Improving Provenance Data Interaction for Visual Storytelling in Medical Imaging Data Exploration

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Abstract
Effective collaborative work in diagnostic medical imaging is not trivial due to the large amounts of complex data involved, a (non-linear) workflow involving experts in different domains, and a lack of versatility in the current tools employed in healthcare. In this paper, we aim to introduce how the integration of visual storytelling techniques together with provenance data in the analytic systems used in medicine can compensate for these issues, by enhancing communication of results and reproducibility of findings through diagnostic provenance data. To this end, we illustrate how we can improve the interaction with provenance data displayed in a graph in order to facilitate authoring and the creation process of visual data stories.

CCS Concepts
• Human-Centered Computing → Interaction Design; Visualization;

1. Introduction
Performing data exploration is generally not trivial, especially in healthcare where the data can be complex in nature and structure, and can be large in size. In addition, data analysis is further complicated by the fact that experts in different fields often cooperate on analyzing the same cases through collaborative workflows. As a result, communicating and interpreting results is not always straightforward, and misunderstanding and human errors can occur.

In our study, we focus on visual storytelling for medical imaging data. We have conducted a survey on the radiology workflow to obtain useful insights on needs and concerns of radiologists regarding current IT tools. Building upon already existing toolkits [GLG¹⁶, FSC⁰⁶], we developed a prototype of a visual storytelling tool that allows users to perform data exploration and to create visual data stories for presenting the findings based on provenance data of the analysis process in diagnostic medical imaging.

The innovative aspect of our research is the use of visual storytelling based on provenance data for scientific visualization in medical data exploration. According to the respondents and the literature, current software systems lack flexibility in delivering results during both the presentation and exploration stages. Our work ties the information provided by images, user interactions, and exploration findings into a visual story, and thus it creates a clear connection between them. Therefore, the main contributions of the final tool, of which we present here the initial results, are an enhancement of effective communication in cooperative work contexts, data reproducibility for informed decision-making, and improvement of collaborative work currently based on text reports.

This way, the level of information details and the complexity of the visual data stories can also be adapted based on the target audience and purpose. For example, users might create more intuitive stories with several frames and descriptive annotations for communication with patients, whereas they might use a lower number of frames and medical jargon for communication with physicians.

We expect that radiologists can reproduce findings during their workflow by interacting with a provenance graph, and present them in a more efficient and visual way. Thus, the provenance graph should enable users in interacting with it in an intuitive manner. This can be achieved by implementing functions aiming at simplifying the provenance data processing based on specific criteria.

2. Related Work
In specifying our model of visual storytelling, we adopted the CLUE (Capture, Label, Understand, Explain) model for data exploration and presentation developed by Gratzl et al. [GLG¹⁶], which consists of three stages: exploration, authoring, and presentation, offering reproducibility of results. A related interesting work is VisTrails, a system that provides an infrastructure for recording and visually analyzing provenance data of exploratory tasks [FSC⁰⁶, CFS⁰⁶, SFC⁰⁷]. Although the use of visual storytelling in medicine has not been deeply explored yet during the last decade, in contrast with the use of data-driven stories for in-
Moving a plane
Cutting a plane
Highlighting
Windowing
Translation
Annotation

and measurements, and preparing a (structured) text report.

ranging the given images, performing some windowing, zooming
self-interviews) technique [OHL∗12] and 17 international potential
users (i.e., radiologists, doctors of nuclear medicine, and residents)
participated. The focus was on investigating how radiologists per-
form medical diagnostic imaging, and how they collaborate with
other radiologists and physicians.

The survey was conducted by using the CASI (computer-assisted
self-interviews) technique [OHL∗12] and 17 international potential

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The most common user interaction techniques
used are selection, rotation, annotation, zooming, scrolling, trans-
lation, and highlighting as shown in Fig. 1.

Collaborative Work. Furthermore, according to the respondents,
collaborative work can be improved by associating key images
and measurements with the structured reports to make them more
easily-retrievable (e.g., by using hyperlinks).

Finally, automation in structure recognition, measurement sys-
tems, report compilation, and windowing is also urgently awaited
by some respondents to lighten the individual workload.


Meeting with radiology experts and conducting a survey was essen-
tial to gather more information and understanding of the workflow
in medical imaging. A questionnaire was designed in collabora-
tion with a radiologist and doctor of nuclear medicine, which was
composed of 15 questions relating to the following aspects of the
radiology workflow:

- Data Used
- Image Assessment
- Data Exploration
- Collaborative Work

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4. A Visual Storytelling Tool for Medical Imaging Data

After conducting the survey, we define the main features of the en-
visioned tool as well as specific elements of the provenance graph.

4.1. The Main Features of a Visual Storytelling Tool

Medical imaging is usually employed in multi-disciplinary envi-
ronments where many kinds of data should be processed, and ex-
erts with different specialized and technical knowledge have to
collaborate. First of all, the data exploration of 3D images can be
performed as illustrated in Fig. 2.

The figure shows an overview of our prototype built upon the
Phovea framework [GLG∗16] and the AMI toolkit [FNN] used for
exploring brain image data. It can be seen how the main window
for the 2D and 3D data exploration (on the left side) is supported by
two widgets for changing the settings and for retrieving provenance
data. This is visually represented by an ordered tree with multiple
branches and thumbnails (on the right side).

On top of that, an authoring tool should be integrated to enable
making annotations about exploration discoveries on the data itself.
Along with this, provenance data for the visual exploration can be
collected and visualized in an interactive provenance graph, pro-
viding information about the analysis process made by the user(s)
and for reproducing particular steps of the analysis. Moreover,
the tool is equipped with a presentation mode to fully incorpo-
rate the visual storytelling concept. Users can present final and
partial results to various audiences, through a sequence of visu-
alizations and using a variety of available visual storytelling tech-
niques [SH10, HMSA08].

4.2. User Interaction with the Provenance Graph

Since many considerations have to be made before achieving our
ultimate goal of developing a validated visual storytelling tool, we
started focusing on the user interaction with the provenance graph,
which is a key element of our project. Navigating through an inter-
active ordered tree including multiple branches for each different
exploratory decision and user, it is possible to extend/author the
data exploration and to adjust it an unlimited number of times at
any phase of the analysis.

In developing an interactive tool and its features, a set of rules
should be defined in order to build interconnected functions upon
them. Since we aim to give users more flexibility, allowing them

Figure 1: The histogram of user interactions performed during
image assessment according to 17 respondents.

Data Used. What emerged from the survey is that most of the
users analyze complex 3D data (e.g., CT and MRI scans) to obtain
different kinds of information depending on the clinical questions.
During diagnosis, reference protocols, patient history, and specific
meta-data (contrast medium given, slice thickness, type of MRI se-
quence) are consulted before the image assessment itself.

Image Assessment. The typical working procedure starts with ar-
anging the given images, performing some windowing, zooming and
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to choose at which level of granularity (or abstraction) the provenance data should be represented, we considered two well-known approaches which illustrate taxonomies to categorize user interactions. Shneiderman defined a task by data type taxonomy, which became a landmark model in Information Visualization [Shn96], whereas Yi et al. stressed the relevance of user intents in categorizing user interactions [YAKS07].

However, our scenario is slightly different since we are in a visual storytelling context where user interactions for authoring play a crucial role. Therefore, we assume that the user intents considered for their categorization are also different. Based on the survey results and adapting the existing taxonomies to our situation, we envision the process of 3D data analysis by visual storytelling tools as a (non-linear) sequence of user interactions to configure, explore, select, derive information from, and annotate the input data. Thus, we obtained six (non-exhaustive) classes of user interactions:

- **Configure** (e.g., show the rendering, switch from 3D to 2D view)
- **Explore** (e.g., rotate, zoom, translate the slicing plane)
- **Select** (e.g., highlight or select a specific area)
- **Derive** (e.g., measure a distance or an angle)
- **Annotate** (e.g., make annotations)
- **Provenance** (e.g., provenance graph interaction)

Whereas Explore and Select do not need further description, we grouped under Configure all the interactions related to 3D data visualization and its configuration. The classes Derive and Annotate include all the user interactions which lead to making measurements and annotation during data exploration, while the Provenance interactions are those related to the provenance graph interaction.

Hence, we define four grouping strategies, each corresponding to a certain level of abstraction, for provenance graph nodes:

- **no grouping applied** (i.e., all the single user interactions are shown)
- **per parameter change** (i.e., only user interactions with parameters significantly different are shown)
- **per user interaction** (e.g., rotation, zoom, highlighting)
- **per user intent** (e.g., Configure, Explore, Select)

We first illustrate this on a simple example in Fig. 3. A provenance graph shows that three rotations were sequentially performed, and among them, the first and second ones were not significantly different in terms of parameter (angle) change. Then, zoom and highlighting were also performed. We omit an explanation of how to define the thresholds, as this is out of the scope of this work. Thus, grouping not only depends on the user interaction categories, but also on the level of abstraction chosen.

In case of grouping per user intent, only two nodes would be...
shown after the initial status: one for representing Exploration, and one for representing Selection. In contrast, three nodes would be shown after grouping per user interaction: one per rotation, one per zoom, and one per highlighting. Finally, only nodes representing user interactions not significantly different in terms of parameter change would be collapsed in the low-level scenario.

However, if we consider more complex cases, some additional rules must be set. As an example, an ordered tree with multiple branches and with nodes belonging to different classes (encoded by color) is illustrated in Fig. 4, left. Since we aim to reduce the information overload in the provenance graph, only nodes relevant for data exploration and (visual) data story creation at a certain level of abstraction should be visualized. To this end, we classify all nodes in the provenance graph into two categories: key nodes (marked by ●) and regular nodes (marked by ○), as illustrated in Fig. 4, center. The grouping function should not group two or more key nodes. Thus, we define a key node as any node of the following mutually exclusive node types:

- **Root** (i.e., the starting node of the provenance graph);
- **Leaf** (i.e., a node with no children);
- **Subroot** (i.e., a node with more than one child);
- any other node with interaction of a different class to its child’s.

The remaining (regular) nodes are considered non-informative, and are grouped downwards onto a key node; see Fig. 4, right. The node size encodes the number of nodes grouped. This algorithm works independently of the level of data granularity, so it can be applied with different levels of abstraction.

5. Discussion

The conducted survey provided a starting point for outlining the main features of a visual storytelling tool that can compensate for the lack of flexibility in authoring and presenting findings of current tools. As described by the survey respondents, they lack an efficient system for communicating effectively and for collaborative work. We consider the survey results reliable because of the sample size (i.e., more than 15 participants).

Using a visual storytelling framework based on provenance data in combination with user interaction techniques for exploration of complex data, research findings can be validated with evidence and previous analyses can be retrieved, reconsidered, and reused during future assessments. In this way, the risk of encountering human mistakes in the decision-making process due to misunderstanding or incorrect interpretation of results can be decreased. According to the potential users’ statements, our prototype meets the initial requirements since it allows other doctors to understand and agree on the conclusions drawn by the investigating doctor. In addition, integrating the visual storytelling concept into traditional imaging data exploration seems to be promising for replacing text reports.

Furthermore, outcomes of medical diagnoses will become more reliable even in a collaborative setting context, since they can be linked back to (provenance) data and authors that generated them. We believe that the grouping function is crucial for the story creation process to offset the large amount of data available and the unrepeatability of analysis steps. Combined with different levels of granularity of the visually represented provenance data and with the associated user interaction categories, it can facilitate users to interact with their (non-linear) analysis process during both data exploration and data story creation. Additionally, color encoding and thumbnails can also improve the provenance graph interaction in both the exploration and presentation stages.

6. Conclusion and Future Work

In the last years, many efforts have been made in investigating the application of visual storytelling techniques in science. Although we are still in an exploratory stage, there is evidence of the beneficial effects of storytelling for data presentation, and of a need to improve communication in collaborative work settings. This has been confirmed by survey results regarding radiology as field of application. Based on this and on previous works, we outlined a visual storytelling tool aiming to compensate for flaws and deficiencies of the current tools used for diagnostic medical imaging.

In future work, we aim to extend our method. We plan to perform a user study to learn more about user intent and to potentially refine the taxonomy of user interactions. Furthermore, evaluating the effectiveness of the tool, and the individual effects of its current features (e.g., how much information is lost per grouping at different levels of abstraction) as well as novel ones such as merging branches based on some of the above-mentioned rules is our next objective. Although the initial case study is radiology, the tool has not been envisioned as domain-specific and it is easy to generalize (e.g., using different features, taxonomies, and levels of abstraction). For this reason, we want to investigate differences in the visual storytelling tool settings for different domains, and the contributing factors of specific application scenarios.

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References


[FNN] FNNDSC: AMI Medical Imaging (AMI) JS ToolKit for THREEJS. 2


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