PortalInk: 2.5D Visual Storytelling with SVG Parallax and Waypoint Transitions

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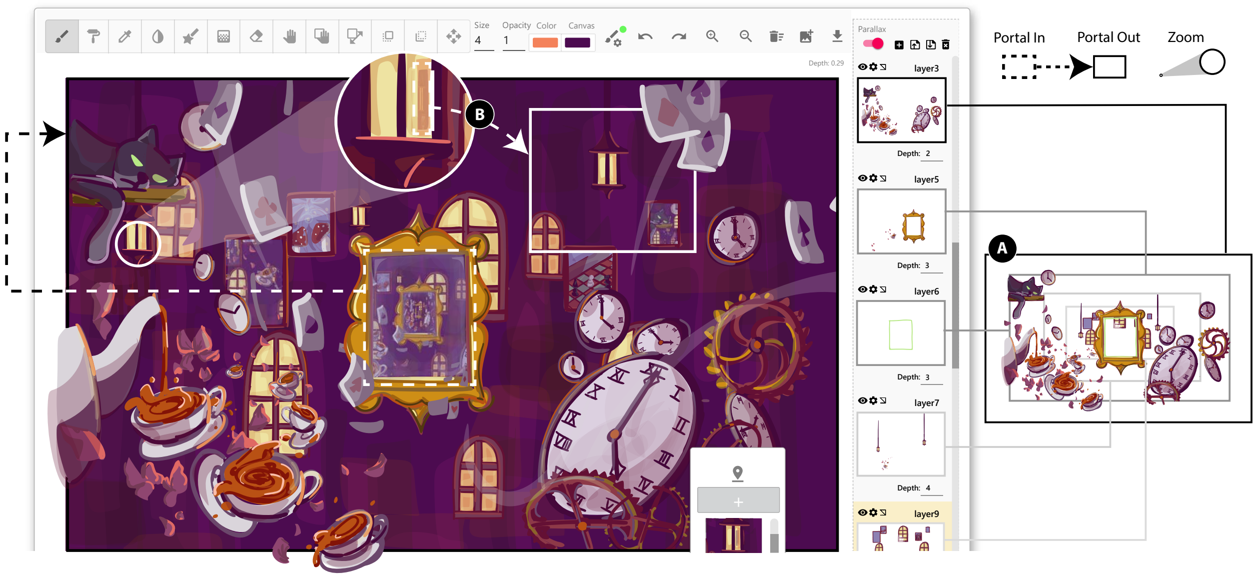

Figure 1: PortalInk allows artists to create 2.5D, spatially nonlinear visual stories *within 2D space* by A) automatically transforming depth-based layers based on the current viewport location to achieve the illusion of distance and B) saving locations within "portals" that users can navigate to.

ABSTRACT

Efforts to expand the authoring of visual stories beyond the 2D canvas have commonly mapped flat imagery to 3D scenes or objects. This translation requires spatial reasoning, as artists must think in two spaces. We propose PortalInk[1], a tool for artists to craft and export 2.5D graphical stories while remaining in 2D space by using SVG transitions. This is achieved via a parallax effect that generates a sense of depth that can be further explored using pan and zoom interactions. Any canvas position can be saved and linked to in a closed drawn stroke, or "portal," allowing the artist to create spatially discontinuous, or even infinitely looping visual trajectories. We provide three case studies and a gallery to demonstrate how artists can naturally incorporate these interactions to craft immersive comics, as well as re-purpose them to support use cases beyond drawing such as animation, slide-based presentations, web design, and digital journalism.

[1]https://github.com/brownhci/PortalInk

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CCS CONCEPTS

• **Human-centered computing** → **Graphical user interfaces**; **Web-based interaction**; **User interface toolkits**.

KEYWORDS

visual storytelling, scalable vector graphics, pan and zoom, portals

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1 INTRODUCTION

> "Would you tell me, please, which way I ought to go?"
> "That depends a good deal on where you want to get to."
> "I don't much care where—" said Alice.
> "Then it doesn't matter which way you go," said the Cat.
>
> *Alice's Adventures in Wonderland*, Lewis Carroll

The story of *Alice* captures a sense of serendipitous freedom and possibility. Like the meandering paths she takes, the breadth of expression for visual storytelling has journeyed from painting in the Renaissance and early modern age to photography in the industrial age to, finally, 2D and 3D graphics processing in the digital age with the emergence of personal computers and powerful graphical processing applications. While 2D visual stories have been widely disseminated across the World-Wide-Web within online communities such as DeviantArt (2000) and Behance (2005), 3D digital art has been widely embraced by the entertainment industry in the form of CGI effects in *Star Wars* and *Tron*, and fully animated stories like *VeggieTales* and *Toy Story*. This development of art in tandem with technology has created distinctive characteristics for what each type of digital art *is* and *looks like*.

However, these cues have begun to blur as advances in non-photorealistic rendering [33, 63] invert prior expectations and enable 3D visuals to more closely resemble and interact like 2D illustrations, akin to pages of concept art and paint. For example, 3D scenes from *Across the Spiderverse* simulate dripping watercolor and strokes of impasto painting, while the muted tones of the 3D models in *Arcane* and *Dishonored* are reminiscent of *fin de siècle*[2] oil paintings. This inversion of expectations between the 2D and 3D spaces creates a sense of wonder as our aesthetic notions of the limits of the digital medium are subverted, evoking a sense of the sublime [32] in both artist and viewer alike. Conversely, 2D illustrations have also bled into the 3D realm with similar effects. Systems in both the commercial and research spaces empower artists to map flat imagery to 3D spaces or translate them to 3D objects [2, 13, 24, 37, 74]. However, because the artist is effectively creating 3D assets within a 2D viewport, they have to learn the spatial reasoning [17, 18] required to bridge the two realms, a task difficult enough that algorithms and systems have been created to help users navigate this mapping [35, 38].

This difficulty is further heightened in illustrative storytelling, where spatial reasoning must also make sense in the context of story progression [3, 19]. How stories unfold linearly, non-linearly, or branch off is intimately tied to how users spatially navigate the artwork. Although prior work has identified associations between narrative linearity and spatial progression in different types of visual stories [7, 10, 44, 76], there is less exploration that breaks down the nature of that space itself—what happens when viewers can switch between 2D and 3D or if space is not continuous?

To address these gaps, we propose a web-based system that blends 2D and 3D channels but allows the artist to remain within the 2D workspace. The resultant stories can be viewed and modified on a 2D screen, but look either like flat 2D *or* pseudo 3D, which we call *2.5D*, depending on the artists' preference. This is achieved via 1) a parallax effect that generates a sense of depth along a z-axis and 2) pan, zoom, and portal interactions that challenge the user's notion of space.

The user's current position on the canvas can be further saved as "waypoints" and directly referenced in the illustration using any closed stroke that functions as a "portal," introducing the ability for artists to craft spatial discontinuities in their scenes. We implement this system using scalable vector graphics (SVGs) to take advantage of their inherent infinite scaling and capabilities to embed JavaScript to maintain interactivity post-export when loaded onto any modern-day browser. We illustrate the potential of this tool via three case studies with artists and a gallery containing 2.5D visual stories and other hypermedia that demonstrate examples of bending continuous space. From the visual outputs and workflows of both, we summarize key patterns on how artists related narrative progression linearity to spatial navigation and re-purposed both parallax and portals for more creative use cases.

Our contributions in this work include: 1) an SVG-based illustration tool that allows users to author space-warping 2.5D visual stories *while remaining in the space of the 2D canvas* and 2) takeaways from long-term usage of the tool that reveal themes in how artists employ SVG transitions to explore, expand, and even subvert traditional linear narratives on the web.

2 RELATED WORK

2.1 Authoring Beyond the 2D Canvas

Since authoring has moved into digital spaces, systems have extended the limited sizes of flat canvases by employing multi-layered zoom interactions. Early work on Zoomable User Interfaces [27, 52], such as Pad [50] and Pad++ [5], employed spatial metaphors to increase the perceived limits of the 2D information plane. In illustration, infinite canvas applications like Endless Paper and Concepts similarly employ vector rendering engines so artists can draw flat shapes that a user can zoom into to uncover new scenes while still remaining in the realm of 2D. Multiple zoom levels revealing new information have also been used in visualization systems such as Kryix-S [66], Mosaic [23], and the Zoomable Multi-Level Tree [11] to create large-scale data stories. These systems are grounded by the notion of infinite zooming within a single, unified surface, which has been shown to leverage spatial memory so viewers can synthesize visual information more easily [11].

Alternatively, systems have also expanded flat 2D authoring to a third dimension. 3D sketching tools such as Mental Canvas [13] and Storeoboard [24] allow artists to organize 2D strokes within a 3D space. The artist works between 3D primitives and 2D projected drawings to manually manipulate flat assets into 3D shapes and environments. This coupling of 2D input with 3D output has also been explored in prior AR drawing systems such as Mobi3DSketch [37] and SymbiosisSketch [2], where users can convert 2D into 3D

[2]Meaning "end of the century," this refers to a 19th-century art movement characterized by world-weariness and escapism.

mid-air sketches. Similarly, DreamSketch [35] combines contextual freeform sketches with generative algorithms to create variations of 3D objects.

These prior authoring tools clearly delineate 2D from 3D spaces: 2D systems restrict themselves to a flat drawing plane for both artist and viewer, while 3D systems operate on a 2D perspective of an underlying 3D coordinate system. While the visual outputs of PortalInk are most similar to those of Mental Canvas or Storeoboard, we differ in that our 2.5D effects are achieved solely within 2D space to preserve spatial continuity for the author. Our system is intentionally designed to generate the same visual effects using a flat, layer-based paradigm, identical to conventional 2D drawings, to allow the author to integrate pre-existing mental models of their workflow. We further discuss this motivation in Section 3.1.2.

2.2 Navigation Paradigms as Narrative Devices

When exploring visual digital stories, user navigation serves as a proxy for the viewer's gaze and carries through the author's intent. In the continuous case, representations of gaze include the step/scroll and pan-zoom interactions. The former gradually guides users to the next desired visual sequence via spatial linearity [45]. Existing systems that employ this scroll interaction, scrollytelling [59], aim to balance a sense of control with exploration while still maintaining a straightforward interface. For example, in web comics, platforms such as Webtoons use the infinitely long scroll to allow artists to express different sensibilities of time [9]. In visualization, ScrollyVis [48] allows creators to author dynamic, data-driven scientific narratives using scroll to break story content into digestible item relations.

Conversely, the latter pan-zoom interaction affords freedom of choice to users who want to interact with their own objects of interest [49, 51]. While many models of pan-zoom exist, a popular one is the u, w-space model of Wijk and Nuij [67, 68], which equates pan-zoom to a camera within a virtual world space. Systems have employed these "camera effects" to enhance emotional conveyance, present a particular aesthetic, or guide narration [40, 58, 60, 61, 64, 65]. Others focus on improving the accuracy, performance, and convenience of the basic pan-zoom paradigm itself. For example, strategies like using partially-indirect bimanual input [51] or converting to hyperbolic space [53] have been suggested to enhance the fluidity of zooming. To remedy context loss issues, Polyzoom [30] introduces the idea of hierarchies of focus regions with increasingly larger scales of magnification. Specifically targeting timelines, EasyPZ.js [57] provides a library for creating multi-scale pan and zoom visualizations by capturing and aggregating mouse and touch events. WritLarge [73] combines pinch-to-zoom and selection into a single gesture for more efficient interactions.

Finally, discrete navigation strategies like point and click are good substitutions when a user wants to break spatial linearity to jump from one view to another. This interaction is common in panel-based comics as a digital surrogate for the physical page turn [21], lending to multiple potential narrative effects depending on the panel layouts. To author different types of view jumps such as branching, changing perspective, or accessing details-on-demand, specification languages such as ComicScript [70] have been created to extend interactivity to static comics. Outside of comics, this interaction is also common in slide-based presentations. For example, HyperSlides [15] converts markup language into hierarchically structured, hyperlinked slides with a unified minimalist aesthetic.

While our system falls into the category of continuous spatial navigation similar to prior systems like Mental Canvas [13] or Storeoboard [24], we also support linear space breaking through visual portals to enable moments of discrete navigation. By allowing creators to toggle between 2D and 2.5D modes for the same illustration, the system also encourages them to experiment with notions of linearity in different spaces.

2.3 Linearity for the Author & Viewer

In traditional discourse, narrative is governed by temporal linearity, either unraveling according to or against its chronological order. When expanded to visual storytelling, an additional dimension of space is added, as the viewer can now choose what to look at to direct the narrative. This relationship between how visual presentation affects spatio-temporal control and linearity has been explored across multiple visual domains. For example, graphics, posters, and annotated charts are generally effective for directing *nonlinear, space-oriented* narrative flows, while videos and slide shows for directing *linear, time-oriented* ones [3]. Time and space can be combined if time is mapped to axes, resulting in timelines [7, 10], or if mapped to sequential arrangements, resulting in composite comics [44, 76]. Alternative strategies sit on a spectrum: the martini glass structure starts with an author-driven single-path then opens up for viewer exploration, while the drill-down story starts with a theme and allows the viewer to investigate particular instances of that theme to reveal details [58].

However, the *experienced* narratology is ultimately constructed from the interactions between the author's design (authorial authority) and the cognitive construct of the reader (user agency) [55]. For example, while what a viewer chooses to look at can determine narrative (non)linearity, the original author still retains control over placement, orientation, and layout of visual elements and thus may implicitly *guide* viewing order. This is achieved through a series of visual techniques such as culturally-guided reading orders (i.e. left to right vs. right to left) [6, 14, 44], orders guided by large sizes and bright colors [25, 26], and gestalt grouping [69, 71]. Due to the interactions available in different creative tools, they thus have different levels of authorial authority and user agency, and by extension, experienced linearity. For example, authoring systems that focus on a singular artistic vision or snapshot of data [31, 34, 36, 37, 72, 75, 77, 78] have high authorial authority, low user agency, and are mostly narratively linear. Those that focus on exploratory sandbox experiences [20, 41] relinquish authorial authority for high user agency and non-linearity. Tools that blend 2D and 3D perspectives for stereoscopic illustration [13, 24] or allow for event-based interactions and animations [54] are high in both, supporting the author's creative agenda and enabling some degree of autonomous exploration for the user.

Our tool supports both high authorial authority and user agency. Additionally, spatial discontinuities and non-Euclidean spaces are represented with a waypoint and portal system that affords non-linearity and potential for branching storylines.

3 PORTALINK

3.1 Design Philosophy

PortalInk is situated within the larger space of tools that extend 2D drawing beyond the flat canvas [2, 13, 24, 35, 37] and is motivated by two key design goals: **1) providing opportunities to create the "digital sublime" from an artist-centric perspective** while still **2) extending natural visual thinking**.

3.1.1 *Creating the Digital Sublime.*

The sublime, initially framed by Kant in his *Critique of Judgment* [32], is "*what even to be able to think proves that the mind has a power surpassing any standard of sense*," and is related to the emerging notion of "hedonic" design in HCI [12]. Both concepts emphasize enjoyable and appealing experiences that challenge the notion that an artifact should be solely functional or *appear* as it functions. Instead, the technology should provoke a sense of awe and astonishment, mythologizing the computer as "above" what should be possible [1, 47]. In the realm of creativity, this notion may be explored through technology enabling artistic expression of the unpresentable or *never-before-seen* [28]. Our system thus focuses on two main features guided by these principles: 2.5D navigation to emulate depth using parallax and a waypoint system to support branching narratives. While 2.5D transitions may exist in web-based visual stories as common *outputs*, they are not commonly incorporated into in-situ, *authoring* interactions. By allowing the artist to create and draw directly in "imaginative depth" within 2D beyond artist shading, the illusion afforded by parallax is especially effective in creating potential subliminal affects [43]. Similarly, the latter waypoint system can introduce moments of surprise for the artist by enabling the rapid creation of spatial discontinuities and non-Euclidean spaces that can be traversed immediately during the drawing process. Reintroducing experiences that artists usually only create post-hoc for viewers back to the artists during their workflow can provide greater motivations to and enhance the enjoyability of the artmaking process. In addition, to ensure that these experiences are always accessible, we thus focus on a pixel agnostic vector graphics paradigm, where all interactions can be embedded and integrated within a standalone SVG file that can be directly interacted with and modified without auxiliary programs or software.

3.1.2 *Extending Natural Visual Thinking.*

Prior work has shown that authoring environments that align with how manual artists work can enhance instead of displace art [29, 39]. Thus, our creation of the "digital sublime" is necessarily contextualized within traditional workflows and how individuals naturally communicate creative ideas. To minimize the context switches required to spatially reason across different space dimensions [17, 18], we intentionally design the tool such that the author works only in 2D space. PortalInk operates directly on the 2D layers a user is drawing—which already have a natural ordering—and automatically lifts them into a 2.5D viewing space. An artist is thus able to apply their existing skill sets, or legacy bias [46], in this more "authentic" mapping from perceived environment to actual environment and gain familiarity immediately instead of working through tutorials. Similarly, we design our waypoint system that transports a user from one location on the illustration to another as "portals" that are authored by drawing any closed path and using a mouse click to indicate the linking process. This visual metaphor is piggybacked [16, 22] off of and has predecessors in popular media such as *Star Trek* and the *Portal* games.

3.1.3 *Assessing Design Goals.*

To understand how effectively our tool has achieved the aforementioned design goals, we also use it to explore the following two research questions:

- **R1.** How can SVG transitions support the way users naturally think about (non)linearity and (dis)continuity within the spatial and temporal structure of visual stories?
- **R2.** How do artists use parallax and portal effects to articulate their creative visions and re-imagine existing use cases?

3.2 2D Navigation

PortalInk's 2D navigation aims to provide a familiar drawing interface for users in continuous space. For clarity, we will use `verbatim` to refer to SVG attributes we are manipulating directly and *mathmode* to refer to intermediary variables in our computations. 2D zooming and panning with an SVG graphic are achieved through its `viewBox` attributes which take four arguments: `x`, `y`, `width`, and `height`. These define the SVG viewport, the rectangular region of the SVG graphic that is rendered to the screen. A zooming event, triggered through the scroll wheel, multiplies the `width` and `height` values by a zoom factor $1 + \delta$, where a negative δ dictates a "zoom in" event which decreases the viewport width and height while a positive δ dictates a "zoom out" event which increases the viewport width and height. This δ value can be further adjusted by the user based on the desired velocity of the zooming.

The `x` and `y` attributes of the SVG `viewbox` correspond to the top-left corner of the viewport, and during a zoom event we also subtract from them by $mouse_x \cdot (\delta/z)$ and $mouse_y \cdot (\delta/z)$, respectively, where $(mouse_x, mouse_y)$ refers to the mouse cursor's screen position relative to the top-left corner of the viewport bounding box. This operation centers the zooming action around the mouse cursor of the user on the screen. In instances where this mouse cursor position is not provided, we set $(mouse_x, mouse_y)$ to be the center of the viewport. Here, z refers to the current zoom factor of the viewport which is the screen width divided by the viewport width. This transformation is summarized as

$$\begin{aligned} \mathtt{x} &= \mathtt{x} - mouse_x \cdot (\delta/z)\,, \\ \mathtt{y} &= \mathtt{y} - mouse_y \cdot (\delta/z)\,, \\ \mathtt{width} &= \mathtt{width} \cdot (1+\delta)\,, \\ \mathtt{height} &= \mathtt{height} \cdot (1+\delta)\,. \end{aligned} \tag{1}$$

A panning event, triggered through left-click-and-drag, will add the change in $mouse_x$ and $mouse_y$ divided by z to `x` and `y` which also centers the zooming action around the cursor's screen position.

3.3 2.5D Navigation

Conversely, the 2.5D navigation aspect of our system relies on the parallax effect to emulate a sense of depth to create a sense of the digital sublime [32].

3.3.1 *Depth-based Layers.*

For the 2.5D parallax effect, we first need to assign a notion of depth to the canvas layers an artist draws on. In our vector system, each illustration layer is represented by an SVG <g> group, and the layer's shapes are stored inside it. The

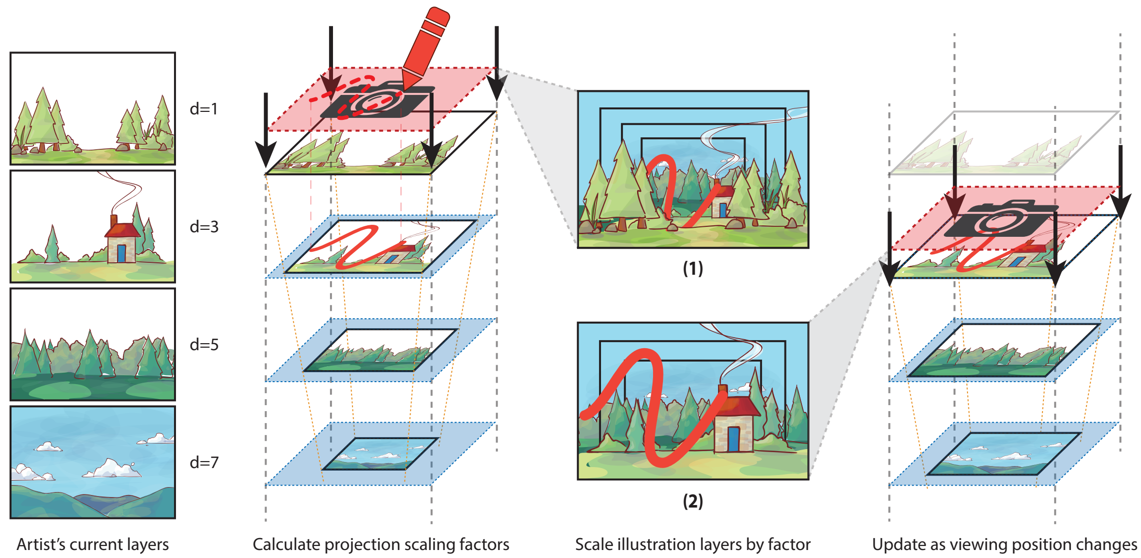

Figure 2: Our system takes in the untransformed layers and the corresponding layer depths to calculate each layer's projection scaling factor, which is then used for the parallax effect (1). As the camera moves deeper into the scene, the relative depth of each layer is updated, causing the scaling factors to be recalculated and the art layers to be re-scaled (2). As indicated by the red pen in the figure, drawn strokes are projected from the camera plane to the selected layer and then saved into the selected layer.

artist already sets an ordering to these layers because they render from back to front, and in our system specifically, the artist sets an additional numerical distance which decides how far away a layer is in parallax. This data is saved as a custom attribute "depth" on the <g> group which the W3C specification allows as long as there are no conflicts with reserved attribute names. Therefore, when the SVG is loaded into the system, we can extract the depth an artist has assigned to a layer during parsing.

3.3.2 ***Parallax Zoom and Pan***. To achieve the 2.5D effect with flat layers, we model the layers as stacked 3D planes viewed by a perspective camera pointing into the stack. Each layer $\mathcal{L} = (d_l, s, t_x, t_y)$ has a depth value d_l, scale factor s, and translations t_x, t_y which are set by the artist via "move layer" and "scale layer" tools. The artist scales and translates layers independent of parallax viewing. Intuitively, the depth value corresponds with how far away the layer is from the viewer. The viewer $\mathcal{V} = (x, y, d_v)$ has a panning position (x, y) and current zooming depth d_v.

The transformation $T_{\mathcal{L}}$ that maps a 2D layer into 2.5D viewing can be decomposed as

$$T_{\mathcal{L}} = T_{||} T_A = \begin{bmatrix} s & 0 & t_x \\ 0 & s & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & fx \\ 0 & f & fy \\ 0 & 0 & 1 \end{bmatrix}, \qquad (2)$$

where $T_{||}$ is the parallax transformation and T_A is the transformation that the artist has set. To model the parallax effect, layers further from the user should be smaller and move slower. To achieve this, we define a layer's *current* depth relative to the viewer with $d_l^* = \sigma_l d_l - \sigma_v d_v$ where σ_l and σ_v denote layer and viewer zoom sensitivity which the artist can adjust in the editor. Then the parallax scale factor f of a layer $\mathcal{L}$ is $f = \frac{1}{d_l^*}$ which comes from the

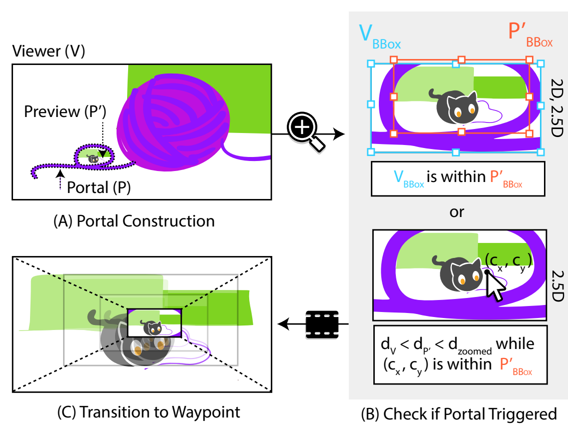

Figure 3: (A) Portals are constructed by linking a waypoint with a preview to any closed path. When the bounding box of the preview exceeds the viewer bounding box or when the depth of the portal exceeds pre-zoom and post-zoom depths when the cursor is within that bounding box (B), the transition triggers automatically (C).

perspective camera model. Parallax translation along the x-axis and y-axis are fx and fy assuming that the viewport center acts as a vanishing point, and when $d^* < 0$, for a given layer $\mathcal{L}$ and viewer $\mathcal{V}$, the layer is behind the viewer and not rendered. Figure 2 visually demonstrates how this scaling works with example layers.

Our system also allows artists to draw in the 2.5D parallax viewing mode. When layer $\mathcal{L}$ is selected, we apply $T_{\mathcal{L}}$ to the cursor position $(mouse_x, mouse_y)$ to pass into the individual illustration

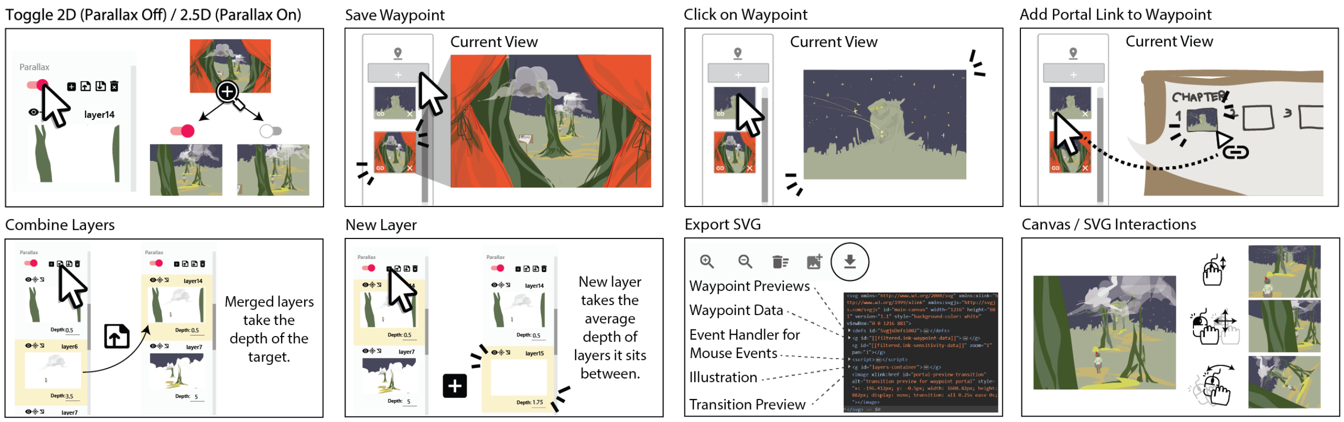

Figure 4: List of interactions (from left to right, top to bottom) include: toggling between parallax off and on, saving the current view as a waypoint, clicking on the waypoint to jump to that view, adding a portal that links to that view, combining layers, adding layers, exporting the SVG with embedded interactions, and the ability to zoom, pan, and rotate the exported illustration.

tools operating on layer $\mathcal{L}$ such as brush, select, and erase. The brush tool in particular has a radius r that should dynamically adjust to negate the scaling from $T_{\mathcal{L}}$. It follows that the adjusted brush radius is $r' = \frac{r}{sf}$.

3.4 Waypoints and Portal Transitions

To support spatial discontinuity for potentially branching narratives, we devise a waypoint and portal mechanism that can transport a viewer from one location on the canvas to another.

3.4.1 ***Saving Waypoints.*** We define a waypoint as a viewer $\mathcal{V}$ with an accompanying preview image of the viewer. For performance reasons, this preview is generated by encoding the SVG string at that view as a URI component, which is then used as the source of an `<img>` tag. This image is stored as the child of an SVG `<pattern>` element with its unique waypoint ID, stored in the SVG file for portals to reference to later. Since we want each preview to fill up the entirety of the portal wherever a user may draw it, we set the coordinate system for pattern content to be relative to the bounding box of the object to which the pattern is applied.

3.4.2 ***Constructing Portals.*** We define a portal P as any stroke that is closed. Since we represent strokes as an SVG path, where the path's `d` instructions specify the border of that stroke, a valid portal is any path whose `d` attribute has exactly 2 of M or m commands, where the capital M refers to an absolute "move to" command in the SVG path specification and a small m refers to a relative movement. An example of such a portal can be seen in Figure 3A. Other instances, where the total count of M and m commands is greater than 2, would introduce multiple distinct closed paths and thus ambiguity in which portal the user can traverse through.

Once a path is identified as a valid portal, we label it with the desired waypoint the user chooses to associate with that portal. A preview P' of this waypoint is generated by creating a new path with attribute `d` equivalent to all the coordinates after the second M instruction of P, with the path's `fill` attribute set to `url(#waypointID)`. We link P and P' so all transformation operations such as move and erase that affect P propagate to P'.

3.4.3 ***Transitions to Waypoints.*** A portal is triggered (Figure 3B) whenever the dimensions of the bounding box of P' have surpassed the viewer bounding box while zooming, regardless of the navigation mode the user is in. However, in 2.5D parallax mode, the current user depth can increase or decrease in constant increments, leading to edge cases where going beyond the depth of a specific layer the portal is on would toggle the visibility of that layer off; the bounding box check with respect to the canvas would thus not work. To remedy this, the system applies an additional check for whether the depth of a portal is between the pre-zoom and post-zoom depth of the user, and if so, still activate the portal transition presuming the mouse cursor is within the pre-zoom bounding box of P'. For this portal transition, we create a copy of P' when the portal is triggered and use CSS animations to morph its bounding box to the canvas bounding box (Figure 3C). Then, we remove that copy and the user is left with an identical interactive canvas again.

3.5 Authoring Interface

A screenshot of the authoring interface, built using React.js, can be found in Figure 1, while a list of possible user interactions supported by the system to enhance author expressivity are located in Figure 4. This interface contains a basic canvas and a toolbar with common drawing functionalities such as draw, fill, erase, size, opacity, color pick, color drop, move stroke, and move layer. It also includes a layers panel and a dialog for storing waypoints.

3.5.1 ***Layer Interactions.*** In the layers panel, users can toggle between the 2D and 2.5D parallax modes to control how their zoom and pan interactions affect the canvas. The latter mode also brings up an indicator of the current depth d_v, which helps to situate the user as they can compare their current location against the depth values of their layers. Users can also add, remove, and adjust the visibility, name, configurations, and depth of layers on this panel, although the layer depth differences will only take effect in parallax mode. They can also add, remove, and merge the layers themselves. The new layer is appended to the bottom of any selected layer, with its depth set to the average of the layers it sits between. On the other hand, combined layers always adapt to the depth value of the target a layer is combined with.

3.5.2 ***Portal Interactions.*** In the waypoint dialog, users can press the add button to store an instance of their current viewer as a waypoint with an accompanying preview image. They can then click on or remove this waypoint, the former of which takes the user back to that view. They can also click on the "link" button, which changes the cursor to a selector, to link any valid portals to the waypoint and add a preview image directly onto the canvas. Note there is no limit on the number of portals that can be linked to each waypoint, although linking a portal that was already associated with another waypoint will override that waypoint. The waypoint mechanism works the same way for both 2D and 2.5D modes.

3.5.3 ***Canvas Interactions.*** As the user draws and configures their layers, they can interact with the illustration in 3 main ways: 1) scroll to zoom, 2) left click and drag to pan, and 3) scroll click and drag to rotate. Based on whatever mode the user is in, the canvas view will update accordingly. To avoid the user getting lost, all canvas interactions reset when the mode toggle button is pressed.

3.6 SVG Embedded Export

We embed either the 2D or 2.5D layer rendering (depending on the current mode the user is in when the export button is pressed), zoom and pan transitions, and waypoint portal transitions into a standalone SVG file. This way, the resulting SVGs may support these functionalities independent of our illustration system, affording greater accessibility and ease of sharing. This is achieved through the SVG <script> tag specified by the W3C SVG2 standard, where JavaScript logic can be included to manipulate both individual elements and element <g> groups within the SVG. The exported file can be opened in any browser and run with full functionality, and it also supports direct embedding into existing webpages through an HTML <iframe>.

To adapt the custom SVG viewing transitions into a standalone file, we employ a rendering loop that applies the transformation $T_{\mathcal{L}}$ described in Section 3.3.2 to the layers in the illustration on each browser animation frame. The W3C SVG2 standard also specifies that SVG elements support DOM event listeners which we attach to the overall <svg> tag (i.e. the SVG graphic itself). The viewing logic of the illustration system is ported into a unified, standalone script to which the respective event listeners are connected. The artist can further embed their preferred pan and zoom speed and sensitivity customization options in the outputted SVG by setting the σ_l and σ_v parameters as constants during export time.

The drawn contents of this exported SVG can be easily modified externally. The layers are structured with <g> tags, following the same convention as existing vector tools, and can thus easily import into tools like Illustrator and Inkscape. While the artwork does temporarily lose its JavaScript interactivity due to different preprocessing of the XML, it can be re-imported back into PortalInk after external graphical edits and re-exported with full interactivity. We include a selection of such exported illustrations from our case studies (Section 4) and gallery (Section 5) below in the supplementary materials.

4 CASE STUDIES

We opted to not conduct a traditional usability study for PortalInk. This is because graphic narratives often require thoughtful sessions of ideation, story-planning, blocking, and drawing, which would extend beyond the scope of 1–2 hour study sessions. Instead, we present 3 longitudinal case studies of artists we recruited to use our system over an extended period of 3 months per artist during the iterative design of the system to inform the design decisions behind each interaction.

Two of the artists were recruited via an artist-in-residency program we specifically created for the project. The third artist was a new research assistant who did not directly work on the system beforehand. Over the 3 months, the artists were asked to first freely explore the tool's capabilities as they devise a story they want to tell. At this stage, they were encouraged to suggest new interaction paradigms or features to support their storytelling. The rest of the time was then spent drafting, sharing the in-process panels frequently in a Slack channel of 18 researchers, designers, and programmers to receive feedback, and iterating on the final visual story. Two artists also went beyond the required visual story and created other interactive illustrations with the tool. We describe each artist's backgrounds, goals, processes and final outputs created in chronological order below. At the time of these case studies, both 2D and 2.5D zoom and pan transitions were implemented in the system. However, the portals were introduced *based on* observations and comments made by the artists during this iterative design process, and so were not available during initial story design. Although portals were completed by the end and accessible to artists, we felt it would be superfluous to ask artists to incorporate them post-hoc since they were not part of the original ideation, even though select illustrations were eventually set up in ways such that portals could be easily slotted in. Nevertheless, we further explore the direct potential of portals through a subsequent gallery in Section 5, where we demonstrate their usage beyond the case study.

4.1 Artist A: *Circle of Life*

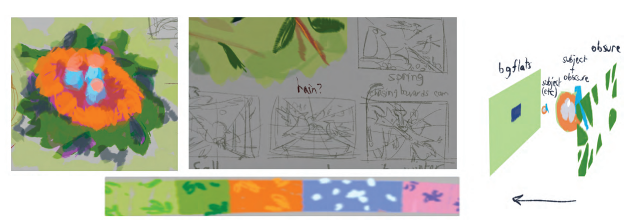

Figure 5: Artist A's planning phase, initially using parallax to separate foreground from background objects and using different color palettes to divide larger scene changes.

Artist A was a student pursuing a B.A. in illustration at a top arts university with prior experience in vector graphics and raster animations. She came in with 3 initial concepts for her story, taking inspiration from her university's Nature Lab: 1) *Circle of Life*:

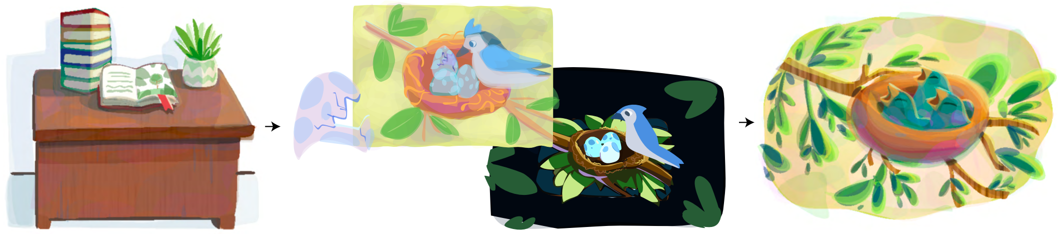

Figure 6: Artist A's finished panels depicting a blue jay's circle of life. Parallax was primarily employed to separate each panel into foreground, primary subject, secondary subject, and background.

mapping the life of a species over time, 2) *Big to Small*: seeing how species of different sizes cohabit, and 3) *Symbiosis*: understanding how two species interact in the wild. After discussion with the team, she decided to focus on the Circle of Life for its easy-to-follow linear story line that allows the viewer to connect with the characters more easily. Specifically, she favored linearity due to its "*easy to understand progression, which is also emblematic of the freedom/creativity that the system as a whole represents.*"

Initial sketches for the story can be found in Figure 5. During this stage, Artist A focused on establishing color palettes that correspond to the potential seasons to separate each mini-scene. Within the mini-scenes, the parallax interactions were employed mainly to direct the viewer's gaze. The artist envisioned a singular focal point in the middle of all the scenes at which the viewer would zoom continuously towards. Thus, each layer in the illustration framed this center and can be categorized into 4 types, listed in order of depth: a decorative foreground, primary subject, secondary subjects surrounding the primary object, and a flat background. However, while Artist A envisioned her final parallax layers to have these clear delineations, she found that her regular workflow while creating the illustrations actually involved *multiple working layers* which she wanted to combine or categorize *at the end* into separate parallax functionalities. To better facilitate this process, we added the layer move and merge functions and set the combined layer depth to always follow the depth of the target layer.

The final panels, narrating a blue jay's life cycle to showcase themes of "*family, coming of age, and independence*", can be found in Figure 6. It features an opened picture book on a table, which upon zooming in leads to an image of a mother blue jay with several of her eggs resting in a nest on a tree branch. Artist A deliberated a couple of times on the exact style of this panel. Initially, she created a sharp, saturated night scene to contrast the subjects against the background. Then, she created another softer, pastel morning scene with less contrast to emphasize the bond between the mother bird and her eggs. The feedback she received on preference between the panels was multi-faceted; while most preferred the watercolor-like painterly quality of the morning scene, some liked the clean shadows in the night scene. It was this feedback process that initially inspired the discussion of potentially adding portals that lead into different branching possibilities or realities of the same scene. The portal mechanism can thus be a strategy for both the artist and viewer to physically visit divergent visual styles that culminate in a panel that merges them: Artist A's final panel of baby birds hatching from the eggs finally unites the painterly qualities of the morning scene with the heightened color contrasts of the night scene. As implied through the illustration title *Circle of Life*, this last scene could lead back to the original stage of the baby birds' lives inside their starting nest; the addition of portals can therefore further facilitate a cyclic extension to this otherwise linear narrative.

4.2 Artist B: *Ant Restaurant*

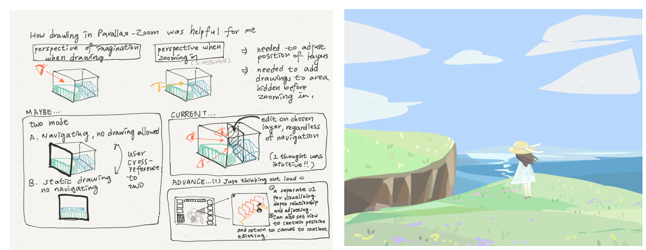

Figure 7: Artist B's notes and experimental illustration while gaining familiarity with the system.

Artist B was an illustrator with a background in computer science and design engineering. For her comic, she wanted to explore the idea of self-contained mini-stories within a larger overarching theme. The viewer should be able to explore each mini-story non-linearly based on whatever sequence initially catches their eye.

Her initial notes on parallax drawing are located in Figure 7 Left. Initially, she reported some necessary context switching as the "*perspective of imagination while drawing*" and the "*perspective while zooming*" she envisioned were different. The former required drawing in hidden areas that would have been occluded during the latter navigation process. Instead of drawing strictly in 2.5D, it thus felt more natural for her to draw in flat 2D without depth-based navigation, then switch back to 2.5D to position the layers and cross-reference between the two. This experience demonstrated the value of a toggle between 2D and 2.5D modes that allows artists to rapidly switch between.

To familiarize herself with the system, Artist B then created a simple illustration featuring a girl on a cliff overlooking the sea (Figure 7 Right). The composition of this drawing shares themes with the organization of the panels of Artist A, including a main subject located in and terrain leading the eyes to the center of the scene, which is further highlighted by light flickering on and off the water at that vanishing point. During iterative feedback, we affirmed

Figure 8: Artist B's finished panels depicting scenes occurring simultaneously at an ant restaurant. Parallax was mainly used to transition between each chamber in the colony.

that this style of composition is conducive to linear storytelling, as viewers who interacted with the drawing all directed their cursors to the middle of the scene and zoomed to the center of the canvas towards the character. This direction is further reinforced by the parallax effect, which similarly directs the viewer's gaze towards the slowest moving target in the furthest layer by zooming the foreground out faster, demonstrating the parallax interaction itself contributes to greater immersion in linear stories.

The final visual narrative created by Artist B, *Ant Restaurant*, can be found in Figure 8. Unlike traditional linear stories where each panel displays the next sequential scene, each scene in this story occurs simultaneously. Navigation thus does not progress the viewer through time, but rather through space within frozen time, allowing the user "*to explore all the chambers and see what the ants are thinking about and kind of follow their track*." While Artist B provides physical arrows as suggestive indicators of which directions the viewer could go to explore the scene, the comic is largely non-linear; a viewer could start *in media res* in the ant kitchen and visit the dining area if they so chose. In this story, parallax is not used to direct attention at all, but rather used as *blocking* to obscure and reveal each self-contained mini story. However, the main issue Artist B encountered was that the degree of freedom afforded by panning was not as much as she had hoped. Her non-linear narrative was constrained by space as viewers inevitably panned to directly adjacent panels to continue the story. Thus, portals arose again as a potential solution to resolve the physical limitations of parallax compositions within a Euclidean-bound canvas.

4.3 Artist C: *Snow White & the Four Seasons*

Artist C has completed illustration commissions for clients for over a decade and was formally trained in Industrial Design. In the beginning of the residency, she wanted to focus on two main types of visual outcomes: 1) graphics suitable for websites or design portfolios and 2) character-centric scenes. In particular, she was interested in using the system to create enticing ways to animate a character and encourage users to more deeply explore a scene.

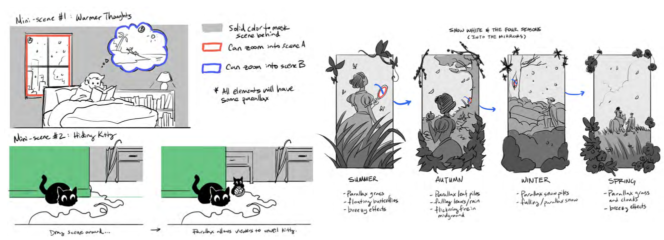

Figure 9: Artist C's panels were outlined in monochrome first, demonstrating different ways to use parallax.

Based on these two goals, Artist C initially sketched out plans for her illustrations, as shown in Figure 9. Mini-scene 1, "Warmer Thoughts," aims to explore alternative paths based on a character's current circumstances vs. their imagined circumstances. Mini-scene 2, "Hiding Kitty," employs a continuous strand of yarn to guide the viewer to manually explore behind a wall to discover hidden objects. Finally, "Snow White & the Four Seasons," uses the proxy of a mirror as a portal through which transports the viewer across the four seasons and the story of Snow White. In these examples, parallax was mainly used to emphasize environment elements such as "*breezy effects, flickering fire in the midground, falling snow, and clouds*," while transitions to new scenes were achieved via a mirror which effectively acted as a portal.

The final illustrations are depicted in Figure 10. (A) uses parallax to invite the viewer to drag the viewport behind the wall to reveal a ball of yarn. When drawing this scene, Artist C also discovered how playful animations of the cat can be instantly created by panning the scene rapidly up and down; because the cat's head, body, and tail rested on layers of different depths, this created a "bouncing" effect that was enjoyable for both the artist and the viewer.

(B) juxtaposes two scenes, a wintry cityscape and a summery vacation island, on the same parallax depth, reachable by zooming through the portal proxies of the window and the thought bubble, respectively. The use case of parallax here is similar to that of

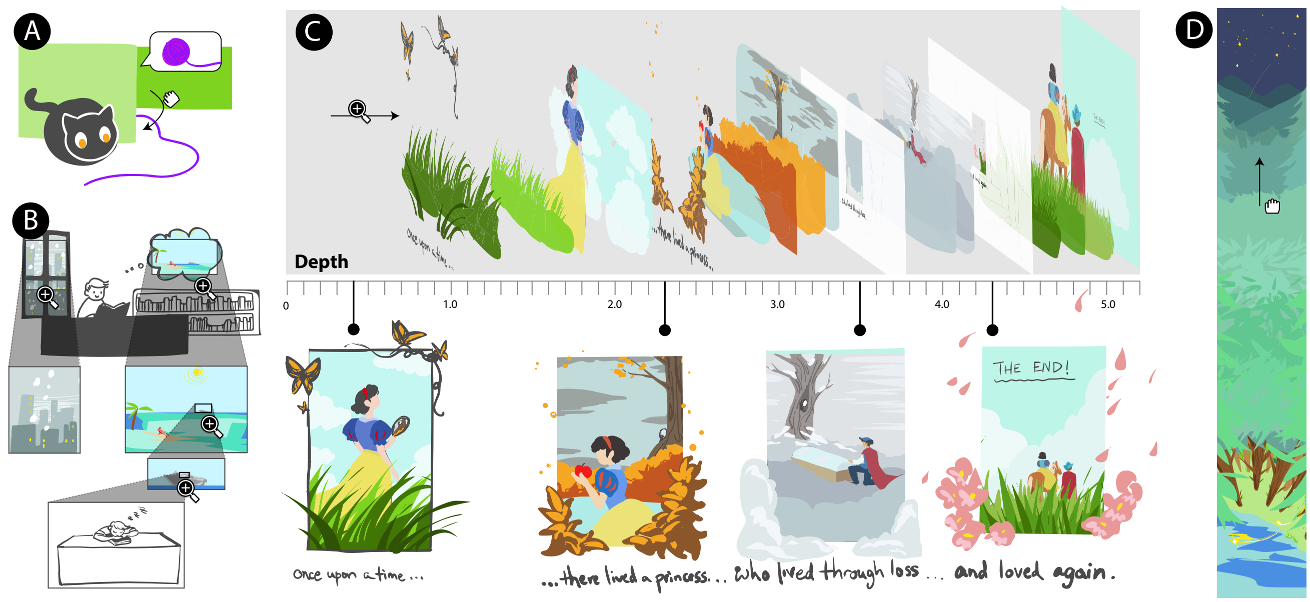

Figure 10: Artist C's four final illustrations, depicting A) a black cat with a ball of yarn hidden behind a wall, B) a person thinking about summer while it is snowing outside, C) Snow White's story as it progresses through the four seasons, and D) a night scene that pans down to a lake.

Artist B's *Ant Restaurant*, where layers with different depth levels serve to block out different scenes. Even though the winter and summer scenes are actually on the *same* depth, Artist C enjoyed manipulating the tunable depth parameters to create the illusion that they occupy *different* spaces. The summer scene is then further zoom-able to a ship in the distance, which then reveals the same character sleeping in his chair.

(C) breaks down each of the main scenes representing each season into mini-layers at different depths that still preserve the pattern of obscure decorative foreground, primary or secondary subjects in the center, and a flat background, as seen before in the composition of Artist A. The resultant four panels of Snow White's story are reinforced by shared themes: seasonal motifs such as snow or fall leaves, Snow White and the prince as the subjects, and the sky as the background. The mirror functions as a common portal to travel between the major scenes. However, when creating these scenes, Artist C did *not* merge these layers into their specific categories, but rather kept them separate. While refining this illustration, Artist C thus did not use the merge layer functionality, but rather felt the constant specific need to create new parallax layers that sat *between* existing ones. This behavior led to the design choice to automatically set new layer depths to the average of their adjacent layers for rapid iteration.

(D) was not an illustration that was initially planned, but inspired while Artist C was using parallax to work on the other drawings. It introduces a new way to apply parallax pan—not just to create the illusion of depth or block out scenes like Artist B did, but rather as a method to create a smooth, gradual change in perspective from looking horizontally at a set of mountains to looking down from the canopy, emulating "*scroll down storytelling through a brief vignette - similar to how mobile vertical scrolling webtoons are read.*"

4.4 Reflections from Designing with Artists

Our artists were able to effectively create the 2.5D stories they envisioned, indicating the tool served its basic purpose. During the case studies, we also observed two main benefits of PortalInk:

4.4.1 ***Enjoyment from in-situ transitions motivated artists to create unplanned, unique story components.*** A common theme that arose during the iterative authoring process was the element of discovery and surprise that led to narrative decisions artists initially did not plan for. For example, Artist B found that when the layer depth differences were low, layers unexpectedly occluded each other. Initially an inconvenience, this eventually inspired her to hide isolated storylines within the main story behind layers, where the occlusion became a mechanism to start/end these mini scenes. This is reminiscent of the martini-glass narrative structure [58] where there is an initial author-directed story path but users can freely and are encouraged to linger and look for "Easter eggs." Similarly, Artist C played around with layer depth values, and found that because they directly correlate which how much a user must scroll to reach that scene, it could be used to build up feelings of anticipation towards specific scenes.

4.4.2 ***Flexibility of the tool and exported SVGs accommodated different artist mental models.*** Due to the artists' different backgrounds and goals, they had different conceptual models of how they wanted their illustrations to be achieved and experienced. For example, Artist A worked from a more traditional framework where panels had clear delineations of scene hierarchy, Artist B still felt more comfortable in flat 2D view, and Artist C wanted to focus on conveying character. These preferences could all be accommodated by manipulating the tool to suit their own purposes:

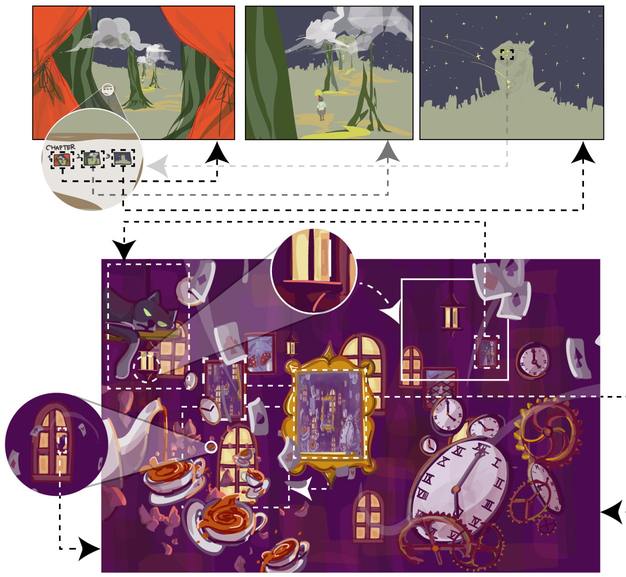

Figure 11: Visual stories that employ portals as sequential chapters (Top) and mechanisms to draw focus to different or occluded parts of the illustration (Bottom).

Artist A relied on layer naming and ascribed depth differences to differentiate scene hierarchies, Artist B used the 2D and 2.5D toggle very frequently as a cross-referencing mechanism, and Artist C iteratively experimented with clever ways to achieve animation and perspective shifts effects using the layer transitions to afford personality to each scene. Unlike other authoring tools that separated the drawing, visual effects, and interactions processes, our system's unified, accessible export also allowed the artists to brainstorm more quickly by sharing their intermediary results with others.

When artists faced challenges conveying their visions, the potential of portals emerged as a common theme. Artist A wanted to include branching alternate realities, and Artist B sought greater freedom to convey non-linearity beyond spatial limitations. Artist C, without prompting, explicitly created pseudo portals using parallax objects like mirrors and thought bubbles. Through iterative feedback with our artists, we discovered the potential of portals as a flexible tool to address compositional and organizational challenges in narrative authoring.

5 GALLERY

The artists in our case studies were contracted to focus on graphical narratives and comics. In addition, portal development mainly occurred during the tenure of Artist C, despite it being alluded to frequently during the iterative feedback process with both Artist A and B. We also identified several applications beyond comics that the artists can envision SVG transitions contributing to. To thus demonstrate the breadth of use cases for the portal functionality, we present a gallery of examples in Figure 11 and 12.

5.1 Portal within Visual Stories

Figure 11 demonstrates additional examples where portals are used to immerse viewers within visual stories. The top illustration depicts a theatrical, linearly progressing scene that starts with a set of red curtains drawing back to a row of bare trees leading the eyes down the center to a castle that resembles a golem. Peeking out from one of the trees is a signpost that outlines the three "chapters" in this story; zooming into any one of them takes the user to a deeper layer of both canvas depth and narrative progression. At the last scene with the castle, there is also a portal that loops the narrative back to the "chapter select" signpost. Conversely, the bottom *Alice in Wonderland*-inspired illustration does not have a clear path of progression, but rather employs portals to draw viewer attention to difficult-to-spot or hidden parts of the scene. For example, the portals in the teacups all lead to an occluded window *behind* the mirror in the center. This mirror has a swirly reflection that functions as another portal that takes the user back to the beginning of the scene. Similarly, other portals include reflections in the hanging lanterns that lead to different zoom depths and floating mirror reflections that highlight the black cat in the upper left corner or lead to another hidden lantern.

5.2 Portals for Hypermedia Navigation

5.2.1 ***Website Hyperlinking.*** Figure 12A demonstrates an example of using the portals for website navigation as an alternative to hyperlinks. Instead of clicking on a button, the user can instead zoom into a portal containing the preview of the linked page. Since a portal can reference any viewport location and be referenced from any closed path, this leads to several use cases: *direct links*, involving a conspicuous portal in and a portal out that is a screenshot of the entire linked page, 2) *framed links* with also an easy-to-spot portal in to highlight a portion of another page on portal out, and 3) *concealed links* with a hidden portal in that leads to an unexpected location on another page on portal out. For example, the user can start on the "Welcome" page, and visit the chatroom, blog, or forum by zooming into their respective previews on the lower half of the page (direct link). On the same page, there is also a "secret" portal represented by a white circle, leading the users to the white moon on the page with the phone (concealed link).

Design-wise, these portals that non-linearly connect each page are placed on a layer with a smaller depth value in comparison to the rest of the interface. They serve to visually differentiate the interactive components from the site from the static ones. As the user pans and zooms throughout the page, the portals with smaller depth will grow at a faster rate and attract the users' attention, even for the concealed portals that are integrated with the website background designs, so they are more likely to navigate into them. Alternatively, a designer could forgo parallax altogether and place everything in the depth if they wanted greater elements of surprise.

5.2.2 ***Presentation Navigation.*** Figure 11B demonstrates the usage of portals and zooming to create transitions between key points of a presentation. Starting from an overarching view of the solar system, the presenter zooms into visual regions like the Sun, Earth, and Moon, which are set up as portals that teleport the viewer to the respective scenes—akin to topic or detail slides. Portals in such scenes may link to other scenes, creating a sequential order to

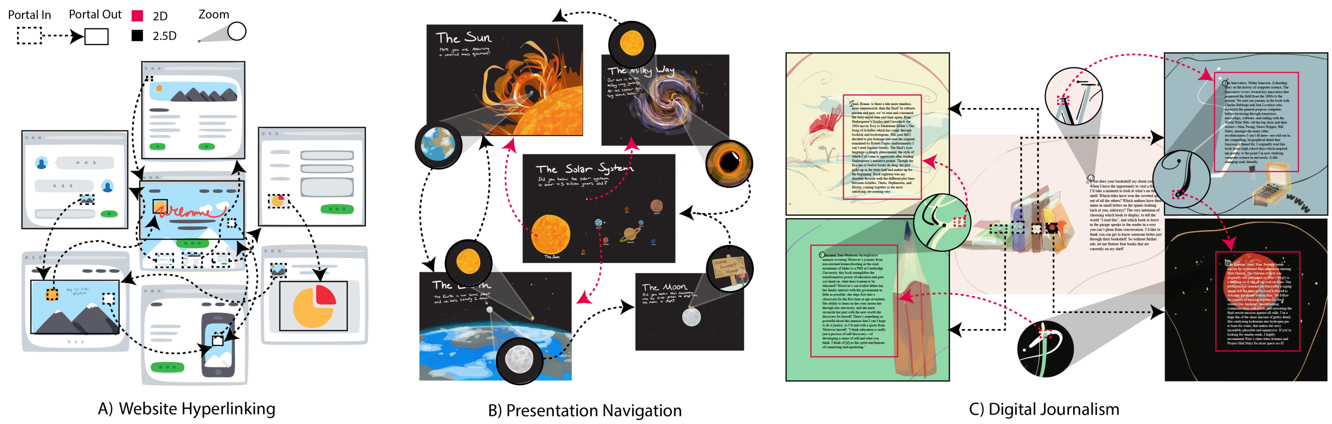

Figure 12: Potential applications of SVG transitions beyond visual stories, including A) website hyperlinking, B) presentation navigation, and C) digital journalism.

the presented ideas. For instance, the Sun scene transitions to the Earth scene which transitions to the Moon scene before returning to the overarching view. Here, the portal system provides a hierarchy to the flow of the presentation. Portals are one-directional, but secondary portals may link back to previous scenes, such as the Sun portal in the Earth scene. Branching presentation flows are also supported through establishing multiple portals in a scene as seen with the Milky Way, which can transition to the Sun or the solar system depending on the presenter's wishes.

As shown with the planets, portal transitions can more generally provide a viewing transition analogous to "clicking to the next slide" offered by presentation software such as PowerPoint, Keynote, and Google Slides. Likewise, zooming and panning create continuous transitions analogous to the slide-in and slide-out transitions in traditional presentation software. Our system further affords variations in the scale and position of the presented content, similar to Prezi and Sozi, and uses panning transitions to move the viewer between presented topics. However, PortalInk augments this process further through non-Euclidean, flexible, and *continuous* branching exploration of the presentation space within an infinite canvas. Unlike standard Euclidean exploration where zooming in from two parallel points never results in them meeting, our non-Euclidean exploration creates opportunities for these points to meet via portals. That is, any exploration path from point A to point B in Prezi is homotopic to a 2D line, whereas in PortalInk the path may traverse entirely disjoint, or even recursive, regions of the $\mathbb{R}^2$ canvas. Importantly, our exploration is continuous as the portals provide morphing previews of destination scenes, maintaining view continuity, unlike Prezi's fade-outs or jump-cuts.

5.2.3 ***Digital Journalism****.* Figure 12C depicts how portals can be employed differently in 2D and 2.5D modes for digital journalism, specifically to explore potential interactions between imagery and text. When traditional editorial content is published online, the viewer usually scrolls through text blocks broken by complementary images. Our example begins with a similar layout of a text block introducing the topic of book recommendations, accompanied by a drawing of a row of books. The user can then zoom into the first letter of each text block in 2D mode, discover the next sequential text block describing a book recommendation, navigate to it via a portal transition, then see complementary images of that book appear behind it. Alternatively, the user can also zoom into the book spine designs on the bookshelf instead and inspect the images for each book first, navigate to it via a portal transition, then read the description for the book and the text that appears afterwards. This freedom of navigation allows the user to choose what to focus on first—either the text or imagery—when reading an online article.

Figure	Lowest FPS	MB	Num <path>	Surface Area (px^2)
2	82.2	0.43	820	6.4 mil
8	67.8	0.54	1115	13.7 mil
10C	77.8	0.94	1781	13.1 mil
10D	80.7	0.52	849	80.6 mil
11A	50.5	2.92	828	15.5 mil
11B	47.6	10.2	2502	2.7 mil
12B	132.6	2.96	2834	14.7 mil

Table 1: A performance breakdown of SVG illustrations on a Chrome browser from the case study and gallery.

5.3 SVG Output Performance

To gauge how a typical 2.5D illustration would run on a standard machine, we also conducted a performance breakdown on a selection of SVG outputs from both our case studies and gallery, which are also included in the supplementary materials. The measurements, located in Table 1, were recorded on the Chrome browser on a Windows laptop running an Intel i7-11800H processor with a RTX 3050 Ti laptop GPU. Overall, we found an inverse relationship between FPS and the file size and number of SVG paths. The largest bottlenecks in performance lay in higher layer complexity–namely more strokes and more path commands–and the presence of SVG filters. The former can be ameliorated by spacing strokes within

Progression Linearity			Spatial Navigation			Figures
Linear	Nonlinear	Branching	xy-space	Auxiliary z-space	Discontinuous	
✔				✔		6, 7 Right, 10C, 11 Top (no portals)
✔					✔	11 Top (portals), 12C
	✔		✔			8, 10D, 11 Bottom (no portals)
	✔				✔	11 Bottom (portals)
		✔		✔		10B
		✔			✔	12A, 12B

Table 2: Visual outputs created using the system from the case studies and galleries categorized into either linear, nonlinear, or branching narratives with either *xy*-space, auxiliary *z*-space, or discontinuous space navigation.

layers more sparsely to partially render strokes when zoomed in; this is why Figure 12B, the solar system illustration, is more performant than Figure 11A, the theatre illustration, despite similar file sizes. The latter bottleneck can be mitigated with GPU acceleration settings in the browser that can be toggled on by the user. In addition, we also provide an option to turn off GPU-intensive filters for the exported SVG.

6 TAKEAWAYS

Our artists found that the tool allowed them to create "*an appealing habitat with a lot of explorable movement*" (Artist A) and our gallery demonstrated additional applications for parallax pan/zoom and portal interactions both within and beyond visual storytelling. Through their combined visual outputs, we identified several patterns in the use cases of 2D vs 2.5D navigation and their roles in the linearity of storytelling, which we hope can inform the future design of 2.5D storytelling or illustration tools. We also found general themes of how users can re-purpose, or "piggyback" [22] the parallax and portal techniques to emulate other mechanical or narrative strategies, and explore their implications below.

6.1 Relating Space to Degrees of Linearity

In PortalInk, the illusion of 2.5D adds a pseudo z-axis for depth to the canvas while the portals contribute non-Euclidean pockets of spaces, both of which the artist and viewer can navigate into. In the discourse between linearity and spatio-temporal navigation [3], new interactions are thus introduced. To map out these interactions, we categorize the visual outputs from both our case studies and galleries into several observed relationships of linearity and space in Table 2. For conciseness, we will use the term xy-space to refer to navigating towards elements with similar depths and the term auxiliary z-space to refer to navigating towards elements on different depths, moving "into" the canvas.

The first category, including Figures 6, 7 Right, 10C, and 11 Top without portals, is a linear progression where the user zooms to greater depths in auxiliary z-space, usually towards the center of the canvas, sometimes occupied by a character (Figure 6, 7 Right) or object (Figure 10C). This style can be extended to a circular, looping narrative with the addition of a portal at the end (Figure 11 Top), introducing spatial discontinuity. Using this discontinuity at *every* step of the progression (Figure 12C) instead of just the last one allows the artist to signal more succinct divides between progressions stages. These uses of space can be similarly seen in branching narratives (Figure 10B, 12A, 12B), where the only differences are that zoom indicators or portals are used to make diverging paths more explicit. Conversely, we found that nonlinear narratives are more commonly associated with pan-based or xy-space navigation (Figure 8, 10D, 11 Bottom without portals). These stories are characterized by multiple points of interest occurring simultaneously in time. The viewer can thus have more freedom in selecting which visual stimuli is personally more appealing. During this exploration, spatial discontinuity in the form of portals can be employed as redirection (Figure 11 Bottom with portals) to attribute semantic meaning or association between disjointed regions of the illustration.

While prior literature has established relationships between time/space and narrative linearity in visual storytelling [3, 7, 10, 19, 44, 58, 76], the most common of which is the dichotomy between nonlinear, space-oriented and linear, time-oriented stories, we demonstrate that **our system thus breaks these conventions by enabling *all* forms of narrative linearity to be craftable within space-oriented stories**. This paradigm provides the author with sufficient creative freedom to create whatever narrative they wish without detracting from user agency, as the viewer still retains autonomous exploration throughout their experience.

6.2 Re-purposing Parallax

The parallax navigation of PortalInk was created to simulate the illusion of 2.5D depth. However, when used in practice during the authoring process of graphical narratives, we found that artists developed more creative use cases to create visual groupings, perspective shifts, and animation:

Visual Groups: In visual storytelling, semantically or symbolically related content are clustered into visual groups [42]. Scenes are similarly grouped into foregrounds, middle grounds, and backgrounds in traditional drawing. We found similar groupings in our illustrations where artists placed foreground elements in a layer with less depth than background elements (Figure 6, 7 Right, 10C). Outside of drawing, this grouping extended to convey additional functional capabilities such as zoomable "links" (Figure 12A) and legible text (Figure 12C). Tying parallax to the layer system, a framework that artists have used for decades from layered acrylic sheets to the layers of commercial art software, naturally further reinforced these visual groups via the additional illusion of depth.

Perspective Shifts: By affording granular control to a viewer, parallax pan also enabled the artist to craft continuous perspective shifts (Figure 8, 10D). This mode of navigation is in stark contrast to the digital page-turn analogy of modern comics [21], and is more conducive to continuity. As the degree of these pans and thus perspective changes are dependent on the mouse sensitivity of the viewer, the viewer themselves also retains greater user agency by self-controlling the potential disruptions of unwanted ellipses [19].

Animation: The style of animation supported by parallax is visually similar to paper puppet or cut-out animation, but behaves differently. Paper puppets usually involve manually moving individual segments of paper, or layers in our framework, and thus require an inherent understanding of movement and how joints interact with one another [4]. However, parallax animation within our system moves all layers with one unified motion—for example, the singular up and down pan interaction by Artist C in Figure 10A–providing a playful and lower barrier-to-entry alternative.

Overall, **parallax re-purposing provided a way to help artists regain agency over the new creative tool**. Specifically, this is accomplished either through relating layers back to the familiarity of visual groups or using it as a hack to achieve the previously difficult-to-achieve techniques of perspective shifting or animation.

6.3 Re-purposing Portals

Portals were intended to emulate a spatially discontinuous scene cut–similar to different panels or ellipses [18] that jump to another scene for more explicit narrative progression. Most of the illustrations we observed used portals in this manner. However, similar to the parallax effects, we also identified cases where portals were used alternatively to explore variations of style or tone for the same sub-scene or as a proxy for a click interaction.

Style/Tone Shift: Within linear storytelling, the traditional usage of portals would be similar to that of a linked list, where each one points to the next immediate stage of story progression. However, artists may also design diverging variations of the same scene (Figure 6). In this case, portals can be used to suggest aesthetic style or tone shifts. These style differences can have implications about how much empathy, credibility, or "completeness" is relayed from a visual outcome [8, 56], despite the content itself left unchanged. Thus, providing options to a user to *choose* which styles to immerse themselves in can lend to a more personal viewing experience.

Mouse Click Proxy: Functionally, zooming into a portal provides an alternative means to simulate a mouse click that takes the user to a new view. However, they differ because portals provide a smooth, gradual transition instead of an immediate jump. This transition has been previously demonstrated to improve a user's sense of presence and distance estimation skills in virtual spaces [62]. In addition, the preview feature of portals can reveal extra information about what the resultant view may look like. Although the extent of this information may vary–for example, depending on the different kinds of "links" achieved by portals in website hyperlinking (Figure 12A)–the user is still afforded greater power in the information behind navigation choices before actions are taken.

While the prior re-purposing of parallax helped artists retain agency, this re-purposing of **portals helped the user or viewer take back control in the form of navigational choice**. Either through hearkening to their personal preferences through stylistic options or providing them greater context to make "mouse clicks," the portal mechanism provides the viewer with greater autonomy without overriding prior author design choices.

7 LIMITATIONS & FUTURE WORK

One potential limitation is that while our case study artists alluded to portals, they did not actually use them in their final outputs. Thus, future work could focus on more longitudinal studies with artists or designers to explore other use cases for portals beyond the ones we suggested in our gallery. In addition, while our outputted SVGs are accessible and directly interactable on most modern web browsers, the automatically generated event-based navigation and animation scripts are not easily modified without re-import, which can be tedious if an artist wants to modify or have personalized events. The list of configurations supported by PortalInk is also not exhaustive. Greater support for more comprehensive scenarios for high-fidelity outputs such as independently floating annotations to enhance legibility or indicators for the "end of a story" within this infinitely zooming paradigm could be added.

Another potential area of future work could involve reexamining general vector graphic file formats to identify more persistent specifications for interactivity without relying on JavaScript. Beyond technical improvements, there also remains an exciting area of open research surrounding 2.5D authoring interactions and experiences, for example—examining the usage of dynamic elements in tandem with 2.5D navigation, incorporating depth-based stimuli beyond visual effects such as audio and haptic triggers, and more thoroughly examining different linear interpolations for scaling to understand their effects on the "momentum" of 2.5D parallax.

8 CONCLUSION

Through the parallax and portal SVG transitions, PortalInk gives artists a new toolbox of compositional, spatial, and temporal strategies to employ in visual storytelling. These strategies play on traditional 2D techniques and derive wonder through "magical" extensions of the familiar—for example, using 2.5D instead of 2D and teleportation instead of page flips—enabling experiences that astonish and captivate the viewer. Furthermore, by being able to draw and interact with both parallax and portals directly in the same interface, artists can seamlessly adapt these features into their existing workflows in 2D illustration. The implications of case studies and gallery examples further reveal how these SVG transitions can open up new possibilities both within and beyond storytelling, as many of the strategies that artists devised while interacting with the tool generalize to visual communication and new viewer effects.

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