



Automatically generating personalized user interfaces with SUPPLE

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ABSTRACT

Today's computer–human interfaces are typically designed with the assumption that they are going to be used by an able-bodied person, who is using a typical set of input and output devices, who has typical perceptual and cognitive abilities, and who is sitting in a stable, warm environment. Any deviation from these assumptions may drastically hamper the person's effectiveness—not because of any *inherent* barrier to interaction, but because of a mismatch between the person's effective abilities and the assumptions underlying the interface design.

We argue that automatic personalized interface generation is a feasible and scalable solution to this challenge. We present our SUPPLE system, which can automatically generate interfaces adapted to a person's devices, tasks, preferences, and abilities. In this paper we formally define interface generation as an optimization problem and demonstrate that, despite a large solution space (of up to 10^{17} possible interfaces), the problem is computationally feasible. In fact, for a particular class of cost functions, SUPPLE produces exact solutions in under a second for most cases, and in a little over a minute in the worst case encountered, thus enabling run-time generation of user interfaces. We further show how several different design criteria can be expressed in the cost function, enabling different kinds of personalization. We also demonstrate how this approach enables extensive user- and system-initiated run-time adaptations to the interfaces after they have been generated.

SUPPLE is not intended to replace human user interface designers—instead, it offers alternative user interfaces for those people whose devices, tasks, preferences, and abilities are not sufficiently addressed by the hand-crafted designs. Indeed, the results of our study show that, compared to manufacturers' defaults, interfaces automatically generated by SUPPLE significantly improve speed, accuracy and satisfaction of people with motor impairments.

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1. Introduction

Today's computer–human interfaces are typically designed in the context of several assumptions: 1) that they are going to be used by an able-bodied individual, 2) who is using a typical set of input and output devices, 3) who has typical perceptual, cognitive, and motor abilities, and 4) who is sitting in a stable, warm environment. Any deviation from these

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assumptions (for example, hand tremor due to aging, using a mobile device with a multi-touch screen, low vision, or riding on a jostling bus) may drastically hamper the person's effectiveness—not because of any *inherent* barrier to interaction, but because of a mismatch between their effective abilities and the assumptions underlying the interface design.

This diversity of needs is generally ignored at the present time. Occasionally, it is addressed in one of several ways: manual redesign of the interface, limited customization support, or by supplying an external assistive technology. The first approach is clearly not scalable: new devices constantly enter the market, and people's abilities and preferences both differ greatly and often cannot be anticipated in advance [5]. Second, today's customization approaches typically only support changes to the organization of tool bars and menus, and cosmetic changes to other parts of the interface. Furthermore, even when given the opportunity, people do not customize [50,63,65], and even more rarely re-customize as their work habits change [52]. Finally, assistive technologies, while they often enable computer access for people who would otherwise not have it, also have limitations: assistive technologies can stigmatize their users; they are impractical for people with temporary impairments caused by injuries; they do not adapt to people whose abilities change over time; and finally, they are often abandoned, even by people who need them, because of factors like cost, complexity, configuration, and the need for ongoing maintenance [11,13,42,68].

In contrast to these approaches, we argue that interfaces should instead be personalized to better suit the particular contexts of individual users. Many personalized interfaces are needed because of the myriad of distinct individuals, each with his or her own abilities, tasks, preferences, devices and needs. Therefore, traditional manual interface design and engineering will not scale to such a broad range of potential contexts and people. A different approach is needed. In this paper, we demonstrate that *automatic generation* of personalized user interfaces is a feasible and scalable solution to this challenge. We make the following specific contributions:

- We formally define interface generation as a discrete *constrained optimization* problem and solve it with a branch-and-bound algorithm using constraint propagation (Sections 3 and 4). This general approach allows our SUPPLE system to automatically generate “optimal” user interfaces given a declarative description of an interface, device characteristics, available widgets, and a user- and device-specific cost function.
- We develop *two types of cost functions* for guiding the optimization process. The first is factored in a manner that enables preference-based personalization as well as fast computation, allowing SUPPLE to generate user interfaces in under 1 second in most cases (Section 5.1). The second explicitly models a person's ability to control the pointer, allowing SUPPLE to generate user interfaces adapted to unusual interaction techniques or abilities, such as an input jittery eye tracker or a user's limited range of motion due to a motor impairment (Section 5.2). Both types of cost functions incorporate usage traces, allowing SUPPLE to generate interfaces that reflect a person's long-term usage patterns.
- We illustrate the extensibility of the approach by incorporating into the cost function a measure of *presentation consistency* among different variants of a user interface. This allows SUPPLE to generate different user interfaces for an application such that these interfaces resemble one another, even if they are generated for different devices (Section 5.3).
- We demonstrate two approaches for *dynamic personalization* of SUPPLE-generated user interfaces: an automatic system-driven adaptation to the current task, and a user-driven customization (Section 6).
- We systematically evaluate the systems issues in SUPPLE and demonstrate that even for solution spaces on the order of 10^{17} possibilities, our algorithm can find the optimal rendering in less than a second in most cases. We also demonstrate that by exploring the solution space in parallel in two different orders, our algorithm's worst-case empirical performance can improve by up to two orders of magnitude (Section 7).
- We demonstrate a practical application of SUPPLE: automatic generation of personalized user interfaces for people with motor impairments. The results of our user study show that user interfaces automatically generated by SUPPLE can improve speed and accuracy for all users—and for people with motor impairments, they can also significantly improve satisfaction—compared to default user interfaces shipped with today's software (Section 8).

Automatic model-based user interface generation is frequently met with skepticism. Prior systems in this area—which, with few exceptions, attempted to incrementally improve existing interface design processes—were perceived to require higher up-front cost (learning a new language, manually building models) and to result in aesthetically less-pleasing artifacts than traditional, manual design approaches [56]. Instead, we believe that the real strength of automatic user interface generation lies not in incrementally improving existing design processes, but in enabling solutions to problems that cannot be adequately addressed by traditional methods. Our SUPPLE system offers alternative user interfaces for those people whose individual devices, tasks, preferences, and abilities are not sufficiently addressed by the hand-crafted designs. In the case of people with motor impairments, the results of our study demonstrate that the benefits of personalized interfaces generated by SUPPLE far outweigh the drawbacks of unfamiliar aesthetics. And, as Fig. 33 illustrates, users with different sets of motor abilities benefit from very different user interface designs, suggesting that manual design methods would not scale.

We have previously presented fragments and refinements of this framework over the course of several years [21,19,22, 23,27,28]. This paper provides the first complete and consistent presentation of the technical underpinnings of the SUPPLE system. The evaluation of the algorithm's performance and the parallel algorithm introduced in Section 7.4 have not been presented before.

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