Experimental Archaeology of Computer Science

Giovanni A. Cignoni – Museo degli Strumenti per il Calcolo, Università di Pisa
Fabio Gadducci – Dipartimento di Informatica, Università di Pisa

Abstract

The technologies of the first computers are very far from us. While not much time passed, reconstructing and properly understanding how an old computer works is a hard task. Few blueprints and technical manuals survived, and these documents are frequently fragmentary. Though the researchers that built and used those computers are often still alive and willing to help, they cannot recall detailed memories of such complex machines.

Hackerando la Macchina Ridotta (Hacking the Smaller Machine, HMR) is a project of the Department of Computer Science of the University of Pisa that applied the methods of *experimental archeology* to computer history. As a result, the chronology of the first Italian computers was rewritten.

Until now, the Olivetti Elea 9003 and the University of Pisa CEP were considered the first computers designed and built in Italy. However, the same project that in 1961 delivered the CEP, in 1957 had built another machine, the MR, which was smaller with respect to memory and input/output devices, but fully functional and used for computing services. Historians has hitherto overlooked, sometimes completely ignored, the MR. Today the reconstruction of its technology reveals a remarkable machine for its time, different and for several reasons even more interesting than its 1961 companion.

The HMR project had also dissemination purposes: the results were used for an exhibition at the *Museo degli Strumenti per il Calcolo* (Museum of Computing Tools) of Pisa. The exhibition also offers teaching laboratories that use the simulators and the hardware replicas that were built as proofing tools of the MR technology rediscovery.

Key words
Experimental Archaeology · Computer Science History · Pisa Electronic Computer

Abstract esteso in italiano

Il rapido sviluppo dell’informatica ha reso assai distanti da noi le tecnologie dei primi

calcolatori. Benché vicine nel tempo, ricostruirle richiede molta sperimentazione per interpolare i dati sopravvissuti, spesso pochi e frammentari, con i ricordi, naturalmente lacunosi, dei protagonisti dell'epoca. *Hackerando la Macchina Ridotta* (HMR) è un progetto del Dipartimento di Informatica dell'Università di Pisa che, con metodi di archeologia sperimentale, ha riscritto la storia dell'informatica nazionale, riscoprendo in particolare la rilevanza del primo calcolatore costruito in Italia, la *Macchina Ridotta* (MR) del 1957.

Fino a oggi l'Olivetti *ELEA 9003* (ELaboratore Elettronico Aritmetico) e la *CEP* (Calcolatrice Elettronica Pisana) dell'Università di Pisa erano ritenuti i primi calcolatori italiani. Tuttavia, lo stesso progetto che nel 1961 realizzò la CEP aveva nel 1957 completato la MR, che, "ridotta" solo per memoria e periferiche, fu utilizzata per servizi di calcolo scientifico. La MR finora era stata trascurata (a volte del tutto ignorata) dagli storici. Oggi, la ricostruzione della sua tecnologia ci rivela una macchina notevole per il suo tempo, diversa e più interessante della sorella che le succedette.

Il progetto HMR è basato sulla documentazione recuperata dall'Archivio dell'Università di Pisa e dalla Biblioteca del CNR. La ricerca è stata svolta con espliciti obiettivi divulgativi: i risultati sono proposti al pubblico nella mostra "La CEP prima della CEP" allestita presso il Museo degli Strumenti per il Calcolo di Pisa. Alla mostra sono associati laboratori didattici che utilizzano i simulatori e le repliche hardware realizzati per provare le ipotesi ricostruttive della tecnologia della MR. Il Museo è oggi in grado di proporre una ricerca originale che ha aggiunto un capitolo importante per la storia della tecnologia in Italia ha conquistato il pubblico incuriosendolo con la possibilità di giocare con le ricostruzioni di un calcolatore d'epoca.

Da questa esperienza, confermata dai numeri dei visitatori e dei partecipanti ai laboratori, il Museo può aspirare a un nuovo corso con l'obiettivo, fra finanziamenti istituzionali, progetti mirati ed entrate proprie, di alimentare nuove attività che lo collochino per la divulgazione al pari delle eccellenze che la città già offre per la ricerca e la didattica nel campo dell'informatica.

L'articolo discute come affrontare la storia dell'informatica in modo da comprendere, preservare e tramandare il funzionamento delle macchine includendo entrambe le "facce" del mondo dei calcolatori: l'*hardware* e il *software*. La sezione 1 è dedicata a

una breve presentazione dell’archeologia sperimentale applicata all’informatica. La sezione 2 riassume le vicende del progetto CEP che a Pisa realizzò la MR prima e la CEP poi, e illustra come i dettagli della MR, scoperti grazie alla comprensione delle sue tecnologie, offrano una nuova lettura dei primi passi dell’informatica Italiana. Infine, la sezione 3 descrive come i simulatori e le repliche realizzati come prove sperimentali trovino un uso divulgativo nei laboratori didattici offerti alle scuole dal Museo degli Strumenti per il Calcolo.

Parole chiave

Archeologia sperimentale · Storia dell’informatica · Calcolatrice Elettronica Pisana

Introduction

In the jargon used at the MIT laboratories, “hacker” is a person who, inspired by a healthy scientific curiosity, wants to fully understand how and why complex systems – like computers – work (Levy, 2010). This is the spirit of the teaching laboratories offered by the *Museo degli Strumenti di Calcolo* (Museum of Computing Tools) to the visitors of the exhibition *La CEP prima della CEP* (The CEP before the CEP) (CEP50, 2012).

The exhibit and the associated laboratories spring from the results of a research project, *Hackerando la Macchina Ridotta* (Hacking the Smaller Machine, HMR), carried out by the Department of Computer Science of the University of Pisa since 2006 (HMR, 2012). The project investigated the history of the first Italian calculators by using a rigorous technology perspective. This approach resulted in the – almost unexpected – discovery of the relevance of the *Macchina Ridotta* (Smaller Machine, MR) and the recognition of its historical and technological value, which previously had been either overlooked or completely ignored. The MR was built in 1957 as part of the same project that later delivered the *Calcolatrice Elettronica Pisana* (Pisa Electronic Calculator, CEP), so far considered, togheter with the *Olivetti ELEA 9003*, the first computer built in Italy.

The “hacking” approach of the HMR project, that is the proper understanding of the involved technologies and their assessment against the state of the art at that time, implied methods of *experimental archeology*. The few blueprints and the fragmentary technical documentation recovered from the archives were interpolated with the memories of the original developers to make hypothesis on the architecture of the first Italian computers. The hypotheses were verified experimentally by using simulators and partial hardware replicas.

As an additional result of this experimental approach, the simulators and the replicas are being used for dissemination: proposed to students, computer enthusiasts, and, in general, curious people, they provide direct experience of the difficulties faced by those computer science pioneers. Moreover, thanks to the relative simplicity of the early machines, their simulators and replicas are suitable – and appealing – examples to demonstrate the concepts and the mechanisms of how any computer works. In fact, despite the incredible performance achieved today, the basics are still the same.

The article presents our experience in approaching the history of computing in order to understand and preserve the technologies and the operations of the machines of the past including both "sides" of computer science: hardware and software. Section 1 is a brief presentation of experimental archaeology applied to computer science. Section 2 summarizes the events of the CEP project and shows how the details discovered by rebuilding the MR technology enrich with new facts the history of Italian computer science. Finally, Section 3 describes how the simulators and the replicas built by the HMR project are used in the teaching workshops offered to the schools.

1. Experimental archaeology of Computer Science

The histories of mathematics, physics, as well as science in general, are well-established research areas. For computer science it may seems premature to talk about "history", even more so since it developed in times in which the risk of loss of documents and evidences is supposed to be low, in some way downgrading the urgency for historical research.

However, computer science is closely linked to technologies and to their short life cycle: a computer technology becomes quickly obsolete and it is then replaced and forgotten. For this reason, especially in the United States and in the United Kingdom, the history of computing is widely recognized as a research area. Besides computer science, the close relations with industry make the field interesting also from the perspective of the history of economics and social development (Mounier-Kuhn, 1994).

The literature is extensive and there are many projects, ad hoc institutions, and cultural initiatives about computer history, often addressed to researchers as well as to a growing audience of so called *retrocomputing* fans. In Italy, the interest is more recent. Many initiatives have the goal of preserving and exhibiting those machines that made the history of computer science. So far, also the Museum in Pisa fell into this category. However, computer science is not limited to *hardware*: the other half of the sky is made by *software* and the hardware was made to *run* it.

How hardware worked, which software was run, how people used those machine, by which kind of interaction and for which purposes are all valuable issues of computer history. An exhibition of switched off machines is a very poor description of the history of computing – and, for sensitive people, a gloomy sight.

Experimental archaeology is the study of technologies of the past carried out by attempts to recreate and use ancient artefacts. The discipline was born in the Fifties and there are many cases of application. The *Damascus Steel* is one of the best-known examples (Reibold et al., 2006). Swords forged with this technology are documented between the X and the XVI centuries in the Middle East. Few artefacts remains, but a debate is still open on the metallurgical technique that was adopted: is the Damascus steel an original technology or just a different name for already known ones such as the Indian *wootz* steel or the Japanese *folded* steel? Another interesting case is given by the *trebuchet*, a kind of huge siege machines whose tricky physics was lost in time (Hansen, 2006).

The methods of experimental archaeology can also be applied to the history of computing. Facts are recent, but the complexity of the involved technologies and the loss of documentation (often poor from the start, a sort of original sin of computer scientists) require experimental methods to fully understand and possibly bring back to life the computers of the past. As a matter of fact, there exist international research initiatives to recover the relics of computing history: we briefly discuss here a few of them.

Colossus was the machine used at Bletchley Park during World War II to decrypt the Axis transmissions encoded with the *Lorenz SZ42* (Copeland, 2004). Besides the historical value related to its role in the war, the Colossus was one of the first digital machines. However, its technology went almost lost: fearing information leaks, the Colossi and all their documentation were deliberately destroyed in the first years of the Cold War. A project for the reconstruction of a Colossus started in 1993 exploiting the very little surviving documents and the memories of the still alive scientists and engineers (Sale, 2012). A Colossus replica is now functioning at the Bletchley Park Museum since 2007.

Still in the UK, the University of Manchester completed in 1998 the reconstruction of the *Small Scale Experimental Machine*, known as *The Baby*, the very first digital calculator ever built (Burton, 2005). It is also worth mentioning the recovering of the complete building instructions of the *Block I AGC*, the guidance computer installed on the control module and on the lunar lander of the *Apollo* missions (Hall, 2012). Finally, among some French projects aimed at preserving and putting old computers back to working conditions, we mention the case of the PDP 9 restoration (Aconit, 2012).

Building a physical replica is appealing, yet expensive. Restoring the original machines exposes instead valuable relics to the risks of damage, and the substitution of faulty parts in order to achieve working conditions may compromise the originality of the piece. Moreover, replicas and originals, tied to their physical locations, are poorly accessible to researchers and, in general, to the public.

For these reasons, an alternative solution is to rebuild the past machine by using software simulators. While a simulator is still difficult (and expensive) to develop, the solution has several advantages. First of all, it does not jeopardize the originals. Then, it may be built at different levels of details, adjusting the effort with respect to both the hypotheses that need to be proved and the spending limits of the rebuilding project. Lastly, a simulator can be easily distributed, making the solution available to the wider public.

In general, there are many simulators available for computers of the past, from the first historic machines to more recent ones – the previously cited Colossus and Baby among them. These resources, besides their historical interest, can also be used for teaching computer science as simpler case studies, easy to be understood down to their minimal details (Yurcik & Gehringer, 2002).

2. The CEP project and the rediscovery of a relevant machine

The birth of the CEP is part of the founding myth of Italian computer science (De Marco et al., 1999; Parolini, 2008; Maestrini, 2006; Andronico, 2007; Mancino & Sprugnoli, 2011). We briefly summarise here the new facts discovered by the HMR project that are reported in (Cignoni & Gadducci, 2012).

In the early Fifties the University of Pisa received from the Counties of Pisa, Lucca and Livorno a huge funding to build a synchrotron, with the aim of launching Tuscany as a prominent area for research. However, the initiative clashed with a better offer from Rome and in the end the synchrotron was built in Frascati.

As an alternative use for the available funding, the Pisa Department of Physics (at the time *Istituto di Fisica*) suggested to build a digital computer. The project received a valuable endorsement by the Nobel laureate Enrico Fermi (Fermi, 1954; Salvini, 2008) and actual works started in early 1955: the *CSCE (Centro Studi sulle Calcolatrici Elettroniche*, that is Centre for Studies on Electronic Machines) was established and charged with the task of designing and building the computer in four years (Meeting memorandum, 1955).

Olivetti was involved in the project since its beginning. The company had since long identified the need to invest in the blossoming field of computers and it offered to CSCE specialized personnel, materials and a relevant cash endowment.

The University CEP was completed in the first half of 1961, with an 18 months delay with respect to the original schedule. It was officially inaugurated on November, 13 and remained in operation for about eight years. The CEP was a remarkable machine, however, the computer world radically changed over the years the project was completed. The CEP technology fully reflects the delay of the project and its financial problems: while still an interesting machine, it was not a state of the art product.

However, in 1957 the CSCE already delivered a fully functional computer, the MR. The first detailed design of the MR was ready by July 1956, and the machine was announced as successfully working on July 24, 1957. The MR was used as a pilot machine to validate the solutions and finalize the design of the “ultimate” CEP *(definitiva*, as it was optimistically called). More importantly, the MR was also used to provide computation services to other research fields. In the few months of its life the MR accounted 150 machine hours “sold” to external research projects: the reports proudly boosted that such a workload would amount to a “total of 8 million lire”. Notably, a particular application of theoretical physics used symbolic computation with the result returned as an exact expression. Its use for research and development of new programming techniques is an evidence of versatility and reliability of the MR. Besides its chronological primacy, the MR was also the machine used for the first educational activities of computer science held in Pisa, starting in 1956.

The comparison of the MR with other machines of its time is quite interesting. Indeed, the

MR adopted several state of the art solutions that were not easy to find all together in the same machine in that period, namely *parallel bit processing*, *ferrite core memory*, and *microprogrammed control*. It suffices to say that none of those three design choices are found on the other two computers installed in Italy at the time: the CRC102 and the Ferranti MK1, bought respectively by the Polytechnic of Milan and the INAC of Rome.

Moreover, the MR was also a fast machine. After careful tuning, performance was incremented by 30% with respect to the initial estimates, so that it could be claimed "superior to all the other machines on the market, including the IBM located in Paris". Actually, "superiority" only concerned speed: the referred IBM 704 had more memory, more flexible I/O devices and was equipped with a *Fortran* compiler. Nevertheless, surpassing the IBM flagship machine on the most straightforward benchmark was a remarkable achievement.

It is surprising that both the chronological and the technological achievements of the MR have been almost forgotten by those who, at various times, worked on the history of the CEP project. Among the reasons (see also (Cignoni & Gadducci, 2012)) that contributed to the oblivion of the MR, perhaps the most crucial is its early description in formal documents as the "central core" of the ultimate CEP, so that many historians underestimated its importance. However, the MR was a different machine and very little of it migrated "as it was" into the CEP. For a technologically minded researcher, the differences between the MR and the CEP are numerous and substantial.

4. Reconstructions: simulators and replicas for teaching labs

In 2006 the Department of Computer Science of the University of Pisa started a project to investigate the technologies of the first computers built in Italy. The project name, that in English sounds Hacking the MR, was chosen to highlight both the technical enthusiasm and the challenges that characterized the initiative. The project started by recovering, identifying and making digitally available the historical documentation of the early years of the CEP project. Then we began to rebuild the MR mainly as software simulators. Up to now, the project has delivered four tools that, in different ways, are MR reconstructions.

Simulator of the 1956 MR. One of the most interesting achievement of our technological investigation was the identification of two versions of the MR. It was possible to retrieve almost all the documentation of the very first design dated July 1956, in particular a large collection of logical, electronic and mechanical blueprints. Due to the availability of its documentation, this version of the MR was the first target of a virtual rebuild.

Simulator of the 1957 MR. The 1956 design was heavily modified and the MR completed in 1957 was very different from its initial version. Unfortunately, very little documentation remains of this version: a short user manual, a very concise technical report and few photos. The rebuilding of the 1957 MR is still a challenging on-going task of the HMR project. The first delivered version of the simulator fully emulates the machine core (CPU and memory) and the manual control panel, that is, the user interface that was one of the most interesting evolutions with respect to the 1956 design. Work is in progress for the simulation of the I/O devices, a part also interested by relevant evolutions. Moreover, to fully recreate the working context experienced by the researchers that programmed and used the MR, we want to extend the simulation of the devices at a level that includes hardware errors and borderline situations.

Replica of the 6 bits adder. During our research we found a note reporting the activities of the early months of 1956. One of the achievements of those days was the building of a 6 bits adder, that is, one third of the 18 bits adder of the arithmetic unit of the MR. Likely, this was the very first piece of digital hardware built in Italy. Since it is historically relevant, relatively simple and easily demonstrable, we decided to build a replica of the 6 bits adder according to the original blueprints and using, as far as possible, components and tools of the period – a few of them were even recovered from the left spare parts of the CEP project.

Educational 6 bits adder. The 1956 adder has an interesting modular structure that makes it good at explaining how binary arithmetic works. For this reason we built also a "modern" version of the 6 bits adder, made by small, handy parts that kids may easily play with and assemble in various configurations. Logic and modular architecture are exactly the same as the original adder, but the electronic implementation uses today components to reduce size and, most importantly, to work with low and safe voltage.

According to the experimental approach, simulators and replicas were developed to validate our interpretation of the incomplete technical documentation of the MR. In particular, the simulator of the 1956 MR was used to assess the feasibility of the very first design and to rebuild the 1956 MR system software, a primordial operating system (Cignoni *et al.*, 2009). The simulator of the 1957 MR was used to investigate the differences from the 1956 version and to evaluate the originality and the relevance of the interesting MR features discussed in Section 2.

Besides their role for the purposes of the HMR project, simulators and replicas are being used in teaching workshops offered by the Museum to middle and high school students. The machines of the past are fascinating means to introduce the hardware and software technologies. Today computers hide their mechanisms behind friendly user interfaces. On the contrary, the first machines expose all the details: usage is awkward, but it is possible to see how and why they work inside. Currently the Museum offers the four workshops described in the following.

A session on the 1956 MR. The simulator of the 1956 MR is used to disclose what happens in a computer when a program is launched. Apart from some differences in the ease of use, the MR and a modern PC behave in the same way: what today is hidden behind a double click can be seen and followed step by step on the MR.

The adder of the MR. The educational replica of the MR adder is used to explain many issues about the “inside” of computers: from Boolean algebra to binary arithmetic, from logical networks to clock frequency.

A session on the 1957 MR. The 1957 MR offered several improvements in I/O device management and control. A session on the simulator MR57 allows to evaluate how important the control interface of a computer and the interaction with the user are.

Programming the MR. A plethora of different programming languages exists nowadays. However, in order to be executed every program must be translated into a language directly comprehensible by the machine. Using the MR we can (must) write programs to the lowest level of interpretation. It is laborious, but it is also an instructive challenge.

The basic “package” proposed to classes visiting the Museum includes several steps: a brief introduction to the history of computer science, the chronology of the Pisa project from the MR to the final CEP, the demonstration of the 6 bits adder replica and a session on the simulator of the 1956 MR.

The whole tour takes about 3 hours including pauses and question times, thus offering to the classes the way of filling half a day of a typical school trip. Should classes be able to organize a second visit, we propose additional laboratories in a learning path of increasing difficulty.

Conclusions

The HMR project shows that, in order to approach the history of technological artefacts, sound technology expertise is needed. At the beginning, we adopted the experimental archaeology methods having in mind "only" the rebuilding of the MR. The relevance of the MR was actually an unforeseen result: it emerged day by day together with the understanding of the machine. A whole chapter in the history of the CEP project has been recovered thanks to an in-depth technical analysis that revealed the differences between the various versions of the MR and allowed the acknowledgment of its importance.

As a further result, the replicas and the simulators are useful "toys" to animate and increase the appeal of the Museum. In the first 6 months of our experience, despite the scarce personnel resources (laboratories and guided tours can be held only three times a week), more than 1800 persons visited the exhibit and about 1400 participated to almost one workshop.

The Museum, established by initiative of Roberto Vergara Caffarelli in the late Nineties, is at last presenting to the public an original research that adds an important chapter to Italian computer history and catches audiences by giving a chance to play with the reconstructions of an old computer. With 40% of the schools coming from outside Tuscany, we also can consider our experience a new asset added to the Pisa cultural heritage.

Acknowledgements

The exhibit *La CEP prima della CEP* and the workshops of the Museo degli Strumenti per il Calcolo were possible thanks to the contribution of *Fondazione Cassa di Risparmio Pisa*, *Fondazione Cassa di Risparmio di Lucca* and AICA, the *Italian Association for Informatics and Automatic Calculation*. For historical documentation, the HMR project relied on the collaboration of the Archive of the University of Pisa and of the Library of the ISTI-CNR of Pisa. For the archive research, special thanks go to Daniele Ronco.

The 6 bits adder was rebuilt in collaboration with the *Computer Museum of Novara* and with the mechanic shops of the *National Institute of Nuclear Physics* and the *Department of Physics* of Pisa. Personal thanks for their valuable contribute go to Andrea Moggi and

Alberto Rubinelli.

Last, a very special thank. A unique and invaluable contribute to our understanding of the MR technologies came from a protagonist of the events: Elio Fabri, one of the four designers of the MR.

References

Aconit, 2012. Association pour un Conservatoire de l'Informatique et de la Télématique, www.aconit.org

Andronico A., 2007. Quando il computer parlava italiano: la nascita dell'informatica a Pisa negli anni '50. In A. Peruzzi (ed.), *Pianeta Galileo 2007*, Regione Toscana.

Burton C.P., 2005. Replicating the Manchester Baby: Motives, Methods, and Messages from the Past. *IEEE Annals of the History of Computing* 27(3).

CEP50, 2012. La CEP prima della CEP. cep50.di.unipi.it

Cignoni, G.A., Ceccarelli D., Imbrenda C., 2009. Il restauro del software di sistema della Macchina Ridotta del 1956. Atti del *Congresso Nazionale AICA*, AICA.

Cignoni G.A., Gadducci F., 2012. Rediscovering the Very First Italian Digital Computer. In *3rd IEEE History of Electro Technology Conference*, IEEE.

Copeland J., 2004. Colossus: Its Origins and Originators. *IEEE Annals of the History of Computing* 26(4).

De Marco G. *et alii*, 1999. The Early Computers of Italy. *IEEE Annals of the History of Computing* 21(4).

Fermi E., 1954. Letter to Enrico Avanzi, August 11. Archivio dell'Università di Pisa.

Hall E.C., 2012. Apollo Guidance Computer Schematics. NASA Office of Logic Design, klabs.org/history/ech/agc_schematics

Hansen P.V., 1992. Experimental Reconstruction of the Medieval Trebuchet. *Acta Archaeologica* 63.

HMR, 2012. Hackerando la Macchina Ridotta. hmr.di.unipi.it

Levy S., 2010. *Hackers: Heroes of the Computer Revolution*, O'Reilly, 2010.

Maestrini P., 2006. La Calcolatrice Elettronica Pisana, una storia che sembra una leggenda.

In L. Dadda (ed.), *La nascita dell'informatica in Italia*, Polipress.

Mancino O.G., Sprugnoli, R., 2011. *CEP La Calcolatrice Elettronica Pisana – Scenario, storia, realizzazione, eredità*, Edizioni Plus.

Meeting Memorandum, 1955. Riunione per la Calcolatrice Elettronica, 9 marzo 1955. Archivio dell'Università di Pisa.

Mounier-Kuhn P., 1994. French Computer Manufacturers and the Components Industry 1952-1972. *History and Technology* 11(2).

Parolini, 2008. Olivetti Elea 9003: Between Scientific Research and Computer Business. In J. Impagliazzo (ed.), *3rd IFIP Conference on the History of Computing and Education*, Springer.

Reibold M. *et alii*, 2006. Materials: carbon nanotubes in an ancient Damascus sabre. *Nature* 444.

Sale T., 2012. The Colossus Rebuild Project. www.codesandciphers.org.uk.

Salvini G., 2008. La nascita dei laboratori nazionali di Frascati e della comunità scientifica. *Analysis* 2-3.

Yurcik W., Gehringer E.F., 2002. A Survey of Web Resources for Teaching Computer Architecture. In E.F. Gehringer (ed.), *Workshop on Computer Architecture Education*, ACM.