Cindy Grimm: Research Statement 2009

Research statement

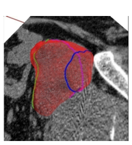
I have two distinct research directions. The first is surface modeling, particularly the representation, analysis, and manipulation of complicated, organic shapes. My research brings fundamental mathematical concepts, such as manifolds, stress and strain analysis, and shape description techniques, to bear on these problems. In addition to this strong theoretical base, I also apply my background in user interfaces in order to supply practitioners with practical tools to use these techniques.

The second research area brings tools and techniques developed by artists to computer graphics, in particular in the area of arranging 3D scenes on a 2D canvas. Much of the other research in this area has focused on replicating particular artistic media on the computer. My approach is to identify artistic *decision making* processes and translate them into usable interfaces.

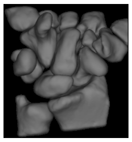
Surface modeling

In recent years my interests in surface modeling have turned towards problems of shape representation and comparison for bio-medical applications. The last decade has seen an explosion in 3D imaging data, both in terms of quantity and quality. It is now relatively easy to capture, and view, 3D volume data sets. It is not, however, so easy to ask quantitative questions such as "How do the cortical folds change during brain development?" or "What shape should this broken bone have?". Answering these questions requires solving several inter-related problems: Reliably extracting anatomical models from 3D image data, identifying corresponding features on similar models, and building a higher-level model (atlas) that expresses what both the average and the expected variation within the model is.

My research addresses these problems in several ways. First, I am working jointly with Dr. Ju (Computer Science) and Dr. Low (Radiology), to develop an interface for quickly and reliably extracting surfaces from image data by drawing contours at arbitrary orientations [1]. Second, I have developed a surface representation which supports surface correspondence and comparison [19]. Jointly with Dr. Bayly (Mechanical), I am using this representation, along with stress and strain measures, to track ferret brain development. Earlier work used this representation to track electrical changes on the surface of a heart [27] (joint work with Dr. Efimov in BioMed). Third, I have developed local shape feature detection which can be used to automatically identify features on organic shapes [11].



Surface editing background: Editing complicated 3D surfaces using a 2D input device is a difficult task. I have developed techniques for editing 2D curves using the appropriate curve representation to support the edit task [17], for specifying and editing complicated blend regions between two intersecting surfaces [20] (jointly with Dr. Cohen, Univ. of Utah), for editing generalized sweep surfaces [13], sketching mesh deformations [6], and hierarchical surface-paste editing for analytical surfaces [16]. **Impact:** These papers were among the very first to demonstrate interactive techniques for complex modeling tasks. Previously, these operations were specified through numeric input.

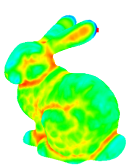


Surface representation background: I have developed three related techniques [15, 16, 19] for representing complicated, arbitrary topology surfaces that are not easily built from simple geometric shapes. These techniques are based on the mathematical framework of *manifolds* and *atlases*. The central idea behind these approaches is that it is much easier to specify a complicated surface by describing what it looks like locally, and then blending those local descriptions together. Manifolds provide the formal mechanism for this approach. Existing approaches either try to glue local descriptions together by matching constraints along the boundary (splines and hole-filling) or produce points on a surface but no analytical, parametric representation (subdivision surfaces, implicit surfaces, and particles). In contrast, manifolds support the building local parameterizations of arbitrary smoothness anywhere on the surface at (nearly) any size.

There are several advantages to the manifold representation.

- Locally overlapping then blending results in much more stable surface fitting, even in the presence of very noisy or poorly conditioned data [18, 19].
- An abstract or average representation of a particular shape, such as the hamate bone (one of the bones in the human hand), can be built then fit to multiple data sets. This supports both fitting of noisy data [18] and the production of mutually consistent parameterizations of different instances of the same shape. The latter is a useful diagnostic tool [24] for comparing variations between subjects (joint work with Dr. Marai, Univ. of Pittsburgh, and Dr. Laidlaw, Brown University).
- The manifold representation allows us to add pieces of surfaces (charts) anywhere, and at any scale. We show how to use this to build surfaces in a hierarchical fashion [16], e.g., building the body then adding the arms and legs. The mathematical formulation is an analytical function for surface-pasting, a procedure which up until now has been performed in an ad-hoc manner through the use of constraints, and which has many restrictions on where and how the surface paste can occur.
- Manifolds also support multiple, different 2D parameterizations of the same data set. Therefore, well-known 2D algorithms, such as reaction-diffusion [21], are easily adapted to operate across the entire surface with little or no adjustment to the algorithms themselves. Additionally, these parameterizations do not need to be tied to the existing geometric one, making it much easier to design parameterizations for specific tasks [19].

Impact: At the major computer graphics conference, Siggraph 2005 and Siggraph 2006, Dr. Zorin and I presented the course, "Manifolds and Modeling", discussing both current and potential research in this area. As part of the course we developed extensive notes (70+ pages) which were distributed on the Siggraph 2005 and 2006 DVDs. I have a contract with AK Peters to publish these notes as a book. In both the jury process (acceptance rate was 39 of 79 proposed courses) and the attendee surveys, this course was identified as fundamental to the field of graphics.



Surface feature background: We have developed two new comparison techniques [12, 11], based on sound mathematical principles, that take into account the local shape of a neighborhood. This approach can recognize salient features such as ridge lines, peaks, flat areas. Unlike previous approaches, this technique also takes into account both size and shape, and, for instance, is a peak big and round, or small and sharp. **Impact:** This is the first work that looks at a set of *local* surface-shape metrics and shows, through extensive mathematical analysis, the strengths and weaknesses of each.

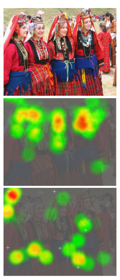
In conjunction with the manifold surface modeling approach, which can provide consistent parameterizations across different versions of the same basic shape, we expect to be able to greatly extend quantified surface comparisons, which currently consist of simple length and radii measurements. This will fundamentally change the types of comparisons available for medical diagnosis. Currently, we can identify matching features on multiple shapes [11] and construct consistent parameterizations from those.

Artistic Tools and Interfaces

Over the years, artists have developed techniques and traditions for effective communication of information in a variety of media. For 2D media in particular, artists have, in a sense, reverse engineered human perception in order to convey shape, depth, lighting, and movement in static images. They also know how to effectively abstract scenes to make them simpler to understand — witness any anatomy textbook or car repair manual. My research combines this "how to" artistic approach with scientific studies of perception [3] in order to provide users with better control over the final image.

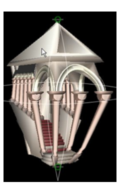
My approach is to turn these artistic techniques, which are expressed mostly as suggestions and recommendations, into interactive tools which automate the technical part of the image-making process while still leaving plenty of room for artistic expression (see, for example, non-linear perspective below). In specific, I have looked at color and texture [5, 23, 26], re-arranging objects in the view plane using non-linear perspective [33, 14, 34, 9], camera control [30, 29, 22, 32], abstraction [10], and creating the illusion of depth and motion [4]. *Note: There are videos demonstrating this work on my web site.*

Three research highlights:



Subtle gaze control: Joint work with Dr. Bailey (RIT) and Dr. McNamara (Texas A&M): The human vision system consists of a small, high-resolution area (the fovea) surrounded by the low-resolution peripheral system. The fovea skips around the scene in response to cues in the peripheral vision in order to build up a complete picture. We use subtle image changes to guide the viewer's gaze to selected parts of the image without the viewer being consciously aware of it [25]. We are currently extending this approach to video, and are exploring specific application scenarios.

Potential impact: There are many human vision search tasks, such as finding tumors or metal items in X-rays, that require training and expertise to accomplish. We propose two possible uses of subtle gaze direction. The first is training — using an expert gaze pattern to train novice users. The second is to augment the search task with results from a computer vision search algorithm, which can be used to ensure that the viewer's gaze is drawn to potentially interesting areas. The potential advantage of subtle gaze direction over more obvious cues is that it does not drastically interrupt the natural gaze pattern nor does it obscure the image.



Non-linear perspective: (Joint work with Dr. Singh, University of Toronto) Artists take advantage of the fact that people only use linear perspective locally to arrange things on the 2D plane. We have developed techniques allowing non-linear perspective [14] along with other researchers [2, 28]; all of these techniques, however, are very time intensive. More recently, we have developed a simple and easy-to-use interface for a class of projections called curvilinear projections [34]. We have extended this work to general non-linear projections using image-space constraints [9], and widgets designed for specific tasks [33]. **Impact:** Non-linear projection is used extensively in traditional art because it more effectively utilizes the 2D canvas than does linear projection. This work encapsulates, in simple interfaces, some common types of non-linear projections.

Lewis the robotic photographer is a joint project developed by myself and Dr. Smart, and entirely implemented by undergraduates [31, 8, 7]. The goals of the project are three-fold. First, it is an application platform in which existing algorithms, such as navigation, can be evaluated. Second, it is a lab-building project designed to get students interested in research (Lewis was deployed at Siggraph 2002's Emerging Technologies with the help of the majority of students then working in the lab). Third, it uses composition rules to control robot navigation and camera positioning [8].

Impact: After the Emerging Technologies exhibition, Lewis was show-cased on several news outlets, including CNN.com, MSNBC.com, the BBC World Service, and the New York Times, greatly raising the visibility of the lab. It has been adopted by the research community as a new robot application, with researchers at Intel, CMU and Nikon designing their own systems. The project continues to be an effective means of interesting students of all ages in research.

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