On Reconstruction of Task Context after Interruption

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ABSTRACT
Theoretical accounts of task resumption after interruption have almost exclusively argued for resumption as a primarily memory-based process. In contrast, for many task domains, resumption can more accurately be represented in terms of a process of *reconstruction*—perceptual re-encoding of the information necessary to perform the task. This paper discusses a theoretical, computational framework in which one can represent these reconstruction processes and account for aspects of performance, such as measures of resumption lag. The paper also describes computational models of two sample task domains that illustrate the sometimes complex relationship between reconstruction and more general human cognitive, perceptual, and motor processes.

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Multitasking, interruption, attention, problem state.

ACM Classification Keywords
H.5.2. User interfaces: theory and methods; H.1.2 User/ machine systems: human factors, information processing.

General Terms
Human Factors, Design

INTRODUCTION
Task interruptions are frequent, ubiquitous occurrences in everyday human-computer interaction [12]. As interruptions have become more plentiful, researchers have increasingly focused on interruptions to better understand how they affect computer users. Generally speaking, two lines of research have emerged in this quest. On the one hand, empirical research grounded in cognitive psychology has aimed to elucidate the cognitive underpinnings of task suspension and resumption processes, focusing almost exclusively on resumption as a memory-based process [2, 8, 9, 13, 14, 18]. For example, one influential line of work has developed a theory called *memory for goals* [2] that posits interrelated encoding and retrieval processes as the central mechanisms for task interruption. This theory has been supported to date by several studies [9, 13, 14, 18] which use *resumption lag*—time needed to resume the primary task—as the primary measure of the effects and disruptiveness of interruption.

On the other hand, applied research in human-computer interaction (HCI) has tended to examine task interruption in the context of real-world task domains. For example, recent work has investigated the effects of interruption relevance and timing on a user's ability to resume the original primary task [6, 7, 10, 11]. Interestingly, although psychological experiments are frequently cited in this applied work, the psychological theories themselves often do not translate easily to the applied domains being studied for at least two reasons. First, the effects observed in applied studies (specifically resumption lag) are typically larger than would be expected in a memory-based account: whereas memory processes may account for effects of tens to hundreds of milliseconds to at most one second, effects in the applied HCI literature are often several seconds or more. Second, the complexity of the context of the interrupted task in applied domains often makes memory-based accounts difficult or implausible; for instance, whereas the task context for a simple experiment may involve only one or two memorized items, the context in an applied domain (e.g., writing a paper or developing computer code) would be much more complex, and recalling the context for the task almost certainly involves more than a single memory retrieval.

This paper discusses a theoretical framework for thinking about task resumption as a process of *reconstruction*. In reconstruction, the user visually re-encodes the task environment to reconstruct the task context immediately prior to interruption. For basic tasks, reconstruction may simply involve finding the next step to be performed; for example, when filling in an online ordering form, a user may scan top-down for the first empty text field and begin entering from there. For more complex tasks, reconstruction may be much more difficult: imagine a scenario in which a researcher is writing a paper and, after a lunch break, needs to reconstruct the task context—check the paper outline, re-read a previously written paragraph, then mentally reconstruct the argument and points needed for the next paragraph—with a combination of reconstruction and memory processes. This paper focuses on a theoretical framework in which to reason about reconstruction-based resumption processes, and then describes computational models for applied tasks that illustrate the benefits as well as limitations of the theory.

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THEORETICAL FRAMEWORK

To better understand reconstruction of task context, we can view task interruption and resumption from the perspective of a general cognitive theory. In particular, we rely on a computational cognitive architecture, specifically ACT-R [3], to provide a deeper understanding of "task context" and the reconstruction process. ACT-R is a unified cognitive theory that integrates various sub-theories of human cognitive, perceptual, and motor processes. It posits that knowledge can be represented as declarative chunks of information as well as procedural rules that act on this information. Each procedural rule checks the status of the various resources (e.g., checks for a visual item on a computer display) and then activates other resources to perform associated actions (e.g., moving the mouse to the item to select it). ACT-R also serves as a framework in which to develop computational models of user behavior and to measure behavior and performance, often with models that interact with a simulated task environment.

ACT-R theory has only fairly recently developed a more rigorous account of task context in terms of a mental resource known as *problem state* [5, 16, 17]. Problem state is the temporary information associated with the current task. For example, in computing the expression 3(2+4), a person might mentally add 2+4=6, and then multiply 3 and 6 to find the answer. While simple reactive tasks might not require problem state (e.g., tracking a moving target), most tasks do indeed require the creation and updating of problem state during the execution of a task. Research on ACT-R theory has shown that problem state can be thought of as a distinct mental resource and can be associated with the brain's parietal cortex [3, 5].

The ACT-R account of problem state has direct implications for an understanding of task interruption and resumption. Because of mental resource limitations, problem state can only be maintained for a single task at a time. When an interruption takes place, the user stores away the current task's problem state and replaces it with a new problem state for the interrupting task. Storing problem state involves rapid rehearsal of the problem state, making it decay less rapidly in memory [3]. Eventually, after the interruption, the user resumes the original task by mentally retrieving the original task's problem state from memory. The memory retrieval may require tens or hundreds of milliseconds, up to approximately one second [3]. This memory-based account nicely accounts for several phenomena in the empirical literature, including the effects of interruption duration, task type, and the presence of warnings before interruption [e.g., 13, 14, 18].

One critical aspect of the memory-based account, however, is often ignored in the psychological literature: What happens when the person fails to recall the original problem state? There may be various causes for a memory failure, most importantly the passage of time, especially since many real-world interruptions last several minutes to hours. According to ACT-R theory, memory decay will, over time, make problem-state information difficult or impossible to recall. Also, complex problem states may include many chunks of information, and as complexity grows, rehearsing and recalling all the various pieces of information becomes increasingly more challenging.

Under the account presented here, failure to recall problem state leads to a *reconstruction* of the problem state. Reconstruction begins with the creation of a new problem state in the associated brain region, which, according to ACT-R theory, requires 250 ms. Then, reconstruction for a particular domain must fill in this newly-created state with information to replicate the lost problem state. This process varies greatly by domain. For instance, if a user is interrupted while reading email, reconstruction may involve re-reading to find one's place and recalling the topic of the email. If a user is interrupted while writing a paper, reconstruction may involve re-reading text, and may also involve other activity such as scanning paper notes or phoning someone for information.

Because of the domain dependence of the reconstruction process, it would be difficult to propose a large but specific theory of reconstruction. Instead, we can specify a theoretical framework that allows us to reason about reconstruction and to account for measures of performance relevant to the process, most importantly the time to resume the primary task. ACT-R provides a useful framework for reconstruction, then, because it incorporates theories of the perceptual and motor processes (e.g., visual encoding and mouse movements) needed for reconstruction. As a methodology, one can (1) perform a task analysis of the domain in question to identify the steps needed in a reconstruction, (2) develop a computational model using ACT-R (or another cognitive architecture) to formally specify this process, and (3) run the model in simulation to account for performance measures of interest.

ILLUSTRATIVE MODELS OF RECONSTRUCTION

This methodology allows us to develop illustrative models for real-world domains in order to demonstrate a formal analysis of the reconstruction process. This paper takes as an example two tasks used in recent studies on interruption [1, 4, 10, 11]: a route-planning task and a document-editing task. The route-planning task asked users to compute distance and fare information for two routes and to select the shortest and cheapest routes. The document-editing task asked users to read through requested changes to a document and to edit the document according to these changes. While users performed these tasks, they were occasionally interrupted by a news-reading task in which they read a news article and decided on an appropriate title for the article.

One particular study [10] investigated the effects of interrupting users at the "best" and "worst" possible points of interruption. These points were found with a GOMS analysis of the tasks and determining "best" and "worst" in terms of whether the interruption occurred between higher-level subtasks (best) or within lower-level subtasks (worst). Previous work has indicated that this distinction also relates

Table 1: Interruption timing (from [10]) and reconstruction-action steps needed for the two illustrative tasks.

Task	Interruption Timing	Reconstruction & Action Steps
Route Planning	*Best*: between completing the second route and selecting the shorter route	*Reconstruction*: None (create new problem state) *Action*: Read the distances of the two routes, compare them, and move the mouse to select the shorter path
Route Planning	*Worst*: between finding information about the next trip and entering it into a table	*Reconstruction*: Find the next unfilled position in the table, read the associated cities, find these cities on the map *Action*: Move the mouse
Document Editing	*Best*: between completion of the last edit and saving the document	*Reconstruction*: None (create new problem state) *Action*: Find the File menu for saving, move the mouse
Document Editing	*Worst*: between placing cursor at editing point and typing	*Reconstruction*: Read the editing comment, read the sentence up to the cursor position *Action*: Type a character

to whether problem-state information needs to be carried over between subtasks at that point [17]. Table 1 indicates the best and worst points as defined for each of the two tasks.

A task analysis was conducted to determine the reconstruction and action steps needed for each combination of task and interruption timing. At the best points of interruption, no problem state—and thus no reconstruction—is needed; all that is needed is the creation of a new problem state associated with the new subtask. At the worst points of interruption, several steps are needed to recover the pre-interruption problem state. For route planning, the interruption occurs before entering found information into a table, and reconstruction involves re-finding this information for entry. For document editing, the interruption occurs after placing the cursor but before typing, and reconstruction involves re-reading the text before the cursor to remember what to type. These steps are included in Table 1.

While such an analysis is illuminating, it does not allow us to estimate measures of performance. To this end, each of the four combinations of task and timing were translated into computational ACT-R model. (Alternative frameworks, such as GOMS, would provide similar benefits; ACT-R is used here because it allows for better generalization to broader theories of multitasking [15, 16, 17].) The models were given approximations of the real interfaces (based on screen shots in [11]) with which to interact. They were then run in simulation using default ACT-R settings, including, most critically, the parameters governing perceptual and motor performance. By simulating the interaction between user and interface, the models generated a measure of the total time to resume the primary task; this measure of *resumption lag* represents the time needed to perform the first observable action in the primary task, and thus includes reconstruction as well as subsequent actions until the point of this first observable action (as represented in Table 1).

The resumption-lag results for both the human users [10] and models are shown in Figure 1. The human users exhibited the main result of the empirical study, namely that interruptions within subtasks (worst) are more disruptive than interruptions between subtasks (best)—note the roughly 6-second difference in resumption lag between conditions. The model reproduces the overall pattern in the empirical data, R^2=.99, and, perhaps more interestingly, provides a quantitative account of the resumption lags, *RMSE*=0.43. While the goodness of fit is, in this case, largely a result of the task analysis, the critical result is that a straightforward analysis of reconstruction steps leads to a good estimate of behavioral measures. The model also provides a breakdown of the time involved in reconstruction versus action; the model strongly suggests that reconstruction can represent a

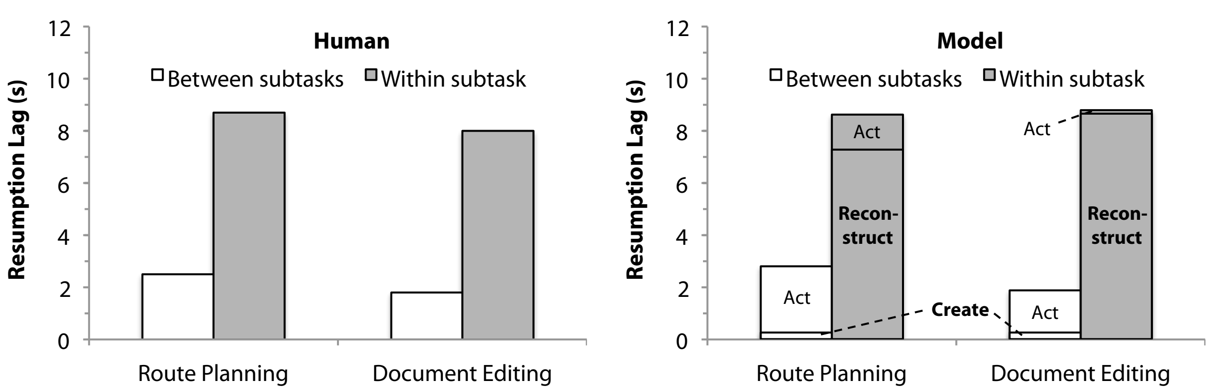

Figure 1: Resumption-lag results for human users [10] and model simulations.

large piece of the total resumption lag—in this case, roughly 7-8 seconds before any forward progress (actions) can be made on the primary task.

DISCUSSION

The human empirical results above, like other results in the HCI literature, cannot be accounted for by memory-based theories of task interruption and resumption: the resumption-lag difference of 6 seconds between conditions is too large simply to be due to a longer memory retrieval of task context. Instead, this paper argues that, for many real-world domains including common HCI tasks, reconstruction of task context is a critical and central process for resumption after interruption. Domains involving a long interruptions and/or complex mental states are the most likely to rely on reconstruction. The theoretical framework here, grounded in ACT-R theory, provides a way of reasoning about task context in terms of problem state and of specifying reconstruction processes in terms of cognitive, perceptual, and motor behavior. The computational models of two task domains illustrate how the framework and models can elucidate the underlying processes of resumption by helping to account for resumption-lag times and the breakdown in times between reconstruction and subsequent actions.

Arguably the greatest limitation for the framework proposed here is that, because of the close interdependence between task domain and reconstruction, there is no easy domain-general way of specifying reconstruction processes. It seems likely that further research could identify broader categories of domains along with general reconstruction processes for these domains; for example, domains that involve writing (like the document-editing task above) would likely require re-reading up to the last-written text to reconstruct problem state, and domains that involve form fill-in would require scanning for unfilled entries. Nevertheless, in the current state of this research, a distinct task analysis and modeling effort would be needed for each new task domain of interest.

It should also be noted that memory- and reconstruction-based resumption processes are not mutually exclusive. In fact, we might expect that part of the reconstruction process may involve cueing of relevant memories by the external environment. Re-reading the last paragraph of written text is one example in which the text cues the user to remember what points he or she was trying to make in the paper. Also, a quick scan of a partially-done task (e.g., drawing of an illustration) may remind the user of the last subtask being performed. The interplay of memory and reconstruction is not well defined at this point (empirically or theoretically), and is clearly also closely dependent on the chosen task domain. Further research that ties controlled experimental paradigms to applied task domains would provide a fruitful avenue to better understanding of these issues.

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