to be published in Leonardo, August 2002
submitted for publication June 2000
revised manuscript submitted April 2001

Abstract: This article presents a new medium in which organic surfaces are drawn in 3d space with the hand. Additional tools move and deform the shape. Special interface hardware includes a head-tracked stereoscopic display and sensors which track the body and handheld tools, allowing the artist to share the space of the artwork. This method provides a fluid, unstructured access to 3d, ideal for quick, spontaneous ideation and investigation of complex structure.

Drawing with the Hand in Free Space

Creating Organic 3d Shapes with Gesture in a Semi-Immersive Environment

Steven Schkolne

in collaboration with
Michael Pruett and Peter Schröder

The gesture has a spontaneity, a freedom, an unfiltered physicality in its instantaneous choice. There is a depth of communication in this moment, the split-second of a photograph, the subtle timing of a comedian. These instants are not planned or contrived, but quickly communicated through a developed intuition. Mark-based traditional media, such as drawing and painting, engage this type of moment repeatedly in a form that engages the body. I view drawing, especially sketching, as a way of physically conceptualizing, a form of thought [1]. Yet lines and the paper they occupy are two-dimensional, not addressing the bodily space. My excursions into 3d creation, assembling disparate objects, seem arduous: much planning for small moments of interaction and response. Computer modeling programs [2] require an indirect manipulation of form through mathematical quantities, typically with a 2d interface. I find that these laborious processes do not support the spontaneity of creation and the physical, corporeal understanding that I am interested in. Without this immediacy, I feel the ability to freely explore and thoroughly engage 3d space lacking.

The medium presented here, which I call *surface drawing*[3], is a response to these concerns. This method is an extension of line drawing to 3d space using the hand in place of a pen. When the hand is moved through space, its path takes form and hovers in the air as surface. This concept is realized with advanced computer interface devices and custom software. Each hand motion is sensed by an instrumented glove, recorded by the computer, and displayed as a coherent *stroke.* An accumulation of these strokes form an object, in much the way 2d lines combine. The action of creating with the hand is somewhat like touching an imaginary object and having it materialize. This method of creation is a

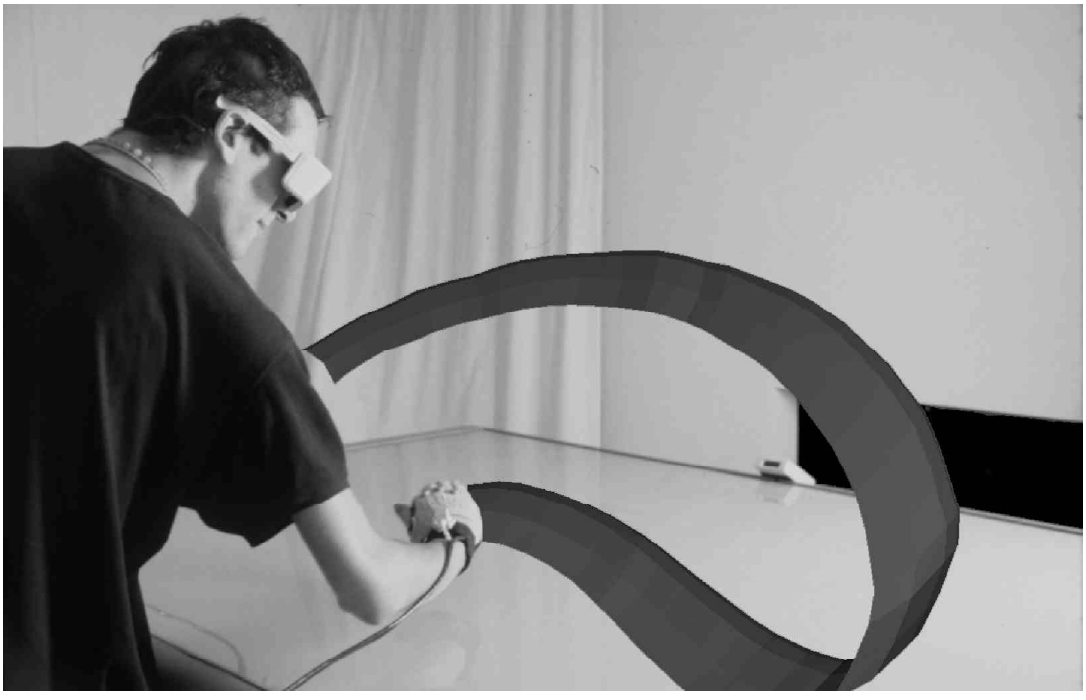
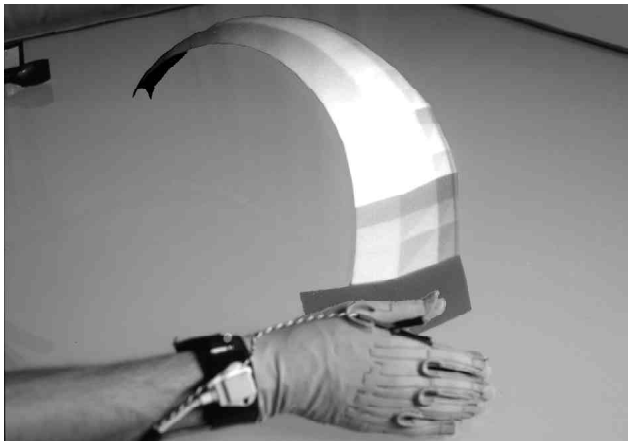
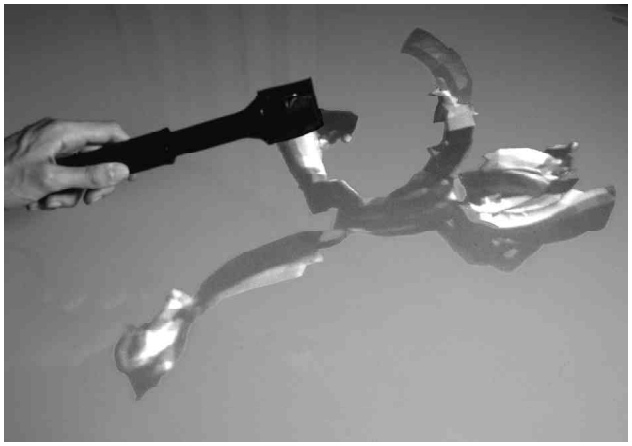
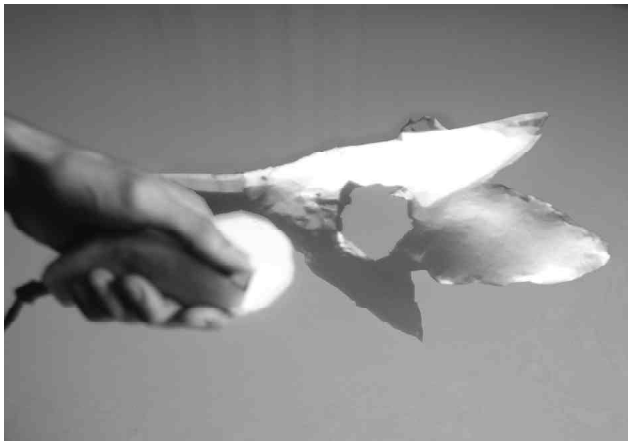


Fig 1. A thin strip of surface is drawn with the hand. Special viewing hardware makes the stroke appear to float above the table, as depicted in this composite image.







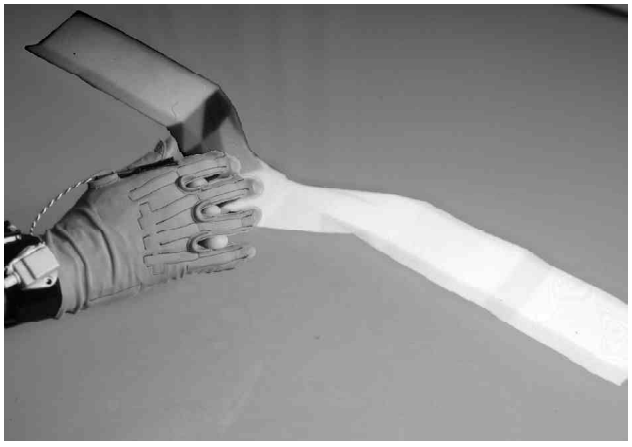


Fig. 2. Basic methods of developing surfaces: (a) The path of the hand in space is captured as a stroke. A sensor on the lower index finger detects the thumb's closing, which initiates the drawing. (b) Sensed tongs are used to rotate this figure drawing. Two pairs of tongs used together can scale an object. (c) An ergonomic 3d eraser with a button on it. The eraser removes a small volume from an object. (d) A magnet, held between the fingers, attracts surface. This tool does not create new geometry, but rather produces small refinements. *photography by Vanessa Stump*

recording of gesture, capturing a performative body as object. The relationship between artist and object is two-way, with the object enveloping the artist, affecting the growth of form.

This method provides much of the relationship to 3d space that I seek. I have pursued this approach, both as an artist investigating visual space and as a computer scientist (in collaboration with Peter Schröder and Michael Pruett at Caltech) developing a system to support this interaction. I am concerned with making a system that is general purpose for the artistic community at large. To this end, I first investigated the ability to make representational surface drawings. More recently I created abstract shapes that develop structural relationships which are unique to this medium. In both of these investigations the focus has been more on geometry than color. This is due to a favoritism of structure, and an anticipation of future work in texture and shading.

The Physical Interface

This concept was realized using the Responsive Workbench [4], a large table that acts as a display surface. Wearing head-tracked stereoscopic shutterglasses [5], objects appear to float above this table within the user's body space. In this environment, a number of physical tools are used to create and manipulate shapes. The user wears a glove [6] on the dominant hand which senses the shape of the hand. Along with a motion tracker on the wrist, these hand motions are turned into shapes [7] by a computer which displays them in realtime. A stroke is started by closing the thumb – pushing it against a sensor on the lower index finger. The color of the stroke can be changed by turning a color wheel that rests on the tabletop.

A pair of kitchen tongs freely moves and rotates objects in 3d space. The motion-tracked tongs have a pressure sensor which detects when they are closed. A second pair of tongs has the same functionality. When the two tongs are used together they can increase the size of the object (by closing both tongs and moving them apart) or shrink it (by moving them closer to one another). Scaling an object changes the size of

the hand relative to the object, and thus details can be added at any scale. Small features can also be created by drawing thinner strokes; This is accomplished by drawing with the hand in a pointing position [8].

Two additional tools modify shapes: an eraser and a magnet. The eraser is molded out of yellow silicone, designed to fit easily in the hand. When its sensor is pressed with the thumb, a small volume is removed from the piece. The magnet fits lightly in the hand, somewhat like a toenail brush. This tool attracts a shape, pulling it slightly towards the hand. This method of *overdrawing* [9] does not create new geometry but rather slightly modifies it.

The pattern of these interactions is very physical. All of the operations are accomplished with motion, the act of creation is a performance whose record is part of a developing interaction. The thought that goes into an object's creation is channeled through motion and perception. Guided by the instant, forms emerge as a reaction to space.

This interest in performance, emotion, action, and the subtlety of the artist's hand is shared with abstract expressionist painting [10]. In the behavior of the medium, some distinctions become apparent. As I have become adept with surface drawing I have grown to move the object constantly as I work. The piece spins quickly, and the process is as much about seeing as doing. This interaction is different from that of action painting, where the canvas is an object of the mark. In surface drawing, marks re-enter and thus re-engage the space of the body, becoming both subject and object. Instead of the static visual field of the painting, this interaction nurtures an intense form of vision which is demanding and engrossing. Through this process, an interactive contemplation of form and relationship with structure emerges that is intricate, fluid, dynamic: as much about spatial awareness, observation, and reaction as it is a place for expressionist catharsis.

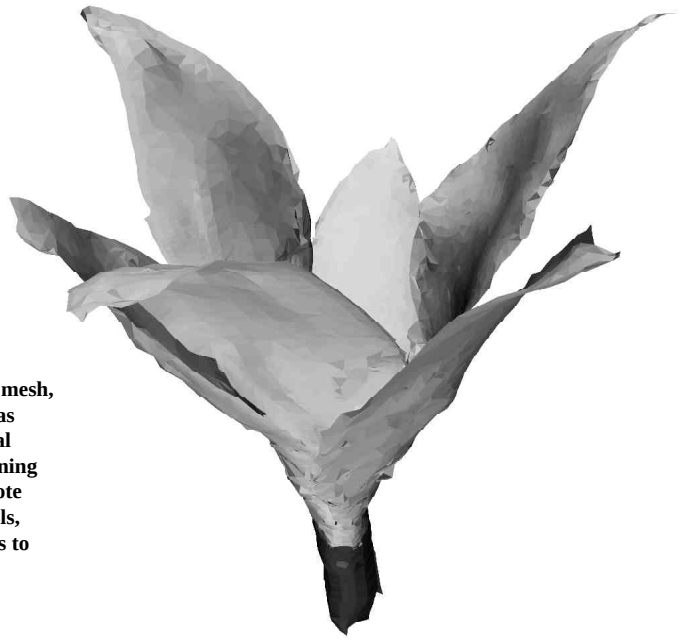


Fig. 3. *fwr*, triangle mesh, 2000. This shape was created from several hand gestures: defining motions which denote the edge of the petals, followed by motions to fill in the interior.

Representational Shapes

My first experiences with this method focus on the creation of representational objects. Constructing such shapes requires the invention of new process. Drawing precise objects, much like in 2d painting, is aided by preliminary sketching. To draw *fwr*, shown in Figure 3 [11], I first sketched some basic petal positions. I analyzed this shape and made marks approximating more final petal positions, which served as guidelines for a refined drawing of the shape. The petals are best drawn edge-first, as the edges are defining characteristics of this form.

I find this method similar in spirit to my 2d representational process, fluid in structure, a reflection of thought through motion very much filled with the instant. I often find myself squinting my eyes and getting a feel for where something should go. In stark contrast to current 3d modeling software, I do not have to think about x-y-z coordinates, interpolating curves, or other linguistic handles. There is little enforced structure, whatever I describe is directly and immediately represented. In contrast to physical media, I do not have to build a structure to support the flower's petals, or concern myself as to how they will stay in place after being drawn.

It is common in line drawing to render a live model in a short pose. I repeated this exercise with one-minute gesture drawings, the resulting surface drawings are shown in Figure 4. Unlike 2d drawing, perspective is not needed. The drawing instead required feeling the model's position in my own work space. As with the flower, this process entailed many motions rolling over and around the figure as it was being created. These quick sketches have a pronounced roughness to them, a gestural quality that is inherent to their process. The chunkiness of these figures is somewhat characteristic of the graphic signature of surface drawings. One can see the body, a crudeness of manipulation that resembles clay. The solidity of clay is replaced with the thinness, the air of foil.

Abstract Shapes

I am currently investigating surface drawings that adopt a more abstract representation. These objects, less focused on replicating extant material forms, appear quite unlike physical sculptures or other computer graphics shapes. Figure 5 shows *fthr*, an example of this purely constructive process. These forms grow incrementally in a spatial balance. A salient characteristic of these objects is that they are hard to represent on the printed page. The three separate views of *fthr* demonstrate a rich three-dimensional complexity. Viewing the printed page, I find picturing the

Fig. 4. These one-minute gestures were drawn from a live model. Their rapid construction and demonstrate the immediacy of surface drawing. All three are untitled triangle meshes, 2000.

mental rotations between each pair to be quite arduous [12]. Such an object is difficult to conceptualize with two-dimensional tools.

This enriched understanding of structure is the greatest potential of this method. The comprehension builds as the space serves as marking ground for shape. Elements are easily placed, relations develop amongst the marks. This constructive process is not predetermined, but proceeds in a loose and fluid manner, letting ideas grow. This physical basis for abstract thought is a perceptual tool which enables conception. The sophistication and simplicity of the constructive process facilitate exploration with a minimum of cognitive overhead.

Other objects in this series take advantage of scale, containing miniature details that are as rich as the larger form they inhabit. Their nature is difficult to represent on the page and in physical reproduction alike: An interactive investigation of the form is needed. Through scaling and rotation, investigating these shapes, the viewer is thrust into a complex spatial dialogue, the precise language of which lies undeveloped.

The objects in this series are an example of the freedom that I have been seeking in three dimensions. This abstraction is employed in a bodily space which directly relates to the artist during construction, and interacts with the 3d viewer's body. The shapes have a materiality, a raw roughness of physicality which they embody despite their inherently aphysical embodiment. The stereotypical emotionally divorced, purely abstract and immaterial nature of the machine has merged with the stereotypically crude, lo-fi and Neanderthal action of the body. This quality is symptomatic of a larger philosophy of mine, that as technology progresses we become more aware of our bodies, of our existence as perceptual entities, rather than fleeing into an abstract mental space that is devoid of body.

Other Applications

This method is a general way of creating 3d shapes, and as such has many

applications outside of pure artistic exploration. The system can be used for the conceptual design of any 3d object: buildings, characters, cars, clothes, furniture, and roller coasters included. Once prototyped, shapes can be brought into standard 3d modeling applications for lighting, refinement, rendering or animation. The digital files can also be used as starting points for manufacture, or directly printed as objects using 3d lithography. Surface drawings are useful for conceptual design. For example, surface drawings can serve as conceptual sketches for a project that will be completed by a traditional method such as object assembly.

Applications of surface drawing are being investigated in collaboration with Designworks/USA [13], an industrial design firm. They are interested in making surface drawings for conceptual prototypes of products, which in their case range from automobiles to cellular phones. In the words of Senior Designer Gary Fitzgerald:

> We are interested in capturing the emotions that drive gestural descriptions of form. We will be exploring the world of subtleties and nuances that only this type of rapid capture enables. This is a story telling experience illustrated as geometry [14].

They have experimented with the setup at Caltech, and I have built a second implementation at Designworks to give their designers more access to the process.

I have also shown this system to audiences in two recent exhibitions [15]. The audience understands very quickly how this medium works: People begin creating shapes instantaneously. Gaining control of this medium is more difficult, and requires experience. Gestural skills translate well into creating shapes, although some artists begin by thinking very two-dimensionally. It takes practice to get the most out of this medium. The learning process that users go through is not one in which they learn how the software works, but rather an understanding of body and space.

Fig. 5. *fthr*, triangle mesh, 2000. Three views of this static object reveal a complex 3d structure. This shape is poorly represented by the printed page. For example, the rotations between the shapes are difficult to visualize. The small diagrams between the images denote the approximate rotations the shape goes through before a stationary viewer. The spatial relationships inherent to this form are not easily conceptualized with two-dimensional tools. The original 3d model is available online [12].

Future Work

The medium as it stands is primarily suited to organic shapes. Perfectly flat

planes, hard edges, and precise symmetries are not supported by the current interface. The error in the tracking system provides a further obstacle to high precision. Thus, for industrial concerns, the medium is not yet suitable for shapes beyond the prototype phase.

Other aspects of shape creation have yet to be developed. For example, there is no facility to control texture and lighting. The larger variety of spatial elements, such as volumes or time-varying components, has not been explored. There are many different tools that could be built, diversifying and enriching the constructive process.

Developments in these many areas will enhance the physical, intuitive access to space which surface drawing provides, enriching the spatial dialogue and enlarging the resulting understanding of structure. In the future I plan to examine the vast landscape of possibility which this 3d environment where any type of action can be translated into form provides. With improved sensing, more sophisticated display, and a wider toolset, the visual language encompassed by these techniques will be rich, growing to become a vital component of human communication.

ACKNOWLEDGMENTS

Special thanks to davidkremers, W. Everett Kane, Gary Fitzgerald, Alec Bernstein, Aaron Rincover, and Al Barr. This work was supported in part by NSF (DMS-9872890, ACI-9721349); other support was provided by Alias|Wavefront, the Packard Foundation, Pixar, Intel, and DesignWorks/USA.

References and Notes

1. This viewpoint is informed by Rudolf Arnheim's work (*Visual Thinking* Univ. of California Press, Berkeley CA1969)

2. Such as Maya <http://www.aliaswavefront.com> and 3ds max <www.discreet.com>.

3. The name surface drawing refers to the extension of line drawing to surfaces. The action of this meduim is much like line drawing, except that the marking tool produces 2d surfaces instead of 1d lines.

4. The Responsive Workbench was developed by Wolfgang Kruger and colleagues at GMD. See Kruger, W. and Fröhlich, B. "The Responsive Workbench", *IEEE Computer Graphics and Applications* (May 1994) 12-15.

5. These glasses provide the illusion of depth by showing different images to the left and right eyes. A transparent LCD screen covers each eye. The left screen turns black as an image for the right eye is displayed and vice versa.

6. The Cyberglove, by Virtual Technologies Inc., Palo Alto CA <http://www.virtex.com>

7. The surfaces are represented as triangle meshes, collections of colored triangles in 3d space with connectivity information. More technical details can be found in: Steven Schkolne, *Surface Drawing: The Perceptual Construction of Aesthetic Form*. M.S. thesis, Computer Science, Caltech, 1999. <http://www.cs.caltech.edu/~ss/sdraw/pubs>

8. Computer users often ask for a feature such as the ability to precisely adjust the stroke width. The interface philosophy here is one of minimalism. It is not necessary to create a stroke-width knob if a similar effect can be acheived with the current tools (in this acase, scaling).

9. This mode was inspired Cohen et. al's work on overdrawing curves. See Cohen, J.M., Markosian, L., Zeleznik, R.C., Hughes, J.F., and Barzel, R. "An interface for sketching 3D curves." *1999 ACM Symposium on Interactive 3D Graphics* (1997). pp. 107-114.

10. Sandler, Irving, *The Triumph of American Painting; a History of Abstract Expressionism*, Praeger Publishers 1970.

11. More images, along with further description of this project can be found at <http://www.cs.caltech.edu/~ss/sdraw/>

12. A 3d version of *fthr* in VRML format is available online at <http://www.cs.caltech.edu/~ss/sdraw/gallery/fthr.wrl>

12. <http://www.designworksusa.com>

13. Personal communication, July 2000

14. Surface Drawing has been exhibited twice, first at SIGGRAPH 1999's Emerging Technologies forum, Los Angeles California, August 1999. The second exhibit was at the 3rd Petrobras Mostra de Realidade Virtual, Rio De Janeiro, June 2000. Both exhibits involved showing audience members how to use surface drawing.