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### ► To cite this version:

Alexis Angelidis, Marie-Paule Cani, Geoff Wyvill, Scott King. Swirling-Sweepers: Constant Volume Modelling. Siggraph Technical Sketches and Applications, 2004, Los Angeles, United States. 10.1145/1186223.1186273 . inria-00537465

**HAL Id: inria-00537465**

**<https://inria.hal.science/inria-00537465>**

Submitted on 18 Nov 2010

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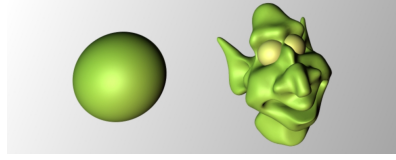
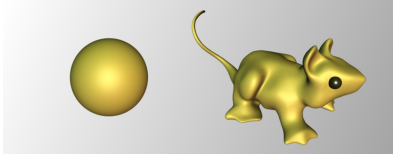
# Swirling-Sweepers: Constant Volume Modeling

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Swirling-sweepers is a new method for modeling shapes while preserving volume. The artist describes a deformation by dragging a point along a path. The method is independent of the geometric representation of the shape. It preserves volume and avoids self-intersections, both local and global. It is capable of unlimited stretching and the deformation can be controlled to affect only a part of the model.

## 1 Motivation

In a virtual modeling context, there is no material. A challenge for computer graphics is to provide a modeling tool that convinces the artist that there is a material. Volume is one of the most important factors influencing the way an artist models with real materials.

The limitation of existing volume-preserving methods is either that they only apply to a specific type of geometric representation, or they only apply to shapes whose volume can be computed, with the exception of [Decaudin 1996]. His technique does not always preserve volume, and is discontinuous at one point.

## 2 Principle of Swirling-Sweepers

A Swirling-Sweeper is a new space deformation based on our framework called Sweepers [Angelidis et al. 2004b]. It is a blend of simpler deformations that we call *swirls*. In Figure 1, we show that a swirl is a rotation whose magnitude decreases away from its center,  $c$ . We represent the magnitude of rotation by a  $C^2$  monotonic scalar function,  $\phi$ , which vanishes outside a neighborhood of radius  $\lambda$  around  $c$ . More formally, a swirl is a rotation matrix raised to the power  $\phi$

$$f(p) = \exp(\phi(\|p - c\|) \log M) p \quad (1)$$

A swirl preserves volume since the determinant of its Jacobian is always equal to 1. There is a convenient way of blending  $n$  swirls to produce a more complex deformation

$$f_n(p) = \exp\left(\sum_{i=1}^n \phi(\|p - c_i\|) \log M_i\right) p \quad (2)$$

See [Angelidis et al. 2004a] for computing exp and log.

**From Swirls to Swirling-Sweepers:** By specifying a single translation  $\vec{t}$ , an artist can input  $n$  swirls. As shown in Figure 2, we place  $n$  swirl centers,  $c_i$ , on the circle of center  $h$ , and radius  $r$  lying in a plane perpendicular to  $\vec{t}$ . These points correspond to  $n$  consistently-oriented unit tangent vectors  $\vec{v}_i$ . Each pair,  $(c_i, \vec{v}_i)$ , together with an angle,  $\theta$ , define a rotation. Along with radii of neighborhood  $\lambda = 2r$ , we define  $n$  swirls. The radius of the circle,  $r$ , is left to the user to choose. The following value for  $\theta$  will transform  $h$  exactly into  $h + \vec{t}$ , and preserves volume for sufficiently small  $\vec{t}$ :

$$\theta = \frac{2\|\vec{t}\|}{nr} \quad (3)$$

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**Preserving coherency and volume:** To preserve coherency and volume, it is necessary to subdivide input vector  $\vec{t}$  into a series of smaller vectors. We use  $s = \max(1, \lceil -4\|\vec{t}\|/r \rceil)$  sub-vectors. This decomposition is shown in Figure 3.

**Achieving Real-Time:** We have a closed-form for the logarithm of a rotation matrix and also for computing  $(\exp N)p$ , when  $N$  is the logarithm of an unknown rotation matrix. These formulas, together with a more complete discussion can be found in [Angelidis et al. 2004a]. They save otherwise expensive numerical approximations.

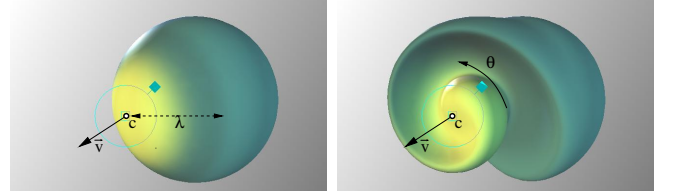


Figure 1: Swirl of center  $c$ , rotation angle  $\theta$  around  $\vec{v}$ .

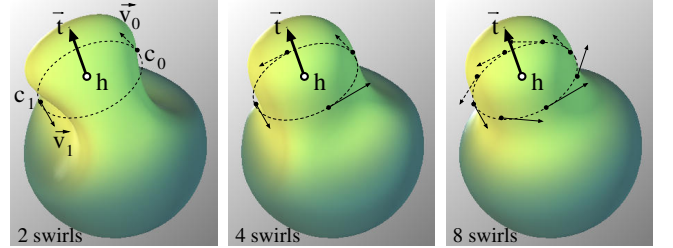


Figure 2:  $n$  swirls arranged in a ring creates more complex deformations. There are no visible artifacts with 8 swirls.

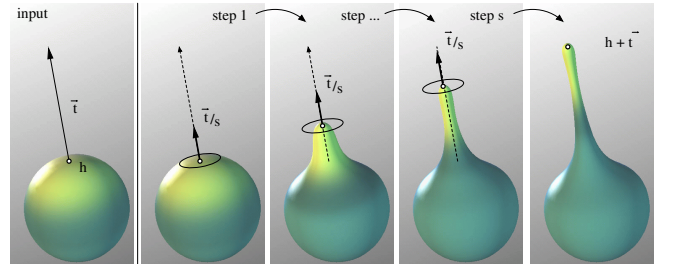


Figure 3: Volume preservation is obtained by composing rings of swirls. The selected point is precisely controlled.

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