Computer graphics (computer science)

Computer graphics is a sub-field of Computer Science which studies methods for digitally synthesizing and manipulating visual content. Although the term often refers to the study of three-dimensional computer graphics, it also encompasses two-dimensional graphics and image processing.

A modern rendering of the Utah teapot, an iconic model in 3D computer graphics created by Martin Newell in 1975.

Contents

Overview

Computer graphics studies the manipulation of visual and geometric information using computational techniques. It focuses on the *mathematical* and *computational* foundations of image generation and processing rather than purely aesthetic issues. Computer graphics is often differentiated from the field of visualization, although the two fields have many similarities.

Connected studies include:

- Applied mathematics
- Computational geometry
- Computational topology
- Computer vision
- Image processing
- Information visualization
- Scientific visualization

Applications of computer graphics include:

- Print design
- Digital art
- Special effects
- Video games
- Visual effects

History

One of the first displays of computer animation was *Futureworld* (1976), which included an animation of a human face and hand —produced by Ed Catmull and Fred Parke at the University of Utah. Swedish inventor Håkan Lans applied for the first patent on color graphics in 1979.[1]

There are several international conferences and journals where the most significant results in computer graphics are published. Among them are the SIGGRAPH and Eurographics conferences and the Association for Computing Machinery (ACM) Transactions on Graphics journal. The joint Eurographics and ACM SIGGRAPH symposium series features the major venues for the more specialized sub-fields: Symposium on Geometry Processing,[2] Symposium on Rendering, and Symposium on Computer Animation.[3] As in the rest of computer science, conference publications in computer graphics are generally more significant than journal publications (and subsequently have lower acceptance rates).[4][5][6][7]

Subfields

A broad classification of major subfields in computer graphics might be:

1. Geometry: studies ways to represent and process surfaces
2. Animation: studies ways to represent and manipulate motion
3. Rendering: studies algorithms to reproduce light transport
4. Imaging: studies image acquisition or image editing

Geometry

Successive approximations of a surface computed using quadric error metrics.

The subfield of geometry studies the representation of three-dimensional objects in a discrete digital setting. Because the appearance of an object depends largely on its exterior, boundary representations are most commonly used. Two dimensional surfaces are a good representation for most objects, though they may be non-manifold. Since surfaces are not finite, discrete digital approximations are used. Polygonal meshes (and to a lesser extent subdivision surfaces) are by far the most common representation, although point-based representations have become more popular recently (see for instance the Symposium on Point-Based Graphics).[8] These representations are *Lagrangian*, meaning the spatial locations of the samples are independent. Recently, *Eulerian* surface descriptions (i.e., where spatial samples are fixed) such as level sets have been developed into a useful representation for deforming surfaces which undergo many topological changes (with fluids being the most notable example).[9]

Geometry Subfields

- Implicit surface modeling – an older subfield which examines the use of algebraic surfaces, constructive solid geometry, etc., for surface representation.
- Digital geometry processing – surface reconstruction, simplification, fairing, mesh repair, parameterization, remeshing, mesh generation, surface compression, and surface editing all fall under this heading.[10][11][12]
- Discrete differential geometry – a nascent field which defines geometric quantities for the discrete surfaces used in computer graphics.[13]
- Point-based graphics – a recent field which focuses on points as the fundamental representation of surfaces.
- Subdivision surfaces
- Out-of-core mesh processing – another recent field which focuses on mesh datasets that do not fit in main memory.

Animation

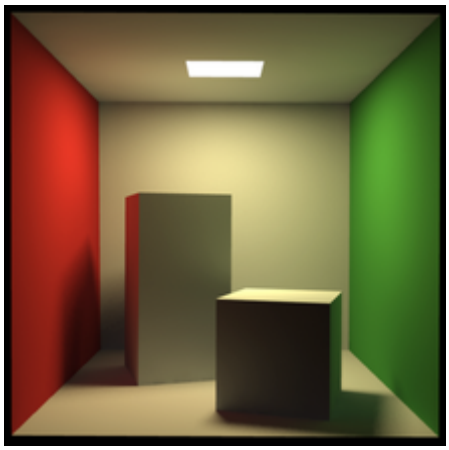
The subfield of animation studies descriptions for surfaces (and other phenomena) that move or deform over time. Historically, most work in this field has focused on parametric and data-driven models, but recently physical simulation has become more popular as computers have become more powerful computationally.

Subfields

- Performance capture
- Character animation
- Physical simulation (e.g. cloth modeling, animation of fluid dynamics, etc.)

Rendering

Rendering generates images from a model. Rendering may simulate light transport to create realistic images or it may create images that have a particular artistic style in non-photorealistic rendering. The two basic operations in realistic rendering are transport (how much light passes from one place to another) and scattering (how surfaces interact with light). See Rendering (computer graphics) for more information.



Indirect diffuse scattering simulated using path tracing and irradiance caching.

Transport

Transport describes how illumination in a scene gets from one place to another. Visibility is a major component of light transport.

Scattering

Models of *scattering* and *shading* are used to describe the appearance of a surface. In graphics these problems are often studied within the context of rendering since they can substantially affect the design of rendering algorithms. Shading can be broken down into two orthogonal issues, which are often studied independently:

1. **scattering** – how light interacts with the surface *at a given point*
2. **shading** – how material properties vary across the surface

The former problem refers to scattering, i.e., the relationship between incoming and outgoing illumination at a given point. Descriptions of scattering are usually given in terms of a bidirectional scattering distribution function or BSDF. The latter issue addresses how different types of scattering are distributed across the surface (i.e., which scattering function applies where). Descriptions of this kind are typically expressed with a program called a shader. (Note that there is some confusion since the word "shader" is sometimes used for programs that describe local *geometric* variation.)

Other subfields

- physically based rendering – concerned with generating images according to the laws of geometric optics
- real time rendering – focuses on rendering for interactive applications, typically using specialized hardware like GPUs
- non-photorealistic rendering
- relighting – recent area concerned with quickly re-rendering scenes

Notable researchers

- Arthur Appel

- James Arvo
- Brian A. Barsky
- Jim Blinn
- Jack E. Bresenham
- Loren Carpenter
- Edwin Catmull
- James H. Clark
- Robert L. Cook
- Franklin C. Crow
- Paul Debevec
- David C. Evans
- Ron Fedkiw
- Steven K. Feiner
- James D. Foley
- David Forsyth
- Henry Fuchs
- Andrew Glassner
- Henri Gouraud (computer scientist)
- Donald P. Greenberg
- Eric Haines
- R. A. Hall
- Pat Hanrahan
- John Hughes
- Jim Kajiya
- Takeo Kanade
- Kenneth Knowlton
- Marc Levoy
- Martin Newell (computer scientist)
- James O'Brien
- Ken Perlin
- Matt Pharr
- Bui Tuong Phong
- Przemyslaw Prusinkiewicz
- William Reeves
- David F. Rogers
- Holly Rushmeier
- Peter Shirley
- James Sethian
- Ivan Sutherland
- Demetri Terzopoulos
- Kenneth Torrance
- Greg Turk
- Andries van Dam
- Henrik Wann Jensen
- Gregory Ward
- John Warnock
- J. Turner Whitted
- Lance Williams

See also

- Computer facial animation

- Computer graphics
- Digital geometry
- Digital image editing
- Geometry processing
- Painter's algorithm
- Stanford Bunny
- Utah Teapot

References

1. US patent 4303986 (https://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US4303986), Lans, Håkan, "Data processing system and apparatus for color graphics display", issued 1981-12-01
2. "geometryprocessing.org" (http://www.geometryprocessing.org). geometryprocessing.org. Retrieved 2014-05-01.
3. [1] (http://www.eg.org/events) Archived (https://web.archive.org/web/20070314004027/http://www.eg.org/events) March 14, 2007, at the Wayback Machine
4. "Best Practices Memo" (https://web.archive.org/web/20140502002308/http://www.cra.org/reports/tenure_review.html). Cra.org. Archived from the original (http://www.cra.org/reports/tenure_review.html) on 2014-05-02. Retrieved 2014-05-01.
5. "Choosing a venue: conference or journal?" (http://people.csail.mit.edu/mernst/advice/conferences-vs-journals.html). People.csail.mit.edu. Retrieved 2014-05-01.
6. "Graphics/vision publications acceptance rates statistics" (http://vrlab.epfl.ch/~ulicny/statistics/). Vrlab.epfl.ch. Retrieved 2014-05-01.
7. An extensive history of computer graphics can be found at this page (http://accad.osu.edu/~waynec/history/lessons.html) Archived (https://web.archive.org/web/20070405172134/http://accad.osu.edu/~waynec/history/lessons.html) April 5, 2007, at the Wayback Machine.
8. "Point Based Graphics 2007 - PBG07" (http://graphics.ethz.ch/events/pbg/07/). Graphics.ethz.ch. Retrieved 2014-05-01.
9. "Ron Fedkiw" (http://graphics.stanford.edu/~fedkiw/). Graphics.stanford.edu. Retrieved 2014-05-01.
10. [2] (http://www.multires.caltech.edu/pubs/DGPCourse/) Archived (https://web.archive.org/web/20070214021951/http://www.multires.caltech.edu/pubs/DGPCourse/) February 14, 2007, at the Wayback Machine
11. CS 598: Digital Geometry Processing (Fall 2004) (http://graphics.cs.uiuc.edu/~garland/class/geometry/) Archived (https://archive.is/20041025104252/http://graphics.cs.uiuc.edu/~garland/class/geometry/) 2004-10-25 at Archive.today
12. "Digital Geometry Processing" (http://www.cs.ubc.ca/~sheffa/dgp/). Cs.ubc.ca. Retrieved 2014-05-01.
13. "Discrete Differential Geometry" (http://ddg.cs.columbia.edu/). Ddg.cs.columbia.edu. Retrieved 2014-05-01.

Further reading

- Foley *et al*. *Computer Graphics: Principles and Practice*.
- Shirley. *Fundamentals of Computer Graphics*.
- Watt. *3D Computer Graphics*.

External links

- A Critical History of Computer Graphics and Animation (https://web.archive.org/web/20070405172134/http://accad.osu.edu/~waynec/history/lessons.html)
- *History of Computer Graphics* series of articles (https://web.archive.org/web/20070302154206/http://hem.passagen.se/des/hocg/hocg_1960.htm)

University groups

- Computer Graphics Usability and Visualization Group (http://gruvi.cs.sfu.ca/) at Simon Fraser University
- Computer Graphics Group (http://www.cs.hku.hk/GraphicsGroup/) at The University of Hong Kong
- Media Technology Research Centre (https://web.archive.org/web/20111205121054/http://www.bath.ac.uk/mediа/) at the University of Bath
- Berkeley Computer Animation and Modeling Group (http://www.cs.berkeley.edu/b-cam/)
- Berkeley Computer Graphics (http://graphics.berkeley.edu/)
- Bristol University Computer Graphics Group (https://web.archive.org/web/20070225063956/http://www.cs.bris.ac.uk/Research/Graphics/)
- C²G² at Columbia University (http://www.cs.columbia.edu/cg)
- Center for Visual Information Technology (http://cvit.iiit.ac.in), IIIT Hyderabad
- Caltech Multi-Res Modeling Group (http://www.multires.caltech.edu/)
- Carnegie Mellon Graphics Lab (http://graphics.cs.cmu.edu/)
- Center for Graphics and Geometric Computing at Technion Israel Institute of Technology, Haifa, Israel (http://www.cs.technion.ac.il/~cggc)
- Computer Graphics Department (https://web.archive.org/web/20070610184922/http://www.mpi-inf.mpg.de/departments/d4/) at Max-Planck-Institut fur Informatik
- Computer Graphics Department at Haute Ecole Albert Jacquard (https://web.archive.org/web/20170914034849/http://computer-graphics.be/)
- Computer Graphics Group at Brown (http://graphics.cs.brown.edu/)
- Computer Graphics Group at (http://www.rwth-graphics.de)RWTH Aachen University
- Computer Graphics at Harvard (http://gvi.seas.harvard.edu)
- Computer Graphics and Immersive Technologies Laboratory (http://graphics.usc.edu/cgit/index.php) at USC
- Graphics Lab (http://gl.ict.usc.edu/) of Institute for Creative Technologies at USC
- Computer Graphics Laboratory (https://web.archive.org/web/20070708173122/http://cg.kaist.ac.kr/) at Korea Advanced Institute of Science and Technology (KAIST)
- Computer Graphics Group (http://www.tecgraf.puc-rio.br) at PUC-Rio
- Computer Graphics Group (http://cg.cs.uni-bonn.de/) at University of Bonn
- Computer Graphics Group (http://www.cs.virginia.edu/~gfx) at University of Virginia
- Computer Graphics Laboratory (http://nis-lab.is.s.u-tokyo.ac.jp/index-e.html) at University of Tokyo
- Computer Graphics Laboratory (http://www.cs.utexas.edu/users/graphics/) at UT Austin
- Computer Graphics Laboratory (http://graphics.ethz.ch/) at ETH Zurich
- Computer Graphics / Geometric Design Group (http://www.cs.rice.edu/~jwarren/graphics.html) at Rice
- Computer Graphics and User Interfaces Lab (http://www.cs.columbia.edu/graphics/top.html) at Columbia University
- High Performance Computer Graphics Lab (http://hpcg.purdue.edu/) at Purdue University
- Computer Graphics and Visualization Lab (http://www.cs.purdue.edu/cgvlab/) at Purdue University
- Computer Graphics and Visualization Lab (http://www.cs.utah.edu/graphics/) at University of Utah
- Computer Graphics and Visualization Lab (http://www.cs.wisc.edu/graphics/GraphicsWeb/index.html) at University of Wisconsin
- Cornell University Program of Computer Graphics (http://www.graphics.cornell.edu/)
- Dynamic Graphics Project at University of Toronto (http://www.dgp.toronto.edu/)
- Geometric Modeling and Industrial Geometry Group (http://www.geometrie.tuwien.ac.at/ig/) at Technische Universitat Wien
- The Institute of Computer Graphics and Algorithms (http://www.cg.tuwien.ac.at/research/) at Technische Universitat Wien
- Graphics and Image Analysis at UNC (http://www.cs.unc.edu/Research/ProjectIndex/GraphicsImage.html)
- Graphics and Imaging Lab (http://graphics.unizar.es/) at Universidad de Zaragoza
- Graphics and Geomatics Group (http://gggj.ujaen.es/) at Universidad de Jaén
- Graphics and Geometric Computing Group (https://web.archive.org/web/20070427212320/http://cg.cs.tsinghua.edu.cn/) at Tsinghua University
- Graphics@Illinois (https://web.archive.org/web/20010201203100/http://graphics.cs.uiuc.edu/)
- GRAIL (http://grail.cs.washington.edu/) at University of Washington
- GRAVIR at iMAGIS (https://web.archive.org/web/20061219013441/http://www-gravir.imag.fr/)

- GVIL (http://www.cs.umd.edu/gvil) at University of Maryland, College Park
- GVU Center (http://www.gvu.gatech.edu/) at Georgia Tech
- IDAV Visualization and Graphics Research Group (http://graphics.cs.ucdavis.edu/) at UC Davis
- IMAGINE Research Group (http://imagine.uniandes.edu.co) at Universidad de los Andes, Bogotá, Colombia
- Imager Laboratory (http://www.cs.ubc.ca/labs/imager/) at University of British Columbia
- MIT Computer Graphics Group (http://groups.csail.mit.edu/graphics/)
- MRL (http://www.mrl.nyu.edu/) at NYU
- Princeton Graphics and Geometry Group (http://www.cs.princeton.edu/gfx/)
- Stanford Computer Graphics Laboratory (http://graphics.stanford.edu/)
- UCSD Computer Graphics Laboratory (http://graphics.ucsd.edu/)
- ViRVIG (http://www.virvig.eu/) at Polytechnic University of Catalonia
- Vision Research Center (http://vision-research.vanderbilt.edu/) at Vanderbilt
- INI-GraphicsNet international network (http://www.inigraphics.net/)
- VRVis Research Center (http://www.vrvis.at/)

Industry

Industrial labs doing "blue sky" graphics research include:

- Adobe Advanced Technology Labs (http://www.adobe.com/technology/graphics/)
- MERL (http://www.merl.com/)
- Microsoft Research – Graphics (http://research.microsoft.com/graphics/)
- Nvidia Research (http://research.nvidia.com/)

Major film studios notable for graphics research include:

- ILM (http://www.ilm.com/)
- PDI/Dreamworks Animation (http://www.dreamworksanimation.com/)
- Pixar (https://web.archive.org/web/20070302102640/http://www.pixar.com/companyinfo/research/)

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