Chapter 9

Conclusions

The modeling, description, and animation of shape is a central issue in computer graphics. Our new model, based on dynamically coupled particle systems that interact according to physically inspired potential functions, is free of topological restrictions. Our model has characteristics of traditional spline models, physically-based surface models, and of particle systems. It can be used to model smooth, elastic, moldable surfaces, like traditional splines. Like physically based surface models, by adjusting the relative strengths of various potential functions, a surface's resistance to stretching, bending, or variation in curvature can all be controlled. And yet it allows for arbitrary topologies, like particle systems.

The ability to split, join, and cut are critical to the free-form modeling of shape. Particle based surfaces have the distinct advantage of being easy to shape, extend, join, and separate. For example, the surfaces can be joined and cut at arbitrary locations. Previous approaches, such as spline based models and deformable models, require manual discretization of the surface into patches (for spline based surfaces) or a specification of connectivity (for spring-mass systems) to accomplish these operations. In addition, the ability to easily change topology greatly simplifies the creation and animation of topologically complex surfaces. Unlike previous surface models, the local connections in our system are determined automatically rather than through manual intervention. It is through the interaction of a collection of primitive elements that global shape emerges.

Our geometric shaping tools are analogous to tools used to shape physical objects. These tools allow for intuitive interaction in which topologically complex surfaces can be easily created and modified. In addition, the ability to grow new particles gives our models more fluid-like properties which extend the range of interactions. Like previous deformable surface models, our particle-based surfaces can simulate flexible materials such as cloth, elastic sheets, and plastic films. The ability of our models to automatically connect and disconnect in response to forces provides for the physically inspired animation of models in which the topology changes over time. The combination of these characteristics make particle-based surfaces a powerful new tool for the interactive construction, modeling, and animation of free-form surfaces.

The flexibility of particle based modeling comes at a cost. A limitation of particle-based surfaces is that it is harder to achieve exact analytic (mathematical) control over the shape of the surface. For example, the reconstructed torus is not circularly symmetric, due to the discretization effects of the relatively small number of particles. This behavior could be remedied by adding additional constraints in the form of extra potentials, e.g., a circular symmetry potential for the torus. Particle-based surfaces also require more computation to simulate their dynamics than spline-based surfaces; thus the latter may be more appropriate when shape flexibility is not paramount. One could easily envision a hybrid system where spline or other parametric surfaces co-exist with particle-based surfaces, using each system's relative advantages where appropriate. For example, particle-based surface patches could be added to a constructive solid geometry (CSG) modeling system to perform filleting at part junctions.

Our demonstrations to date have been limited to 2D pointing (input) devices and a modest number of particles. Further investigation into the use of true 3D input devices, preferably with force feedback, would complement the flexibility and intuitive nature of this modeling technique. Implementing these two ideas on the more powerful computers of the future could result in "computational modeling clay".

Oriented particles can also be used to automatically fit a surface to sparse 3-D data even when the topology of the surface is unknown. Particle systems can compute complete, detailed, viewpoint invariant geometric surface descriptions. Both open and closed surfaces can be reconstructed, both with and without holes. We can also use our surfaces to segment 3-D volumetric data, and to incrementally construct 3-D object models from motion sequences. Unlike most other deformable models, the topology of the surface need not be initially specified. Because of the flexibility of the technique, and because it is an optimal surface fitting approach, we believe this approach will form the basis of a powerful new class of shape models for computer vision applications.

We have demonstrated that we can interactively shape, extend, join, and separate, particle based surfaces (Figure 8.7). Using shaping tools, we can create topologically complex surfaces (Figure 8.11). We have shown that particle based surfaces simulate a wide range of behaviors, such as the draping of cloth, the stretching of elastic surfaces, the flexibility of thin plastic films, the ability to break or tear, fluid like behavior, the variation of physical properties based a temperature, the diffusion of heat, and interaction with other objects. We have interpolated both open and closed surfaces through collections of sparse 3D points and segmented scalar 3D data. The surfaces are viewpoint invariant and support optimal fitting based on the selected energy functions. A reconstructed surface model can be used as the starting point to interactively create a new shape, manipulate, and then animate it within a virtual environment. Thus particle systems provide a powerful new interface between surface reconstruction in computer vision, free form modeling in computer graphics, and computer assisted animation.