Combining 2D and 3D Animation

Ariella Gilmore*
ariellalgilmore@ucsb.edu
Dept. of Media, Arts, and Technology
University of California Santa Barbara

Sonia Hashim*
shashim@ucsb.edu
Dept. of Computer Science
University of California Santa Barbara

Jennifer Jacobs
jmjacobs@ucsb.edu
Dept. of Media, Arts, and Technology
University of California Santa Barbara

Fig. 001. Excerpt from frame from hybrid hand drawn sequence in *Mary Poppins Returns* by Duncan Studios and Walt Disney Motion Pictures.

1 INTRODUCTION

As novices in animation and being curious about the development and merging of the creative practice of animation drawing from 2D craft as well as integrating 3D content production pipelines, we sought to engage in a process of co-production to better understand this domain. Our goals were (1) to attempt formalizing a design space around motivations and artifacts and (2) to learn how to design better creative computational tools to support work that bridges 2D and 3D animation. By examining existing tools and methods, conducting an "in-the-wild" survey with practitioners across multiple sub-genres of animation, and specifically learning more about their practice and use of tools as well as conducting an in-depth interview with Dmitry Shkylar, the pipeline Technical Director responsible for the 17 minutes of hand drawn animation on the feature film *Mary Poppins Returns* (see Fig.001), we attempted to address the following research questions: what workflows and processes do animators rely on to combine 2D and 3D elements involving animation? And, can we learn how to build better tools to support combining ideas from 2D and 3D animation?

In constructing visualizations of survey responses and analyzing data integrated from different domains and disciplines, we share our findings on emerging trends in this space, offer concrete suggestions for tools and pipeline development and suggest possible lines of future inquiry to further concretize understanding of this domain.

2 BACKGROUND

2.1 Definitions

Before proceeding, it is necessary to provide some definitions for key terms used throughout this analysis. Firstly, 2D animation in this work refers to either traditional hand drawn animation or 2D input that draws from that practice. To elaborate, computer generated imagery (CG or CGI) can refer to computer based workflows for creating output. This can include 2D practice where 2D drawings are either digitally created or scanned and edited. 3D animation refers to work originating in computer based tools created using geometric primitives like 3D solid objects or meshes and a virtual camera. We also use the term hybrid 2D and 3D animation to refer to any practice that involves combining these distinct domains and borrows from ideas in each of them. Note hybrid animation can refer to many types of work including combining computer generated imagery with stop motion, but in the context of this work we use hybrid animation to strictly refer to combining 2D and 3D animation. Lastly, we rely on the concept of the 12 fundamental principles of animation. These principles, derived from traditional hand drawn character animation, add a feeling of liveliness to the output and include the following: Squash & Stretch, Anticipation, Staging, Straight Ahead Action & Pose to Pose, Follow Through & Overlapping Action, Slow In & Slow Out, Arc, Secondary Action, Timing, Exaggeration, Solid Drawing, and Appeal [15].

2.2 Expanse of Work

Some notable examples of combining 2D and 3D animation highlight the myriad of ways in which these two domains intersect. The non-photorealistic render (NPR) style of *Spiderman: Into the Spider-Verse* made it the first commercially successful film to leverage NPR and bridged elements of 2D practice into 3D animation. Anime, the specific sub-genre of animation originating in Japan, also utilizes 2D textures painted onto 3D models to create spatial depth in work such as *Weathering with You* or *Your Name.* Another genre featuring the intersection of 2D and 3D animation is live action and animation film such as the recent *Mary Poppins Returns.*

*Both authors contributed equally to this work.

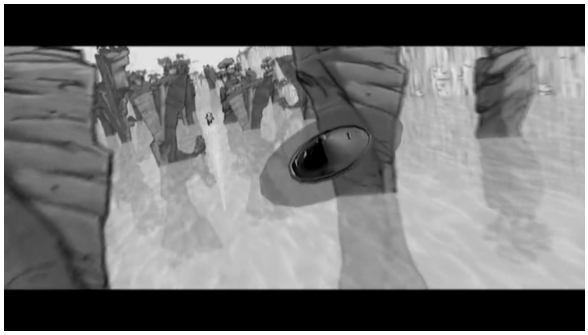

Fig. 002. Still frame showing 3D based storyboarding tool that relies on 2D illustrations shown in *The Pixar Story* by Leslie Iwerks on Netflix.

TV not only includes animation that also interfaces with a variety of styles that interweave 2D and 3D elements but also special effects (VFX) that may rely on crowd simulations, motion graphics, or particle effects that use 2D and 3D elements. Some shows that our survey participants (discussed below) worked on include the Fast & Furious TV shows, SpongeBob Squarepants, and Fairly OddParents. Some animators working in this space, such as Ian Worthington (Worthikids) or Nick Fox-Gieg [6, 18], contribute to short films which are distributed online through YouTube or Vimeo. Apart from consumer content, commercials and educational materials may also leverage hybrid animation either in the context of film-based animation or animated images that become interactive when viewed through a digital platform. Moreover, content that combines hybrid 2D and 3D animation exists on multiple distribution formats and channels from feature films to television, mobile content, web based content, dynamic images and social media, and video games. In sum, many exciting examples of media content that draw from both 2D and 3D animation are prevalent across several domains.

2.3 Behind-the-Scenes

Initially this work was prompted by the discussion and analysis of Leslie Iwerks' documentary *The Pixar Story* and the *Spiderman: Into the Spider-Verse Animator's Commentary* [1, 9]. Iwerk's film documents the development of Pixar as well as CG workflows and feature films executed entirely in 3D. There is an overarching theme of movement away from traditional animation. However, equally apparent is the strong necessary influence of 2D elements ranging from John Lasseter's storytelling background rooted in traditional animation to Pixar's internal storyboarding animation tool that places 2D illustrations into 3D environments developed for *The Incredibles* to better support the skills director Brad Bird and his core creative team's experience with *The Iron Giant* (see Fig. 002). Also, casual shots of workflows showcasing development on early films illustrate animators annotating CRT monitors already suggests the potential impact of 2D based workflows. Next, the animators' commentary for Spider-Verse highlights challenges that animators faced in developing animation to accompany the visual style of the film from developing spatiotemporally-consistent 2D ink lines to add expression on characters faces to animating at a different frame rate to create choppier, stylized motion.

2.4 Animation Tools & Workflows

An overview of several animation tools and workflows illustrates the variety of challenges and processes used to address some of the scenarios described above. Beginning with in-house production tools for animation studios, literature explains some of the challenges that Dreamworks, Disney, and Pixar have encountered in integrating 2D styles into 3D based pipelines. For instance, Dreamworks animation tool Premo, built in partnership with Intel, developed for *How To Train Your Dragon 2* and used in all pictures since then, features fully deforming characters, environments and lighting in real-time to provide feedback to animators [4]. The artist facing interface is enabled by an optimized graph management system to allow for "direct manipulation of full-resolution final-quality rigged characters, while seamlessly integrating 2D drawing and video as reference [7]." The look ahead evaluation system (Premo comes from premonition) supports real-time interaction and blends 2D references to develop 3D outputs.

Next, Walt Disney Animation Studios relies on proprietary tools and sophisticated algorithms built on a Maya foundation which includes key features like art-directable deformers and sculpting tools as well as detailed interfaces that rely on direct manipulation as the primary affordance [4]. Disney also has a custom tool Meander for combining 2D drawing projected onto 3D geometry used in the experimental shorts *Feast* and *Paperman*. Meander was motivated by an interest in leveraging the strengths of 3D workflows such as temporal and spatial coherence and precision with the more expressive and line-based aesthetics of traditional animation [16]. The tool begins with a traditional 3D CG pipeline and exposes a responsive 2D environment where hand-drawn strokes are attached to geometry and move based on vector fields derived from the 3D animation. Through this process, final artists create keyframes on top of CG renders and in-betweens are generated using motion fields. Several technical elements contribute to this result including rendering motion fields, creating "silhouette ribbons" that stay on the silhouette as geometry shifts, "motion pasting" hand drawn strokes from one frame into another, "motion betweening" curve interpolation via linear programming using corresponding sets of strokes identified by the artist, and combining elements of raster and vector graphics to create an efficient and editable representation of strokes [14, 16].

Also, as documentation is available, it is worth discussing the specific challenges in integrating hand drawn animation into the feature film *Moana* [10]. Hand drawn animation was present in two major aspects of the film. First, Maui's tattoos featured a supporting character that would interact with 3D based characters. Tattoo animations were completed on paper, scanned and painted using Harmony by Toon Boom then rendered and converted into animated textures bakes onto Maui's body mesh for interactive visualization so 3D animators would be able to work on interactions between 2D and 3D characters. The other workflow, using hand drawn animation to represent tapa that comes to life (tapa is a traditional cloth common in Polynesisan culture made from Mulberry trees), relied on Meander. While rough animation was done on paper, given the intricate art direction, it was more efficient for the clean up animator to author final lines using Meander.

While there is less literature available on Presto – Pixar's in house animation tool, the key modalities supported are direct manipulation and real-time feedback [8]. While Presto encompasses rigging, animation, layout and simulation, and provides features to work across multiple shots, the user interface (UI) is focused on animation and includes features such as embedded sketching [4]. Another recent extension for 2D based input is in a sketching tool for rigging. This "sketch to pose" functionality enables multiple modes where a 2D curve is used to deform a 3D rig with context-aware solvers based on both the rig set-up and curve representation that each animator chooses to use on a regular basis [13]. Some of these features are indicative of the benefit in using ideas from 2D animation such as guidelines as the integrated basis for creativity support in 3D content pipelines.

While several methods and tools support other media with hybrid 2D and 3D animation, we touch upon them briefly. These include cel-shading (an NPR technique used commonly in games to create a cartoon-like look with bold outlines), 2.5d matte painting (spatializing 2D textures projected onto 3D geometry), and performance capture. Some other tools such as Quill, Oculus's virtual reality (VR) animation tool, draw on ideas like onion skins from 2D animation for creativity support [5]. Also while our work focuses on animation in the context of film, it would be remiss to not mention tools that facilitate other animated content such as animated pictures. One such interface allows an artist to segment elements of a static picture to generate a kinetic texture that can interact with an image that can be further segmented based on depth to create depth cues for interaction [17]. For instance, balloons in an image can be selected, a motion vector can be indicated, and background and foreground elements can be identified to either obscure or be obscured by automatically generated elements of a moving texture.

One last tool worth exploring in depth on the basis of its increasingly widespread adoption is the Blender Grease Pencil. The tool provides a mechanism to create 2D hand drawn animation within a fully integrated 3D content production environment. More specifically, animators can draw free-form strokes that are not limited to a single plane in a 3D viewport [11]. The main benefits shared by the creators of the work are a non-destructive workflow that does not require transferring animation from paper to digital representation, leveraging 3D capabilities for camera position and poses that are challenging to execute in 2D alone, editing strokes instead of redrawing them, and integrating 2D drawing in a fully featured 3D content production system.

Many tools exist that leverage ideas from both 2D and 3D animation. There is a clear trend towards providing creativity support for both stylization and ease of use using ideas that originate in 2D to transform 3D workflows. Also, given the plethora of target outcomes current tools are predominantly designed to be task specific.

3 METHODS

Our aim was to engage in a process of co-production and ask experienced animators to share elements of their background, practice, and experience with tools in the context of making hybrid 2D and 3D animations. Our target community consisted of those with significant experience marked by completed projects. Several distribution channels were used including an art and computation mailing list, Facebook groups centered on animation, and reaching out to personal contacts in industry. The survey itself was divided into five sections: background & practice, 2D animation, 3D animation, tools, and wrap-up.

In more detail, the background & practice section relied on Likert-scale based questions to formalize the extent to which animators were trained in either 2D or 3D and the number of elements in their work that consisted of 2D or 3D animations. In addition, open-ended questions asked them to share their work as well as the goals of their projects and how they learned animation. Similarly, the 2D and 3D animation sections consisted of both open-ended and Likert-scale questions. Using the same format, one question in each section probed the applicability of each of the 12 fundamental principles of animation from character animation (Squash & Stretch, Anticipation, Staging, Straight Ahead Action & Pose to Pose, Follow Through & Overlapping Action, Slow In & Slow Out, Arc, Secondary Action, Timing, Exaggeration, Solid Drawing, and Appeal) [15]. Participants were also asked what they were animating in 2D (or 3D) and why or how they might like to apply 2D (or 3D) beyond their current practice.

In the tools section, participants were asked to respond to a series of questions with respect to two distinct tools that they most commonly use and their respective affordances. Based on industry pipelines, we hypothesized that commercially available end to end 3D content production tools may be insufficient for hybrid 2D and 3D animations and that tools would commonly be used in conjunction with one another. Also presenting questions with respect to multiple tools might prompt some degree of internal calibration. Instead of limiting participants based on pre-selected tools, our aim was to generate an "in-the-wild" result to understand the range of tools and affordances used in current practice and distill any emergent cohesive themes [2]. Again through a combination of open-ended and Likert-scale questions, participants were asked about the expressivity, tinkerability, and learnability supported by each tool, the input modalities that they most commonly relied on in working with each tool (e.g. coding, direct manipulation), and the most useful features of each tool.

Finally, in the concluding section of the survey, participants were asked if they might share what would constitute a dream animation tool and if they would be open to a semi-structured follow-up interview. One semi-structured interview was scheduled with Dmitry Shkylar based on his role as the pipeline Technical Director in charge of the 17 minute sequence that heavily leverages hybrid hand drawn animations in *Mary Poppins Returns*.

4 RESULTS

4.1 Background & Practice

In total, eight responses were received. Contributors had varying backgrounds and included a hobbyist focused on game development, professional animators at Dreamworks Animation, an artist trained as a stop motion animator, and an engineer working on developing a VR animation tool at Oculus.

With respect to training, six out of the eight responses included that they at one point learned animation in a formal setting such as majoring in animation. However, there were significant discrepancies indicated in their formal training. It is worth noting that one participant who majored in animation shared went to school for it at a time when "there were no computers involved nor was computer animation being taught." Another shared being trained in stop-motion animation. While most indicated studying animation in college, one respondent shared they went to Animation Mentor, a boot-camp style animation school based in Emeryville, California. Only one respondent indicated being self taught through "mostly from online tutorials."

There was a wide divergence in the extent to which training primarily focused on 2D or 3D animation. A similar pattern was evident in seeking how many elements in participants' work consist of 2D and / or 3D animation. One mapping explored was the relationship between the focus of their training on 2D and 3D elements versus the percentage of elements in their work that involved 2D and 3D animations (see Fig. 003). One participant indicated that their current project has 2D elements that are handled by another animator and shared that the balance of 2D and 3D elements fluctuates over time.

4.2 2D Animation

The next section focused on experience with animating in 2D. Elements created in 2D included 2D character animation, 2D motion graphics, particle effects (such as smoke, cloud, fire), crowds to reduce scene complexity, and animation tests for work in 3D. Motivations ranged from ease of use, strictly using 2D as a form to explore ideas for 3D, production style requirements to reducing complexity in 3D environments. One participant indicated that working in 2D was useful for elements that "need to be expressive or change radically from one frame to another." Participants were also asked to indicate the applicability of the 12 fundamental principles of character animation in their 2D work (see Fig. 004). When asked how they would expand their use of 2D animation beyond their current practice, participants shared interest in more hybrid work for film stylization, using 2D animation as input modality for 3D work (i.e. "fully 3D hand-drawn animation"), using 2D animations for diagrams, prototypes, and educational materials (i.e. "use visuals to explain an idea/concept or to illustrate a lesson"), and to expand the depth of their own practice by exploring different visual styles through work in 2D.

4.3 3D Animation

With respect to work in 3D, participants shared animating crowds, motion graphics, capturing different camera angles for "live action" shots and building complex worlds for feature films ("[e]verything" as one shared). Their work was motivated by their enjoyment of working in 3D as well as "solutions and efficiencies that aren't always available in 2D" citing examples like "a solid rigid object." Again, participants ranked the frequency with which the 12 fundamental principles of character animation appear in their 3D work (see Fig. 004). Many also had ideas for how they would like to extend using 3D animation beyond the confines of their current practice. One participant wants to see 2D machine learning-based image processing techniques made accessible in 3D animation workflows. Others shared interest in creating NPR stylizations of animations or extending their practice into other domains such as education, independent game development, and augmented reality (AR) / VR applications.

4.4 Tools

In responding to their experience with tools, participants not only relied on multiple platforms (ranging from 2D work in pencil and paper or stylus input on a tablet to desktop native applications) but also engaged with a wide variety of tools. Some tools mentioned included (in alphabetical order): 2D proprietary software at Dreamworks, 3ds Max, After Effects, Blender, Harmony (ToonBoom), Lightwave3D, Maya, Moho, Pencil Paper, Premo (Dreamworks proprietary software), Procreate, Proprietary(?), Rough Animator, and Unity. One visualization shows the number of times each tool was mentioned (see Fig. 005). In analysis, only one tool per answer supplied was used based on the response (e.g. if Tool 2 was pencil paper and Dreamworks 2D software, the response details are indicated as being relevant to pencil paper). Also given that it was not feasible to disambiguate which proprietary software was referred to by one participant, applicable responses are marked by Proprietary(?).

Participants were also to share the manner in which they work with a tool. Unfortunately, the first three responses were not usable as there was an error in the survey set-up requiring a selection on each row. The visualization of these properties (easy to try out new ideas, lose track of time when working, process leads to new ideas, coding, adjust parameters (x = 10), direct manipulation (moving a vertex) indicates valid responses based on each tool (see Fig. 006). Please note that the property "lose track of time when working" was used as indicator of flow based on the idea of optimal productive engagement developed by Mihaly Csikzentmihaliy [3], and the property "process leads to new ideas" was used as indicator of reflection in action based on Donald Schon's work on engineering design workflows [12].

Visualizations were used to explore Likert-scale rankings in terms of how expressive a tool may be (I'm limited to a specific style / genre / set of outcomes to I can express any idea I have), how much abstract understanding versus tinkerability the tool supports (I need to have a theoretical understanding to I can arrive at the desired result through experimentation), and how learnable a tool may be (easy to learn to very challenging). The visualization showcases the properties of the tools in juxtaposition with one another (see Figs. 007, 008, 009). Note that multiple scores, when available, for each tool were averaged.

Then, participants shared open ended reflections regarding their tools of choice. Participants indicated using particular tools for a variety of reasons ranging from the tool supporting their ability to develop and engage with their practice, being compatible with industry pipelines, being a requirement for a specific show's workflow, having a large degree of expressivity ("flexibility and potential"), being complimentary with another tool of choice ("Tool 1 makes the raw material that feeds into Tool 2"), and supporting learnability and exploring creative possibilities. Some motivations for using specific tools included the following:

Fig. 003. Visualization of the percentage of training (informal or formal) involving animation focused on creating 2D animations and 3D animations versus the percentage of elements in their work that have 2D or 3D animation. Each participant is indicated with the same color for both 2D and 3D.

- Paper & Pencil: “it’s fun to draw on paper”
- Moho: “intuitive program to animate in”
- After Effects: “wide range of styles”
- Premo: “intuitive”; “Premo is a real time animation tool. There is no lag, playback problems etc. which makes it better than all other animation software tools available”

When asked what they would change about a particular tool, participants indicated an interest in having instant feedback available, updating software to make it feel more current, and changing the user interface to make it more intuitive. Notably, improving viewport renderers or making feedback renders instant were requested on three different tools. Some offered other, specific elaborations on select tools as follows:

- After Effects: “After Effects does not have a very good native curve deformer like Harmony”
- Blender: “faster conversion of Grease Pencil into meshes, also voxelized so nothing is wasted in the interior of the object”
- Unity: “a sturdy timeline that works as smoothly as Premiere or Final Cut”
- Maya: “make maya more intuitive and robust based on what an animator needs and how an animator works”
- LightWave3D: “make use of more current technology”
- 3DS Max: “more intuitive interface like Unreal Engine’s blueprint interface for animations”

Finally, participants shared their ideas for dream tools to create animations. Ideas focused on input modalities as well as features for interacting with animations within the workflow. Two participants indicated interest in using camera input to act out either poses or faces to set up starting points for animating rigs. One shared the idea of a stylus that encodes six degrees-of-freedom (DoF). With respect to supporting interactions within a pipeline, one mentioned wanting to use a “headset-free autostereo device like Looking Glass." Others shared adding a drawing engine to Harmony Toon Boom and adding easy rigging perhaps through a VR based tool to Moho. Two added their reflections on what would constitute a more useful tool: “less technical, more interactive; ie. less formulas/values, more visual, direct manipulation” and ““the best animation tool is one that does the majority of the hard work and gives the artist room to push the poses / timing as needed.”

5 CASE STUDY: A CONVERSATION WITH DMITRY SHKYLAR

5.1 Background & Experience with *Poppins*

We had the opportunity to interview Dmitry Shkylar, a Technical Director at Dreamworks Animation, who was also the pipeline Technical Director at Duncan Studios for the hand drawn animation sequence featured in *Mary Poppins Returns*. He had a an atypical career trajectory starting off as an embedded systems developer for Leapfrog, a Chile Software. During the 2008 financial crisis, he

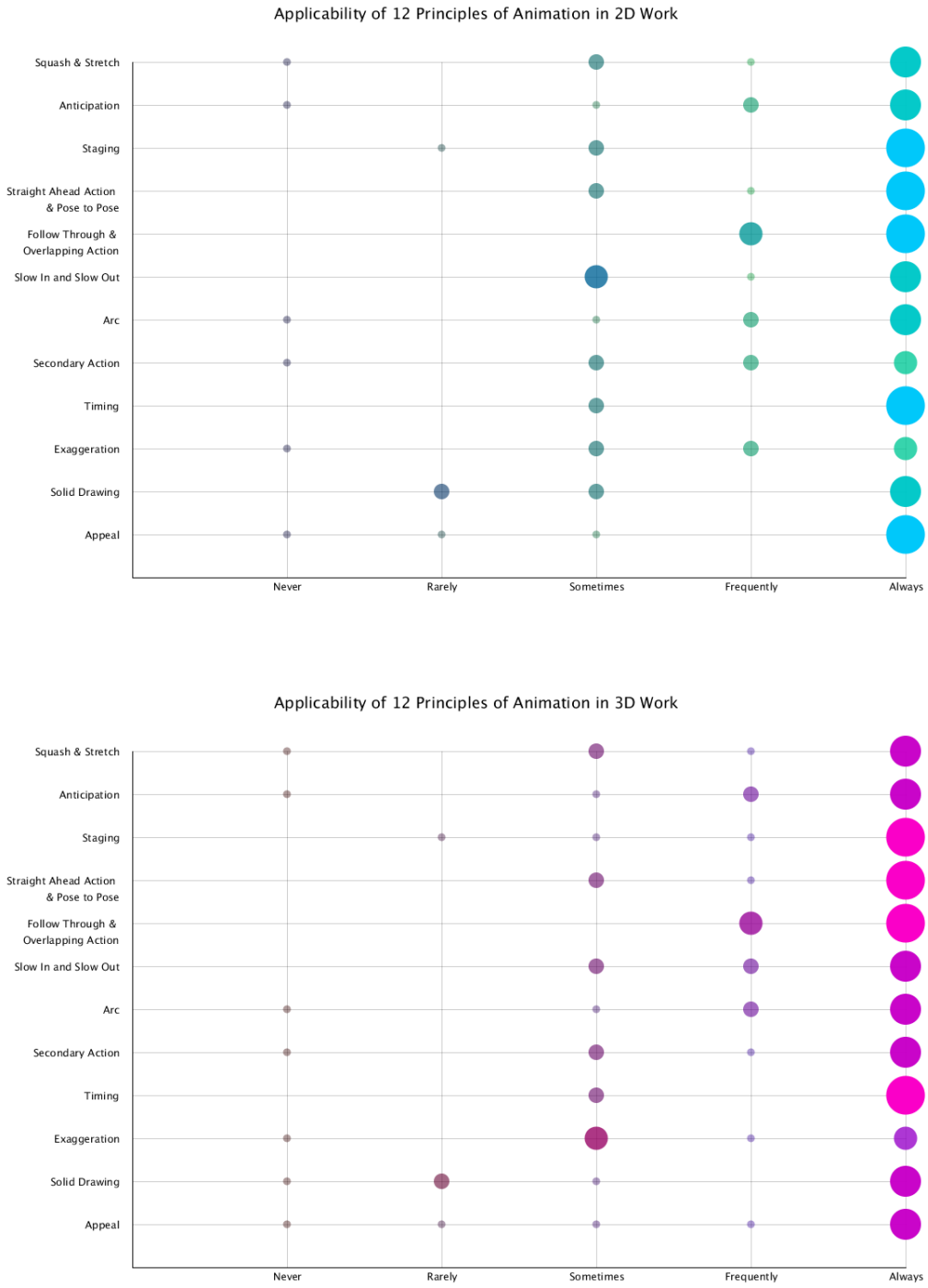

Fig. 004. Applicability of 12 fundamental principles from character animation to 2D work and 3D work in hybrid contexts where size of circle indicates amount of overlap in responses.

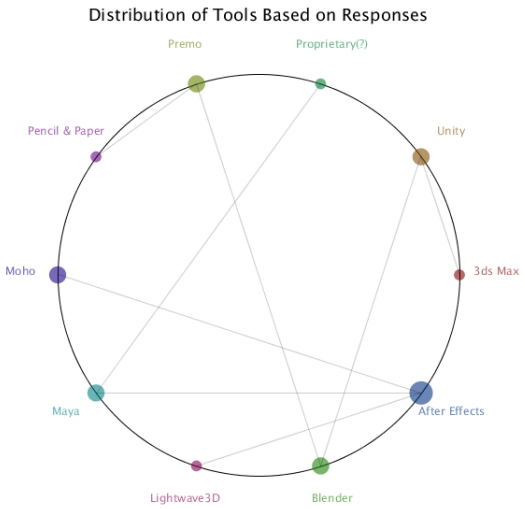

Fig. 005. Lines between tools indicate tool 1 and tool 2 for a given participant and the size of the accompanying circle represents the number of answers received pertaining to each tool.

started realising his true interest in film and began working on his computer graphic portfolio. From Chicago, he found his way to Hollywood by accepting a job at Dreamworks Animation as a lighting technical assistant. This role combined technical skill as well as artistry in lighting. He enjoyed this combination, but his promotion ladders only supported one or another. This lead him to his role at Duncan, a 2D animation studio, where he was once again able to merge technical experience and artistic in developing and managing the pipeline for the hand drawn animated sequence mixed with live action shots in *Mary Poppins Returns*.

The unique storytelling and feedback requirements of combining live action with 2D animation in *Mary Poppins Returns* prompted Shkylar to create an original pipeline. He relied on a traditional VFX workflow. Unlike a traditional animation film, multiple studios were involved. This workflow included filming each live action sequence on green screen stages, scanning the stage using LIDAR and recording camera tracking at Framestore's London studio and then shipping all of this collected data to Duncan where it was integrated into Maya. Using the information provided, each shot was tracked seamlessly. The LIDAR scans created the geometry of the stages and 2D visual development artists followed up with hand painting each background. These paintings were projected onto the 3D geometries. The team at Duncan also received a color transform file and camera distortion file that were used to ensure live action and animated characters perceptually appeared to occupy the same color space. Their composites in Nuke were sent back to Framestore's Canadian studio for final color grading. Shkylar and his team were able to create systems to automate these tasks so each shot would be rendered for dailies (daily review of filmed footage for review by the production management). This system was entirely coded by Shkylar with input from his VFX supervisor. Since this work, others have made this code more general and have used this type of pipeline in other notable works.

Shkylar discussed the challenges and successes of this pipeline. He mostly had positive comments about being able to reach deadlines because details such as shot names and frame ranges were tightly integrated in the production management software Shotgun by the production staff. The centralized organization helped streamline the work. One of the challenges he shared in managing many pipelines is using off-the-shelf software packages. Specifically on *Mary Poppins Returns*, each department had to lock down different versions of Maya, because annual releases are not back patched, which can result in minor but significant changes that impact work at various stages in the pipeline. These software updates are generally challenging especially at large studios such as Dreamworks because new versions need to maintain functionality integrated with proprietary tools.

5.2 2D & 3D Practices, Challenges, & Future

Shkylar discussed a number of films and works that incorporate the hybrid of 2D and 3D storytelling. Specifically, Shkylar highlighed some recent Anime films such as "Weathering with You" and "Your Name" that use 3D to spatialize 2D sets. These films used 2D textures projected onto 3D geometry, which add depth and contribute to sense of immersion. Next, he underscored the importance of story driving each technical detail. The general perspective that artists and technical directors have is making sure everything is in service to the story. At every step in the film pipeline, each person must constantly think about how their emphasis in each particular shot contributes to the story element of that shot. Hybrid 2D and 3D methods provide another means to direct audience focus. Shkylar further elaborated on how lens size creates a specific tension or scenic environment, and how relying on traditional cinematography methods has impacted animation. Roger Deakins, a prominent live action cinematographer, started consulting on these different projects where he brings in live action sensibilities. In a contrasting manner, Shkylar's background in learning computer graphics taught him that having anything that is absolutely black will look wrong in a film, but after working with Deakins, he was encouraged to incorporate those elements which were then included in the *How to Train Your Dragon* movies and contributed to their overall look.

There are many challenges in developing 3D work informed by 2D styles. In particular, non-photorealistic rendering (NPR) to support a certain look is not supported by off-the-shelf tools. Individual studios, though, have customized their own solutions. One way to support an NPR look is to integrate toon shaders and other non-photorealistic styles within a renderer. However, this will require custom tailoring or writing new systems since most physically-based renderers are not as extensible. Shkylar referenced "The Lego Movie" where the original goal was to use Pixar's proprietary software Renderman, but given the high render times in tests, the team realized they would quickly exceed the film's rendering budget. So, the company pivoted to using their own rendering system. Animal Logic created and implemented a renderer optimized for Lego brick intersections and the specific scattering algorithms that contributed to the desired look for the film. The main challenges posed

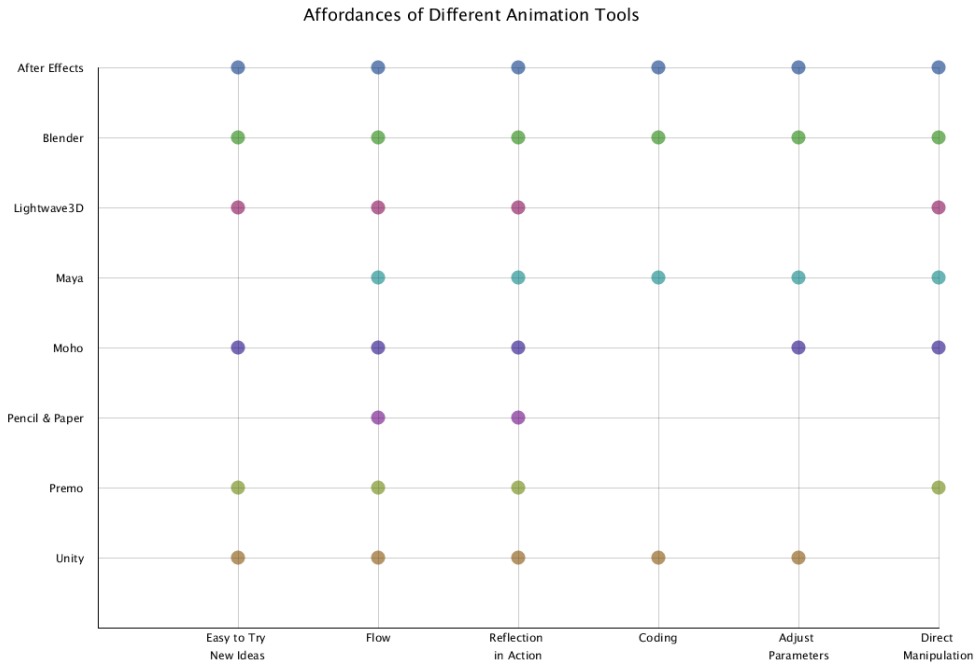

Fig. 006. Properties applicable to participant's experience with each tool.

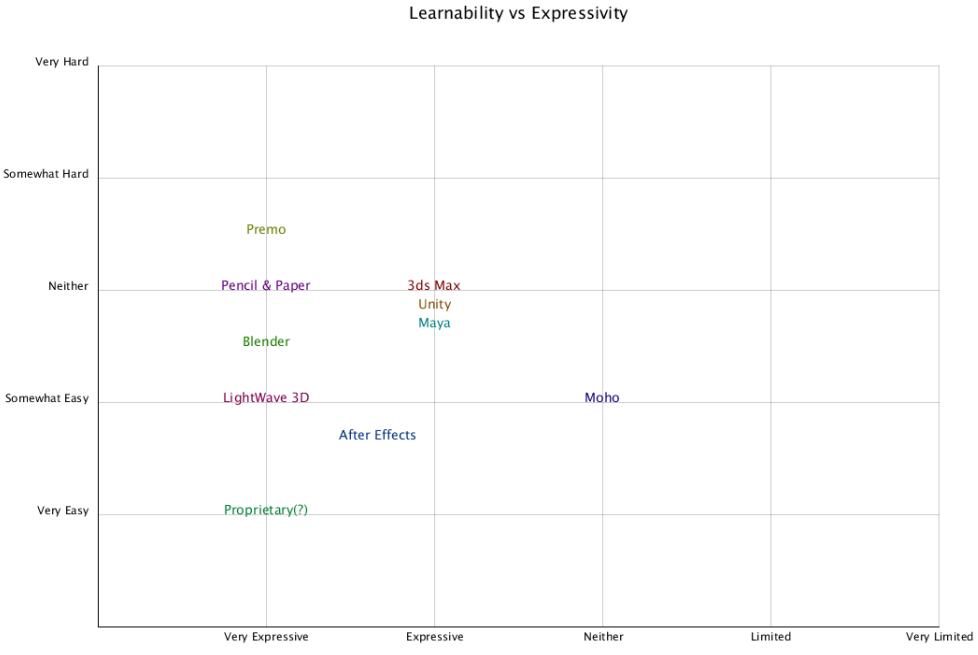

Figure 1: Fig. 007. Tool mappings of learnability versus expressivity.

Fig. 008. Tool mappings of tinkerability versus expressivity.

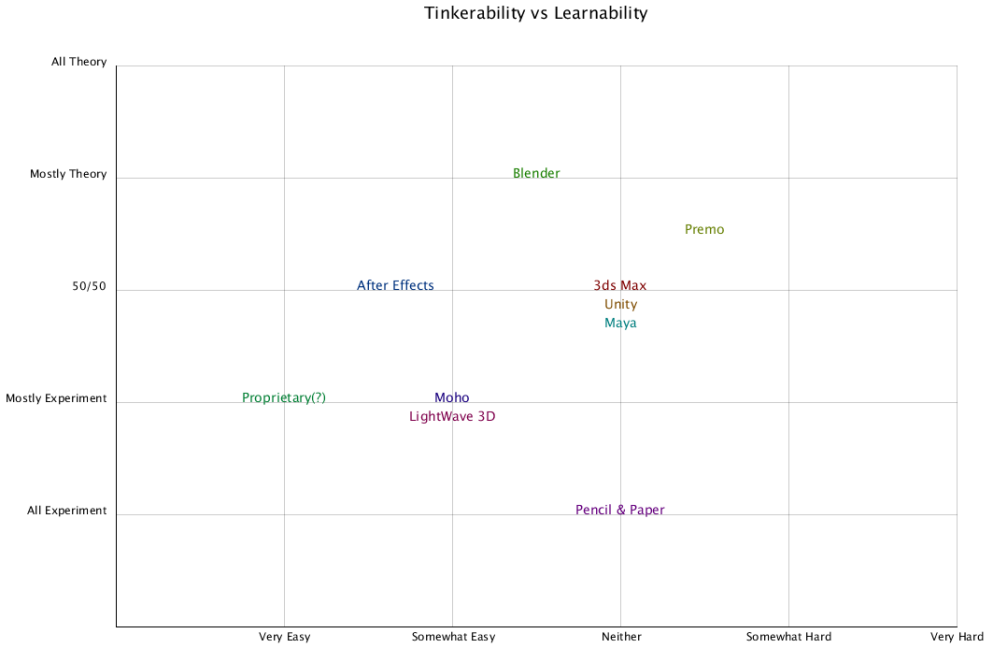

Fig. 009. Tool mappings of tinkerability versus learnability.

by animation were to create custom rigs to support Lego like movement, deformation, and spawning Lego blocks in a way that would simulate motion blur.

Besides understanding how to render 2D and 3D work as well as support novel visual styles through innovations in animation, another challenge is that many of the practicing 2D artists are Disney veterans from the 80's and 90's. As more people are focused on creating 3D animation, 2D skills are not being passed down to the younger generations. This could lead to these skill sets fading. Students learning 2D animation are taught with a focus on storyboarding or TV where the practice of refining a shot is less applicable as tighter deadlines mean shots can only be rendered a couple of times. The Disney veterans understand how to develop a shot to the highest degree and consistency. For instance, when tasked with lighting for eyes and teeth, shots take extensive refinement. This skill is not picked up in school and instead would have been learned on the job. Shkylar mentioned that art direction involving significant 2D animation might lead to difficulties in even staffing a show.

Although there are significant obstacles facing the development of hybrid 2D and 3D animation, Shkylar shared that he has not been this excited about the industry in quite some time. As the previous holy grail of physically-plausible CG has become attainable and studios are looking to differentiate themselves in other ways, Shkylar wonders if there will be an increase in cross-pollination of 2D ideas in 3D work. Physically-plausible looks use to be the gold standard because of the desire to recreate photorealistic looks, but now with the dramatic increases in computing capabilities, almost every film is able to look physically-plausible. As people develop NPR styles, ideas from 2D may increasingly inform animation as a practice. The recent 2018 film "Spider-Man: Into the Spider-Verse", received fantastic reviews and the development process revealed many instances of borrowing ideas and modalities originating in 2D to inform the final look of film. In the next three to four years (the length of production cycle for animated films), Shkylar predicts many more NPR and stylized films.

Overall, Dmitry Shkylar discussed his background and experience in working on a film where there is a hybrid of 2D and 3D, but also how hybrid styles are providing new ways to set films apart and create a new avenues for storytelling.

6 ANALYSIS

6.1 Background & Practice

First, we consider our results on background & practice. While most participants were trained formally, there was a wide divergence in the types of training they received as well as perceived relevance to their practice. In particular, it seems that some ideas in animation are universal and learning in one domain can be applied to other specific sub-genres. As one participant shares "2D teaches a lot of fundamentals (principles and draftsmanship) that carry over to 3D - even if the work is in 3D, principles that inform the work are still mostly taught traditionally (2D)."

Not only is on-the-job training valuable, but animators also indicate that a core set of principles exist that can be applied in multiple contexts. This suggests that the process of making informs learning and that the same principles should be visible and clearly art-directable in animation tools and pipelines. Also, animators may be able to extend their experience across a wide set of tools and sub-genres into new work. This may translate into less time needed for re-training on tools and indicate a viable, broader audience that may be able to utilize either versatile or specific tools once connections to known methods from their domain of experience are illustrated. Perhaps, animators for hybrid 2D and 3D animation can be drawn from a wider set of practitioners without requiring tool-specific or even 2D or 3D specific training. Lastly, one participant discussed a collaborative set-up with one animator focusing on 3D elements and the other focusing on 2D elements. This suggests a collaborative workflow that may be useful to support in the context of hybrid projects.

Overall, the visualization of 2D and 3D training and elements in their work shows that animators tend to be trained in 2D, but have more 3D elements in their actual practice (see Fig. 003). This could be because it is easier to conceptualize 2D animation when first learning, but once knowledgeable about the different techniques it is easy to transfer that knowledge into a 3D space which supports more complex shots.

6.2 2D Animation

Participants' work in 2D showcases the wide variety of applications of 2D animation in context of hybrid work. Application domains ranged from traditional character animation for narrative films to reducing complexity for game development. Additional effects such as particle systems or motion graphics that could apply to dynamic images were also discussed. Tools and pipelines must address the wide variety of outcomes and uses that are intended. This might be achieved in one of two ways. On one hand, a tool could support animating in 2D for hybrid work in multiple contexts. On the other, tools and pipelines could be customizable or re-configurable based on the target work.

The range of responses regarding the applicability of the 12 fundamental principles of animation were unexpected (see Fig.004). Respondents felt strongly about the relevance of the principles in terms of whether or not they are context dependent or universal irrespective of the tool or medium. It is worthwhile noting as is seen in the visualization that secondary action and exaggeration seem to play a less significant role in 2D animation whereas timing in addition to follow through and overlapping action seem to be the most frequently applicable. This could help with ordering exposure in an interface and supporting features that correspond to each principle in a given tool or pipeline.

2D is also notable in that half the participants shared using 2D primarily for look development in terms of either transforming visual style or exploring opportunities for work to be later executed in 3D. Many participants indicated a strong interest in expanding the use of 2D animation in exploratory contexts: "I only use 2D as a tool to explore ideas for 3D animation," "to explore the characters and their style of movement," for "[e]exploring different style looks and technical executions." Another participant underscored the expressivity of 2D animation especially for rapid changes between frames. This suggests a 2D interface could be leveraged for its usefulness in rapid development as indicated by its expressivity and ability to support exploration. In this manner, a 2D tool could serve

a dual function as a self-contained domain as well as a launching point for hybrid or strictly 3D work. For instance, recall the storyboarding tool introduced in *The Pixar Story* which relies on layered 2D animations [9] or the embedded 2D reference materials that are made accessible in Premo [7].

6.3 3D Animation

The range of projects in 3D showcases the industry standard of using 3D to animate entire worlds. Beyond "characters, animals, props," 3D is also used for motion graphics, camera simulations, and crowd simulations. As 2D facilitates dynamic and expressive exploration, 3D facilitates spatial robustness and efficient animation suggesting the benefit of combined workflows that enable animators to work with both representations. Similarly, the various elements animated in 3D work also support the idea of using simple re-configurable pipelines based on the target outcome.

The most surprising element about the applicability of the 12 fundamental principles of character animation with respect to 3D is the striking resemblance of the data to the applicability of those principles in 2D (see Fig. 004). This may derive from the observation, as shared by some participants, that they were able to extend their training from 2D into their 3D work or from the other point emphasized by many that the 12 principles are fundamental and therefore always applicable irrespective of the workflow. In the latter case, these visualizations may only support the extent to which the principles are relevant which may vary according to context. However, as mentioned above, this could guide which principles should perhaps be most visibly supported and easy to engage with in a given interface or pipeline.

Two significant themes emerged from asking participants how they might want to extend their practice in 3D animation. Firstly, several were keen to apply their ability to create 3D animations to other creative domains and explore animating in the context of AR / VR, game development, and educational projects. This suggests that tools that enable more diverse outputs could support work for multiple platforms and expand the media content available in multiple industries as there is already an audience able to engage with common interfaces. Secondly, multiple participants indicated growing interest in NPR style animation highlighting its increasing importance and perhaps even its prevalence in years to come. Supporting NPR animation in commercially available tools and pipelines may enable experimentation, look development, creativity, and production at a wider scale than the scenario in which those affordances are limited to in-house production tools of major entertainment studios. Also creating idioms or means to easily adapt current working styles to creating NPR stylized animation could be helpful for the animation community.

6.4 Tools

First, the visualization showing the usage of each tool indicates the diverse preferences and practices of the survey respondents (see Fig. 005). It is easy to see that After Effects is the most common and that some tools such as Blender, Maya, Premo, and Unity are also prevalent. It is also interesting to note amongst the affordances supported by each tool that those with the greatest number of users based on the distribution of responses also support almost all the properties evaluated (see Fig. 004). Furthermore, all the tools indicated a high level of engagement where practitioners lose their sense of time when working with a tool. This indicator of flow may derive from the work itself which is unimpeded or equally absorbing across different interfaces. Similarly, across all tools, respondents shared that the process of working leads them to new ideas. Again this may be attributed to the dynamic nature of animation as opposed to the affordances of any particular tool. It may be worth investigating which specific features contribute to difficulty or ease in trying out new ideas. Also, it is worth emphasizing that respondents were asked to answer based on the manner in which they themselves interacted with a tool as opposed to indicating whether or not the tool might support a specific feature (for instance, Unity does support direct manipulation through manually adjustment of a rig). We note that several respondents indicated using coding to achieve their desired result as opposed to strictly relying on adjusting parameters or direct manipulation of objects on screen. This suggests exposing programming or alternative (non-textual) programming may be useful to support when designing workflows to help artists reach desired results.

Examining learnability versus expressivity (see Fig. 007), we observe that most tools are considered to be very expressive. There seems to be a subtle trend indicating that more expressive tools may be easier to learn. This may follow from the fact that it is possible to match a desired intention to an outcome, and developing fluency and ease of use with the tool is correlated to the outcomes one feels capable of creating. With respect to expressivity, multiple participants shared their perspective that it is the role of the animator or artist to achieve a desired outcome or create a means for expression irrespective of the capacity of a particular tool: "The artist is what determines how expressive they are. Not the tool." This interpretation of tying expressive capacity to skill may also contribute to why many of the tools were assessed to be very expressive rather than pointing towards features of the tool that may contribute to the artist's ability to be expressive in the context created by the tool.

With respect to tinkerability versus expressivity (see Fig. 008), we note that workflows depend largely on a balance between relying on abstract understanding and leveraging experimentation. Participants again shared that the role and responsibility of the artist is to determine the means to achieve a desired outcome. One noted that having a robust understanding of the theory enables one to succeed in obtaining an outcome that matches an original intention. It is interesting to note that the tool that enables the greatest degree of experimentation and is the most expressive is pencil paper. Given that the medium involves risk (considering the affordances (see Fig. 006), it was noted that it is not easy to try out new ideas with pencil paper), it is surprising that tinkerability is most supported in a workflow using paper. Perhaps paper has a disposable quality that encourages risk-taking or trial and error.

Finally, in considering tinkerability versus learnability (see Fig. 009), there is a subtle emergent trend between the tinkerability and learnability of a tool. In other words, the extent to which experimentation can be used to determine outcomes seems correlated with how easy it is to develop familiarity with a tool. This trait might be useful for animation tool designers when they consider the user experiences they want to target and the degree to which

experimentation, or tinkering, is supported. Also, most tools were marked as being easier to learn indicating either transference based on familiarity with tools that rely on exposing similar processes or intuitiveness.

Participants' motivations for using particular tools encompassed four main areas: intuitiveness, enjoyment, expressivity, and context based fit. These were all precipitated by reactions to the depth of engagement permitted by the tools. For instance, practitioners valued being able to explore multiple creative possibilities and interact with real-time feedback. They also appreciate seamless workflows with industry pipelines or job based necessity requiring the use of a tool. The key observation is that a tool was considered appealing based on features that permitted an animator to increase the depth and immersivity of their practice. This points to an element of empowerment that is a critical element of all computational creative support tools. Tools that enable practitioners to do more with their practice beyond current constraints and apply their work directly in multiple contexts may draw greater usage.

In highlighting desired modifications for how they accomplish a current task in interfacing with one of their most commonly used tools, participants revealed two themes. First, there is an interest in borrowing from successful interfaces in adjacent domains and other animation tools in order to increase the efficiency and intuitiveness of tools they commonly use. Perhaps, standardization across computational creative tools by establishing common idioms and best practices may help better determine the locus of effective creative interfaces. Second, improving the quality of feedback renders by either adding instant feedback rendering or improving an artist viewport renderer emerged as a significant theme. As noted in the properties of workflows, the process of working leads to new ideas. As reflection in action seems to constitute a major component of this practice, providing a means for reflection and supporting immediate feedback may help improve creativity in this domain.

Participants also shared what would constitute their dream tool. Their comments precipitate a discussion on what the role of the animator should be and showcased a desire to work with a greater degree of interactivity. It is worth investigating what starting points can be used to generate poses that can be fine tuned along with timing. For instance, webcam input and 6 DoF stylus both enable more efficient input. A headset-free stereo device or VR based rigging tool would also enable more feedback and provide an opportunity for direct manipulation. All in all, workflows that create a more immediate sense of engagement and lay the foundation for extracting greater emotion and story out of a sequence while minimizing groundwork may be the most compelling to work with.

7 FUTURE DIRECTIONS

While our analysis has yielded some concrete results to guide the development of tools pipelines that support integrating 2D and 3D animation practice, one the primary intentions of this work is to identify future lines of inquiry in this space. As a starting point, what constitutes animation varies according to each practitioner. As one of the major suggestions for pipelines is developing reconfigurable workflows, it may be worthwhile extracting some of the definitive distinctions between sub-genres. Extending this line of reasoning, a future goal may be to delineate what the role of the animator is to provide a better basis for tool functionality and abstract away work that is considered tedious or unnecessary.

Another significant theme is the use of 2D via direct manipulation as an input modality to facilitate creativity support. More research into the ways ideas from 2D such as onion skins or curve deformation can be exposed in interfaces may facilitate the cross-pollination of 3D animation with 2D practice. One particular area applying hand drawn strokes in 3D content pipelines seems to have reached a mature state of development in tools such as Meander and Blender Grease Pencil. It may be worth analyzing the spectrum of design possibilities achieved by these tools and their limitations. Also, the manner in which 2D and 3D elements interact and influence one another is ripe for further exploration.

Finally, the growing interest in NPR dominates much of the conversation of hybrid 2D and 3D work. Several directions for future work emerge include: identifying a means to set up and animate rigs in a style that compliments the intended NPR look, exploring the design space enabled by NPR to see if projects converge or remain stylistically distinct as well as the extent to which current tools support look development, and lastly investigating how the principles of animation can pushed to further NPR styles that leverage the expressivity of 2D craft.

8 CONCLUSION

While our work was limited based on the number of responses and, in terms of in-house production tools, only provided data from some participants familiar with the Dreamworks Animation tool Premo, we have provided concrete objectives for developing tools and pipelines to support hybrid 2D and 3D animation, shared the results and insights from our in-depth conversation with technical director Dmitry Shkylar, and identified overarching themes in the space of combining 2D and 3D animation that are discernible. Two major directions are present. First, ideas originating in 2D and direct manipulation constitute an input modality provide efficient, artist friendly interaction in the context 3D pipelines. Secondly, there is a growing interest in creating NPR stylizations where 3D work will be cross-pollinated with practices originating or strongly influenced by 2D craft. So, even though traditional hand drawn animation may be less prevalent as a stand-alone style, hybrid 2D and 3D animation will increasingly shape the discipline moving forward.

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REFERENCES

[1] 2019. *Spider-Man: Into the Spider-Verse Animator Commentary.* https://archive.org/details/animator_commentary_spiderverse

[2] Leah Buechley and Benjamin Mako Hill. 2010. LilyPad in the Wild: How Hardware's Long Tail is Supporting New Engineering and Design Communities. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (Aarhus, Denmark) *(DIS '10)*. Association for Computing Machinery, New York, NY, USA, 199–207. https://doi.org/10.1145/1858171.1858206

[3] Mihaly Csikszentmihalyi. 1991. *Flow: The Psychology of Optimal Experience.* Harper Perennial, New York, NY. http://www.amazon.com/gp/product/0060920432/ref=si3_rdr_bb_product/104-4616565-4570345

[4] Paul DiLorenzo, Matthew Gong, Fredrik Nilsson, Martin de Lasa, Warren Trezevant, Evan Goldberg, Cyrus A. Wilson, and Rob Jensen. 2014. State of Animation Tools in the Industry. In *ACM SIGGRAPH 2014 Panels* (Vancouver, Canada) *(SIGGRAPH '14)*. Association for Computing Machinery, New York, NY, USA, Article 6, 1 pages. https://doi.org/10.1145/2614208.2615530

[5] Facebook. 2020. Quill. https://quill.fb.com/

[6] Nick Fox-Gieg. 2020. NFG: short films. https://fox-gieg.com/jenny.html

[7] Matthew Gong, Fredrik Nilsson, Alex Powell, Jason Reisig, Alex Wells, Stuart Bryson, Esteban Papp, and Paul DiLorenzo. 2014. Premo: A Natural-Interaction Animation Platform. In *ACM SIGGRAPH 2014 Talks* (Vancouver, Canada) *(SIGGRAPH '14)*. Association for Computing Machinery, New York, NY, USA, Article 3, 1 pages. https://doi.org/10.1145/2614106.2614123

[8] Pixar Graphics. 2014. Presto demonstration at NVIDIA's GTC conference. https://vimeo.com/90687696

[9] Leslie Iwerks. 2007. The Pixar Story. https://www.netflix.com/title/70083532

[10] Kim Keech, Rachel Bibb, Brian Whited, and Brett Achorn. 2017. The Role of Hand-Drawn Animation in Disney's Moana. In *ACM SIGGRAPH 2017 Talks* (Los Angeles, California) *(SIGGRAPH '17)*. Association for Computing Machinery, New York, NY, USA, Article 3, 2 pages. https://doi.org/10.1145/3084363.3085079

[11] Joshua Leung and Daniel M. Lara. 2015. Grease Pencil: Integrating Animated Freehand Drawings into 3D Production Environments. In *SIGGRAPH Asia 2015 Technical Briefs* (Kobe, Japan) *(SA '15)*. Association for Computing Machinery, New York, NY, USA, Article 16, 4 pages. https://doi.org/10.1145/2820903.2820924

[12] D. A. Schön. 1992. Designing as Reflective Conversation with the Materials of a Design Situation. *Know.-Based Syst.* 5, 1 (March 1992), 3–14. https://doi.org/10.1016/0950-7051(92)90020-G

[13] Ryan Stelzleni, Bret Parker, Tom Hahn, Sarah Shen, Dan McGarry, and Chen Shen. 2015. Sketch to Pose in Pixar's Presto Animation System. In *ACM SIGGRAPH 2015 Talks* (Los Angeles, California) *(SIGGRAPH '15)*. Association for Computing Machinery, New York, NY, USA, Article 26, 1 pages. https://doi.org/10.1145/2775280.2792583

[14] Walt Disney Animation Studios. 2020. Meander. https://www.disneyanimation.com/technology/innovations/meander

[15] F. Thomas and O. Johnston. 1995. *The illusion of life: Disney animation.* Hyperion. https://books.google.com/books?id=2x0RAQAAMAAJ

[16] Brian Whited, Eric Daniels, Michael Kaschalk, Patrick Osborne, and Kyle Odermatt. 2012. Computer-Assisted Animation of Line and Paint in Disney's Paperman. In *ACM SIGGRAPH 2012 Talks* (Los Angeles, California) *(SIGGRAPH '12)*. Association for Computing Machinery, New York, NY, USA, Article 19, 1 pages. https://doi.org/10.1145/2343045.2343071

[17] Nora S. Willett, Rubaiat Habib Kazi, Michael Chen, George Fitzmaurice, Adam Finkelstein, and Tovi Grossman. 2018. A Mixed-Initiative Interface for Animating Static Pictures. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) *(UIST '18)*. Association for Computing Machinery, New York, NY, USA, 649–661. https://doi.org/10.1145/3242587.3242612

[18] Ian Worthington. 2020. Worthikids. https://www.youtube.com/channel/UCxXu9tCU63mF1ntk89XPkzA

SUPPLEMENTARY

Survey Questions

Our full survey can be accessed here: http://bit.ly/mat594x2d3d.

Interview Structure

.0.1 Objectives.

(1) Understand what workflows / processes are used to combine hybrid 2D/3D animations.
(2) Learn more about the role / potential of hybrid 2D & 3D animation workflows.

.0.2 Questions (focus on Mary Poppins Returns).

(1) What made you take on the role as pipeline TD for the hand drawn animation sequence in *Mary Poppins Returns*?
(2) Can you tell us more about working on Mary Poppins Returns?
    - What workflows / processes did you rely on for Mary Poppins Returns?
    - What were some of the significant gaps / challenges you faced in constructing maintaining a pipeline to support hybrid 2D / 3D animation?
    - What worked well and what didn't?
    - What would you have done differently?
    - Is there a tool you'd like to see developed in this space / Is there a need that has to be met to support work in this space?
(3) What is the impact of hybrid 2D/3D storytelling and output?
    - What should be done or best practices in 2D / 3D?
    - Are there certain types of genres or types of animation that would only be applicable to 2D and 3D or both?
    - What challenges did you face across the 2D or 3D elements of the work required and were there any aspects that were particularly frustrating or enjoyable?
(4) Do you think it will become more / less prevalent? (past examples – *Cool World, Space Jam, Moana, Mary Poppins Returns, Spiderman: Into the Spider-Verse*)
    - How is the hybrid of 2D and 3D animation being further developed?