Attuning Notification Design to User Goals and Attention Costs

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Why is the attentive user interface paradigm important for human-computer interaction? The human attention system is so sensitive to various methods of notification that traditional design involves too much compromise and guesswork.

In today's world, users want to be notified about multiple sources of information while engaged in other tasks. *Notification systems* are interfaces specifically designed to support user access to additional digital information from sources secondary to current activities. Many such interfaces, especially examples such as Web page advertisements and animated software agents, seem to be ineffective and distracting, and are abandoned or ignored after brief use. We believe dissatisfaction results from incorrect estimates of the user's task prioritization during design time. Consequently, information is introduced at inappropriate times and with unsuitable presentation choices. Factors such as the nature of ongoing activities, perceived urgency, and attentional focus require changes in the way information should be delivered. By tracking priorities of user attention and inferring workload characteristics through eye gaze, physical or biomedical sensors, and input devices, attentive user interfaces (AUI) [8] and more specifically, attention-centric systems [1], can adapt information delivery to avoid overloading the user. This interface adaptivity suggests a key paradigm with enormous potential for notification systems.

To best leverage the AUI paradigm for notification design, we explore how we might understand the associated costs and benefits of user notification in terms of its impact on user attention. We introduce a framework that allows these costs and benefits to be described and design options to be compared. Based on this, we show how user goal representations can be integrated with information design guidelines from usability studies. This demonstrates vast potential for AUIs in notifying users—compelling *attentive notification systems.* We also suggest some challenges for this emerging research community.

The paramount challenge of notification is preventing unwanted distraction to the primary task, while still delivering information in an accurate and timely manner. In many cases, very little distraction can be tolerated. For example, a typical in-vehicle information system may notify the user about navigation instructions, incoming communications, and other information secondary from the main task of the user—driving the car. Such systems should be designed to ensure notification is provided without diverting attention from driving-related tasks. In other cases, a user is willing to accept some distraction in exchange for valued information. Desktop computer users may perform daily word-processing tasks while casually

utility benefits	
user goal	**general goals**
identify state changes understand patterns and trends assimilate complex information monitor resources over time gain awareness of collaborators	**Comprehension** information is related to existing knowledge and stored for future use
make decisions modify primary task approach provide response acknowledge status	**Reaction** immediate response to a notification stimulus, with or without shifting attention
pace daily activities prompt task transition receive urgent/timely information synchronize with colleagues	**Interruption** intentional and inherently useful reallocation of attention from other tasks
reduce stress emote humor cultivate enjoyment augment meaning or presence increase feeling of security	**Satisfaction** overall enhancement and approval of the general computing experience

attention costs	
situation parameter	**cost factors**
Context	goal relationships of tasks task perceptual-motor qualities data-link dependencis relative tasks priorities interruptability focus/peripheral location platforms and environment
User characteristics	skill and automaticity cognitive and perceptual abilities current overall mental workload sender/receiver roles demographics
Information characteristics	granularity discrete/continuous modality (visual or auditory) complexity representation richness anticipated value synchronizaton context relevance

Table 1. Attention benefits and costs. Notification system users expect to gain benefits associated with fulfillment of user goals (left side) by sacrificing attention from other tasks. Costs can be exacerbated by factors of the current situation (right side).

maintaining awareness about unrelated information of interest, such as that found in a news ticker or an email status indicator. They depend on alerts or alarms to stay informed about critical information and trigger necessary reaction. All too often, however, users become distracted from their current activities by overactive notifications insensitive to user priorities.

Certainly, systems that manipulate and depend on user attention should be developed according to user-centered design and cognitive engineering [6] in order for the human-computer interaction component to succeed. Users select and accomplish goals associated with system use based on how an interface's physical representation of information conforms to expectations. Designers must ensure benefits of presenting a notification outweigh associated costs. Costs and benefits of notifications to user attention either must be established prior to employment of a system, or can be determined at runtime by designing notification systems that are attentive. Conceptual models assist in this consideration and allow comparison of presentation alternatives, helping predict what will work.

Tradeoffs of System Use

As a first step toward a conceptual model of user notification goals, we consider general goals and tradeoffs required for their achievement. We draw from the convergence of ideas of researchers pursuing these questions. Horvitz characterizes a user's attention system as the most constraining factor in notification systems design [1]. His paradigm involves a Bayesian inference model that decides whether interrupting a user will create sufficient payoff in terms of expected information. This model would be ideal for filtering information to be presented to the user interested in receiving valuable notifications, such as the receipt of urgent email or a reminder for an important meeting. Maglio and Campbell articulate a similar trade-off describing benefits to the user in providing additional information with escalating costs of obtaining information [3]. To minimize the costs associated with continuous presentation of secondary information sources, they look for "peripheral" presentation options that preserve the focus of user attention. Combining these approaches with sensing of user attention leads to a perspective that fully accounts for the complete range of user notification goals.

We assert that it is useful to think of "attention" as a constrained resource that can be traded for some utility. This utility is enabled by perceiving additional, valued information while performing other tasks. This *attention-utility trade-off* can be stated as follows:

The success of a notification system hinges on accurately supporting attention allocation between tasks, while simultaneously enabling utility through access to additional information.

The attention-utility theme concisely captures the source of scarcity (the attention of the user) along with the user's purpose in using the notification system (utility associated with access to an additional source of information). Certainly this relationship is not smooth and differentiable, but still generally describes the cost of achieving user goals—a cost that reliably yields benefits when using AUIs to infer the state of a user's attention, model priorities, and render information appropriately.

Table 1 itemizes component cost-benefit factors of the attention-utility trade-off. Users ultimately use a notification system to gain benefits, which come from specific types of utility. We recognize four general sources of utility that can result from associated user goals (left side of the table). The general goals of comprehension, reaction, and interruption can be

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thought of as critical parameters—key measures of system success that can be benchmarked to reveal design progress. These goals are unique in that the user is willing to sacrifice a certain amount of primary task attention in order to achieve them. Other important system features and user needs must be typically supported in user interfaces to include privacy, reliability, and trust. These features can negatively influence the amount of required attention without providing a distinct benefit that independently motivates system use.

The level of cost, determined by the amount of attention removed from ongoing tasks, may be elevated as a result of the factors presented on the right side of Table 1. For example, above-average attention cost factors may include a user's lack of skill in perceiving unfamiliar or complex notification information. Unfortunately, cost factors may not carry a constant value across different situations or result in expected benefits. Poor designs may result from a user *accepting* a certain cost in anticipation of a certain utility without actually *receiving* that utility. Usually, the attention required for a user to perceive and process a notification is diverted from attention focus on a primary task, but cost only results if primary task performance is negatively impacted. Attention supplied during natural breaks in a primary task can minimize cost. The many cost considerations—and strategies to reduce them—amplify the importance of inferring and leveraging the state of a user's attention and semantic value of the notification for interface design.

Modeling Notification Benefits

The attention-utility trade-off provides the foundation for a conceptual model of user notification goals that can improve design decisions for notification systems. To appreciate how user notification goals can vary, as well as how expected information presentation would differ, it is helpful to consider two intuitive scenarios. Both scenarios involve a desktop computer user engaged in an urgent document-processing task who is also interested in stock price information. In the first scenario, the user wants to track performance trends over a long period of time and has no interest in near-term trading. In the second, the user wants to monitor prices to guide transaction decisions throughout the day.

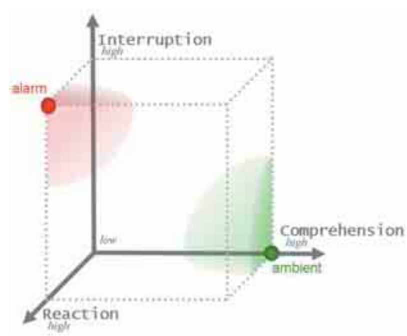

Figure 1. Framework reflecting the user goals for interruption, reaction, and comprehension—critical parameters for system success. Two types of systems, ambient and alarm, are depicted according to the goals they support.

In scenario one, the user desires awareness of stock information, but does not want to disrupt the primary task. This user should be able to casually glance at a display and register stock information almost peripherally. An interface would fail if it explicitly diverts attention with obtrusive animation, colors, or other such presentations. Ambient systems seem ideally suited for this task. Ambient notification systems are typically calm or peripheral interfaces used continuously for an extended duration, allowing users to be aware of state changes and detect patterns or trends in a memorable way (high comprehension goal) without prompting significant reaction or introducing interruption (low reaction and interruption goals).

In scenario two, the user is likely to value notifications that interrupt the primary task and guide timely decision making. Here, the cost of not paying attention to the interruption is higher than performance costs associated with the primary task. When an alert grabs the user's attention in this situation, he or she expects the information will be presented in a valuable and timely fashion. However, if the notification does not attract attention adequately, the user may not receive the notification in an opportune manner, implying a failure of the system. This user desires a system functioning as an alarm—a notification that provides valued transition from a primary task (high interruption goal), prompts an immediate response (high reaction goal), but does not introduce content worthy of long-term assimilation (low comprehension goal).

user notification goal	recommended display	not recommended
low interruption • minimal attention reallocation from primary task **high reaction** • make decisions, provide response **low comprehension** • long-term knowledge gain unimportant	in-place animations (blast and fade), small-sized	scrolling animations (ticker), large-sized
low interruption • minimal attention reallocation from primary task **low reaction** • no immediate response **high comprehension** • understand patterns and resources over time	scrolling animations (ticker), fast update	in-place animations (blast and fade), slow update

Table 2. User performance tradeoffs for text-based animation in notification displays.

Clearly, effective notification depends on design attributes capable of preventing unwanted distraction while delivering critical content in a timely and appropriate manner. Specific design options—such as information layout, use of animation, and graphical encoding—all affect support of user notification goals because of the way they affect user attention. A conceptual model should allow designers to match scenarios of use with appropriate information design options (use of motion, display size, font and color attributes, among others). To model the sources of utility and attention cost and associate design attributes, we introduce a framework (see Figure 1) that depicts the three critical parameters—interruption, reaction, and comprehension—as axes. Alarm and ambient systems, described earlier, are illustrated as well.

The axis scales correspond to the level of importance a user places on benefits resulting from each parameter (three critical general goals listed in Table 1). It is important to note that in plotting systems within this framework, there is no ideal blend of parameters or target point. An attentive notification system would sense the desired parameter levels and associated attention costs and convert to the appropriate type of display by adapting presentation options to fit the user's priorities. This form of AUI would provide the ideal rendering of information, balancing dynamic notification needs with attention constraints. Therefore, for our conceptual framework to be useful it must be able to associate design options with user goals.

Integrating Empirical Usability Test Results

Many human factors affect the information design options for notification systems ([10] provides an overview). Challenges of standalone interface design are compounded—as people split attention across different tasks, design choices ideal for full attention use can fail in notification systems. Information presentation options have important effects on focused attention, especially related to use of audio, colors, and animation (motion). As an example, text-based animation is a likely choice for displays constrained to limited screen space, and would support the scenarios described earlier (a user primarily engaged in a browsing task while periodically monitoring news and stock information). Many animation techniques are available, some of which can be described as "in place" (for example, fading or blasting) and "scrolling" (for example, horizontal tickering or rolling). Variations in animation speed, font attributes, and display size produce numerous design options that may either be detrimental to user attention [3] or effectively allow primary tasks to proceed without distraction [5].

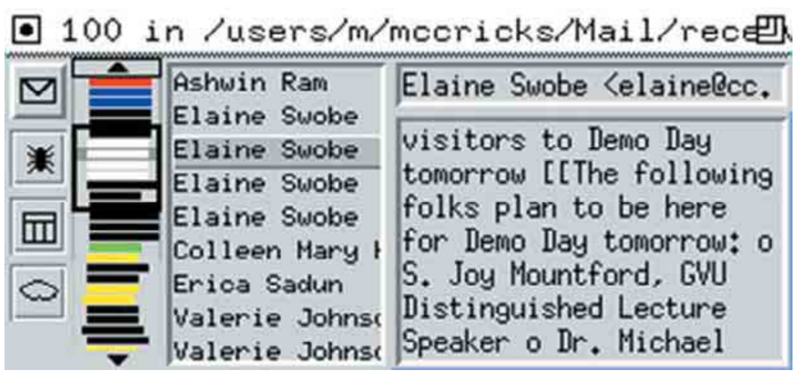

Figure 2. The Irwin notification system. Displayed are overviews of several resources using (from left to right) icons, a graphical encoding of the selected information resource, and two textual views.

Designers must be able to relate effects of various information design options to user notification goals. For instance, we conducted two studies in a dual-task condition where participants performed a Web page browsing task while monitoring and reacting to secondary information displayed using textual animations. Our studies revealed user-performance trade-offs evident in the use of various text-based, smooth animation methods (see Table 2). That is, for those interested only in gaining an understanding of the information over an extended duration, a scrolling stock ticker would be most effective. In contrast, during periods of active stock trading, when rapid reaction to changes is important, an in-place animation would be best. Recalling the attention-utility tradeoff, these two examples include different benefits: the first involves high long-term comprehension and no immediate reaction, while the second requires high reaction and less long-term comprehension. Using the appropriate type of animation prevents primary task distraction, ensuring minimal notification cost. To this end, our conceptual framework associates research results with user goals, general classes of systems, and specific systems (as illustrated in Figure 4).

Usability results viewed through the conceptual framework can also suggest important design paradigms. As an example, we consider two conclusions gleaned through evaluation of actual notification systems: Irwin [4] and the Scope [7]. Irwin was designed as a small, omnipresent tool that assists users in maintaining awareness about Internet resources such as email folders, Usenet newsgroups, Web pages, and weather data. Information is gathered from several sources and displayed on a central visualization; various icons, colors, and auditory cues keep its user updated (see Figure 2). Users of Irwin were observed over a five-month period, leading to identification of many usability problems. These can be reduced to a single key challenge: determining how to notify without distracting, yet providing expected urgency according to dynamic fluctuations in user goals. Our conceptual framework provides clarity—during an extended period of use, a point representing user notification goals may move throughout the design space quite radically. To match information design schemes with changing goals, the changes must be anticipated (which is quite difficult) or dynamically sensed—an advantage offered by the attentive system paradigm.

As a second example, consider the Scope notification system [7] (see Figure 3), an AUI for alerting and providing overview about incoming email, calendar tasks, and other information. Since the system learns a user's priorities, the interface can present information according to inferred expectation of urgency. Like Irwin, the Scope presents a summary of several resources in a glanceable, omnipresent view. However, the Scope is unique in its goal to clearly convey notification urgency (as inferred by the system) by presenting new items accordingly. Interface choices such as the circular radar metaphor, pulsing icons, and fly-in animation communicate urgency. These information design options (shown to have various strengths and weaknesses) can be improved with results from basic attention research associated with regions of the conceptual framework. The AUI characteristic of the Scope provides a distinct advantage: presentation requirements are continuously refined according to dynamic insight about user expectations—once the best presentation options are adopted for this interface design, the real-time knowledge about user priorities will maximize the attention-utility tradeoff.

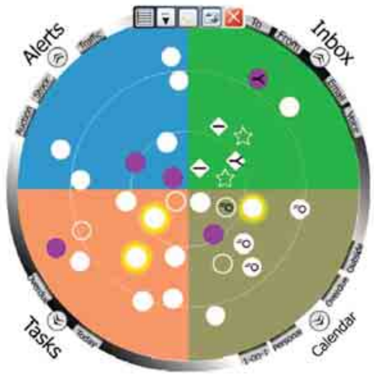

Figure 3. The Scope notification system [7].

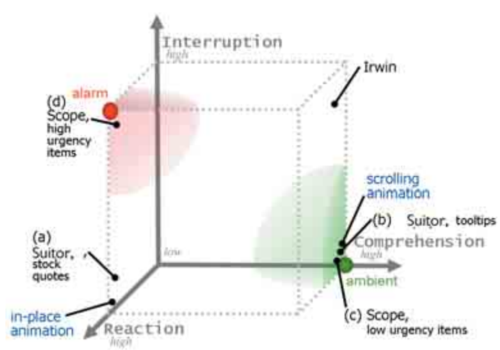

Figure 4. The framework for user goals traded for attention resources. Shown here are plots for three systems and two animation options.

Completing the Design View

Both systems described here support various user notification goals. To more fully convey the usefulness of our conceptual framework and the potential of AUIs, Figure 4 illustrates design model plots of Suitor (see [2] and the article by Maglio and Campbell in this section), the Scope, and Irwin. The Suitor AUI determines a user's notification priorities, shifting design models appropriately during runtime. For example, if the user is an active investor and the system notices that he or she is browsing for information on IBM, Suitor will display stock quotes about the company. This supports the goal—inferred from the user's attention—of reacting to stock price variations for a company of interest (point a). Based on our empirical studies, Suitor should use in-place textual animation to best support user goals and maintain lowest attentional cost. By contrast, if the user shifts to a document-editing task, Suitor displays helpful tooltips intended to increase understanding of the document editor (point b). As a result, the recommended display changes to scrolling animation, supporting long-term comprehension. The second system, the Scope, receives notifications of high or low priority, causing the design model to shift. Based on the designers' descriptions, users will not want to be interrupted by low-priority items, but desire comprehension of these notifications throughout the day (point c). However, immediate reaction is an important goal for high-priority items (point d). Finally, as a non-AUI, Irwin has only one plot because the system does not adapt to user attention. The Suitor and the Scope examples reflect the enormous advantages of AUIs for meeting diverse user goals with information display specifically adapted to keep attentional costs minimized and utility benefits maximized.

The Vast Potential of Attentive Notification Systems

In developing our conceptual model of notification user goals, we recognize that AUIs have the potential to become the notification systems of choice. Several factors summarize the importance of the AUI paradigm:

- AUIs introduce the ability to model and adapt to a user's attentional state, bringing the right information at the right time to the user in a way that is not achievable with a traditional notification system.
- Systems trained to individual characteristics can prevent problems associated with cognitive differences and interface learnability.
- AUIs can sense change in user goals and adapt a design model and information presentation appropriately.

Responding to the challenges of notification design and to help harness the attentive paradigm for notification design, we have introduced the attention-utility trade-off as a foundation for conceptual modeling of user notification goals. In a review of usability testing, we showed how presentation options can differ in support of goal-related utility and impact to user attention. Our framework, based on critical parameters, integrates user goals, system design models, and presentation options—simplifying design choices for developers and suggesting concerns for researchers.

Considering the growing demand for ubiquitous and multitasking systems, this underlying paradigm—and the AUIs it produces—will become central to computing and human-computer interaction. However, there are many challenges for this emerging research community. The framework introduced here provides a widely inclusive design space that should be filled with existing systems and analyzed to identify the best places for AUI augmentation. The community should also endorse universally accepted critical parameters, which can support a reference-task research agenda [9]. We provide a suggestion, but other possibilities may lead to improved modeling of user goals. Standard reference tasks should be selected, publicized, and adopted as a common metric for system testing. Finally, interface evaluations should be conducted and reported for the purpose of achieving scientific growth—allowing the community to recognize and leverage the great benefits and advancements afforded by AUIs. **C**

References

1. Horvitz, E. Principles of mixed-initiative user interfaces. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '99)*. ACM Press, NY, 159–166.
2. Maglio, P.P., Barrett, R. Campbell, C.S., and Selker, T. SUITOR: An attentive information system. In *Proceedings of the Conference on Intelligent User Interfaces (IUI 2000)*, ACM Press, NY, 169–176.
3. Maglio, P.P. and Campbell, C.S. Tradeoffs in displaying peripheral information. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '00)*. ACM Press, NY, 241–248.
4. McCrickard, D.S. Maintaining information awareness with Irwin. In *Proceedings of the World Conference on Educational Multimedia/Hypermedia and Educational Telecommunications (ED-MEDIA '99).*
5. McCrickard, D.S., Catrambone, R. and Stasko, J.T. Evaluating animation in the periphery as a mechanism for maintaining awareness. In *Proceedings of the IFIP TC.13 Conference on Human-Computer Interaction (INTERACT 2001),* 148–156.
6. Norman, D.A. *Cognitive engineering. User Centered System Design.* D.A. Norman and S.W. Draper, Eds. Lawrence Erlbaum, Hillsdale, NJ, 1986.
7. van Dantzich, M., Robbins, D., Horvitz, E., and Czerwinski, M. Scope: Providing awareness of multiple notifications at a glance. In *Proceedings of Advanced Visual Interfaces (AVI 2002).*
8. Vertegaal, R., Velichkovsky, B., and Van der Veer, G. Catching the eye: Management of joint attention in cooperative work. *SIGCHI Bulletin 29*, 4 (1997).
9. Whittaker, S., Terveen, L., and Nardi, B.A. Let's stop pushing the envelope and start addressing it: A reference task agenda for HCI. *Human-Computer Interaction 15*, 2-3 (2000), 75–06.
10. Wickens, C.D. and Hollands, J.G. *Engineering Psychology and Human Performance, 3rd Edition*. Prentice Hall, Upper Saddle River, NJ, 2000.

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