iStoryline: Effective Convergence to Hand-drawn Storylines

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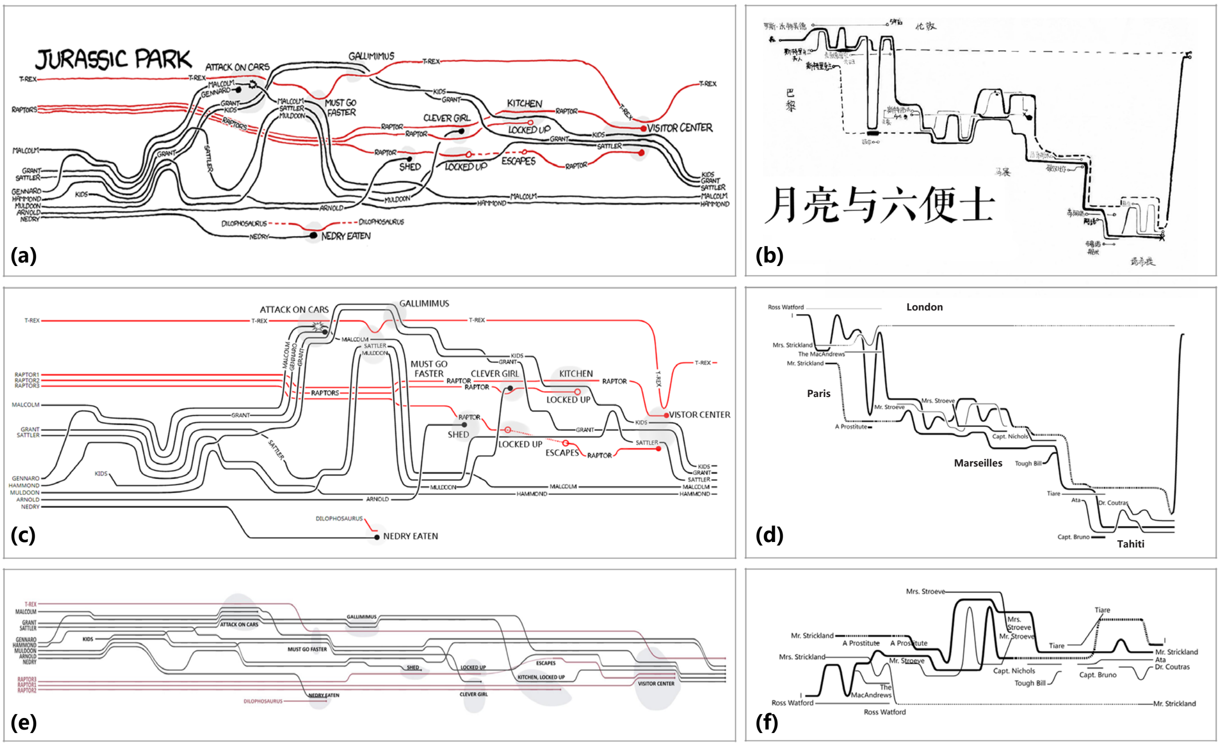

Fig. 1. Storyline visualizations for the movie *Jurassic Park* and *The Moon and Sixpence*: (a) and (b) hand-drawn illustrations, (c) and (d) iStoryline illustrations; (e) and (f) StoryFlow illustrations.

Abstract—Storyline visualization techniques have progressed significantly to generate illustrations of complex stories automatically. However, the visual layouts of storylines are not enhanced accordingly despite the improvement in the performance and extension of its application area. Existing methods attempt to achieve several shared optimization goals, such as reducing empty space and minimizing line crossings and wiggles. However, these goals do not always produce optimal results when compared to hand-drawn storylines. We conducted a preliminary study to learn how users translate a narrative into a hand-drawn storyline and check whether the visual elements in hand-drawn illustrations can be mapped back to appropriate narrative contexts. We also compared the hand-drawn storylines with storylines generated by the state-of-the-art methods and found they have significant differences. Our findings led to a design space that summarizes 1) how artists utilize narrative elements and 2) the sequence of actions artists follow to portray expressive and attractive storylines. We developed iStoryline, an authoring tool for integrating high-level user interactions into optimization algorithms and achieving a balance between hand-drawn storylines and automatic layouts. iStoryline allows users to create novel storyline visualizations easily according to their preferences by modifying the automatically generated layouts. The effectiveness and usability of iStoryline are studied with qualitative evaluations.

Index Terms—Hand-drawn illustrations, automatic layout, design space, interactions, optimization

1 Introduction

The storyline is an effective visualization of the evolution of the complex relationships between entities in a variety of datasets, such as movies [30], emails [39], tweets [25], and source codes [32]. In general, storyline visualizations use lines to represent characters and groups of lines for interacting characters. Storyline researchers simplify complex interactions using optimization methods, such as greedy [25, 39] and genetic [40] algorithms. To illustrate the evolution of stories and relationships, several design principles have been suggested [39, 40]:

D1 Lines in the same group should appear next to each other.
D2 Otherwise, lines must be far from each other.
D3 A line must remain straight unless its group changes.

For an aesthetic and compact layout, several optimization goals are defined for the storyline visualizations [39, 40]:

G1 reducing line wiggles.

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G2 reducing line crossings.
G3 reducing white space.

However, these guidelines are inferred primarily by researchers through their own observations from *Movie Narrative Charts* [30] and graph layouts [13]. They successfully capture the essence of typical storyline visualizations, but the automatically generated storylines still fail to imitate hand-drawn illustrations properly. The main reason for such a gap is that automatic methods tend to produce homogenized layouts that are optimized strictly to serve the aforementioned goals. Compared with hand-drawn illustrations, automatic storylines have two major limitations:

Missing narrative elements. Automatic layouts chiefly portray characters, their scenic interactions [39, 40] and locations [7], but are not sufficient for the effective visual representation of a story. Other important narrative elements, such as plot, tone, and point of view [8], are overlooked completely. Those elements have been studied widely in the literature [8, 12], yet they are often subjective and thus difficult to incorporate into the automatic methods.

Repetitive layout. Automatic layouts usually follow the same visual style and fail to incorporate creativity, often leading to repetitive and boring visualizations. Hand-drawn illustrations are typically more expressive and attractive, although they are not designed in absolute harmony with the optimization goals [25]. These "spur of the moment" creations are also impossible to be covered by automatic methods.

The first limitation motivates us to understand how artists draw storylines from narratives. We also want to know what narrative elements and aspects are preferred and how they are visualized in storylines. However, no existing works have explored the design space of hand-drawn illustrations, and instead, previous studies only considered *Movie Narrative Charts* [30]. Understanding the design considerations behind these illustrations is impossible, especially given the scarcity of samples. Thus, a comprehensive large-scale preliminary study is required to obtain sufficient illustrations from different artists. This work has strong implications for future research on storyline visualizations, such as developing new layout algorithms or user interactions.

The second limitation requires a new storyline authoring tool that integrates human creativity deeply into the automatic method. Existing techniques [25, 39] only support few interactions and modifications, such as changing line orders or bundling lines. Many high-level edits, including altering line trends, are tedious and difficult, even impossible to achieve through primitive interactions. Approaches that involve users in the optimization process and constraint algorithms for generating diverse results according to user preferences remain unknown.

In this work, we first describe the design space of hand-drawn illustrations to deepen the research area of storyline visualization and reduce the gap between hand-drawn storylines and automatic layouts. This aim is achieved through a preliminary study prepared by Digital Media and Computer Science students. In the study, we asked participants to create storylines manually according to their personal understanding of the underlying stories. We identified the common features they selected. Then, we interviewed the participants regarding their design considerations and activity-ordering processes. The features are organized as a design space and formulated as a set of optimization constraints. Using these constraints, we develop an authoring tool enriched with a set of interactions that enable users to focus on presenting narratives instead of on tedious design work (e.g. changing line paths). Finally, we demonstrate the effectiveness of interactions through use cases and evaluate the authoring tool through user studies. Results indicate how our approach can dramatically improve the aesthetic quality of storyline visualization. Our contributions are as follows:

- We conduct a preliminary study to propose the design space of the storyline visualization, summarize the key aspects of narratives that people consider important, and identify the mechanism of how people use such aspects to create hand-drawn storylines.
- Based on the design space, we propose "iStoryline", an authoring tool with a new layout optimization framework that considers customized constraints through a set of interactions to enable users to create expressive storylines.

2 Related Work

Storylines have gained popularity for their effectiveness in representing complex stories [7, 25, 39, 40]. In this section, we summarize the key techniques proposed in the current storyline visualization research and the authoring tools available for storytellers.

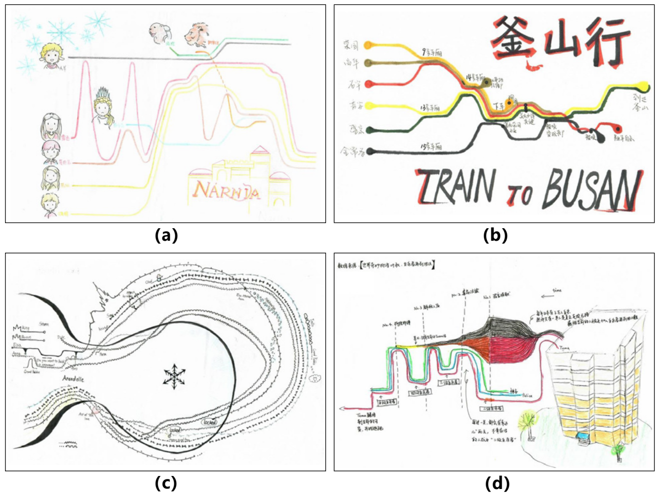

Fig. 2. Hand-drawn illustrations achieved from the preliminary study depicting innovation in storyline visualizations.

2.1 Storyline Visualization

The storyline technique was popularized in 2009 when Randall Munroe created several hand-drawn storylines for XKCD comics [30]. The growing interest in applying the concept to visualization led to the development of automatic storyline layouts [25, 28, 32, 39, 40]. These techniques can generate storyline visualizations that depict enormous entities and scenic interactions.

Reda et al. [34] and Kim et al. [19] adopted storylines to portray temporal relationships in evolving social and family structures. Their techniques are not generalized to represent complex relationships in other datasets because of application-specific constraints. Ogawa and Ma [32] proposed a general approach for creating storyline visualizations, but the simplicity of their design goals resulted in a layout that failed to resemble XKCD's hand-drawn illustrations. Tanahashi et al. [40] created aesthetic and legible storylines with a layout approach based on a genetic algorithm. They formulated a set of guidelines and aesthetic principles to generate storylines adopted by several follow-up methods [25, 28, 40]. However, their layout approach is slow when applied to large datasets. The greedy-based approach in StoryFlow [25] increases time performance considerably and improves the overall legibility and aesthetics. Moreover, StoryFlow provides a set of primitive user interactions such as line straightening, bundling, and dragging, to allow users to refine layout results. Aesthetic and legible storylines for streaming data were generated by Tanahashi et al. [39] with good scalability and efficiency.

The aforementioned studies improve performance and expand the application scenarios, but all share a common direction based on the design goals first proposed by Ogawa and Ma [32] for optimizing layouts automatically. Thus, the visual appearances of their layout results are similar and do not improve much. Although the defining characteristics of storylines are captured, none of these works fully examines the design considerations of artists when creating storyline illustrations. Whether important elements of a narrative are fully covered by the automatic algorithms remains unclear. There exists a gap between automatically-generated and manually-drawn storylines. To fill this gap, we conduct a study to review the hand-drawn storylines systematically and understand the design space.

2.2 Authoring Tools

Research on authoring tools [20, 27, 35, 42–44] for creating visualizations has attracted considerable attention in recent years. Data-Driven Guides [20] facilitates the creation of infographics through guides obtained from the data. Liu et al. [27] introduced a novel framework based on "lazy data binding" and presented a system called Data Illustrator. InfoNice [42], which has been incorporated into Microsoft Power BI, allows average users to create data-driven infographics easily. The functionalities of authoring tools are also regulated by the balance between the user's perception and the optimization methods in creating aesthetic designs [41]. Apart from the functionalities, the user interface has been carefully designed for iVolver [31] and the CS tool [17]. High-level interactions supported by these interfaces enable novices to easily engage with data. The aforementioned tools focus on creating general infographics and presenting complex stories [11, 24]. However, these tools cannot be directly applied in creating storylines, which require special design principles (D1-D3) and aesthetic goals (G1-G3).

With free-form tools, such as Adobe Illustrator [1] and Photoshop [2], artists can create any arbitrary design of their choice. Despite their flexibility, using these free-form tools to create storylines is time-consuming and error-prone. Growing research in general storytelling has resulted in various authoring tools (e.g., [6, 10, 16, 22]). However, their design features and visualization strategies also often result in interactions that are too primitive for creating compelling storyline visualizations. For example, StoryFlow [25] provides users with the flexibility to edit individual lines in the layout. Nevertheless, such interactions are inadequate for efficiently supporting high-level design preferences, such as altering the overall trend of lines. Ogievetsky [33] contributed Plotweaver, an online storyline editing tool which was inspired by XKCD illustrations [30]. Plotweaver automates the process through an algorithm and facilitates the creation of storylines that resemble hand-drawn illustrations. Although considerable freedom is given to users, it is time-consuming and the layouts generated are not well optimized. Despite the limitations, a similar model can be extended for creating a novel and interactive authoring tool.

To bridge this gap and enhance the user experience, our tool incorporates automatic storyline techniques and high-level user interactions to enrich the authoring process. Compared with existing approaches, our method allows greater freedom for users to be creative, and assigns tedious adjustments to an optimization algorithm. Thus, users can focus on the presentation of narratives and the efficient editing of storylines.

3 STORYLINE REVISITED

The narrative elements (i.e., actor, event, time, location, and plot [8, 12]), are associated with one another and processed in an organized manner to create conclusive and appealing stories. Narratives may also include minor but affective elements, such as relationships or actors information [8]. These elements nicely appear in hand-drawn storylines. Conversely, extant automatic storylines are generated only on the basis of actors, their scenic interactions [25, 39], and locations [7], but ignore some aforesaid elements, such as plot. A possible reason for the discrepancy between hand-drawn and automatic storylines is that previous research emphasizes the creation of a compact layout without a complete understanding of user requirements. A recent work about the human-like orthogonal network [18] has raised the same concern where two user studies are conducted to identify how the algorithm should encode user requirements.

We believe such preliminary studies can directly change interactive visualization designs [9]. Thus, we decide to set aside all three design principles and three optimization goals and take a step back to view the wider picture. Following similar procedures by Dwyer et al. [14] and Kieffer et al. [18], our study has two stages (Fig. 3). In the first stage, we conducted a study to explore how narratives were ***translated*** into hand-drawn visual elements and layout by storyline designers. We collected human-generated visual elements, that is, visual designs proposed by designers to convey specific narratives. In the second stage, we conducted a follow-up study to evaluate human-generated elements to check if those elements could be ***mapped*** back to meaningful narrative messages and their legibility and aesthetics were compared with those of automatic layouts. The two user studies identified 1) the most essential and affective visual elements for narratives and 2) the design pipeline followed by artists to portray expressive storylines.

3.1 From Narrative Elements to Hand-drawn Visual Elements

The first stage of our study involved asking participants to manually draw a storyline layout of a narrative on paper. The goal was to examine what users considered as important narrative elements, what visual elements were commonly employed for narratives in hand-drawn layouts, and the pipeline of creating storylines. This stage took three weeks. Results are available online for further studies[1].

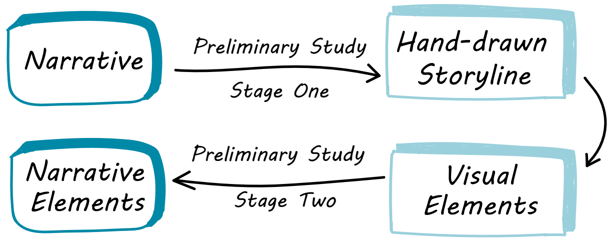

Fig. 3. Preliminary study: in the first stage the participants manually drew a storyline of a narrative; in the second stage the participants were asked to map a selection of visual elements back to the narrative elements.

Participants: We recruited 74 third-year undergraduate students (24 females, 50 males). 32 students majored in *Digital Media* and the rest majored in *Computer Science*. Engaging students in information visualization research has been practiced by other researchers [36, 37]. All participants watched movies or read narratives at least once per week, and none had storyline visualization experience. The study was conducted while all participants were taking an *Information Visualization* course (eight weeks, four lectures per week). Prior to the task, they had three introductory lectures on information visualization and a detailed lecture on storyline visualization. Note that our participants had no or very little prior experience with visualization. The lectures could help them understand how storyline visualizations were generated.

Tasks and Procedure: Participants were asked to draw storylines manually using pen and paper for the narrative of their own choice. Each participant was expected to refine a story, generalize the most important narrative elements based on their perspective, picture the narrative elements, and create a visually pleasing storyline. Before the actual task, we informed participants on the potential risks and obtained their permission to use and publish their drawing anonymously for research purposes. Pilot tests indicated that guiding participants toward the basic idea (design principle D1 and D2) of the storyline visualizations was necessary because excessive freedom would not lead to a general conclusion. However, we did not limit participants in terms of line styles (straightness, orientation, color, and thickness), because these were exactly the visual elements that we wanted to explore in hand-drawn storylines. The task was assigned to them as a bonus homework, which motivated participants to pursue high-quality illustrations. Participants had two weeks to finish the task until they were satisfied with their layout. Participants had the option to abort the task, but none of them took this option. Finally, participants were asked to submit one layout on a voluntary basis.

We assessed the assignments according to their level of creativity within the limits of storyline design principles (D1 and D2). Participants designed a wide variety of creative storylines. Four interesting sample storylines are shown in Fig. 2. We selected illustrations with good aesthetic quality or novel features. First, two of the co-authors independently graded the 74 submitted hand-drawn illustrations on a scale from 1 to 5 (each of the two authors graded half of the illustrations). Then, the two authors discussed the results and arrived at a joint decision on which illustrations to keep. After selecting the illustrations, the two authors independently marked the visual elements. In the end, they discussed the selected visual elements and decided which were the most appropriate ones. As the result, 34 hand-drawn illustrations and 19 visual elements are identified (Fig. 4), which are further discussed with participants in a follow-up interview.

Interviews: We interviewed 14 participants who adopted novel visual elements. According to our general experience with storyline visualizations, we asked the following questions:

Q1 *What elements did you consider as the most essential in a movie/story and what visual elements were used to convey them?*

[1] https://istoryline.github.io/

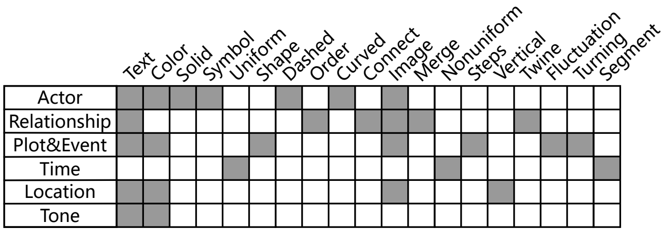

Fig. 4. Mapping between visual and narrative elements.

Q2 *How did you emphasize minor but affective elements?*

Q3 *What sequence of actions did you follow to deal with the innovation in the storylines?*

Q1 asked for essential elements that could be regarded as the skeleton of a story and should be considered in the storyline design space. A skeleton storyline layout can present the story evolution, but it may not be attractive and intuitive because of missing details. Some minor details, such as the narrators' mental map, the narrative trend, and complex relationships, usually play important roles in the expressive context. An example is the simple plot *"Tom finally committed suicide due to long-time depression."* Automatic layout methods would generate a straight line representing the character that runs from left to right until it reaches an ending point that represents death. Viewers would never guess the cause of death unless the more explicit information is shown. To our knowledge, no previous storyline method has considered the minor but affective information in their designs. Thus, Q2 ascertained the participants' special design for these minor but affective elements. Bal [8] claimed that narrators usually follow a pipeline or a set of steps to generate stories. The effectiveness of artistic work can also be augmented by following step-by-step illustrations. Therefore, Q3 attempted to understand the authoring process of storylines.

Results: In response to question Q1, many participants reported actors (12 ×), key events/conflicts (7 ×), time (6 ×), and the relationship between actors (3 ×) as essential elements for stories. Their responses met our expectations and confirmed the essential elements encoded in previous storyline designs. However, relative to the usual visual elements used in prior storylines, many novel designs that encode these narrative elements were found. For instance, instead of straight lines, we found numerous different line formats in the hand-drawn designs, such as dashed and curved lines (Fig. 2(c)), twined lines (Fig. 2(b)). We also noticed various plotting styles in the hand-drawn storylines, including the turning (Fig. 2(c)), step (Fig. 1(b)) and fluctuation layouts (Fig. 2(d)).

In response to question Q2, 8 participants asserted that *plot* was an interesting aspect for the narratives. Note that *plot* here refers to the demonstrating style of the sequence of events in a narrative [8], and is not considered in the previous storyline designs that regarded straightness and compactness as aesthetic metrics. Responses also revealed that many participants (13 ×) paid special attention to narrative details, such as emotional changes, mental status, first appearance, and the moment of death. Emotional changes and mental status are related to *tone* which refers to how the narrator and characters are affected by story events or other characters [8]. Participants reported that these affective elements would influence the story evolution and that their appearances in the storylines were helpful to the better understanding of the story. However, these details are not considered in prior storylines because they do not affect the outcome directly. Given the responses to Q1 and Q2, we identified the most essential and affective narrative elements, and the visual elements used to convey them.

We observed a common process of creation (for Q3) despite the variety of the visual appearances of participants' final storylines. The process contained roughly four steps: arrangement, placement, creation, and embellishment. Participants started their storyline creation by constructing a vertical order of actors on the canvas. We noticed that, from the very beginning, many participants (8 ×) started predicting the overall distribution of actors, instead of simply positioning individual actors. In the second step, participants placed key events on the canvas (6 ×). They refined the backbone of the storyline until they were satisfied with the structure. In the third step, most participants (13 ×) edited the path of individual actor lines, such as orientations and wiggles. This step was the most time-consuming and creative because the participants reported that "line orientations and paths can directly affect the final layout". The participants usually did not have a clear idea of the line styles beforehand, and thus, they refined their designs repeatedly to achieve a pleasant and consistent mapping between the narrative and visual appearances. In the last step, participants featured the lines on the canvas, including colors, styles, and labels, to render them expressive and aesthetic. Although participants typically followed these four steps sequentially, they needed several iterations to improve the final results. In order to validate the effectiveness of the visual elements found in this stage, we conducted a follow-up study.

3.2 From Visual Elements to Narrative Elements

The second stage of our preliminary study aimed to examine a selection of visual elements found in the first stage. Two aspects were considered: whether these elements could be mapped back to narrative elements, and whether they affected the aesthetic and legibility of storylines despite not conforming to the design principles and optimization goals.

Participants: We recruited a new group of 25 participants (17 males, 8 females) with an average age of 21 years. Participants were undergraduate students majoring in different areas: eight in *Computer Science* and the rest in *Biology* and *Engineering*. None of them had experience with storyline visualizations.

Tasks: We wanted to evaluate the human-generated visual elements found in the first stage. Thus, participants were asked to map the visual elements to narratives. We only evaluated the visual elements that violate the optimization goals and thus reflected the main differences between hand-drawn and automatic layouts. We identified five such visual elements: Step, Fluctuation, Turning, Twine, and Curved (Fig. 6). The first three elements refer to the way a story is told, Twine represents a relationship between actors, and Curved signifies the actors' experiences or characteristics. Multiple mappings are possible. We also wanted to ascertain whether the same element would always lead users to the same context. We compared the hand-drawn storylines and the storylines generated by the state-of-the-art method [25].

Participants were asked to finish three tasks for each visual element:

T1 *Describe a possible story for the visual element and associate it with a narrative element: an actor, a relationship or a plot/event.*

T2 *Rate the visual element in both the hand-drawn and automatic storyline conditions from different aspects.*

T3 *Discuss the implication of the visual element in the storylines.*

Procedure: First, one of the five visual elements was selected and its visual symbol (Fig. 6) was shown to participants. Then, the participants were asked to start T1. In T1, we provided a general direction, such as "what it could represent," "what relationship they have," and "how the story evolves." Participants should create or find a short story that could be described by the given visual element. We then presented two stories containing the visual element, and participants were asked to start T2. Each story was presented using a hand-drawn storyline and a storyline generated by the state-of-the-art method [25]. Participants were instructed to rate the given visual element under both conditions on a five-point Likert scale of five measures: aesthetics, legibility, engagement, entertainment, and attractiveness. Note that the visual element did not appear in the automatic layout. Thus, participants were requested to rate the corresponding visual design. We varied the order of testing elements using a Latin rectangle. Half of the participants started with a hand-drawn layout, and the other half started with an automatic layout. In T3, participants were asked to discuss whether the given visual element could convey the narrative in the hand-drawn illustrations. We worked with the participants through the study to ensure that they understood the questions fully.

Results: We analyzed the response to T2 as follows. We gathered a total of 50 gradings (2 stories × 25 participants) for each visual element. All results consistently showed that each hand-drawn visual element outperformed the corresponding visual design in the automatically generated storyline. Ratings on aesthetic and legibility (Fig. 5) confirm that the hand-drawn layout is more aesthetically pleasing and legible than the automatic layout for five tested visual elements.

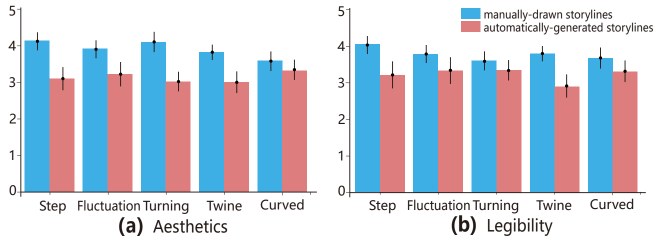

Fig. 5. Measurements results (Error bars are 95% CIs).

We analyzed the responses to T1 and T3 as follows.

Step: Many participants mentioned "it conveys clearly how a story evolves" (22 ×) or "the story happens at different locations" (3 ×). They gave expressive narratives, such as "actors work together to achieve the same target progressively," "life comes across accidents and goes down from there." Some participants stated that it reminded them of the movie "Dangal" when "Geeta and Babita fight for the championship of the wrestling competition from the low level to the high level."

Fluctuation: Many participants had a clear opinion about this visual element (19 ×) that the plot switched between two sides. They also recalled some famous stories, such as "Journal to the West" and "Forrest Gump." In these stories, actors overcame difficulties step by step and experienced many ups and downs.

Turning: Most participants reported that the turning element can be associated with diverse narrative contexts, such as a flashback in the story (2 ×), an end connecting to the start (5 ×), and a sudden U-turn in the plot similar to a reversal drama (10 ×).

Twine: Most participants mentioned that the twine element was associated with the mutual relationships between actors (16 ×), such as falling in love or intense interactions (5 ×) like fights and conflicts.

Curved: Many participants stated that the curved element signifies the actors' thoughts, emotional changes, or other mental activities (24 ×).

Qualitative data reveals that all participants could recall several narratives after watching the visual symbol of the step element, and most of them could relate the fluctuation element to certain stories. More than half of the participants recalled interesting plots, such as the reversal ending, because of the turning element. The twine and curved elements were also successfully mapped back to the mutual relationships and the personal information of the actors, respectively. Thus, we believe the participants could associate visual symbols effortlessly and accurately with the correct actors and events in the story.

In summary, the second stage study suggests that the five user-generated visual elements could be associated correctly with some appropriate narrative context. Moreover, hand-drawn illustrations that consider visual elements are more understandable than automatic layouts that pursue compactness and straightness of lines. According to the results of the preliminary study, we present a design space that associates narrative elements to visual elements in Section 3.3.

3.3 Design Space and Human Rationale

Visual perception and cognition are based on the users' personal experiences and desires [21, 26]. Thus, assertions of narrative elements differ from person to person. How people conceive a narrative, create illustrations, and order their activities cannot be generalized. Determining a storyline illustration in the preliminary study that can be considered as a standard for various elements of a narrative is not feasible. Therefore, we explored a design space after careful examination of storyline illustrations and the analysis of interview responses. In the design space, we identified common features from the judicious choices made by participants that contribute to the enhancement of storyline visualizations. The identified features are grouped according to the elements of the narrative [8, 12] in the design space. The five dimensions of our design space are Actor, Relationship, Plot and Event, Structure and Location, and Decoration (Fig. 6). Coulter et al. [12] defined the element plot as the sequence in which events are placed, and they regarded structure as the time and location given to the events. Decoration represents visual elements that are widely used in different narrative dimensions, such as actor and structure. The design elements in each dimension are elaborated according to the participants' design rationales.

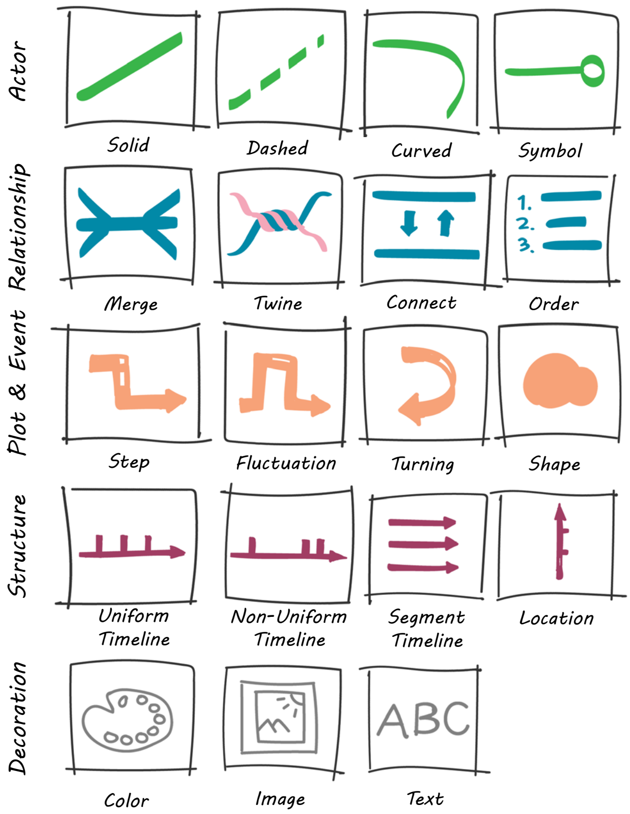

Fig. 6. Design space maps narrative elements to various visual elements which are collected from hand-drawn illustrations.

Actor: Similar to the line design in the previous storyline [25], a line is used to represent an entity. Instead of straight lines, we propose four different line styles:

- ◇ Solid: Solid straight lines indicate actors.
- ◇ Dashed: Dashed lines represent the actors' identification or status.
- ◇ Curved: Curved lines reveal the actors' lives or mental map.
- ◇ Symbol: Lines with symbols reveal that something happened to the actors, such as birth or death.

Relationship: Relationship refers to how actors interact in a narrative. Four visual elements are introduced:

- ◇ Merge/Split: Merging lines indicate actors teaming up while splitting lines indicate the team is splitting up.
- ◇ Twine: Twining lines portray a complex relationship between actors, such as hate or love relationships and conflicts.
- ◇ Connect: Connected lines denote the union relationship.
- ◇ Order: The order of lines determines the closeness among actors.

Plot & Event: The sequence of events in a narrative is demonstrated as a plot. Four visual elements are proposed:

- ◇ Step: demonstrates that the story evolves progressively.
- ◇ Fluctuation: indicates that the plot switches between two sides.
- ◇ Turning: suggests a big transition in the plot.
- ◇ Shape: highlights significant events in the narrative.

Structure: This dimension focuses on how events are distributed from the temporal and spatial sides. Four visual elements are identified:

- ◇ Uniform Timeline: follows the actual timing of events.
- ◇ Non-Uniform Timeline: exaggerates the distribution of events.
- ◇ Segments Timeline: organizes events using parallel timelines.
- ◇ Location: demonstrates events according to where they occur.

Decoration: Visual elements in this dimension serve to supplement the meaning of other visual elements. Image and text elements can be used to identify actors, label locations, and highlight key events. Colors can be also used to present the tone element. For example, some participants tend to use light or bright colors to represent characters that are well-received and dark gray colors to illustrate tragedies.

Some visual elements are portrayed in the sample illustrations. For example, Fig. 2 (b) clearly demonstrates the *merge/split*, *twine*, and *connect* elements to reveal various relationships between actors. Fig. 2 (c) and (d) present the *turning* and *fluctuation* layouts to symbolize the plot evolution. Design space portrays the human potential for sharing narratives as visual representations. The features we deduce are employed not only by the interviewees. Other participants in the first stage also incorporate these features in their illustrations. However, the interviewees exhibit good maturity level in using these features. The comparison of automatic layouts with the design space shows the existing automatic methods cannot clarify all the elements of the plot. We develop a comprehensive set of interactions covered in Section 4 to enable the automatic methods to support the diverse visual designs, through which users can edit layouts according to their preferences.

4 iSTORYLINE

The design space and diversity in layouts collected from the preliminary study cannot be covered using a single layout algorithm. Thus, iStoryline is developed to integrate a set of flexible and intuitive interactions to support creative designs and find a balance between automatic layout solutions and freeform drawing tools.

4.1 Design Considerations

Given that the performance of existing storyline methods has improved considerably, we do not pursue a completely new solution and instead investigate the extant ones. We adopt StoryFlow [25] as the automatic layout part of iStoryline for two reasons. First, StoryFlow has very good performance in generating storyline layouts in real-time, which is critical for an authoring tool to support flexible interactions. Second, the optimization model of StoryFlow is relatively easy to extend, thereby supporting the workflow followed by artists.

For the creativity part of iStoryline, we intend to provide users with a familiar editing experience to adjust automatic layouts easily. First, iStoryline should be equipped with sufficient and intuitive user interactions to allow users to express their designs of various narrative elements. The designs are then translated into constraints of the back-end optimization model. For example, many artists deliberately twist character lines to emphasize or deliver subtle information, which is a clear violation of the design principle D3, straightness [40]. Hence, the system must support interactions that capture such intention and convert them into optimization constraints of the back-end model. Second, our studies also show that users often create storylines in an iterative fashion. Thus, our system should also follow the workflow practiced in making hand-drawn illustrations and refine the underlying constraints in a progressive manner.

4.2 System Workflow

The original StoryFlow pipeline [25] contains three consecutive optimization stages, i.e., ordering, alignment, and compaction, which are all performed automatically and require no user input. Thus, to extend the StoryFlow framework and integrate human creativity into the optimization models, iStoryline creates four interaction-centric stages, i.e., arrangement, placement, creation, and embellishment (Fig. 7), and interleave them with the three optimization-centric stages of StoryFlow. In the arrangement stage, we introduce an interaction, *shifting*, to help users construct the desired order of actors throughout the entire storyline. In the placement stage, users can refine the backbone of storylines using the *bending* interaction. The creation stage determines the line path, which is the core part of the authoring process. In this stage, we also introduce three interactions, namely, *scaling*, *curving*, and *linking*, to fine-tune the detailed trajectories of individual actors. In the final stage, several embellishing tasks, such as image inserting and labeling, can be performed to improve the aesthetic quality of the final storyline.

4.3 Interaction Design

The core part of our system entails user interactions, which is the key to bridging user creativity and the automatic layout algorithm. We defined a set of interactions according to the design space to facilitate efficient user creation of compelling and optimized storylines.

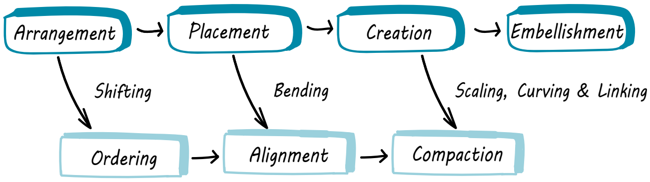

Fig. 7. iStoryline workflow with three optimization stages (light blue) and four interaction stages (dark blue).

The first category of interactions presents no violation of the old guidelines and are mainly for embellishment. For example, in the last stage, users can either change visual attributes (such as line width, style, and color) or add visual decorations (such as labels and icons) to the final visualizations. Although these interactions are simple and do not add any constraints to the optimization process, they are responsible for a sizeable part of the design space. Trivial visual elements, including text, image, and shape, are supported by these interactions.

The second category focuses on the remaining visual elements, such as step, fluctuation, and curved, evaluated in the second stage of the preliminary study. Five interactions are highlighted in this section, and they may violate the old guidelines [25], such as minimizing line wiggles and white space. The interactions are shown in Fig. 8, where solid and dotted lines represent the states before and after the interaction.

Shifting. In the ordering stage, automatic algorithms reorder actors to minimize line crossings. Thus, the *Relationship (order)* element in the design space is used purely for aesthetic purposes, and the order with minimal line crossings may not be the arrangement preferred by users. Consequently, the shifting interaction is designed in the first stage to help users easily achieve the desired actor order. Although this operation is also discussed in StoryFlow [23], it only works locally and cannot move a whole line at a time because the crossing minimization algorithm may disturb the new order. In iStoryline, the *shifting* interaction allows users to drag and drop an entire line to a new location, and the dropped place is recognized to ensure that the line order is changed globally. To achieve such interaction, a set of constraints is generated through Eq. 1, which defines the preferred order between the f-th character X_f and the remaining characters. For example, (X_u, X_f) indicates that the u-th character X_u is placed above X_f, and (X_f, X_d) indicates that the d-th character X_d is placed below X_f. The constraints are added to the ordering optimization process, which is then solved using a constrained-crossing reduction algorithm [15].

$$\{(X_u, X_f), \ldots, (X_f, X_d)\} \tag{1}$$

Bending. This interaction is designed to help users relocate the positions of events easily, which may eventually produce skewed layouts, and supports the plot dimension of our design space, such as *step* and *fluctuation* in the *Plot&Event* dimension. Users can drag a group of line segments to a new place. Consequently, the whole layout can be re-aligned according to the constraints described by Eq. 2. If the new position of the p-th group S_p which is a set of interacting characters is lower than that of the q-th group S_q, then all line segments of characters $\{X_i\}_{i \in S_p}$ must be lower than those of characters $\{X_j\}_{j \in S_q}$. The constraints can be added to the alignment step of optimization to control the overall shape of the layouts. Thus, *bending* enables users to transform the straight layout into step-shaped or fluctuating layouts.

$$S_p < S_q, X_{i \in S_p} < X_{j \in S_q} \tag{2}$$

Scaling. The old optimization goals strive to minimize the white space. However, artists increase white space for different purposes, such as emphasizing separations. Hence, this *scaling* interaction is used to change the white space between lines or line groups. Users first draw a horizontal line to indicate the time range that should be scaled and subsequently draw a vertical line that intersects with the first line to define the magnitude of the scaling factor. Therefore, the system should resize the white spacing accordingly, and unnecessary spacing should still be minimized. This interaction enables users to enlarge or shrink space locally in the layout, thereby supporting elements in

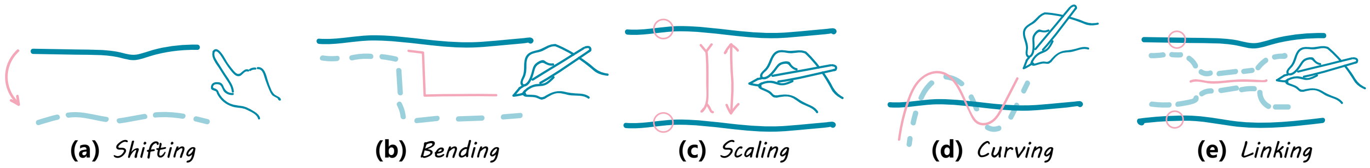

Fig. 8. Vocabulary of interactions in iStoryline. Shifting supports Relationship(Order) element while Bending and Scaling support Plot (Step) and Plot (Fluctuation) elements. Curving is associated with Actor (Curved) element, and Linking supports the Relationship (Twine) element.

the *Structure* dimension, such as *non-uniform timeline* and *location*. Moreover, this interaction can be utilized to generate appropriate white space before inserting images, icons and labels to embellish storylines.

Curving. This interaction is developed because of the frequent use of curved lines in hand-drawn illustrations which corresponds to the *curved* element in the *Actor* dimension. Users draw a trajectory on top of a region to indicate where and how the underlying line segments should be reshaped. Let P_{ij} and $P_{ij}^{'}$ represent the new and original positions of the i-th control point of the j-th actor line, while O_{ij} is the target position, which is decided by user interaction. New paths of characters' lines are generated by optimizing the energy function in Eq. 3, where minimum energy is applied to displace points at position $P^{'}$ to the target position O. The parameter α balances the original and target positions and is set to 0.1 in our application. The sharp turns of those resulting curves are reduced using cubic splines to keep the lines smooth and aesthetically pleasing.

$$minE = \sum(P_{ij} - O_{ij})^2 + \alpha(P_{ij} - P_{ij}^{'})^2 \tag{3}$$

Linking. The *linking* interaction helps users emphasize the relationship among characters using highly expressive elements, such as *merge*, *twine*, and *connect*. Users can simply select the characters that they want to operate and choose the specific visual element to reveal the relationship among characters. We directly insert the corresponding visual element into the layout given that these elements are all local and do not require global optimization.

4.4 Implementation

iStoryline is developed using client-server architecture. At the server side, the optimization module is provided by StoryFlow [25], which is implemented in C#, and the entire application is hosted by the framework Nancy [3]. We extend the optimization module to support high-level interactions. The client side is a web-based user interface implemented in Vue.js [4]. Similar to StoryFlow, iStoryline allows users to load datasets in XML format, which contains the necessary information, such as actors, locations, and events with start and end times. The output of iStoryline is saved in the SVG format.

5 Use Cases

In this section, we compare the various interpretations of the storyline layout generated by iStoryline (Fig. 9) with the original narrative (*The Chronicles of Narnia: The Lion, the Witch and the Wardrobe* [5]). We aim to find out how close the interpretations are and to what degree the visual elements used in iStoryline improve the understanding of the narrative. We also compare iStoryline results with the automatically generated layouts from StoryFlow and the hand-drawn illustrations on two narratives (*Jurassic Park* [38] and *The Moon and Sixpence* [29]). Note that all iStoryline layouts in this section are generated according to the original hand-drawn illustrations by the paper authors. However, since iStoryline provides a rich set of user interactions, users can refine the storyline layouts according to their personal understanding.

The Chronicles of Narnia: The Lion, the Witch and the Wardrobe: The story is about the Pevensie children and their journey in the fantasy world called Narnia [5]. Most of the story takes place in Narnia where they meet the White Witch, who has cursed Narnia to a hundred years of winter. Humans encountered in Naria are supposed to be brought to her. In the climax of the story, two of the children, Peter and Edmund, join the Narnian army against the Witch's army. The Lion Aslan aids them and kills the Witch. Finally, the Pevensie children leave Narnia and return to the real world.

Fig. 9 (a) illustrates the story evolution crafted by iStoryline. We first load the story data and acquire an initial layout (Fig. 9 (b)) generated by the optimization module (*StoryFlow*). We then follow the iStoryline workflow (Fig. 7) to modify the initial layout according to the hand-drawn layout (Fig. 2 (a)). We *shift* actors to separate the two worlds, namely Narnia and Earth, *bend* the kids' lines, and *scale* the white space to indicate when they enter/leave Narnia. Obviously, compared with the iStoryline layout, the StoryFlow layout is more symmetric and compact with fewer line crossings, wiggles, and white space because of its adherence to the optimization goals. However, we believe that wiggles and white space improve understanding. We compare the various interpretations of the iStoryline layout with the original narrative.

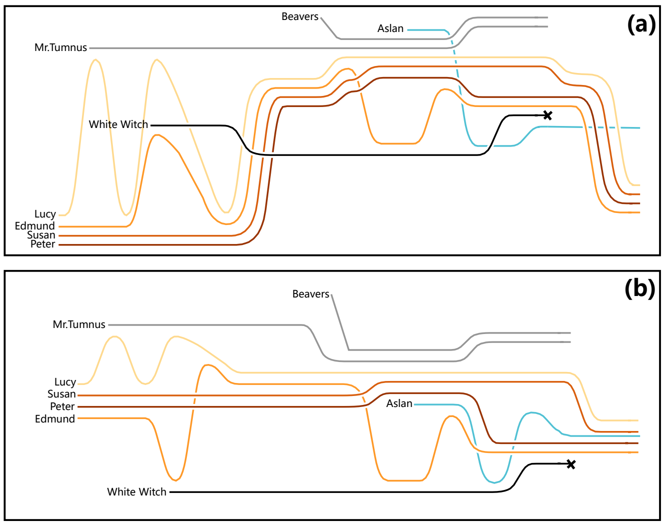

Fig. 9. Illustrations of (a) iStoryline and (b) StoryFlow layouts for the movie *The Chronicles of Narnia: The Lion, the Witch and the Wardrobe.*

In the iStoryline layout, the children lines have two big shifts (one at the beginning and the other at the end of the story), indicating that the four children comprise a team: they go together to a place and return together to their original place. Identifying the place as Narnia is straightforward. Thereafter, all the plots that take place in Narnia can be spotted easily. Then, follow-up ideas occur: the Lucy line has a wiggle going from the real world to Narnia where she meets Mr. Tumnus, then she returns to the real world and stays with her siblings. Subsequently, the children enter Narnia and Edmund meets the Witch.

iStoryline uses *Structure (Location)*—the y-axis—to encode location and uses *Plot & Event (Fluctuation)* to demonstrate that the plot switches repeatedly between two sides. Such intuitive and effective representations appear many times in iStoryline. For instance, in the original narrative, when Edmund and Lucy enter Narnia, and Edmund meets the Witch, we use *Actor (curved)* for the Witch's appearance to imply that she intentionally approaches Edmund and places an enchantment on him. However, all this information cannot be easily detected in StoryFlow, as shown in Fig. 9 (b). The reason is that StoryFlow prefers straight lines which cannot represent rich information.

The Moon and Sixpence and Jurassic Park: We follow the same procedure to create the other two use cases. Fig. 1 shows the hand-drawn illustrations ((a) and (b)), iStoryline layouts ((c) and (d)), and StoryFlow layouts ((e) and (f)). The overall visual appearance indicates that StoryFlow is more compact but iStoryline and hand-drawn illustrations convey more narrative information. iStoryline effectively imitates the hand-drawn features. Specifically, at the climax of the narrative *Jurassic Park* [38], Fig. 1(a) and (c) clearly indicate that the humans initially come under attack from two sides by raptors and then manage to escape when the raptors fall prey to T-Rex. Finally, humans leave the island while T-Rex flees to another direction and stand victorious on the island. However, in Fig. 1(e), humans lines come between raptors lines and T-Rex line, which suggests that humans are under simultaneous attack by T-Rex and raptors. In the story of *The Moon and Sixpence* [29], Fig. 1(b) and (d) utilize the y-axis to encode the geolocation information. Therefore, identifying the places in which “I” travel and the people who “I” interact with at each place is easy. However, such information is very difficult to detect in the StoryFlow layout (Fig. 1(f)). In Fig. 1(b) and (d), we notice that Strickland’s wife stays in London all the time, although most of the time she does not appear in the narrative. However, in Fig. 1(f), we cannot ascertain the location of Strickland’s wife and the intention of the sharp curve remains unclear.

6 Evaluation

In this section, we aim to evaluate the usefulness and effectiveness of iStoryline. Specifically, we want to learn 1) whether users can easily associate narrative elements to visual elements and use iStoryline to create a meaningful storyline (Stage one in Fig. 10), and 2) if the iStoryline results are intuitive in telling stories (Stage two in Fig. 10). To address these two issues, we conducted two separate user evaluations (Fig. 10) with two different target groups (storyline makers and reviewers). The first assessment was a user experiment to understand the usability of iStoryline and the accessibility of our interactions. The second assessment involved experts evaluation with three experts from different domains: a professor (PD) in Industrial Design, a professor (PM) in Digital Media, and an advanced engineer (PE) from a leading e-commercial company.

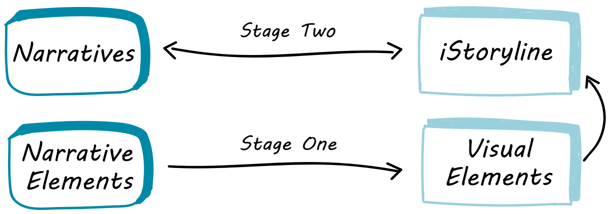

Fig. 10. User Evaluation. Stage one: user experiment for the usability of iStoryline; Stage two: expert evaluation for comparing the various interpretations of iStoryline layouts with the original narratives.

6.1 Task-Based Evaluation

We conducted a task-based study to assess the effectiveness and intuitiveness of the interactions supported by iStoryline, and we further held a semi-structured interview with the participants.

Participants: We recruited 12 students (6 males and 6 females) who major in Digital Media (9), Computer Science (2), and Agronomy (1). Nine of them joined the preliminary study (Section 3.1) and submitted hand-drawn storyline illustrations. All of them had experience using graphics editors, such as Adobe Illustrator [1] and Photoshop [2].

Procedure: We conducted interviews individually. First, we gave a short introduction (3 minutes) on the authoring tool and each user interaction. Then, we demonstrated a simple example (3 minutes) for creating a storyline layout. Afterward, participants were asked to practice until they become fully familiar with all the interactions listed in Section 4.3. Participants were then asked to generate a storyline layout by interactively adjusting one of eight automatically-generated layouts using iStoryline. At the end of the study, participants were asked to rate the intuitiveness and effectiveness of each proposed interaction using a five-point Likert scale, and provide further suggestions.

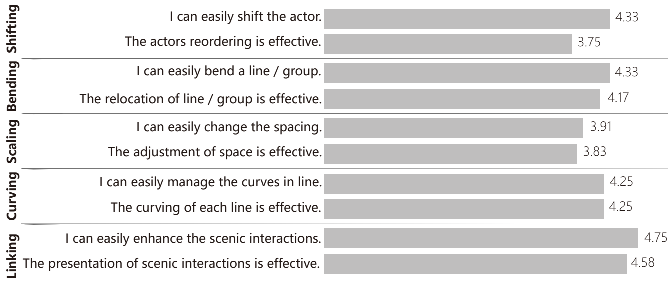

Fig. 11. Overall ratings of the task-based evaluation.

Rating Results: Participants rated each interaction on two measures: effectiveness and ease of use. Effectiveness was assessed by how much the participant was satisfied with the results achieved through the interaction, whereas intuitiveness was judged by how easily the participant accomplished the task. Fig. 11 shows the questions and corresponding average ratings with encouraging overall results. Participants were able to remember all interactions easily and create the storylines efficiently. Although we allowed them to ask questions on the functions of the system during the study, no participant raised queries. In all cases, we observed the authoring process (Fig. 12) always started from moving actors (a), and then aligning events (b), scaling white space (c), and finally embellishing (d), thereby indicating the general workflow of the participants matches the common course of activities in Fig. 7.

User Feedback: Overall, participants were satisfied with iStoryline and stated that it was easy to learn and use. All of them enjoyed using iStoryline for editing the storylines, and they believed they can create a storyline layout that satisfies their requirements. Several participants particularly appreciated “Shifting” and “Scaling,” which allowed them to edit the storylines and the white space easily. However, some participants reported unexpected changes from “Shifting” when they tried to reorder actors, which affected their grading of iStoryline. These comments show that we have addressed the second limitation of automatic layouts as described in the Introduction (repetitive layout).

6.2 Experts Feedback

The interviews with experts aim to compare the various interpretations of the iStoryline layout with the original narrative. The interview had two stages. In the first stage, we introduced iStoryline to the experts and ensured that they fully understood the storyline visualization and our system. In the second stage, we provided experts with two different storylines corresponding to two different narratives. Then, the experts were asked to complete two tasks:

Task 1 Given four short narrative events (by oral storytelling), mark the corresponding visual elements in the iStoryline layout.

Task 2 Given three visual elements in the context of the whole iStoryline layout, discuss the possible plots that may occur in the original narrative.

The Chronicles of Narnia and *The Moon and Sixpence* were used in each interview. We considered two possibilities before the interviews: 1) experts who were familiar with the two narratives might easily recall the asked narrative elements and identify the asked visual elements; 2) otherwise they might not complete the tasks promptly. However, feedback from both types of experts (familiar and unfamiliar with narratives) was valuable to us because we were interested in whether the iStoryline layouts allowed people to understand previously unknown stories. To our knowledge, no previous work has done such study.

In Task 1, we asked experts to spot four narrative events in *Narnia* that correspond to the *Plot&Event (fluctuation)*, *Actor (curved)*, and *Structure (location)* in Fig. 6.

1. When the Pevensie children enter Narnia together and when they return to the real world.
2. When the first time Edmund and Lucy enter Narnia together and Edmund meets the Witch.
3. When Edmund betrays his siblings and meets the Witch secretly.
4. The final battle.

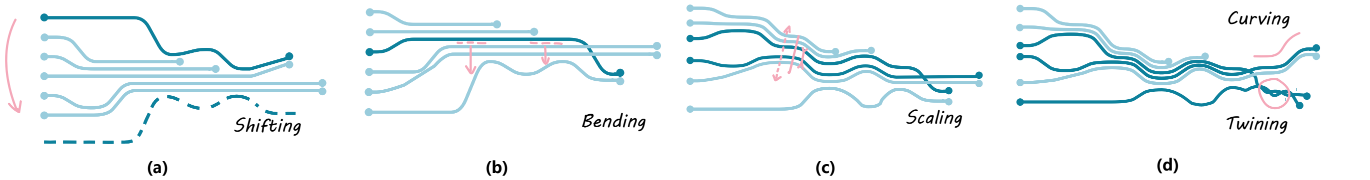

Fig. 12. The authoring process by a participant for creating a storyline for the movie "Train To Busan" (see Fig. 2(b)): (a) shifting, (b) bending, (c) scaling, and then (d) curving and twining. The dark blue lines are selected to facilitate interactions (shown as pink lines).

All experts marked the associated visual elements in the iStoryline layout correctly, even though none of them were familiar with the story.

In Task 2, we asked the experts two questions (1 and 2) related to the storyline. Then, we pointed out one marked event / visual element in the iStoryline layout (3) and requested the experts to discuss the possible corresponding event in the narrative:

1. Who is the main actor in the story.
2. The main location where most subplots take place.
3. Discuss Strickland's life before he meets Dirk Stroeve.

We found that, although none of the experts knew the story before, they answered the first and second questions promptly: all of them chose "I" as the main actor, and when we further asked for the second main actor, all of them chose "Strickland". All experts reported that many events occurred in Paris, and one of them mentioned Tahiti as another key location in the story. One expert became confused with why the line of "I" in Marseilles and Tahiti is dashed (signifying a "partial" presence), and he wanted to learn more about the story. For the third question, the experts gave different answers regarding Strickland's life but all of them assumed that Strickland live unhappily before meeting Stroeve.

We also showed the experts the StoryFlow layouts of the two narratives (Fig. 9(b) and Fig. 1(f)) and asked them to complete both tasks. In the first task, some experts struggled when spotting the narrative events in the storyline because of the missing visual elements. In the second task, all experts encountered difficulty in interpreting the narrative details in the StoryFlow layouts. They all reported that the visual cues from iStoryline were appropriate for understanding storylines.

After completing the two tasks, we conducted post-interviews with the experts. Overall, the experts confirmed the effectiveness and intuitiveness of iStoryline layouts. Expert PM, who was familiar with the storyline visualization, mentioned that "a narrative is more than the characters and relationships" and "iStoryline effectively reveals some important changes in the story, which is impossible to achieve in the automatic storyline techniques." Expert PD mentioned the emotional changes of the characters, story evolution, and conflicts were the most attractive elements in the story and iStoryline is designed to add effective features to these elements, thereby making the storyline very attractive. Expert PE was really impressed by iStoryline layouts. He mentioned that "iStoryline layouts look more vivid, and express more details." We also received valuable suggestions from our experts. For example, Expert PE, who has more than 10 years of expertise in Multimedia, mentioned that as an interactive storyline technique, iStoryline would be very useful in video editing.

7 Discussion

The use cases and evaluation show the effectiveness and usefulness of iStoryline for creating expressive storylines. This section discusses the implications and limitations of this study.

Implications. Our work has several important implications. First, this research presents the first attempt at a better understanding of the narrative elements in hand-drawn storylines through a large-scale, two-stage study. Several important narrative elements of storylines neglected in prior studies [25, 40] are identified for the first time. Second, based on the two-stage study, we further propose a novel comprehensive design space to characterize the visual elements for creating storylines. In addition, we identify the authoring pipeline that the participants followed to create hand-drawn storylines. The design space and pipeline can shed light on creating new layout algorithms and interactions for future research on storyline visualizations. Third, this work presents iStoryline, the first web-based authoring tool which realizes the design space to empower average users to create expressive storylines quickly. The tool integrates human creativity and machine power through a highly interactive user interface following the identified pipeline. Lastly, the two-stage study which was conducted as a part of a visualization course proves effective in engaging participants and can be adopted by future research. By assigning students homework to create storylines manually, this work collects relatively high-quality hand-drawn storylines as well as the feedback for subsequent analysis, which allows us to gain deep insight into how the subjects created storylines manually and what narrative elements they preferred most.

Limitations. Our work has several limitations. First, several design elements, such as *Plot&Event (turning)*, are currently not supported by iStoryline because they are incompatible with existing optimization models. As a proof of concept, iStoryline realizes most of the essential elements of the proposed design space. According to the user feedback, the visual elements supported by iStoryline can meet most user requirements. We plan to extend the optimization model and improve iStoryline to cover the remaining elements of the design space. Second, iStoryline does not allow for a sketching style in the creation of storylines. Prior studies suggest that sketched visualizations are more attractive and interesting for novice users [23]. Sketching styles can be integrated into iStoryline in the future. Third, iStoryline requires advanced preparation of story data and does not allow a user to create a new storyline from scratch. An efficient method to create storylines from conception is worth further study.

8 Conclusion

In this research, we explore and analyze how humans utilize narrative elements to enrich the expressiveness of storylines by conducting a preliminary study. Surprisingly, we find that humans usually disobey a well-established design principle (D3) and several widely-adopted optimization goals (G1 to G3) to create storylines while considering narrative details. After revisiting hand-drawn illustrations collected from the preliminary study, we present a novel design space which associates narrative elements to visual designs in storylines. Based on the design space, we further design and develop iStoryline, a web-based authoring tool for creating hand-drawn style storylines. iStoryline supports a set of intuitive interactions which involve users in the underlying optimization process of creating storylines. iStoryline enables users to create their desired storylines efficiently. We demonstrate the effectiveness and usefulness of iStoryline through use cases and evaluation.

Several avenues exist for future work. As a preliminary system, iStoryline works for relatively small storylines with several characters (less than fifteen). We plan to optimize the code and algorithms of iStoryline and design new interactions to handle large storylines with numerous characters. Moreover, the current system targets traditional PC users. In the future, we intend to improve the system and adapt it to touch-based devices to support more natural user interactions.

Acknowledgments

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References

[1] Adobe Illustrator CC, 2017. Retrieved Dec 1st, 2017 from `http://www.adobe.com/products/illustrator.html`.

[2] Adobe Photoshop CC, 2017. Retrieved Dec 1st, 2017 from `http://www.adobe.com/products/photoshop.html`.

[3] Nancy, 2017. Retrieved Dec 1st, 2017 from `http://nancyfx.org/`.

[4] Vue.js, 2017. Retrieved Dec 1st, 2017 from `https://vuejs.org/`.

[5] A. Adamson. *The Chronicles of Narnia: The Lion, the Witch and the Wardrobe*. Walt Disney Pictures & 20th Century Fox, 2005.

[6] F. Amini, N. H. Riche, B. Lee, A. Monroy-Hernandez, and P. Irani. Authoring Data-Driven Videos with DataClips. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):501–510, 2017.

[7] D. Arendt and M. Pirrung. The "y" of it Matters, Even for Storyline Visualization. In *Proceedings of the IEEE Conference on Visual Analytics Science and Technology*, 2017.

[8] M. Bal. *Narratology:Introduction to the Theory of Narrative*. University of Toronto Press, 3rd edition, 2009.

[9] A. Batch and N. Elmqvist. The Interactive Visualization Gap in Initial Exploratory Data Analysis. *IEEE Transactions on Visualization and Computer Graphics*, 24(1):278–287, 2018.

[10] M. Brehmer, B. Lee, B. Bach, N. H. Riche, and T. Munzner. Timelines Revisited: A Design Space and Considerations for Expressive Storytelling. *IEEE Transactions on Visualization and Computer Graphics*, 23(9):2151–2164, 2017.

[11] W. Chen, T. Lao, J. Xia, X. Huang, B. Zhu, W. Hu, and H. Guan. GameFlow: Narrative Visualization of NBA Basketball Games. *IEEE Transactions on Multimedia*, 18(11):2247–2256, 2016.

[12] C. A. Coulter and M. L. Smith. The Construction Zone: Literary Elements in Narrative Research. *Educational Researcher*, 38(8):577–590, 2009.

[13] J. Díaz, J. Petit, and M. Serna. A Survey of Graph Layout Problems. *ACM Computing Survey*, 34(3):313–356, 2002.

[14] T. Dwyer, B. Lee, D. Fisher, K. I. Quinn, P. Isenberg, G. Robertson, and C. North. A Comparison of User-generated and Automatic Graph Layouts. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):961–968, 2009.

[15] M. Forster. A Fast and Simple Heuristic for Constrained Two-Level Crossing Reduction. In *Proceedings of the International Symposium on Graph Drawing*, pages 206–216, 2005.

[16] J. Fulda, M. Brehmel, and T. Munzner. TimeLineCurator: Interactive Authoring of Visual Timelines from Unstructured Text. *IEEE Transactions on Visualization and Computer Graphics*, 22(1):300–309, 2016.

[17] S. Huron, S. Carpendale, A. Thudt, A. Tang, and M. Mauerer. Constructive Visualization. In *Proceedings of the Conference on Designing interactive systems*, pages 433–442, 2014.

[18] S. Kieffer, T. Dwyer, K. Marriott, and M. Wybrow. Hola: Human-like Orthogonal Network Layout. *IEEE Transactions on Visualization and Computer Graphics*, 22(1):349–358, 2016.

[19] N. W. Kim, S. K. Card, and J. Heer. Tracing Genealogical Data with TimeNets. In *Proceedings of the International Conference on Advanced Visual Interfaces*, pages 241–248, 2010.

[20] N. W. Kim, E. Schweickart, Z. Liu, M. Dontcheva, W. Li, J. Popovic, and H. Pfister. Data-Driven Guides: Supporting Expressive Design for Information Graphics. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):491–500, 2017.

[21] M. Kozhevnikov, C. Evans, and S. M. Kosslyn. Cognitive Style as Environmentally Sensitive Individual Differences in Cognition: A Modern Synthesis and Applications in Education, Business, and Management. *Psychological Science in the Public Interest*, 15(1):3–33, 2014.

[22] A. Kuhn and M. Stocker. CodeTimeline: Storytelling with Versioning Data. In *Proceedings of International Conference on Software Engineering*, pages 1333–1336, 2012.

[23] B. Lee, R. H. Kazi, and G. Smith. SketchStory: Telling More Engaging Stories with Data through Freeform Sketching. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2416–2425, 2013.

[24] M. Liu, J. Shi, Z. Li, C. Li, J. Zhu, and S. Liu. Towards Better Analysis of Deep Convolutional Neural Networks. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):91–100, 2017.

[25] S. Liu, Y. Wu, E. Wei, M. Liu, and Y. Liu. StoryFlow: Tracking the Evolution of Stories. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2436–2445, 2013.

[26] S. Liu, J. Yin, X. Wang, W. Cui, K. Cao, and J. Pei. Online Visual Analytics of Text Streams. *IEEE Transactions on Visualization and Computer Graphics*, 22(11):2451–2466, 2016.

[27] Z. Liu, J. Thompson, A. Wilson, M. Dontcheva, J. Delorey, S. Grigg, B. Kerr, and J. Stasko. Data Illustrator: Augmenting Vector Design Tools with Lazy Data Binding for Expressive Visualization Authoring. In *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, 2018.

[28] Q. Lu, X. Y. Zhu, L. Liu, and S. B. Cao. An Effective Demonstration for Group Collaboration Based on Storyline Visualization Technology. In *Proceedings of the International Conference on Computer Supported Cooperative Work in Design*, pages 47–52, 2014.

[29] W. S. Maugham. *The Moon and Sixpence*. Modern library, 1919.

[30] R. Munroe. Movie Narrative Charts. `https://xkcd.com/657/`, December 2009.

[31] M. A. Nacenta and G. G. Méndez. iVoLVER: A Visual Language for Constructing Visualizations from In-the-Wild Data. In *Proceedings of the ACM International Conference on Interactive Surfaces and Spaces*, pages 438–441, 2017.

[32] M. Ogawa and K.-L. Ma. Software Evolution Storylines. In *Proceedings of the International Symposium on Software Visualization*, pages 35–42, 2010.

[33] V. Ogievetsky. Plotweaver. `http://ogievetsky.com/PlotWeaver/`, March 2013.

[34] K. Reda, C. Tantipathananandh, A. Johnson, J. Leigh, and T. Berger-Wolf. Visualizing the Evolution of Community Structures in Dynamic Social Networks. *Computer Graphics Forum*, 30(3):1061–1070, 2011.

[35] D. Ren, T. Höllerer, and X. Yuan. iVisDesigner: Expressive Interactive Design of Information Visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2092–2101, 2014.

[36] J. C. Roberts, P. D. Ritsos, J. R. Jackson, and C. Headleand. The Explanatory Visualization Framework: An Active Learning Framework for Teaching Creative Computing Using Explanatory Visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 24(1):791–801, 2018.

[37] B. S. Santos, B. Q. Ferreira, and P. Dias. Using Heuristic Evaluation to Foster Visualization Analysis and Design Skills. *IEEE Computer Graphics and Applications*, 36(1):86–90, 2016.

[38] S. A. Spielberg. *Jurassic Park*. Universal Picture, 1993.

[39] Y. Tanahashi, C. H. Hsueh, and K.-L. Ma. An Efficient Framework for Generating Storyline Visualizations from Streaming Data. *IEEE Transactions on Visualization and Computer Graphics*, 21(6):730–742, 2015.

[40] Y. Tanahashi, S. Member, and K.-L. Ma. Design Considerations for Optimizing Storyline Visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2679–2688, 2012.

[41] K. Todi, D. Weir, and A. Oulasvirta. Sketchplore: Sketch and Explore Layout Designs with an Optimiser. In *Proceedings of the CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pages 3780–3783, 2016.

[42] Y. Wang, H. Zhang, H. Huang, X. Chen, Q. Yin, Z. Hou, D. Zhang, Q. Luo, and H. Qu. InfoNice: Easy Creation of Information Graphics. In *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, 2018.

[43] H. Xia, N. H. Riche, F. Chevalier, B. de Araujo, and D. Wigdor. DataInk: Direct and Creative Data-Oriented Drawing. In *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, 2018.

[44] C. Xie, W. Chen, X. Huang, Y. Hu, S. Barlowe, and J. Yang. VAET: A Visual Analytics Approach for E-Transactions Time-Series. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):1743–1752, 2014.