Navigational Instruments for Design Spaces

December 4, 2020

This review will cover the history of some active software instrument scenes, and establish the terminology of 'software instruments' referring to playful tools and serious toys. We will use the computational meta-medium in which software instruments are orchestrated as a means to organize skillful traversals of *design spaces* containing many useful or expressive artifacts.

Survey of Graphical Instruments

In this section, I will discuss software instruments including both computational notebooks and explorable explanations. We'll briefly tour the 'explorable explanations' art scene, that uses these tools to do fun things with informative material, especially by making the data accessible to poking and prodding.

Explorable explanations are an increasingly popular form among independent researchers and educators, especially in the spaces of videogame design and machine learning. Computational notebooks are a form of self-documenting script-based workflow which has gained popularity among lab scientists as well as computer scientists. These scenes are currently producing novel *computational mediums* suited to the definition, exploration, and exposition of a vast variety of complex subjects.

Alan Kay

- Some Works - Dynabook - Smalltalk

Vi Hart

- Some Platforms
  - Joint PI, Communication Design Group [CDG]
  - Researcher at Khan Academy, 2012 - 2015
  - Vihart YouTube channel (1.34 million subscribers)
- Some Works
  - Parable of the Polygons (with Nicky Case, self-published, 2015)
  - Doodling in Math: Spirals, Fibonacci, and Being a Plant [1 of 3] (YouTube, 2011)

In How To Snakes (Vimeo, republished from YouTube, 2011) \cite{https://vimeo.com/147792656}, Vi Hart demonstrates the use of a modular plastic snake toy as a tool for recreational mathematics and personal expression, with affordances such as: - wearing the snakes - dropping the snakes - making a space-filling fractal curve - jumping rope with a snake - wearing snake as a mustache - stop-motion game of Snake (1976) - configuration space of snakes in terms of 'left' 'right' and 'forward', similar to Logo - but snakes can't run into themselves, so how many valid configurations are there? - binary encoding with two-color snakes - fractal snake (for each head you cut off, add two) - wearing the snakes on your fingers and making them longer - stop-motion game of Snake but the snake runs into itself and dies

This video is 2:09 minutes long, and elegantly connects space-filling curves with group theory (of valid snake configurations, called 'slithers'), while also making light of the somewhat arbitrary definition of a slither. While slithers ares shown to be extensible beyond 90-degree turns, they are also clearly irrelevant to cases where the snake

is a mustache (or otherwise functioning as a 3D physics object), let alone a hydra (or otherwise incorporating a branching operator that rapidly fills up 2D configuration space).

The above affordances are listed in the same order as presented in the video. Concepts are introduced after concepts they depend on, which are introduced after motivating examples, which also serve as periods of reduced tension, supporting the surrealistic narrative arc. It is clear that any hinged modular toy could have been used to convey these concepts, except that it hinges on a cultural reference involving snakes, and that it is really very fun to chant 'snake'.

Reza Sarhengi

- Some Platforms - Organized Events - Bridges Math/Art Conference

Bret Victor

- Some Platforms
  - Joint PI, Communication Design Group [CDG]
  - Designer at Apple Inc., 2007 - 2011
- Some Works
  - Up and Down the Ladder of Abstraction (interactive essay, self-published)
  - Inventing on Principle (talk at Game Developers' Conference [GDC], 2012)

Nicky Case

- Some Works - Parable of the Polygons (with Vi Hart, self-published) - Loopy - World in Emoji
  - Edited Volumes - explorabl.es ()
  - Explorables as design tools

Jer Thorp

- Organized Events

Jonathan McCabe

- Some Platforms - - Some Works - Cyclic Symmetric Multi-Scale Turing Patterns (Bridges, 2010)

Casey Reas

- Platforms
  - Founder, Processing Org
- Edited Volumes
  - Form and Code, Princeton Architectural Press, 2011

Kate Compton

- Some Platforms - Some Works

Tarn Adams

- Some Platforms - Dwarf Fortress - Some Works - [villain system]

Emily Short

- Some Works
  - Galatea
  - Annals of the Parrigues
- Edited Volumes

Jason Grout

- Some Platforms - Jupyter Developer at Bloomberg - Mathematics Professor at -- () - Contributed Libraries - SageMathCell (UTMOST Phase 1) - IPython Widgets
  - Notebooks as frontend design tools

William Stein

- Some Platforms - CEO, CoCalc - Mathematics Professor at UW () - Organized Events - SageMathDays

Mike Bostock

- Some Platforms - CEO, **ObservableHQ** - NYT graphics desk (?) - Contributed Libraries - d3.js - Protovis
  - A proliferation of interactive visualizations is available from outlets including the New York Times graphics desk. How are those written?

Chris Olah

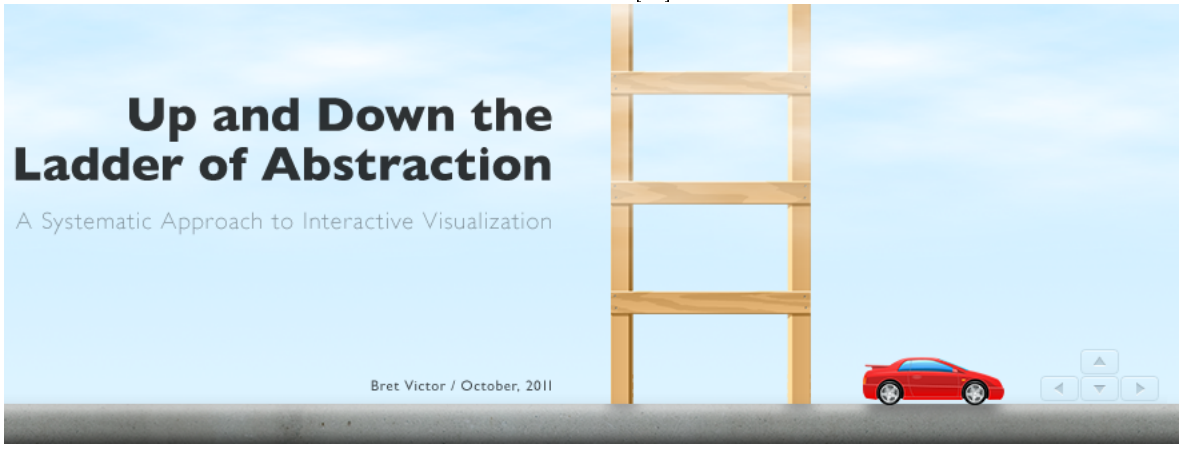
- Some Platforms - **distill.pub** - Some Works

DESIGN: the hands-on essay

Alan Kay secured funding for the Communication Design Group (CDG) in 2013, and hired Dan Ingalls (his collaborator on Smalltalk), Vi Hart (then working at Khan Academy), and Bret Victor (formerly working at Apple) to run it
\cite{https://tashian.com/articles/dynamicland/}.

A Humane, Dynamic Medium

Bret Victor's work is linked on the explorabl.es site curated by Nicky Case (and many collaborators
\cite{https://github.com/explorableexplanations/explorableexplanations.github.io#explorable-explanations}), in particular his influential piece 'Up and Down the Ladder of Abstraction' from 2011.
Kay wanted to make another group like Xerox PARC [...]



An Expressive, Extensible Medium

Vi Hart is an artist known for her amusing educational videos about mathematics.

Vi Hart cites Reza Sarhengi, the founder of the math-art conference Bridges, as a formative influence \cite{https://theartofresearch.org/a-history/}, in the context of her decision not to study in a mathematics department but rather, in experimental music.

> I already had spent enough time in the field to know that what they teach in school captures very little of the beauty of mathematics, and I could find that elsewhere. More than I am a mathematician I am a composer...

AUTODIDACTIC and pertaining to VIDEOGAME DEVELOPMENT.

Dynabook -> Vi Hart -> explorable.es, distill.pub, observableHQ

SCIENCE: the computational dashboard

A proliferation of literate programming has been seen in .

ACADEMIC and pertaining to MATHEMATICAL RESEARCH.

SageMath -> Jason Grout -> matplotlib, IPython widgets, binder

(You can punt to future touchstones, as well.)

Conclusion

At this point we've seen a lot of design spaces. Let's go in-depth on some specific, playful tools for dealing with (and simultaneously, defining) design spaces.

Case Studies in the Computational Meta-Medium

In this section, I will discuss in depth two unique instruments for navigating design spaces: a casual creator from the popular Sims series which defines the facial features of expressive virtual avatars, and a computerized oracle deck which unfolds as a nonlinear narrative in a mode of reflection upon an inexpressible tragedy.

The paper on The Sims 3 Create-A-Sim (CAS) was presented at the Casual Creators Workshop at the Conference on Computational Creativity in 2020. It contributes a model of the avatar creator containing both an inner evaluation loop (where a vector of weights defines a facial geometry of the avatar), and an outer evaluation loop (where the user perceives the character represented by the avatar going about their Sim life), where execution occurs as often as the user chooses to revise or update their Sim.

"exul mater" and its accompanying paper were presented at the (un)continuity exhibition at the Electronic Literature Organization Conference in 2020. "exul mater" is a novella in an oracle deck (taking about 2 hours to read), told in the scenes between cards. Placing pairs of cards reveals letters between the figures regarding their conflicting and conflicted commitments to each other, and to space-operatic forms of cybernetic power. A postmortem is also online, containing more detail regarding prior interface designs, and reflections on creating the non-hypertextual multimedia elements: https://jazztap.github.io/exul-mater/statements/

Entering the Design Space of Digital Portraiture: A Case Study in Avatar Creation Tools

We describe creativity support tools for digital portraiture in terms of their design spaces, which conveniently possess both a high-dimensional linear space of representations, and a highly expressive nonlinear space of referents. Using the casual creators tropes of parameterization and paper dolls, we investigate how distinct 'face spaces' are made playable by these tools and toys. We consider in depth The Sims 3's Create-A-Sim mode, a 3D avatar creator whose expressive range is further expanded by a modding community through intentional and highly technical interventions. Finally, we connect these skills to practices using professional creativity support tools for digital portraiture. We argue that the skillful practice of creating beautiful and evocative avatars is encoded simultaneously in software tools and in artistic communities, enabling a form of conversation between the portrait artist and their medium.

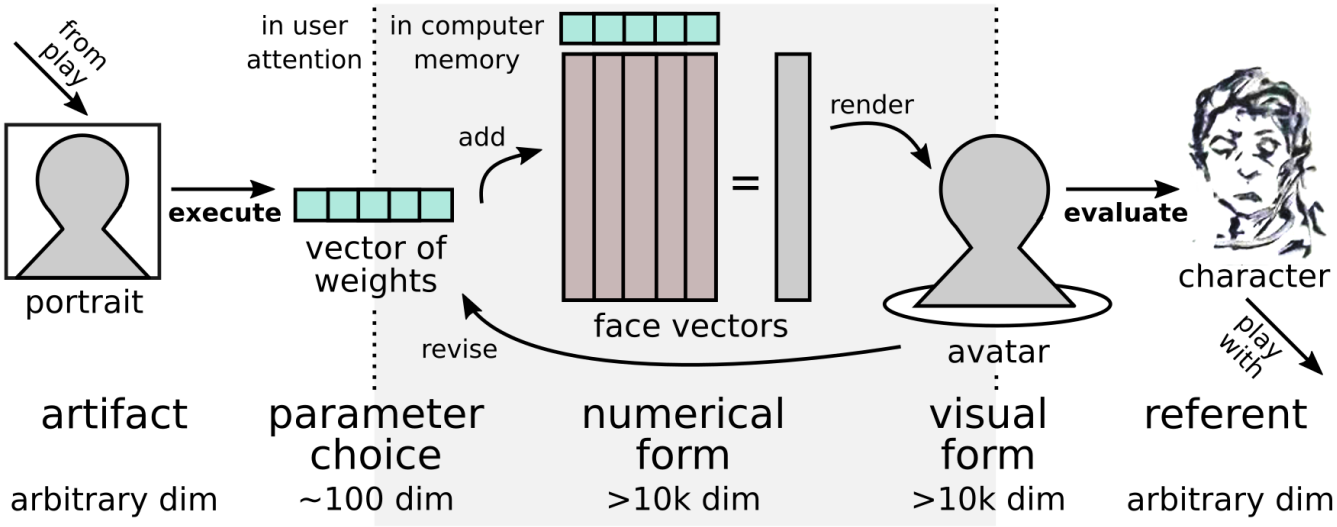


Figure 1: Outer and inner evaluation loops in an avatar creator, annotated by the dimensionality of data at each stage. From left to right: 1) The portrait (or similar artifact) that we want to locate in the tool's expressive range. 2) The parameterization chosen, as a vector of slider values and/or part choices. A compressed representation of the portrait, relative to the avatar creator. 3) The numerical representation of our avatar geometry, i.e. the chosen linear combination of basis elements. 4) The interactive visual representation of our avatar geometry, incorporating textures, animations, and camera settings. 5) The referent, i.e. the character whose avatar is being made. All data representations of a character capable of growth are necessarily incomplete, so their dimensionaility is ill-defined.

Introduction

Art students undertake years of life drawing to learn how to capture human likenesses in graphite and clay. Yet videogames which allow players to create their own character must somehow facilitate avatar creation by novice users, without making a hash of their first attempt with an unfamiliar system. Therefore, videogames with avatar customization invariably supply a combination of 'known good' starting avatars, and possibly an additional system of procedural modification [?].

These systems enable the exploration of a certain 'face space' - far being from the only one that exists, but certainly compatible with e.g. facial animations specific to the game, - which may not contain only good avatars. Indeed, more permissive editors tend to be capable of producing a wide variety of 'monstrous' faces. The humorous exploration and celebration of these possibilities formed the premise of the 'Monster Factory' Let's Play series [?]. This paper will explore an argument that the existence and accessibility of these distressing and typically unintended results is indeed necessary and co-constitutive of the value in a creativity support system for digital software.

In order to make this claim, we need to describe both the technical and expressive dimensions of portraiture. We will focus on the case of 3D polygon-based avatars, because this is the current technological standard for roleplaying games produced by major studios, and in order to use The Sims 3 (TS3) as our case study. While 2D avatars present a compelling example in the domains of videogaming, tabletop roleplaying, and social media, we leave a detailed exploration to the craft literature of the respective software, and therefore leave their technical description aside.

Faces are highly expressive, able to convey aesthetic judgement [?] and other forms of data that resist quantification. Humans are also good at distinguishing between collections of points representing a face, and statistically similar collections that don't [?]. Since our computers aren't, they need either very well-fitted manifolds in order to navigate 'face space', or a modestly good fit and a human pilot. And if it's fun for the human to lend their knowledge of face space and its strange boundaries to the computer, then perhaps it's more fun for them to refine that knowledge co-creatively.

Portraiture is virtual

Davidenko [?] characterizes various synthetic manifolds (i.e. the expressive range of a generative model) embedded in a (universal) face space equipped with the perceptual distance between any two human faces, and develops a minimal 20-dimensional 'face space' of silhouetted face profiles which are suitable as visual stimuli for cognitive experiments. We extend this approach to describe the elaborate 'face spaces' which are made explorable by avatar

creators in TS3 and similar games, with an eye toward eventually extending the work to face spaces of an illustrative or photographic nature (i.e. lacking a fundamental wireframe representation), that use either projection techniques (as in life drawing) or texture synthesis (as in generative adversarial networks).

In order to characterize spaces of 3D faces in the context of player creativity, we in fact encounter an intricate pipeline of data structures and percepts. We interpret an output of 'portraiture' as encompassing an entire space of possible images of the character represented by an avatar (see Fig. 1, far right), which document the user's evaluation of the nonliving yet growing character they have represented in the game or fiction.

Simultaneously, we interpret an input of 'portraiture' as a particular set of image references (e.g. the face of a person from school, or from a movie, or from another videogame) which the user aims to reproduce, mimic, or modify using the avatar creator. The same artifact may evoke similar or divergent referents in different users, just as the 'same referent' may be represented by different artifacts according to different users. An online gallery may easily contain several different Sims of the same character from popular culture.

Both characters and artifacts exist in a semantically rich space. The avatar creator software incorporates certain claims about this space (e.g. 'eye distance varies within this range', 'the height of the inner corner of each eye varies independently of the curve of the lower eyelid'), using a linear basis for additive recombination of facial features, and a rendering algorithm to permit their observation. The immediate visibility of features permits their recombination to be improvised, just as a well-crafted instrument does [?].

Instruments are actual

We choose to study avatar creator software as an instrument in its own right, which encodes part of the skillful practice required to create human likenesses. Their expressive range is only ever partially summarized by their own interface, especially as the numbers of facial feature sliders proliferate, and unpredictable interaction effects [?] start to predominate the output. Even if parameter space is linear, perceptual space is not.

Tubb and Dixon identify the array of sliders with *analytic* creative interaction, which tends to break down the combinatorial explosion in a face space with many features [?]. In elaborating on our Sims case study, we will see that *reflective* interaction (i.e. not winnowing, but expanding representations) enters through alternation between gameplay and avatar creation. Conversely, The Sims 4 moves toward *tacit* interaction - its slider panel GUI is replaced by 'direct manipulation' of the Sim face (via well-curated *bone sliders*, a mapping we discuss in 'mesh-based geometry'), with panels replaced by 'coarse' and various 'detail' layers.

To avoid confusion between toys (in the case of small parameter spaces) and tools (in the case of very large parameter spaces, up to and including sculpting software), we call the avatar creation software an 'instrument'. Like musical instruments, they can be played more or less skillfully. Like analysis instruments, they provide generalizable insight into the character of universal face space.

The design space of portraiture is vast

Artists learning to draw in the contemporary tradition must perform mimesis of a reference artifact (be it the pose of a model on a stage, stock photos of actors, or even the drawings of master artists), and are taught to regard this as a productive process. Not only are divergences inevitable anyway, but the process of reaching a landmark in design space is an embodied learning experience [?]. Creating from imagination, then, is just like walking to this landmark across a rugged fitness landscape, - per the navigation-functionality analysis in $9.3 of [?], - except the artist must recognize the landmark despite its previously unseen form.

Developing a method of documenting forays into the design space of portraiture allows us to not only compare particular results, but also to consider the expressive range of the tool or composer. Reflective tool design [?] makes an artifact of the part of an artist's skill (often discussed as their 'style') that is encoded into e.g. a basis for a certain face space.

Stylization is the visible evidence of a certain set of constraints on the region of design space that a given set of artworks (typically by a closely-knit group of artists) thereby explore. Deliberate constraints are often self-imposed. In Techne Theory (p.188), Staten describes design constraints as 'maze walls' in design space, that (at various levels of tangibility, epsecially the subconscious) define skillful practice itself [?]; a contoured space deeply contingent on material history.

In the realm of avatar creation, these contours may arise either from the tools being used (e.g. the character creator might not have this celebrity's exact eyebrows), or from particular ways of using those tools (e.g. not using items that didn't ship with the game, in order to create 'no-CC' content). More fundamentally, the contours of universal face space are concealed where they align with the tool's face space, and revealed where they don't.

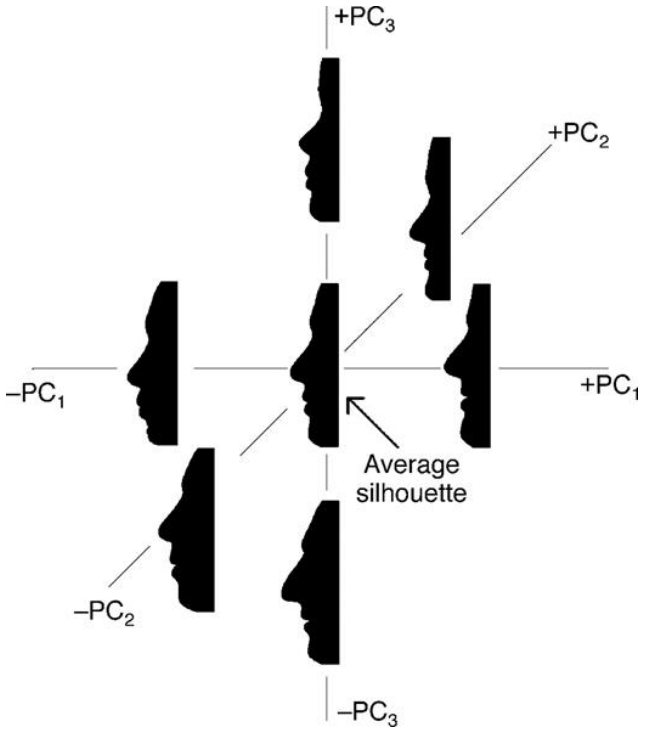


Figure 2: Axes in a non-videogame face space developed for use as controlled stimuli in facial perception studies. Note that 2D contours carry enough information to recognize distinct people, and that only three out of 20 axes in the parameterization are shown. (Reproduced from Davidenko, Fig.13.)

Search methods

We suggest a specific reading of artistic procedures as evolutionary algorithms (after Dennett, via Staten), where the face space of a given creativity support tool operationalizes a single level of abstraction. In particular, sets of landmarks in design space closely resemble the procedure of quality-diversity search [?], which maintains a set of increasingly 'good' points in various regions of design space.

It is vital to observe that interactive explorations of design space can be in constant communication with their perceptual landscape (equipped with its rugged fitness function), whereas automatic procedures are better at characterizing computationally intensive properties of the artifacts being designed. Nonetheless, small breaks in this interaction make a design space more interesting, not less. For instance, when a Sim has a child, even if their parameters are more or less evenly combined with their partner's, the ruggedness of perceptual space can lead to surprises (e.g. if the child inherits a supernatural feature).

Instruments comprise a domain-specific language equipped with direct manipulation, in software terms. Avatar creators are software instruments, and their avatars are similar to Montfort's 'player character ... a constraint and possibility defined by the [software's] author' [?]. While general-purpose sculpting software can be adapted for use as avatar creators, they produce an experience much less similar to 'steering', and much closer to being the vehicle responsible for a safe traversal of design space.

The design space of face geometry is consistently formalized

In this paper, we take particular interest in the language of a linear basis for a face space, that is, some subset of a 'universal face space' containing all likenesses of persons.

Mesh-based geometry

Meshes consist of a set of points in 3D space, connected by edges forming triangles which discretize a surface. Surfaces that are roughly egg-shaped, but possessing eye sockets and a jawline, can be said to resemble skulls. With the appropriate proportions and elaborations, eventually a face will emerge. Meanwhile, each vertex position should

Figure 3: Create-A-Sim displaying modded sliders. Note parameter choices (left) and the avatar on a turntable (right) dominating the Create-A-Sim interface. Red annotations are by the mod author, illustrating how to access the modded sliders by entering the 'Face/Head and Ears/Advanced/Ears' submenu and scrolling to the bottom. (Reproduced from 'Pointed ears as CAS sliders' by CmarNYC, via Mod The Sims.)

be chosen thoughtfully, to minimize the number of triangles in the resulting surface (to minimize the difficulty of rendering).

We may define a basis for face space as 1) a 'face mesh' of this form (including a fixed list of edges between vertices), and 2) a collection of 'vertex sliders', each consisting of a linear deformation to the positions of the vertices. In practice, certain subsets of vertices are assigned with variable weights to certain 'bones', allowing 'bone sliders' which deform the position, scale, and rotation of bones (and ergo those subsets of vertices) to produce more expressive mappings [?]. Because these linear operations compose algebraically, all sliders are basis elements of the face space.

Practical guides to the creation of new sliders (i.e. basis elements in face space) can be found in Sims modding forums [?, ?], relying on a variety of community tools to interface with the game's data formats.

Texture maps and lighting

Diffuse texture maps model the response of each point on the surface to direct illumination, i.e. what color is reflected. Normal texture maps allow bumps and other surface details to be added to the mesh surface without changing the number of vertices. The combination of these comprises one possible 'complexion' or 'skintone'.

More advanced texturing and shading techniques, including subsurface scattering (to model the soft translucence of human skin), are prevalent in heavily produced games that invest their resources into 'realism' [?]. The relationship of The Sims as a series and of its various communities to this rhetoric is complex. In this paper, we aim to avoid reliance on on the intensive character of 'realistic' avatar creation, as we are concerned with a separate form of 'skill' encoded into a face space.

Yet the evaluation of a face space will necessarily depend upon its rendering. A relatively heavily-produced game such as The Sims (or Skyrim) affords strong curiosity about face space, especially insofar as what needs to be fixed is made evident. Indeed, dissatisfaction with first-party textures can itself drive custom content creation [?] to critique and address the gap.

Case study of interactive portraiture

We proceed to consider avatar creation in a modded instance of TS3, looking for moments of expressive payoff resulting from complex technical procedures (such as the slider tutorials discussed above), which distort and remediate the game's world-model [?]. By considering various iterations of Create-A-Sim (CAS) as a family of modifiable instruments for portraiture, we demonstrate that parameterizations of design space are always tentative.

Sliders

Sliders are categorized into five parts of the face, and divided among four or more panels in each part. Somewhere between three and a dozen sliders are available in each panel. By default, all of this is hidden, and avatar editing is performed using a gallery of examples. In The Sims 2, the example facial features can be right-clicked to blend toward them by 10%, but this resets the slider GUI for that part's axes (and not their values), allowing extreme features to be created without mods.

The NRAAS family of community-maintained mods for TS3 (available at `nraas.net`) implements most of the features we will proceed to discuss, including a litany of bug-fixes and error traps appearing alongside changes to gameplay, and quality of life features such as the addition of most cheat console capabilities into the game UI, and the option to force Create-A-Sim (CAS) to display. In particular, this means that Sim parameterizations (including sliders, skintones, and other non-clothing accessories) need not be locked in, so that extended avatar editing remains a part of the gameplay loop.

Slider range, and caricature NRAAS enables CAS to display an arbitrary number of custom sliders, and can also expand the ranges of all sliders (including those of the base game) by an arbitrary factor - because the value of a slider becomes the floating-point weight of a vector, which is not actually bounded by the suggested range. This is useful for producing humanoid characters with exaggerated or animalistic features, in the style of special effects makeups.

The Monster Factory strategem of 'no middle sliders' calls for all sliders to be moved, preferably to an extreme position, regardless of the result. This maximizes the salience of the relationship between any two sliders in the face space, and since these relationships produce the rugged landscape of the space, some of its broad contours can be seen.

For instance, if the eyes are way over there, what will happen to the curvature of the nose bridge area if we lower the brow ridge? We can try it and see. Maybe the brow bone is a child of the eye bone, and the entire silhouette of the brow region changes. Or maybe the brow bone is still where the eyebrows were, and the nose bridge ends up longer.

Adapting Calvino's terms for a combinatorial expressive space [**?**, **?**], these slider choices define the *crystal* nature of the face space, acting as authorial choices. They are subject to the *clinamen,* which is any deviation from pattern that destabilizes the percept by a minimal intervention. In order to locate a potential clinamen, the player-author collaborates with the avatar creator, in conversation with their gameplay intent.

The clinamen in face space depends on the highly nonlinear relationships between sliders, and their ensuing effects on face perception. (Almost all of the points in high-dimensional spaces are in 'corners', further from the center than extremal points along any one axis are [**?**].) For instance, Monster Factory begins with a garishly additive, over-detailed bout of character creation, which promptly lands in an odd corner. These avatars are then juxtaposed with the world, which the game engine happily furnishes their interaction with, since nothing unusual has occurred from its point of view. As a result, suspension of disbelief creeps back in, and characters emerge.

Slider defaults, and vanilla pudding Certain service roles in TS3 generate new sims with a face that isn't randomized, but whose sliders are simply all set to zero. The NRAAS mods include both batch processing tools (e.g. by drawing from a gallery of premade Sims) and enhanced console commands for solving the problem (e.g. by loading each affected Sim into CAS, or by remixing them from other Sims in the neighborhood).

The activity of eliminating default faces from the neighborhood involves player community awareness of the face space, which is shared among players through this troubleshooting. It also demonstrates a mode of engagement where NPC avatars are actively expected to be the subject of *exploratory* interaction (co-creation) with the face space [**?**].

Interaction with texture maps and accessory slots

While a Sim's facial geometry is determined by their sliders (relative to the base head mesh), the rest of their appearance depends on skintone, hairstyle, and other bespoke assets.

Combining makeups Unlike other sculpting software (e.g. Sculptris, 3D-Sculpt) that enables direct painting, CAS provides a variety of makeups (split amongst five slots), with up to four customizable color channels each. This is useful not only for eyeshadow and face-paint, but also for eyebags, 'contact lenses' (including both costume lenses, and realistic options using more than one color channel), and any other feature that can be placed into a facial texture.

NRAAS can prevent makeup from taking up its own slot, allowing arbitrary combinations thereof. Clearly, a much smaller number of 'good' design options are opened up than bad or pointless ones by this choice. Yet this is a trade-off that certain users are happy to make, which is not surprising - to bother with mods at all means making instrument more tool-like (improving user control), at the cost of making it less toy-like (intensifying user effort).

Iris scale and hat bones Sliders can also interact with makeup and accessories. For instance, the iris and pupil sliders of #aWT change the radius of these features (regardless of which eye texture the user has applied) by moving the vertices of the eye mesh. Modders have also created sliders for the bones to which things like hats, glasses, and teeth attach, that modify their position to prevent (or accomplish) clipping through the face of a Sim with extreme features.

This represents an extension of face space to accomodate specific textures and accessories. So our story about face space cannot be that it is a nice and rendering-agnostic characterization of expressive range. Rather, it is made into an evolving site of identity work, in its capacity as a small lab of non-narrative world-building activity, as is The Sims as a series [?], as are the communities that have built themselves around it.

Conclusions

Call for face spaces

Linear approximation by sliders is an imperfect but tractable method of modelling universal face space. As an analogy, consider the RGB (red-green-blue) color space, which cuts through the space of all possible spectral signatures (as a submanifold). RGB color space consists of all possible blends of only three frequencies: a certain red, green, and blue, which each activate their respective receptor in the human eye. But RGB is a poor representation for designers, because the hue and tone of a color varies wildly as red, green, and blue are added or subtracted. A well-chosen linear change of basis will convert RGB space into HSV (hue-saturation-value), or another perceptual color space, which has the same expressive range but is easier to navigate.

Certain 'explainable AI' tools are designed to identify human-interpretible bases for expressive linear spaces. For instance, photorealistic 2D face spaces have enjoyed a surge of popularity due to recent work in generative adversarial networks (GANs). The SpaceSheet interface [?] is in fact an avatar creator incorporating real-time user modification of the parameter space, represented as a spreadsheet containing a high-dimensional vector in each cell, which is rendered as a point in the face space of the GAN. Unlike the paper-doll avatar creators commonly available online [?], GANs have not yet seen popular incorporation into feminine play.

Because of the comparative complexity of 3D rendering, libraries specific to avatar creation [?] may be useful in general for creating web applications that rely on morph targets. faceMaker [?] is a well-executed, very plain example of this kind of software. It has a substantial expressive range, but unfortunately, no landmarks besides the default face. Their most characterful slider by far is 'style', which produces avatars with the huge eyes and tiny necks of a Disney princess when moved from 'real' to 'cartoon'. It also predominates easily over other sliders. Nonetheless, imagining other 'style' sliders (e.g. for assorted interpretations of vampires) is a fun exercise.

Call for instruments

Instruments are a technology that changes over time. Instruments are defined by their design space, as when sculpting software uses clay as a (visual) metaphor to describe brush-based manipulation of a surface mesh. Yet play with instruments also re-defines their design space, as when situations arising in a life simulation game reflect back on the avatars populating that space, e.g. via the player-author seeking out specific custom content.

Reflective design is a mode of design research oriented toward documenting design knowledge in software instruments and other intelligent interfaces [?]. Avatar creators are instruments of this research when they are oriented toward understanding a face space, meaning that they both make claims (on their author's behalf) and challenge them (through their users). Two people attempting to use the same instrument to recreate the same person will find surprising differences in those representations.

The reference of avatars to a character who is important to the player, i.e. self-relevance, is a powerful means for players to understand and control their self-perception [?]. Ratan and Dawson provide evidence that when *avatar-body disconnection* after use is minimized, then avatar self-relevance after use (i.e. during downtime) is maximized. By this argument, indirect control of household Sims (and AI control of self-relevant but non-household Sims) would actually strengthen their connection to the player who isn't actively playing the game.

However, the strength of self-relevance depends on whether the design space of the expressive instruments in the game, including the face space of the avatar creator, is able to accomodate the *player's* creative range. Therefore, even when its face space is not the explicit subject of design inquiry, any life simulation game (e.g. the Sims-like Paralives, or the roguelike Ultima Ratio Regum [?]) depends upon it to connect deeply with its players.

Call to create communities

Each instrument affords a common language by which universal face space can be explored, allowing landmarks to be shared in the form of directions to them. Therefore, we assert that the Simming community itsel(ves) represents the primary good created by a platform which creates both support for novice creators, and room for virtuosity.

Avatar creators are deeply connected to social sharing, arising in the majority of 3D massively multiplayer online roleplaying games [?], as well as in paper-doll avatar creators shared online (e.g. on the website `meiker.io`). For instance, the Mii Parade that shipped with the Wii console was a space in which the 3D Mii avatars could 'mingle' with Miis from other consoles [?]. Using the sliders to change the X/Y placement of certain features on the Mii's head, it was possible to create a variety of masked and alien Miis, e.g. in order to figure out how someone else had entered a certain popular character into a Mii competition.

An intervention to seed this sort of community on other platforms might look like a creative jam oriented around using a particular existing or novel instrument of portraiture. For instance, turnkey stylizers like AI Gahaku [?], which projects selfies into a face space based on Renaissance art, are designed for social sharing. Unfortunately, this kind of face space typically lacks diversity [?], and remediation (e.g. via photo editing) is not afforded in a turnkey design.

As a platform, The Sims facilitates reflective learning [?] thanks in no small part to its maximalism as a life simulator. It supports usage by academics to facilitate skill development and personal expression, using authentic problems such as portraiture [?].

Acknowledgements This section could not have been written without the insight of folks who have partaken in the Casual Creators discussion group, ensuing from the Curating Simulated Storyworlds discussion group. They include Melanie D., Kavi D., Tamara D., Jason G., Isaac K., Max K., Cat M., and many others.

Procedural Montage: A Design Trace of Reflection and Refraction

Narrative media may vary the adjacency of fixed textual passages to drive rhizomatic readings through a montage procedure. We present the design of "exul mater", a hypertext fiction which locates perlocutionary acts in virtual spaces and resonant gaps. We reflect on sculptural fiction, the (de)formance of complex systems, and tarot reading as methods of layering metaphorical blends into polysemous juxtapositional elements. "exul mater" consists of one set of such elements and their pairwise juxtapositions, as presented through an interface which supports higher-order 'gap-filling' reading(s). We draw on peer feedback to address challenges to readability arising from the narrative application of procedural montage.

"exul mater" is a computerized oracle deck, questioning cybernetic power and identity, which is performed by a querent who arranges illustrated cards to reveal narrative texts. Using combinatorial narrative, it probes the multiple faces of each figure in its encoded myth (heightened by tropes of science fantasy and magical corruption), whose contradictions and diffractions reveal their conflicted interiority.

Its central figure attempts to reconcile a series of illegible tragedies with the totalizing scientific ontology which enabled these self-same triumphs to occur. The mutual incompatibility of these multiple truths is destabilizing, leading to a simultaneous and escalating aggrandizement and loathing of her loved ones.

The spaces in between its figures are sites of escape, of experiences that have not been reconfigured by a colonizing form of military-industrial technology. This rationalizing influence invades their moments together and animates the material forces that tear them apart, attempting merely to form neat strata. This deck argues against clinging to powerful stories for too long, and in favor of messy stories which fail to privilege any one reading, which can disrupt the imbalanced synthesis of history.

Introduction

We describe "exul mater", a short web-based story in a branching, card-based format. We consider the properties of this narrative system which induce apophenia, the eager perception of connections and meaning in unordered collections of like things (e.g. seeing strokes as forming letters, or letters as forming words). Its reader is invited to reminisce upon an immutable collection of events, which nonetheless may yield many different stories, as a querent would receive meaningfully different readings from the same tarot deck.

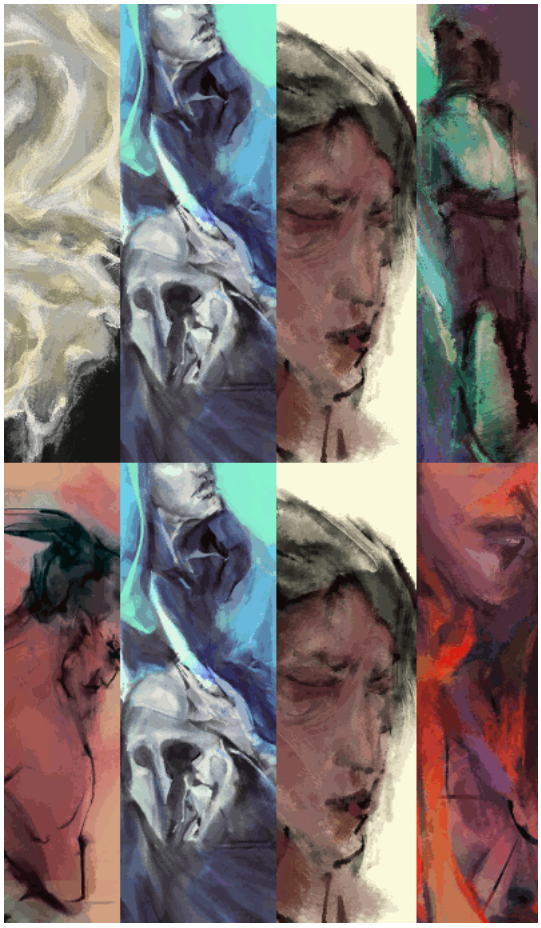


Figure 4: Contrasting montages of cards with comparable themes and figures. Here, the 'priestess' and 'magician' cards are fixed in the center. The priestess may harbor dangerous thoughts, or a traitor. The magician may adopt reserve, or venom.

We locate "exul mater" amongst analog forms of procedural narrative, which include tarot reading, shuffle literature (Montfort and Husárová), and other games of order or causality (Short, "Card-Deck Narratives"). Although a linear causality of events exists in "exul mater", it is not surfaced by our narrative's text, which more closely resembles a sequence of frame stories. This work does not attempt to complete a telling regardless of the reader's path, but instead presents each route as a deformance (McGann and Samuels) of the virtual space of narratives encoded by the deck. Our reader is thus encouraged to perform narrative between the scenes, within the constraint of which cards exist in their hand, to locate events whose significance was hidden. In this paper, we present the design of "exul mater", along with feedback from peer researchers of narrative design and visual culture. In the following text, quotes from this written correspondence are provided at the beginning of each section in gray intertext.

Construction

Our method of polysemous elements and productive gaps attempts to make a fixed topology of narrative content open-ended, by letting the reader select imprecisely among multiple selections of its scenes.

"exul mater" uses a concordance-like textual layout. Multiple scenes are laid out in alignment with each other, and are overlaid by the cards determining them (per 'Edge selections' below). Recent scene texts remain in alignment, faded out, until their card is completely replaced.

Cards are illustrated, representing characters (persons, institutions, or worlds) or themes (creatures, sites, or abstract concepts). As the text interrogates progress and hybridity through mythic tragedy, we ground out to images of sorceresses and their familiars.

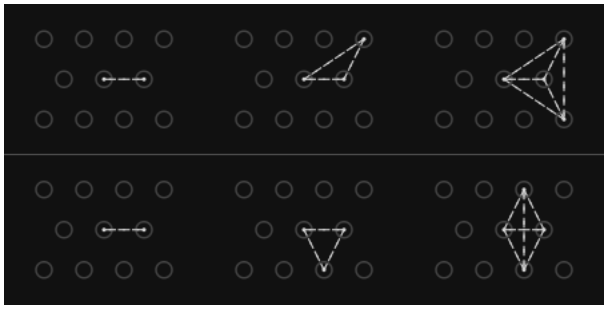


Figure 5: Diagram of storylet space, in six frames. Each node represents a card, and the center node is the first, fixed card. The two rows portray two routes, which diverge in the middle column: the second card chosen was the same, but the third card chosen was different.

Edge selections

"I like how it feels like you're tinkering with this ancient device, trying to uncover a story in faded text. I had to reread each fragment many times but the interactivity makes that feel like a puzzle." -Reader 5

"The different permutations of the story build off of one another nicely, even with different arrangements of player input." -Reader 4

"One of my favorite parts is the small references between the three [routes] that give unity to the piece, but I also feel like just a few more connections between the three [routes] could have been made to help encourage you to keep rereading." -Reader 5

Each pair of cards induces one scene, which represents a missive, reflection, or something else epistolary. When one card in a two-card spread is replaced, the previous scene text is placed to the side and faded (but not completely hidden). If the new text was faded (rather than absent), it is revealed in place. Otherwise, its movement would disrupt reading.

We present the cards in a fixed branching sequence. After each choice of a card by the reader, we discard the alternative (if any) and reveal one or two new cards (which are predetermined). In order to view alternative routes, the reader can rewind to the top of the deck at any time.

Each route of four cards corresponds to six scenes: respectively, the vertices and edges of a tetrahedron. Each edge is adjacent to four edges (two by replacing each card), while the sixth and opposite edge could be reached in two moves, using only two-card spreads. (Routes of more than four cards would imply higher dimensional simplices, and their respective combinatorics.)

Although one-card spreads are trivial (no scene is revealed), three-card and four-card spreads are also possible. If three cards are present, then three pairs are present, and each of their scenes is revealed simultaneously. (This triple is one face of the tetrahedron, so each adjacent face shares one scene.) If any one card is removed, both pairs broken are faded.

If four cards are present, then all six pairs are revealed. Removing one card breaks three pairs. Because all four cards are opaque and take up screen space, it is unlikely that all revealed scenes will be readable. The deformance necessarily performed by the reader is thereby made visible.

Virtual spaces

Because they can return to their previous position by a simple series of actions, the reader is encouraged in a circular motion of review, similar to other shuffle literature (Montfort and Husárová) in its reflective framing.

Traditional tarot decks likewise encode a vast virtual space of readings into the combinatorics of various spreads of cards. Tarot spreads produce a superimposition of orderings designed to draw out intuitive answers to personal questions (Parrish) (Manning, "Tarot as Procedural Storytelling"). The range of possible and plausible readings from any tarot spread are malleable through the use of decks with varied suites, names, and imagery (Short, "Expressive Range in Tarot Decks").

Our system in "exul mater" is an example of sculptural fiction (Reed, "Changeful Tales") where the reader performs the work, whilst the author designs the space it may occupy. Such work creates apophenia - the recognition of patterns or subtext - inevitably, yet at unpredictable moments.

For instance, Fallen London (Failbetter Games) is a browser-based persistent-progression game with occult themes, which implies to the player a more extensive and involved world than could be directly implemented. Because it plays out daily over the course of actual years, the user has time to prod at the seams of that world, and it may grow to fill the available mental space.

We claim the polysemous juxtapositional elements in any given apophenic fiction are in fact interwoven and mutually reinforcing. "If you hammer a nail into a piece of wood, the wood has a different resistance according to the place you attack it: we say that wood is not isotropic. Neither is the text: the edges, the seam, are unpredictable." (Barthes, 36). Tarot decks, especially, are in diffraction (Barad) with themselves - each of their elements with another possesses constructive or destructive resonances.

Contradictory orderings

We imagine the four voiced characters in exul mater as flickering signifiers (Raley, quoting Hayles). By allowing the presentation of each figure to vary widely between their scenes, which sit in an indeterminate order, they may "present [themselves] as a constantly refreshed image". Their polysemy is actually located in this variability, as much as their illustration(s) seek to surface it.

Our aesthetic goal is to enable many readings of literally the same scene, just as the montage effect describes a single face read with different expressions for what shots flanked it. We describe actual variation between, and imply virtual variation underneath, each presentation in each scene. This gestures at the performative fiction of identity, as undertaken by people attempting to be recognized as characters.

The reader may rearrange scenes (edges) in exul mater at will, within their current spread, which is topologically a simplex (i.e. a triangle of three cards, or a tetrahedron of four cards, and so on). Mere juxtaposition can produce virtual narrative (King) that is imagined yet unwritten, that is present without happening. By different elements of the scenes being diffracted with their neighbors, so every reading of the text is performed by reader intervention.

For instance, any spread of three cards will produce a triple of texts. "Neighboring stories" of this form share two cards. But not all triples are neighbors, resulting in textural gaps. In addition, the branching selection of cards reveals rival interpretations, by various shifts of perspective.

Inferred causality

"I can't, however, decide whether it is a stream of consciousness fragmented and pieced together to tell a story or fragmented mourning and sorrow that refuse to arrive at a destination." -Reader 7

"I wonder if, through divination, the daughter's exile can be ended, or if it is only a lens through which to understand." -Reader 2

"Much like tarot, it's best to glean an initial impression of the figure and what it might mean upon seeing it appear." -Reader 1

Each scene in "exul mater" is triggered by and comments on the relationship between two cards, typically in the form of a character addressing another character about their involvement in it. Relationships can be as simple as murder - because such acts foreclose on future possibilities, thus dictating causality - or as complex as vengeance. The relationship, as a perlocutionary act, emerges from those acts it implies and is implied by (Blommaert, 22). But in a puzzle whose solution is "love", the only word prohibited is "love" (Borges, 34).

If the same character may act in many different capacities, then even small casts imply very many different scenes. But the ideal place to position a scene is at a saddle point (a narrative watershed, from which outcomes diverge), where relationships are about to be reconfigured. Human readers are excellent at interpolating in between, imagining how a character reached point B from A - we may imagine fraught months of deception, from only the evening the spies nearly were caught.

Plot may be seen as a scheme to exhaust every interesting configuration of a relationship. This is clearest when a climactic scene teeters over the saddle point toward tragedy (e.g. the protagonist at the altar entering a loveless marriage), only to swerve back again. We propose that a virtual form of this other world exists if and only if the reader was made to pause and think of it.

Consider the narrative motion experienced by the remaining scene (out of three) when one card out of three is changed. This effect can be causally productive, enacting a cut (Barad), by changing e.g. the reason for an action taken, or the outcome of those choices. Following this action, the revealed text now has a virtual counterpart, a might-have-been.

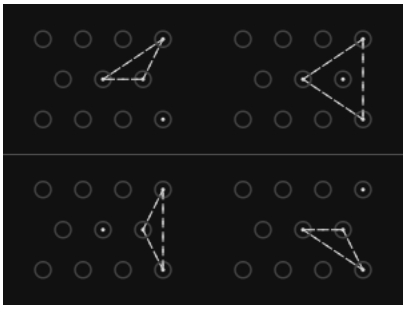


Figure 6: A space of three-card spreads, with (horizontal and vertical) adjacency given by replacing any one card. Adjacent spreads share exactly one edge, corresponding to a fixed scene, which experiences that movement as a triangle closure. Taken altogether, these scenes comprise a four-card spread (see previous figure, top-right).

We call the movement between adjacent spreads a triangle closure, alluding to the more general form of narrative closure, as found between successive panels in a comic book (McCloud). These near-misses, layered upon each other, together comprise a set of alternative causalities, which we regard as a re-reading.

Productive gaps

Calvino's combinatorial approach in The Castle of Crossed Destinies (Cannon) generates a multiplicity of plots from spreads of the popular Rider-Waite tarot (a deck of playing cards including the set of character archetypes known as the major arcana). Any given card possesses no single reading - rather, its meaning lies outside of itself, in its order with its neighbors. Yet the mere presence of unused cards in a narrative might entice the reader to find further nuance inside of the idea that a given iteration has presented.

These 'productive gaps' are lacunae (Manning, on lacunae), narrative elements which exist at the margins of the work, whether in friction with its meaning, or by visibly failing to exist. Lacunae are virtual, located in between texts, as apophenia and intuited connections. They are typical of narrative metacognition, as Calvino demonstrated by compelling his characters to read each others' stories, with no ability to negotiate a 'correct' reading amongst themselves.

Triangle closures, as a movement between readings of flickering signifiers, are themselves a meaningful gap which the reader may be driven to account for. Our aesthetic goal is (additionally) to enable many readings of literally the same spread, as the reader settles on one possible causal interpretation, especially if we cannot predict or even account for that interpretation (Kumari et al.).

Recombinatorial engines

Shuffle literature plays with polysemy and metaphorical blending, similarly to the mathematical intuition underlying a proof, in which exists an intricate contingency of the metaphorical blends (Lakoff and Núñez) forming each entity: "[...] the proof always springs from the insight, and not the other way round - and that the insight itself has its source [...] in a delicate and obstinate feeling of the relevant entities and concepts and their mutual relations." (Grothendieck)

Current works of digital narrative also deploy lacunae and resonance to locate the pleasures of rearranging a text, as demonstrated by the following two examples.

Telling Lies (Barlow) presents its topology through a heavily diegetic search interface, which relies on the gaps created by revealing only the five videos earliest in its timeline whose transcript contains a keyword match for any given query. In an operationalized variety of deformance (McGann and Samuels), the reader is forced to arrange the most meaningful series of records that could exist for them at each moment, bootstrapping their knowledge of the characters and their relations from nothing.

The Ice-Bound Concordance (Reed et al.) casts the player as the assistant to a posthumous author, who has written a novel but cannot arrange it. The virtual space of all the novels that could be written is explicitly the object of inquiry. Mechanically, the subset of sockets (cards) selected enables certain events (scenes) in each chapter, by certain boolean combinations.

Ice-Bound presents a small subset of the possible tokens for each chapter, so that the reader has no hope of realizing all of its plots without revisit. To lock in any given theme (which unblocks future sockets) at the end of

chapter, the player must search the companion book for imagery, sealed documents, and ephemera from the digital author's life, filling the lacuna ("where did this idea germinate?") with a resonant image or story.

Obstacles

Playtester feedback has revealed various issues of obscurity in "exul mater" over its development. As meaning-in-gaps is most effective when it resonates at a personal level (by elision of detail), it is prone to being enigmatic too, like a cipher without its key. We consider possible remedies to the confusion engendered by our context-dependent text content.

Obscured characters

"It may be beneficial to provide some background story to the characters so I have an idea of what has led to the point of contemplation and questioning." -Reader 1

"[...] for me the strength of this piece comes from being able to detect the emotions and relationships even if the details are obscured, and so I feel like not being able to figure who a character is at odds with this." -Reader 5

"I think as a way [of] providing more (albeit loose) framework, the player can choose which dyad of characters to investigate with the different tarot lenses, and a dramatis personae of the characters and/or cards as they relate to that dyad." -Reader 3

"exul mater" represents its cards as selected major arcana, and identifies each with a character. Cards are the common threads between multiple scenes, and together produce an emotional, thematic palette for the world in the story. A card is an original illustration (with character-specific imagery) paired to a short epithet, which may either name a character unambiguously, or else a suitable major arcana. (The name of the archetype is contingent on the card's position in the text, as the same illustration can have many names.)

We label the observer of each scene in the style of a script. A fixed point of view is infeasible when no single character is aware of all the scenes we need to establish each saddle point in the complex system which we portray them as navigating. Even characters observing the same scene will necessarily have different interpretations, which are desirable to contrast.

As character relations need only be revealed one or two at a time, each scene is only three paragraphs. Even shorter passages (ideally down to 100-word drabbles) would exert greater juxtapositional force, but are more difficult to ground out to characters. Whereas lyricism and emotional resonance require quick identification of specific characters in various guises.

And we don't even know if the reader knows a certain name for a character, or a certain relation of theirs. Any ambiguity in which name means which character is potentially counterproductive. Yet it arises naturally through both the multiplicity of individual characters (leading to a proliferation of names), and direct parallels between the relationships of various characters (i.e. repeating patterns, rhyming plots).

Unfamiliar interface

"I felt like the fact that some of the passages were retained while new ones appeared was supposed to invite me to compare and contrast the passages but I don't think that came across in my behavior. Instead, I ignored passages I had already read and interacted with the machines looking for new prose." -Reader 6

"Seeing prose appear as I arrange the tarot cards makes me curious what the relationship is between the cards and the text, and I wonder if the names mentioned are gods of some pantheon foreign to me. [...] As I read further I understand that these names aren't those of gods, but of mortals." -Reader 2

Although using tarot as a metaphor prompted a number of our peer respondents to accept the fragmented qualities of "exul mater", this was not always sufficient guidance.

Further iteration on the work led to a drag-and-drop interface (choose m out of n cards), which is the most common representation of subset selection in shuffle literature. We also tried interfaces using fixed slots (put n lights in m sockets, as in Ice-Bound), or a set of switches (m out of n can be active together, as in multiple-selection lists), or a rotating simplex (let the camera face m out of n vertices, with purely theoretical precedent). None were as legible.

The possibilities of interpreted spatial proximity, beyond excluding cards occluded by others, remain latent. The possibilities of on-hover text for clarification (e.g. against an explicit database, as in Inkle's Heaven's Vault) are more evident, but less feasible for our implicit knowledge representation.

Other forms of description folding on keywords or short phrases include hover text (e.g. Obsidian's Tyranny) and shimmer text (e.g. various Twine games). Hover text fragments can cause their hidden referent (a footnote, or a linked article) to appear beside the text. Shimmer text fragments can be cycled through a few authored variations, and may include character creation choices, collapsible summaries, or reframings of perspective (e.g. Reed et al.'s Ice-Bound). Each mode of juxtaposition is expressive and produces its own resonances.

Difficult texts

"Recasting this project as a manuscript would let you keep the obscurity and let us project onto the piece. As a game there wasn't enough connection between the playable elements and the story for me to understand it." -Reader 8

"But I was never able to figure out if each configuration of the piece was a window into a larger story, or if each configuration was supposed to be a different story from the other configurations." -Reader 9

The scene texts in "exul mater" carry the weight of both carrying a literal scene and producing figurative resonances. These fragments easily become alienating unless the card images are very literal. Rather than describe an intersection of scenes, these are more like entities that carry between scenes.

Our scenes are not written from single words; each relationship between characters has emotional overtones, so we used song lyrics interleaved as couplets to prompt each scene. The scene text must evoke or enact or discuss an interaction the given pair could have in one of their mutually defining capacities.

In "exul mater", using figures who ascribe different forms of villainy to each other, whose actions are forced by systems which they each articulate differently, we seek to describe systemic violence. Between scenes are the saddle points upon which those tragedies are willingly replicated. The beliefs and traits of each participating entity must cohere; they should prove the unexpected coexistence of certain roles, and so articulate what cannot be systematized (Raley).

Future plans

We anticipate seeing more and more shuffle literature incorporated into narrative games, especially those seeking to be highly replayable, yet being limited by the cost of content, or by the burden of avoiding self-contradiction (due to statefulness). In future works, we plan to investigate further structuring interface elements, beyond the prompts. Perhaps scenes can be indicated as events upon a timeline, or character aliases can be called out with a contextualizing highlight.

"exul mater" is available online. It was prototyped using the ObservableHQ, which supports interactive recombination of elements. While authoring, this allows us to see the selected text alongside the juxtaposed images, and to edit text with zero recompilation delay. However, the prototyping notebook is a general-purpose tool. While our code is open-source (using a flat representation of scene text, inspired by Inkle's ink langage), it is not a well-documented authoring tool. Because the structure of branching simplices is distinct from the locative fiction supported by existing sculptural hypertext authoring (Kitromili et al.), we may extend our notebook to facilitate authoring new decks.

We look forward to seeing the craft of flickering signifiers continue to be developed in procedural formats, inspired by both the capacities of modern hypertext, and traditional forms of magic and myth-making.

Traversals of Design Space

This section defines a domain-agnostic terminology for navigation in high-dimensional design spaces, oriented toward researchers in computational creativity producing co-creative systems, who desire the accessibility of casual creators or explorable explanations, whilst respecting the deeply domain-specific structure of their design space in the computational medium.

definitions, pragmatic reading, extrapolate from related work

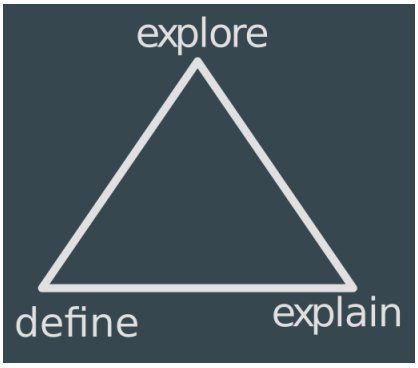


Figure 7: Our schema for methods of navigating design space, emphasizing the mutually reinforcing yet opposed natures of exploration, definition, and explanation.

Explore

to bake a cake
to 'approach a monument'
(I think the other way to get around the burden of content-authoring is to use a type system that encodes the entire semantics.)

In practice, I have never been able to design a data structure *from scratch* that is flexible and powerful enough to have expressive utility. Except in the case of learning to draw figures, which I experience as reification:

a) In locating a virtual, to be made actual. The strokes on the page become the silhouette of a figure projected into the camera plane, even though this figure is virtual.

(This use of 'virtual/actual' can be replaced with 'absent/present'.
\cite{https://courses.nus.edu.sg/course/elljwp/deconstruction.htm})

b) In discovering features of the reification that I did not think of in the figure; owing to constraints, they appeared anyway. This is the difference between drawing an eye that represents an eye, or drawing an eye that defines the eye socket of the skull and thus imparts spatial orientation and proportion, in *addition* to its (relatively subtle) effect on the gestalt expression.

This phenomenon is due to the principle that 'music is made of silences', or that 'edges are dual to vertices'. (The entire list of features can reconstruct the whole, and so can the entire list of gaps between features.)

In some mental data structure, I have represented the anatomy of the figure, which contains various relationships and invariants that discourage me from considering a contradictory stroke, so that I am free to select among an array of 'possible next strokes' at random, and moreover this freedom increases as I gain experience with figure drawing.

An instance of this data structure for the *subject* is what I mean by a point in design space. An effective, co-creative software partner encodes some of the skill - meaning the relationships between forms implied by strokes - sometimes literally. The Create-a-Sim sliders, for instance, operate on an entire polygonal mesh (the data structure of the *representation*), as though the strokes comprising the Sim base mesh were printed on some strange analogue of the rubber sheet on which the 'stretchy fish' of Thompson's On Growth and Form were printed.

These relationships of form are the subject of the next section, which pertains to grammar.

Define

to write a recipe
to 'produce a grammatical utterance'

Explain

to recommend a recipe
to 'document a work'

Bibliography

[import x3]