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A New Theme for Educating New Engineers: Computational Visualistics*

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A multimedia degree program for *educating new engineers for new themes* is described. The subject of Computational Visualistics was introduced at the University of Magdeburg, Germany, in the fall of 1996. This five-year diploma program has computer science courses as its core: students learn about digital methods and electronic tools for solving picture-related problems. The technological areas of endeavour are complemented by courses on pictures in the humanities. In addition to learning about the *traditional* (ie not computerised) contexts of using pictures, students intensively practice their communicative skills. As the third component of the program, an application subject such as medicine gives students an early opportunity to apply their knowledge in that they learn the skills needed for co-operating with clients and experts in other fields. We present Computational Visualistics in the context of recent discussions on reducing the separation between the *two cultures* as described by C.P. Snow.

INTRODUCTION

The last decade has seen the beginning of an explosion around the keyword *multimedia*. Practically all aspects of today's work with computers are affected by it. The hardware industry is building PCs for processing the vast amounts of data that are accumulated from working with high-resolution images and high quality audio. The integration of pictures with text, sound, and embedded executable code on the Internet plays an important role in the success of e-commerce.

THE IMPORTANCE OF PICTURES

Many jobs are being created in various branches of the multimedia segment of the information technology industry, with the creation of many more jobs forecast. These are jobs for highly educated people: multimedia engineers with well-developed communicative skills who not only have mastered technology but are sensitive to the non-technical contexts of their work.

Dealing with digital pictures effectively and adequately will be one of the fundamental engineering challenges in the years to come. Computers and other new imaging techniques allow us to produce more and more pictures, which need to be processed by both computers and humans. We contend that the preoccupation with pictures on computer screens and human-computer interaction through pictures is one of the topics of lasting value that will emerge from the multimedia age.

Pictures are increasingly used as a means of presenting, discussing, or convincing. The technical progress of recent years has led to an explosion in the availability of data presented visually. Recall, just as an example, the enormous quantity of pictures taken by satellites, which cannot possibly be coped with *manually*. Furthermore, its digital form opens the way to manipulating that data almost without limitation. In the entertainment industry, such *makeovers* can be quite desirable, but in political and economical contexts, however, the consequences may be catastrophic.

Imaging is the computational generation of visual images as representations of almost any property or combination of properties in the world, and it plays an

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increasing role in medicine and material science, in astronomy, geography, aerodynamics and particle physics, to name just a few application fields.

In the long term, the fabrication of visual impressions that do not reflect reality, up to and including so-called *virtual reality*, may have even further reaching consequences. Films like *A Bug's Life* or *The Matrix* are well-known examples of the use of model-based, digital image generation to create a purely imagined *reality*. The economic potential of visually intriguing computer games cannot be overestimated. In a more practical context, similar techniques may be used in flight simulations for pilot training, as well as in planning tasks such as city management and urban development or even in archaeological research and other presentations of historical information (see Figure 1).

Pictures are a particularly sensitive part of human communication since they are (in contrast to verbal signs) *perceptoid* signs: to understand them we employ perceptual mechanisms that are similar (or even equal) to the mechanisms for visually perceiving the scenes referred to. Therefore we have an unconscious tendency to interpret every depicted scene as factual, whereas we usually approach verbal descriptions with much more scepticism. Engineers who manipulate pictures (or develop methods for that purpose) should be aware of these sensitivities and try to avoid a merely technical (ie technocratic) perspective.

NEW ENGINEERS AND THE TWO CULTURES

C.P. Snow's diagnosis that modern (Western) society is split into *two cultures* still holds after 40 years [2]. In his *Rede Lecture*, Snow used that expression to refer critically to the communication breakdown between art and the humanities on the one hand, and science and engineering on the other. Since recent developments in teaching may be seen in that light, a closer look at the underlying difference may help to better understand the concept of *new* engineers.

In a nutshell, engineering is the endeavour to construct systematically and methodically material artefacts (or engines) that are defined by some given purpose. If they serve that purpose they *work*; if they don't work then they are *broken*. In contrasting engineering with the empirical sciences, there is essentially a difference in focus, and not in general attitude. As Brooks put it: *The scientist builds in order to study; the engineer studies in order to build* [3]. The engineering enterprise can be understood as one of the most prominent consequences of a shift in the

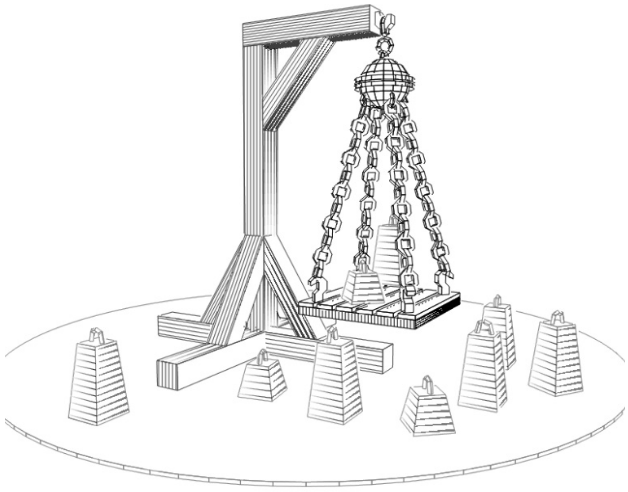

Figure 1: Computer-generated sketch of one of Otto von Guericke's vacuum experiments: the *semispheres of Magdeburg*, 1672 [1].

late medieval period, prepared by Bacon, explicitly stated by Galileo, and ideologised by Descartes [4, Vol.2]: a shift that made possible the enormous acceleration of technical development of the subsequent four centuries. It was to begin focusing more or less exclusively on how nature can be *used for our goals* as the only guiding principle for rationality of arguments.

The ancient and medieval philosophers had sought to understand nature in its own right (or with respect to God's aims), without projecting onto it our own views. This approach was called into question since mere access to the nature of things (or to God's own aims, respectively) could not be rationally defended. Understanding nature seemed possible only as a means of dominating nature. Engineering comes, so to speak, as a late consequence of the biblical injunction to *subdue the earth* (Genesis 1:28).

The humanities, on the other hand, are usually conceived as an investigation following the old Delphic motto γνῶθι σε αυτόν, (*know thyself*): the unremitting endeavour of self-interpretation, where human beings try to understand their very own nature. The notion of dealing in a systematic manner with the questions of self-knowledge, which also includes the ethical component *How do we want to live?*, dates from the ancient Greek philosophers of two and a half millennia ago [4, Vol.1]. Human beings, as the central object of investigation, are conceived of as ultimately setting their own goals and purposes. Unlike a machine, a person who is not following one's goals is not *broken*, but simply following his/her own goals. The actions of that person must be rated with respect to the objectives he/she expresses. This also includes the actions of research. The reflexive nature of such a hermeneutic investigation must lead to standards of rationality and methods of argumentation rather different from those of the empirical sciences or engineering [4, Vol.3].

Even from this simplified sketch, it is clear that the underlying methodologies of the two cultures are quite different: *subdue the world* vs *know thyself*; constructing machines that follow some pre-set goals vs interpreting phenomena related to the self-determined aims of humans. It should be noted that these characterisations apply to the *cultures* in general, and not to the individual people who *inhabit* them.

The success of the scientific-technical culture with its strictly purpose-driven arguments certainly speaks for itself. However, the underlying program of *subduing the earth* is not uncontroversial: who sets the goals to be pursued? Who chooses the purposes that rule development and application of technologies? Who decides, for example, whether money is spent to set up another computer game rather than for a device to help people with impaired hearing (see Figure 2)? Are we, as a final example, allowed to manipulate nature *ad libidum*, even our own nature?

Criticism of a purely technocratic perspective has grown louder and louder since at least the late 1960s. An integration of the two methodologies becomes increasingly necessary if the problems, often evoked by the very use of engineering, are to be solved in the new millennium. In the words of the German philosopher Habermas, this is the question of whether our societies are able to find a satisfying relation between our enormously grown technical powers and democracy as the institutional forum for discussing how we want to live [6].

A general solution for integrating the *culture of subdue the earth* with that of *know thyself* cannot be approached here. However, building bridges from both sides is a task worth undertaking. In particular,

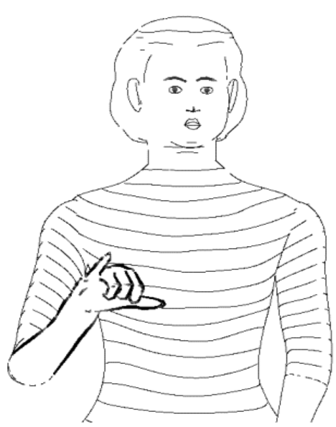

Figure 2: First frame of a computer-generated sketch animation for the word *never* in German Sign Language [5].

looking for new methods of educating engineers, or perhaps: methods for educating *new* engineers as Denning put it [6], is a first step. In the future, a successful engineer...

> *must, in addition to being competent in engineering, be a skilled listener for concerns of customers or clients, be rigorous in managing commitments and achieving customer or client satisfaction, and be organised for ongoing learning* [7].

A shift can be observed away from conceiving of engineering as merely *art for art's sake* toward the development of a communicative expertise in assisting other people in solving *their* particular problems in the expert's field. That is, the technical competence must be embedded in, and directed by, a wider communicative expertise.

COMPUTATIONAL VISUALISTICS: THE STRUCTURE

One example of an adaptation of engineering education intended to prevent the *technocracy fault* is the degree program in Computational Visualistics introduced by the Department in Computer Science of the Otto-von-Guericke University at Magdeburg in the fall of 1996. Following the slogan *new engineers for new themes*, the technical focus of this five-year diploma program[1] is on all aspects of the handling of pictures using computers. Its backbone is formed by three prime columns:

- *Methods*: the algorithmic handling of pictorial data structures,
- *Reflection*: aspects of dealing with pictures in the humanities,
- *Application*: an example domain with clients outside computer science.

The first column covers computer science. Students learn about digital methods and electronic tools for solving picture-related problems. In order to ensure accreditation with the German professional bodies, at least 50% of the course work has to be within the core of computer science[2] (see Figure 3). This technical core is complemented by courses in the humanities reflecting on pictures, which occupy

1. German universities traditionally do not offer Bachelor's degrees: scientific and engineering programs usually lead after four to five years to a diploma as the first degree, which is roughly equivalent to a Master's degree, ie with an integral focus on scientific work.
2. This compares to 67% for the undergraduate program in computer science, the remainder being primarily mathematics and a minor.

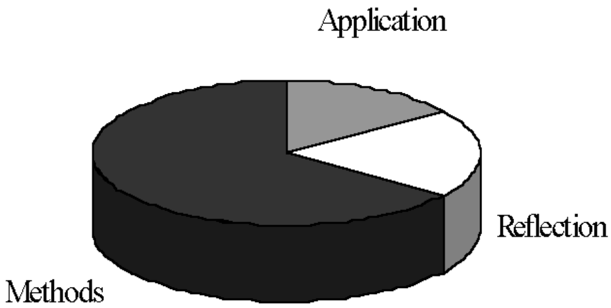

Figure 3: The columns of Computational Visualistics and their temporal distribution.

about 25% of the students' credit hours. Besides learning about the *traditional* (ie not computerised), contexts of using pictures, and the theories developed there, students intensively practice their communicative skills. An application subject covers about 15% of the credit hours required, and gives students an early opportunity to apply their knowledge. They learn the skills needed for co-operating with (eg carefully listening to) clients and experts of customer fields such as medicine.

This tripartite division follows current analyses in educational science [8]: the competence we want to teach is not the result of merely acquiring certain techniques and methods, ie a certain technical *repertoire* our students are provided with after graduating. In practice that repertoire is always used within a particular *context of application* with its particular properties. Moreover, there are usually experts in that field of application who have their own traditions and methodologies. They act as clients of computational visualists, and have little interest in being patronised in their own field of expertise. *They* specify the problems to be solved by computational visualists, as well as the criteria for evaluating the solutions proposed. A third factor of competence is defined as the ability to *reflect the conditions* of successfully applying a method of the repertoire in a given context, eg a visualising technique in material science; although a method might in fact be successfully applicable to reach the goal, there can be conditions in the context of action that argue against the application of that particular method (negative side effects).

For example, it is easily possible for a computational visualist to generate from a CAD model the top two pictures in Figure 4. An architect, as the computational visualist's client, might want to use them when dealing with his/her own customers. However in certain situations, the architect prefers the lower, sketchy version: it is perceived as showing a preliminary draft in an early design stage, therefore encouraging discussions between architect and his/her clients. The other two renditions are more likely to be perceived as showing a final (ie unchangeable) design, thus inhibiting the architect's clients from articulating their wishes for design alterations. As a consequence, the architect is left with a sub-optimal solution for his/her customer. Visualists asked by the architect to develop a solution for visualisation problems thus need to listen carefully to the architect to catch these connections and provide all the necessary rendering possibilities with the solution.

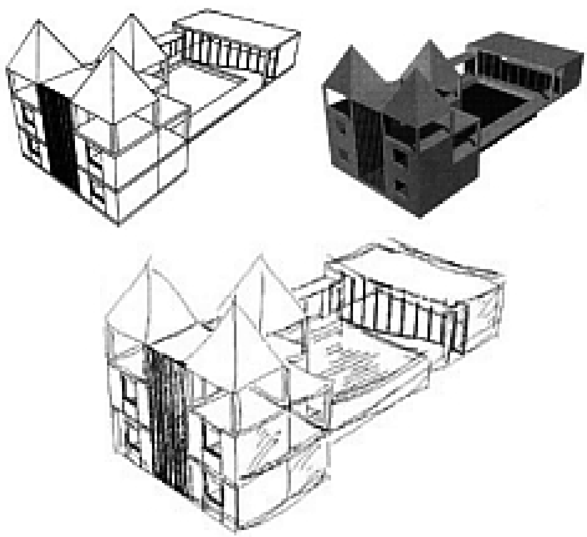

Figure 4: Three different renderings from the same geometric model [9].

This example shows how technical competence in computer graphics must interact with communicative and social skills, and an understanding of the mechanisms and conventions of using pictures (ie using all three columns of Computational Visualistics) in order to lead to a reasonable solution of the task at hand. The additional intellectual instruments acquired when dealing with the approaches and methodologies of the humanities and of the example application domain have another desirable side effect: skills on the methodological and the meta-methodological level are the key to life-long learning. This aspect of integrating the two cultures enhances the candidate's ability to quickly adapt to other application domains, and to new developments in the technical field itself.

COMPUTATIONAL VISUALISTICS: THE CONTENTS

Methods

Computer science provides the *toolbox* for computational visualists. Besides the basics of computer science (including the complete standard courses of mathematics for computer scientists), picture related themes are central. Computer graphics, for example, deals basically with the generation of realistic[3] images of mostly fictional scenes. Those pictures can be made in naturalistic style, ie., as if a real scene had been photographed (*photo-realistic*). The construction process is model-based (see Figure 5)and consists essentially of two phases: first, a three-dimensional geometric model is provided (modelling); second, the model is projected onto a two-dimensional image plane (rendering). Pictures produced in that manner can be easily changed and redone by altering the model. Replacing the rendering program results in pictures similar to engravings or charcoal drawings (review Figure 4). Even artificial holograms are possible (see Figure 6) [11].

Another field of computer science important for Computational Visualistics is human-computer interaction: this entails studies on ergonomic aspects of using graphics, icons, windows, menus, and other presentations on the screen, but also research on immersive systems, popularly known as *virtual reality* (see Figure 7). Computer visualists are particularly interested in the conditions and effects of graphical user interfaces with specific techniques, like head-mounted displays or data gloves, or with certain restrictions, like small, low-resolution screens, users with reduced vision, or time-critical situations.

Image enhancement and compression, pattern matching and computer vision, scientific visualisation and algorithmic geometry, object modelling, animation, and multimedia database systems are further essential pieces of the technical repertoire. Themes in computer science not related to pictures, such as software engineering or knowledge-based systems, round off the methods column[4].

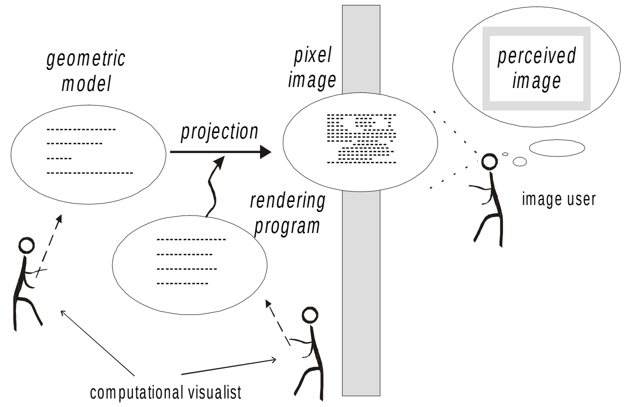

Figure 5: Schema of model-based computer graphics.

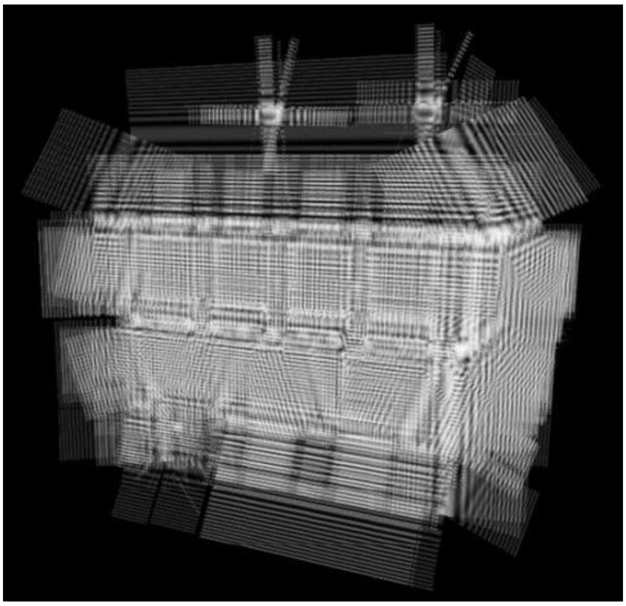

Figure 6: Synthetic holography: A simple 3D-sketch of a house, efficiently calculated on the basis of texture maps [12].

Figure 7: View of the virtually reconstructed Imperial Castle of Magdeburg used in an archaeological exhibition (originally in colour). Courtesy of M. Masuch.

Reflection

The conditions for the meaningful application of computer visualistics methods are discussed in humanities courses under the main title of *general visualistics*. This title refers to the structural relation between computational visualistics and computational linguistics. The latter has been established at universities for several years and deals with all computational aspects of natural language. Computational linguistics has certainly to be seen against the background of general linguistics, which has existed as an individual discipline of the humanities for about 100 years. A comparable *general visualistics* has not been formed

3. Here, *realistic* is used to mean that visual aspects of a three-dimensional spatial configuration are depicted [10].

4. Basics (with mathematics), computational visualistics core lectures, and other computer science courses are taught in a ratio of 38%:38%:24% (or 25%:25%:16% with respect to the whole curriculum respectively).

so far. Instead, aspects of that hypothetical discipline are investigated in several contexts of humanities departments, among them design and art history, but also psychology (perception, cognition) and philosophy (semiotics, theory of arguments), education (pictures in teaching), and political science (pictures in political campaigns).

A typical example of the contributions of general visualistics is given by *object constitution*, covering the conceptual dependencies between the image surface and the image content (the material objects we usually see *in* a picture). Object constitution originally refers to the *invention* of spatial, persistent, and countable objects in the mental development of infants, and thus it belongs mainly to psychology [13]. But it is also used in a more general sense for naming the philosophical arguments in the relation between visual Gestalts and spatial objects in the proper sense [14]. The differentiation between the two fields of concepts covers, for example, the fact that spatial objects have more sides than are *de facto* depicted.

As a logical characteristic of geometric Gestalt principles organising visual perception, the representation of individual geometric shapes within a coordinate system of locations of *one* perceptual situation can be achieved. But in general, it is logically not possible to associate those shapes as the same individual in *different* contexts without taking non-visual aspects (basically part-whole relations) into account. The transformation to spatial objects not only integrates several perceptual situations and their corresponding coordinate systems of places and times [15]; it originally leads to the concepts of objects that do not disappear when we do not look at them, that have parts and distinguishable visual aspects: one can view them from several perspectives, and thus one can recognise the very same object even if it looks different at different times (from various viewpoints).

The philosophical presuppositions and implications of object constitution are indeed quite complicated, and not the theme here. The relevance for computational visualistics becomes clear when we recall that most geometric object models commercially available for computer graphics consist simply of an unstructured collection of polygons. They are logically equivalent to Gestalts, not to spatial objects, whereas the latter are frequently necessary, at least in non-photorealism, eg., when specifying the rendition style of objects, which is one of the problems often mentioned in articles on current research issues in computer graphics [16]. Similar considerations hold for computer vision: the experience of about two decades shows that pure bottom-up approaches based on Gestalt principles alone are insufficient for the recognition of objects in the ordinary sense [10]. This result could have been predicted, if only the conceptual background of object constitution were known by computer scientists.

Psychological considerations about the mode of interaction with pictures is another area of humanities that is relevant for image engineers. In general, a distinction has to be made between a *deceptive mode* and a *symbolic mode* of interaction [17]. Somebody (*A*) is classified as being in deceptive mode if *A* reacts as if an object *O* were present in a context that contains merely an object *P* (which we understand as a picture of *O*). In this case *A* is not aware of the presence of *P*, nor of the absence of *O*, and therefore involuntarily does not adequately react to the situation at hand (see Figure. 8). We consider *A* as being in symbolic mode if *A* uses *P* as a sign for something else; *A* thus necessarily knows that *P* is there and *O* is not. However, in virtual reality settings (review Figure 7), a particular type of mixed form can be observed. In this *immersive mode*, *A* reacts voluntarily in a manner inadequate to the real situation at hand by consciously treating signs (*P*) as the objects they

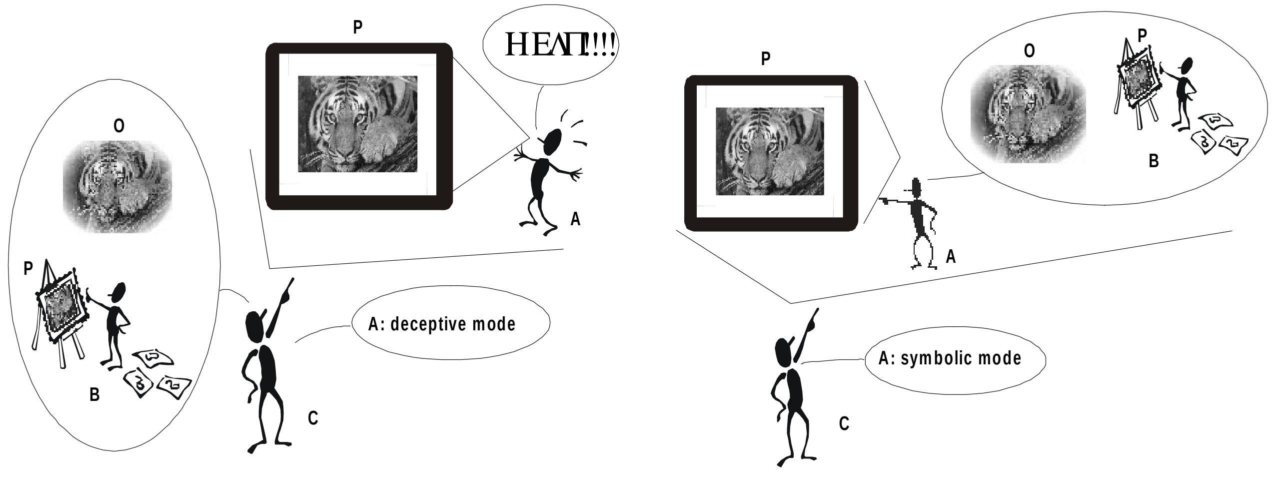

Figure 8: Illustration of the attribution of the deceptive mode and the symbolic mode.

refer to. Knowing about the mental mechanisms responsible for the immersive mode of action and the levels of reflection involved is crucial for designing virtual reality applications.

Computational Visualistics at Magdeburg currently embraces five areas (psychology, philosophy, education, political science, design), although aspects of general visualistics are studied in other departments of the humanities as well. The selection is not meant to exclude other aspects in principle, but simply reflects the strengths and interests of the current faculty.

Application

The field of application complements the program by addressing from the start the problems of co-operation with clients from other areas by means of one concrete example domain. Three general tasks can be identified independent of the application field:

- the students learn the basics of that domain and develop insights into its particular terminology and research methods;
- special problems that cause the experts of the application domain to employ a computational visualist are described, together with solutions and approaches already elaborated there;
- the students become aware of the problem of co-operation itself, develop realistic expectations (a *feeling* for the domain) by means of actual scenarios, and practice strategies to overcome problems in communicating with clients. For example, for a small software project in the second year, tasks are given by clients from the application areas and solved as a service by teams of three students under the supervision of a senior computer scientist.

At present, three application areas are offered: medicine, material science, and image engineering in EE. In medicine, for example, introductions to human biology and pathology, the basics of medical imaging (eg from the physics of X-rays to high-tech radiology), and techniques of advanced medical image analysis and visualisation form the curriculum. A typical task in this field is provided by an interactive multimedia textbook on anatomy that integrates texts, sketches, and clinical pictures (see Figure 9). Two more application areas are currently in preparation, focusing on pictures in mechanical engineering (*construction and manufacturing*), and on simulations and computer games from a humanities point of view.

Closer to the latter theme, students of the program have implemented a geometrical model of the ancient Imperial Castle of Magdeburg, which was built about a millennium ago, but destroyed in the 13th century. This model is used to implement an interactive tour through the virtually reconstructed castle as well as

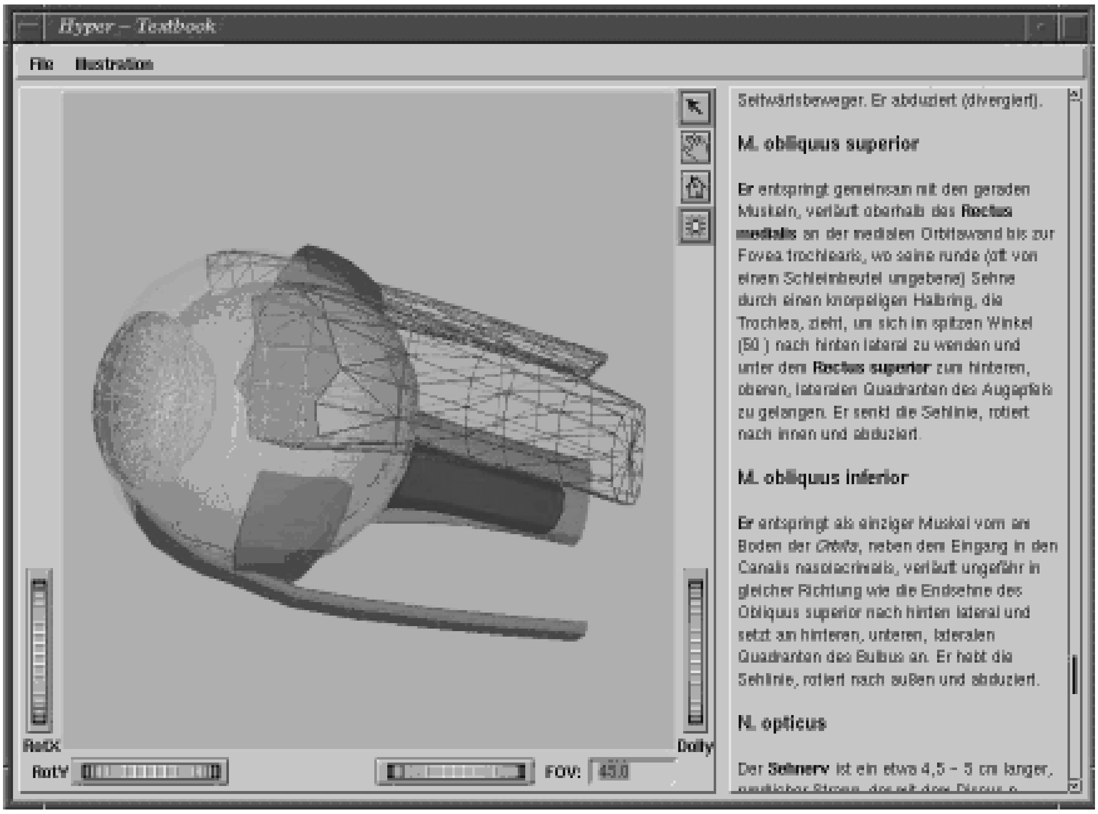

Figure 9: Application of computational visualistics in medicine: a screen shot of an interactive textbook on anatomy [18].

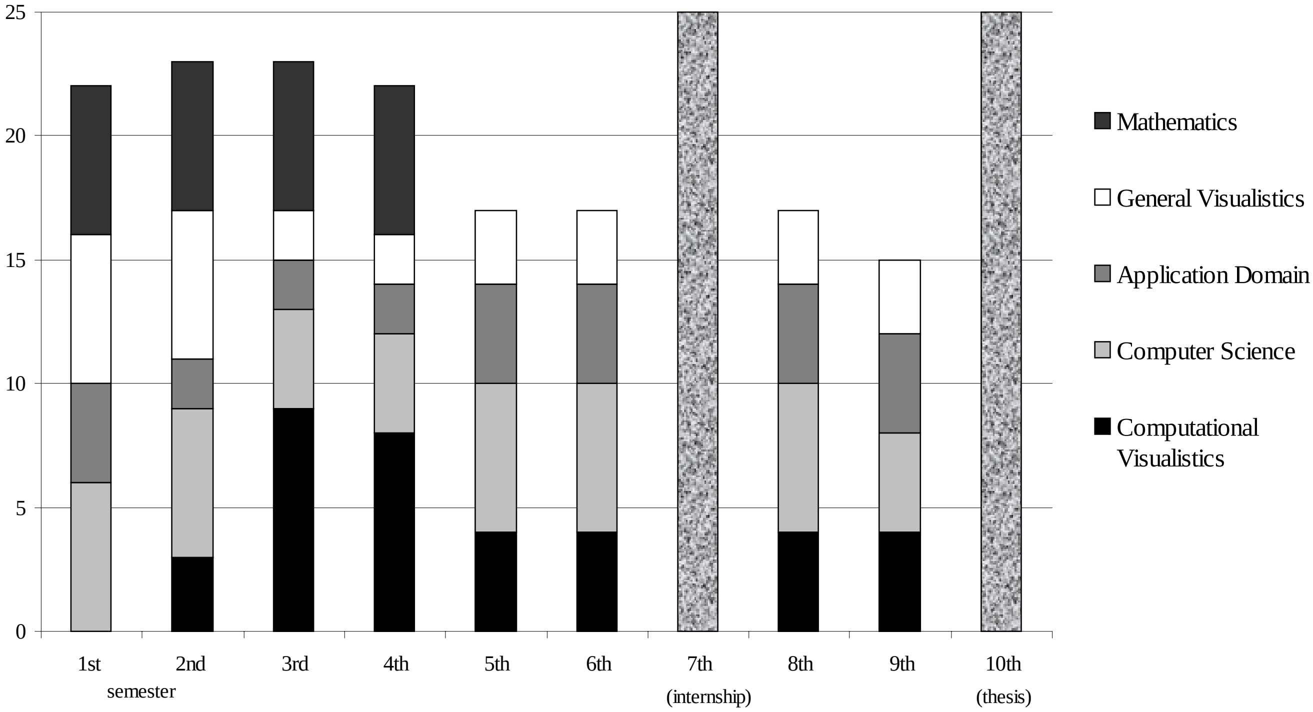

Figure 10: A schematic overview of the curriculum.

an educational computer game for a museum exhibition about history (review Figure 7).

The application domain, chosen by the students during the first weeks of their study, is intended as an example of the methodological skills we hope to teach the students. This will enable them to familiarise themselves more easily with other domains as necessary later on.

Figure 10 summarises graphically the standard curriculum (students may rearrange their schedule of lectures to suit their needs, up to a point). Similar to the computer science program offered by the faculty and in accordance with German university practice, the program is split into two phases: two years of basic studies are followed by three years of advanced studies. Within the later period, two semesters are reserved for an industrial internship (usually the seventh semester) and the preparation of the diploma thesis (the last semester). Credit course points scale the coordinate axis in Figure 10. Basic studies consist of lectures worth on the order of 90 points; advanced studies demand another 78 points (not counting the internship or the thesis).

PRELIMINARY EXPERIENCES WITH THE PROGRAM

The new degree program met with an overwhelming response on the part of high school graduates. Whereas there were initial concerns that the topic of computational visualistics might be too off-beat to attract good students, quite the opposite was in fact true. The enrolment numbers are given in Figure 11 (for 1999: preliminary numbers of application only). The numbers in Computational Visualistics have consistently been even higher than for the university's computer science program.

Interestingly enough, about 25% of the new students in each year have been women. This number is significantly higher than for any other engineering program offered by the university, where women represent barely 10% of the student population, and in some departments even less than 5%. We assume that the aspect of integrating the *two cultures* is especially decisive for women who chose Computational Visualistics. Each year, a survey of the new freshmen students is carried out to determine their motivation and expectations. Perhaps the most interesting result of these surveys is that many of the new students would not have studied computer science if Computational Visualistics had not been available.

In 1997, the University of Magdeburg introduced a MSc in Computational Visualistics aimed at foreign students who have their BSc with a major in any subject emphasising pictures and at least a minor in computer science[5]. Course work focuses on graduate courses in computer science and courses in general visualistics. A PhD program is available as well. In 1998, another German university, the University of Koblenz-Landau, started offering the same diploma program, with minor variations adapted to that university's own resources and strengths.

5. See also *www.computervisualistik.de.*

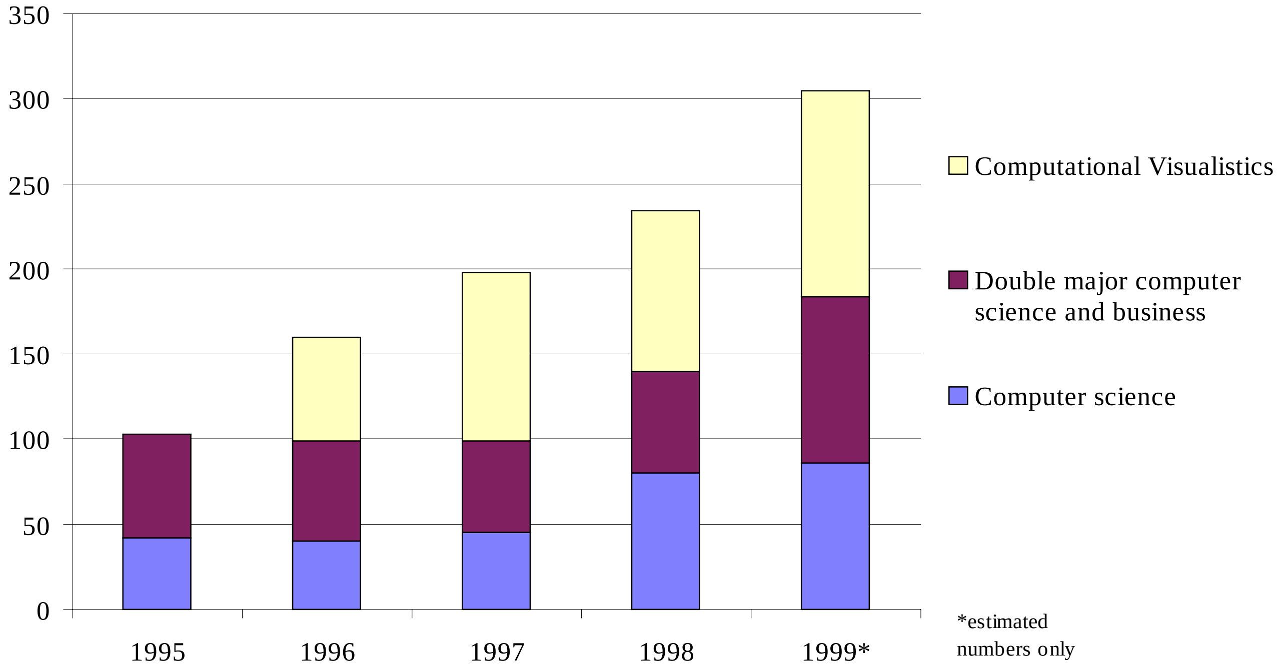

Figure 11: Development of enrolment (NB: the numbers for 1999 are estimations based on the applications two months before deadline).

To our knowledge, the degree program in Computational Visualistics is at present unique in teaching a field of engineering (the development of methods and tools for working with computers) together with corresponding aspects from the humanities (reflections on human uses of pictures), thus aiming directly at bridging the gap between Snow's two cultures.

CONCLUDING REMARKS

Is the notion of brdging the two cultures in a particular multimedia degree program relevant outside of Europe? Snow's dictum about the inability of the two cultures to communicate sufficiently with each other holds essentially for all societies that are primarily influenced by the European history of ideas, including in particular the Americas, Australia and New Zealand, and possibly Japan. The rapidly expanding results (and side effects) of science and of engineering, however, reach every society on this planet, and consequently have to be addressed by every society as well as possible.

If, as indicated above, one of the crucial questions of the next century in this context is whether our societies are able to find a satisfying relation between the enormously developed technical powers and a democratic forum for discussing how we want to live together under such conditions [6], a sound education that tries to overcome the restricted directives underlying the two cultures, encapsulated in the slogans *subdue the earth* and *know thyself*, is essential, especially for engineers. The two cultures are themselves proper results of the intellectual development over about 2,500 years in Western societies, and cannot be completely understood without that context. The only hope for overcoming the problems induced by this development is to know the forces that have driven it and still drive it. This is particularly relevant for other cultures that want to profit from modern technology and participate in its development.

The program in Computational Visualistics as described here is to be seen as an example. Some of the arguments for establishing it may be of use for similar endeavours in engineering education. We have to build a lot of bridges from both sides to have a chance of succeeding with both technology *and* democracy.

ACKNOWLEDGMENTS

I want to heartily thank Thomas Strothotte who has given me the invaluable opportunity to gain inspiring insights into the theory and practice of educating *new engineers for new themes.*

The sources of figures 1, 2, 4, 6, and 9 are given in the respective captions

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BIOGRAPHY

Jörg R.J. Schirra was born in Saarland, Germany in 1960. He studied computer science, physics, psychology, and philosophy at the University of Saarland, at Saarbrücken, Germany. He also worked there after having received his diploma in computer science as a researcher in the Special Collaborative Project *Artificial Intelligence and Knowledge-Based Systems* of the German Research Council (DFG) until 1993. In 1994 he received his doctoral degree in computer science there. Subsequently he spent one year as a post-doctoral fellow at the International Computer Science Institute (ICSI) at Berkeley, California. At the University of Magdeburg, where he has been working since 1996, he is responsible for organising the diploma program in Computational Visualistics.