Hans-Peter Seidel

Hans-Peter Seidel, Director at the Max Planck Institute for Computer Science in Saarbrücken, is a leading expert in computer graphics – one of the few Europeans in a research field dominated by scientists from the United States.

Photo: Ruth Albus

The majority of the information that we obtain about our environment comes to us via our eyes. This promises a rosy future for computer graphics. Still: the enormous data sets that must be juggled to play realistic animations or even videos make the job of the computer scientist a tough one – so too the high demands on the eye that each simulation has to satisfy. A team headed by the Leibniz Prize winner **Prof. Hans-Peter Seidel** *based at the* **Max Planck Institute for Computer Science** *in Saarbrücken is developing mathematical techniques that substantially reduce the computing power needed for convincing animations – and that can run on every modern graphic card.*

What's the best way to find out about Michelangelo's David or the inside of an Egyptian tomb? To hop on a jet, in a car or train and, after an hour-long trip, stand in line with all the other like-minded art lovers, before eventually arriving at your destination with an aching stomach and sore feet? Isn't there a better way? Maybe – if the Internet revolution keeps developing at the same breathtaking pace. And: if scientists like Hans-Peter Seidel remain committed to their research.

The eloquent professor, 45 years young, is sitting in his study on the second floor of the Max Planck Institute for Computer Science in Saarbrücken. A bench stands on a wooded slope in front of his window on which, in the summer, students sit engrossed in reading. At first glance, there's nothing particularly unusual here: shelves laden with books, pencil and paper on a desk for visitors. The only reminder of the Director's type of work is a small, sophisticated but somewhat carelessly placed graphics workstation in front of his desk: Seidel is the head of the Computer Graphics Group and is something of a computer graphics "guru", if such a title can seriously be used to describe such an important scientist. A large number of people, however, have left his laboratory filled with new ideas – without even quite realizing that.

On video games, for example: "Graphic card developers do occasionally pay us a visit when new developments are around the corner," he reports. "There are even video games that use algorithms that have been originated here in Saarbrücken," he adds – techniques that rapidly compute realistic shadowing simulation. However these spin-offs shouldn't be overrated: Seidel is interested in computer games, but he hardly ever finds time to play around with them. His interest is much more fundamental: The development of efficient techniques for analysis and rapid image synthesis. "Electronic image processing is becoming increasingly important – ultimately people do gain most of their information through their eyes. Digital television, telepresence and 3D-internet: Those are all technologies founded upon developments in computer graphics," explains Seidel.

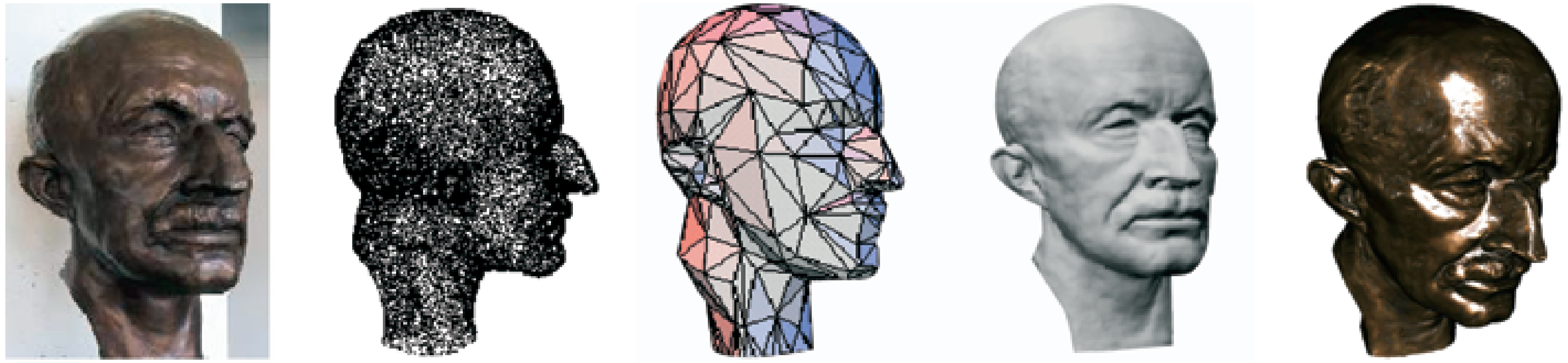
From Sculptures to Virtual Data Streams

Let's take a closer look at Michelangelo's virtual David. Those planning to make the statue available in a virtual form to art lovers via the World Wide Web – turning it around by mouse, enlarging it, even touching it with a data glove – are faced with the problem of modeling complex structures and surfaces with the least possible effort. After all, storage and computational demands for the digital model need to be mastered even by smaller computers. Coping with the enormous data volumes that are shoveled through hardware from high-resolution videos and halfway realistic animations still causes countless computers serious problems.

Thinking back to the infancy of computer graphics brings memories of rotating heads that were portrayed on the screen – usually less than successfully – with a mesh of triangles. The finer and more realistic the depiction needed to be, the more close-fitting the runs in the mesh. Making a sphere look convincingly round needed an almost uncountable number of such "polygons". Storage and computational hardware demands needed to rotate the objects were correspondingly high. For serious applications, however, the number of data points required to represent a statue in a virtual museum needs to be kept to a minimum. That this problem, among other things, can today be tackled more elegantly than with a network of ultra-fine, memory-hungry polygons is thanks to Peter Seidel – and the so-called B-splines, which he tackled as the subject of his postdoctoral work in Tübingen.

The two-dimensional solution for this problem has, in principle, been known for some time. Drawing programs users are already familiar with it: Bezier curves or "splines", curved lines that the computer constructs in a flash from a series of cubic functions. They appear on the monitor as bowed lines that wind themselves around a set anchoring point: with a single spline it's possible to define a wavy line using only a handful of mathematical terms. Previously these curves had to be constructed from a multitude of small, linear pieces using the vector chain principle.

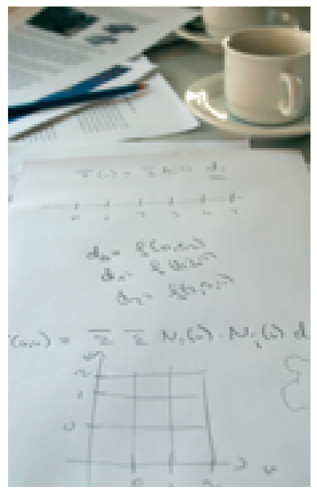
Similar ideas can be applied to surfaces: they can be visualized as smooth, rounded triangular surfaces that are used as puzzle pieces in constructing the facade of a rounded object. With such "triangular splines" the effort needed to mathematically describe the surface of, for example, a coffee cup can be dramatically diminished. "The problem, however, was to reconstruct a



A bust isn't the easiest of objects to carry around. In virtual form, however, it can be comfortably viewed using a normal computer. BDRF algorithms that run, thanks to a mathematical trick, on standard graphics cards enable realistic reflections to be portrayed, even without the use of complicated lighting simulations.

smooth curved surface using triangular splines whose edges could no longer be differentiated – that seamlessly progress from one to the other", recounts Seidel. This challenge – in effect polishing smooth a low resolution net of polygons – could not be overcome by the computer science of the day. The problem has meanwhile become a piece of mathematics history. Hans-Peter Seidel discovered a formal mathematical procedure to transform the cubic polynomials of B splines into their so-called polar forms. These deliver surprisingly simple, computer-manageable terms for the control points or coefficients of these curves. In Canada, where Seidel worked as an assistant professor between 1989 and 1992, he extended this method to eventually incorporate construction of smooth surfaces to fit any triangulations. This made it possible to describe curved surfaces as if they were enveloped by a rubber film made of a large number of triangular patches. After 3D scanning, computer graphics could now depict (triangulate) the geometry of, for example, a bust using fewer polygons than beforehand. This is rather like reconstructing an Apollo rocket using not only flat but also rounded building blocks in a wide range of sizes.

Approximating complicated objects using an ever fewer number of triangular splines is, however, only one aspect of the game. Portraying virtual surfaces constituted in this fashion realistically in a computer is something else altogether. The computing power needed to "light" a virtual scene quickly encounters limitations. "In principal, for every lighting simulation you have to calculate the energy that each triangular piece exchanges with every other in the scene. Typically in such a procedure, the increases in storage requirements at ever higher definitions is immense," explains Hans-Peter Seidel.



Most ideas are developed in Seidel's team not on a screen but with ordinary pencil and paper. Seidel places great importance, however, on finding uses for them outside the "ivory towers" of academia. In the end they have to function in normal commercially available graphics hardware and not just in high-end computers.

One solution is to calculate only those interactions that are essential to the final image. This is exactly what programs developed by Seidel and his team do: working with very large 3D data sets in real-time – encompassing efficient data acquisition, storage, rendering and synthesis of vast triangular meshes – is a specialty of the Computer Graphics Group.

The software developed here checks the number of polygons needed to realistically depict every object in a scene – lampshades, desktops, walls, carpets – prior to the computation of the virtual lighting. The program takes into account the geometry (more polygons in complicated areas and less, in comparatively flat areas) and even how far the object is from the observer. On top of this, so-called depth or shadow maps make it easier for the computer to orientate rapidly in the simulated scene. "We only calculate what the viewer can see," states Seidel. A clever little trial-and-error algorithm using "test rays" progressively cuts down the number of interactions that need to be computed within a set of error limits. Eventually the error arising from this type of reduction becomes so great that its adverse effects would become noticeable.

The process is astonishingly successful. "This method allows us to reduce substantially the storage requirements for radiosity computations. In place of a million interactions sometimes only ten thousand are needed for a realistic image," claims Seidel.

Is that enough however for our virtual museum? Not quite. "In the last few years a lot of work has gone into calculating lighting simulations. The interaction of light with different types of surfaces was, however, somewhat neglected," clarifies Seidel. The reflective properties of many objects are often much more complicated than was previously thought. Human skin is a good example. Rays of light are not simply reflected from your face; they penetrate the skin and migrate more or less under the surface to reemerge at another point. This complexity is the reason why, despite all efforts to create realistic facial animations, a computer-generated Marilyn Monroe still doesn't exist. Even "simple" painted automobile fenders often look different on screen than in real life – the different layers of paint, each with distinct refractive properties, still haven't been taken into account in models. This complexity is the reason why researchers have been reticent up till now to come to grips with these types of scenario. Hans-Peter Seidel, therefore, maintains he needs not only mathematicians and computer scientists in his team but also physicists: "if you want to know how an object reflects light you'd better find out what's going on under its surface."

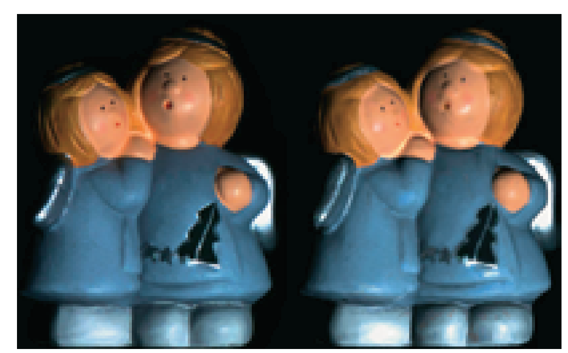
Photos: Ruth Albus / computer simulations: MPI for Computer Science

Graphic Cards that Think in Four Dimensions

Realistic physical models that successfully simulate complex refractive and reflective behavior, even of simple wallpaper, are still too demanding for computers. Once again, intelligent simplifications of the problem can help. There are functions that describe the color and intensity of reflected light not only depending on the angle of incidence but also on the angle from which the observer views the light. In this way, a dull piece of wood can be made to shine when observed from the right angle. The disadvantage of BDRF (Bidirectional Reflectance Functions), however, is that they are four-dimensional. This means they cannot be processed by most graphic cards – unless, that is, some sort of trick is employed to "accommodate" their chips.

To do this Seidel and his colleagues dissect the four-dimensional BDRF functions with mathematical processes that split them into the product of two two-dimensional factors. The computer scientists then simply write the values of both of these functions into the memory units of graphic cards. These are actually designed for computer games and contain conventional bitmaps. The crux: these memory blocks have the advantage that they can be read and multiplied with each other in a flash by the hardware – fast enough to reconstruct the BDRF functions in real-time.

The process isn't particularly complicated even when acquiring the BDRF function of an object such as a marble sculpture or a bronze bust. The Computer Graphics Group uses a small photo studio for the job in which various test objects are photographed at different angles and exposures. "To keep things simple we try to make do with ten to twenty shots," says Seidel. As a computer scientist and software developer, Seidel considers it self-evident that he should also deal with data acquisition. He views the entire computer graphics processing chain holistically – from image analysis (the acquisition and reduction of data) to im-



Comparison of the original (left) and the simulation on the monitor (right) shows that data from 3D scanners can now be so accurately processed that digital representations of real objects are now hardly inferior to photos – the only difference being that the "virtual" angel on the screen can be turned and viewed in real-time from all sides.

An antidote to "data flood": algorithms that pare down polygon meshes make large data sets manageable on standard computers – such as that needed to take a virtual flight over a bend in the river Saar.

Simulating the reflective properties of complex surfaces in computers needs not only expertise from computer scientists and mathematicians but also from physicists – physicists are needed to understand what happens when light interacts with the surface of objects. Seidel's research group, for example, is actively involved in investigating "hairy" objects, which still provide programmers with headaches.

age synthesis employing simplified and, above all, fast algorithms, which are tailored to the computer's capabilities.

In this way, computer graphics in Saarbrücken grows from their roots up: from the development of scanning procedures, which directly relay data to graphics software. Once the images and 3D scans have been obtained the computer builds up not only a spatial representation of the object being photographed but also reconstructs the reflective properties of each point on its surface.

Using BDRF, faces appear significantly better – when still not completely real. However, inert surfaces such as wood, synthetic materials or metals do come very close. Not only can digitized objects give a truly deceptive reproduction of their original models they can be orientated in real-time on the screen with a mouse. "Basic research in computer graphics needs to stay in contact with the ground. We try to develop algorithms that play to the strong points of standard graphics cards on the market," says Seidel. This is the only way that the beautiful, new world of graphics can be deployed not only in high-end computers but also in smaller computers – such as those used by firms planning ever more products solely on the screen or by doctors preparing for operations with a virtual trip down an artery.

Industry is also profiting from real-time computer simulations of objects. A new automobile can take a virtual trip through the countryside before its prototype has even been built.

Seidel's career development demonstrates that he has continually orientated himself on the technically feasible and has always tried to view computer graphics "from both sides". After graduating in Tübingen he started programming the first available computers (from Atari) in a postgraduate study year at Berkley – finding out "what the boxes of tricks were capable of," as he puts it. His work on B splines, which he started after his doctorate (1985 to 1989 with distinction) was as part of his "habilitation" (the German postdoctoral lecturing qualification) at the University of Tübingen (1987 to 1989) and originally sprang from their mathematical interest.

However, his work on "Simulation of Light Propagation within Complex Scenes" while holding the chair in computer graphics at the University of Erlangen-Nuremberg thrust him into the mainstream of computer graphics – a research area in which, as an outsider, he was continually having to prove himself. Seidel, born in Stuttgart, was 33 years old at the time. In the meantime his unimpeded mathematician's perspective on this rapidly growing field has more than proved itself. The Leibniz Prize, awarded to him in February, is testimony to his success.

The concrete applications that spring from his work are definitely factors that have contributed to his reputation in the field and in industry circles. Minolta, for example, is currently interested in 3D scanners and the BRDF process from Saarbrücken. Being close to the eventual applications, however, is no "one-way street" and, even less, research aimed simply to win funds. "Inquiries from industry help us learn to validate our methods and to test them using real examples," says Seidel. Visualizing a fender doesn't simply benefit the designers in an automobile firm; it also helps the scientists in Saarbrücken, conversely,

Computer simulations: MPI for Computer Science

The Leibniz Prize 2003

The Gottfried Wilhelm Leibniz Prize is the most valuable research prize in Germany. It is awarded by the "Deutsche Forschungsgemeinschaft" (DFG) and is intended to improve the working conditions of outstanding scientists and to facilitate new research. Each prize is endowed with 1.55 million euros and flows into research over a period of five years. The DFG has awarded the prize 207 times since 1985, and the prizewinners include a considerable number of young scientists. This year eleven scientists have been honored, four of whom are from Max Planck Institutes. In addition to Prof. Hans Peter Seidel the DFG has recognized the following Max Planck scientists.

Dr. Winfried Denk (45), medical optics, Max Planck Institute for Medical Research in Heidelberg. The DFG views Denk as a scientist who "crosses boundaries" between physics and neurobiology. He worked on the pioneering development of two-photon microscopy that will open up "entirely new approaches" in brain research.

Prof. Gerhard Huisken (44), mathematics, Max Planck Institute for Gravitational Physics in Golm. The DFG recognizes Huisken as "one of the world's top researchers" whose work is the development of the shape of surfaces with the passage of time, a research field he co-founded in the 1980s.

Prof. Ferdi Schüth (42), inorganic chemistry, Max Planck Institute for Coal Research in Mülheim. Schüth receives the prize with a reputation as a "creative and multi-talented young scientist." His primary interest lies in the investigation of new types of materials called mesoporous solids.

to exposure weaknesses within their algorithms.

Hans-Peter Seidel is on the editorial board of several highly regarded journals and jointly organizes a number of important conferences, which he helped to bring to Germany for the first time. In addition, he is the only non-American member of the ACM Siggraph Award Committee, well known to insiders as the "Mount Olympus" of computer graphics. Small wonder, then, that Seidel is not only building bridges between mathematics and computer technology but also literally between worlds. His credo, that "contacts are unbelievably important," refers not only to users and colleagues in the USA but also to young people who are just starting to find their way in science. "Germany needs to get much more international – good brains are in short supply in the country," expounds Seidel. "Whether young researchers leave after gaining their doctorates or end up by staying is unimportant. What counts are the contacts that remain afterwards."

This is an idea, which he has remained faithful to. To make it easier for foreign students to study in Germany computer science lectures at the University of Saarland, which Seidel as a teacher is committed to teach, are held in alternate years in German and English – English is, after all, spoken as standard in his working group. The postgraduate masters course in Computational Engineering that he initiated in Erlangen is taught in German or English and was one of the first internationally orientated courses in the country. It seems only natural that Seidel now helps to coordinate large European computer graphics research projects; a third of his post-docs come from abroad.

The disadvantage of leading such a sought-after research group is all too often felt. In the last few years, eleven of his colleagues alone have gained posts as professors in Germany and abroad. More will surely follow. This continuous fluctuation doesn't make his job as a researcher any easier – "even though I'm naturally delighted for every colleague who can progress in this career." If computer graphics, with help from the Saarbrücken group, continues to develop so rapidly Seidel may not need to travel to meet up with old colleagues in the future. A virtual handshake with a data glove every now and then will probably suffice.

Stefan Albus

"Scientific exchange is crucial. Germany needs to get much more international," claims Hans-Peter Seidel. The postgraduate masters course in Computational Engineering initiated by him in Erlangen is taught in German or English and was one of the first internationally orientated courses in the country.

Photos: Ruth Albus