Using Old Computers for Teaching Computer Science

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Abstract. Research on the history of computing often needs to adopt experimental archaeology methods: the rebuilding of old hardware and software requires us to proceed by hypothesis and experimentation. This is one of the key assets of the HMR project, whose main goal is the study of Italian computers from the Fifties and Sixties. The results obtained by the HMR research are made accessible to the public through exhibitions and workshops held at the Museum of Computing Tools of the University of Pisa. The visitors of the Museum, mainly students from middle and high schools, are introduced to the basic concepts of computer science through fascinating old machines. The paper reviews some of the results of the HMR project and presents how historical computers, either preserved at the Museum or rebuilt by HMR, are shown to the public to teach principles and mechanisms of computer science.

Keywords: computing history, computing museums, teaching.

1 Introduction

Computer science is a still young discipline. However, given the rapid evolution of technologies, it is already difficult to preserve the memory of its protagonists and of their results. In a few years, hardware and software become out-dated. Before they are recognized as relics of the past, they risk being forgotten and lost. The History of Computing thus needs commitment and resources.

Such a history, however, should not be just a celebration of the past. Among other things, the charm of vintage computers and their stories may be of help in order to make scientific and technological disciplines more appealing for students. Indeed, old machines are both odd and fascinating: they may stimulate young people to invest time in the study of computer science and electronics; or, at least, they may provide them with the basis to be informed users and consumers of technology.

The teaching of computer science requires a suitable array of examples. However, today hardware and software are often too complex to be properly dealt with. On the other hand, the computers of the past offer us real-life examples: they are intriguing because of their age or of their historical role, yet they are simpler, built on a human scale (often literally) and understandable in all their details.

The paper presents the experience of a fruitful interaction between historical research and scientific dissemination. The HMR project [1] at the Department of Computer Science of the University of Pisa investigates the history of Italian

A. Tatnall, T. Blyth, and R. Johnson (Eds.): HC 2013, IFIP AICT 416, pp. 121–131, 2013.

informatics by adopting methods and techniques that stress the technological aspects of the discipline. The Museum of Computing Tools [2] of the same University provides precious pieces of its collections.

Section 2 briefly describes the HMR project, its methodologies and main results. Section 3 is devoted to some of the machines in the collection of the Museum: it presents how, during the guided tours, they are narrated and illustrated in order to explain, in addition to their history, the underlying mechanisms by which they work. Section 4 describes the reconstructions made by HMR and in particular the simulator of the Macchina Ridotta, the very first Italian computer, designed and built in Pisa in 1957. The presentation is focused on the use of the simulator in the educational workshops offered to schools by the Museum.

2 The HMR Project

HMR is a research project focusing on the recovery of the history and the technology of old computers – with a special attention to Italian ones. HMR has historical and technological goals: on the one hand, HMR aims at recovering the facts concerning the development of those early machines; on the other hand, HMR plans to rebuild past computers through simulations and replicas. HMR is a project of the Department of Computer Science of the University of Pisa, ongoing since the beginning of 2006.

The project acronym stands for *Hacking the Macchina Ridotta*, with an explicit reference to the hacker culture [3]. In fact, in order to rebuild the computers of the past a full understanding of their technology is mandatory. A superficial knowledge does not suffice: all the details need to be explored and understood with curiosity and commitment. These same words are written in the definition of hacker which is given e.g. in the Internet Glossary RFC 1392 [4].

The *Macchina Ridotta* (MR, meaning Smaller Machine in Italian) was the very first computer designed and built in Italy: it made its début in Pisa in 1957. The MR was a result of the same project that in 1961 delivered the more famous *Calcolatrice Elettronica Pisana* (CEP, meaning Pisa Electronic Computer). The MR has been the first computer investigated by the HMR project. Today HMR has widened its research goals, but the MR still remains in the acronym in order to highlight the origins and the initial accomplishments of the project.

In fact, the MR almost completely disappeared from the history of Italian computer science [5]. It was the in-depth investigation of the recovered MR documentation that made possible to rediscover it and, by rebuilding its technology, to understand its achievements and its relevance. From an historical point of view, HMR added a new chapter to the annals of Italian computer science.

In March 2008, HMR celebrated the 50th anniversary of the MR with a lecture in the course on History of Computer Science. MR's birthday was chosen as the date written on the MR User Manual: March 1, 1958. Actually, the MR has been running since July 1957, but in early 1958 it started to deliver computing services to Italian research projects: a clear sign of its functionality and reliability. The Manual was concrete evidence and a valuable symbol of the presence of users external to the small group of computer pioneers that build the MR, such as the researchers of the Physical Chemistry Institute which programmed the MR for their purposes. A few months ago, the 55^{th} anniversary of the MR was remembered by Google BlogSpot [6].

Information technologies developed quickly. The hardware was (and still is) superseded year after year. Old machines are forgotten, often scrapped. The other half of computer science, the software, was encoded in formats that rapidly become obsolete, the storage media degrade with time and today they are often unreadable. The same documentation is often lost, and maybe it was incomplete since the beginning – a long-standing bad habit of computer scientists. The protagonists of the events are often still with us, but their memories cannot keep track of the many details of such extremely complex systems. There is the need of digging in warehouses and archives as well as reassembling the pieces, in order to compare them with other contemporary computers and with the technological knowledge of the time. The gaps must be filled with assumptions and hypotheses which have to be checked and validated by experiments through simulations and replicas. The methodologies adopted by HMR [7] and other rebuilding projects in the world, like for instance [8] and [9], are thus reminiscent of those adopted in experimental archaeology.

The early Pisa computers are still the main objectives of HMR: there is still much to discover and rebuild. However, additional investigations focused on a range of topics, from the story of the first Olivetti machines, with their connections with industrial design and arts, to the evolution of personal computing from the early arithmometers of the XIX century to today portables. In all those cases, the results are also finalized to the dissemination and popularization of computer science.

3 The Computers at the Museum

Over the years, by rescues, recoveries, acquisitions, or donations, the Museum of Computing Tools of the University of Pisa gathered a relevant collection. Among the most valuable pieces, some of them are unique, such as the 1961 CEP and the Olivetti 9104, the latter explicitly designed for the Institute for Computing Applications in Rome. Other important artefacts are some early Sixties Olivetti products and a number of machines that, starting with the first arithmometers, made the history of personal computing.

HMR works with the Museum to narrate computers and their histories from both a scientific and a technological perspective. The computers of the past, explored as relics or rebuilt as actual or virtual replicas, are the protagonists of teaching and popularization initiatives that are unique in Italy. The following sections describe the most significant pieces that, in the activities performed at the Museum, have been used as examples to tell the stories and the technologies of computer science.

Historical data and technical information about the early Italian computers have been collected using as much as possible first-hand sources. For the CEP, the main reference is the original documentation in the Archives and Libraries of the University and the CNR. Useful sources are represented by foreign reports such as [10] and [11].

The literature on Olivetti computers mainly focuses on corporate events [12]. Reliable technical data are less documented, even if they can be found in foreign reports, as the files on ELEA 9003 [13] and 6001 [14] recorded by the U.S. Navy, or the correspondence between Canepa (head of the Olivetti Observatory of New Canaan) and Picone (director of INAC in Rome) in [15].

An overview of the evolution of those machines is out of the scope of our paper. For a recent summary in English of the main events concerning the CEP project, as well as the ELEA series, we refer the reader to [5] and the references therein.

3.1 Bull Gamma 3, 1953

The Gamma 3 Bull was built in 1952 [16]. It is one of the first European examples of commercial electronic machines, relevant to the history of French computing as well as to the Italian: Olivetti went into the computer business in 1949 by signing an agreement for the distribution in Italy of the Bull machines.

Since 1931 Bull started to produce electromechanical tabulators based on the patents of Norwegian Fredrick Rosing Bull. The Gamma 2 (1951) was the first one equipped with electronic circuits with diodes and vacuum tubes. The Gamma 3 was an immediate development and, in various versions, was produced in about 100 specimens until the early Sixties.

The Gamma 3 is proposed to visitors as an example of machine architecture with separate memories (in technical jargon, Harvard and not Von Neumann), thus, it is not in fact a modern computer. The specimen at the Museum is one of the first models, and the program memory was still made up of a massive plug-board and the software was actually hardware made of wires and pins inserted into the plug-board. Luckily, the complex operation of coding a program was not too frequent: several pre-coded programs were available and “loaded” into the machine directly by changing the plug-board. While showing the details, the most daring visitors are given the opportunity to test the weight of the programs of the Gamma 3!

The Gamma 3 is a witness of other facets of informatics. First of all, it uses punch cards. Second, it is a demonstration of how the market is sometimes independent of the technological level of the product. The Gamma 3 was a success even though it was an outdated product, for the aforementioned architectural characteristics and the odd mix of hardware technologies: alongside the digital electronic circuits, the Gamma 3 features a number of old electromechanical relays circuits.

3.2 Olivetti ELEA 6001, 1961

The ELEA 9003 was the first electronic computer produced by Olivetti. While a prototype of the ELEA series was presented at the Milan Fair in 1959, the first units were only delivered during 1960. ELEA 6001 followed a year later. Even if it is a follow-up product, a careful examination reveals a quite interesting machine.

In fact, the 6001 was an evolution of the 9003 designed to make the system more modular and versatile, thus able to satisfy different customers with respect to financial investment and application needs. It shared with the 9003 the general architecture and the set of peripherals, as well as the elegant exterior design by Ettore Sottsass. From a technological point of view, the 6001 introduced microprogrammed control and floating point arithmetic. It was a great market success (about 150 units sold, compared with about 40 of 9003), winning also scientific customers (it was e.g. purchased by the University of Padova, by the Politecnico of Turin and by the CNR of Rome).

In the Museum, the 6001 is proposed to the visitor as the final achievement of the series of wise R&D investments that, despite entering late in the market, led Olivetti to set-up a successful Electronics Division in just a few years.

3.3 Calcolatrice Elettronica Pisana, 1961

The 1961 CEP is showcased at the Museum. Apart from its historical value, its size and the (faithfully reconstructed) layout of its cabinets offer to visitors the unique experience of walking into a computer and discovering the components and their functions: the same, apart from the dimensions, of today computers.

The "walk" allows one to observe the input/output control board (actually, a 3 meters long rack), to appreciate the individual bits of the ferrite core memory, to recognize the registers of the processor, the read-only memory of the micro-programmed control, and the ALU components, up-to the individual stages of the parallel 36-bit adder.

Depending on the audience, a visit to the CEP may offer different levels of technicalities. The details offered by the Power Supply Unit range from the electrical representation of 0s and 1s to the trade-off between speed and energy consumption obtained by adjusting voltages. The matrix of the micro-programmed control allows the presentation of the mechanisms for decoding and executing machine instructions. The modular design of circuits together with the original instruments used for the construction and maintenance of the CEP provide an opportunity to actually understand what it meant to build a computer in the Fifties.

Due to the financial difficulties met by the project in its final years, the 1961 CEP was completed late and so it was, in some ways, already outdated. In particular, it was not possible to move toward a fully transistorized machine (thus reducing space, power consumption and heat dissipation issues), while this technological leap was taken by Olivetti with its ELEA series. This aspect of the CEP history let the visitors reflect on how risky can be for the technological future of a country to stop the research funding. The "walk" inside the CEP can also involve the visitors in a playful "transistors hunt" to find the few spots where, as a proof of their technological awareness, the Pisa researchers were able to introduce the new electronic components – thus discovering other traces of the participation of Olivetti to the CEP project.

3.4 Olivetti 9104 CINAC, 1966

In 1955 the CNR National Institute for Applied Computing (INAC) in Rome bought a Ferranti Mark I*. The Ferranti was one of the first European commercial computers, produced since 1951, and a direct descendant of the 1948 Manchester Baby Machine, the first modern computer. The Ferranti INAC was the second computer to operate in

Italy, a few months after the purchase by the Polytechnic of Milan of a CRC 102A, which had however less memory and worse performances.

In the early Sixties INAC decided to replace the Ferranti with a more modern machine by entering into an agreement with Olivetti. The new computer was eventually delivered in 1966, when the Olivetti Electronics Division had already been sold to General Electric. It was a one-of-a-kind specimen, identified as Olivetti Elea 9104 and renamed CINAC (for Computer INAC) by the CNR.

The 9104 was derivative of ELEA 4001, an average-size computer that was supposed to replace the ELEA 6001. The project was discontinued after the sale of the Olivetti Electronics Division to General Electric, but one of its variations, initially called ELEA 4-115, had great commercial success as GE-115.

The agreements between INAC and Olivetti established that the new machine had to be able to completely emulate the Ferranti. The request originated in the wealth of experience and, above all, of software libraries that the CNR Institute had developed in the long term adoption of Ferranti: a heritage that could not be lost and that can be interpreted today as a great attention to backward compatibility.

The emulation layer was extremely faithful: the Ferranti console and one of the typical viewers for the Williams memory banks were cannibalized and interfaced with the 9104, thus fully replicating the way programmers and operators were used to work. The presence of the original pieces of the Ferranti is thus another element contributing to the uniqueness and curiosity of the relic.

In addition, for the more technologically interested, the presence of the viewer of the memory banks is an opportunity to explore the theme of the storage technologies that preceded the ferrite cores, in this case the Williams Tubes adopted by Ferranti.

4 Vintage Computers That Work Again

A computer should always be shown in working conditions otherwise the exhibition is limited to the historical value of the relics, even if in some cases it is worth at least to appreciate the exterior design. An exhibition of switched off computers is, at best, only half of the story.

There are several ways to revive a vintage computer: restoration, rebuilding, simulation. Whatever the chosen way is, it is always a challenge in terms of time, efforts, and costs. Usually, the first difficulty is to obtain the technical information. As a consequence, the reviving process often needs to proceed by hypotheses and experiments. By applying these methods, HMR produced actual and virtual rebuilds of the MR.

- *Replica of the 6 bit adder*. Our research 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 bit adder. Likely, this was the first piece of digital hardware assembled in Italy. We built a replica according to the original blueprints, using components and tools of the period – a few of them recovered from the spare parts of the CEP project.
- *Educational 6 bit adder*. The 1956 adder has a modular structure that makes it suitable for explaining how binary arithmetic works. We thus built a version made by handy parts, which the students may play with. The logic and

modular architecture are the same as the original adder, but the electronic implementation today uses components to reduce the size and to work with low and safe voltage.

- *Simulator of the 1956 MR*. Our technological investigation was able to identify two versions of the MR. It was possible to retrieve almost all the documentation of the 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 has been 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, little documentation remains of this MR version: a short user manual, a concise technical report and few photos. This second simulator fully emulates the machine core (CPU and memory) and the manual control panel. Work is in progress for the simulation of the I/O devices, including hardware errors and borderline situations.

A detailed discussion of the problems faced by HMR in the rebuilding of the MR is in [7], while in [17] the use of the simulator of the 1956 MR for the "restoration" of its system software is presented. In the following we focus on the use of the 1957 MR simulator in the teaching workshops held at the Museum. The virtual MR is used to revive the look and feel of an old computer and to show and discuss some of the principles and mechanisms according to which past and present computers work.

Fig. 1. The only surviving photo of the Manual Control Panel of the 1957 MR

4.1 The Control Panel Manual MR 1957

Fig. 1 reproduces the only surviving photo of the Quadro di Controllo Manuale (QCM, literally the Manual Control Panel), that is, the console of the 1957 MR. Fig. 2 presents the virtual QCM as it is reproduced by the simulator. The QCM was the main interaction interface with the MR. Among its main components there are:

- *Indicatore del Numeratore* (IN, literally numerator display, 10 lights, top right), displaying the binary value of the program counter;
- *Indicatore della Memoria* (IM, literally memory display, 18 lights, under IN), connected to the MR memory to display the binary value of the last written word; however, since the ferrite core memories have to be rewritten after each reading, IM shows also the last read word;
- *Tastiera della Memoria* (TM, literally memory keyboard, 18 vertical switches, under IM), used to bit-wise set a word to be written in memory;
- *Tastiera delle Istruzioni* (TI, literally instruction keyboard, 18 vertical switches, under TM), used to bit-wise set an instruction (for example, in Fig. 2 an unconditional jump instruction to the memory address 100 is set on TI);
- *Chiavi di Arresto Condizionato* (CAC1/2/3, literally keys for conditional stop, 3 vertical switches, bottom left), used to prepare the 3-bit codes that allow to stop the execution of the MR programs at defined breakpoints;
- *Commutatori dei Modi di Funzionamento* (literally switches for working modes, from left to right CNR, CRT, CEI, CAIM, 4 switches with 2 or 3 positions, bottom centre), used in combination to set the MR in different operating modes, such as the step by step execution of programs (by instructions or micro-instructions), the execution of instructions from memory or from TI, the loading of data or programs in memory by connecting I/O devices, in a way we may call direct memory access;
- *Pulsante di Avviamento* (PA, literally start button, bottom right), used to enable the clock pulse generator and to start the working cycle of the MR.

Understanding the role of all the QCM components is the result of a long process of analysis based on the recovered documents: scientific papers, project reports, internal notes and blueprints. The documentation collected in the Archives is fragmentary. Moreover, many documents are extremely concise. In a few cases we found only draft versions of documents and blueprints which still had errors, not to mention old fashioned terminology and notations.

Rebuilding the MR was like solving a big technological puzzle: putting pieces together, some recovered from the documents, other derived by assumptions made according to the knowledge of the time. The simulation, before becoming useful for dissemination, has been the key tool for testing the reconstruction hypotheses.

The methods and simulation tools used by the HMR project are actually a result of current research in modelling and simulation [18] and they are part of the teaching carried out at the Simulation Course held for the master degree in Applied Computer Science of the University of Pisa.

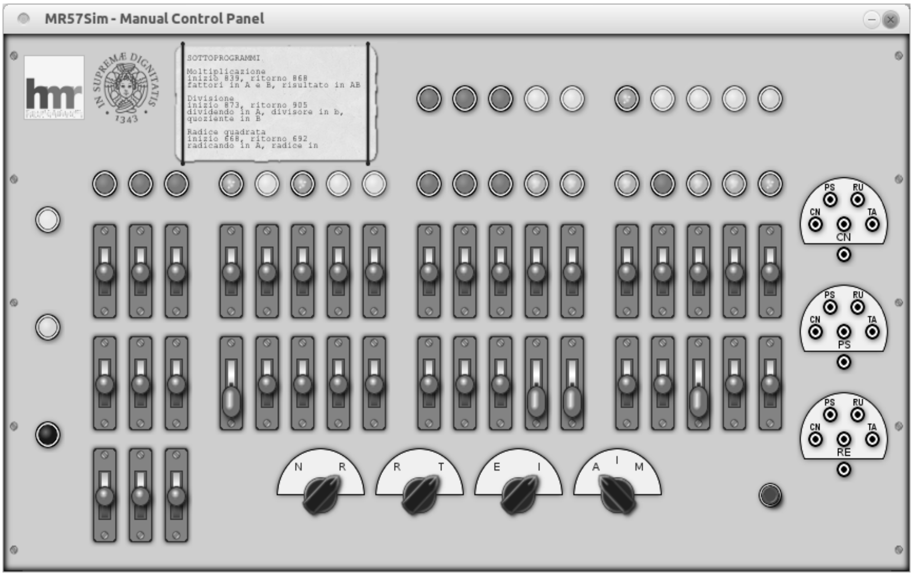

Fig. 2. The Manual Control Panel as reproduced by the simulator of the MR

4.2 The MR Simulator as a Teaching Workbench

The MR simulator is used in the workshops offered by the Museum to middle and high schools. The aim of the workshops is to introduce the concepts and the mechanisms of computer science by showing a fascinating device:

- most of the interaction with the MR is through the QCM, by reading the IN and IM displays and by setting data and instructions on TM and TI; everything is done bit-wise, a great exercise in binary arithmetic;
- the MR had a quite small set of instructions, all using the same format that is very simple and rational – today we would call the MR a RISC machine; this makes the MR easy to be presented, understood and used in a short time;
- the way the MR is operated exposes all the mechanisms that today remain hidden behind friendly user interfaces; from loading code into memory to starting it by manually executing unconditional jumps, all the events happening in a computer when a program is launched are fully disclosed;
- MR, as practically all computers of its time, was not conceived to interact with the user during program execution; however, by using the ability to set and activate breakpoints, it is possible to make pseudo-interactive programs useful to explain the basics of human-machine interfaces.

A typical demonstration session with the simulator starts by the execution of single instructions directly from TI, by setting the 5 bits (10 to 14) of the instruction code and the 10 bits (0 to 9) of the operand. A further step is to run simple programs that allow the use of the MR as a simple calculator – with display and keyboard in binary.

For a “gaming” experience, a program transforms the MR into a classical slot machine. Besides the fun, the example is interesting for the kind of user interaction that it implements. Moreover, the underlying random number generator uses an algorithm that was developed in the mid-Sixties, that is, about ten years after the MR time. This is used as an opportunity to reflect on the universality of computers and to recall fundamental concepts of computation such as the Turing equivalence.

The simulator is also extremely accurate in reproducing in real-time the performance of the MR. It is possible to run benchmarks and measure how fast the MR was – with about 70 KIPS, it was quite a good runner for the time.

Finally, the simulator carefully reproduces also the look and feel of an old computer. Indeed, its accuracy offers an intriguing side-effect, debunking (and explaining) the classic movie representation of computers packed with blinking lights. In the case of the MR, the lights on the QCM were implemented by cold cathode gas-filled triodes (type Z50T). Their times of ionization/de-ionization were, respectively, 50 and 200 μs, much longer than the clock cycle of the MR that, depending on the type of microinstruction, was 4 or 8 μs. As a result, the lights on the QCM more than blinking, were emitting an incomprehensible and flickering gleam: they were fully on or off only when the machine was stopped and the bit values remained constant.

5 Conclusions and Future Work

Besides any other consideration, the history of computing can be a valuable teaching tool, allowing us to introduce in a soft way basic concepts of computer science to the general public and to students.

The article outlined some of the major results of the HMR project and offered an overview of some of the most significant historic machines preserved at the Pisa Museum of Computing Tools, showing that the reconstructions and the original memorabilia can contribute to the teaching of computer science. The success so far encountered by these initiatives, both in terms of public participation and in the media, seems to confirm the value of this approach.

For the future, we are working to set up a permanent exhibition at the Museum devoted to personal computing, starting from the very first mechanical (yet digital) machines like the XIX century arithmometers, up to the first fully portable computer of the end of the XX century. In the planned setting, the turning point between personal calculators and personal computers will be the Olivetti Programma 101, universally considered a jewel of Italian technology and design. The Museum has in its collections a few P101's, and we hope to be able to restore at least one in working conditions. And, of course, there will be a fully featured simulator.

Acknowledgements. The desk research was carried out in collaboration with the Archives of the University of Pisa and the Library of ISTI-CNR of Pisa. With regard to the archive, a special thanks goes to Daniel Ronco.

The 6-bit adder has been reconstructed in collaboration with the Computer Museum of Novara and the workshops of the National Institute of Nuclear Physics. We remember with great pleasure the days spent working with Andrea Moggi (INFN) and Alberto Rubinelli (the Museum of Novara).

Finally, special thanks go to Elio Fabri, one of the protagonists of the MR, who, with his memories and the documents he preserved, provided us with an invaluable contribution to the understanding of the technologies of the first Italian computer.

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