Story CreatAR: a Toolkit for Spatially-Adaptive Augmented Reality Storytelling

Abbey Singh*
Dalhousie University,
Halifax, Canada

Ramanpreet Kaur†
Dalhousie University,
Halifax, Canada

Peter Haltner‡
Dalhousie University,
Halifax, Canada

Matthew Peachey§
Dalhousie University,
Halifax, Canada

Mar Gonzalez-Franco¶
Microsoft Research,
Redmond, Washington, USA

Joseph Malloch‖
Dalhousie University,
Halifax, Canada

Derek Reilly**
Dalhousie University,
Halifax, Canada

ABSTRACT

Headworn Augmented Reality (AR) and Virtual Reality (VR) displays are an exciting new medium for locative storytelling. Authors face challenges planning and testing the placement of story elements when the story is experienced in multiple locations or the environment is large or complex. We present Story CreatAR, the first locative AR/VR authoring tool that integrates spatial analysis techniques. Story CreatAR is designed to help authors think about, experiment with, and reflect upon spatial relationships between story elements, and between their story and the environment. We motivate and validate our design through developing different locative AR/VR stories with several authors.

Keywords: augmented reality, space syntax, storytelling, proxemics, f-formations, authoring toolkit, head-mounted display

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interactive systems and tools—User interface toolkits; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Interaction design—Interaction design process and methods—User centered design

1 INTRODUCTION

Augmented reality (AR) head-mounted displays (HMDs) provide an immersive, hands free experience. Untethered AR HMDs such as the Microsoft HoloLens [37] and Magic Leap One [2] permit indoor AR experiences that can span multiple rooms, and even entire buildings. This creates new opportunities for *locative storytelling*, defined in this paper to include both stories that adapt to the physical environment they are experienced in, and stories that are created for specific locations. Authors can use an immersive HMD to present characters and objects at-scale as seen from the user's visual field of view (FoV), albeit constrained by the display's FoV. This differs from handheld AR: when the viewer must hold the screen, the content they will see when entering a room is less predictable [47], and it is more difficult to see and interact with "life-sized" content such as a human avatar, particularly as the viewer approaches the content. Since recent untethered AR (and VR) HMDs employ inside-out tracking, authors can precisely place story elements anywhere in a room and across multiple rooms without the need for physical markers. By contrast, marker-based approaches limit content placement to regions where the marker is clearly visible to the device's camera.

*Abbey.Singh@dal.ca
†rm216536@dal.ca
‡Peter.Haltner@dal.ca
§peacheym@dal.ca
¶margon@microsoft.com
‖jmalloch@dal.ca
**reilly@cs.dal.ca

AR HMDs offer to authors the promise of rich integration of virtual story elements and physical environments. When the physical location is unavailable, the experience can be simulated on a VR HMD that renders both the content and its intended setting. When authors know the location of their story, they can use physical navigation, visual unfolding, proximity and orientation, and other spatial aspects as tools for effective AR storytelling. However, authors face significant impediments to accomplishing such integration. As a story becomes more complex or covers a larger space, manual placement can become time consuming. Such that it can be difficult to consider all visual perspectives and physical approaches for placing story elements so that they integrate seamlessly with the environment.

Content placement is made yet more difficult when a story is meant to be experienced in different or unknown locations. For example, an author may want a flexible story to take place in several different locations or to adapt to an unknown location. While approaches have been explored for spatially aware or site adaptive AR/VR [16, 21, 36, 50], just-in-time adaptation and room-scale techniques find the local optimal placement due to the limited amount of environment knowledge. This does not necessarily find the global optimal placement for story content based on the layout of an entire building.

In this paper we present Story CreatAR, the first authoring tool for locative media that integrates spatial analysis methods from architecture and urban planning (*space syntax*) and socio-spatial theory from the social sciences (*proxemics* and *F-formation theory*) to facilitate the development of both site-specific and site-adaptive narrative experiences for immersive AR and their simulation in VR.

Story CreatAR is designed to help authors think about, plan, and test the spatial organization of their story, independent of the environment their story will be experienced in. It aligns story elements with spatial qualities that enhance their meaning and impact. Using Story CreatAR, authors can:

- define *placement rules*, indicating how story elements should be placed based on spatial characteristics (e.g., visual complexity, openness, visual integration),
- define *traversal rules*, assigning navigation behaviour to characters based on distance, urgency, and spatial features,
- tie interactive story elements to spatial characteristics and proxemic relationships,
- group elements so they can be placed together, and define a series of groupings with overlapping membership to express a story's event sequence, and
- define *formation rules*, fine tuning how groups of elements are placed using F-formations, proxemics, and room boundaries.

Story CreatAR is designed to support an authoring workflow based on these five key features. It provides authors with access to rich humanoid avatars [39] and their animations [24], spatialized audio, and objects they source themselves. The author can flexibly label and group this content in ways that are meaningful for their story, with motivation that it may be easier to structure events and apply placement, formation, and traversal rules. Basic spatial characteristics can be combined and labelled into what we call *attributes*: high-level spatial properties with names that are meaningful to the author (e.g., hidden area, broad vista, meeting place). Authors can load floor plans of target locations if known (or sample locations if not), triggering automatic spatial analysis. Authors can directly view how story elements will be placed based on the defined rules. When the author is satisfied with the story or wants to test an intermediate draft, a Unity Scene [45] is generated, which can be used for post-processing, testing or deployment in VR (using Oculus Quest), or deployment onsite in AR (using HoloLens 2).

The conception and design of Story CreatAR followed an iterative user-centered design process, working closely with new media artists and authors from inception to refinement, in order to identify desired features and to evaluate our design. In this paper we detail our design process, including the development of several locative stories for AR HMDs that can also be experienced in VR. We then describe the Story CreatAR interface and systems implementation, and outline directions for future work.

2 Related Work

2.1 Spatial Analysis

2.1.1 Space Syntax

Space syntax [7] refers to a body of metrics and analysis techniques for understanding the spatial characteristics of a building or urban area, and is often used for predicting how people will engage with and flow through that space. A detailed background of space syntax is beyond the scope of this paper, but is readily found elsewhere [4]. Space is measured and classified using a number of techniques: axial (line of sight or traversal), isovist (visible area from a point), convex (enclosed region), manual classification (e.g., room, building, road), or segment (each segment identified by some primary measure such as line of sight). From these, several spatial characteristics of an individual location can be derived, including its *openness* (a measure of the open space surrounding a location), its *visual complexity* (roughly a measure of the number of different vantage points from which a location is visible), and its *visual integration* (a measure of how likely a location will become visible as a person moves about a space). Locations with varying degrees of openness and visual complexity are shown in Figure 1. Through agent-based analysis we can generate a location's *gate count* (the likelihood a location will be crossed as one traverses the space). Segment analysis by room includes constructing a *connectivity graph*, where rooms are nodes and connecting doorways are edges. With this graph we can determine a room's *centrality* (how likely it is that a room will be encountered as one moves through the space), and *accessibility* (how easy it is to access from anywhere in the building). Many other measures are defined within space syntax, and space syntax analyses often combine different techniques. Various tools integrate space syntax analysis including Grasshopper [12] by Rhino, UCL depthMapX [18], and QGIS [3]. In Story CreatAR we use depthMapX.

depthmapX [46] is an open source spatial analysis tool developed at the Space Syntax Laboratory, University College London. DepthmapX facilitates spatial analysis at a building or urban scale by analyzing floor plans or city maps, respectively. Isovist-based spatial properties are computed using a visibility graph analysis, while agent analysis provides metrics relevant to movement flow and behaviour. The tool also provides segment-based and other analyses. DepthmapX takes input in a vector graphics format such as Drawing Exchange Format (DXF); raster images of 2D floor plans will first need to be converted into vector format using a tool such as

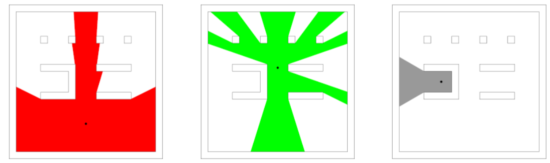

Figure 1: Left: Location with high openness. Middle: Location with high visual complexity. Right: Location with low values for both.

Inkscape [32] or AFPlan [49]. Story CreatAR integrates depthMapX via its command-line interface and CSV output containing space syntax analysis values for each position in the floor plan.

2.1.2 Proxemics

Proxemics [8–10, 25–27, 34] refers to human use and subjective experience of space. Proxemic distance can be categorized as intimate, personal, social, and public. Intimate space indicates that you are in close proximity to another person, typically with a loved one. Personal space is the type of space where you are talking with a friend. Social space is often used in group conversation, such as talking to colleagues. Public space refers to the space between strangers in a park, for example. Notably, the physical distances for proxemic spaces differ between cultures. Therefore, adapting distances for target users is important.

ProxemicUI [8] is a software framework for proxemics-aware applications. ProxemicUI processes Open Sound Control (OSC) messages containing position and orientation information for tracked entities captured by a tracking source (e.g., Azure Kinect). It uses this information to create proxemic events, which are only executed when tracking data and external event data meet the requirements for one or more associated user-defined relative/absolute distance/orientation rules. Story CreatAR incorporates ProxemicUI to respond to proxemic events between avatars and the viewer.

2.1.3 F-formations

F-formations [17, 22, 31, 33, 35] describe the spatial relationships between people in social spaces. F-formations occur when multiple people are involved in an interaction and orient themselves with respect to the space they inhabit and to each other. There are three different social spaces: o-space, p-space, and r-space. O-space is the region where the social interactions take place. The source of interactions like people or objects face this region. P-space refers to the space where the objects involved in the interaction reside. R-space is the region beyond the p-space. The position and orientation of people walking in pairs, playing in a field, eating at a table can be represented as F-formations. F-formations inform how avatars are grouped together in Story CreatAR.

2.1.4 Room-based analysis

Room-based analysis techniques permit the identification of rooms given a floor plan. Over the past two decades, a range of techniques have been demonstrated, working with vector graphics [19] or raster images [1, 49], sometimes to extract a 3D representation [40], or for navigation support [48]. In Story CreatAR this is used to help authors specify placement boundaries for story assets. For example, consider placing three pieces of furniture in the same room, named "Common Room". Room-based analysis can associate this "Common Room" with a room in a target setting based on room properties. We can use the output of room-based analysis to construct a connectivity graph automatically, allowing authors to associate story assets with rooms that are difficult to access (low *accessibility*), or ones that are likely to experience a lot of foot traffic (high *centrality*).

Architectural Floor Plan (AFPlan) [49] is an open-source tool used by StoryCreatAR for room-based analysis. As input AFPlan takes a 2D image of the floor plan (.jpg, .jpeg, or .png format). When the floor plan is uploaded into AFPlan, morphological cleaning is used to reduce noise in the image. Then, machine learning and convex hull closing approaches are used to close gaps in the floorplan, which helps to segregate rooms. Lastly, connected component analysis is performed to detect and color-code components (i.e. rooms). The output from AFPlan includes a color-coded image (Figure 2), and room vertices and areas (CSV format). This data is used in Story CreatAR to restrict placement of story elements within associated rooms. AFPlan also outputs vector graphics formats, which can be used by depthMapX in the spatial analysis pipeline of Story CreatAR.

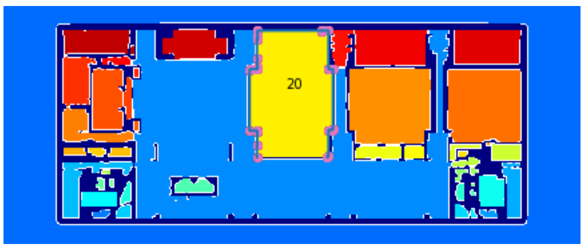

Figure 2: An analyzed floor plan with a room selected in AFPlan.

2.2 Narrative Forms in AR/VR

Story CreatAR can support a variety of narrative paradigms. *Linear narratives* [11] provide a narration in which the sequence of events in the story occur in chronological order. Story CreatAR allows events to follow chronological order through time-based event sequencing. Story CreatAR centers on plot with its avatar-driven narratives.

Ergodic narrative forms require active effort to work through and navigate. This includes *Non-linear narratives* [6], which include events like flashbacks and foreshadowing: stories that do not follow a strict chronological sequence. In Story CreatAR, location and progression through physical space can be used to represent nonlinear temporal relationships between events. *Generative narratives* have normally involved the production of different versions based on medium (e.g. hypertext vs. paper), but StoryCreatAR allows narratives to adapt such that they can be experienced in multiple settings.

Interactivity can create increased immersion and empowerment by allowing audiences to have some degree of control over the experience [43]. The goals, feedback, and interpretation (GFI) framework [14] emphasizes the importance of feedback for user actions in interactive narrative. Agency can be provided to the viewer in Story CreatAR through their choice of where to go and which story elements to interact with. A tool for creating narratives should consider the sensemaking process of its audience [13]. To do this the narrative must support readers as problem solvers. Interactive narratives should also consider narratology [15], roughly how a narrative's structure impact's reader experience. By directly supporting user interactions, character-driven plot, socio-spatial triggers through f-formations and proxemics, and content placement that is sensitive to the physical environment, StoryCreatAR supports a sense of "being there" for those experiencing the story [15], and supports embodied and interactive forms of narrative sensemaking.

Three common types of plot used in interactive narrative are epic (viewpoint of an individual), dramatic (human relationship based), and epistemic (solving a mystery) [42]. Such interactive plots are often character-driven, so Story CreatAR focuses on avatar-based stories, meaning stories that hinge on the viewer observing and interacting with avatars in the story setting. All three types of narrative plots can be created using Story CreatAR.

Genette [23] breaks narrative stucture into three parts: plot, discourse, and narration. Five main concepts of narrative structure are order, duration, frequency, mood, and voice. Ultimately, it is up to the authors to decide what aspects of narrative structure to include in their story. Story CreatAR supports order, duration, and frequency through its event mechanic; events have customizable preconditions that allow sequencing, duration, and repetition of events in the story. Through integration with MoveBox [24] StoryCreatAR provides rich animated characters and vocal styles as key narrative elements.

Design guidelines for immersive AR/VR narratives are emerging. For example, in immersive AR/VR viewers are more likely to experience a sense of presence, so stories should offer ways for the viewer to actively engage in the narrative [20]. By choosing a familiar genre, the viewer can try AR/VR "while engaging with somewhat predictable story beats" [20]; this is a feature of the stories our authors created, particularly Tyson's Peak.

Narrative can be represented using a plot graph and this can be useful for non-linear, interactive, and/or locative narrative. Mobile Urban Drama [28] uses graphs to create mobile location-based narratives. In the story the beginning and end are specified, and nodes in the graph represent events. Graph visualizations have been shown to improve author's awareness of story content [51]. We are exploring how graph representations can help planning for spatially-adaptive VR/AR narrative using Spill, a story written by one of our collaborating authors for Story CreatAR.

2.3 Spatially adaptive placement for AR/VR

Research in spatially adaptive placement of AR/VR content has increased significantly in recent years. In this section we consider work in adaptive AR/VR that can be relevant to locative AR storytelling and its simulation in VR.

FLARE [21] uses a declarative approach to define constraints for virtual object placement in the physical world, which is used in real time to adaptively place objects in indoor AR applications. FLARE precisely places objects in a single room by accounting for the room's geometry. Its declarative rules define constraints about content interrelationships, relationships between content and viewer, and relationships between content and certain geometric features (e.g., flat surface). Story CreatAR complements this approach by supporting adaptive placement of objects and groups of objects with direct reference to spatial characteristics that are meaningful at "building scale" (e.g., a room's *accessibility* with respect to other rooms, or line of sight characteristics spanning rooms).

Scenograph [36] is a system that adapts VR experiences to fit within the constraints of physical spaces, mapping entire experiences to a room (tracking volume) using space compression techniques. In contrast, Story CreatAR maps single entities or groups of entities using spatial analysis techniques onto the floor plan as a whole.

VRoamer [16] dynamically creates a walkable VR experience by matching pre-generated virtual rooms and corridors with physical spaces. Therefore, the placement in VRoamer is limited to a strict greedy approach to determine content placement, whereas Story CreatAR determines placement based on space syntax analysis of the entire floor plan, allowing for spaces across the building to be used effectively.

Dreamwalker [50] creates a VR environment that allows users to walk and avoid obstacles in the real world while being fully immersed in VR. Dreamwalker chooses a path in the given virtual world that most closely matches the specified physical world path. Story CreatAR allows authors to specify relationships between virtual content and the physical world through spatial analysis.

The use of space syntax for adaptive placement of AR content has been minimal to date. Reilly et al. [41] presented an open source Unity plugin that applies three space syntax properties to determine the initial placement of game assets. Their work was preliminary and involved a manual procedure for space syntax analysis. We have incorporated parts of their placement algorithm into Story CreatAR, but we have additionally automated and extended space syntax analysis procedures, support other types of spatial analysis (proxemics, room detection), and focus on storytelling.

2.4 Authoring tools for narrative

In a vision paper Hargood et al. [29] propose (but do not implement) a systems design for tools that use spatial analysis to allow locative narratives to be remapped to different locales. Story CreatAR includes features that correspond to the design proposed in this work, specifically a rule-based association of narrative elements with abstract descriptions of spatial locations, which is mapped dynamically to target locations when a story is deployed.

Tanaka and Gemeinboeck [44] present a framework for creating locative media by mapping spatial interactions from location data to the creation of locative media. Story CreatAR maps story content to physical environments by performing an analysis of the entire space. Both the framework and Story CreatAR follow a similar design process. Spatial interactions are performed through each user's positioning and movement, which is one dimension of the experience, however, in Story CreatAR spatial analytics are used to create the foundations for the experience through object placement.

Twine [5] is a hypertext authoring tool that relies on a graph-like representation to create the narrative. To extend Twine to include more complex features such as media, conditional events, etc. coding is required. Story CreatAR uses a graphical user interface (GUI) to support non-technical authors. StoryPlaces [30] is another hypertext authoring platform for locative narrative, with the potential to map stories to new spaces. Like Story CreatAR, they separate and perform mappings between content and location, however, they do not support an authoring interface to define such mappings. StoryPlaces navigates spaces through a mobile device. Story CreatAR uses immersive AR/VR, and provides spatialized audio and animated visuals, which is designed to help the user navigate and stay connected throughout the experience.

3 Methodology

We followed an iterative user-centred design approach in two distinct phases: phase one involved expert interviews and participatory brainstorming, sketching and storyboarding, followed by scenario-based cognitive walkthroughs using a medium fidelity prototype, which lead to a first implementation of Story CreatAR and a first story implementation, "The Lost Child". In phase two we added features based on author feedback, experiences developing The Lost Child, and in direct support of three longer stories by different authors. This effort lead to our current Story CreatAR implementation, which is described in detail in a later section. In the remainder of this section we describe our design process and outcomes in more detail.

3.1 Phase One

While authoring tools for locative narrative have supported a range of mappings between narrative elements (e.g., climax, avatars/objects, elements of surprise, exposition, events) and environments (e.g., visibility, bottlenecks, proxemics), a comprehensive set of possible mappings does not exist. These mappings can be used to dynamically place narrative elements within the environment in a way that makes sense for the story. Since we were interested in broad support for locative narratives, we brainstormed mappings over several sessions, in collaboration with two locative media artists. We compiled narrative attributes that might be represented or affected by spatial properties, listed a wide range of spatial properties and spatial analysis techniques, and then proposed and discussed possible mappings between the spatial properties and narrative attributes. These mappings were added to and modified throughout our early design work. Through this work we identified ways that other spatial relationships (geometry and distance, proxemics and F-formations) could be integrated with space syntax to provide more comprehensive support for narratives, as well as how spatial analysis could be useful as narratives progressed, and not just for determining initial placement of narrative elements.

We conducted semi-structured interviews [1] with two local practitioners in locative narrative. We asked them to describe their design experiences and decisions regarding content format and placement, as well as narrative flow. Our experts described a highly iterative process, arriving at narrative flow through an emergent understanding of their target environments, using sketches and maps when offsite, and performing periodic onsite tests. This influenced the design of Story CreatAR in several ways: story elements can be added incrementally, spatial rules can be adjusted iteratively and their effects visualized on a layout map, and offsite testing is supported through deployment to VR. Both practitioners advised against relying heavily on textual elements, preferring audio and graphical content, and one emphasized that spatialized audio is effective for guiding people through narrative experiences. Since Story CreatAR targets HMD AR and testing in VR, we incorporated these recommendations by focusing our support on immersive narrative experiences that do not use textual messages, but instead use life-sized avatars, and using spatialization of dialogue as directional cues.

For the scenario-based cognitive walkthrough we used a number of simple stories during the design process to help us test how planned features might support a range of narratives. These scenarios included stories on a murder mystery in a mansion, an exploration of Anne Frank's house, The Three Little Pigs, and an open-ended exploration of lives past, set among gravestones. For example, we brainstormed as a group how The Three Little Pigs might be experienced in a building with several rooms connected by an atrium or hallway, generated a storyboard, and used this to determine the spatial and narrative relationships needed for the story to adapt to any space meeting these minimum requirements.

Our iterative design process started with scenario storyboards and personas, followed by a collaborative 10+10 sketching activity to arrive at a candidate interface design for creating the relationships between the narrative elements and spatial attributes. This design was mocked up in PowerPoint and reviewed by team members using scenario-based cognitive walkthroughs. The collaborating locative media artists provided feedback on initial design concepts presented in sketches and prototypes, and proposed and collaborated on story concepts. From this a set of user stories were defined to drive an agile development process leading to a functional prototype developed in Unity. This prototype was then used to implement a simple short story written by a collaborating author called "The Lost Child", described in the next section. The story utilized spatial rules for placing characters in the story, and a proxemics-based event trigger for interacting with them. Along with other projects in AR storytelling, we presented our design process, UI, and example story to an expert panel at Snap Creative Challenge. An expert panel composed of a lead and senior researchers at Microsoft Research, the BBC, and Snap Inc. assessed the video presentation of the work by providing feedback and asking questions. Feedback was positive, but there was some concern whether authors would understand and employ spatial analysis effectively using the tool. In response, we added the ability to combine low-level spatial characteristics into spatial *attributes*, and defined a set of default high-level attributes that were meaningful to authors and could be used out-of-the-box.

[1] This paper has supplementary downloadable multimedia material available at http://ieeexplore.ieee.org provided by the authors. This includes a PDF file, which lists the question used in the semi-structured interview. This material is 29 KB in size."

3.2 Phase Two

In the second phase, we collaborated with three media studies students at Dalhousie University to implement three longer stories using Story CreatAR. None of the students had experience creating locative AR or VR stories, but were interested in experimenting with the new medium. During this phase we met weekly with the authors, demoing Story CreatAR features, discussing potential uses of spatial analysis for immersive AR narratives, and exploring examples of AR and VR narrative in literature and on commercial platforms. When writing their stories the authors were asked not to constrain their narratives to fit the current capabilities of the tool, but rather that we would implement features to meet the needs of their stories.

Story drafts were made available to the development team, who identified additional Story CreatAR requirements implicit in the story details. When story drafts were ready to be implemented, we followed a different approach with each author. In the first instance the author provided a complete draft and a developer used Story CreatAR to generate the story. In the second, the author and a developer worked together to produce a graph-based representation of the story whose elements mapped to Story CreatAR rules and features. For the third story, the author used Story CreatAR directly in a think-aloud approach and was able to ask the developer questions.

4 Case Studies

In this section we describe three of the four stories written in parallel with the development of Story CreatAR—*The Lost Child*, *Tyson's Peak*, and *Standville Museum*—and reflect on how they motivated design decisions and Story CreatAR features. The fourth story (*Spill*) informs our future work and is described in section 6.1.

4.1 The Lost Child

The Lost Child was created in collaboration with Colton for the Snap Creative Challenge. It is an interactive story about a concerned father who has lost track of his son's whereabouts. The viewer assists the father in locating the lost boy. At that time Story CreatAR was in an early state of implementation, so the story was implemented directly in Unity, while still considering proxemic events, spatialized dialogue, custom animations, and space syntax-based placement.

4.1.1 Impact on Story CreatAR Design

This story primarily relies on dialogue usage, proxemic events, avatar animations and placement. Therefore, it suggests that the tool needs to provide a way to attach dialogue and custom animations to an avatar, and to play that dialogue when the player is within a specific distance of the avatar. The story also emphasizes the need to arrange elements such as avatars into a given formation: in this story, concerned bystanders gathered around the father.

4.2 Tyson's Peak

Figure 3: Avatars gathered in the common room for Tyson's Peak.

Tyson's Peak authored by Tory is a murder mystery screenplay. Caught in a snowstorm, the viewer is taken in by a group of eight friends in their ski cabin. Trapped in the cabin by snow, one member is murdered with poison. The player listens and converses with the characters to learn more about each character through this story filled with deceit and affairs. Portions of Tyson's Peak are presented in our video figure.

Tory has limited technological expertise, but has won several creative writing prizes. She first wrote a complete draft, and then a developer implemented the first 7 minutes of the story. The implementation process used the placement functionality of Story CreatAR completed in phase one to define the avatars and props of the story with their associated space syntax attributes. The story implementation first included preparing required assets such as props. The draft included high-fidelity details regarding the props, however we were limited to royalty free models which were used as substitutes. Avatar-based story elements were created in Story CreatAR, and third-party models were imported for props. Tory was provided with a list of potential avatars to choose from with the option to request custom avatars. Voice lines for dialogue were recorded, edited, and imported. Functionality for configuring conversations and dialogue was developed alongside this story and implemented directly in Unity. Once the assets were placed using Story CreatAR, conversation nodes—a way to gather avatars in conversation—were manually attached as components. These conversation nodes initialize where the avatars spawn. Then, a list of conversation players were used to define dialogue between avatars. Lastly, a state controller was used to progress the story utilizing timers to trigger traversal events.

A recording of the VR story playback was shared with Tory as she did not have a VR headset and ongoing COVID-19 restrictions were in place. The reaction from Tory was positive, complimenting the asset usage and flow of the story. The choices from the Tory's story design were reflected in the final product. For example, the looping dialogue was noted by the author's supervisor "I found this really good for teaching the participant how the game works – it's anti-realistic, but effective". Tory responded with "this was a choice – and based on experience of video games (Pokemon and Zelda) which use this to cue the participant to move on".

4.2.1 Impact on Story CreatAR Design

This case study clearly identified functional requirements including the need to place avatars in a conversation, add dialogue, group and manage assets, and create and assign animations to avatars. We exposed the ability to create generic conversations with associated dialogue in the Story CreatAR UI, helping to automate the scene creation process. Moreover, Tyson's Peak illustrated the need to place conversation nodes using placement rules, since individual avatars may come and go during the conversation. Avatars in the conversation were assigned dialogue, but custom animations were required to make them appear more life-like. This case study also illustrated the need to manage and group assets: grouping organizes the large amount of assets required for the story into different categories, and is a useful way to apply the same placement, formation, or transition rules to many story elements at once. This case study further showed the need for generalized event management to progress the story as there was little author support for that at the time. Traversal and timer events were added to progress story action.

4.3 Standville Museum

David, a novice computer user and experienced book writer, authored *Standville Museum*. David and their supervisor directly used Story CreatAR to create the initial placement of assets in his story. In the story, the player takes the role of a detective who entered an art museum with his son. This story takes an ominous turn when the detective's son gets kidnapped, and follows multiple trajectories leading to different endings, based on user decisions. The objective in the story is to find the detective's son by solving riddles and finding clues.

Due to COVID-19 restrictions, David and the developer met remotely, he used Remote Desktop to control the developer's screen to use Story CreatAR. First, David added story elements: avatars and objects. Notably, on his first time through he moved on to the placement screen without creating any groups for the story elements, even though they are located on the same screen. Later, David expressed his confusion towards the utility of groups. However, grouping story elements for placement would be useful in his story as he wants to place multiple objects within a room. Second, he added different default attributes to his story elements to specify placement constraints. For example, one of the protagonists were given the "Open Area" attribute. Significantly, David did not create new attributes or focus on the lower-level space syntax characteristics when placing his story elements, even though he was exposed to these characteristics as part of his collaboration. David reapplied the rules to view different placements of the story elements. Then, he saved his scene and made minor adjustments to the placement of the story elements. As David was a first time user of Unity 3D, he had difficulty making the minor adjustments in placement and orientation to his story elements and was aided by a developer.

4.3.1 Impact on Story CreatAR Design

Standville Museum required some story elements to be placed in the same room, and that certain rooms be connected to each other. This led to the incorporation of the room-based floor plan analysis tool, AFPlan [49]. David also wanted precise control over where certain clues were placed; this suggested a need for placement specifications such as "On wall", "Against wall", and "In Room X", which could be accomplished by integrating a tool such as FLARE [21]. To provide precise control, we added the ability to place objects in rooms and for more specific placement David will have to perform manual adjustments to the objects placement. Two other features, however, were not implemented due to prioritization and time constraints. The first is the ability to make minor adjustments to story element placement through a drag and drop interface in Story CreatAR itself instead of waiting until the Unity Scene is generated. Second, showing images of third party objects instead of a file name when creating story elements.

Overall, David enjoyed Story CreatAR, stating, "I liked that we don't have to worry about going around the map and placing everything". He provided a number of recommendations to improve the UI that we plan to incorporate such as visually illustrating that a spatial attribute is being assigned to individual story elements when it is assigned to a group those elements are members of.

5 System Design

5.1 Overview

Story CreatAR was developed as a Unity plugin. Unity [45] is a robust game engine for cross-platform development including AR/VR. Story CreatAR will become an open source software upon publication. A novel user could independently run Story CreatAR in Unity and use it to implement their story. They could easily create avatar-driven narratives, however, they would require developer support for advanced features or story specific events (e.g., spinning around a stump three times).

Figure 4 shows an overview of how Story CreatAR is used. The author creates their story by specifying and grouping story elements and events, and then adds constraints for their location and behaviour by way of placement, formation, and traversal rules. Spatial analysis tools (depthMapX and AFPlan) are used to import spatial attributes for a deployment or testing environment. Then, the author can generate a Unity scene to visualize the placement in the selected environment. The author can additionally test the experience of the story in VR, or onsite in AR. The author can reiterate this process until they are satisfied with their generated experience.

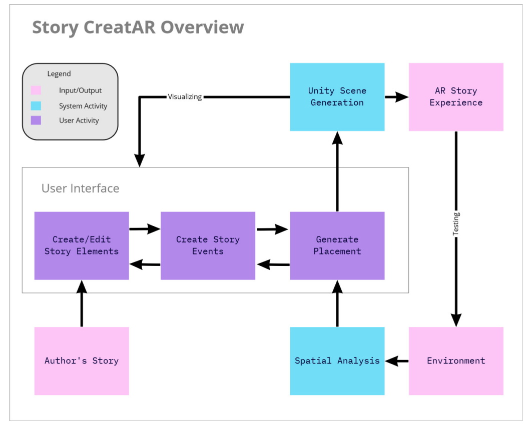

Figure 4: Overview of Story CreatAR

5.2 Authoring Support

5.2.1 Content Creation

Story CreatAR provides a range of ways to create and import content, including human characters (avatars), props such as tables or chairs, and 3D sound. Content can be third-party assets, the author's own work, or the default assets from Story CreatAR. Content associated with a name is known as a *story element* in the interface. An additional content type known as *compound story elements* allow authors to create conversation nodes, used to create conversations between avatars or between avatars and the player. Story elements may be part of 0-to-many groups. Groups have a unique identifier and consist of 1-to-many story elements. The default assets in our system consist of rigged avatar-based story elements from the *Rocketbox Avatars* [39]. MoveBox [24] is an open source toolkit that allows content creators to view and record motion capture data directly in Unity in real time using a single depth camera such as Azure Kinect or Kinect V2. Authors are able to integrate both the Microsoft Rocketbox avatars and the MoveBox toolkit to generate realistic human characters for their stories.

5.2.2 Asset Placement

Asset placement depends on spatial analysis of the environment. Spatial attributes are used to place story elements in appropriate locations. This allows authors to specify generic placement rules once and play their story in many environments. Higher level placement rules called *attributes* can be associated with story elements. Each attribute has a meaningful name, which is associated with one or more spatial characteristics. Currently the spatial characteristics we support are openness, visual complexity, and visual integration, and a range of values for each spatial characteristic: lowest (lowest 0 - 20% of values), low (lowest 20 - 40%), moderate (40 - 60%), high (60 - 80%), highest (80 - 100%), or any (0 - 100%). The attribute names (e.g., "Hidden") and values (e.g., "lowest") were derived from how the authors spatially described elements in their story drafts. To illustrate an attribute, an author might place a garbage can in a *Hidden* space, which is associated with the lowest visual complexity values and low visual integration values. However, a clue may be placed in an *Easy to Find* and *Open Area* space. Table 1 illustrates a sample of attributes and their spatial meaning that the author has access to in the interface. Additionally, the author can create custom attributes by specifying a unique name and the values for the space syntax characteristics.

A story element's own attributes have a higher priority than group attributes so that the author can provide unique placement for story elements within a group. The ordering of each is based on the order they were added, with first added having highest priority. Authors

Attribute Name	Openness	Visual Complexity	Visual Integration
Hidden	Any	Lowest	Low
Easy to Find	Any	Any	Highest
Open Area	Highest	Any	Any
Random	Any	Any	Any

Table 1: Attributes with their corresponding spatial characteristics.

can also override attribute priorities for each individual story element by choosing to edit the story element and inputting the priority (1 = highest, n = lowest) for each attribute until they are in the desired ordering. For example, Bob is in the group "Main characters". The author wants Bob to be placed in an open area next to the other main characters, but if the location does not permit that, then Bob should hide. Therefore, Main characters will have the attribute open area and Bob will have the attribute hidden. By default, the priority for Bob is (1) Hidden (2) Open Area. To get the desired outcome, the author needs to prioritize open area as (1).

Using the attributes and priorities, the initial placement of story elements is formed. Conversation nodes can be placed in the same way. After the author is satisfied with how the tool placed the story elements, the author can save the story element's positions into a new Unity Scene. The author can then choose to make manual micro adjustments to each asset's placement in the Unity Scene.

In the Story CreatAR interface there is also the ability to create rooms. A room is specified by the size of the room (small, medium, large), the number of entrance points the room has (1,2, many), and the other rooms it should be directly connected to. These properties are specified so that the created room is automatically associated with a physical room on the different maps. The theoretical rooms can be specified as a placement rule in the interface such that the object with the rule attached has to be placed within that room.

5.2.3 Event Configuration

In the Story CreatAR interface, the author may create conversation nodes, which is the currently supported *compound story element*. Conversation nodes have different properties: type of conversation, formation, initial and all avatars placed, out of range audio, and conversation dialogue for when the avatars are talking amongst themselves and when they are talking to the viewer. Type of conversation is either intimate, personal, or social, which refers to the proximity of the avatars. Formations [17] are either circle, semi-circle, or line, which refers to how the avatars are placed. The simplistic terminology used to define the formations in the interface hides the inherit complexity of spatial analysis, while making it easier for authors to understand. Initial avatars include the avatars in the conversation at story's start time. *All avatars* include avatars that will be in the conversation at some point during the story, but may not be there at the story's start time. Out of range audio such as crowd noise can be attached for when the player is out of range of a conversation node. Dialogue players can be attached to a conversation to create different sets of dialogue. Conversation dialogue requires a trigger to activate, which for example can be a proxemic relative distance rule where the player must come within 2.5 meters of the conversation [8]. When specifying the conversation dialogue the author can choose if it is looping, the wait time between loops (in seconds), as well as a set of voice lines. Each voice line specifies an actor (avatar) to say the voice lines, the audio file, and the volume of the audio.

The conversation node is placed based on the attributes specified in the placement phase. Each conversation location requires a list of initially placed avatars (0-to-many), the formation, and proximity [8], which can be used to place avatars uniformly around the f-formation shape.

Story CreatAR has options for specifying two types of global events: traversal and timer events. In the traversal event the author specifies an avatar to move (from avatars created in their story), where it must move to (if it is part of the conversation node, the conversation node will be an option), and the speed of movement (walk, fast walk, run). The avatar moves to the destination using A* path finding. In the timer event the author specifies the amount of time to wait for. These aid in the progression of the story.

5.3 Spatial Analysis

5.3.1 Axial/Isovist Analysis

DepthmapX is used to perform visibility (i.e., based on "line of sight" and isovists) analysis of a floor plan. From the CLI we can load a floor plan, calculate its isovist properties and visibility relations through depthmapX's visibility graph analysis. Then we retrieve the result in a CSV format consisting of space syntax characteristics including visual integration, isovist area (openness), and isovist perimeter (visual complexity). These values are extracted from the CSV and converted to ranges used in the interface (0 - 100). The CSV output is saved, so that authors can swap floor plans without needing to recalculate the space syntax values every time.

5.3.2 Convex/Segment Analysis

Our current support for convex analysis involves extracting a connectivity graph, which assigns IDs to rooms and indicates how rooms are connected (i.e., through doorways). This data structure forms the basis of a range of convex analyses in space syntax. To obtain the connectivity graph we use the open source AFPlan tool, which identifies rooms and doorways in the vector floor plan. At present room ID and geometry data are used to ensure that story elements are placed in the same room.

5.3.3 Placement Generation

When spatial analysis of a particular floor plan is complete, and an author has constructed a set of placement rules they would like to test, story elements (including avatars, props, conversations) can be placed. To do this we have adapted the open source Unity plugin created by Reilly et al. [41]. Story CreatAR generates the JSON ruleset required by the plugin, and a greedy algorithm is followed to satisfy the constraints; lower priority rules are relaxed as necessary to find a solution given a target floor plan.

5.3.4 Proxemics and F-formations

We integrated the ProxemicUI framework [8] to use proxemic relationships for conversation nodes. Story elements in Story CreatAR are assigned trackers which monitor their position and orientation in space so they can be used as entities in ProxemicUI rules. For example, a rule might detect when the player tracker is within the range of 2 to 3 meters of any entity OR facing an entity. Proxemic rules are currently used in Story CreatAR for avatar interaction, in particular between the player and conversation nodes as the player first approaches a group and then participates in a group conversation.

5.3.5 Avatar Formation Rules

All stories included avatar-to-avatar conversation as a key narrative element. These conversations need to support resizing as avatars enter/leave conversations as the story progresses. Conversations can happen in different F-formation arrangements (e.g., a circle). For example, in Story CreatAR given a list of avatars, a formation, and proximity, an appropriate radius for the circle can be calculated. Using the radius and the initial list of avatars the circular F-formation can be generated. As avatars leave the conversation the remaining structure does not change, but when new avatars wish to enter a conversation the formation is restructured. Optionally a prop can be included in the center (p-space) or boundary (o-space) of the conversation, which attracts the avatars attention. If the player gets close enough they join the conversation and the attention of the avatars is directed to the player.

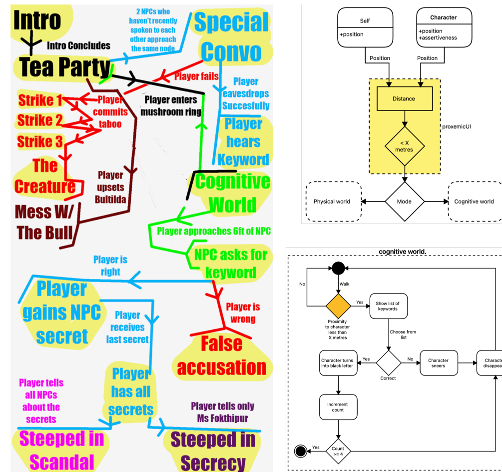

Figure 5: On the left: a graph-like representation of the story "Spill". On the right: State machines extracted from the author's story description for two aspects of the story logic.

5.4 VR/AR Interaction

Due to the COVID-19 pandemic, stories have been solely deployed and tested in VR, as we were unable to test in the public buildings in AR. The user interaction required in the first stories has been based on user proximity, so the Unity camera component is used to support the interactions. For this we are using MRTK [38] to support switching between VR and AR. For our VR test deployments we implemented basic controller-based navigation using the Oculus Integration package for deployment to the Oculus Quest.

6 Discussion

6.1 Story Graphs

We are currently exploring how story graphs can help authors use Story CreatAR. For this we are collaborating with Colton, who has authorial expertise through academia and personal projects, and technical expertise through one year of computer science education and knowledge in interactive media design. His story "Spill" revolves around a formal tea party where norms of social behavior and the spread of whispered gossip affect progression of the narrative. The viewer "plays" the story by trying to collect secret gossip from other guests at the tea party (represented by virtual avatars) and by searching for a lock-pick which will enable entry into the host's chambers. Acting inappropriately causes the other guests to become aggressive rather than sharing their secrets, and the player may be kicked out of the party, thus ending the AR (or simulated VR) experience.

Due to the complexity of inter-character relationships envisioned in this story, we collaboratively reconstructed Colton's written notes into a graph representation, with nodes for entities (characters, objects), spaces (rooms), and events; and edges representing static and temporal relationships, trajectories, and transitions 5. While the story is highly specific, we explore how this more formal representation will aid in translating the story's requirements into rules for Story CreatAR, and will drive prototyping of a planned graph interface in Story CreatAR for expressing such relationships.

A graph representation can help to visualize the flow of the story before it is implemented by having related nodes in close proximity, and arrows to provide direction, branches, and connections throughout the story. This is especially useful for organizing and visualizing a complex story [51] before implementing it in Story CreatAR where story elements, compound story elements, etc. are provided in lists. For example, the graph has a node called "Special Convo" and if the player eavesdrops successfully they will hear a keyword. In translation to Story CreatAR a conversation node is added called "Special Convo", which contains avatars talking to each other about a keyword and allows for the player to eavesdrop. Graph representations are also useful for revealing rule conflicts which might otherwise be hidden in long lists.

6.2 Limitations and Future Work

Preliminary feedback from authors and experts about Story CreatAR is positive. Since we followed a user-centred design approach, the features in Story CreatAR largely reflect needs that emerged while the stories were written, especially since we made efforts to not constrain the authors during the writing process. However, we must acknowledge that our authors were also influenced by the motivations of our research: that is, to incorporate spatial analysis to facilitate locative AR narrative. As a result, our authors explicitly considered layout in their stories, and became acquainted with spatial analysis concepts during design activities and discussions. In addition, our authors could depend on support from the development team when realizing their story using the tool: we do not expect that all authors would have access to similar technical expertise.

More work is required to assess how well Story CreatAR supports a wider variety of stories, and to understand the learning curve for authors using the tool for the first time. While *attributes* are designed to abstract spatial complexities, more work is required to (a) construct a set of meaningful attributes that covers the needs of different stories, and (b) ensure that these attributes are understood and used effectively by authors. A range of other convex analyses aspects will be incorporated in future work (for example, to determine a room's *accessibility* with respect to the entire building) to create new attributes. To extend our tool, an event could be triggered by user interaction not only limited to proxemics, but also including hand gestures, spoken words, and option selection. More research is required to determine the impact of these features on the viewer. Moreover, traversal rules will be extended to integrate spatial properties (specifically *gate count*, a measure of traffic) in the assignment of paths that an avatar takes. For example, a sneaky agent would be more likely assigned a path with low traffic.

Currently, we have only informal, subjective impressions that the placement of story elements, event composition, and interactivity supported by Story CreatAR were effective for those experiencing the story. In future work we would like to compare story experiences for layouts produced by Story CreatAR with ones created manually, and ones produced randomly, as well as conducting studies on the story experiences in AR and VR.

7 Conclusion

Authoring locative AR stories becomes difficult when placing large and complex narrative content within a physical environment, and when narrative content is deployed in multiple spaces or in spaces unknown to the author. In this paper we presented Story CreatAR, a tool that uses spatial analysis techniques to abstract information about physical environments, such that an author can express relationships between story content and spatial characteristics. The four case study stories by novice locative media authors were created in parallel and helped to both motivate the design of the system and demonstrate the use of Story CreatAR in practice. From these experiences, we created several features and enhancements to meet requirements for implementing these stories. Not only will our tool and approach be useful for authors creating locative AR narratives, but could also be extended to object and event placement in heritage sites, games, and interior design.

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