Geometry Versus Imaging: Extended Abstract

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Geometry Versus Imaging.

There are two quite distinct ways of making pictures with computers. The geometric way is quite widely understood—and often thought to be the only way. The imaging way is less intuitive—and leads to a different marketplace which is probably as large or larger than that for geometry. The terminologies, theories, and even heroes of the two worlds are quite distinct, and the hardware devices to implement them are strikingly different.

Figure 1 illustrates the two domains and their interrelationships. Geometry-based picturing begins with the description of objects or scenes in terms of common geometric ideas—polygons, lines, spheres, cylinders, patches, splines, etc. Recall that these are mathematical abstractions, not pictures. To make a digital picture of a geometrically described object requires that it be *rendered* (or *rasterized* or *scan converted*) into pixels. Geometric concepts live in real continuous space, requiring floating point for accurate computer representation. Famous names are Pythagoras and Euclid. The theorems of analytic geometry are of paramount importance.

Imaging-based picturing begins with a set of discrete samples—pixels—of a continuum, usually placed on a uniform grid. As Figure 1 shows, these samples *may* come from scan conversion of geometry, but in general they do not. In the majority of cases they come from non-geometric sources such as digitized satellite photographs, computed tomographic (CT) or magnetic resonance (MR) medical scans, digitized X-radiographs, electronic paint programs, seismic sensors, supercomputer simulations of partial differential equation systems, or laboratory measurements. In all cases, an array of numbers (samples) is the original data—not a "display list" of geometric primitives. Imaging generates pictures from this data by directly displaying them on the computer screen. The imaging domain is discrete by definition and integer arithmetic typically suffices. Famous names are Nyquist and Fourier. The Sampling Theorem is of paramount importance.

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†The full text of this paper can be found in *Computer Graphics World*, November, 1988.

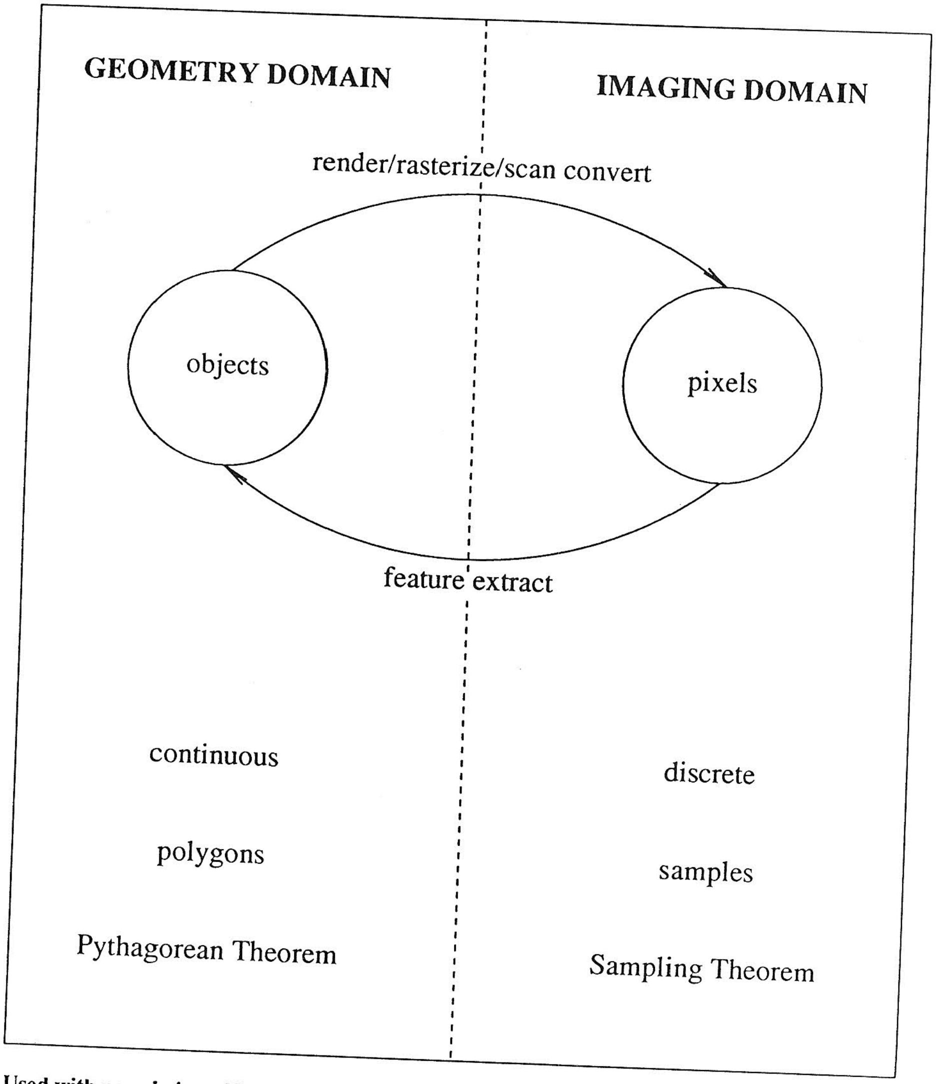

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Figure 1

As Figure 1 also points out, it is possible in some cases to extract geometric data from sampled data and reenter the geometric domain (and then render the geometry to reenter the image domain!). This step is not required, however, to make pictures—contrary to the opinion of a surprisingly large number of people. In fact, it frequently introduces thresholding artifacts (jaggies) which may be highly undesirable—as in medical diagnostic imaging which insists, and depends, on no alterations of its data. Direct imaging of data arrays avoids such artifacts.

Notice that the distinction between geometry and imaging is *not* that between image synthesis and image analysis. An electronic paint program is an excellent example of a non-geometric synthesis technique—an imaging technique. Nor is it the distinction between "computer graphics" and "image processing". Image processing is only a subset of imaging, and computer graphics loosely covers picturing from both domains. The fundamental difference is whether the elemental datum is a geometric or a numeric entity—a polygon or a pixel.

Architectural Differences.

The geometry and imaging distinction is reflected in special-purpose hardware *accelerators* available for each. All graphics computations discussed here *could* be implemented on a general-purpose computer, such as a workstation host, minicomputer, mainframe, or personal computer. But in the late 1980s, it is still the case that these offer insufficient price/performance for geometry and imaging computations. The general-purpose machines with relatively lower computational power simply cannot do the computations in a tolerable amount of time or lack sufficient memory; the more powerful machines use cycles which are too expensive compared to what can be purchased for much less in accelerators.

Geometry accelerators are measured in terms of the number of geometrical objects they can manipulate in realtime. Imaging datasets are typically so large that realtime is not yet an appropriate measure for them (unless programmability is sacrificed). So imaging accelerators are measured in terms of the number of pixels they can comfortably manipulate on the order of 100 times faster than a host computer. Some geometry engines do a little imaging, and some imaging computers do a little geometry. The purpose of the next section is to clarify the distinctions.

GEOMETRY SOPHISTICATION METER

Shading "Shade"	Geometry "Shape"	Anti-aliasing	Complexity #Primitives Per Picture
shading language			
materials			
shaped lights			
distributed lights			
matte/glossy			
displacement maps			
environment maps			
bump maps			
image texture maps			
radiosity			
refraction			
procedural textures			
Phong shading	hyperpatches	motion	100,000,000
transparency	patches	textures	10,000,000
Gouraud shading	quadrics	specular	1,000,000
multiple lights	nurbs	edges	100,000
flat shading	polygons	lines	10,000
none	lines	none	1,000

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Geometry sophistication increases up each column, from bottom to top.

The state of realtime geometry machines in 1988 is below the lines in each column. The RenderMan Interface addresses the entire chart with particular emphasis above the lines.

Figure 2

IMAGING SOPHISTICATION METER

Techniques	Dimensions	Filtering	Complexity #Pixels Per Image
3D painting, FFT,			
and compositing			
volumetrics			
volume imaging			
warping			
classification:			
thematic,			
MR, and CT			
FFT, Walsh, and			
other transforms			
compression			
soft-edged painting		very wide	
and soft fill		bessel	1,000,000,000
convolutions and		sinc	100,000,000
filters			
histograms and	volume movies	cubic	10,000,000
equalization	volumes	gauss	1,000,000
point operations	image movies	box	100,000
matte algebra	images	none	10,000

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Imaging sophistication increases up each column, from bottom to top.

This chart measures imaging accelerators, but some *geometry* accelerators do limited imaging - below the lines in each column. Image computers can address the entire chart.

Figure 3

Sophistication Meters.

Figures 2 and 3 are *sophistication meters* for geometry and imaging respectively. They are attempts to summarize the major techniques and terms in the two domains. Both charts are ordered from bottom to top in each column by increasing sophistication. The horizontal lines in the columns mark the *realtime lines* for each chart. These are placed somewhat generously and are explained more fully below. Notice that the terms used on the two charts are almost completely different.

Geometry Sophistication Meter. The capabilities of realtime geometry accelerators in 1988 lie below the realtime lines of Figure 2. The most obvious observation is that most of what is known about geometry-based graphics has not yet been pulled into realtime. This is particularly true of the "shading" of geometric objects—their visual content—which is in general more difficult than the shaping of the objects—their geometry. The recently proposed RenderMan Interface is exactly a roadmap to all the non-realtime geometry-based graphics.

Imaging Sophistication Meter. The first thing to notice about Figure 3 is that sophisticated imaging applications are tremendously complex in terms of pixel count. This is the world addressed by imaging computers. Some geometry accelerators confusingly offer restricted imaging capabilities as well as geometry. The realtime lines in this chart indicate where in the scheme of things this limited imaging lies. In particular, it is restricted to essentially 1.25K × 1K display memories. Of course, the host computer in geometry workstations can always do the imaging—by definition of computing—but then it executes at general-purpose price/performance, not the order-of-magnitude lower price/performance of a special-purpose imaging accelerator. This is standard "you get what you pay for" general-purpose computing.

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