

Computer-Assisted Animation of Line and Paint in Disney's *Paperman*

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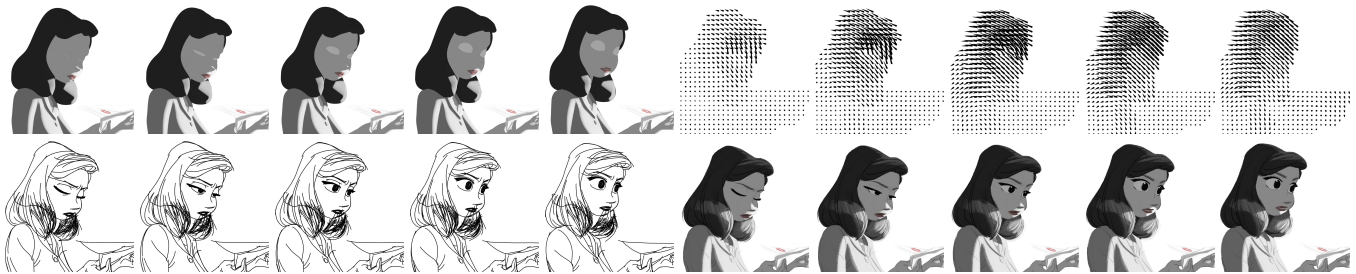


Figure 1: Example sequence showing the CG renders, motion fields, hand-drawn stroke centerlines, and the final line renders

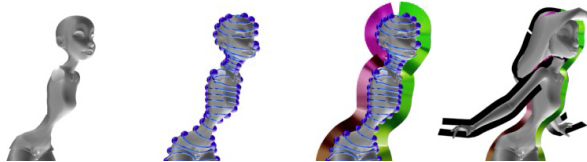
1 Introduction

We present a system which allows animators to combine CG animation's strengths – temporal coherence, spatial stability, and precise control – with traditional animation's expressive and pleasing line-based aesthetic. Our process begins as an ordinary 3D CG animation, but later steps occur in a light-weight and responsive 2D environment, where an artist can draw lines which the system can then automatically move through time using vector fields derived from the 3D animation, thereby maximizing the benefits of both environments. Unlike with an automated "toon-shader", the final look was directly in the hands of the artists in a familiar workflow, allowing their artistry and creative power to be fully utilized. This process was developed during production of the short film *Paperman* at Walt Disney Animation Studios, but its application is extensible to other styles of animation as well.

2 Initial pipeline stages

The front-end of the pipeline revolves around the creation of motion fields via which the final lines can be advected, thus reducing the time needed for artists to create non-key drawings and helping to preserve temporal coherence. Similar to a CG production, 3D models are created, rigged and animated. However, because the CG render is not the final look of the film, the process may be simplified by using simpler models or even representative geometry such as planes, spheres, and cylinders.

Motion Render: We render motion fields (forward and backward) per-frame per-element, such that each pixel in the image contains a 2D offset (Figure 1 top-right) describing where that point on the CG model will be in the next (or previous) frame.



Silhouette Ribbons: Lines in traditional animation often describe silhouettes of shapes. So that we can ensure that lines near the character's silhouette stay on the silhouette, even as the underlying geometry rotates out-of-plane, we create silhouette "ribbons" by dividing the character into topologically-cylindrical components and offsetting the silhouettes perpendicular to the camera direction. The main advantage of this technique is dealing with situations where one part of a character moves in front of another (i.e. an arm moves in front of the body). In such cases, the artist is still able to loosely sketch silhouettes for the arm outside of its actual boundary, and they will still be advected according to the arm's motion. The final

motion field can also be dilated in image-space to extend the outer silhouettes even further.

Motion Paper: In order to achieve our stylized look, it was necessary to add texture to the strokes. To ensure temporal coherence of the texture, we advect a simple tiled paper texture according to the motion fields while also having a "boil" parameter that determines how much the texture changes through time. This produces a unique paper texture for each element in each frame (see video).

3 Final line and paint

Once the initial CG animation stages are finished and all motion has been rendered, the final line artists may then begin creating the initial key drawings in a 2D vector-based paint program on top of the CG renders. The motion fields allow for two powerful operations to drastically improve the workflow for creating the non-key drawings and preserving temporal coherence of the final-line stage: motion pasting and motion betweening.



Motion Pasting: Motion pasting is an operation where a group of strokes in one frame are selected by the artist and then "pasted" into another frame, such that through all intermediate frames, the strokes are advected by the motion fields defined by the CG animation. Notice in the above figure that the green strokes follow the back of the hand precisely.

Motion Betweening: Motion betweening is an implementation of inbetweening that combines a curve interpolation technique with the motion field advection. The artist selects a group of strokes in one frame, then selects a corresponding group of strokes in another frame. The system is then able to compute the optimal correspondence (based on the strokes' relative positions/orientations) using a simple linear programming technique. For each stroke match pair, one stroke is advected forward in time, the other backwards, and then a linear curve blend produces a final inbetween curve with linear blend weights favoring the closer keyframe.

4 Results

Figure 1 shows an example result where motion pasting and motionbetweenings were heavily leveraged. Notice that few new strokes were created in this sequence despite the fact that the lines only loosely match the features of the 3D model.

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