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Archimedes in Bits: The Digital Presentation of a Write-Off

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Abstract
The Archimedes Palimpsest is considered by many to be the most important scientific manuscript ever sold at auction. It was purchased at a Christie's sale on October 1998, by an anonymous collector for $2,000,000. The collector deposited the Palimpsest at the Walters Art Museum, Baltimore, for exhibition, conservation, imaging and scholarly study in 1999. Work has been ongoing ever since. The Archimedes Palimpsest contains seven of the Greek mathematician's treatises. The manuscript was written in Constantinople (present day Istanbul) in the 10th century. In the 13th century, the manuscript was taken apart, and the Archimedes text was scraped off. The parchment was reused by a monk who created a prayer book. The Archimedes manuscript then effectively disappeared. Since 1999, intense efforts have been made to retrieve the Archimedes text. Many techniques have been employed, including multispectral imaging, x-ray flourescence imaging and synchrotron x-ray scanning at the Stanford Linear Accelerator Center in California. The imaging efforts have led to a re-evaluation of the work of Archimedes, and to the retrieval of entirely new texts from the ancient world.

Keywords
Archimedes, medieval manuscripts, digital imaging, conservation

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Archimedes in Bits

The Digital Presentation of a Write-Off
William Noel
A Speech Presented at the first Annual Lawrence J. Schoenberg Symposium on Manuscript Studies in the Digital Age
November 1-2, 2008
Today I talk not about Archimedes, the man and the myth, but about a book, technically known as Codex C, which is the unique source for “The Method”, “Stomachion”, and the only Greek text of “Floating Bodies”.
Codex C was almost certainly made in Constantinople in the tenth century, copied from earlier manuscripts. Isidore of Miletus, one of the architects of Hagia Sophia, was instrumental in the transmission of Archimedes works.
Sometime in the thirteenth century, Codex C was palimpsested. It was disbound, the text erased. The conjoint leaves were then cut in half. These leaves were then reused, together with erased parchment from other books, to make a prayer book, or Euchologion.
The manuscript became a prayer book. Archimedes’ writings and other erased texts disappeared from knowledge.
From at least the sixteenth century, the manuscript was used at the Great Lavra of St Sabas, in Palestine. It stayed there, incognito, until the nineteenth century.
By the 1840’s the manuscript was in the Metochion of the Holy Sepulchre in Constantinople. The manuscripts at the Metochion were catalogued by Papadopoulos-Kerameus in 1899. Ms.355 was our prayer book. But PK also transcribed some of the under-text, which was mathematical in nature.
Papadopoulos-Kerameus’s catalogue came to the attention of Johan Ludvig Heiberg, the great expert on Archimedes. He visited the Metochion to study the manuscript in 1906, and discovered the unique Archimedes texts in the book. These he proceeded to publish over the next eleven years. It is on Heiberg’s work that all subsequent Archimedes Scholarship has been based.
Heiberg had photographs made of many folios in the manuscript. These are now kept in the photo archive in the Royal Library in Copenhagen.
Following World War One, and in difficult circumstances, the manuscripts at the Metochion were moved to the National Library in Athens. Several precious manuscripts were lost in the process, including this manuscript, now at The Walters Art Museum, and the Archimedes Palimpsest, which entered a French private Collection.
The manuscript was sold at auction, by Christie’s New York, on October 29th, 1998.
It was bought by an anonymous private collector for 2 million dollars plus buyer’s premium. At the time of the sale it was made clear that the manuscript would be made available for study.
The manuscript was in much worse condition than it was when Heiberg studied it. On the left is a photograph that Heiberg had made of a leaf of the Palimpsest in 1906. On the right is the same page today, covered with a modern painted forgery.
Professor John Lowden identified the forgery as having been copied from a publication on Greek manuscripts, published in 1928. There are four such forgeries in the book, two of which cover the introduction to The Method.
The manuscript has also suffered very badly from mold. On the left is a Heiberg photograph of the unique surviving page of the Stomachion. On the right is the same page today, largely devoured by mold.
This book is the ultimate write-off. But it was not written off by the manuscript’s new owner.
He deposited the manuscript at The Walters Art Museum, where it has been the subject of ten years of conservation, imaging and scholarship.
The project is managed by Mike Toth of R.B. Toth Associates. It is his job to make sure that the project is run on schedule, at a reasonable cost, and to the highest possible performance.
The Conservation is being undertaken by Abigail Quandt, Senior Conservator of Manuscripts and Rare Books at The Walters Art Museum.
This is a photo-micrograph of a core sample from the Palimpsest, which reveals that the Archimedes ink is little more than a stain, and that the collagen in the parchment is breaking down. This image was part of a study that Quandt commissioned from the Canadian Conservation Institute.
Severely weakened & perforated by mold, parchment is easily torn. Normally parchment is tough. Much of the Palimpsest, however, is like tissue paper.
Quandt had to disbind the book prior to imaging. One big problem was the modern glue on the spine (where it is whiter in the picture). This glue, put on in the second half of the Twentieth Century, is tougher than the parchment that it supports.
It is not surprising, therefore, that it took Quandt four years to disbind the manuscript. This is a rare action shot............
The very first page of the book is on the left. After Quandt took it apart, Professor Reviel Netz (more of whom later), identified the leaf as a previously unrecognized part of “Floating Bodies”. It became clear that with imaging it would be possible to extract more Archimedes text than Heiberg could read.
Before imaging, Quandt and her colleagues mechanically removed lots of dirty wax from the parchment. This wax is the residue of burnt candles, the wax of which had fallen on the book while it was being used as a prayer book.
The modern glue was carefully removed using a mixture of isopropanol and water.
All the particulate matter taken from the surface of the pages has been retained, and catalogued by the leaf that it came from.
These are some small fragments of the codex that need to be returned to their rightful position.
Under ultraviolet light it is possible to see that sometimes they have text on them.
With their text transcribed, their place can be identified, and they can be put back in their proper location.
The gutters of the pages often needed the most work. Here is a typical example of damage.
Here is Quandt working on the damaged gutter
Here is a “before shot”, an “after shot”, and an ultraviolet image of the mended parchment, that reveals the Archimedes text.
Eventually the manuscripts were ready for imaging, and a mat was made for each leaf for that purpose.
The Imaging Team:

Bill Christens-Barry
Equipoise Imaging LLC

Roger Easton
RIT

Keith Knox
Boeing Corporation
The primary text that the imaging team used is called multi-spectral imaging. The team takes images of the Palimpsest at different wavebands of light. (In the illustrations above we are running from ultraviolet on the left through to infrared on the right, and the Archimedes text is most apparent, running horizontally, in the ultraviolet). The team then combine these images together in post-processing to bring out the erased text.
Our early efforts were spectacular. This is the same page, first under natural light, and then processed to bring out the under-text.
They were also total failures. The results were noisy and extremely difficult to read.
We got better at it. We merged a red natural light image, with a blue ultraviolet florescence image. Since the parchment is light in both, it will come out light. Since the prayer-book text is dark in both, it will come out dark. And since the Archimedes text is dark in the ultraviolet image, but light in the reddish regular image, the idea is that it will come out red.
And this is the result. The Archimedes text is clearly distinguished from the prayers on top of it, and from the parchment beneath it. The algorithm used to create this was devised by Keith Knox. It is easy to apply, and works over large sections of the manuscript. It should also work on many other palimpsested texts, in principle.
A quick comparison: natural light on the left, processed “pseudocolor” on the right. The diagram now shows up well.
Sometimes the results are really extraordinary.......
In the summer of 2007, we re-imaged the entire manuscript in sixteen wavebands of light, cover to cover, using instrumentation by a great guy, the late John R. Stokes, of Stokes Imaging, Austin Texas.
Bill Christens-Barry of Equipoise imaging built the lighting system out of LEDs (Light Emitting Diodes). This lighting system allows for portable, inexpensive multi-spectral imaging, and is now commercially available as the “Eureka lights!”
This is the same set up, in blue.
Here is Archimedes Method Proposition 14 in sixteen different wavebands of light. On none of them can the text be red. It takes post processing of the different wavebands to create a product that is legible.
The Pseudocolor images that we create are not pretty, but they are for the most part effective. But, to see how useful they are, you need to zoom in.
And in...
And in....
And in......
And in......
And in.
We apply very similar post processing to get a fundamentally different view, one that strips off the over-text.
This is particularly useful for getting a sense of the diagrams, which are of extraordinary importance in Archimedes Scholarship.
Of course these optical techniques had limitations when it came to reading texts on pages that were particularly dirty, or which had forgeries painted on top of them. These were extremely challenging.
In April of 2004, we convened a meeting of top imaging scientists to brainstorm about a way forward with the particularly difficult pages.
Three scientists came up with the same idea: X ray florescence imaging. These scientists are, from left to right:
Bob Morton, of Conoco Phillips
Gene Hall, Professor of Chemistry at Rutgers University
Uwe Bergmann, Staff Scientist at the Stanford Synchrotron Radiation Laboratory
X-ray fluorescence imaging works in the following way: if an atom is struck by an X-ray it will shed an electron with a specific energy. If we can measure the energy of that electron, we can determine the atom that it comes from. Since the ink had a high iron component, it should be possible to determine where the iron is.
We took a leaf of the Palimpsest to the EDAX company in New Jersey, who make X ray tubes, and they very kindly lent us their equipment. We found that we could determine high iron content in the Palimpsest. What we needed to do was to map the iron content, and at a reasonable speed. For this, we needed a larger instrument.
The best we could find was the Stanford Synchrotron Radiation Laboratory at The Stanford Linear Accelerator Center. This is an oval particle accelerator that is about the size of a football field.
Electrons spin around the accelerator at the speed of light, and shed Synchrotron radiation - very powerful, tunable X rays - as they circle. We were on beamline 6.2, where Uwe Bergmann ran the operation.
Of course we cannot move the beam, so we have to move the Palimpsest, leaves of which we set up on an XY stage in front of the beam.
It took about twelve hours to scan one column of one page, but the result was Archimedes text that the scholars could read.
Nigel Wilson, on the left, author of Scribes and Scholars, and Scholars of Byzantium, is one of two scholars working on the transcription of Archimedes works. He lives in Oxford.
Reviel Netz, Professor of Ancient Science in the Classics Department at Stanford, who was already engaged in the translation of Archimedes works, is also working on the transcription of the Palimpsest.
The Pseudocolor allowed them to read more than Heiberg could see of the Archimedes folio 105-110, which contains the text of Archimedes’ Method Proposition 14.
Our work paid off. I received the following email from Netz:

Reviel Netz (netz@stanford.edu)  
Fri Apr 13 09:49:13 2001

In a couple of months the first intellectual fruits of our labour will be published, together with a complete transcription of one crucial side of one page, most of which is unknown to modern science.

To sum up, the new reading from Archimedes' Indivisibles Proof should call for some reconsideration of the position of Archimedes in some key areas of the history of mathematics, especially the two related conceptual fields of the calculus, and of infinity.
SCIAMVS 2 (2001), 9–29

A New Reading of *Method* Proposition 14:
Preliminary Evidence from the Archimedes
Palimpsest (Part 1)

Reviel Netz
Stanford University

Ken Saito
Osaka Prefecture University

Natalie Tchernetska
Trinity College, Cambridge

To the memory of Wilbur Knorr (1945–1997)

I Introduction

The Archimedes Palimpsest, referred to in Heiberg [1910–1915] as ‘Codex C’, had a complicated history that is understood only in part (see e.g. Netz [2000]). Originally a tenth century manuscript containing several works by Archimedes, it was palimpsested as a Greek prayer book in the twelfth or thirteenth century, and then remained unknown to the scholarly world until it was rediscovered in Istanbul at the end of the fifteenth century.
The story also caught the popular imagination, and received press attention. This was important, as many people who helped with the project did so because they heard about it through the press.
Netz also came to a new interpretation of the Stomachion. It was known that the treatise concerned a square, made up of 14 pieces. But no one really had a clear idea about what Archimedes was doing with this square.....
Based in part on new images of the Palimpsest, Netz thought that it might be that Archimedes was working out how many ways the 14 pieces could be combined to make a perfect square. He asked Bill Cutler to work it out, using a computer program.

The answer was…….
17,152.

If Netz is right, and many believe him to be, this would make the Stomachion a very early treatise on the mathematical discipline of Combinatorics.
Netz and Wilson worked primarily on the Archimedes texts. If you remember however, there are other palimpsested texts in the manuscript which had never been deciphered. Natalie Tchernetska, who was at the time working on a PhD on Greek palimpsest practices, looked into the other folios.
In 2002 Tcherneska identified five folios of the manuscript in which the under-text was not written in two, but in one column. She identified these leaves as containing the text of speeches by the attic orator Hyperides. Hyperides was one of the ten canonical orators of antiquity, a contemporary of Demosthenes and Aristotle. Some fragments of his work were discovered on papyrus in the Nineteenth Century, but this is the first Hyperides text to be discovered in a codex, and is a major find for scholars interested in Athenian law and politics.
In 2005, a third text of great interest was discovered in the Palimpsest. Netz and Wilson had been picking out odd phrases that were philosophical in nature for some time. Then Wilson discovered Aristotle’s name in a margin. Scholarly interest grew as no existing text could be found that matched the fragments that could be deciphered.
Here I show you two views of the same leaf. I have circled the word Aristotle at the bottom of the pseudocolor image.
It took the combined efforts of many scholars from around the world to decipher these texts, and they are still working on them.
It was not until 2006 that we finally found out who wrote the prayer book. An iron map created at Stanford of the first folio of the manuscript revealed the colophon. The prayer book was written by Johannes Myronas and was finished on April 14, 1229. Judging from the specific characteristics of the prayers, analyzed by Stefano Parenti, the book was almost certainly written in Jerusalem.
The transcriptions provided by the scholars were turned into TEI P5 XML by Chris Blackwell of Furman University, Neil Smith of Holy Cross, and Alex Lee of Chicago, and by their students.
All the images, raw and processed, together with the transcriptions of the unique texts, and supporting documentation, had to be prepared for the web by the project’s data manager, Doug Emery, of Emery IT.
The Project has a website that gives all sorts of background information. It is [www.archimedespalimpsest.org](http://www.archimedespalimpsest.org).

WELCOME. The subject of this website is a manuscript of extraordinary importance to the history of science, the Archimedes Palimpsest. This tenth century manuscript is the unique source for two of Archimedes Treatises, *The Method* and *Stomachion*, and it is the unique source for the Greek text of *On Floating Bodies*. Discovered in 1906 by J.L. Heiberg, it plays a prominent role in his 1910-15 edition of the works of Archimedes, upon which all subsequent work on Archimedes has been based. The manuscript was in private hands throughout much of the twentieth century, and was sold at auction to a private collector on the 29th October 1998. The owner deposited the manuscript at The Walters Art Museum in Baltimore, Maryland, a few months later. Since that date the manuscript has been the subject of conservation, imaging and scholarship. The Archimedes Palimpsest project, as it is called, has generated a great deal of public curiosity, as well as the interest of scholars throughout the world.

This website attempts to give information on the Palimpsest, and on the progress of the project in general. It is designed to be of interest to a wide range of audiences, and many people have contributed to it. I do hope that you find answers to some of the questions you may have concerning the manuscript and the progress of the project on this site.

William Noel
Curator of Manuscripts
The Walters Art Museum
All the raw data is presented at [www.archimedespalimpsest.net](http://www.archimedespalimpsest.net). It is published under a Creative Commons License, so anyone can use these images, and anyone can try to improve upon the results of the project using this data.
The anonymous owner of the Palimpsest is passionate about the project, makes all the decisions (really, he does), and pays for all the work to be done.
His and the team’s dedication has produced results beyond expectation, though the project has taken a toll on them...
2007 AFTER TREATMENT
And the result is that what was ten years ago a fragile, unique, frequently illegible, and certainly expensive testament to the minds of Archimedes and Hyperides, is now legible and freely accessible on desktop computers around the world.