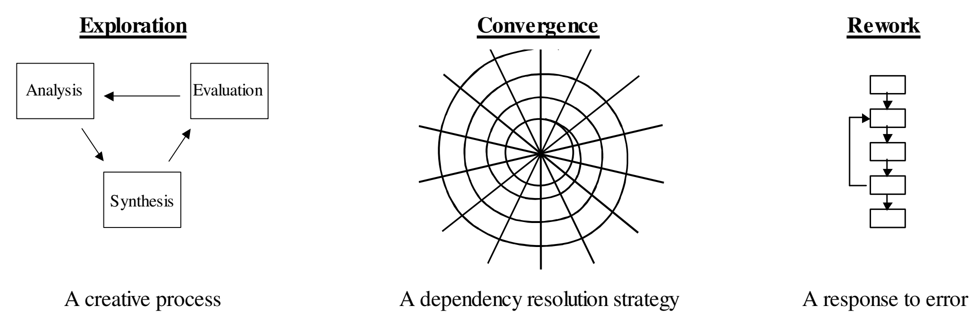

Figure 1: Iteration may stem from a number of causes

1. **Exploration**: Concurrent, iterative exploration of problem and solution spaces is fundamental to the creative process;
2. **Convergence**: Many design problems may be viewed as the selection of product parameters to satisfy complex dependency relationships. Where the problem is complex and/or requires integration of many personnel from disparate disciplines, an iterative process is often used to converge upon a satisfactory solution; and

3. **Rework**: Repetition of tasks may form a response to errors or unexpected events during the design process.

The effects of iteration on process behaviour were observed to vary with its cause and other domain-specific factors. Furthermore, the strategies used to plan design iteration were dependent upon its perceived behaviour and importance; observed strategies ranged from the explicit scheduling of a number of iterations through to the use of many coarsely grained, poorly integrated plans which allowed room for manoeuvre. For example, in a company where developing a complex product required considerable analysis effort, the need for cross-discipline interaction and concurrent engineering caused `convergence' iteration to form a strong, well-acknowledged influence on process behaviour.

A key complicating factor in modelling process plans was found to be the subjective nature of design tasks and iteration. While it was relatively easy to elicit small segments of process network, the individual segments often appeared to overlap and it was difficult to fit them together to form a coherent process. It eventually became clear that this difficulty was exacerbated by each engineer's holding a unique perspective on the process and on the location of possible iterations.

To illustrate, figure 2 depicts three alternative viewpoints of the concurrent design and manufacture of a component. From the programme manager's perspective, a convergent dialogue occurs between the design and manufacturing groups. However, the team developing the component perceives a sequence of many different tasks. A researcher conducting a protocol study might look closer still: from this perspective an iterative process emerges again, composed of many repetitions of a generic activity set. This subjectivity accounts for much difficulty in the planning, management and modelling of iterative design processes.

In the example case study, the largest plan contained less than 120 individual tasks; coherency was maintained by the researcher's understanding of the complete model. However, the complexity of the design process would render this approach infeasible for modelling a full project plan; future research will thus address the challenge of synthesizing a single picture of the complex design process by eliciting distributed, subjective knowledge.

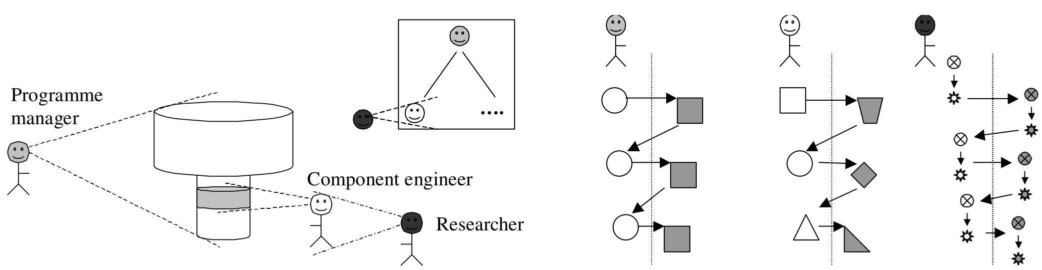

Figure 2: Design tasks and iteration are subjective concepts

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