Visual Modeling

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The goal of visual modeling research is to develop mathematical models and associated algorithms for the analysis and synthesis of visual information. Image analysis and synthesis characterize the domains of computer vision and computer graphics, respectively. For nearly three decades, the vision and graphics fields have been developing almost entirely independently—this despite the fact that, at least conceptually, the two disciplines are bound in a mutually converse relationship. Graphics, the direct problem, involves the synthesis of images from object models, whereas vision, the inverse problem, involves the analysis of images to infer object models.

Visual modeling takes a unified approach to vision and graphics via modeling that exploits computational physics. In addition to geometry, *physics-based modeling* employs forces, torques, internal strain energies, and other physical quantities to control the creation and evolution of models. Mathematically, the approach prescribes systems of dynamic (ordinary and partial) differential equations to govern model behavior. These equations of motion may be simulated using standard numerical techniques. The equations unify the representation of shape and motion, making the modeling primitives responsive to simulated physical environments, physical constraints, user interactions, and all sorts of input data sets.

Significant effort has gone into the development of *deformable models*, a powerful class of physics-based modeling primitives inspired by the behavior of natural materials. Deformable models move rigidly or deform in response to applied forces in accordance with the principles of continuum mechanics [1]. In applications to computer vision, deformable models may be used to infer image disparity and flow fields or infer the shapes and motions of objects from their images [2, 3]. In this context, external forces that impose constraints derived from image data are applied to the models. The forces actively shape and move models to achieve maximal consistency with imaged objects of interest and to maintain the consistency over time.

The following list surveys various deformable models and some important vision problems to which they have been applied:

- *Models for piecewise-continuous reconstruction:* Multivariate interpolation and approximation of piecewise continuous functions from large quantities of incomplete, noisy data using controlled-continuity regularization [4]. Reconstruction may be done in a spatially adaptive manner [5] and may be generalized to nondeterministic functions [6].

- *2.5D models for computing visible surface representations:* Efficient fusion

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of low-level visual data at multiple scales into a consistent representation of the visible surfaces in the scene and their discontinuities [7].

- *Signal matching models:* Estimation of the disparity between similar signals that have been deformed with respect to one another, with applications to stereo and motion estimation [8].
- *Deformable contour models:* Interactive extraction of extended image features, such as bright and dark regions and edges, and the tracking of such features in image sequences [9]. A useful technique for applications such as biomedical image analysis [10] and the analysis of facial images [11].
- *Deformable 3D models:* Recovery of 3D object shape from images and 3D information using deformable generalized cylinders with weak symmetry constraints [12] and dynamic models with local and global deformations [13].
- *Models for estimating nonrigid motion:* Recovery of the nonrigid motion of flexible single or multipart 3D objects from image sequences and dynamic 3D data [3, 14], including recursive estimators (Kalman filters) based on deformable models [15, 16].

For the purposes of computer graphics, realistic images and animations of elastic [17, 18], inelastic [19], and thermoelastic [20] objects—even anthropomorphic faces with tissue and muscles [21]—may be synthesized when the applied forces arise from animation control systems and the interplay of deformable models and simulated physical environments. It becomes immediately evident that physics-based modeling primitives offer a much greater degree of realism than is possible with conventional, geometric models. The natural behavior of physically-based models makes them very intuitive from a user's point of view; however, an important advantage of a physical simulation over the real world is that users may readily adjust the behavior of models at will, and even suspend or amend physical laws according to the requirements of the modeling task.

In particular, the use of physics as a metaphor for shape design offers a significantly richer variety of modeling scenarios than do the purely geometric primitives employed in conventional shape design systems. Such flexibility promises potentially limitless possibilities in the context of computer aided design. The "computational modeling clay" and "computational construction kit" metaphors are suggestive [1].

With regard to implementations, visual modeling is spawning new vision and graphics algorithms which exploit the power of parallel computers with associated hardware to support real-time image acquisition, graphical display, and human-computer interaction. Emphasis is placed on the development of physics-based models that can be simulated and visualized at interactive rates on such systems, permitting the user to experience the virtual reality created in the machine.

The long-term goal of the visual modeling research program is to develop the ability to capture models of objects automatically from image sensor input, to manipulate models interactively in simulated physical environments, and to visualize the results of model-based designs in real time using state-of-the-art computers.

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