Books and Devices from the Old
– their Renaissance in Computer Graphics –

Bernd Eberhardt, Haşmet Gürçay[†], Frank Hanisch, Tobias Hüttner, Oliver Licht, and Benjamin Nill

Wilhelm Schickard Institut für Informatik, Graphisch Interaktive Systeme (WSI/GRIS), University of Tübingen, Germany

Abstract

In the following we present three of our institute's activities concerning cultural heritage. First we present a reconstruction of the Antikythera Mechanism, which is the world's oldest calculator of astronomical purpose. The implementation extensively uses engines and sensors from the OpenInventor Graphics Library. This is a particularly interesting example of a delicate object which cannot be exhibited (without the use of a virtual Computer Graphics model) since it is too valuable and delicate.

Secondly we illustrate the use of Computer Graphics to make valuable medieval books available to the public. A new texture mapping approach, allows the bilinear interpolation of texture coordinates on an arbitrary triangle mesh. This approach uses projective texture mapping and can therefore utilize the hardware of modern graphic workstations.

Lastly we present an application of modern 3D Computer Graphics in the field of reconstructing ancient scientific instruments. The first-four-species calculator of Wilhelm Schickard is made accessible to the public in the World Wide Web using Java3D.

All three examples illustrate the use of latest technology to model ancient books or devices.

1. Introduction

Reconstruction and virtual models are a general concept of 3D Computer Graphics. Houses, ancient building and books or mechanical devices can be reconstructed and animated in 3D. These virtual objects in contrary to the "real" or physical ones can be exhibited. Moreover, the presented subjects can be enriched with online explanations and are attractive to visitors who can perform experiments themselves.

Such a reproduction can furthermore be used to document the actual condition of those pieces to be able to detect changes and to serve as a basis for conservation decisions. This may be an explanation how modern 3D Computer Graphics can be used to teach, demonstrate and conserve our cultural heritage. Medieval Books and ancient mechanical devices are good examples illustrating the obvious need of replicas because the visitor of an exhibition wants to flip the pages or drive the handle of the objects.

The objects of our scholarly interest however, become important because of their own nature. Each of the presented examples has a history of its own and it is meaningless to present the work done here without an explanation of the nature of the objects.

2. The Antikythera-mechanism

In 1901 a wreck was found on occasion by Tunesian sponge-divers just offshore the small island of Antikythera in Greece (and thus the name) which was full of statues, amphorae and crockery made of stone and bronze, and that had probably travelled from Rhodos to Rome, when it sunk in a storm. All treasures were rescued and sent to the National Museum of Athens. And from archeological evidences (found statues, pottery etc.) it is clear that the ship must be from ca. 80 BC.

Among the objects found there was an unspectacular looking "lump" of calcified metal, largely corroded by water. When it accidentally split into fragments, traces of graduated scales and gear wheels were detected as of an astrolabe. Analysis of the material hinted at an antique origin, because the metal was bronze, which was not used for gears in the Middle Ages. But still these lumps did not drew much atten-

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[†] supported by the DFG

Figure 1: *Fragment A of the Antikythera mechanism.*

Figure 2: *Reconstruction by Price from [6].*

tion until recently just a few scholarly ones. It's not jewelry, a wonderful statue or some other object which bares its importance on the first sight. Derek de Solla Price was the first who saw the immense significance of these bricks (see Fig. 1 for an example) to the history of science.

From his expositions [6] we know most of the substance of the mechanism. He made X-ray pictures of the fragments and these pictures revealed that there were actually 32 fine gear wheels inside. Price could describe the actual positions of the wheels and carefully counted the number of teeth to a large extent, so that finally a reconstruction of the whole amazing gearing system could be made. Derek de Sola Price proposed this device to be a mechanical computer to calculate astronomical data like moon-sun, synodic and siderial month, etc., since the counting of the teeth and the relation of the gears revealed unique astronomical ratios which otherwise would be difficult to explain.

2.1. The device and its gear trains

The casing of the device looks like a rectangular box and is about 30cm high. On the front face you see 2 big hands - similar to those of a clock -, and an inner and outer ring. On the back you can recognize 2 big and 2 small hands and several adjustable rings. Through X-ray pictures of Price (the only ones made so far![†]) we know the gears inside the mechanism. Price proposed the following reconstruction:

[†] Computer Graphics in medicine has developed wonderful tools extracting entities out of a series of CT or MR pictures and getting an actual 3D model. We are certain that many mysteries of the mechanisms, which are still present, could be revealed applying these techniques to the original artefact. Moreover, delicate and rude cleaning of the artefact is not needed and the model can rest
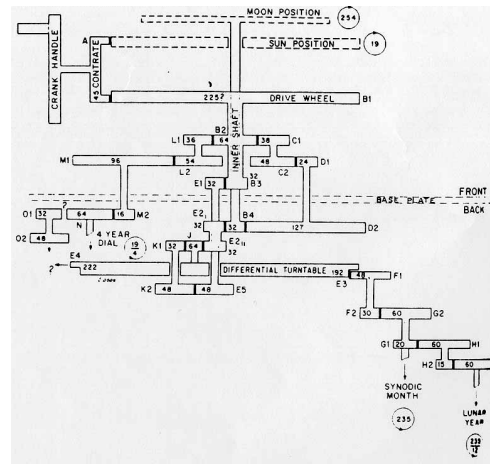
This was the starting point of our reconstruction. Each gear wheel was modeled using the CAD-system PYTHA. Like in the fragments the teeth on the wheels have a triangular shape and where then translated in the openInventor file format to be read later as a database.

The position of the gear wheels (i.e. the center of the axle) was also constructed using the CAD-System. This location had to correspond (approximately) to the place in the original fragments.

Each gear train is implemented as a net of Inventor Engines.[7] Thus, two connected gear wheels are constrained via Engines and Callback functions. If the state of a gear is changed the SoCalculator gives the right entity for a new position. The angle of each gear wheel depends on the position of the drive wheel, i.e. the big 225 wheel.

In addition there are engines to animate the box. The interface allows an initialization of the mechanism, i.e. the position of the dials can be adjusted specifying a particular date of interest known to the astronomer using the device. These values can be either typed in or set via drive buttons. Figure 3 shows an image of the interface (on the left) with the reconstruction of the mechanism.

The final pictures (Fig. 4) of the antikythera mechanism are views from the front and back with the dials.
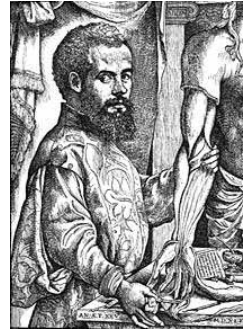
3. The "Epitome" or "Homine Figuris" of Andreas Vesalius

"Andreas Vesalius (1514-1564) was a Flemish anatomist who founded the sixteenth century heritage of careful ob-
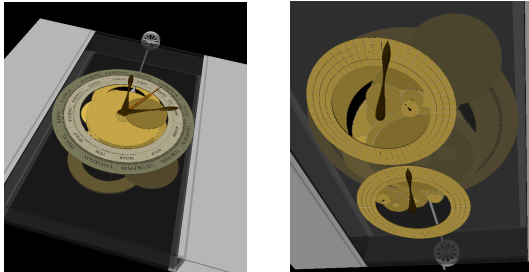
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in its original state. However these techniques are yet not applied in the case of the antikythera mechanism.
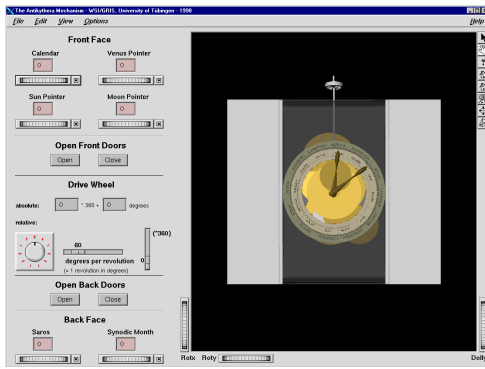
Figure 3: *WSI/GRIS reconstruction of the antikythera mechanism using SGI's Inventor.*

Figure 5: *Andreas Vesalius (1514-1564) and the titlepage of his main work, the* Epitome.

Figure 4: *Front and back side of the mechanism.*

servation in anatomy characterized by *refinement of observation*. Vesalius changed the organization of the medical school classroom, bringing the students close to the operating table. He demonstrated that, in many instances, the former anatomists as *Galen* (130-200) and *Mondino de' Luzzi* (1275-1326) were incorrect (the heart, for instance, has four chambers). He conducted his own dissections, and worked from the outside in so as not to damage the cadaver while cutting into it. Vesalius also wrote the first anatomically accurate medical textbook, *De Humani Corporis Fabrica* (1543), which was completed with precise illustrations."[2]

He also produced a summary of the *Fabrica*, called *Epitome*, less bulky and less expensive, for the use of medical students and those with little or no anatomical knowledge. In the *Epitome* the illustrations seem to have been considered more important than the text and in consequence the format is even larger than that of the *Fabrica*, where the figures are about six centimeters shorter. The first Latin edition of the *Epitome* was printed by Johannes Oporinus, a friend of Vesalius, in Basel simultaneously with the *Fabrica*.

"The *Epitome* has 12 unnumbered sheets signed A-M; two further unsigned pages are printed on one side only, containing the figures which were to be cut out and put in place on both the skeleton and the body representing the nervous system." [3]

There exist copies of the *Epitome* that have the superimposed flaps with the anatomical details mounted thus following Vesalius' own instructions on the preparation of the two manikins: "We wish to advise those who obtain unprepared copies, and put them together by their own efforts and industry, on the method of cutting each from the superfluous paper and pasting them on, and then of coloring them according to their ability and desire. In order to provide strength, it will be useful to glue a piece of parchment to the back of the entire sheet so that it may not in vain be divided into as many pieces as there are figures comprising it. " There are only a few copies of the *Epitome* with unmounted flaps, one is located at the institute of medical history of the University of Padova, where Vesalius worked for five years as a research assistant. This book was the basis for our work.

One last remark of [2] summarizes very well the importance of Andreas Vesalius for modern medicine: "Vesalius's careful observation, his emphasis on the active participation of medical students in dissection lectures, and his anatomically accurate textbooks revolutionized the practice of medicine. Through Vesalius's efforts, medicine was now on the road to its modern implementation, although major modifications and leaps of understanding were, of course, necessary to make its practice actually safe for the patient."

An object like the *Epitome* is very sensible. The only way to reproduce its content is to take photographs of the single pages. Scanning for example is impossible, since such books may not be folded up that wide without possible damage. Our data basis were therefore 25 slides of all the pages plus slides of front and back cover. We scanned these slides with an resolution of 2.000×3.000 pixels. This results in 6 mega pixels per image or 18 MB storage capacity using truecolor and no compression.

The polygonal model of the book itself was produced with our standard modeling tools and is stored in a CAD format. The measurements for this model can be taken directly with the help of standard measuring tools. We have produced an

animated book model, i.e. it is possible to "turn over" single pages just as with a real book. The geometry necessary for this task is already contained in the model and is activated when needed.

3.1. Texture cutting by projective texture mapping

Due to the generation process of the images, we cannot use the whole images as textures. Usually, it is not possible to fold up the book and to take photographs in a way, that the pages are aligned exactly in the camera window. Therefore, we have to select a part of the image for texturing. Texture selection can easily be achieved by manipulating the texture coordinates of a mesh, i.e. a polygonal model of a surface.

There exist many approaches for generating texture coordinates for a given mesh. In [5], a comprehensive summary of techniques and solutions for this problem is given. All these techniques calculate texture coordinates Ω for a set of vertices of a surface, which form a triangulation and therefore a discrete approximation of this surface.

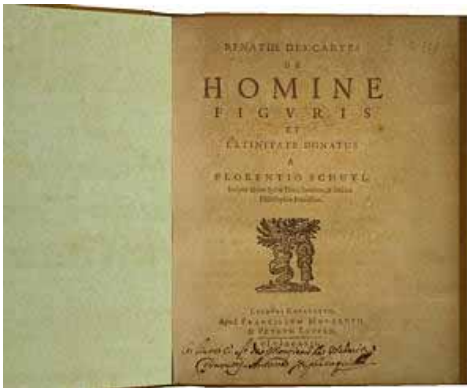**Figure 6:** *Part of the image selected for texturing.*

Figure 7: *Virtual book model with this texture.*

The selection process is demonstrated in figure 6 and figure 7. Figure 6 shows the part of the image which shall be used for texturing. The result can be seen in figure 7.

Similar selections have to be made, if digital maps shall be applied to digital elevation models. Due to the cartographic mapping, the map is not aligned to the Cartesian coordinate axis.

Current rasterization hardware is only able to perform normal linear interpolation along the two Cartesian axis during the rasterization and texture mapping process of a triangle.
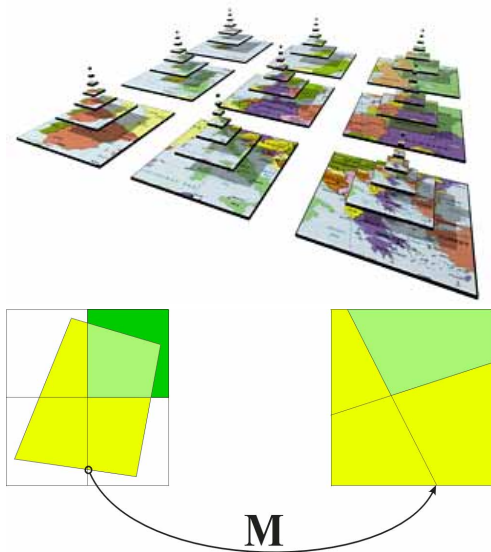
We can calculate a projective transformation M, which allows a bilinear interpolation on the quadrilateral $[X_0, X_1, X_2, X_3]$. This transformation matrix M can be computed using MAPLE.

3.2. Tiled textures

As already depicted, we use the approach of [4] to extend the texture capabilities of *OpenGL* to handle arbitrarily large textures. It is shown in figure 8, how this works in principle. We use a tiling of the whole texture in a set of MIPmap pyramids, which are precalculated and stored on disk. We do not store all levels, since smaller levels can be recalculated more quickly. Each single pyramid can use at its finest level the maximum resolution *OpenGL* offers for a single texture. We call this structure a *MIPmap pyramid grid (MP-Grid)*.

Each of these MIPmap pyramids of the *MP-Grid* offers now the possibility to adapt it to the viewer's position by only loading those levels of the pyramid which are necessary. The question which levels are necessary can be answered using the three dimensional bounding box of the polygons which shall be textured with this pyramid. The projection of this bounding box on the viewing plane of the viewer's camera depicts the maximal pixel number necessary to texture the content of this bounding box correctly. Rounded up to a power of two the maximum of the dimensions can be used to determine the maximum level of this MIPmap pyramid which has to be accessible in memory. This is a conservative estimation of the number of levels needed. Polygons which are parallel to the viewing plane can be textured correctly and these are the polygons that need the highest texture resolution. With this, the whole *MP-Grid* can easily be adapted to a changing viewers' position and is a sparse representation of the whole MIPmap in texture memory. We can even use textures, that won't fit into texture memory at all.

To use the texture cutting approach from the last section also for *MP-Grids*, we have to do a tessellation of the texture in the original Cartesian coordinates at the tile boundaries. Only in the original Cartesian coordinate space, the proper

Figure 9: *Bird eye view of the book.*

Figure 8: *Left side: a data structure for large textures: the* MP-Grid. *Right side: a* MP-Grid *with projective texture cutting.*
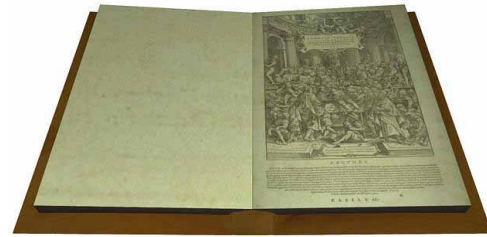

Figure 10: *Turning a page.*

texture coordinates for the temporary points can be calculated which will then again be transformed by *M* (see figure 8).

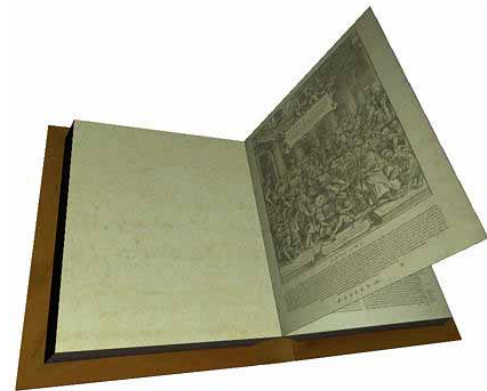### 3.3. Results produced with our approach

In this section, we present some screenshots (figures 9 - 12) produced with our prototype implementation. We call it *showBook* and its only requirement is the existence of an *OpenGL* runtime environment on a specific system. Thus it runs on a broad range of computer system, ranging from a small laptop up to a SGI Infinite Reality system. The amount of texture which can be displayed depends only on the executing system. On our laptop with 32MB RAM, we had to reduce the number and resolution of the textures to navigate around the book, since the graphic system is emulated by the CPU (Pentium 166). The screenshots were taken on a SGI O_2 with 384 MB RAM and 180 MHz. On this system, we interactively handled the textures of several book pages with the full resolution of 2.000×3.000 pixels and the pages can be turned in realtime. The application performs even better on modern Pentium II systems.

4. The first four species Calculation device of Wilhelm Schickard

We have to admit that we have reconstructed the following device with some local patriotism. Wilhelm Schickard

(1592-1653) was professor of orientalic languages, astronomy, mathematics, and geodesy at our university. The faculty of computer science in Tübingen bears his name (the reason for that will get obvious in the following). Therefore it was clear that we dedicated ourselves to make a modern reconstruction of his device. It is almost unknown that not the great french mathematician Blaise Pascal invented what we call a modern calculation device in 1642 but Wilhelm Schickard in 1623 — the year Pascal was born.

In a letter dated 20th September 1623 Schickard wrote to his dear friend Johannes Kepler: ".. What you have managed to calculate by hand, I've tried the last days to perform in mechanical ways and have constructed a machine consisting of eleven complete and six garbled gearwheels. It calculates instantly and "automatically"(this word was written in greec letters!) given numbers: adding, subtracting, multiplication and division. You would burst out laughing if you would be here and live to see how the left digits, if it goes over the tenths or hundreds, increase from its own or while doing a subtraction taking something off."[8]
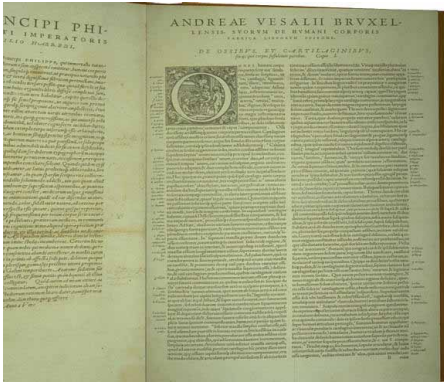
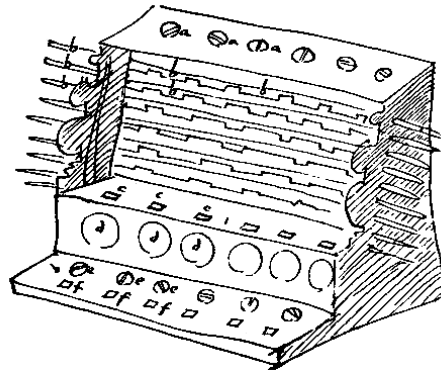**Figure 11:** *First page of the book. Someone has written a remark on the side.*

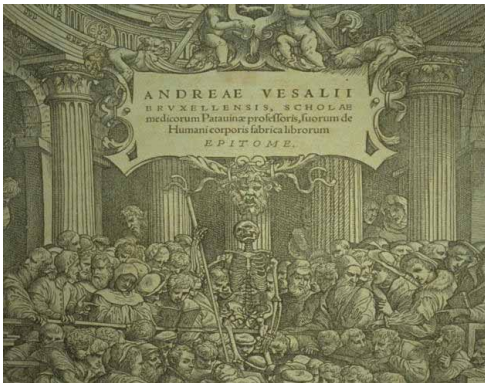**Figure 13:** *Schickard's drawing from a letter to Kepler.*

Figure 12: *Detail of the front page.*

It is always astonishing to recall that in total 17 gear-wheels could perform all four manipulations.

In the time of Katharina the Great some of the belongings of Johannes Kepler (and also this letter) came to Pulkowo near St. Petersburg in Russia. Amongst the papers of Kepler on the famous Rudolphinic tables there was a drawing of Schickard (Figure 13).

It is again from a letter dated 25th February 1624 to Kepler: "From the mathematical device I will make a better one another time; take this one for sake of a hurry (the above picture): *a a a* (see the labeling in the picture) are the little knobs of upright cylinders holding the multiplications of the decimals, and they may be observed, if needed, through the moving sliders *b b b. d d d* have fixed (gear)wheels on the inner side with ten teeth, which are connected in such a manner, that if the right one rotates ten times the left one revolves one times ...."[8]

Schickard goes on describing his device and seeking in his bequest we find another drawing of the machine (Fig.

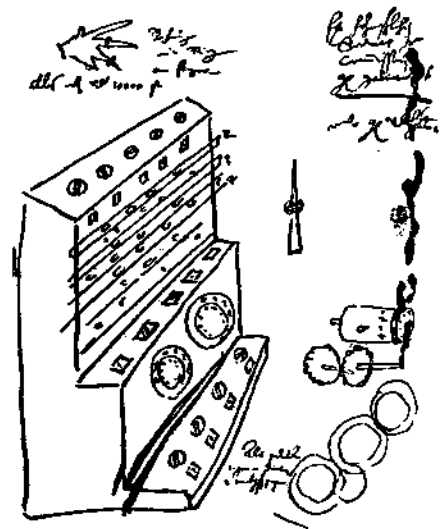14) and notes on the machine for his mechanical engineer on what should be enhanced.

Figure 14: *Schickard's drawing from his notebook.*

Thus there is knowledge on how the machine looked like and how it should work. But there is nothing more. There are already several reconstructions of the calculation machine and we do not want to explain how it works, this is the subject matter of experts in history of science. However, as mentioned in the introduction these reconstructions are accessible just to a limited audience.

We had the idea to make the machine available to an international comunity of interested people via the World Wide Web. We not only wanted to provide pictures and historic information about the reconstructions, but enable the visitor to use the machine and perform simple computations. The user should feel like Schickard proposed: "...burst out laughing,

..and see how the left digits, if it goes over the tenths or hundreds, increase from its own ..."

With JAVA 3D we have a modern technology to rebuild the machine.

4.1. Reconstruction of Schickard's computer using Java 3D

The model of Schickard's calculation machine was build using a VRML modeler (actually we again used the Pytha modeler and converted the data into the VRML language). Visualization and animation of the model in the World Wide Web was then added by using a Java Applet and Java 3D. Conversion between VRML and Java 3D was done with a conversion tool of the Java3D and VRML Working group. The schematic workflow is shown in figure 15. To be more
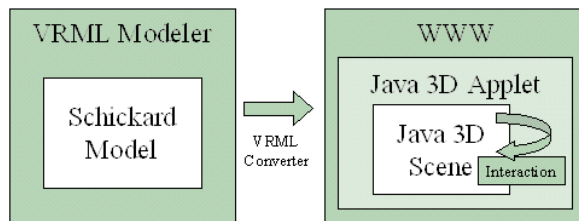

Figure 15: *Setup of the reconstruction.*

concrete the packages we used are:

- JDK 2 (alias version 1.2.1)
- Java 3D
- JFC/Swing

The programming platform JDK 2 is a prerequisite for the Java Standard Extension Java 3D and includes the Java Foundation Classes, especially the Swing packages for creating a programs' GUI.

The main steps and ideas regarding our reconstruction were the following:

- Scene Modeling: As we only had limited access to the reconstructed model of the Schickard Calculator device presented by the Heimatmuseum Tübingen, we measured the proportions by hand and modeled all the geometry by ourselves. Furthermore we added textures and sound to approximate the real device.
- Scene Visualization: We built a simple scene viewer with a global interaction behavior (move, zoom, pan). Furthermore we implemented scene nodes for constrained behaviors like picking with followed animations, left/right movements for a slider or the turning of a gear wheel, that stimulates its neighbor to turn every 10th step.
- Interaction: We implemented functionality to rotate, zoom and pan the model as well as picking behaviors to turn buttons, wheels and sliders.

- Animation: The buttons, wheels and sliders each use a thread of its own. This multi-thread approach results in an excellent responsiveness of the model.
- Help: We integrated a guided tour explaining the handling of the device. Following the description step by step the user performs a simple multiplication. Another essential part is the implementation of a direct help system: If enabled, the user may point his mouse cursor to an unknown detail to get a comprehensive description of its meaning and usage.
- Graphical User Interface: Apart from a message field we supplied buttons for several predefined viewing points and additional functionality like resetting all user input, making the case transparent, toggling textures, toggling direct help. All components are logically grouped by titled borders. Another way to support the user is the modification of the mouse cursor: current actions can easily be differentiated by the cursor shape.

We close with some still pictures of the project (see Figures 16-20). You see different views and comments how to use the machine.
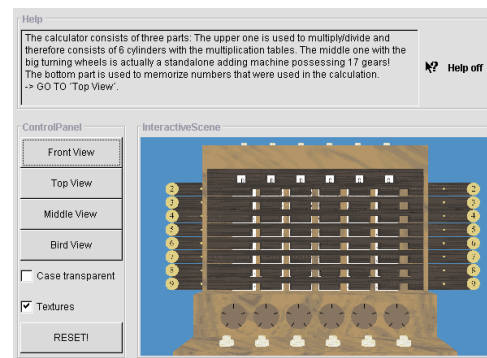

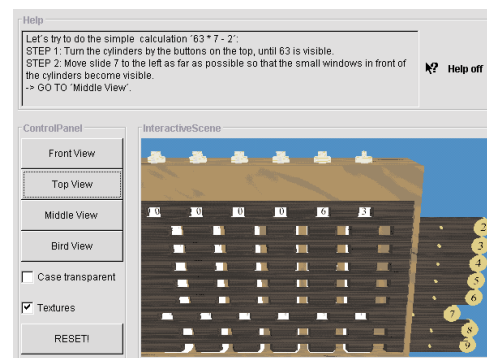**Figure 16:** *Front view of the machine.*

Figure 17: *Schickards' machine from the top.*

The installation of the required Java packages is a little bit cumbersome at the moment but it is to be expected that Java
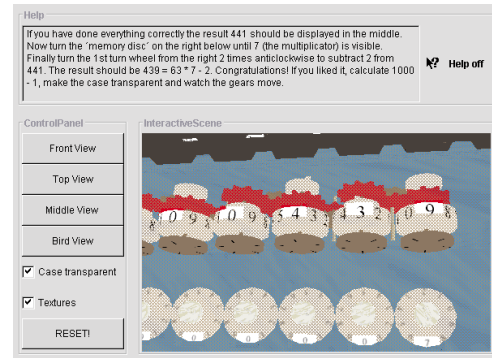
Figure 18: *Some intermediate view.*

Figure 20: *Looking into the machine.*

Figure 19: *Birds eye.*

matica of the University of Padova and professor Maurizio Rippa Bonati from the *Biblioteca Medica "Vincenzo Pinali"* of the University of Padova for their help during the image acquisition process. Without them, we would not have been able to acquire the material necessary to realize the Vesalius project.

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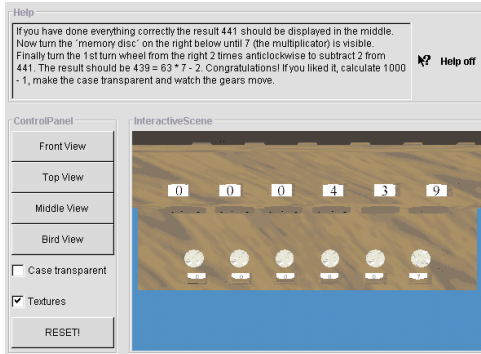
3D and the setup will become integrated in standard releases of Web browsers in future.

5. Summary

We have presented three examples of delicate objects which where reconstructed using three different approaches in 3D Computer Graphics, namely Inventor, sophisticated texture mapping and world wide web oriented approaches using Java 3D. All three objects are, from the historical/cultural point of view, interesting and have now been made accessible to the public using Computer Graphics. The models presented are a consequent step in the evolution of multimedia to provide the consumer not only with textural and audiovisual information but concrete objects that function.

It was fun "bringing these objects to new life", but without the deep knowledge of our teachers we would have been blind. Therefore, we would like to express our deep gratitude especially to Prof. Dr. M. Schramm from the history of science department at our University and all colleagues in his seminar.

Secondly we would like to thank professor Guido Maria Cortelazzo from the *Dipartimento di Elettronica e Infor-*