Goal and Spatial Memory Following Interruption

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Abstract

The process of resuming an interrupted task has been understood by task level goals (Altmann & Trafton, 2002). Recent empirical evidence has implicated spatial memory as a component of the resumption process suggesting that spatial level representations are important as well. We collected eye track data in an interruptions paradigm to examine the perceptual processes involved in resumption. Four models were created to illustrate the importance of the role of spatial representations and further, to demonstrate how the task level and spatial representations can be integrated.

Keywords: Goals; Interruptions; Cognitive Modeling

Introduction

Most computer-based tasks are described in terms of the tasks and goals that are needed to perform them. There are, in fact, many task analytic and computational methods for describing tasks and goals for computer based tasks (e.g., various GOMS methods). Another aspect of computer-related tasks that has typically received less attention is the spatial location of widgets within the task. In this paper, we explore the relationship between pure goal-based representations with spatially-motivated representations within an interruption paradigm.

Altmann and Trafton (2002) described the process of resuming a suspended goal. They proposed the activation-based Memory for Goals theory, which includes three constraints: (1) the interference level, (2) the strengthening constraint, (3) and the priming constraint. The constraints determine what goal will be most active in memory at any given time. The Memory for Goals theory proposes that the question "What was I doing" is cognitively equivalent to the retrieval of the highest activation goal memory. In general, the memory for goals theory focuses on the memory representations and processes that occur while resuming a goal and leaves unspecified any influence of spatial cognition.

Later research suggested that memory for goals was associated with at least a general memory for spatial location (Ratwani & Trafton, 2006) in simple computer-based tasks. Determining spatially where in the primary task one was prior to being interrupted was an important component when resuming an interrupting task.

Based on the memory for goals theory and additional empirical data, Ratwani and Trafton suggested several different strategies for how people resume an interrupted task: (1) restart the (sub-)task, (2) use an environmental cue, (3) and use a spatial memory for the location.

Ratwani and Trafton's results showed that participants resumed their task by perceptually retracing their steps they looked at what they had already accomplished, and then continued. The task that was used (described below) allowed Ratwani and Trafton to separate pure perceptual retracing and a spatial component. They found that spatial memory (specifically memory for spatial location) was being used as part of the resumption process after an interruption. The data showed that spatial memory was an important part of resuming a computer-based task after an interruption, but it did not specify the exact mechanisms or representations of the spatial memory or the relationship between spatial and task-related goal memory.

The different strategies for resuming an interrupted task rely on different aspects of the environment and memory. One obvious strategy is to retrace one's steps from the beginning of the task until the point where one was interrupted is reached. This is essentially a restart strategy and there is some direct evidence for restarting a suspended goal in the interruptions literature (Miller, 2002). This is an example of a more general strategy of using the structure of the task to determine where to resume the task.

A second possibility for resuming a task is that participants may use some type of environmental cue to resume the primary task (Altmann & Trafton, 2002; Trafton, Altmann, & Brock, 2005). In the task used in the experiment described here, there was an environmental cue (described below) that provided accurate information about what actions had been performed prior to the interruption, but less accurate information about the spatial location where the interruption had occurred.

Finally, memory for spatial location might be used to return to where one was in a task prior to being interrupted. Recent research in the visual search domain has shown that memory representations for the location of objects can be maintained over a delay (Lleras, Rensink & Enns, 2005). Further, the ability to remember approximate spatial information has been observed in computer based tasks (Ehret, 2002). Memory for spatial location may be represented at two levels: a fine grained level whereby one may be able to recall the precise location of an object as well as a more general category level whereby one can identify the region which contained an object (Huttenlocher, Hedges, & Duncan, 1991). While Ratwani and Trafton (2006) suggested that a memory for approximate spatial

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14. ABSTRACT
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location was used to resume after an interruption, the specific process of this mechanism has not been elaborated. The spatial memory strategy requires that there is an association between the memory of what the interrupted goal was, and spatially where the interruption occurred

The ACT-R cognitive architecture has been used to model experiments in a number of psychological domains. ACT-R 6.0 is the latest software implementation of the ACT family of theories of cognition (Anderson & Lebiere, 1998; Anderson et al. 2004). The ACT-R theory distinguishes between declarative knowledge, which people are aware of and can describe to others, and procedural knowledge, which may be unconscious but can be demonstrated in behavior. Declarative knowledge is represented in the architecture as chunks with pairs of slot and values, while procedural knowledge is represented by production rules with sets of conditions and actions. ACT-R's perceptual-motor modules allow models to interact with computer interfaces.

A goal module represents current cognitive intentions and helps to organize and direct behavior towards the fulfillment of those intentions. Cognition unfolds within ACT-R as the serial firing of production rules that manipulate or make requests for chunks from modules through dedicated buffers. ACT-R allows researchers to model cognitive processes and collect quantitative measures that can be compared directly with quantitative measures of human performance.

In order to explore the role of spatial memory after an interruption and to explore the relationship between spatial and task-related memory, we improved the methodology used by Ratwani and Trafton (2006). We also built ACT-R models of the three strategies that could be used to resume an interrupted task (restart, environmental cue, and spatial memory). We expect that the experiment itself will replicate Ratwani and Trafton's earlier finding that spatial memory is implicated in the resumption task, and we expect the model that uses spatial memory to show the best fit to the data. The models will also allow us to explore which of several cognitively plausible spatial representations are most likely being used in computer-based tasks.

Experimental Method

Participants

Nineteen George Mason University undergraduate students participated for course credit.

Materials

The primary task materials consisted of columns of numbers; each column contained 11 three digit numbers ranging from 100-999. Fifteen unique templates containing slots specifying which numbers were to be even or odd and the location of these numbers were used to generate the columns of numbers, each template had at least five odd numbers. Based on the templates, two sets of 15 columns of numbers were created for presentation. The specific numbers that filled the slots in the template were randomly generated for each participant. Each number subtended .6º of visual angle, each cell subtended 2.9º and each number was separated by 2.3º of visual angle.

The interrupting task was a list of 10 addition problems each containing four single digit addends ranging from 1-9. The addends were randomly generated for each interruption.

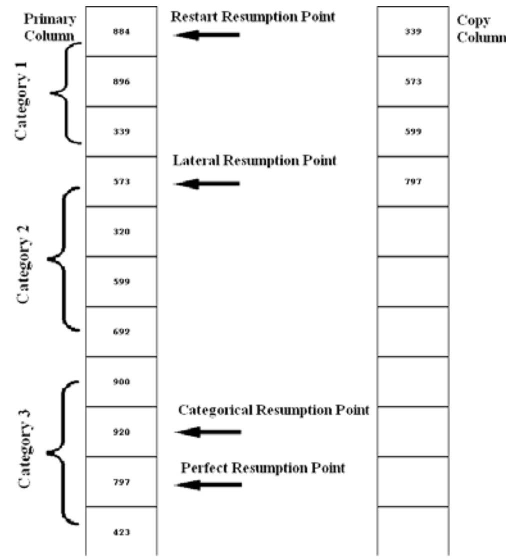

Figure 1. The experiment primary task.

Design

A within subjects design was used; one set of 15 columns served as interruption trials and one set as control trials resulting in a total of 30 trials per participant. This allowed for matched trials between the two conditions. Presentation order of the all the trials was randomized. Each interruption trial contained a single interruption which occurred equally among three positions in the task (early, middle, and late).

Procedure

Participants were seated 50 cm from the monitor. Stimuli were presented using E-Prime (Schneider, Eschman, & Zuccolotto, 2002). The primary task required participants to type the odd numbers from the primary column into a separate copy column (see Figure 1). Because only the odd numbers from the primary column were typed into the copy column the vertical position of the odd numbers in the copy column was generally different from their corresponding position in the primary column. The participants were instructed to start at the top of primary column and to work their way down to the bottom. Upon completion of the column the participant pressed the space bar in order to move on the next trial.

On the interruption trials the interrupting task immediately appeared and fully occluded the primary task screen. During the 15 second interruption participants were instructed to answer as many addition problems as possible. Upon resumption of the primary task, the copy column of previous responses was still displayed. The location of the last number entered in the copy column could serve as a cue as to where to resume in the primary column. However, as discussed above, because the vertical positions of the odd numbers in the primary and copy column may have been different, this position in the primary column may not be where the interruption occurred.

Measures

Based on the reaction time data we calculated an inter-action interval (IAI) for control trials and a resumption lag for interruption trials (Altmann & Trafton 2004). The IAI was the average amount of time between actions (i.e. the average amount of time in between entering odd numbers). The resumption lag was the duration of time from the completion of the interrupting task to the first action back on the primary task (e.g. entering an odd number). Eye track were collected using a Tobii 1750 operating at 60hz. Each of the cells in the original and copy columns was defined as an area of interest. A fixation was defined as five samples.

Model Descriptions

In order to examine the process of resuming a primary task following a secondary task interruption, we constructed a series of models using the ACT-R 6.0 cognitive architecture (Anderson & Lebiere, 1998; Anderson et al. 2004). These models systematically explored the three high-level strategies identified by Ratwani and Trafton (2006): (1) restarting the task, (2) using the spatial location of an environmental cue, (3) and using a spatial memory for the location of the interruption. Four models were selected as implementations of the high-level strategies. One model each represented the restart and lateral strategies, and two models represented spatial memory strategies, one for general location and one for specific location.

Although the models and the experimental participants did not use the exact same task environment, they shared all the critical features. The model task environment was written in LISP. The pixel coordinates of the stimuli in the models' visual environment (the visicon in ACT-R) matched the coordinates of the stimuli in the experimental task environment. The 15 patterns of even and odd three-digit numbers, each used once in a control trial, and once in an interrupted trial, were the same. The order of trial presentation, and the exact even and odd numbers used, were randomized, as in the experiment.

Commonalities Between Models

The productions that modeled performance in the primary and secondary task were identical in all of the models. Additionally, approximately two thirds of the resumption task productions were common to all of the models. Table 1 lists the steps that occur between the end of the interruption and the end of the resumption. The task resumption process was broken into three parts for all models: (1) cue use, (2) search, and (3) primary task resumption.

Table 1: Breakdown of Overall Resumption Process

Step	Breakdown Component
End of Interruption	
1. Determine task	Cue Use
2. Find cue	
3. Retrieve goal	
4. Determine resumption point	
5. Find resumption point	Search
6. Find interruption point	
7. Find next primary task	Primary Resumption
8. Next primary task action	
End of Resumption	

The cue use portion of the resumption breakdown (Table 1, steps 1-4) incorporated the use of the environmental context to determine what task to resume and where to resume that task. In the experiment, the sudden onset of the interruption caused participants to suspend the goal of completing the primary task, entering odd numbers, and begin the secondary task, simple addition problems. Model subjects determined that the task had changed, what the new task was, and where to begin that task. In the models, the change to the visual environment (the visicon in ACT-R) caused the models to change the active goal from the odd numbers task goal to the addition task goal.

Ratwani and Trafton (2006) found that in nearly every resumption case, participants looked at the cue (i.e. the last number entered) prior to looking at the primary column of numbers. Likewise, in all of the models, the cue use portion of the resumption process involved attending to the last input odd number in the copy column and retrieving related chunks from declarative memory (see Figure 1). As suggested by Altmann and Trafton (2002), all models then retrieved the interrupted primary task goal. Different models used different strategies to determine an initial visual-location in the primary column, called the resumption point.

In the experiment, participants had to resume the primary task of entering odd numbers following the interruption. To do this, participants had to find the location in the primary column of the last odd number they entered, called the interruption point. In all of the models, the search portion of the resumption process involved finding the location of the interruption point (Table 1, steps 5-6). Exactly where the model started searching, the resumption point, was a major difference between models. The search proceeded from the resumption point to the interruption point by searching down the primary column in all of the models.

In the experiment, the end of the resumption process was demarcated by the first key-press following the interruption. The first key-press was the first digit of the next odd number in the primary column. In the models, the primary task resumption portion of the resumption process (Table 1, steps 7-8), involved finding and entering the next odd number in the primary column. This process was exactly the same in all of the models and was exactly the same as the primary task.

All of the models used the default ACT-R 6 parameter settings, except for the maximum associative strength (mas) parameter. The mas parameter controls the amount of spreading activation from the chunk representing the environmental cue to the chunk representing the primary task goal. The mas value of 15 was used in all models. This value is slightly higher than other ACT-R models because we were attempting to implement the priming constraint from Altmann and Trafton (2002).

Differences Between Models

The models differed primarily in the process of determining the resumption point (Table 1, step 4), the starting point of the search for the interruption point. The models: (1) restart, (2) lateral, (3) perfect spatial memory, and (4) categorical spatial memory, simulated different strategies for using information, from the task environment, and from memory, to determine the resumption point. These strategies resemble the high level strategies outlined by Ratwani and Trafton (2006).

The restart model always used the top of the primary column as the resumption point. This represents the high-level strategy of using the structure of the task, in this case the spatial location of the first sub-task, without any memory for the spatial location of the interruption, to determine the initial location in the primary column.

The lateral model always moved laterally from the copy column to the primary column. The resumption point was the number in the primary column at the same vertical position as the cue in the copy column. This represents the high-level strategy of using the spatial location of the cue, without any memory for the spatial location of the interruption, to determine the initial location in the primary column.

Spatial memory strategies use memory for the spatial location of the interrupted goal to determine the resumption point. These strategies used the cue to prime the retrievals of the goal that produced the cue, and the spatial location associated with the goal. Two models represented this category of strategies. One represented perfect memory for the exact visual location of the interruption point; the other represented general memory for the categorical location of the interruption point (Huttenlocher, Hedges, & Duncan, 1991).

The categorical spatial memory model used memory of the categorical spatial location of the interrupted goal to determine the resumption point. The screen was divided into 3 approximately equal spatial categories: top, middle and bottom. The resumption point was set to be the middle of each spatial category. Depending upon the location of the interruption point within the spatial category, the resumption point was either above, below, or the same as the interruption point. The search direction switched from down the column to up the column when the bottom of the column, or the next category center was reached. [1]

Experimental Results and Discussion

The resumption lag (m = 3755.8) was significantly longer than the inter-action interval (m = 1740.7), $F(1,18) = 96.8$, $MSE = 381715.9$, $p<.001$, showing that the interruptions were disruptive to primary task performance.

The eye track data were examined to explore the perceptual and spatial processes that people used as they resumed the primary task after the interruption. The focus was on the location of fixations to the primary column of numbers during the resumption lag. If participants were starting the task over again, their first fixation to the primary column should always be to the top of the primary column. In 99% of the interruption trials, participants fixated somewhere other than the top of the primary column, suggesting that participants were not starting the task over after the interruption.

Next, we examined whether participants were relying strictly on a cue to resume the primary task. Participants consistently (~99% of the time) looked to the number they last entered in the copy column immediately upon resumption of the primary task. The location of the last entered number could be used as a cue to guide them back to where they left off in the primary column. For example, participants could fixate on the cue to determine the number they last entered and then saccade directly across to the corresponding position in the primary column and continue from that point. If participants were relying on the cue to resume, the first fixation in the primary column after the interruption should be to the same cell number as the location of the cue (i.e. if the cue was in cell 6, one could resume at cell 6 in the primary column). If participants were relying strictly on the cue the average location of the cue should be the same as the average location of the first fixation on the primary column. The average cue location (m = 3.3) was significantly different from the average location of the first fixation to the primary task (m = 4.9), $F(1,18) = 56.7$, $MSE = .418$, $p<.001$. Thus, participants did not rely strictly on the cue to resume the primary task. Based on these results, participants did not seem to be using either a restart strategy or using the cue as a position marker. We next explore experimental evidence that participants were using a spatial strategy.

In order to examine how accurate participants were at returning to where they left off, the initial fixation to the primary column after the interruption was compared to the cell location of the number that was last entered prior to the interruption. For example, if the interruption occurred at cell 6 and the participant returned to cell 4 this distance was calculated as -2. This difference was calculated for each

1. We created a series of models that contained different instantiations of the models – different numbers of categories, top, or middle restarts, etc. We are only presenting the best fitting models in all cases.

interruption trial for each participant to determine how close participants were able to resume. A distribution of these values showed that participants were able to return to within 2 cells of where they left off in over 60% of the cases. This strongly suggests that participants were using some kind of spatial memory to resume. Note that these results replicate the earlier Ratwani and Trafton (2006) finding that people seemed to be using some sort of spatial memory to facilitate resumption of the primary task.

What is clear from this data is that participants are using some type of spatial memory to help them resume the primary task. What is less clear is the type of and representation of spatial memory that participants are using. Our goal in modeling this task was thus twofold: (1) To build an explicit model of resumption for a simple task and (2) To explore different types of plausible spatial representations and strategies to better understand the nature of spatial cognition both within an interruption task and spatial cognition more generally. To the extent that a specific spatial model fits the pattern of experimental data well, it would provide support that people are using that type of spatial representation and spatial strategy during the resumption process.

Model Results and Discussion

The results from the model simulations were compared to the experimental data. By comparing the overall resumption lags in Table 2, a general sense of which model more closely fits the experimental data can be observed.

Table 2. Resumption Lag experimental and model data with model fit statistics.

	Total RL	Cue Use	Search	Primary Resumption	R^2	RMSD
Experiment	3.76	0.79	1.46	1.60	-	-
Restart	6.07	0.77	3.61	1.69	.40	1.24
Lateral	4.64	0.77	2.19	1.68	.75	0.42
Perfect	2.97	0.99	0.30	1.68	.02	0.69
Categorical	3.70	0.83	1.24	1.63	.88	0.13

Note: The total resumption time was not included in model fit statistics since individual components were. Model and data fits based on (Schunn & Wallach, 2001).

The true differences between the models can be seen by comparing the resumption lag components. The overall experimental resumption lag was broken down into these components as well in order to compare the models to the data. The cue use time reflects the amount of time spent looking at the last number entered in the copy column. Search time reflects the amount of time used to find where one last left off in the primary task prior to the interruption and the primary resumption is the amount of time until the next odd number is entered once one is back on track (i.e. they have found where they left off). The fit statistics comparing the models to the data are based on these three components. Notice there is little variability between models in terms of cue use and primary resumption because the models use the same productions for those processes; differences are accounted for by random noise in the model. The search time is the critical component that differentiates between the models. The point at which the model first attends to the primary column upon resumption is the driving factor behind the search time and the process for how each model determines this resumption point is different for each model. The 4 models will be discussed in turn, focusing on the non-spatial models first, then moving to the spatial models.

Non-Spatial Models

The restart strategy results in the longest search time since the model always attends to the top of the primary column. This search time also has the largest deviation from the experimental data amongst all of the models. Empirically, the restart model is the furthest from the experimental data and results in an approximately 2 second longer resumption lag. This model shows that people are not consistently starting over their sub-task.

The lateral model produces a fit with data that is much better than the restart-strategy model (see Table 2). This model relies strictly on the cue and attends to the cell in the primary column that is directly across from the location of the cue. This model performs well for interruptions that occur early in the primary column of numbers since the correct resumption point in the primary column is near the location of the cue. However, for interruptions which occur later in the task (e.g. cell 8), returning to where the cue is may result in a rather long search time. Consequently, this model has a relatively decent fit to the data, but does not have the best fit because of the increased search time when the primary resumption point is not near the cue. Note that in our current experiment the cue moved spatially – it progressed as people entered numbers. In an unreported follow-up experiment, participants entered a cue that did not move at all. In this case, the lateral strategy is identical to the restart strategy. We are currently running our current models on the “stable” cue experiment.

Spatial Models

The perfect spatial memory model perfectly remembers the spatial position before the interruption and returns there upon resumption. Not surprisingly, it has the shortest search time and the fastest resumption lag. This model suggests that people do not use perfect spatial memory to resume an interrupted task: their spatial location memory is approximate at best. So what type of imprecise spatial memory do people have?

We instantiated a categorical spatial memory model that divides the primary column of numbers in to three general regions of space (i.e. top, middle and bottom). The categorical model comes closest to matching the experimental data, as seen in Figure 2. This model returns to the center of the spatial category, but still has to search within the category to find the specific resumption point. This within category search produces a much smaller search time relative to the other models and search time that is much closer to the experimental data.

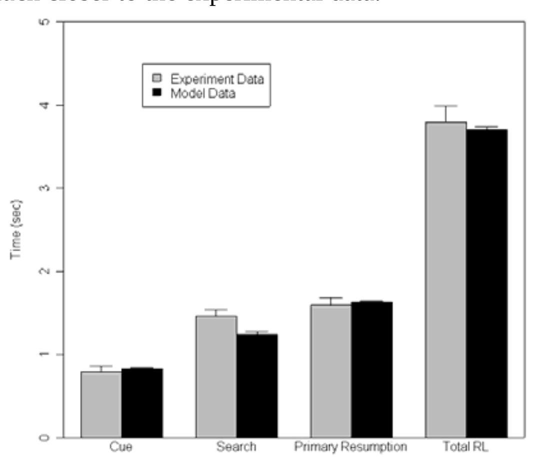

Figure 2. Experiment and categorical spatial memory model comparison.

While the spatial category model is closest to matching the experimental data in regards to the resumption lag breakdown, this gives no indication of how well the specific resumption points from the model match the actual experimental data. We generated a distribution of resumption point differences for the model just as we did for the experimental data. Differences at this level pinpoint some of the weaknesses in the spatial category model. First, the distribution based on the model is narrower than the distribution based on the experimental data. The experimental data showed that participants were able to return to within 2 cells following the interruption in over 60% of the cases; the model returns to within 2 cells in 100% of the cases. Since the model always resumes at a point within the category that it first attends to, the range of resumption points is limited by the size of the category. Thus, the inaccuracies of the model are fixed by the boundaries of these categories. Second, the experimental data is centered on -1 while the model resumes at a point centered on 0, which is perfect resumption. In the experimental data, participants tend be more conservative in where they resume, generally resuming a few cells back from where they left off. Participants may be biased towards a conservative resumption because of the relatively high cost of resuming ahead of where they once were (i.e. liberal resumption). A liberal resumption is costly in terms of search time for participants because they spend time searching ahead of where they were and prior to being interrupted and then have to search backwards. The model resumes at the center of the category with no bias towards a conservative or liberal resumption.

General Discussion

This paper examined the relationship between task memory and spatial memory by examining the role of spatial location information in an interrupted task. Our experiment showed that spatial memory is implicated in resuming a computer-based task. Our spatial category model showed that both task memory and spatial memory are implicated in resuming a computer-based task. Additionally, our model showed that spatial location memory is approximate, not exact.

From a subgoal-resumption point of view, our model and data also suggest that the memory for goals model should be modified to include a spatial location component. Note, however, that our model does not suggest that spatial location is embedded into every goal. Rather, it suggests that spatial location can be retrieved through associative activation when needed.

Human performance may involve a combination of strategies, rather than the consistent application of a single strategy for resuming an interrupted task. The selection of a particular strategy may not be random, but may depend on aspects of the environmental context of the interruption. One way to improve this model would be to combine several of the strategies that were used in a pure sense in this report.

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