Graphics and Imaging: Trends Toward Unification?

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Summary

Computer Graphics (image synthesis) and Imaging (image analysis and understanding) have traditionally been considered distinct disciplines, each with their own theoretical foundations and techniques. As each field matures, many interrelations have been discovered and exploited, causing the border between the disciplines to become blurred and leading to conjectures that they are, in fact, parts of a single discipline. The goal of this panel is to examine various aspects of the relationships and interactions between the fields and present several views of the directions the fields are taking in regards to one another. Each panel member has worked in both the graphics and the imaging areas, and each brings a unique perspective on the topic.

James Coggins describes a number of collaborative research efforts which employ both synthesis and analysis skills to solve problems in a variety of different applications areas. Ivan Herman, a member of the Eurographics Working Group on Relationships Between Image Synthesis and Analysis, discusses some of the successful relations to date between the fields and the need for increased interactions. Theo Pavlidis, author of the book *Algorithms for Graphics and Image Processing*, believes that, although the fields will probably not merge, we cannot ignore the growing common body of knowledge. Matthew Ward justifies the merging of the fields with analogies to other scientific and engineering disciplines, and Norman Wittels describes the need to generate synthetic image sets to rigorously test image analysis algorithms.

Dr. James M. Coggins

At UNC, the fusion of computer graphics and image pattern recognition is a fait accompli reflected in our physical facilities, in our research collaborations and in the approach we take to our research.

Our Graphics and Image Laboratory houses equipment used in all aspects of our computer graphics and image analysis research. This equipment includes color workstations, specialized processors, and interaction devices, including a head-mounted display, a treadmill, and a bicycle.

Our research collaborations reinforce the unity of the image generation and analysis fields by focussing attention on entire application problems. By investigating whole applications and not isolated abstract component problems, we are forced to use the whole arsenal of graphics and image analysis tools.

Image pattern recognition operations are essential to label aspects of real data that are relevant for further study, such as volume visualization, measurement, graphical manipulation, or modelling. Computer graphics methods are essential for visualizing the results of computer vision algorithms.

The mathematics required to render excellent images is the mathematics of image processing informed by models of human visual perception. Students working in computer graphics require an understanding of Fourier analysis, filtering, and sampling and aliasing. The mathematics of shape is becoming recognized as being crucial for both computer vision and for computer graphics.

Closing the loop between image understanding and image generation is a natural and necessary step in creating interactive visualization environments, as illustrated in our molecular graphics, medical image presentation, and scientific image analysis work.

A list of concepts that students in any image field should understand include the following:

- interactions of energy and matter
- models of human spatial vision
- models of human color vision
- visual illusions
- stereopsis
- properties and uses of the Gaussian
- interpolation
- convolution
- Fourier analysis
- filtering
- sampling and aliasing
- the histogram; thresholding
- intensity windowing
- properties of orthonormal matrices
- parallel and perspective projection
- transformation matrices in 2D and 3D
- image display hardware fundamentals
- object-oriented software design

Ivan Herman

It has become clear in recent years that the great distance between the two large fields of Image Synthesis and Image Analysis (the latter encapsulates such large areas as Image Processing, Computer Vision, Image Coding Techniques, 3D Reconstruction, etc.) is not natural. Although historically these two large fields of Computer Science and Technology have developed in parallel with no or very few mutual contacts, we face nowadays a whole range of theoretical problems as well as application areas where the mixture of these two approaches is not only fruitful but also necessary. The spectacular advances in recent years in medical imaging and its applications, in scientific visualization, in the need of sophisticated input and interaction techniques, etc. have all contributed to this development.

Dr. Theo Pavlidis

Graphics deals with the production of images from descriptions while Image Analysis deals with the production of descriptions from images. Image Processing deals with image to image transformations. Therefore all three areas deal with the same data structures (for example quad trees) and similar basic algorithms (for example region traversal used in scan conversion and in segmentation). All three can be considered as subsets of a general discipline: pictorial information processing.

The following are some examples of specific areas where the interaction can be particularly useful.

Manual Input: When the input is through an interactive editor (using a mouse for example) the location of the data is subject to error. We have demonstrated in the past (Pavlidis and Van Wyk in SIGGRAPH'85) that interactive input can be improved if certain imaging techniques are applied. In particular rather than trying to imposed constraints through complex menus we may let the system infer the parts where constraints are desirable and modify the drawing to satisfy the constraints exactly.

Automatic Input: When the input is obtained automatically (through a range sensor for example) the need for image processing techniques is even more obvious than in the previous case. Many of the solutions involve curve or surface fitting and the challenge there is to define control points and other parameters automatically. Examples of such efforts can be found in the papers on finding splines for font descriptions. Techniques for feature detection in image analysis can be useful in this problem.

Dr. Matthew Ward

Most scientific and engineering disciplines today contain components of both synthesis and analysis. Chemists analyze existing chemicals and create copies as well as new chemicals. Biologists study life and create synthetic DNA. Computer scientists and engineers create networks of computers (both real and simulations) and analyze their behavior/performance. In each case the result is a better understanding of the underlying concepts/models and potentially new ideas to improve analysis or synthesis techniques.

In the area of visual realism in graphics, the underlying model we are trying to understand is the characteristics of object surfaces and how light interacts with these surfaces and appears to the human eye. In image understanding the goal is to take the end result (the image), and with this same underlying model try to classify what the objects are in the image. In the area of visualization, we try to present information in a way which best takes advantage of our visual perception abilities, while researchers in neural nets use this (limited) understanding of perception to create systems which try to emulate the human vision system.

Granted, there are areas of graphics and imaging which do not fit exactly into this analysis/synthesis pairing. Image coding, for example, is mainly concerned with data encryption, compression, and communication. However, there are very few concepts from graphics which have absolutely no relation to image analysis, and vice versa. It is time that this relationship is more fully exploited. This is evidently occuring at several universities, where Graphics and Image Processing Laboratories are merging into entities called Image Science or Visual Science Research Labs. Perhaps we are now on a boundary, similar to that between alchemy and chemistry, where the ad hoc, shallow techniques are giving way to methods rooted more deeply in a theoretical foundation. We have finally attained a large enough core of knowledge in both fields to realize how much is shared, and are starting to examine things which have yet to be shared.

One specific area being explored at WPI is the segmentation of shadows in an image. We can monitor the advances in techniques of shadow generation in graphics, seeing single, point light sources on simple planar objects give way to multiple, non-point sources shining on complex, curved-surface objects. Similarly, shadow segmentation has started with the same simplifying assumptions about lighting and surfaces and is slowly relaxing these constraints using model-based techniques. The fact is, the better we can synthesize the process, the more we can integrate model-based rather than simple intensity based methods to solving the problem.

The process could also be reversed, using the results of image analysis to better select an intensity to use in synthesizing shadows in images. Most existing algorithms for computing shading and shadow intensities use formulae riddled with "tweakable" constants and approximations of known relationships in physics to get a "fairly realistic" shadow. What is missing is the quantitative experiments using real images as input to justify the use of these formulae, although it seems like an easy enough procedure to explore. The fact is, we know that light does not drop off linearly with distance and that different materials reflect light in drastically different ways, so there is much room for improvement in our models and techniques.

Dr. Norman Wittels

Visualization uses computer graphics to display information for interpretation and understanding by humans. Knowledge about the characteristics of the display system (CRT, printer, film recorder, etc.) are combined with knowledge about what is visible in scenes [1] and what in scenes attracts the attention of the human visual system [2] to produce a display that allows humans to generalize and visually interpret the data [3]. Artistic selection and emphasis are an important part of the process; there is little emphasis on display accuracy.

Image processing algorithms are used to extract information from digital images. Unfortunately, there is no equivalent of the Shannon theorems [4] for visual information so design and optimization of algorithms is not generally rigorous [5]. In the absence of theory, artistic judgement often supplants analysis - that is why image processing papers and texts contain "before" and "after" images instead of numbers. When the problem is constrained (the domain is bounded and some information exists about the objects of interest), algorithms are compared by measuring their ability to extract information from "best" and "worst" case natural images. Of course, the problem remains to determine whether a set of test images contains the "best" and "worst". Traditionally the solution is to expand the size of the test set: machine vision systems are often subjected to months of "run-off" (waiting for the worst to arrive). The goal of this work is to produce a complete set of test images.

Computer graphics can be used to generate test images for some constrained image processing problems. Physical models of objects, lighting, cameras and lenses are combined with radiosity and ray-tracing techniques to produce images which accurately reproduce, on a pixel-by-pixel comparison, natural images. By varying all object, lighting, and sensor parameters over the entire specified range, a complete image test set can be produced. The strength of this approach is completeness. The performance of image processing algorithms applied to such images, particularly when combined with statistical information about parameter variations, can reliably predict how they will perform with natural images. There are two weaknesses. First, the number of images can be prodigious: the tasks of producing, storing, and using them is daunting. Second, current computer graphics techniques do not allow accurate simulate of all scenes.

As an example, consider automated pavement inspection. A survey vehicle travelling at highway speeds (100km/hr) observes a lane of pavement (4m wide) detecting cracks and other surface distress at high resolution (1-2mm). Models of crack contrast [6] that were made to design pavement illumination systems [7], have been used to alter pavement images [8] to produce an image test set covering the full range of pavements and imaging conditions [9]. Both natural and computer generated (fractal) pavement images have been used as the starting images. These test images have been useful in evaluating the effectiveness of image processing algorithms for automated pavement evaluation.

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