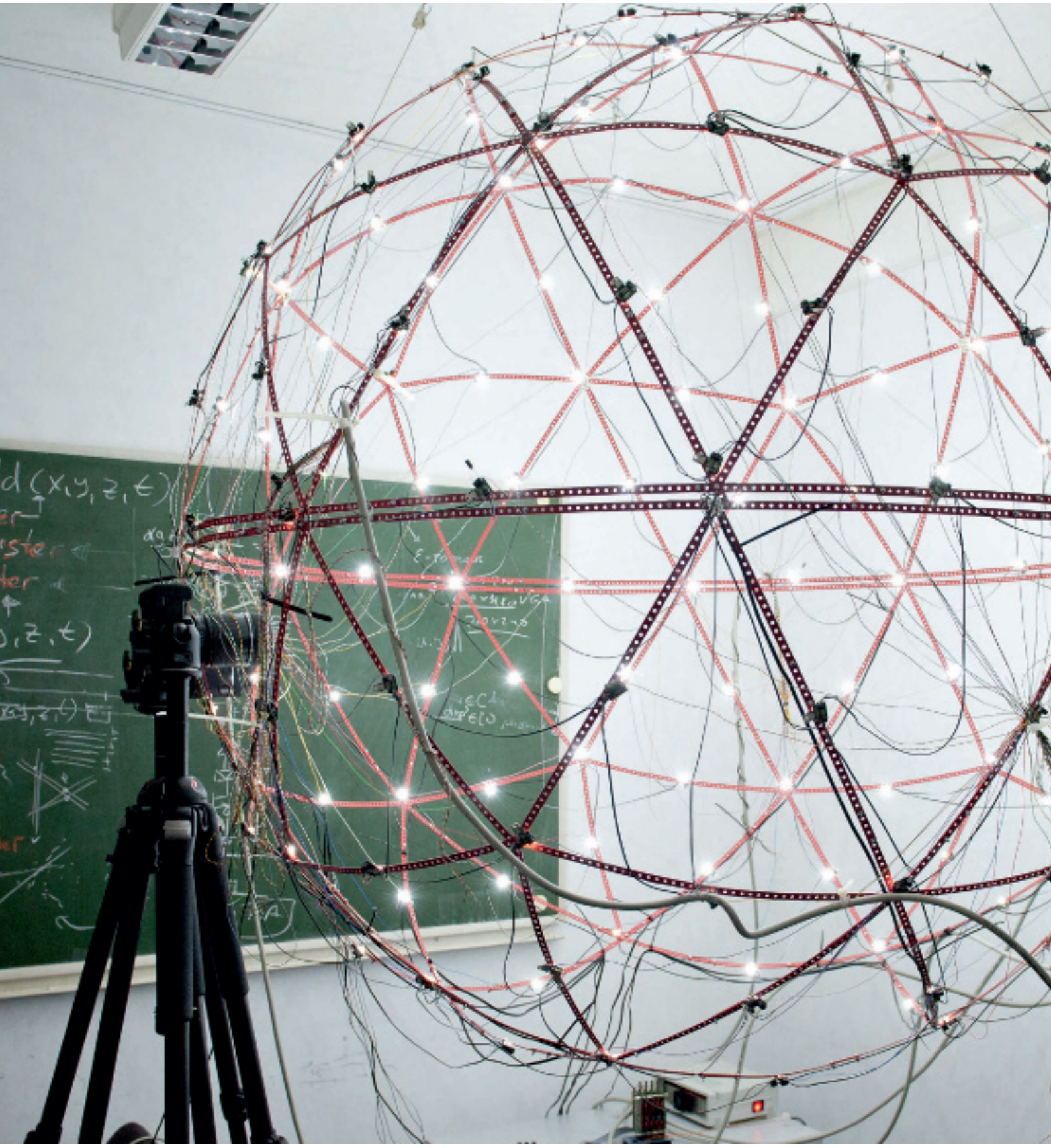


Photos: Manuela Meyer (left); MPI for Informatics

Images Take **Shape**

Humans need only a two-dimensional photo or film to be able to perceive a face or a body in 3-D. Researchers working with **Thorsten Thormählen** at the **Max Planck Institute for Informatics** in Saarbrücken are teaching this skill to computers, thus creating new ways of working with images and films. Applications already exist: a 3-D makeup guide and a program that can be used to manipulate human bodies in movies.

TEXT **TIM SCHRÖDER**

The light stage (left) helps in the development of the face analysis program. The Saarbrücken researchers use it to create images in different lighting conditions in order to analyze the three-dimensional structure.

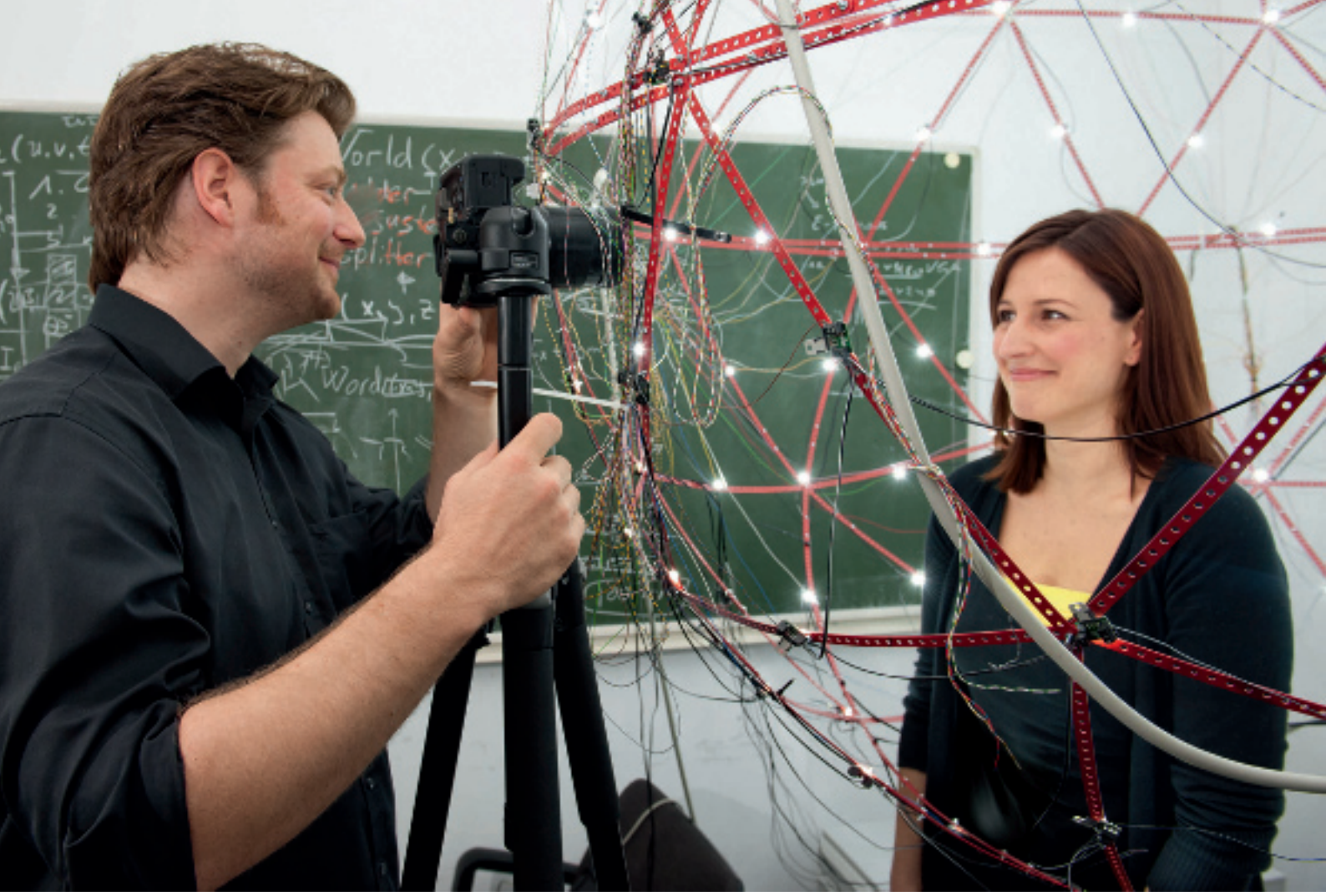


Photo session for science: Thorsten Thormählen takes a photo of his colleague Kristina Scherbaum for test purposes. Using such images, the researchers can determine a face template and create a library of different types.

It was looking a lot like Christmas in Thorsten Thormählen's lab in recent months. A huge light stage hung from the ceiling. Together with his colleagues, Thormählen had bolted metal strips from an Erector set to a round skeleton and then fitted it with several dozen LEDs. The light stage, used by the researcher to photograph faces, measures a good two meters in diameter.

Thorsten Thormählen and his colleagues at the Saarbrücken-based Max Planck Institute for Informatics are working at the boundary between reality and the computer world. They transplant images of real, three-dimensional objects into virtual scenes or manipulate the bodies of movie stars in video clips.

An activity that sounds almost like data falsification is actually genuine basic research – the Saarbrücken-based researchers want nothing less than to teach the computer to understand scenes. A human intuitively recognizes another human in a video. A computer, however, sees only a cloud of colorful pixels when a sequence of images is loaded into its system. "We want the computer to extract real, three-dimensional objects from a two-dimensional scene," says Thormählen, summing up the mission of his "Image-based 3-D scene analysis" research group. For us humans, it's child's play. Even in a two-dimensional photo, we can see whether a house or a car is in the foreground. Teaching a computer to make intelligent observations is much more challenging.

TWO-DIMENSIONAL IMAGES DELIVER 3-D INFORMATION

A large light stage, for example. The researchers are extending an idea that Kristina Scherbaum and her mentor Volker Blanz implemented a number of years ago. They succeeded in reconstructing a three-dimensional image of a face from a conventional photo. Thormählen, Scherbaum and their colleagues are now beautifying the virtual, three-dimensional faces by creating the appropriate makeup for them.

"It works," says Thormählen. "We photographed women at CeBIT and had our newly developed software determine the most suitable makeup for them. It is demonstrated in a three-dimensional visualization of the face." The ideal makeup guide in 3-D? It sounds almost trivial. In fact, Thormählen is working at the frontier of computer graphics with this software. This research is becoming the test case for determining whether a computer can extract correct 3-D information from a two-dimensional image. So what is the purpose of the light stage?

It is a vital tool for photographing faces in detail in a variety of lighting conditions. If a computer is to be

Photo: Manuela Meyer

» The ultimate goal for the graphic designers is to develop an artificial head that is indistinguishable from the real thing. It would be equally attractive for video games, theater movies and Internet applications.

taught how to convert two-dimensional photos of faces into 3-D model heads, it must be trained in advance to do so using 3-D face data. To start the project, the researchers arranged for 56 women to sit, one after another, on the stage and took photos of them from different angles and in different lighting conditions. Stripe patterns were then projected onto the faces of the test subjects, showing the curvature of the nose, cheeks and chin.

Makeup advice from the PC: The program first generates a realistic image of a face (left) and then suggests a makeup style (center). The face is shown with unflattering makeup for comparison purposes (right).

MATHEMATICAL FORMULAE FOR FACIAL DETAILS

Scherbaum and Blanz's proven software, which generates 3-D heads, was then deployed. This software collected information on all 56 faces, generating a standard head, a digital face template – a data record that the computer can use at a later stage to accurately recognize a face as a face.

If a two-dimensional photo of a new face is subsequently imported into the system, the portrait is measured using the existing template and is transformed – or morphed, to use the technical term – into a 3-D face model. The program thus describes the new face using the knowledge already stored in the system – a nose like face 25, cheekbones like face 34, a chin like face 56.

The software then performs an optimization process. It generates a 3-D image of the face, translates it back to 2-D, compares the data with the photo prototype and enhances the 3-D image again in the case of doubt. Until everything finally matches. One difficulty with this process is capturing, as mathematical descriptions, the countless details that humans comprehend at a glance. The computer is able to compare a new face with the stored patterns only if it has the necessary formulae to do so.

This work not only helps researchers discover the exact three-dimensional shape of a face, but it also helps them identify the properties of skin. The computer can calculate these details exactly for each pixel based on the surface reflectance, as the exact position of the LEDs on the light stage is known. The computer can even determine the position and depth of individual pores on the skin. The result is a very life-like "skin model" on the computer.

THE OBJECTIVE: A LIFE-LIKE HUMAN IMAGE

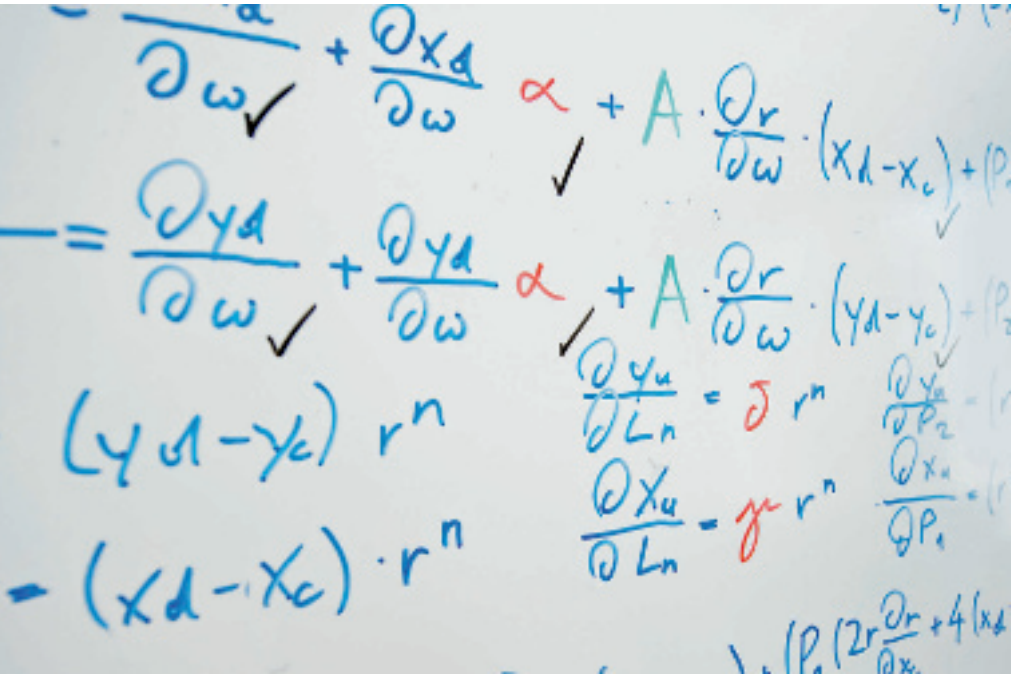
Of course, this is a considerable amount of work for a paltry makeup guide. For Thormählen, it is certainly more than that. He is attempting to come as close as possible to a life-like image of a human and is thus following a trend in computer graphics. The ultimate goal for the graphic designers is to develop

A variety of information is stored to generate a life-like model of a face (from left): diffuse part of the reflected light, normal surface direction (color-coded), 3-D position of the surface (color-coded), strength of the directed part of the reflected light, strength of the glossiness, and strength of the volume scattering.

Photos: MPI for Informatics

an artificial head that is indistinguishable from the real thing. It would be equally attractive for video games, theater movies and Internet applications.

It all depends on nuances, especially the interplay of light and the surface of the face. After all, humans are incredibly good at differentiating between genuine and fake faces. The wrong reflectance in the iris, and a digital android becomes repugnantly artificial. Illumination of the skin is also important. A face does not reflect light in the same way that a mirror does. Certain sections are scattered and reflected diffusely. Consideration must also be given to the light that penetrates into the skin and is reflected by the skin's deeper layers. It gives the face its typical warm, "life-like" character. This is one reason why too much makeup can look unnatural.



Kristina Scherbaum and Thorsten Thormählen discuss new ideas. Filou, the dog, makes sure that nobody steals a note with the latest research approaches and also entertains with a variety of tricks.

Photos: Manuela Meyer

Thormählen is trying to make the true-to-life artificial head as similar as possible to his makeup model. Of course, the computer must also be loaded with makeup information for the high-tech, 3-D makeup wizard. Thormählen and Scherbaum photographed the subjects with and without makeup. To do this, they hired a professional makeup artist from a Saarbrücken theater to apply makeup that best suited each individual woman.

THE COMPUTER AS MAKEUP ADVISOR

The makeup artist's extensive knowledge about the makeup that best suited each face type, i.e. the eye and hair color that suits each complexion, now has to be converted into data by the Saarbrücken computer scientists. This will be added to the mountains of data available on morphable face models and the skin information derived from the light stage. The researchers must now consolidate this information, not intuitively in the way that humans can, but in the analytic formula language that computers understand.

Now, if a researcher scans a photo, the computer generates a 3-D face model, which it compares with the known faces in the database. A pale complexion? Then somewhat less rouge and a little more eye shadow would be suitable. At the end, the software suggests the makeup that best suits the new face. The artificial face can be turned and tilted and viewed in different lighting conditions – in sun-

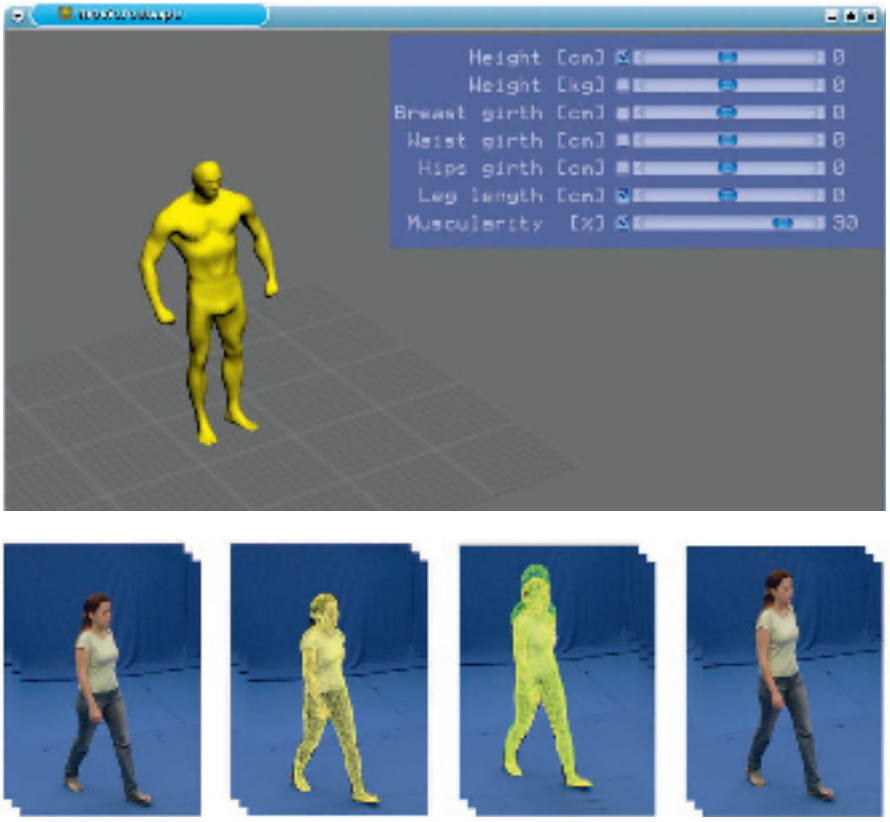
shine or in a dimly lit disco. Thanks to the high-resolution photos taken on the light stage, the faces have a deceptively real look.

REAL SKIN MODELS FOR COMPUTER GAMES

Thormählen's team originally wanted to develop a software program that offered women makeup suggestions that came close to the theoretical ideal of beauty. According to psychologists' findings, such an ideal is characterized by sallow skin, fuller lips, thinner eyelids, long, dark eyelashes, higher cheekbones and a narrow nose. With good makeup, it could be possible to really sculpt the face to achieve such a look. The researchers ultimately felt it was more appropriate to aim for an individual optimum look and not the ideal standard.

The makeup system developed by the computer scientists represents the state of the art in computer graphics. The last five years have seen the emergence of sophisticated morphable models and real skin models. These could potentially have a wide range of applications, e.g. Internet services in which true-to-life, virtual employees speak, provide tips or help users operate equipment. The computer games industry is also a growing market. According to data provided by the German Trade Association of Interactive Entertainment Software (Bundesverband Interaktive Unterhaltungssoftware, BIU) and auditing firm PricewaterhouseCoopers, the industry is undergoing rapid expansion. In the games industry, global sales of computer games topped USD 50 billion in 2008. The games market has long since overtaken the DVD and Blu-ray movie business, which realized sales of just under USD 35 billion in the same year.

The more realistic the artificial figures and the virtual worlds are, the more attractive they are, and the more money customers are prepared to spend on them. Life-like faces play an important role in this area, as does the movement of figures. Thormählen scored a real coup in this regard last year. Using the new MovieReshape software, he succeeded in modifying the shape of the protagonists in a real video.



Virtual bodyshaping: The 3-D model of a body can be morphed arbitrarily – the man on top has been given particularly strong muscles. Since the model is being manipulated in accordance with its natural proportions, a body also appears natural while in movement (bottom).

VIRTUAL POUNDS FOR HOLLYWOOD STARS

Up until then, talented computer graphics designers could perform such modifications only in photographs, by airbrushing out the beginnings of a politician's paunch or a TV star's wrinkles, for example. It was inconceivable that the same thing could be done in movies with 25 images per second. However, the new software can be used to easily make slight modifications to the people in the movie simply by moving small sliders back and forth on the screen to reduce or increase the size of the actor.

While no actual product exists yet, the prototype for the new image processing software has delivered very impressive results. The demo video has already attracted hundreds of thousands of clicks on the Internet: a *Baywatch* actor is shown jogging through the sand on the beach, in one shot with a flat chest, in another with more curved muscles. In another clip, an athlete shoots balls into a basketball hoop while his beer belly grows.

Critics complain that "not even videos are safe from forgery now." Thorsten Thormählen acknowledges these concerns. For him, however, the new software is a tempting tool for jazzing up professional video recordings. "Previously, some Hollywood stars would put on a few pounds for a movie role," says Thormählen. "This

Photos: MPI for Informatics

» Thorsten Thormählen scored a real coup last year. Using the new MovieReshape software, he succeeded in modifying the shape of the protagonists in a real video.

can now be done on the computer using our software without any stress whatsoever."

THE PROGRAM LEARNS TO DISTINGUISH BETWEEN BODIES

The ease with which the *Baywatch* Adonis runs along the beach hides the fact that developing MovieReshape also involved hard, mathematical work. As in the case of the artificial head, a digital model first had to be created. In this case, it was a morphable body model. Once again, the computer calculates a realistic, three-dimensional model from a two-dimensional scene. After all, the manipulation of a movie clip is convincing only if it is consistent with a realistic potential change in the three-dimensional movie object.

To produce the three-dimensional model, the researchers first scanned in the bodies of approximately 100 test subjects. The computer then learned to distinguish between fat and thin, long and short, or powerful and slim thighs. If the researchers then import a video clip into their computer, the program automatically adapts the digital body model to the figure in the image. It does this for each individual image in a movie clip. As already mentioned, a flicker-free video contains 25 images per second. It still takes hours to perform such an automatic image analysis. But then the process speeds up. Once the computer has analyzed all the images and the actor's position, one movement of the slider is sufficient to increase or decrease the size of the body as desired – consistently in all images in the movie clip.

It sounds easy. The trick, however, is to morph the body in a way that is anatomically correct. It's not enough to just lengthen the stomach and legs. The thickness of the limbs or the torso must also be changed. Otherwise the figure quickly becomes a caricature. The software extracts the mathematically formalized knowledge about the right proportions from the body scans saved in the system.

The computer also needs something else: correct knowledge of how a skeleton moves anatomically. For this, Thormählen was able to draw on an established procedure that has long been employed by computer scientists. This procedure uses a skeleton that defines the positions that bones can assume, or the angles that joints can make. Thormählen joined this artificial skeleton to his morphable body model. "This means that the software can position arms and legs in a way that is anatomically correct in an image sequence," he says.

THE 3-D MODEL RESURRECTS CHARLIE CHAPLIN

The end result is that Thormählen and his colleagues have more or less automated the editing of moving images. This is exactly what the computer graphics industry needs. There is demand for programs that can load a computer with prior knowledge about the human figure. It is only with this prior knowledge and the appropriate software that the computer will eventually be able to modify the figure semi-automatically, or perhaps even completely automatically. "Currently, a lot of the work is still done manually, pixels are moved around on the screen using the mouse, areas are colored in or have their colors changed," says Thormählen. Programs that automate these time-consuming tasks are therefore eagerly sought after.

Not only can the three-dimensional model be used to customize the actors' bodies to the requirements of the script or even to suit popular taste, but it could also help animate actors. Ultimately, a certain amount of filming could one day be replaced by a photo shoot – filmmakers would then trans-

Gaining weight despite exercise: The young man's stomach grows larger as he shoots some hoops.

Photos: MPI for Informatics

Filming for video modification: Kristina Scherbaum and Thorsten Thormählen capture image sequences for the MovieReshape program in the video studio. It is easier for the software to adapt the artificial skeleton of the digital body model to the captured image sequences against a monochrome background rather than a real background.

fer their actors' movements to the computer. Even Charlie Chaplin could be resurrected in this way. All that would be necessary would be to load his head and body from old movie scenes into the computer. The computer could then make Chaplin walk and jump as desired. "We haven't solved all the problems yet, but with a little work, we could teach our software to do this," says Thormählen. Last December, he presented MovieReshape at SIGGRAPH Asia, one of the world's most important conferences in the computer graphics industry.

The software would also be useful for sports analysis. It could, for example, demonstrate an ideal sequence of movements to an athlete, using his or her own image. It could be used to produce motivational videos in gyms: "This is how I would look if I worked out three times a week."

The next objective for Thormählen's team is to accelerate the morphing process and automate it even further, reducing the time needed for a computer to analyze the video data. In terms of faces, the computer scientist is hoping to make them even more life-like. The skin already looks authentic. Now, convincing movement and deceptively genuine facial expressions must be added. New and faster algorithms are needed to do this. "It would mean that a computer system could even identify moods," says Thormählen. Controlling a computer using gestures or facial expressions would also not be beyond the realms of possibility. Computer game fans would not be the only ones who would benefit from such a development. Such a function could also make it easier for paraplegics to work on computers. ◂

GLOSSARY

Morphable body model
A body model that can be realistically morphed and made to move in three dimensions. It can be used as a template for manipulations in two-dimensional movie clips. Like the 3-D face model, it is generated by a software program that compares bodies from arbitrary two-dimensional movie clips with a catalog of scanned body shapes and gestures.

Morphable face model
A three-dimensional model of a face that can be manipulated. A software program creates it from an arbitrary person by comparing the face with a catalog of existing faces.

MovieReshape
A computer program that facilitates the fast and easy manipulation of body shapes and proportions of actors in movies. The software operates with a 3-D body model (see above).

Photo: Manuela Meyer