Chapter 19

AUTOMATING A DESIGN REUSE FACILITY WITH CRITICAL PARAMETERS

Lessons Learned in Developing the LINK-UP System

C.M. Chewar, Edwin Bachetti, D. Scott McCrickard, and John E. Booker
Center for Human-Computer Interaction and Department of Computer Science, Virginia Polytechnic Institute and State University, Blacksburg, 24061-0106 VA (USA)
E-mail: {cchewar, mccricks}@cs.vt.edu, {ebachett, jobooker}@vt.edu

Abstract We propose an interface design process compatible with scenario-based design methods, but specifically intended to facilitate three primary goals: design knowledge reuse, comparison of design products, and long-term research growth within HCI. This effort describes a computer-aided design tool suite, LINK-UP, which supports the design process for specific genre of systems that cross many domains-notification systems. We describe the vision for LINK-UP, contrasting underlying concepts with typical task-based modelling approaches. To achieve its stated goals, the design process is organised and guided by critical parameters, presenting several challenges that we reflect on through the results of a design simulation study. The possibilities envisioned through this approach have important implications for the integration of reusable design knowledge, HCI processes, and design support tools.

Keywords: Claims, Knowledge-based interface design User interface design and specification methods and languages, Notification systems, Task modelling.

1. INTRODUCTION

Our work probes two themes within human-computer interaction: approaches for reusing and improving design knowledge from project to project, and the design and evaluation of systems used in divided-attention situations (*notification systems*). Central to our goals is a desire to produce automated design support tools that help designers reason and gain inspiration about key questions related to the behaviour of an interface. We envision a system that complements a scenario-based design process [1], in which formative interface development efforts focus on channelling re-

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quirements and design ideas into narrative scenarios and concise claim statements that evolve through iterative design activities. The majority of the paper discusses the implications of such a system –LINK-UP– developed specifically for our design concern of interest, but extensible to other types of interfaces. However, we first situate this work by providing some background on the prospects of reusing and quantifying design knowledge, as well as our design genre of interest and similar automation efforts.

1.1 Reusing Design Knowledge

As we consider how research growth within Human-Computer Interaction (HCI) can be achieved, supporting design knowledge reuse seems paramount. This goal fits squarely into the movements within the software engineering and HCI communities toward reusable design knowledge. The most dominant approach to software and design knowledge reuse seems to be the patterns movement, coupled with Unified Modelling Language (UML) descriptions. Since patterns include records for design tradeoffs that are observed through actual use, they rely on expression of reasoning about design decisions, which is achieved through claims in scenario-based design methods. *Claims* articulate the positive and negative effects (tradeoffs) of an artefact as feature on a user in accomplishing a task [1]. To achieve design knowledge reuse, Carroll and Sutcliffe argue that research should focus on producing "designer digestible" packets of knowledge in the form of claims, grounded on theory [2,11]. Sutcliffe's Domain Theory provides a structure of abstraction, formal definitions, reuse program evaluation metrics, and generic tasks that can be used to catalog design information [10]. Related work provides approaches for generalising claims for cross-domain reuse [12] and for reuse specifically within the notification systems genre [8].

1.2 Quantifying Design Knowledge

In reflecting on how reuse approaches can include some judgment of design quality, we look to other important arguments with HCI literature. Newman has pointed out the importance of basing design activities on *critical parameters*–figures of merit that are manageable and measurable, transcending specific applications and focusing on the broader purpose of technology [7]. He argues recognising and adopting critical parameters for classes of systems enhances ability to conduct meaningful modelling and recognition of design progress between iterations of a single design and among different designs. To our knowledge, no approach to design reuse or automated design support systems integrates the idea of critical parameters.

1.3 Designing Notification Systems

Our genre of interest, notification systems design, is primarily concerned with interactive or display systems delivering information to users that are primarily engaged in another ongoing task [6]. These interfaces can be found in many implementation forms and on a variety of platforms. Perhaps classic desktop systems are the most readily identifiable–instant messengers, status programs, and stock tickers. However, other familiar examples hint at the range of potential notification systems, such as ubiquitous representations of network traffic, in-vehicle information systems, ambient media, collaboration tools, and multi-monitor or large screen displays. Systems have overarching goals of providing appropriate utility through delivered information in a way that favourably balances demand on user attention. Many examples of claims can be found in [1,2,9,11,12]. For convenience, an example of a simple claim pertinent to notification systems design is:

Use of **tickering text-based animation** to display news headlines in a small desktop window:

+ Preserves user focus on a primary task, while allowing long-term awareness

– BUT is not suitable for rapid recognition of and reaction to urgent information.

Previous work has presented arguments to support the identification of notification system critical parameters [4],[5], which focus design on controlling user *interruption*, *reaction*, and *comprehension*. A claim about a notification system artefact can be quantified with its critical parameters:

Tickering text-based animation ∈ {*low* interruption, *low* reaction, *moderate* comprehension} (as established in [4])

The example continues in the next section, as a basis for our system vision.

2. VISION: A SYSTEM FOR DESIGN SUPPORT

In considering how to support design knowledge reuse and growth for notification systems, several arguments from the Computer-Aided Design of User Interfaces (CADUI) community are influential. Since notification systems design is inherently focused on supporting primary and secondary task performance, approaches that seek to understand and model desired task behaviour are key. In particular, the Enhanced Task-Action Grammar (ETAG) provides a proven mechanism to describe interface expectations and connects HCI and software engineering concerns [3]. Wilson and Johnson present considerations for task-based models developing the connection between design phases, identification of optional and compulsory features of the existing task model, and development of the envisioned task model [15]. Building on this foundation, we propose an interface design process compatible with scenario-based design methods, but specifically intended to facilitate three primary goals: design knowledge reuse, comparison of design products, and long-term research growth within HCI.

For example, a designer of a notification system for collaborative work status should be able to benefit from lessons learned in developing previous, similar systems–perhaps a notification system for news headlines or weather information. Claims about appropriate artefacts used in other domains can be accessed for reuse by designers to meet user notification goals. In conceptualizing and developing this system, we have determined that critical parameters provide a meaningful mechanism to specify and describe claims, allowing structured design process transition and reuse.

2.1 LINK-UP, Our Envisioned System

The LINK-UP system (Leveraging Integrated Notification Knowledge through Usability Parameters) operationalises our proposed interface design process. The root concept of the system is to provide notification systems designers with a facility for task-based design advice, consistent with the Wilson and Johnson definition [15], guiding progression throughout an interface design process. This design advice comes in the form of claims, demonstrating an automated approach to claims reuse. In general, claims stem from requirements analysis and provide the basis of the existing and envisioned task model, motivating the design decisions leading to the interface model. Testing of an interface model grounds claims by empirical observation, making them useful and reusable in other design efforts [12]. To continue the example started previously, a designer of a notification system can recognise a need to support notification delivery that results in low user interruption and reaction, but moderate gain of comprehension. In this case, the claim introduced earlier would be returned as a matching technique to meet user requirements.Characterising claims with critical parameters (as illustrated in section 1.3) also allows designers to compare this claim with claims describing other techniques, such as in-place fading and blasting animation. As designers proceed through a design cycle, they continuously question the values of targeted and actual critical parameters for key interface decisions. Claims stored a design knowledge repository are accessed and modified at several points with interactive system tools. Fig. 1 depicts LINK-UP's general architecture, relating it to Norman's conceptual models [8]. Further details about all LINK-UP steps are provided in section 5, but we first focus on Requirements Analysis (1), the initial step where we capture the design model and start to recognise challenges with using critical parameters.

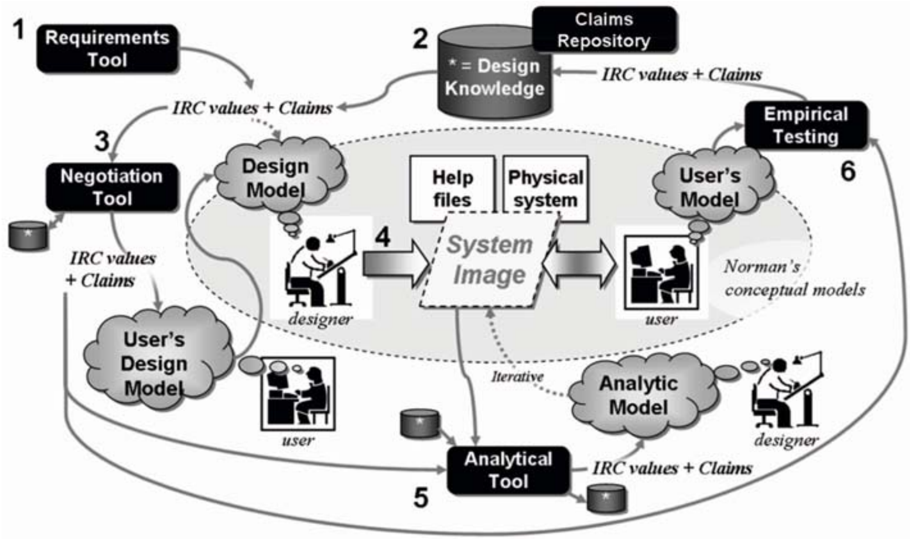

Figure 1. General architecture of LINK-UP. The light grey region in the center depicts Norman's conceptual models [8], which are extended through our work. Numbers refer to steps though the process, and are referenced and explained in sections 2.2 and 5.1.

2.2 Capturing the Design Model

Modelling the usability engineering process, LINK-UP's first step ("1" in Fig. 1) is gathering and analysing user requirements to drive interface design, to include understanding tasks, information characteristics, user background, and other aspects of the situation. In Norman's terms, this forms the *design model* [8], based on dimensions of successful dual-task design recognised in research [14]. Notification systems designers are provided with convenient access to these considerations, as the system ascertains the critical parameter levels of desirable user interruption, reaction, and comprehension (or *IRC values*), expressed simply as triplet of ordinal scale values between 0 and 1.

Using the LINK-UP system, designers search for influential and reusable claims from previous projects and gather them ("2" in Fig. 1) in a manner similar to the Internet shopping cart metaphor used on e-commerce sites. Several indices are used to access this design knowledge within LINK-UP, to include the generic tasks that the system will support (e.g., monitoring or alerting), design choices (e.g., use of colour or animation), and IRC values as the most influential index. Much of this information can be gathered from ETAG specification [3] or direct input by the designer.

In order to use IRC values as indices, they first must be calculated. To facilitate this, a web-based questioning system probes requirements relating to the critical parameters. Using easy to understand questions, LINK-UP guides reasoning about notification tasks and usage factors (such as those summarised in [5]). An algorithm converts designer responses to IRC values (transparent to the designer) accurately and consistently for a wide variety of design models. Section 4 describes the methods used to guide development and validation for accurate and consistent generation of critical parameters, which have included expert walkthroughs with a variety of systems and lab-based design simulation. This process within LINK-UP for characterising the design model to access and judge effectiveness of claims in a design knowledge repository overcomes a key challenge in the use of critical parameters. We elaborate on this challenge in the next section and then describe our related study.

3. CHALLENGES WITH CRITICAL PARAMETERS

Revisiting the concept of critical parameters, as introduced in [7], experience in developing LINK-UP helped recognise several challenges in using them to guide design knowledge reuse (as we propose in our high-level vision). We introduce each challenge, commenting when appropriate on how it was addressed in the design of the LINK-UP system.

- **Target appraisal.** Designers must be able to transform abstract requirement variables to qualitative critical parameters. Although requirement variables for any class of system (describing the design model) are likely to be quite numerous with wide ranges of possible values, some mechanism must be present that funnels these variables into abstract design goals expressed as critical parameter values. This is the specific focus of step 1 in the LINK-UP system, which we assess in the following section.
- **Iterative assessment.** Designers must be able to estimate critical parameter values throughout the design cycle to gauge the impact of decision-making on design progress. In short, analytical and empirical testing processes must be able to calculate effects necessary to determine whether the critical parameters will be reached. LINK-UP steps that address this challenge are discussed in section 5.
- **Benchmarking.** Through iterative assessment, benchmarks must be established to summarise state-of-the-art effects of actual systems used in real world situations. In this case, design characteristics for specific parameter ranges (e.g., low interruption) would be collected, assisting other designers with understanding implication of various parameter values. This is also a challenge noted by others, which can be used to form reference tasks for research programs [13]. A benefit of an automated system like LINK-UP is acceleration of consensus and collection of benchmarking data.
- **Definition.** A common conception of parameter definitions, as well as

acceptable units and methods of measure, must be established so that they can be universally applied–a process worked out through the acceptance of benchmarks. While the researchers may be moving toward common definitions of essential usability metrics, there is still a long way to go. Certainly, related work in the behavioural science fields provides a good starting point that can be bridged to the specific needs of design.

- **Selection.** Researchers must be satisfied that they have exhaustively included the right parameters in consideration of the system class and that all parameters apply to all systems within that class. The LINK-UP system is based on critical parameters of interruption, reaction, and comprehension, argued as essential usability metrics within relevant notification systems literature [4],[5]. As this system and research area matures, acceptance of these parameters will become more widespread.

Our architecture situates the design phases that are important for notification systems. As a vital first step, we consider target appraisal in the study presented in the next section–the first concern a designer would be presented with during requirements analysis in a design process and a topic of interest in the CADUI community.

4. DESIGN SIMULATION STUDY WITH LINK-UP

Without consistency among designers in the determination of critical parameters, effectiveness of the system would be severely limited. If two designers were to specify very different critical parameter values for the same design model, the claims returned in a search result would not fit the needs of this design model. Therefore, our current efforts in implementing and validating LINK-UP probe establishment of a well-defined process for target appraisal. To this end, we have developed a questionnaire and an underlying algorithm in our system, taking designer's abstract requirement variables and transforming them into qualitative critical parameters values. A key validation concern with this tool allows designers to generate accurate and precise results for a full range of notification system design models.

We hypothesize a user test with our tool would validate several system objectives. Our first objective enforces accuracy of critical parameter establishment against expert consensus; we expect agreement within 20%. This value was selected based on the best expert-to-expert parameter assessment agreement rates previously obtained with manual assessment methods. Our second objective ensures that different designers are able to derive similar critical parameter values given an identical design model, for which we also expect agreement within a standard deviation of 20%. These objectives apply throughout the full range of possible parameter values. Of course, we also expect that designers generating critical parameter values with this tool will obtain more accurate and precise results than designers with no tool at all (using manual, heuristic-based estimation). Before beginning formal testing, we tuned the algorithm with a number of system and requirements walkthroughs by different experts, ensuring expert users could achieve agreement between manual and tooled parameter assessment.

4.1 Methodology

The first phase of testing, which probed the accuracy and precision of our tool, consisted of 10 undergraduate computer science students that received credit in an HCI class for their assistance in a design simulation study. These participants were instructed to consider themselves designers of notification systems and were given four design problems, such as the example below:

> *You have been asked to design a desktop notification system that provides sport score updates for several games that users select. You anticipate that users (probably typical college students) will want to glance at this system quite frequently during a course of several hours, as they perform other desktop processing tasks. These primary tasks include word processing, making presentations, chat, and surfing the Internet. Although you feel it will be important for the notification system to be always visible, you don't think it should take up much screen space or be overly distracting. You don't think that users will usually want to click on anything to receive updates–but it is possible they they'll want to use the system to launch to more details about close scores or important games. However, you guess that most users will just want to know scores.*

After reading a given design problem, participants used the tool to answer approximately 16 multiple-choice questions. An example question is "*Which statement describes the general relationship between the importance of the primary task and receiving the notification?*" After answering all questions, the parameter values are calculated via an underlying algorithm and sent to the LINK-UP system. Following the generation of the critical parameter values, participants responded to a post-test survey to determine if the questions addressed all factors they felt impacted interruption, reaction, and comprehension. In addition to testing these novice designers, we obtained benchmark parameter values for each of the four design problems from an impartial expert that assisted in the development of the IRC system. We conducted a second phase of testing to determine if the tool provided designers with more accurate and precise results than designers without the tool. This required 10 additional participants from the same population who solved the same four design problems. Instead of an automated questionnaire, these participants were given a list of general heuristics to guide their reasoning, but then used their best judgment to specify quantitative values for the three critical parameters.

4.2 Results and Conclusion

In interpreting the results, we calculated the absolute difference between each participant's derived parameters and the benchmark results. This yielded an overall difference of 18.0%, which is well within our expected threshold for accuracy. The accuracy per parameter for the IRC values was 16.6%, 17.9%, and 19.5% respectively. While all three individually are also within our threshold, upon further analysis of the comprehension parameter, the majority of the disagreement between expert and novice designers came from two outliers in two of the four design problems. This reveals the only weakness in achieving accuracy across the full range of parameter values.

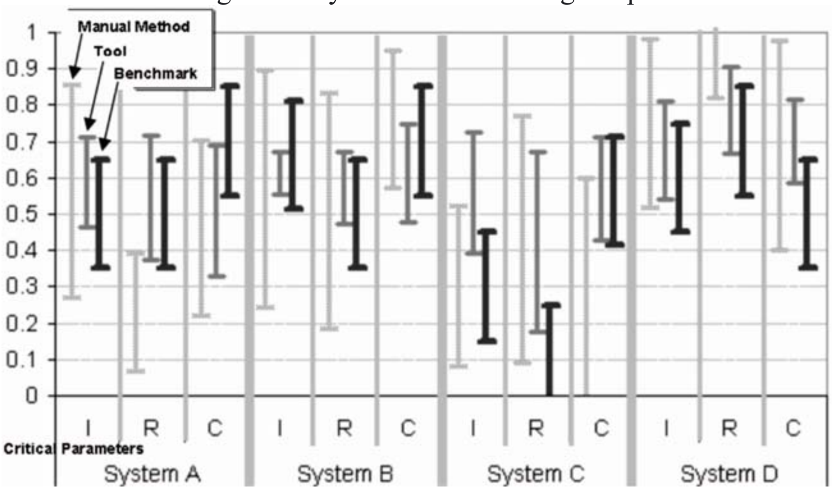

Figure 2. Accuracy and precision results, indicating the superior performance of the tool over the manual critical parameter assessment method, as well as the general match between participant results with the tool and expert derived benchmarks.

Testing for precision was done by taking the raw parameter values and calculating the standard deviation. The results were also favourable, yielding a standard deviation of 14.1%, well within our expected threshold. In looking at the standard deviations by parameter and problem, we note a problem with consistently assessing reaction in one of the design problems, suggesting additional fine-tuning work or perhaps rephrasing the problem.

To ensure that the tool indeed provided better support for calculating critical values, we compared the benchmark differences of results obtained by participants who had used the tool with those that did not. A single factor ANOVA revealed a significant difference ($F(1, 238) = 7.35, p<0.01$). Details of results can be seen in Fig. 2. Overall, these results are very favourable for the prospect of integrating critical parameters into a design support system like LINK-UP, since we can at least ensure target appraisal.

5. GENERAL IMPLICATIONS AND NEXT STEPS

The success in developing and validating the Requirements Analysis module has provided confidence that the other challenges with using critical parameters can be overcome. Just as we were able to develop general questions to characterise essential components of problem situations, we are working on methods to refine details from participatory design processes and analytical and empirical usability test results, making conclusions about actual critical parameter values of notification system artefacts. At this point, we can continue a conceptualisation of the LINK-UP system and comment on broader implications of our general approach.

5.1 LINK-UP, Beyond Requirements Analysis

The claims collected in step 2 assist designers in reasoning about scenario-based design phases [1]. However, to aid participatory design efforts and validate the design model IRC values, the LINK-UP system provides a tool for designers to produce an interactive claims-review session with potential users ("3" in Fig. 1). Designers can present prototypical usage scenarios to the user, who then assesses the claims (and underlying, transparent IRC values). Users accept or reject claims according to their needs, forming the *user's design model (UDM)*—a conception of the system effects gleaned through the IRC values associated with the final claims set. In turn, the agreement of the UDM with the design model helps the designer know when to progress from one stage to the next (in this case, to production of the physical system ("4" in Fig. 1)). This resolves a key concern cited with other task-based design approaches [15]. It is anticipated that designer-user claims negotiation is an iterative process involving multiple users. Once a system image is available, the LINK-UP system supports analytical (expert) evaluation ("5" in Fig. 1), with the hope that most usability problems can be caught early in the development process and without requiring costly user evaluation. Currently to support this stage, we use a heuristic method to analytical evaluation, based on heuristics tailored for notification systems. LINK-UP facilitates execution of the analytic method, recording of results, and estimation of the actual IRC values, or the *analytical model*. In this step, the claims set's corresponding IRC values are assessed in light of the physical product, providing a means for developing practical guidelines and comparing design choices–another limitation noted in other task-based design support techniques [15]. Designers are able to gauge whether targeted critical parameters will be achieved in the design, receiving automated support to pinpoint specific design problems. Similar to the previous step, the next tool within the LINK-UP system facilitates the execution and results analysis for an empirical user testing session ("6" in Fig. 1). Here, the system uses the original set of claims to adapt a general instrument for collecting usage data. Based on users' qualitative feedback and quantitative performance, actual IRC values are determined to characterise the *user's model* (as defined in [8]) and effectiveness of the claims. While the step allows formative and summative testing of the designed interface, it generates new knowledge related to new and existing claims. The key function of the tool assists the designer in comparing actual with intended efforts, informing the next design iteration.

5.2 Implications: Integrated Design Knowledge Reuse

The conclusions drawn from our studies suggest several implications for integrated design knowledge reuse. The LINK-UP system provides continuous and integrated access to the design knowledge repository, facilitating knowledge reuse. Through access to the claims database, designers are able to build from and test previous design claim tradeoffs, contributing to a growing body of knowledge. To enable these features in a manner that preserves content quality and user trust, the system includes meta-analysis and maintenance features for expert administrators, such as full claims editing, association of claims with related theories, example systems, and design artefacts. The concept of this system extends the existing notion of claims analysis [1] to one of *claims engineering*–design efforts will continuously improve the quality of reusable claims.

As we continue to develop the system, validation efforts will be structured around lab-based simulation studies, and content creation will result mainly from student design efforts and conversion of existing related literature. However, as soon as possible, we would like to start testing the system's support for actual long-term development efforts. We welcome opportunities to challenge LINK-UP's utility (and that of its critical parameters) through collaborative design efforts within the notification systems field, seeking to broaden its functionality by integrating and extending CADUI research.

To summarise, the LINK-UP system provides a web-based interface to guide the usability engineering process for a notification system. Designers interact with five major design support tools, saving and building on progressive session results throughout the process. These tools include support for requirements analysis and negotiation, analytical and empirical testing, and design knowledge access. Design progress within a single design and through a meta-analysis of several systems is guided by a set of claims (serving as design hypotheses) and associated critical parameters (acting as engineering targets and results). The design knowledge repository will grow and improve through use, becoming a living record of notification systems research made possible by thinking about design through critical parameters.

We have begun formalising the way we develop and evaluate notifications systems. To generalise this effort, we have recognised potential for a similar process of design knowledge reuse to be applied in the areas of information visualisation and community networks. Based on initial success, we feel that the general process, integrated with critical parameters, can be valuable to other genres in the user interface community.

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