Painters, Murderers, Mathematicians *

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This article outlines the history of our visualization of the interior of the human body. It throws some light on the emotional context and the underlying idea of man. In order of appearance on the historical stage, the leading characters are: painters, murderers (more precisely: executed persons including thieves driven merely by need, women with illegitimate children, etc.), and mathematicians as well as computer scientists (the latter subsumed under mathematicians).

In the Christian cultural sphere, until the renaissance, a glance into the interior of the human body was accompanied with grave risk. Though the instruction "Thou shalt not make thee any graven image" [2] applied only to any representation of God, the medieval church had early on extended this ban to angels and other beings of everyday life. To be on the safe side, artists of those days would start out with allegoric representations of the interior of deceased saints, for instance under the legitimation of *Vanitas mundi*.

In the Islamic cultural sphere, at least in its major part, any representation even of the exterior of 'beings that have been created by God' (Quran) was forbidden – which, to Arabic art, only left open the rich magic worlds of geometric and floral designs that we nowadays still admire in tiles, carpets, and tapestries.

Ever since the renaissance, painters with anatomical interest led the defiance of the explicit interdiction of the nearly almighty Church, sneaked at night to the places of execution and dissected the corpses of executed persons – without their premortal assent, of course. Leonardo da Vinci (1452 – 1519),

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[2] King James Bible, Deuteronomy, chapter 5

possibly the most famous progenitor of this development, wrote to a friend [11, manuscript 796]:

And if you should have a love for such things, you might be prevented by loathing, and if that did not prevent you, you might be deterred by the fear of living in the night hours in the company of those corpses, quartered and flayed and horrible to see. And if this did not prevent you, perhaps you might not be able to draw so well as is necessary for such a demonstration; or if you had the skill in drawing, it might not be combined with knowledge of perspective; and if it were so, you might not understand the methods of geometrical demonstration and the method of calculation of forces and of the strength of the muscles; ...

Obviously, the only guarantee of the 'truth' of the account was the mastership of drawing, see Fig. 1.

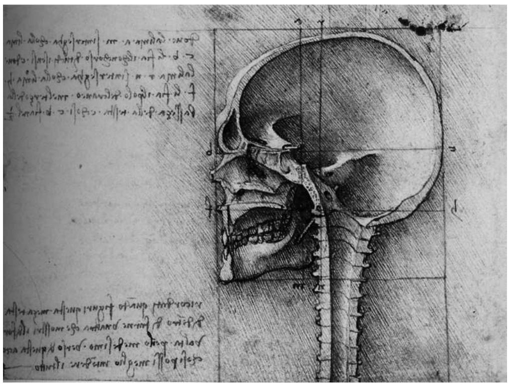

Fig. 1. Leonardo da Vinci (1489): *Anatomical study of a skull* ([8, 4]). Compare with Fig. 4

After dissections had found their accepted place within academia, it was still primarily corpses of executed persons that were used. In Dutch painting, 'anatomy paintings' evolved even as a genre of its own.

The interior of the human body (1656): the murderer Joris Fonteijn

The artistically densest depiction of the situation that I know of, is Rembrandt's *Anatomy of Dr. Deyman* from 1656 (to be clearly distinguished from the much smoother *Anatomy of Dr. Tulp* from 1632). In those days, dissections were still walled by a taboo: it was shameful to fragment the corpses of 'honorable' burghers. In contrast, condemned persons had 'no honor', their corpses were given over to the guild of surgeons (who then were as yet not distinct from pathologists or anatomists). Without proper cooling methods dissections had to take place in a hurry, immediately after execution.

The oil painting in the Rembrandt-typical brown tinges (Fig. 2) shows the corpse of the serial killer Joris Fonteijn, a Flemish tailor also known as "Black Jack", who died on January 17, 1656, on the gallows. The painting was done in the same year, but heavily damaged by fire soon after. The murderer's face, composed in the golden section of the (original undestroyed) painting, stares directly at the observer, clearly recognizable, debased. The anatomist Dr. Deyman (half cut off) holds the Dura Mater in his hands, the brain swells out of the opened skull.

Fig. 2. Rembrandt (1656): *The anatomy of Dr. Deyman*

The compassionate look of the then 50 year old Rembrandt was explicitly directed to the human being in general, his perishability, his destructibility.

In our times, generations of students of medicine dissect corpses – who, after all, had agreed to the procedure during their life times. In public opinion, dissection is no longer debated, let alone regimented, its medical use is understood to clearly outweigh all possible concerns. Nevertheless almost all students of medicine have to cope with feelings just as those described above in the historical context – the well-known initialization rite.

Mathematics enters the scene

The discovery of X-rays at the end of the 19th century revolutionized the world of images: for the first time, the interior of the *living* human body could be studied directly (of course, within certain dose limits). X-ray images, however, were only silhouettes, which was not entirely satisfactory. In this situation, the Austrian mathematician Johann Radon (1887 – 1956) appeared on the historical scene. He investigated, from a purely abstract point of view, the question:

For a closed planar domain, can an integrand function be recovered from its line integrals over the continuous family of all directions?

Even though Radon had not given any thought to practical aspects of his mathematical problem, we may modify his question in view of its X-ray imaging application to be:

Given measured intensities of finitely many different rays that pass through some material, can the spatially distributed material density be well-approximated?

For the solution of his abstract problem, Radon introduced a transformation which today is named after him. In 1917, he succeeded in deriving an inversion formula believed to answer his abstract question exactly. His proof of the formula was so elegant that today it is still part of the classical curriculum (see Frank Natterer [10]). Unfortunately, the classical Radon inversion formula is not pertinent to applications: already small errors in the measured data (input) can totally blur the image to be calculated (result). In the language of mathematics: the problem turned out to be "ill-posed" – a feature that much later has been found to be tractable. Since then numerous mathematicians, especially in Russia, Germany, the Netherlands, and the USA have pushed the research field *Computerized Tomography*, abbreviated as *CT*. In view of practical applications especially in medicine, this research soon focussed on the search for efficient algorithms (i.e. methods of computation). For the interested layman, a short digression may be in order:

Algorithms for computerized tomography. First, observe that an image is nothing else than an assembly of $N \times N$ pixels (i.e. digital image points). To reconstruct such an image, we have to solve a system of linear equations with N^2 unknowns, which in the technically relevant case ($N = 1024$) means roughly a million unknowns. Popular algorithms that date back to Gauss, would require about $N^6 \approx 10^{18}$ operations; they do not exploit any special structure of the problem and are therefore too slow.

In 1968, without any knowledge of Radon's work, the English engineer Godfrey N. Hounsfield (*1919) suggested an algorithm with only about $50N^4$ operations, which was a real breakthrough in those days, and built the first commercial CT apparatus in 1973. In 1979, together with the physicist Allan M. Cormack (1924 -1998), who already in 1963/64 had made groundbreaking contributions to the topic, he received the Nobel prize for 'Medicine or Physiology' in 1979. In 1974, with explicit knowledge of Radon's work, the mathematicians L.A. Shepp and B.F. Logan published an algorithm [12] that only requires $N^3 \approx 10^9$ operations (without getting the Nobel prize, of course). Basically, their method is the one still found in our present CT devices. For the determination of the one million unknowns in a typical CT, a present commercially available PC would use not more than 5 *seconds*, whereas the method of Hounsfield would 'burn' estimated 70 *hours* and thus not be of any interest for clinical application.

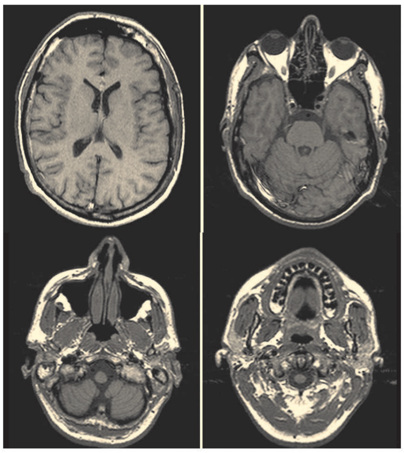

Fig. 3. MRT image: planar sections through a skull

In the meantime, problems of this kind occur not only in CT, but also in magnetic resonance tomography (MRT), in positron electron tomography (PET), and in ultrasound; in all these cases, we may resort to these fast CT algorithms, or their even more efficient successors. Today, 'medical imaging' has a firm position in clinical routine. The only limitations to the inquisitive look into the interior of the human body remain the physiologically tolerable radiation dose (with CT and PET) and the restricted resolution.

Nowadays, in order to obtain 'true' images from the human interior, nobody need die. The conceptual vicinity of 'minimally invasive medicine' is clearly visible. Nevertheless, executed persons still play a role, as shown by the following example.

The interior of the human body (1993): the murderer Joseph Jernigan

On August 5, 1993, Joseph Paul Jernigan was executed by poison injection in Huntsville, Texas. Twelve years before he had killed an old man during a burglary. In his will, Jernigan donated his body to the Anatomical Board of the State of Texas. The man consequently became world famous as the first *Visible Male.*

His corpse did not satisfy all criteria: he was too overweight (in prison, the delinquent had gained so much weight that he nearly did not fit into the scanner); part of his testes, his appendix, and one tooth were missing.

Nevertheless, he seemed to be the best available candidate within the *Visible Human Project*. The anatomist-pathologist Vic Spitzer, one of the principal investigators, pronounced concerning his choice of Jernigan's body (quoted from Meredith Wadman [14], p. 657):

It's very difficult to find an intact, non-traumatized, non-pathologic cadaver. I'm not condoning execution. But I don't believe in wasting resources either.

Immediately after execution, the Anatomical Board took the still warm body. First, it was brought to a local funeral parlor where it was deposited in blue gel. Then it was transferred to a charter plane, flown to Denver, Colorado, and delivered to the Colorado Medical Sciences Center. About eight hours after execution first MRT and CT scans of the whole body were taken; in order to be able to apply these techniques, the body was required to be dead for 'not too long'. Afterwards it was deep-frozen and microtomed in roughly 1800 slices of 1 *mm* thickness. Each of the slices was photographed and digitalized, all pixels were carefully electronically stored.

The whole case was followed up by a long discussion about its ethical foundations. From the procedure as such it is clear that, at the time of his will, Jernigan had no idea that his body would be digitalized and that his data would be published in the Internet (since Nov. 1994), even under his full name. However, in conversations with his lawyer, he had expressed that "he felt like he could give something back for what he had taken" [14].

In the same month, a 59 year old anonymous housewife from Maryland rose to be the first *Visible Female*. She had died naturally from a heart disease and had also donated her body to anatomy, this time well informed (including her husband) about the Visible Human Project.

Today, the Visible Male and Visible Female data (15 GByte/40 GByte) are freely accessible via Internet: after filling in an application form to get a license from the US National Library of Medicine and under observing certain obligations of correct citation, they can just be downloaded. Meanwhile both visible human data sets together have been compressed by the Bremen mathematical group of Heinz-Otto Peitgen using wavelets so that they can be purchased as two CD ROMs. Subsequently, further Visible Human initiatives have spread all over the globe, e.g., in Korea [13], China [2], Japan, and in Germany. More waves of mass data are rolling towards us.

The virtual human I: the form

Methods like CT or MRT supply only two-dimensional images, in the best case stacks of them, as shown in Fig. 3; though in the Visible Human more information indeed accumulates, but it is again two-dimensional. However, most people are three-dimensional, important exceptions having been described by Herbert Marcuse [9].

It was not until recently that computer science and mathematics have provided sufficiently fast and reliable algorithms to generate correct *geometric 3D models* from 2D image stacks: in this way, virtual humans have been born, which today can be viewed within our familiar seeing categories using 3D glasses and wandering through it by means of a 'space mouse'.

Fig. 4 shows a sagittal section (in two-dimensional projection) through the three-dimensional representation of the skull of a patient. This image is now 'true' in the following sense: it is based on measured data corresponding to an individual and has been computed by reliable mathematical methods which, however, cannot, with mathematical certainty, exclude possible anatomical errors. Nevertheless, if you look back to the drawing of Leonardo da Vinci in Fig. 1, five hundred years seem to shrink to no time at all!

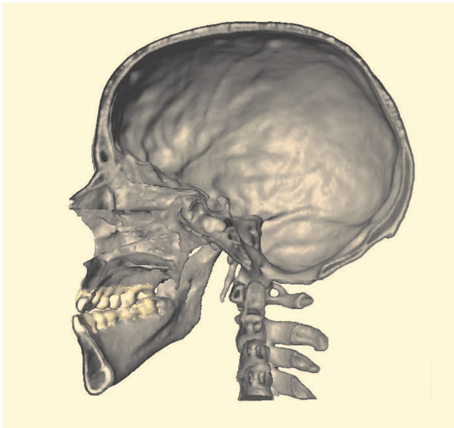

Fig. 4. Virtual patient: section through three-dimensional skull (ZIB). Compare with Fig. 1.

If appropriately programmed, a three-dimensional representation permits the selection of single graphical 'objects' in the computer, or, in other words, an arbitrary fragmentation of the body, without being forced to resort to corpses! The corresponding emotional shock is typically no longer sensed by the working scientists (the usual 'déformation professionelle'), but well perceived by observers who are exposed to such techniques for their first time (mostly expressed by some laughter). Already in the near future, the education of students of medicine will be more and more based on virtual anatomical 3D atlases. [3]

The preliminary climax of this development is, certainly unquestioned within the Berlin Brandenburg Academy of Sciences and Humanities, the 'vir-

[3] VOXELMAN data can be found under http://www.uke.uni-hamburg.de/institute/imdm/idv/gallery/index.en.html

tual academy member': Figure 5 shows a (perhaps not very typical) cutout stemming from a heroic self experiment of a real academy member. We want to clearly point out that this member is a mathematician, but (as far as known) not a murderer; otherwise the data are anonymous, of course. [4]

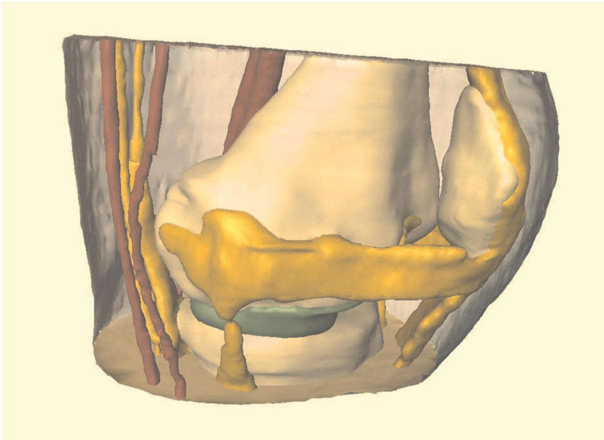

Fig. 5. Virtual academy member's knee: three-dimensional respresentation of the knee joint with muscles, ligaments, and blood vessels.

With the conveniently manipulable visual representation of humans at hand, we are now in the situation where Goethe's Mephisto may well continue to scoff: [5]

The parts lie in the hollow of your hand,
you – only – lack the spiritual band.

The virtual human II: the function

Goethe's scoff is, however, no longer fully justified, since physicists, engineers, and mathematicians have readily gone far beyond: They try to model (mostly in terms of partial differential equations) and to simulate (on the computer) the function of single parts of the human body in close detail. This turns out to be really hard. As an example: the function of the kidney is so poorly understood that there is as yet no useful mathematical model. Nevertheless, for medical technology, especially for therapy and operation planning, new perspectives have opened; examples from the author's research group are the cancer therapy hyperthermia ([3]) and facial surgery [15].

[4] The immediate conjecture is wrong: it is not the author himself.
[5] author's adaptation of a translation by Theo N. Wolf

At the end of this road stands the dream of a modular function model of the *total* individual human body, which takes the systemic coupling of the partial models into account; in fact, only such a combination of form *and* function would eventually justify the name 'virtual human'. Despite the intimidating complexity of this interdisciplinary task the author, already in 1985, when still at the University of Heidelberg, had campaigned for a project called HOMUNCULUS, which, however, in those days did not find enough approval in the acadmic community. Since 1993, the bioengineer Peter Hunter, Auckland, and his research group have started to realize such a project under the name PHYSIOME [7]. In this type of project, both mathematical modelling and efficient simulation will certainly play a key role.

Imagination behind the images

As in nearly all areas of modern science and engineering, our understanding, meant in the sense of the Latin 'ratio' *and* 'emotio', cannot keep pace with the speed of technological development. That is why we want to pause here for a moment of contemplation.

- *What kind of idea of humans lies behind these images of human bodies?*
- *Are we on our way to conceive ourselves just as a sum of our parts?*
- *Don't we already have more than the parts "in the hollow of our hands"?*
- *Which perspectives are approaching us?*

In order to look into the interior of the body we utilize methods of non-destructive material testing. This arouses the image of the body as a 'collection of material'. The object oriented 3D representation, too, inspires humans as the sum of their parts. Fortunately, numerous scientists have passed beyond this much too simple picture: They are already heavily engaged with modelling the function of some of the parts and their interplay. The Virtual Human as described, seems to be a concretion of de La Mettrie's [6] idea of *l'homme machine*. It is a pity that many of our present contemporaries also adopted his mechanistic simplification – in striking opposition to the modesty of those scientists actively doing research in this field: The construction of the Virtual Human reveals itself as extremely complex and requires an interdisiplinarity of hitherto nearly unexperienced extent. Along this line of development we surely can expect more than the "parts", but probably not "the spiritual band".

At present, physicists and engineers are developing a new generation of imaging techniques. Once they are ready for operation, individual persons may conveniently have use of their 3D data, if they want and can afford the data acquisition; of course, prices will drastically fall upon mass demand. Up to now, only sufficiently well-to-do people have their tailor's measurements

[6] Julien Offray de La Mettrie, since 1748 member of the Prussian Academy of Sciences and Humanities by order of Friedrich II.

deposited at the Rive Gauche in Paris. In the future, they will carry their 3D data on their personal chip card and provide them on demand. We will also construct a *Couturier Virtuel*, perhaps even affordable for everybody.

This would now be a nice "End II for lending libraries" (Dürrenmatt [5]). However, the same mental structures surface in a more severe context: The conceptual vicinity to *transplantation medicine* catches the eye. There, too, the danger exists that humans are imagined just as the sum of their parts or at best as a mechanistic system. There, too, hastiness plays a major role. An individual's legal control of their own body expires with the exact time point of the brain death, defined by a medical doctor who "writes the zero line". In their (well worth reading) joint book about this topic, Ulrike Baureithel and Anna Bergmann write:

Just as the concept of the brain death is based on a body image*, in which organs are taken out of their systemic connection [...], so is the therapy of transplantation based on [...] the same principle of* fragmentation*. [...] The 'old' and the 'new' organ are subordinated to a* mechanistic *principle of exchangeability, which suggests an organ without any history of its own.* [7]

However, in this frontier area of our modern medicine the "spiritual band" of the human body is manifesting itself by clear signals (again due to [1]):

- The vehement repulsion commands of the recipient's immune system, which has actually stored his *individual history*, must be suppressed for his whole remaining life time by drugs like Cortison (*immune suppression*).
- A rather high percentage of recipients, as well as the relatives of the donors, have to cope with massive psychological stress – which has led to the appearance of the new discipline of *transplantation psychiatry.* The *"alien inside one's own"* causes mental problems; it opposes the 'magic imagination inheritage' of humans.
- Some scientists, on the basis of irrefutable obervations, arguing fully on a 'material level', introduce concepts like *organ memory* or *body memory* into the phenomenological description, as a kind of memory of the explanted organ to the body of its donor. Recent investigations about the possible existence of 'gut brains' – so to speak a 'distributed computer' versus the cerebral brain as the 'central computer' – fit nicely into this picture.

At the very last, we do want to say what seems to go without saying: In order to look into the interior of the human body, we no longer need people condemned to death. In principle, corpses of excuted persons have done their jobs, they, too, are now entitled to have their peace of the death, just as 'honorable' burghers. Obviously, mathematicians have contributed to progress in the way that nowadays death penalties are obsolete – also from this point of view.

However, in the context of organ 'donation', condemned people have once again got a familiar role. In a document [6] from 1994, the NGO Human Rights

[7] translated from [1], p. 193, interleaves and emphases by P. D.

Watch reproaches the People's Republic of China with the increasing number of death penalties: The organs of executed persons, among them a majority of political dissidents, are sold internationally (but, curiously, to ethnic Chinese only).

Summarizing, it seems that the fragmentation of our imagination of the human body and the fragmentation of geometric 3D images are more closely connected than perceived in the beginning.

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