Towards Automated Analysis of Eye Tracking Studies using the Workflow Technology

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Abstract: Eye tracking studies have become one means to evaluate user behavior. For example, eye tracking is used in marketing research, psychology, human-computer interaction, or visualization. Analyzing eye movement data can help to find where on a stimulus and at what areas of a stimulus a participant focused on. Eye tracking can be used besides classical benchmark metrics such as completion times and accuracy rates of correctly given answers. However, evaluating eye movement data is a time consuming task, as a large amount of data has to be analyzed. Typically, multiple software systems have to be used, each having a different format of the data. This leads to tedious work, as the analyst has to reformat the data and learn how to use different software systems. Therefore, we suggest to analyze eye movement data using workflow technology. This allows to automatically analyze the data, and have a reproducible result. The analyst is not concerned with the technicalities and can rather focus on the interpretation of the analyzed data. Allowing an automatic evaluation using the workflow technology, requires that the analysis functionality is available via web services. In this paper, we contribute a workflow system based on web service operations. The web service offers functionality of an eye tracking analysis framework for the automatic analysis of eye movement data. The workflow system can be used to model and execute different types of eye tracking evaluations.

1 Introduction

Analyzing eye movement data has become an important part in user studies. Nowadays, eye tracking is used in research areas such as psychology, marketing, human-computer interaction, or visualization [Duc02]. Classical benchmarks such as completion times and accuracy rates of correctly given answers can be extended by including eye movement data in the analysis. This helps to analyze where on a stimulus and at what objects of a stimulus a participant inspected. However, analyzing eye movement data is a time consuming and error prone task. For each step, the analyst needs a different software system and the data has to be converted into the right format. Using different software systems makes it hard to reproduce the analysis steps in a later study. To overcome those problems, in an earlier work we have implemented an eye tracking analysis tool called eTaddy (Eye Tracking Analysis, conDuction, and Designtool for user studYs) [BRE13]. However, eTaddy has the limitations, that analysis steps have to be repeated manually and a complete analysis processes can not be applied to a different eye tracking study. To tackle those issues, we now contribute a workflow systems, which uses the functionality of eTaddy via web service operations. The web service operations access the existing functionality and database of eTaddy. Workflow technology is then used to orchestrate the web service functionality. The workflow system communicates with the web service operations via SOAP messages. Using workflow technology saves the analyst time to concentrate on the interpretation of the eye movement data and visualizations.

To the best of our knowledge no similar systems exist, which use workflow technology to analyze eye movement data. Classical evaluation of eye movement data is done manually using different software tools. Therefore, the implementation of eTaddy is a first step to allow an automatic analysis of eye movement data using workflow technology.

The rest of this paper is structured as follows. In Section 2 we give an overview of the analysis of eye tracking studies and the eTaddy tool. In Section 3 we introduce the concept of workflows for eScience. In Section 4 we show how we extended the existing eye tracking analysis framework with a web service interface and in Section 5 we present two simple eye tracking workflows as a proof of concept. We discuss our work in Section 6 and give an overview about relevant related work in Section 7. The paper closes with a conclusion and future work in Section 8.

2 Eye Tracking

During the last decade, eye tracking has become one means to analyze user behavior in user studies. Eye tracking is used in different research areas such as neuromarketing, human-computer interaction, psychology, or visualization [Duc02]. Analyzing eye movement data can give further insight into where on a stimulus and at what objects of a stimulus participants looked. Eye tracking can be used besides analyzing accuracy rates of correctly given answers, or completion times. During an eye tracking study, fixations and saccades are recorded. Fixations usually last about 200 to 300 ms. Common metrics for fixations are the number of fixations (fixation count), the fixation duration in milliseconds, and the fixation position. A saccade describes a rapid eye movement which typically lasts about 30 to 80 ms. During this timespan visual information is suppressed. A sequence of fixations and saccades is called scanpath. If specific regions of a stimulus are of interest for an analysis of eye movement data, areas of interest (AOIs) can be defined [HNA+11].

Analyzing eye movement data can either be done statistically or using visualizations. Using statistical significance tests like Student's t-test or an analysis of variance (ANOVA) the evaluation is quantitative. A qualitative evaluation of eye movement data can be achieved by using visualization techniques. This allows to explore the eye movement data and find hypothesis which can later be analyzed statistically. Typical visualization techniques for eye tracking are attention map or scanpath visualizations. An attention map as shown

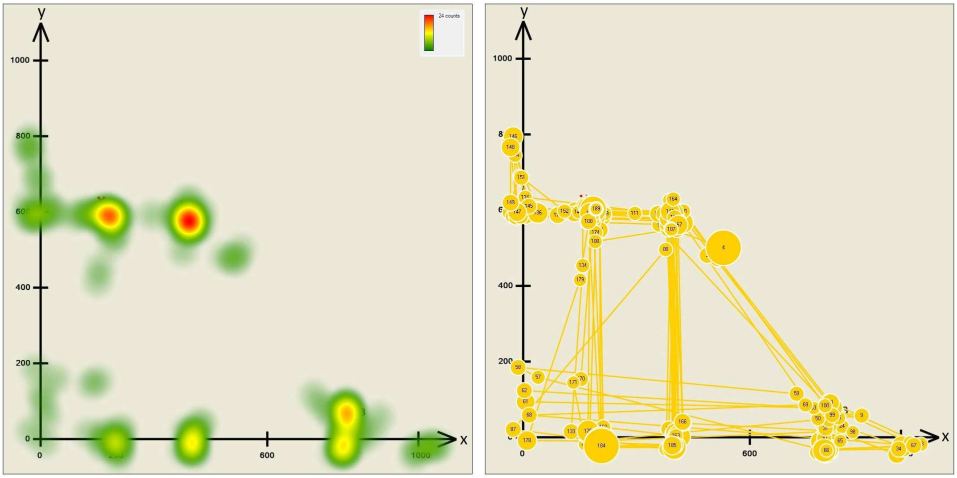

Figure 1: On the left, a classical attention map visualization is shown on top of a stimulus. The stimulus shows a synthetically generated coordinate system with arbitrary units where participants had to give the coordinates of different points. An attention map aggregates fixation data of all participants and represents them with a color coding. On the right, a scanpath visualization for one participant is shown. A scanpath represents fixations as circles, where the circle radius corresponds to the fixation duration. The saccades are represented by lines. Images created with Tobii Studio 2.2.8.[1]

in Figure 1 on the left is an aggregation of collected fixation data. The fixation position and duration of all participants is clustered and color coded. Green corresponds to few fixations and red to many fixations. An attention map allows a user to gain an overview about the eye movement data. On the right side of Figure 1 a scanpath visualization is shown for one participant. Each fixation is indicated by a circle where the radius of the circle corresponds to the fixation duration. Lines connecting fixations are saccades. This visualization technique allows to see the temporal order of eye movement data. However, it becomes cluttered easily if many fixations are shown or if scanpaths of multiple participants are shown.

The analysis process of eye movement data usually is time consuming. A complete analysis usually takes about a week to a month. Analyzing eye movement data of 30 participants, for three tasks with 30 stimuli would lead to 2,700 scanpath and over 10,000 fixations. Furthermore, the software for an eye tracking analysis is often distributed over multiple computers, i.e. the eye tracking computer and the computer of the analysts, and different software systems, i.e. the eye tracking software, the visualization tools, and the statistical tools. This means, that eye movement data has to be formatted to fit each software's requirements. If the domestic participant information or other data collected during the study is hand written, it first has to be transcribed into machine readable data. This has to be done manually by the analyst beforehand. Transcribing the data is error prone and the data has to be checked for those errors. The eye tracking data itself can be exported from the eye

[1] http://www.tobii.com/en/eye-tracking-research/global/products/software/tobii-studio-analysis-software/

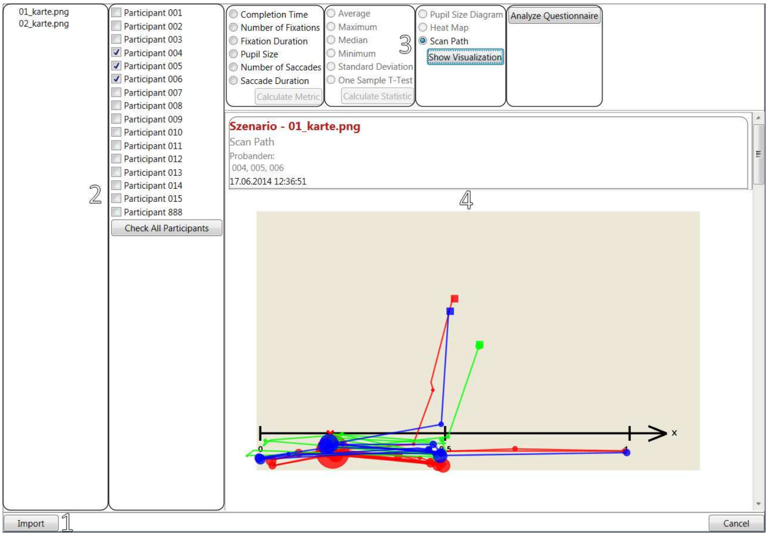

Figure 2: Eye Tracking Analysis, conDuction, and Designtool of user studYs (eTaddy) [BRE13] is a software to create eye tracking user studies, collect data, and analyze the eye movement data. For the analysis, the user has to import the eye movement data into a database (1). Afterwards, a stimulus, as well as participants can be chosen (2). Several eye tracking metrics, statistics, and visualization are available (3). The results of a calculation are shown in a timeline (4).

tracker automatically into a comma separated value file (csv). However, exporting one data set with 10,000 fixations takes about 15-30 minutes. Another issue is the reproducibility of an eye tracking analysis. All data generated during an analysis and all steps performed during the study have to be saved and logged carefully. This leads to even larger amounts of data which has to be stored and later analyzed.

To overcome some of these problems, in an earlier work we have implemented a software system called eTaddy (Eye Tracking Analysis, conDuction, and Designtool for user studYs) [BRE13]. eTaddy allows an analyst to design an eye tracking study and collect study data besides eye movement data. Furthermore, it supports an analyst by offering a single analysis tool for an evaluation of eye movement data. Figure 2 shows the analysis window of eTaddy. First, eye movement data has to be imported into a database (1). At the moment, eTaddy allows to import data from the eye tracking systems Tobii[2] and SMI[3]. Further parsers can be developed to include data from other eye tracking systems. The underlying data model is a general model for eye movement data and not dependent on a specific system. The domestic information is collected by eTaddy during the study process itself. After importing the eye movement data an analyst can choose a stimulus for investigation (2). Furthermore, multiple participants can be selected for an evaluation (2). eTaddy offers different eye tracking metrics, statistical calculations, and visualization techniques (3). An analyst can

[2]http://www.tobii.com/
[3]http://www.smivision.com/

calculate completion times, fixation counts, fixation durations, pupil sizes, saccade counts, and saccade durations. For a statistical evaluation, eTaddy offers to calculate the average, maximum, median, minimum, standard deviation, and Student's t-test. A pupil change diagram, an attention map, and a scanpath visualization can be displayed. This functionality is available in eTaddy using plug-ins allowing the user to easily add new functionality. Furthermore, a questionnaire with domestic information about participants is evaluated automatically. Every calculation or visualization technique is shown in the center part (4) of the window. Calculations are saved in the database and shown at the next start of eTaddy in chronological order. This allows an analyst to take up his evaluation at a later point in time.

The benefit of eTaddy is that it allows the user to evaluate eye movement data with one analysis tool. However, eTaddy still has some limitations. For example, each analysis step has to be manually initiated by the analyst. If a step has to be repeated several times this can become tedious and tiresome. Although, each calculation is saved in the database a reproducibility of the steps in a different eye tracking study is not possible. Therefore, a mechanism is needed that allows the user to define a general eye tracking analysis process which is then automatically initiated and executed.

3 Workflows for eScience

The usage of workflow technology for the automation of business processes is widely accepted in the domain of business applications [LR00]. Workflows are another core concept of service oriented architectures (SOA) [PG03] beside services, loosely coupled, and reusable components providing a unified interface. Workflows enable the orchestration of services to create new and potentially more complex functionality from existing functionalities in a user-friendly manner. This is achieved by modeling and the use of a workflow infrastructure that takes over deployment, control flow navigation, and interaction with the existing functions. Furthermore, workflow technology provides desirable non-functional properties like scalability, reusability, robustness, and sophisticated fault and exception handling.

In the last years, there is a notable movement towards workflow technology in the eScience domain [TDG06]. Here, we can distinguish two fundamental approaches. There are workflow systems especially developed for the eScience domain. As these systems typically have some deficits [TDG06], especially in the field of non-functional properties, a second approach is pursued. In this approach, conventional workflow technology, already used in business applications, is extended and adapted for the special needs of the eScience domain [GSK+11, SK10, SHK+11].

We have developed a scientific workflow management system (SimTech SWfMS) based on conventional workflow technology [SK10]. The workflow system was developed in the scope of SimTech - a cluster of Excellence and many related simulation technology projects.[4] We use the Business Process Execution Language (BPEL)[5] as a workflow

[4]http://www.simtech.uni-stuttgart.de/
[5]http://docs.oasis-open.org/wsbpel/2.0/OS/wsbpel-v2.0-OS.html

language. BPEL is a dominant industry standard for the orchestration of web services. To integrate existing legacy applications with BPEL, typically wrappers are developed, providing the functionality of these applications over a web service interface. The SimTech SWfMS has been successfully applied in different scenarios, i.e. for the automation of a Kinetic Monte-Carlo (KMC) simulation of solid bodies [SHK+11]. Through automation and particularly the ability of our workflow system to execute various instances of a workflow model in parallel, parameter studies can be carried out in a substantially greater scale and in much less time. In this way new research opportunities were opened for scientists.

Analysis of eye movement data is an iterative process, where results have to be interpreted and decisions have to be made based on these results. Usually, analysis steps are repeated during the evaluation. However, so far those analysis steps are not automated. To automate the analysis of eye movement data a workflow can be used modeling the ordered execution of the analysis steps. In the following, we show how we applied the workflow technology to the analysis of eye movement data.

4 Eye Tracking Web Service

To create an eye tracking workflow the individual analysis steps have to be offered as web service operations since web services enable reuse and seamless integration. The functionality for eye movement analysis in eTaddy is available using plug-ins. Therefore, a web service wrapper can be implemented that offers the functionality of each plug-in as one operation of the web service. During an eye tracking study a large amount of data is generated which has to be analyzed. This data is stored in a database that is used by eTaddy as well as the web service. Figure 3 shows the basic principle of the communication between eTaddy and the workflow system. The workflow system communicates via SOAP messages with the web service.[6] To reduce the size of the SOAP messages, the web service operations exchange references to data rather then the data itself whenever possible. Furthermore, the web service wrapper implementation accesses the plug-in functionality from eTaddy.

Figure 4 shows an example communication with a web service. At first a SOAP message is sent to the web service (1). This message contains information about the target operation as well as the input data for this operation. Each plug-in in eTaddy requires one stimulus and at least one participant. Therefore, the stimulus and a list of participants are sent in the message. The wrapper implementation then translates the SOAP message into a C# object (2). The incoming message does not contain the input data but a reference to this data. Thus, the relevant data has to be fetched from the database (4). Afterwards, the plug-in function can be called (5) by the wrapper implementation (3). The result from the calculation is then serialized into XML code again (6) and send as a SOAP response message back (7). In Section 5 we show how the web service described so far can be used by workflows for the automation of eye tracking analysis.

[6] http://www.w3.org/TR/soap12-part1/

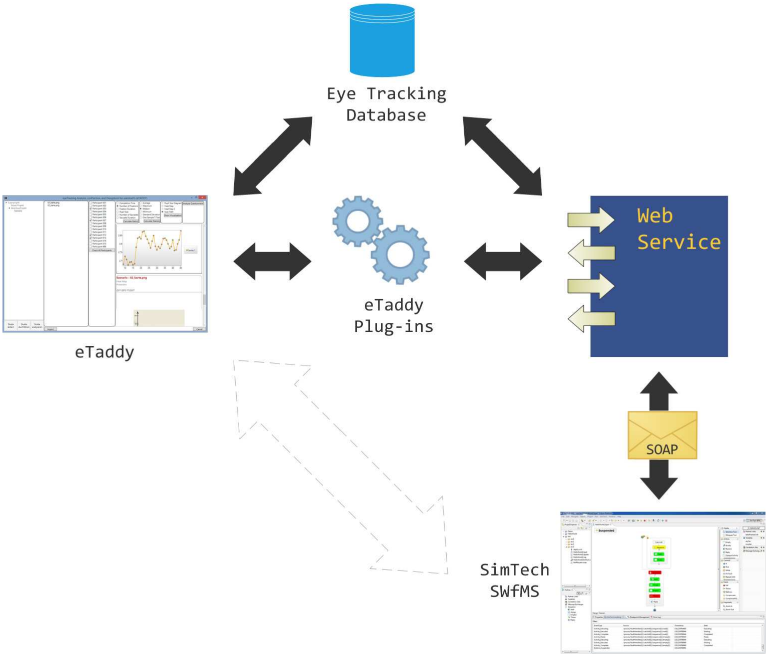

Figure 3: The functionality of eTaddy, namely the metrics, statistics, and visualizations, can be accessed through plug-ins. The eye movement data is saved in a database. A web service wrapper implementation exchanges references to the data in the database and communicates via SOAP messages with the workflow system where the eye movement analysis is modeled.

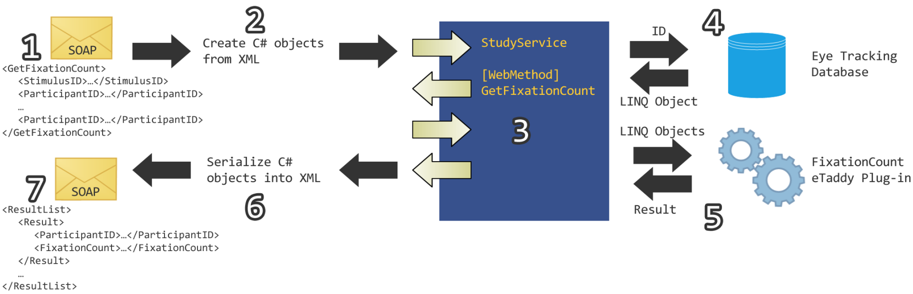

Figure 4: A workflow sends a request as a SOAP message containing the function and the necessary parameters. The parameters are cast into a C# object and sent to the web service. The web service retrieves the appropriate data from the database and calls the function. The result is then serialized into XML and sent back as a SOAP response message to the workflow.

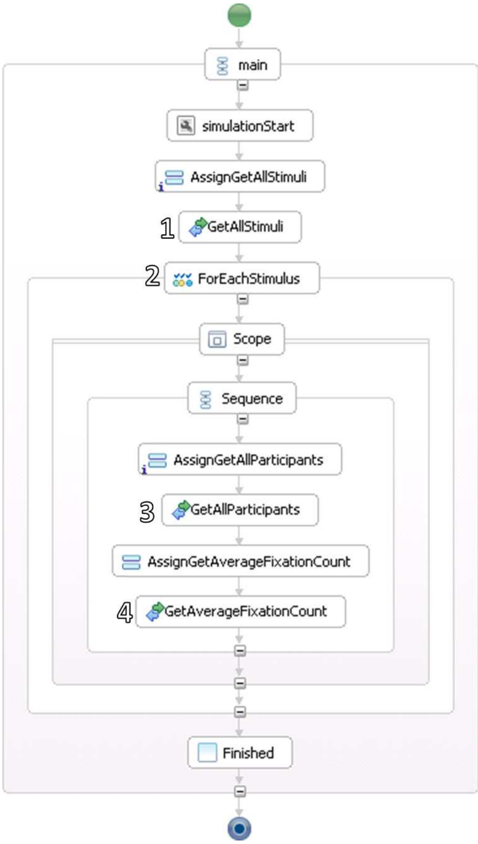

Figure 5: Example workflow calculating the average fixation duration of a given list of stimuli and a given list of participants. First, all required stimuli are fetched from the database (1), then for each stimulus (2) the list of participants is retrieved from the database (3), and then for each participant the average fixation count is calculated (4).

5 Eye Tracking Analysis Workflows

To demonstrate how our web service system can be used in practice we have implemented two simple workflows representing two examples for an eye tracking analysis and a proof of concept. The first workflow calculates the average fixation duration for each participant. The second workflow creates two attention map visualizations for two participant groups in parallel.

5.1 Average Fixation Duration

The first workflow was created to show how a functionality that is already available in eTaddy can be modeled as a workflow. The workflow shown in Figure 5 calculates the average fixation duration for all stimuli and each participant. First, the workflow calls the web service to retrieve all stimuli from the database (1). In the following loop (2), the workflow calls the web service to retrieve for each stimulus all participants from the database (3). Then, the workflow calls the web service operation which invokes the plug-in of eTaddy to calculate the average fixation count for all of these participants (4). Instead of performing several actions manually, the workflow allows to execute these actions in an automated manner. This process would be more difficult in eTaddy as each stimulus would have to be selected separately by the analyst. The implementation with a workflow allows to speed up the calculation process and to reduce errors.

5.2 Participant Group Attention Map

The second workflow shown in Figure 6 creates an attention map for two different participant groups. The participant groups are created based on the age of the participants. At first, the user has to select a stimulus. This is achieved by using a separate window, where the user can input the ID of a stimulus. Then, the workflow selects the web service to retrieve all participants from the database (1). Afterwards, the workflow uses a flow activity which describes the parallel execution of two sequences (2). In the left sequence, the workflow uses a data manipulation activity to select all participants younger than 22 years from the participant set (3a). Then the workflow calls the web service which invokes the eTaddy plug-in to calculate the attention map for this participant group (4a). Similarly, in the right sequence, the workflow selects all participants older than 22 years from the participant set (3b). Then, the workflow calls the web service which invokes the eTaddy plug-in to calculate the attention map for the second participant group (4b). This is a functionality which is not available in eTaddy. eTaddy does not offer the option to automatically group participants based on their domestic information. Furthermore, the calculation of the attention maps is done in parallel, leading to a shorter time span to receive results. This example also shows that it is easier to create new functionality for additional types of analysis faster, if workflows are used.

6 Discussion

Analyzing eye movement data using workflow technology allows the analyst to concentrate on the interpretation of data and visualizations. The analyst does not have to bother deciding which participants to group or selecting a calculation for each stimulus and selected participants. On the one hand, this allows the analyst to save time. On the other hand, the available workflow can later be executed again either with the same or different

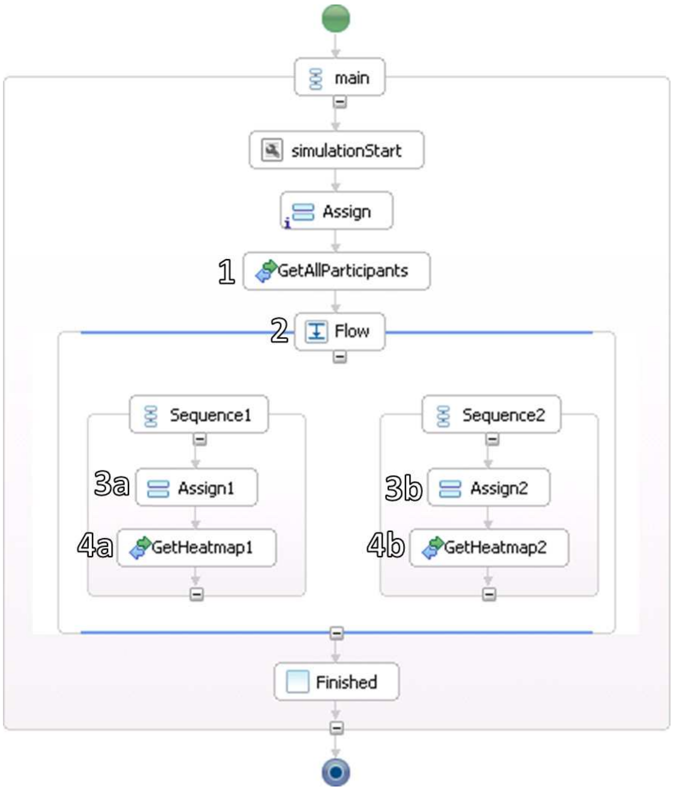

Figure 6: Example workflow calculating two attention maps for two groups of participants. First, all participants are retrieved from the database (1), then the attention maps for the two groups are created in parallel (2). On the left, the participants younger than 22 are used (3a) and then the attention map for this group is calculated (4a). Parallel to this, the participants older than 22 are used (3b) to create the second attention map (4b).

eye movement data. Furthermore, a workflow can be shared with other researchers and revised if necessary to the needs of other researchers in a short time. However, a complete automation of eye movement analysis is not possible without human interaction. Often, the analyst has to decide on a next step which does not depend on selected parameters, for example if an attention map or a scanpath is generated. Furthermore, the appropriate workflow for an eye movement analysis depends on the hypothesis to be verified. Therefore, the user needs to be able to influence the workflow behavior and decide on the next steps to be executed. In the current implementation this lack of integrating a human user is one limitation which will have to be tackled in future work.

7 Related Work

In Jäger et al. [JAZ+05] a similar approach like the one described in our paper has been followed to improve the analysis of geospatial data. The data, available in several heterogeneous data sources, has been made accessible over web service interfaces. Then, the Kepler scientific workflow system [ABJ+04] was used to model and execute geospatial data analysis processes. In contrast to our work, the main challenge was the heterogeneity of data sources. Whereas in our work we focus on the automation as a means to avoid errors and speed up the analysis process.

In Cummings et al. [CPP+08] a scientific workflow system is used to automate complex edge plasma simulation processes. The authors first provide arguments, why the manual or script based execution of such simulations is not feasible or possible. Then, they describe their solution to model the simulation process as a scientific workflow. Afterwards, they describe the automatic execution with a scientific workflow system. The analysis of eye tracking data is far less complex and can be executed by hand. However, the general benefits of the scientific workflow approach are very similar, although we apply it in a totally different domain. Automating simulation and analysis processes provides significant time savings, full control of the execution, and the ability to repeat exactly the same process at any time. Furthermore, to the best of our knowledge there currently exists no approaches for analyzing eye movement data automatically.

8 Conclusion and Future Work

Analyzing eye movement data using a workflow system is a time saver and allows the user to concentrate on data and visualization interpretation. In this paper, we have contributed an option to extend the functionality of the existing eye movement analysis framework eTaddy. We added a web service interface to eTaddy and then orchestrated the provided operations using workflow technology. The operations of the web service provide access to the existing functionality and database of eTaddy. Furthermore, we have demonstrated how possible workflows for eye movement analysis can look like. We used workflows to automate processes that had to be executed manually before. We have also shown that workflows can provide new functionality that was not available in the original eye tracking analysis system. Although, new functionality is available for the analysis using the workflow system so far the analyst has no option to interact with the workflow. This will be part of future work. We want to extend our workflows to include a human component. The analyst can then decide at specific parts of the workflow what next steps to execute. Furthermore, more complex analysis tasks will be modeled using the workflow technology.

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