Evaluation Methods for Comparing Memory and Communication of Analytic Processes in Visual Analytics

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ABSTRACT
Provenance tools can help capture and represent the history of analytic processes. In addition to supporting analytic performance, provenance tools can be used to support memory of the process and communication of the steps to others. Objective evaluation methods are needed to evaluate how well provenance tools support analyst's memory and communication of analytic processes. In this paper, we present several methods for the evaluation of process memory, and we discuss the advantages and limitations of each. We discuss methods for determining a baseline process for comparison, and we describe various methods that can be used to elicit process recall, step ordering, and time estimations. Additionally, we discuss methods for conducting quantitative and qualitative analyses of process memory. By organizing possible memory evaluation methods and providing a meta-analysis of the potential benefits and drawbacks of different approaches, this paper can inform study design and encourage objective evaluation of process memory and communication.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation (e.g., HCI)**]: User Interfaces – *evaluation/methodology*.

General Terms
Experimentation, Human Factors.

Keywords
Process provenance, memory, evaluation, visual history

1. INTRODUCTION
Visual analytics applications provide an interactive means of exploring data and making sense of information, with tools giving analysts the flexibility to approach problems in any number of ways. Many analytic investigations are inherently complex processes due to the size and complexity of available data sets and the nature of hypothesis testing. The resulting complexity and potential variability in human analytic processing can make it difficult to remember the steps and rationale that led to the formation of hypotheses, the generation of specific data views, and the realization of conclusions. Obviously, process uncertainty can lead to problems, such as when an analyst needs to recall their steps weeks or months after an investigation to review rationale or explain the process to management or other analysts.

It is not surprising, then, that researchers have designed process provenance tools to help capture and visually represent the history of analytic processes [11, 15]. For example, *VisTrails* is a provenance tool that helps track the progression of exploratory visual analytics of scientific data over time [4, 6]. The tool logs the computational steps taken to create different visualizations and generates visualizations of workflow history. Providing analogous functionality, the *GraphTrail* system records and presents analysis pathways taken during exploration of network data [10]. Another visual analytics tool, *CzSaw*, supports provenance of text document analysis with dependency graphs that visualize entity relationships [19]. *CzSaw* also supports visual history by showing the data views that were open at different times throughout an analysis.

Such analytic provenance tools can serve multiple purposes [16]. While conducting an analysis, workflow logs allow analysts to reference previous stages of an analysis to help keep track of data manipulations or explored hypotheses. In complex analyses that consist of multiple analysis sessions or extend over long periods of time, reviewing earlier steps can help an analyst clarify memories of past actions and current goals. In addition to supporting the analytic process itself, provenance tools can be used to help communicate the steps of the process to others. It would be expected that having better memory of process would make it easier to communicate that process, and visual representations of the process history might be expected to be especially well suited for communication purposes.

Though many provenance aids exist to support analysis and memory, how do analysts, researchers, and developers know if the tools are effective? From an intuitive standpoint, we could say that tools can be considered effective if analysts find them helpful and continue to use the tools over time. While such a standard makes some practical sense for determining the usefulness of single tool, it is less helpful for improving design and understanding which of the tools' features are most helpful. Objective methods are needed to evaluate how well provenance tools support analysis performance, memory, and communication. Many researchers have conducted studies to evaluate analytic performance, with traditional metrics including task time, instances of insight, and correctness of analytic findings as compared to known solutions [e.g., 1, 2, 13, 22]. However, few attempts have been made to objectively evaluate memory and communication of analytic processes. In this paper, we present several possible methods and discuss the advantages and limitations of each.

2. BACKGROUND
Controlled studies are commonly used for evaluating how particular applications or features affect performance on analysis tasks. When paired with quantitative evaluations, controlled studies are well suited for formal statistical analyses to help present results. The drawback is that ecological validity is often sacrificed for increased control, and analysis tasks are often

simplified to ease evaluation. In addition to controlled studies with focused tasks, the use of qualitative methods and case studies can be invaluable for understanding how visualizations are used in realistic and meaningful contexts [21]. Qualitative methods, such as those that apply grounded theory, can provide useful and holistic analyses of visual analytics applications [18].

A number of researchers have included evaluations of process history and provenance tools in their work. For example, Dunne et al. [10] conducted a three-month field study with archaeologists to understand the practical effectiveness of their *GraphTrail* visualization and to gain insights about how users build visual history maps. The researchers also conducted a qualitative lab study to better understand how analysts might use the tool's history tracking functionality. Taking a different approach, Heer et al. [15] analyzed user interaction logs for the *Tableau* visualization software to better understand how users used the undo/redo functionality when working with visual history interfaces.

These studies demonstrate how case studies, qualitative evaluations, and log analyses can be valuable for understanding how analysts use process-tracking tools. However, other methods are needed in order to objectively quantify tool effectiveness or to formally compare specific design options. The challenge is that it is difficult to evaluate the degree to which process history is beneficial. It is possible to evaluate the effects of analytic history tools on analysis performance by considering analysis outcomes. For instance, Del Rio and da Silva [8] conducted an evaluation of *Probe-It!*, a provenance visualization tool that shows how maps were created via tree representations showing workflow and contributing information sources. Their study found that the majority of participating scientists successfully completed map analysis tasks with the help of the provenance tools, and far fewer successes were observed without the provenance aid.

While evaluation of analysis outcomes can be useful for determining the effectiveness of provenance visualizations during analysis, real-time support for analysis is just one of the potential benefits of provenance tools. Quality of analysis performance is not indicative of the quality of *memory* of the analytic process at a later time, which is often necessary for repeating the analysis or communicating the steps to others. The analytic process used by a particular analyst to achieve a given goal will often be a unique approach. Further, many analyses and investigations are exploratory in nature, leading to nonlinear processes involving backtracking and multiple lines of logic. Gotz and Zhou [12] explain that the concept of *insight provenance* involves both the history of steps and their rationale during an analytic process. Analysts should be able to reproduce the logic and approach taken to achieve insights and reach a conclusion. Memory of the analytic process is important for accurate communication, such as during collaboration or for presentation. In our work, we are studying methods for evaluating how visual design influences the quality of memory of process and rationale.

Communication of the analysis process is not necessarily the same as presentation of the results or conclusions of an analysis. Results presentations generally involve the final logic and rationale to justify how that data were interpreted, whereas process communication is more concerned with explaining the steps taken to analyze the data and arrive at the conclusions. Process communication is important for collaborative work or meta-analysis of an analytic approach. It can be useful to know which data and hypotheses were considered and which were not.

While evaluation-based research of memory of process history is limited in visual analytics, research in workflow support and personal information management is relevant to evaluation methods for memory of events and processes (e.g., [7, 17, 20]). Czerwinski and Horvitz [7] conducted research with visual reminder systems to aid workflow memory. In a small user study, the researchers recorded participants for an hour of regular computer work. Later, participants were asked to write down the events that happened during that hour. Participants provided their written memories after 24 hours and then again a month later, and the researchers used the written accounts to assess the number of correctly recalled events and the accuracy of the given times of those events.

In a study with a similar type of reminder tool, Park and Furuta [20] evaluated a tool that saved continuous screenshots of computer work and allowed users to browse the history of images. Because the researchers were focusing on supporting task continuity after workflow interruptions, their evaluation consisted of an activity (making travel plans) that was divided over two work sessions separated by one or two days. To evaluate the tool, the researchers measured how long it took participants to resume the task and start new work at the beginning of the second session. This method evaluates memory based on the time it takes to review and refresh workflow memory and to be able to use that memory to make further progress. The approach demonstrates practical usefulness, though the evaluation criterion is based on a participant's somewhat subjective decision of how much review is necessary. In the following sections, we discuss other methods suitable for evaluating the accuracy of process recall.

3. EVALUATING PROCESS MEMORY

Memory and communication of a process can be assessed by comparing a recalled process to the ground truth process. The goal is to account for specific actions and the rationale for using those actions to move towards an objective. The primary outcomes include accuracy of remembered steps, step ordering, and time estimates for the duration of steps or the entire process. In this section, we discuss methods for establishing a baseline process for comparison with a remembered process, and we discuss methods for evaluating process memory and communication.

3.1 Establishing Ground Truth

In order to accurately evaluate memory of analytic processes through experimentation, a baseline is needed to serve as ground truth for comparison. Ideally, the baseline process summary will serve as a record of the steps involved in the analysis in the order that they were executed. Additionally, an accurate event timeline of events would also account for the duration of each step, making it possible to compare times with the perceived times spent on different stages of analysis. Depending on the desired level of granularity for process memory, the ground truth process could consist of a detailed list of all actions in the analysis, a thematic list of higher-level stages of the process, or anywhere in between. In addition to the actions or steps taken, a baseline that accounts for the participant's rationale makes it possible to also evaluate memory of logic and intent throughout the process.

3.1.1 Prescribed Baseline

The challenge with creating an accurate baseline is that each participant's process will be different for any real analysis. Creating a ground truth consistent across participants would require an approach that required all participants to conduct the analysis in the same way. This could be achieved by asking participants to follow a given procedure or to observe a pre-

recorded analysis. Such an approach would greatly simplify the evaluation and increase experimental control. On the other hand, forcing analysts to follow and remember a predetermined process is not realistic, and the results of such an evaluation may not be as meaningful as one that allows true analytic autonomy.

Further, using a prescribed process eliminates the need for analysts to have any rationale for choosing each step, so evaluation of memory of the participants' intent or rationale would not be meaningful with this approach. It would be possible to provide a summary of contrived rationale at different steps of a given process, but this would reduce realism because study participants would be remembering arbitrary explanations rather than their own thought process from an actual critical-thinking activity.

3.1.2 Individualized Baseline

An alternative to a prescribed, consistent baseline is to create a customized baseline for each individual based on his or her actual process. Formalizing the steps of an analytic process is not unknown territory in the visual analytics field—researchers have shown a number of methods for recognizing steps of analyses. For example, think-aloud protocols require analysts or study participants to verbally explain their thoughts and actions throughout the analysis, providing a record of the both the steps and rationale of the process [3, 5]. In their research of provenance tools, Dou et al. [9] demonstrated the effectiveness of video, think-aloud protocols, and system logs to detail analytic processes. The researchers found that system logs were able to account for approximately 79% of the findings identified by the traditional video and think-aloud methods.

The advantage of using individualized baselines over a prescribed baseline is that it supports more realistic analysis and can account for process variability among different analyses. On the other hand, this natural variability of individualized baselines may result in reduced experimental control for the evaluation. Another drawback is that the individualized approach can take extra time to establish the baseline after reviewing an analysis session. It is important to establish a protocol for determining individualized baselines from the collected process data, and this alone can be challenging. System logs and think-aloud methods can reduce the amount of time needed to identify key events or actions in the analysis, but most types of analysis will still need additional review and coding to determine the baseline.

3.1.3 Self-Reported Baseline

If we are most interested in evaluating process memory or communication at a later time, it is possible to ask the analysts or participants to self-report their processes immediately after the analysis. The self-reported summary could then be used as a baseline for later comparisons. The advantage of self-reports over coding is that self-reports allow for a ground truth based on what participants think they did, rather than what coders think they did.

Unfortunately, the problem with self-reporting approaches is that memory degrades quickly, and even immediate post-analysis reports might not be accurate descriptions of the actual processes. Further, accuracy and reliability of self-reports can be limited by participant communication abilities. From our own experiences and tests thus far, we have found these to be common problems; thus, we do not recommend the use of self-reporting for a process baseline. However, self-reports can still be useful for explaining rationale or highlighting key steps that can be considered along with video coding, think-aloud updates, or lots to help determine individualized baselines.

3.1.4 Summary of Baseline Trade-offs

Each of the described methods for establishing ground truth of the analytic process has its advantages and disadvantages. Table 1 shows a simplified organization of the trade-offs among the prescribed, individualized, and self-reported baselines. A prescribed baseline is ideal for a consistent process and supports the highest level of experimental control, but a prescribed analysis severely restricts the realism of an analytic process, which may be a serious concern for ecologically valid studies of provenance tools. Individualized baselines are a promising for high analytic realism but at the cost of effort and some control. The choice of an appropriate approach for a particular study depends on the goals and priorities of that study, and either an individualized or a prescribed approach could work well in an evaluation of process memory. On the other hand, our experiences have shown that self-reported baselines have a major disadvantage of low reliability, which presents a high risk of invalidating an evaluation. Consequently, we recommend against the use of self-reported ground-truth for evaluation of process memory.

Table 1. Trade-off summary for three methods of establishing a ground truth baseline for process memory. High strengths for factors are denoted with +, moderate strengths are denoted with o, and weaknesses are denoted by −.

	Type of Ground-Truth Baseline		
Factors	**Prescribed**	**Individualized**	**Self-reported**
Cost & Time	+	–	o
Control & Reliability	+	o	–
Analysis Realism	–	+	+

3.2 Eliciting Process Memory

Once ground truth has been established, it is possible to compare a memory or communication of the analytic process with the baseline. Process memory can be assessed based on accuracy of the remembered analysis steps, the order of those steps, and the time taken to complete each step. In this section, we discuss methods for eliciting process memory.

3.2.1 Process Reproduction

A thorough way to assess memory of a process is to require an analyst to repeat the analysis process for the same analytic task using the same tools. For the evaluation of provenance tools, participants would be able to use the tools to help them to recreate the steps of the analysis. This *process reproduction* method has the advantage of allowing highly accurate process replications, which can then be compared to original tool usage and executed actions in the baseline analysis. Because the method for process recall would be the same as the original analysis method, the same coding method could be used for both the baseline and reproduction analyses (though provenance-referencing steps would have to be filtered out from the reproduction phase if provenance tools were available in the memory elicitation analysis).

The process reproduction method can account for both accuracy and order of steps. On the other hand, reproduction may not be

appropriate for assessing process times because it would be expected that steps could be completed faster during the second time through. Additionally, if it is possible to rely on provenance aids to recreate actions, the reproduction might not be useful for evaluating memory of rationale for the actions. To mitigate these weaknesses, the reproduction approach could be augmented by asking participants to explain the rationale for each step and to estimate the time taken for steps. The given rationale and times could then be compared to those of the original analysis as determined by think-aloud protocols or post-analysis interviews.

A major disadvantage of the reproduction approach is that reproducing an entire analysis can be time consuming, which can significantly increase the cost of the evaluation. Also, because process reproduction relies primarily on actions, this approach does not account for communication.

3.2.2 Written or Verbal Walkthrough

Rather than having analysts or participants reproduce the analysis, another option is to ask the participants to walk through the steps of the analysis. For many types of analysis, this approach can be faster than full reproduction. Similar to the reproduction approach, *written or verbal walkthroughs* accounts for free recall of steps as well as order. Additionally, participants' reports can include time estimations.

Walkthroughs are dependent on communication ability, which can be viewed as an advantage if process communication is a major element of interest. But the dependency on communication ability undoubtedly adds complexity to the walkthrough method. A consistent interview protocol is needed for eliciting details, and responses will need to be coded for comparison to the baseline process. Some people are likely to be more inclined to give more details than others, so consistency can be a challenge. While an interviewer can help encourage a participant to provide additional details in a verbal walkthrough, collecting sufficient details may be more problematic with a written report without a moderator. Further, clearly accounting for content and order can be difficult for both written and verbal methods. Descriptions are often not chronological—people will add more details as they remember them, so the coding effort will need to construct a coherent chronology from the given events.

3.2.3 Step Ordering

The reproduction and walkthrough methods both require participants to recall the steps of their processes, which makes the evaluation of order dependent on recall. The *step ordering* evaluation method avoids this problem by eliminating free recall of steps and focusing only on order. In step ordering, the ground truth process must first be coded and broken down into key steps for each participant. Then, to evaluate memory of order, the participant or analyst is asked to organize the steps of the process into the correct ordering. This could be done, for example, by labeling index cards or using a simple software application (such as PowerPoint) that allows ordering labeled items. The given order can then be easily compared to the true order of the baseline process (as will be discussed in 3.3.2).

The primary advantages of the step ordering method are that it is fast, easy to quantify, and maintains a fairly high level of control for assessing order recall. One disadvantage is that it may likely involve more recognition than recall because it gives participants the correct steps. Furthermore, it may be possible to guess a plausible order based on available steps. If the progression of steps is obvious, the evaluation will not be useful. In addition, the step ordering method is generally not well-suited for assessing immediate post-analysis memories because it requires time to code and break down the key steps (unless the analysis relies on a prescribed process, rather than a free analysis).

3.2.4 Modified Step Ordering

As an alternative to conducting step ordering by providing only the correct steps from the baseline process, a *modified step ordering* method can introduce extraneous steps into the set of steps to be ordered. Analysts or participants can be told that some of the steps are wrong or extra, and they will have to both recognize and order the correct steps. The advantage to this modified step ordering approach is that it could make the correct ordering less obvious. Additionally, this method makes it possible to include a measure of recognition accuracy based on the inclusion or exclusion of erroneous steps in the guessed ordering.

The drawback of the modified step ordering method is that it increases complexity of the evaluation and reduces control. It could be difficult to determine what extraneous steps to add. If the extra steps are created from a set of plausible steps for the analysis task and data set, then all participants might not be able to have the same additional steps. Again, the exception would be if a prescribed analysis process were used as the baseline, in which case the same extraneous steps could be used for all participants.

3.2.5 Summary of Memory Elicitation Trade-Offs

The strengths and weaknesses of the discussed methods for eliciting process memory are summarized in Table 2. Process reproduction has many advantages but suffers from the high cost of reproducing an analysis and the time needed to code the steps. Written or verbal walkthroughs offer most of the advantages of process reproduction at lower cost. Walkthroughs are also greatly dependent on communication ability, which could be considered as either a benefit or a limitation depending on whether a study is focusing on memory only or on communication as well. The step ordering methods are limited to evaluating order only, but they may be appealing for their simplicity, control, and low cost.

Table 2. Summary of trade-offs for methods of eliciting process memory. High strengths for factors are denoted with +, moderate strengths are denoted with o, and weaknesses are denoted by −.

	Process Memory Elicitation Method			
Factors	**Repro-duction**	**Walk-through**	**Step Ordering**	**Mod. Step Ordering**
Cost & time	–	o	+	o
Control & Simplicity	–	–	+	o
Step recall	+	o	–	o
Rationale recall	+	+	–	–
Process order	+	+	+	+
Step duration	–	+	–	–
Communication independent	+	–	+	+

While we have separated the types of methods for eliciting process memory in order to organize the discussion of trade-offs, it is important to note that method selection does not have to be limited to any single method. It is certainly possible to combine properties of different methods, such as how verbal explanations could be used during process reproduction to provide additional information about rationale or step duration.

It is also possible to use multiple elicitation methods in sequence. For example, because step ordering methods are fast but do not account for free recall, it could work well to use step ordering after measuring process memory using a technique that does involve free recall (i.e., walkthrough or reproduction). Of course, the order that methods are used is important. It would not make sense, for instance, to ask participants to provide a walkthrough after they complete a step ordering activity because the step ordering method provides the steps of the process. It would be expected that participants might recall the steps listed from the step ordering method rather from their memories of their processes.

3.3 Analyzing the Results

After establishing a baseline process and recording a remembered version of the analysis, the next step is to compare the two to assess the accuracy of the process memory. Quantitative measures and methods can be helpful for clear comparisons of results for different analysis trials or participants, though these methods depend on qualitative methods for identifying the component steps for quantification. Qualitative analyses of process memories and explanations are also important for meaningful interpretations of quantitative findings and differences.

3.3.1 Percentages for Process Coverage

One example of a quantitative method for assessing process memory is to approximate the percentage of process coverage from the remembered version. The number of recalled correct steps can be counted and compared to the number of steps in the baseline process. Similarly, counting the number of extraneous or erroneous steps can allow for calculation of error percentages. These measures are relatively simple to apply to free recall methods such as process reproduction, written walkthroughs, or verbal walkthroughs. In addition, because the measures are normalized as percentages, they can accommodate processes of different numbers of steps, as might be found with individualized baselines. The quantitative results can be easily compared for different visualization tools, analyses, or experimental conditions using descriptive or inferential statistics.

Of course, counting steps requires some type of coding method to identify the steps in both the baseline and remembered processes. Percentage of recalled steps is a simple measure, but it can serve as a straightforward means of comparison. For more meaningful explanations, step percentages can be combined with qualitative descriptions of process memories and their differences.

3.3.2 Rank Correlations for Step Order

In addition to the number of correct steps, quantitative methods can be used to help assess the accuracy of order of steps in the remembered process. To compare step orderings to the ground truth ordering, rank correlations, such as Spearman's rank correlation, can be used. Rank correlation analyses for process order cannot account for extraneous steps because the correlations assume a correspondence between the steps in the recalled and baseline processes; however, this is reasonable because it does not make sense to test the order of events that have no correct place in the sequence of steps. Correlation measures are useful because they provide standardized test values regardless of the number of steps, which is important when evaluating against an individualized process of variable length. Rank correlations can be easily applied to results from the *step ordering* method of eliciting process memory because steps have already been identified, and the given steps match those in the baseline. However, rank correlations could still be used with recall methods (i.e., process reproduction, walkthroughs, or step ordering) by coding the key steps of the recalled process and including only the correctly recalled steps for the correlation with the correct ordering of those steps in the baseline.

3.3.3 Times for Step Duration

Besides step order and the percentage of recalled steps, another metric to consider for process memory is memory of the amount of time taken to complete individual steps or the entire analysis. Reported time estimations are trivially quantitative for numerical estimations given in a walkthrough. Alternatively, estimations of perceived step times could be assessed using relative times by ranking the duration of steps. Rankings could then be compared to the true ordering using rank correlation tests.

3.3.4 Times for Recall Efficiency

Another possible time measure is the amount of time taken to recall, explain, or reproduce the process. While comparing perceived step times from the remembered process to those of the baseline makes it possible to evaluate the accuracy of perception of step duration, measuring the time needed to recall the process provides a measure that corresponds to the difficulty or efficiency of recalling the process. Collecting this measure involves recording the time taken to reproduce the analysis with the process reproduction approach, explain the steps using the walkthrough approach, or order the process steps using the step ordering approach. For analysis, faster times can indicate easier recall, but recall times must be analyzed in conjunction with accuracy measures (e.g., coverage percentages or order correlations) for meaningful interpretation. For example, a fast explanation that is incorrect is not better than a correct slow explanation. An efficiency ratio of recall accuracy to recall time can aid interpretation of speed and accuracy with a single metric that can be analyzed with traditional quantitative methods.

3.3.5 Subjective Ratings

Depending on the complexity of the analytic task and the communication abilities of analysts or study participants, it can be difficult to code steps to assess process coverage or step ordering. As an alternative to establishing an objective protocol to determine quantitative measures of memory quality, a more subjective rating system may be used. Human raters can review both the original analysis process and the remembered version, and then they can assign a score to indicate the quality or accuracy of the memory or explanation.

The rating approach is best suited for free-recall methods, such as process reproduction or walkthroughs. Because they are somewhat subjective, the primary advantage of a rating approach is that it allows flexibility and can accommodate human judgment for the quality of a process memory or explanation. The scoring protocol can include holistic ratings to account for the combination of process accuracy, process ordering, duration accuracy, and recall time. Additionally, more focused criteria can ask raters to score specific qualities of a remembered process, such as communication clarity, speed, accuracy of process coverage, or accuracy of step order. Quantitative ratings can be

analyzed with traditional quantitative methods to compare memory and communication results from different study conditions.

A potential disadvantage of a rating approach is that it can be costly or difficult to recruit and train raters. Ideally, the raters will be blind to the study conditions. Also, rating necessitates consideration for the number of raters and rater reliability [14, 23].

3.3.6 Selection of Analysis Methods

Comparisons of memory results from different tools or study conditions are useful for identifying differences in effectiveness and outcomes. The components of an evaluation methodology should complement each other; appropriate analysis methods will depend on the goals of the study and type of data collected. We encourage the use of multiple types of data analyses (including both quantitative and qualitative methods, when appropriate) in order to provide a more complete understanding of visual analytics tools.

4. CONCLUSION

We can evaluate memory and communication of analytics processes by comparing remembered or reproduced processes to a ground truth process. When analyzing responses and coding actions, primary metrics can include presence of remembered steps, step ordering, and time estimates. For objective comparisons, it is important to establish a baseline sequence of steps. While relying on a prescribed analytic process is useful for high experimental control and simplifying evaluation, such an approach reduces the realism and meaningfulness of process memory. The creation of individualized baselines for each participant's analysis supports a more realistic evaluation but at the cost of ease and control.

We discussed several methods for measuring process memory and communication. The process reproduction method has the advantage of supporting realistic and accurate replications of analyses that can be directly compared to a baseline analysis. However, process reproduction can be time consuming and require additional modification to elicit memory of step rationale. Free recall through written or verbal process walkthroughs can be faster than full reproduction and can more naturally incorporate rationale reports, but dependency on communication ability adds complexity to the approach. Finally, the step ordering method is fast and provides a convenient means of evaluating process order, but the approach involves recognition rather than recall, and it would not work well for processes composed of obvious progressions of steps. These limitations can be partially mitigated by modifying the step ordering method to include extraneous analysis steps, but the trade-off is added complexity for results analysis.

Thus far, we found that existing evaluation efforts of process memory is limited in the realm of visual analytics. In ongoing research, we are working on a controlled experiment to evaluate the effectiveness of process memory aids, and we are testing the presented evaluation methods to study the effectiveness of visual history tools. As we progress with our research, we will further our knowledge of which methods are effective and useful for evaluating memory and communication of analytic processes.

By organizing potential methods for evaluating analytic process memory, we hope that this paper can inform study design and encourage objective evaluation of process memory and communication. Every method has its own set of advantages and disadvantages, but a meta-analysis of methods is useful for helping researchers to select the best methods for their purposes.

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