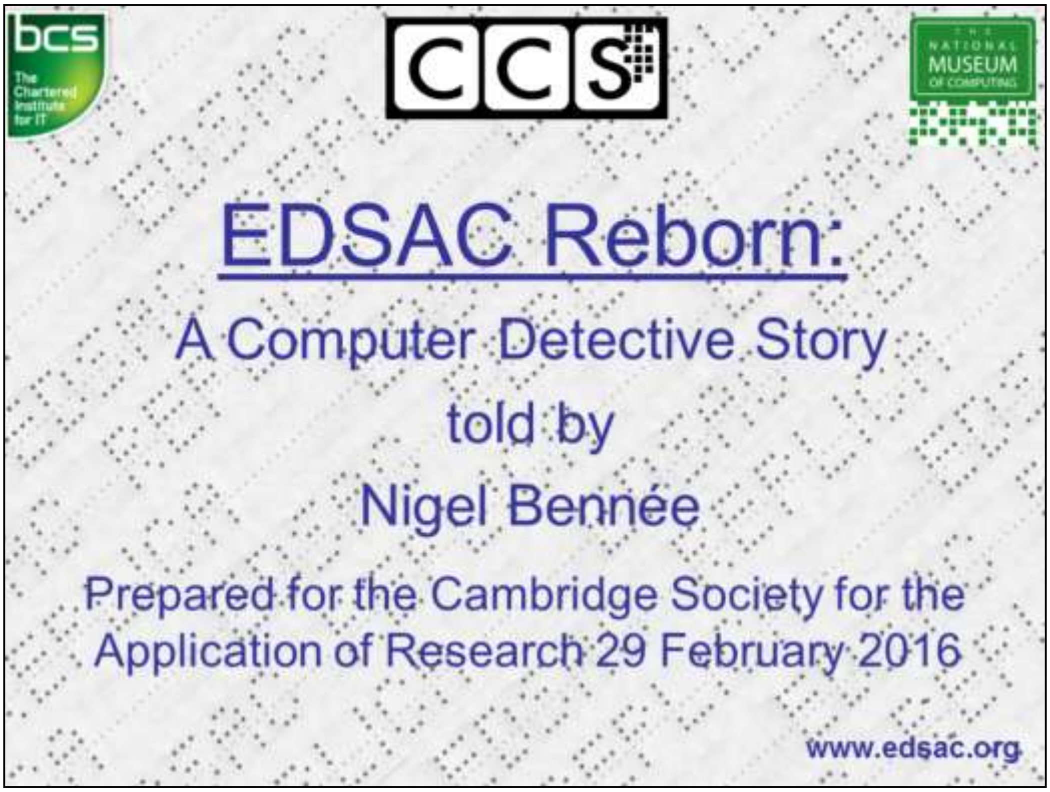


EDSAC Reborn:

A Computer Detective Story

told by

Nigel Bennée

Prepared for the Cambridge Society for the Application of Research 29 February 2016

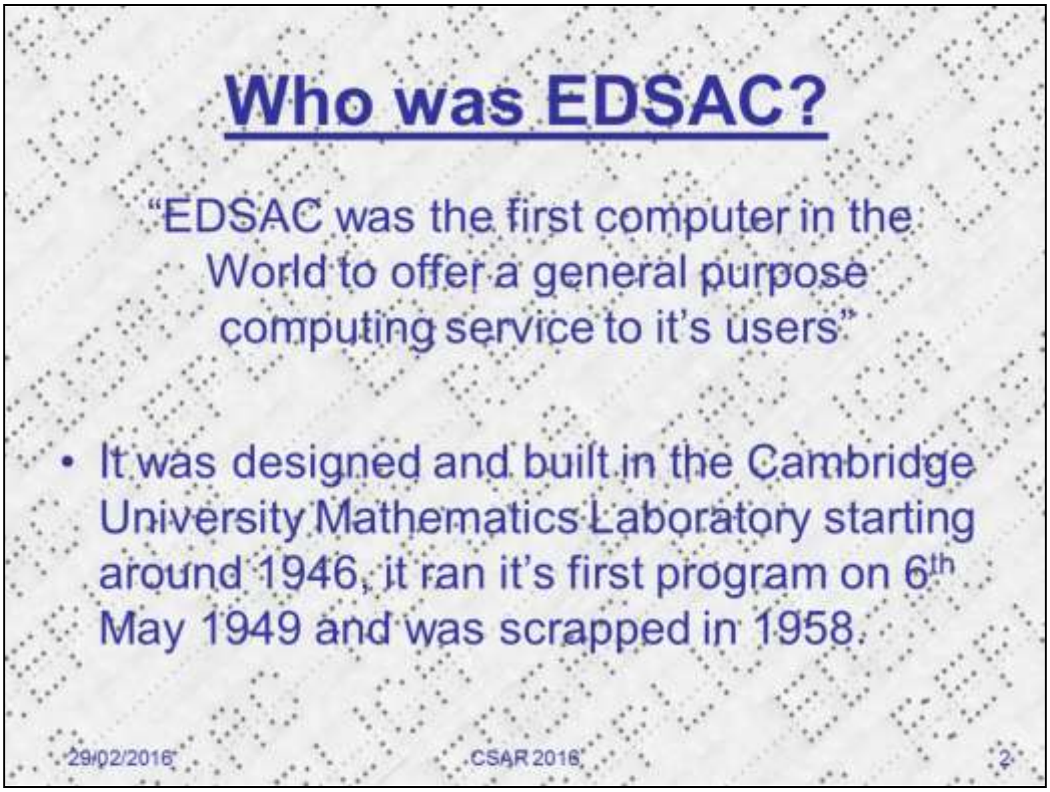
www.edsac.org

Thank you David/Valerie

First of all please raise a hand if you have heard of EDSAC .

Good/Excellent.

All stories have characters so I must start by introducing the principal character.



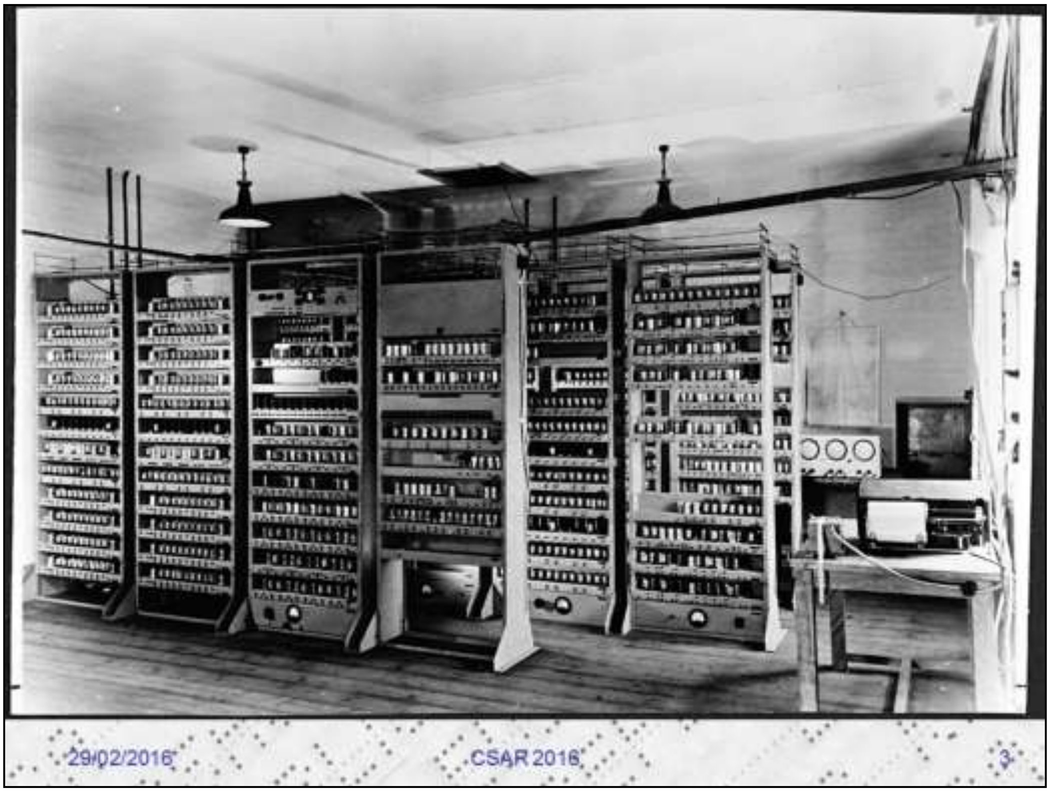
Who was EDSAC?

"EDSAC was the first computer in the World to offer a general purpose computing service to it's users"

- It was designed and built in the Cambridge University Mathematics Laboratory starting around 1946, it ran it's first program on 6th May 1949 and was scrapped in 1958.

EDSAC was the first computer in the World to offer a general purpose computing service to it's users.

It was designed and built in the Mathematics Laboratory of the University by Maurice Wilkes and his team from around 1946. It ran its first successful program on the 6th May 1949 and was unceremoniously scrapped in 1958. A short but certainly not tragic life.



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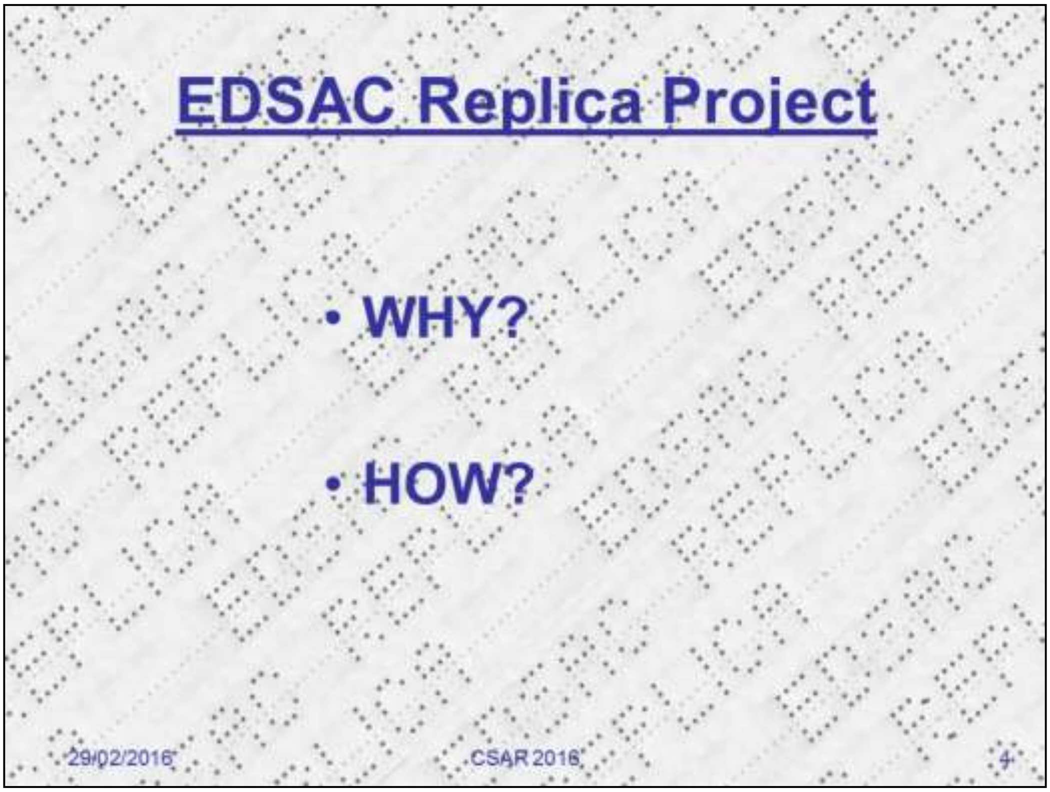
This image is of EDSAC as it would have appeared to it’s users in 1949 and is the machine the EDSAC Replica Project seeks to replicate. I will not attempt to give a brow by blow account of the EDSAC Replica project because the content has already grown to such a size and the detail so specific to the technology that although I am sure there will be some of you in the audience that would be fascinated, I believe that most would be very bored. I don’t want to bore you so I have chopped the content about and digressed from the obvious track in an attempt to make it interesting. We’ll see. I have made a list of links to websites, that I think you will find interesting, at the end of my presentation. I recommend their perusal, particularly the edsac.org for it contains a brilliant video record of key events in the project filmed and edited by our very own retired BBC TV producer David Allen.



EDSAC Replica Project

- WHY?
- HOW?

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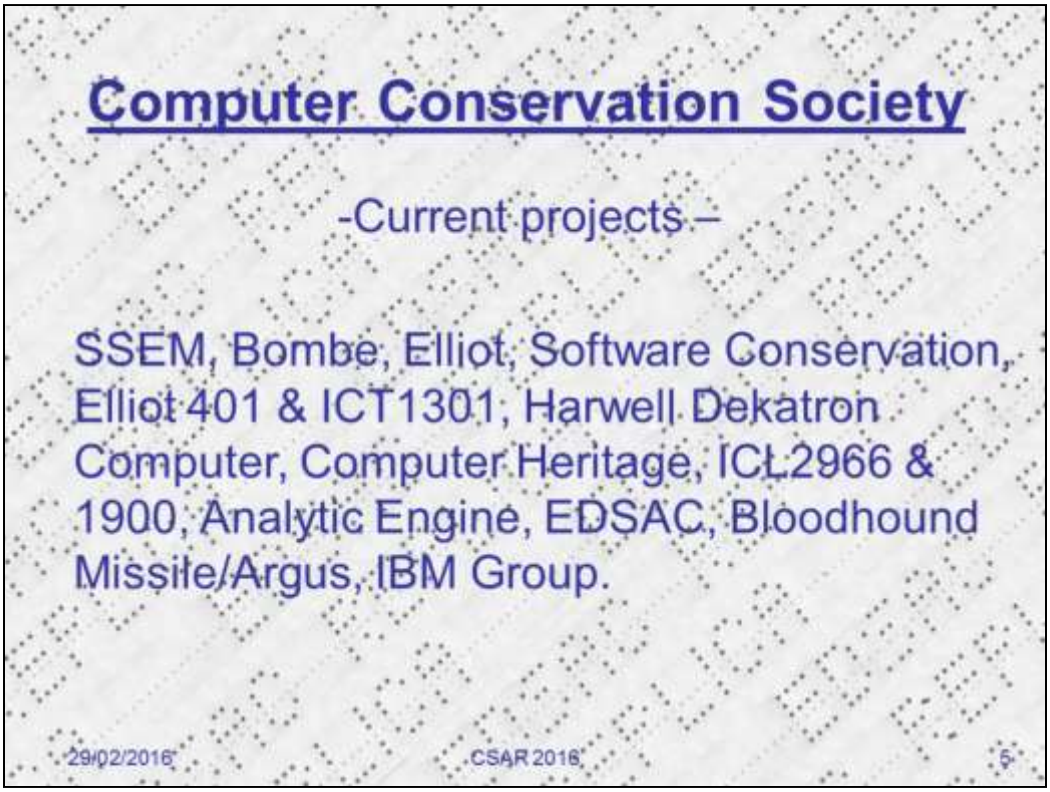
In my talk I will address the two questions
Why? Are you reconstructing a 65 year old computer?
(A question a have asked myself sometimes)
How did you go about doing it?



Computer Conservation Society

-Current projects –

SSEM, Bombe, Elliot, Software Conservation, Elliot 401 & ICT1301, Harwell Dekatron Computer, Computer Heritage, ICL2966 & 1900, Analytic Engine, EDSAC, Bloodhound Missile/Argus, IBM Group.

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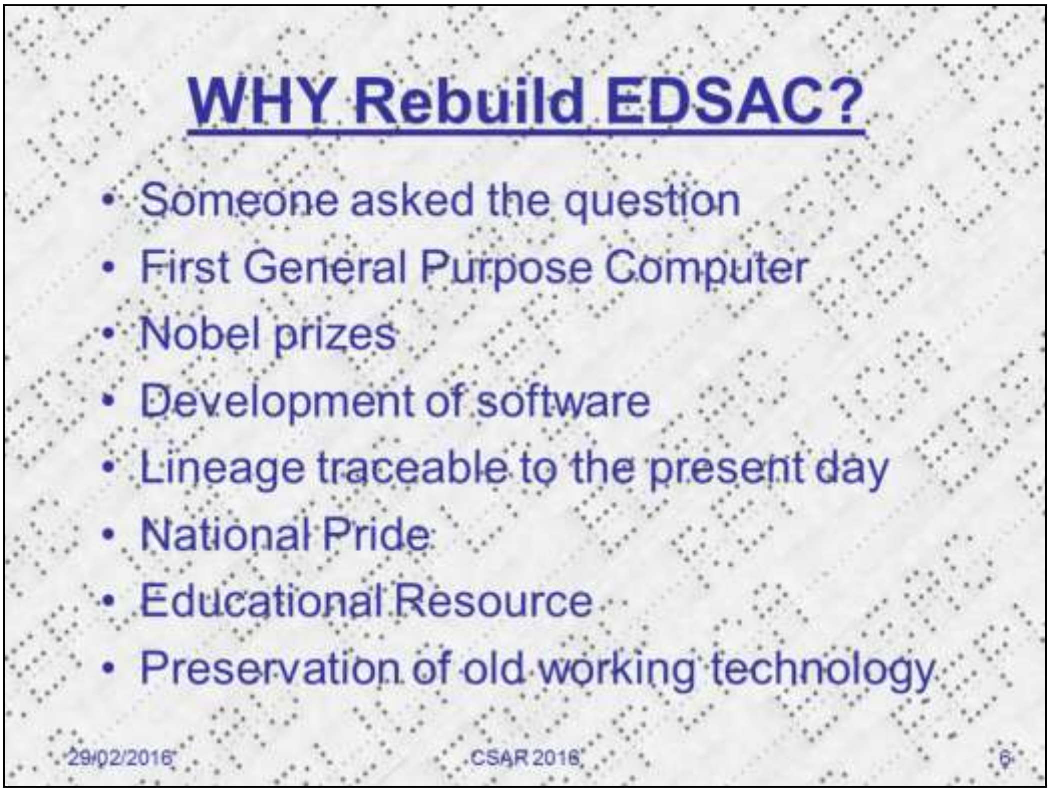
I must first put the project into proper context.

In 1988 the then Curator of the Computer Collection at the London Science Museum, Doron Swade, became aware that around the country were individuals who had salvaged computers that had reached the end of their commercial lives and wanted to share them and wanted help. Together with Chris Burton and Tony Sale the Computer Conservation Society was founded where like minded people could share their interests and help one another in preserving their artifacts. It was formally established as a charity in 1989. It is a joint venture between the British Computer Society, the London Science Museum and the Manchester Museum of Science and Industry. Membership is open to anyone who is interested.

* The Computer Conservation Society, like so many things these days, is run by volunteers and organises itself around projects. It has had several important past successes such as the restoration of Pegasus, which until recently could be seen running regularly at the Science Museum. The Small Scale Experimental Computer, better known as the Manchester Baby is on display at the Manchester Museum of Science and Industry.



WHY Rebuild EDSAC?

- Someone asked the question
- First General Purpose Computer
- Nobel prizes
- Development of software
- Lineage traceable to the present day
- National Pride
- Educational Resource
- Preservation of old working technology

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To get back to the question Why EDSAC?

This slide lists a few of the factors that kick started the formation of the EDSAC Replica Project.

At a reception in Cambridge in 2010, the then President of the Computer Conservation Society, David Hartley, was describing to Hermann Hauser what the Computer Conservation Society did and Hermann asked whether anyone had rebuilt the EDSAC. On hearing that no one had Hermann asked David how much it would cost. In response to David's "I have no idea" Hermann asked "why don't you find out and let me know". Together with Kevin Murrell of the National Museum of Computing at Bletchley Park and Chris Burton another founder member of the CCS, David trawled the archives to determine how much information was available. After 6 months work they reported to Hermann that it would cost about £250,000 and take about three years working with volunteers. Hermann's instant response was "so let's do it!" Hermann kindly seeded the kitty and the project was born. I should point out that the project is completely funded by donors both corporate and private. No tax payer money is involved.

* I said earlier that EDSAC was the first general purpose computer to be designed for it's users - so what about the other computers and why were they different.

EDSAC's immediate contempories in the 1940s were Colossus, ENIAC and EDVAC. These all used similar technologies involving thermionic valves, electromechanical relays and switches. Colossus was designed to do the single task of helping to break the German Lorenz code and was not therefore general purpose; ENIAC was designed to be general purpose but its primary use was to support the calculation of ballistics tables. It lacked the memory to hold programs which instead had to be set up on massive patch panels. It could take several days to change programs. EDVAC was a close cousin to EDSAC but many times bigger and as a result did not become operational until 1952. It was the draft design of EDVAC that inspired Maurice Wilkes design for EDSAC.

There are other lectures that could be given on computing in the 1930s and 40s but they are not for today.

* Many researchers benefitted from having computer facilities available to them for the first time but the ones usually quoted, rightly, are the winners of three Nobel prizes that all cited EDSAC in their Nobel prize addresses.

X-ray crystallography was beginning to get to grips with proteins but was generating prodigious amounts of data that realistically could only be processed by automatic means.

Kendrew & Perutz received the prize for Physics in 1962 for determining the structure of Myoglobin.

Martin Ryle invented the synthetic aperture radio telescope and shared the Nobel prize for physics in 1974 with Anthony Hewish. Combining the signals from several independent telescopes required heavy duty processing.

Andrew Huxley and Alan Hodgkin explained the mechanism of the action potential and the propagation of nerve pulses across cell membranes. EDSAC helped model these processes which led to the Nobel prize for Physiology in 1963.

It’s a pity that Fred Hoyle, in his book “The Black Cloud”, only referred to EDSAC as “the Cambridge Computer” as it clearly was EDSAC from the context.

* It should be self evident that before computers there was no software. One of the observations that Wilkes made after EDSAC was operational was to the effect that “now we have EDSAC we must find out how to use it”. Using EDSAC meant writing programs for it and it was John Wheeler, a research student at the time, who created many of the basic software concepts we have today. The ideas of “subroutine”, “relocation” and “software library” were all due to him. The coding “language” of EDSAC although primitive by today’s standards was directly assembled from paper tape into the appropriate order codes, what we would call today - machine instructions, before being placed in memory. This was done by the “initial orders”, which we would describe today as an “assembling relocating bootstrap loader”. It did quite a lot and was again down to John Wheeler. The Summer conference of 1949 held in Cambridge was

attended by many who would go on to be prominent in the field of computing. The archives contain a note from a young Edsger Dijkstra in which he said “at the time I did not realize how much of my life would be spent on computer software”

* During the time that EDSAC was being built Lyons Corner House had “lent” an engineer to the team to basically learn how to build a computer. Lyons had decided that having such an automated device would be of great benefit to their back office operation and wanted to be in on it at the beginning with their Lyons Electronic Office or LEO. EDSAC was the father of LEO I and hence the immediate ancestor of all the LEOs manufactured by the LEO Computer Company. An abbreviated genealogy sees LEO Computers merging with English Electric; English Electric merging with Elliot Automation and then General Electric. Many other terminal branches of the infant UK computer industry ended up within the International Computers and Tabulators company, ICT which later morphed into ICL. After adsorption by Fujitsu and the abandonment of the ICL brand name the only fragments of any surviving EDSAC DNA would be found in the present day BAE systems, if at all. Perhaps that is a challenge for our own DNA archaeologist Peter Forster.

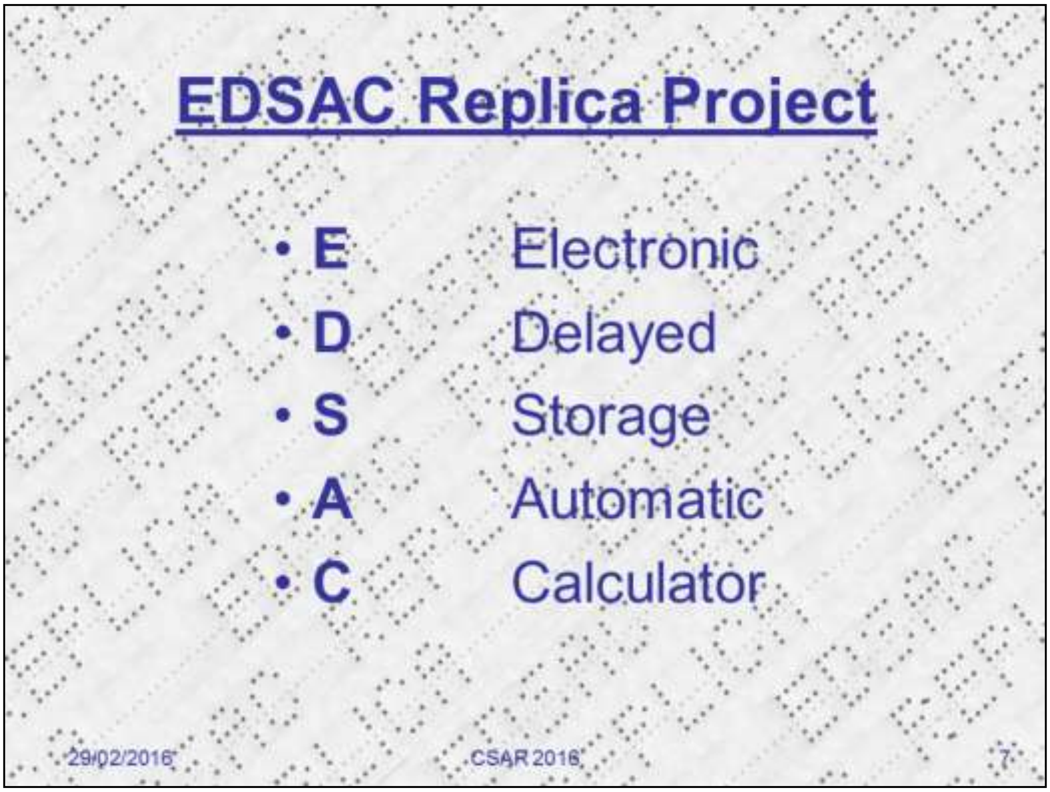
Due credit must go to Fujitsu who have recently announced their sponsorship of the National Museum of Computing which is much appreciated as it too receives no funds from Lottery or Government.

* I hope it is not too xenophobic to suggest that we can legitimately have a certain sense of National Pride in our past innovations and successes. Achieving a working replica of such an iconic machine is a motivator to many of us.

* It is our intention that EDSAC will provide a useful educational resource and we have many plans in that direction. We see (a direct synergy) no contradiction with helping school children write and execute programs for a computer that died before their parents were born and supporting such initiatives as those of the Raspberry Pi Foundation and the BBC, to get children coding. Anyone who wants to try their hand at programming EDSAC can access the Warwick University simulator. The URL is in the list at the end of these slides.

* As mentioned before not only preserving the past but demonstrating it working is one of the objectives of the CCS.

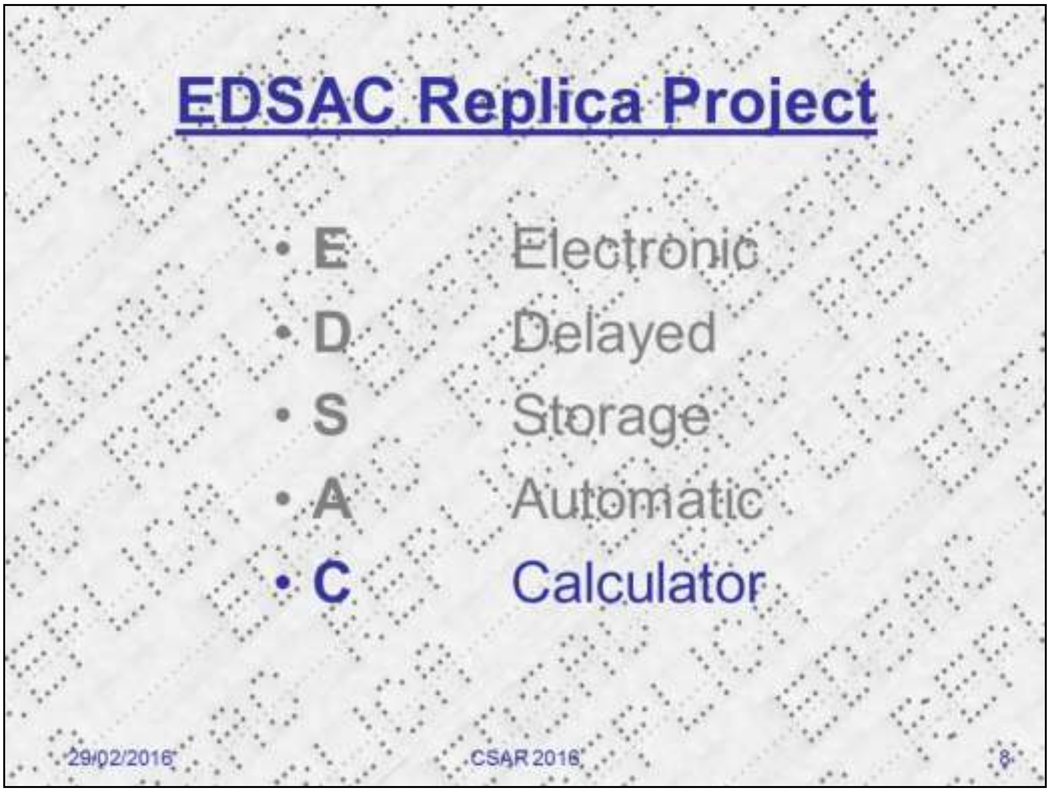
Finally I hope that the visitors to TNMoC will get as much pleasure in watching EDSAC demonstrating it prowess at noughts and crosses as seeing the Flying Scotsman steam through their local railway station.



EDSAC Replica Project

- **E** Electronic
- **D** Delayed
- **S** Storage
- **A** Automatic
- **C** Calculator

So how did EDSAC gets it’s name. It is of course an acronym: all the words are significant and provide a useful framework to help place EDSAC in its historic technological context. So I would like to take a short diversion to show how the application of technology moulded the environment in which EDSAC was born.



EDSAC Replica Project

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The terms Calculator and Computer have gone through subtle changes of meaning over the last 70 years. Mechanical calculators had existed for a few hundred years since the time of Pascal and Leibnitz but when they became used in earnest for big commercial or scientific problems the people who turned the handles became known as computers. More important is to recognize that humanity has had the concept of computation or calculation being performed by an external mechanism for at least 2000 years.

The Antikythera Mechanism

Front

Back

Wikipedia

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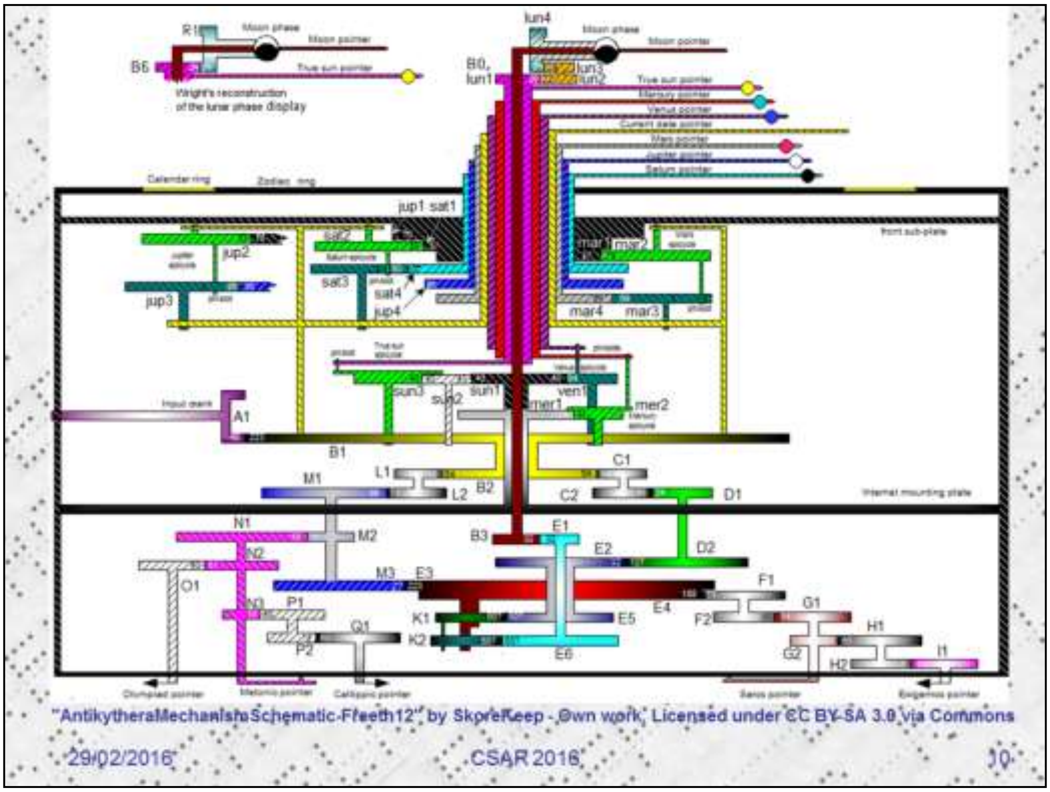
The Antikythera mechanism shows without any doubt that the Greeks had an understanding of the movements of our local Solar system and were able to capture that understanding in a physical representation. It would seem that the available technology, alloys of copper and their ability to work them, was sufficient for this purpose.

It is more than a slide rule but it is not programmable. It is an analogue computer because for an infinitesimal change of the input all the outputs change by an infinitesimal amount provided the gears are meshed to start with.



"AntikytheraMechanismSchematic-Freeth12" by SkpreKeep - Own work. Licensed under CC BY-SA 3.0 via Commons

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This slide shows the complexity of the mechanism as recreated by an enthusiast. I would like to point out that this central bundle of shafts has no less than 8 concentric shafts. Some of you present may recall a CSAR lecture on the Rolls Royce RB211 jet engine for Concorde where they reported on the problem of getting three concentric shafts to work properly. To be fair they were travelling a bit faster and in a rather hotter environment but none the less one can only be in awe of the craftsmen who applied the technology of the day and produced this mechanism 2000 years ago.

I don’t think it too fanciful to opine that the peoples of the pre-bronze age, 2 to 3000 years earlier, probably had a partial understanding of the motions of the planets but that it was their technology that limited the tasks that could be performed to showing the occurrence of the Summer Solstice.

The Summer Solstice Sunrise at Stonehenge 2005

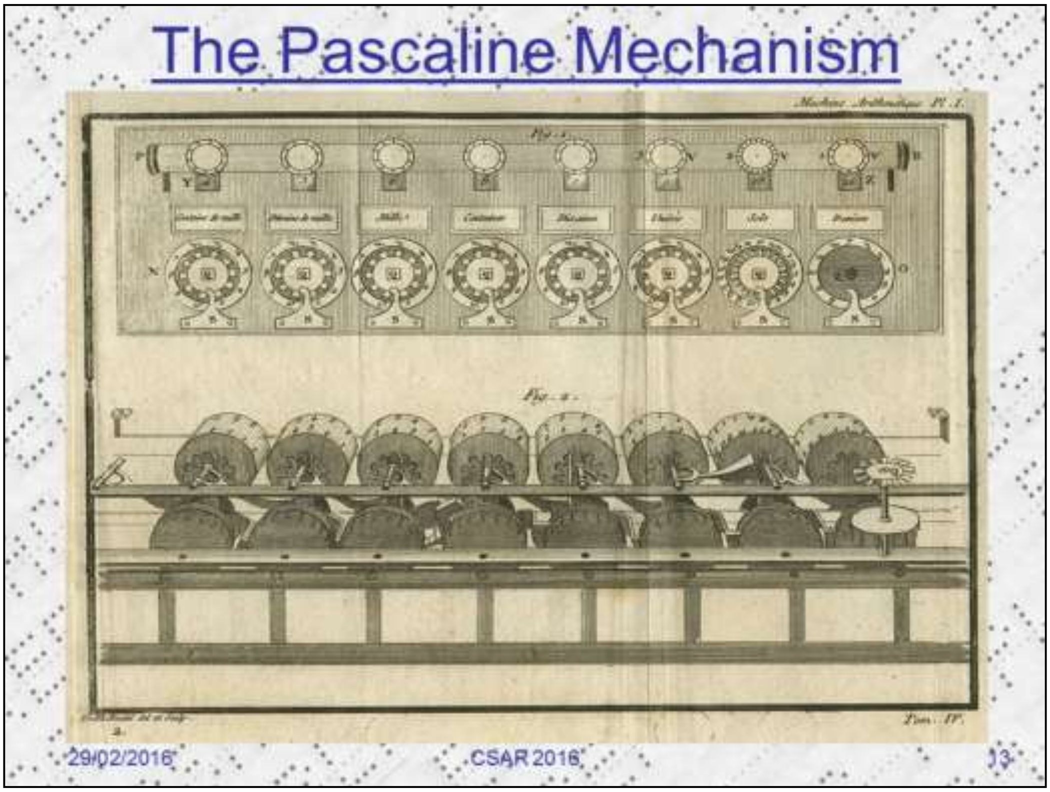
Wikipedia

We have to skip forward over 1500 years before we find a transition from what were analogue computers to digital even though the technology had not really changed.

Pascal's Desktop Calculator

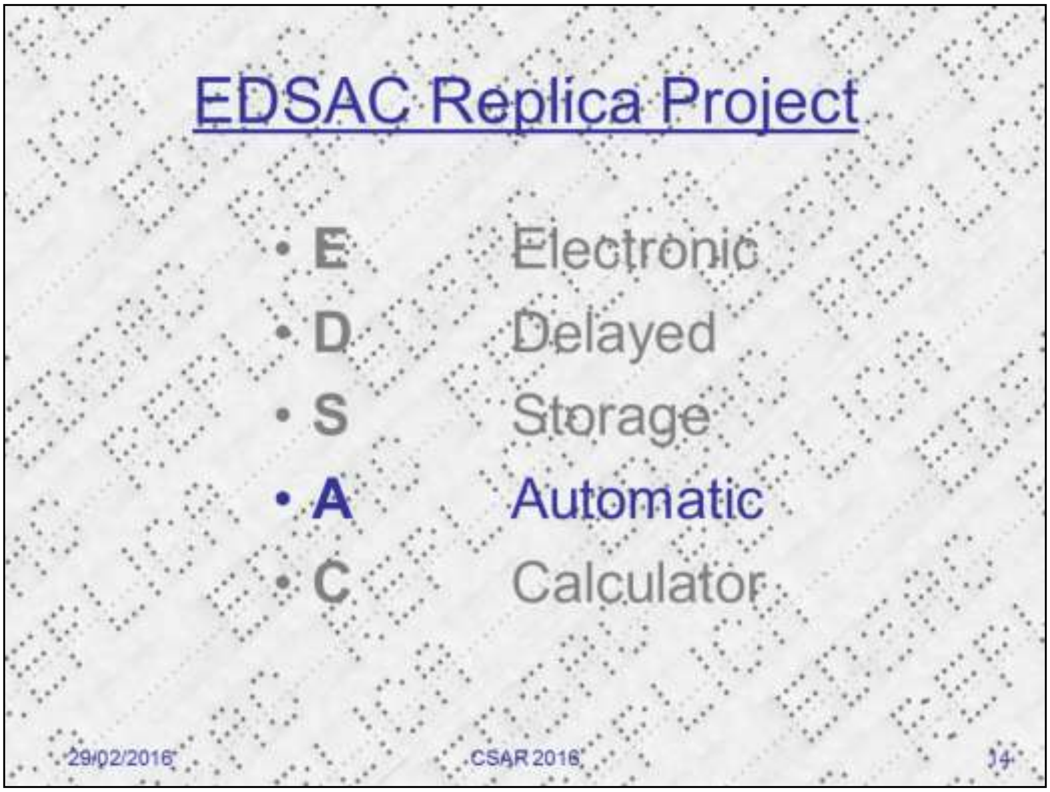
Copyright 2005 David Monniaux/via Wikimedia Commons

1500 years we find that the available technology is still clockwork wheels made from alloys of copper. But it is worthwhile pausing here because Blaise Pascal invented the desktop calculator. More fundamental though is that this was a digital, finite state machine. It performed addition and subtraction in real time. As digits were entered via the dials the result was immediately updated but only on whole digits, not between digits. It was a true digital calculator. So we have the same 2000 year old technology but a new conceptual paradigm.



The Pascaline Mechanism

Although invented to help his Father's back office functions as a supervisor of taxes Pascal attempted to market the calculator as the Pascaline with limited success. He built around 20 of the devices several of which are now in French museums. Note that the Pascaline also handled the mixed bases of Sois and Deniers (20 sois to a franc, 12 denier to a sois)



EDSAC Replica Project

- **E** Electronic
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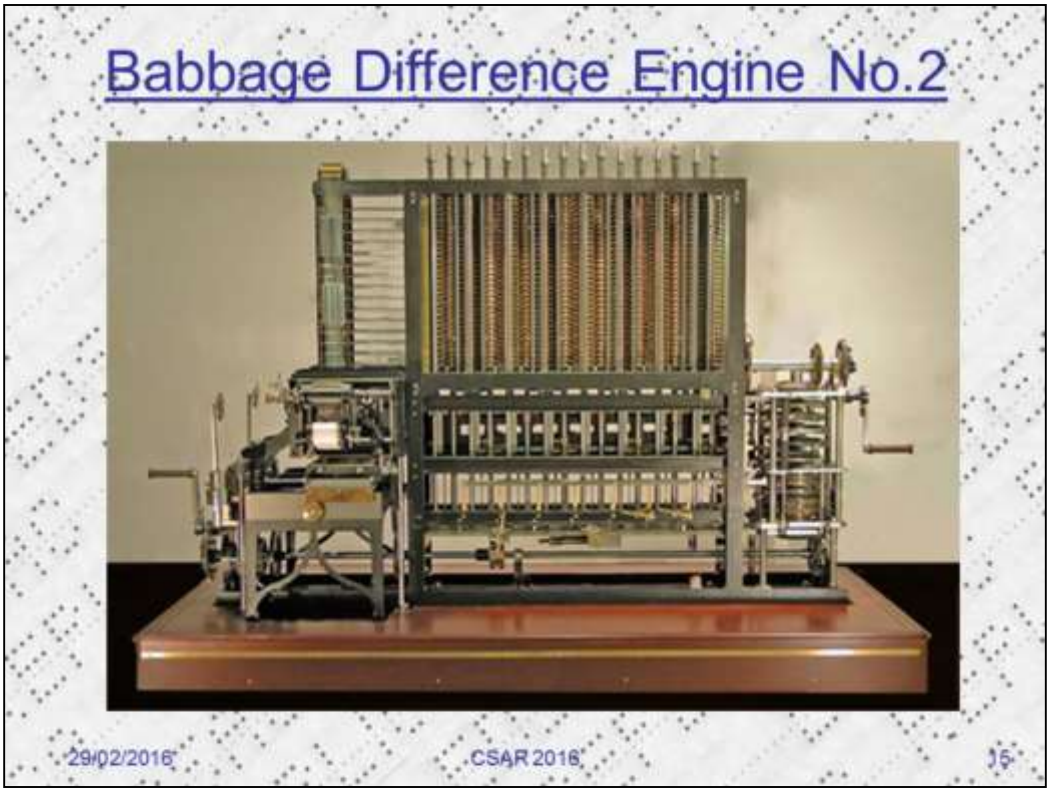
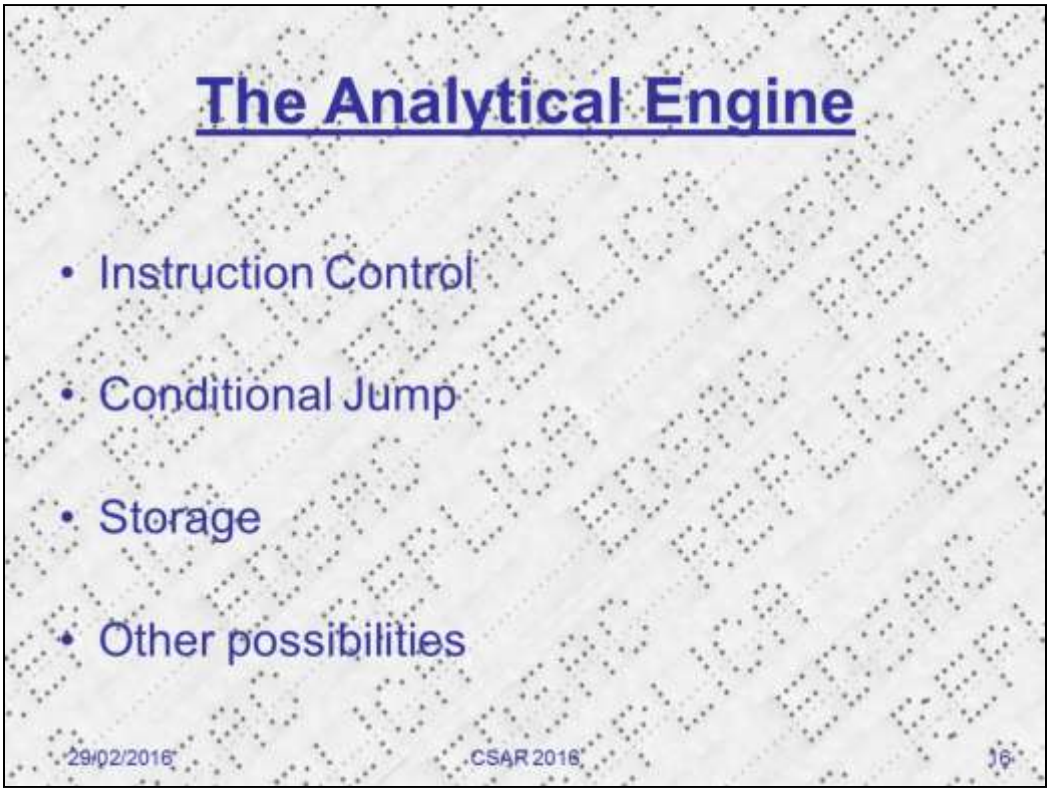
To become truly Automatic we must skip forward another 200 years to Charles Babbage. We still have the same basic technology of brass and clockwork albeit more refined. Engineering had already produced some big things like steam engines already.



Babbage Difference Engine No.2

Babbage wanted to automate the labour intensive and error prone function of producing various astronomical tables that he had worked on with Herschel. The calculations of many tables were amenable to a mathematical technique known as the method of differences so Babbage designed and demonstrated a model of his Difference Engine No 1 to Government and got funding to design and manufacture a full blown machine. As is well known he failed to deliver the complete engine for a variety of reasons and after several injections of funds by the Government they cancelled the project thus setting a precedent for Government IT projects of modern time – Over Budget followed by cancellation with no net benefit to the taxpayer. Babbage continued producing innovative ideas even before the project was cancelled and he improved the design and fully documented the Difference Engine No 2 shown. His design would have worked because in 2000 Doron Swade and his team at the Science Museum successfully added the printing mechanism to the replica they had built in 1991 from Babbage's drawings and models and it worked. It weighed 5 tons so not a desk top device. In fact several other people did pick up on Babbage's designs and produced smaller Difference Engines which they successfully sold in his lifetime.



The Analytical Engine

- Instruction Control
- Conditional Jump
- Storage
- Other possibilities

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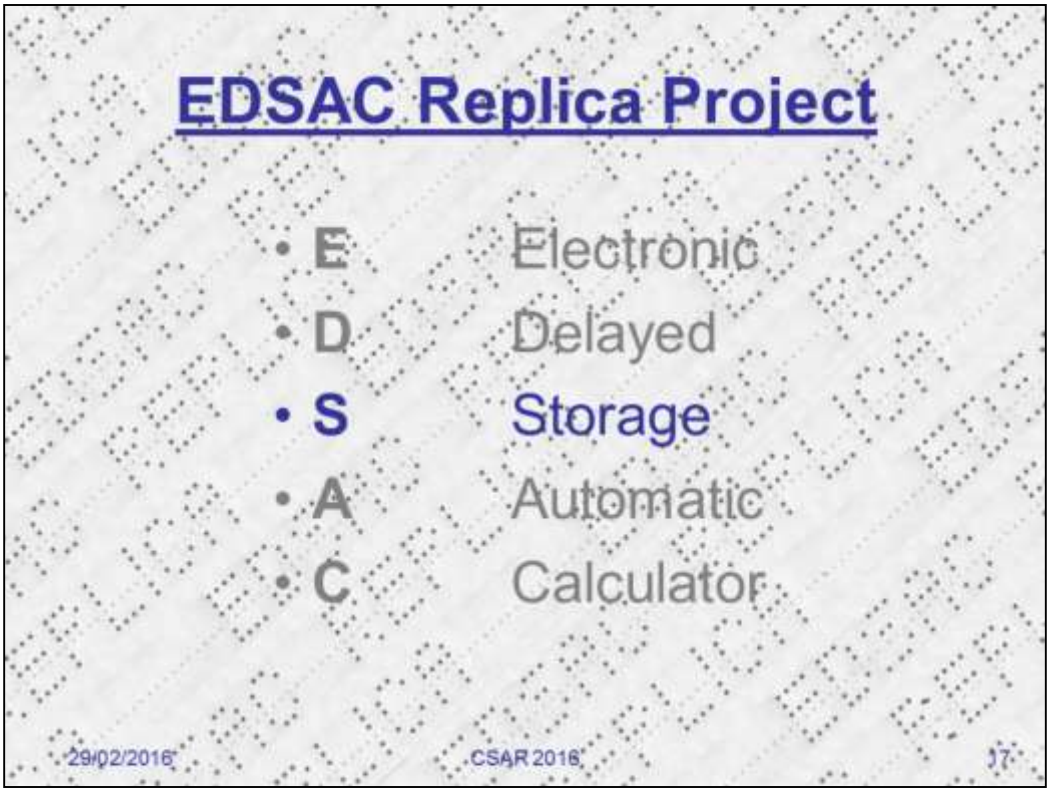
By this time Babbage had seen the limitations of a machine with a fixed function and started on the design of his Analytical Engine. The Analytical Engine incorporated several concepts that we now recognise as essential for a true computer.

- By controlling what the engine could do by way of an external control “tape”, modelled on those used in the Jacquard loom, Babbage realised that an arbitrary number of different functions could be performed.
- He also saw the power of being able to change the course of a calculation according to some condition existing within the engine. i.e To go to a different part of the control tape rather than the next sequential control instruction. This of course was the conditional jump.
- As far as our story goes it is his specification of a store to hold 1000, 50 digit numbers (about 20KB) which shows how he recognised the limitations of lack of memory in his previous engines. But he was still in the clockwork era and although electricity and the electromechanical relay overlapped his life they had no impact on his designs.
- We must not ignore Ada Lovelace, of whom much has been written based on very little documentation. She clearly understood the potential of having a working Analytic Engine including applications beyond arithmetic. As no computer existed at the time no one could be called a programmer in today’s sense of the word but she did design algorithms for this Virtual Computer. She had no alternative but to engage in Thought Experiments. She foresaw that computers need not be restricted to arithmetic calculation but would be applied to other areas of human thought i.e. music, language, symbolic logic etc. A very interesting lady, maybe a Virtual Programmer for a Virtual Machine.



EDSAC Replica Project

- E Electronic
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- **S Storage**
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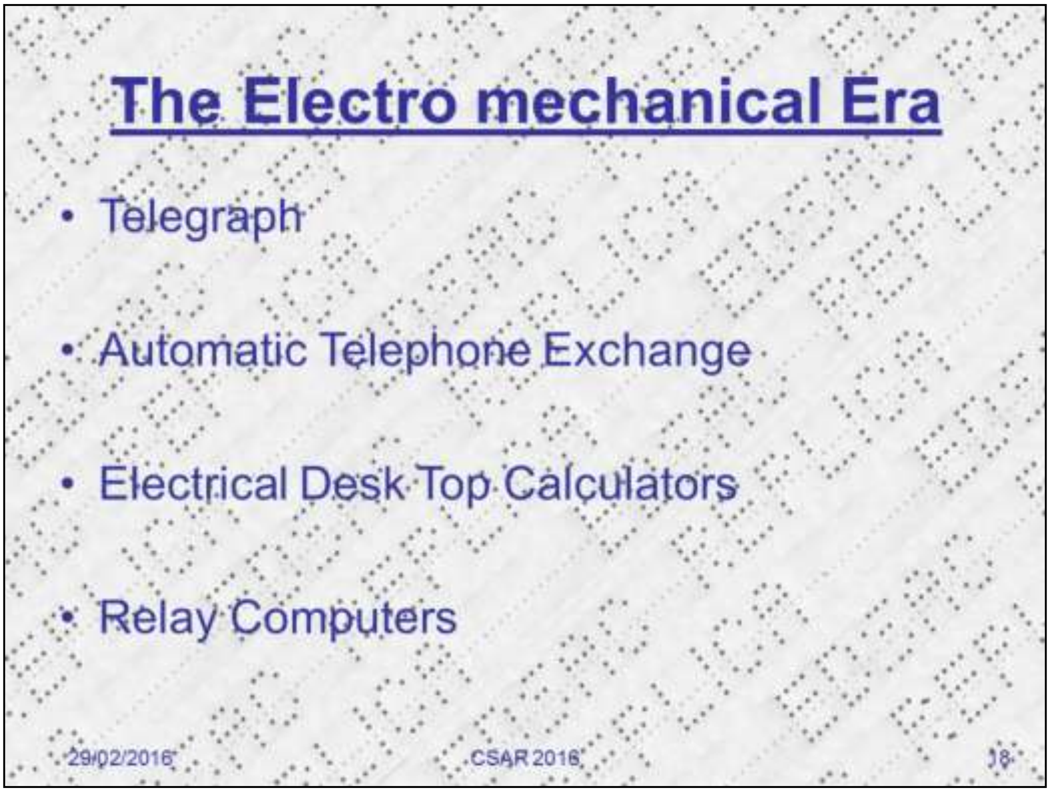
Babbage lived during the culmination of the clockwork engineering era. The Electromechanical era was waiting just around the corner. The application of the electromechanical switch/relay was probably first applied to the telegraph or ticker tape, enabling messages to be send over large distances with wires and batteries. The early telephone network became automated using this technology and by the end of the first quarter of the 20th Century the automated telephone exchange was probably the most complex “device” built by man. Desk calculator developments had continued after Pascal and in due course became electrified with electric motors and relays. By the 1930s people were building very large calculators using relay technology notably a Dr Konrad Zuse in Germany. He used 35mm film perforated with instructions to control his Z computer/calculators and had it not been for WW2 intervening may well have become better known in his time. He had the same problem as everyone else in that his machines had no appreciable storage.

Acoustic delay lines were adapted for use in early RADAR developments. They were used “open-ended” in clutter cancelling circuits. Those involved in early electronic computers still had the problem of lack of storage for their calculating engines (ENIAC) It was not until 1947 that John Mauchly applied for a patent for a memory device which involved recirculating acoustic (ultrasonic) signals in a delay line. If an acoustic pulse is injected in one end of a tube full of mercury and the emerging delayed signal at the other end is amplified and reshaped before reinjecting it, the pulse could be kept circulating “forever” or until the power failed. This topic could easily be another lecture so I must drop it here apart from saying that this is the technology EDSAC used.



The Electro mechanical Era

- Telegraph
- Automatic Telephone Exchange
- Electrical Desk Top Calculators
- Relay Computers

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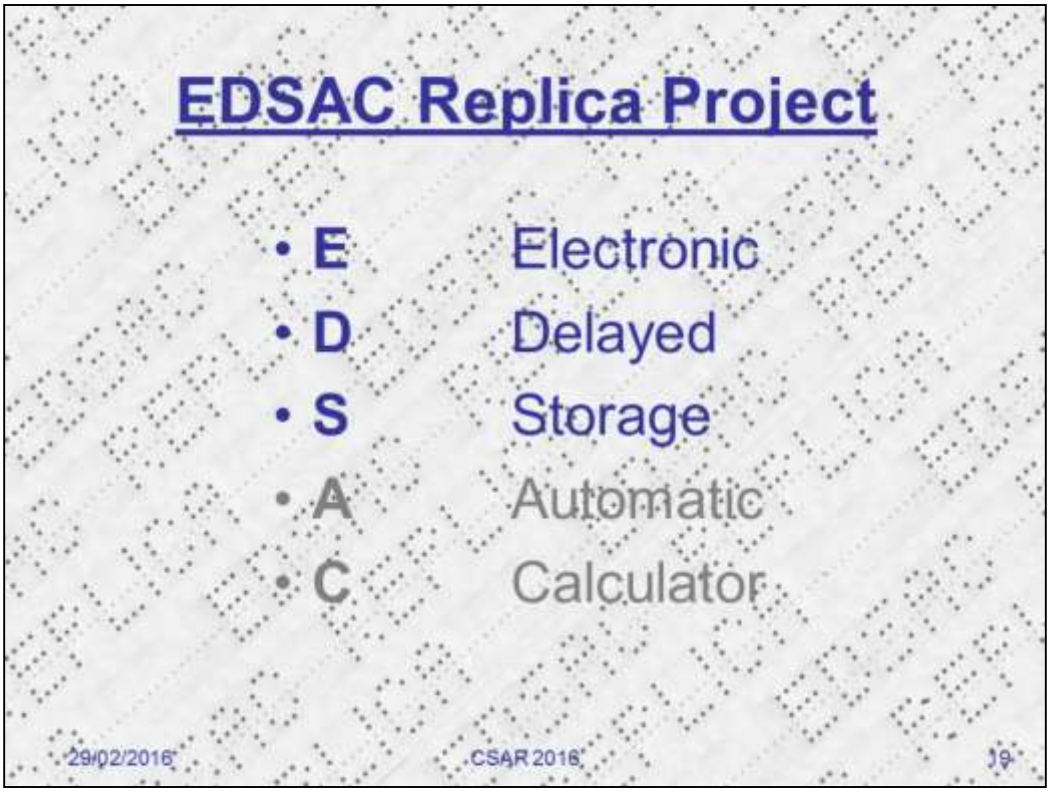
Babbage lived at the peak of the clockwork engineering era. The Electromechanical era was waiting just around the corner. The application of the electromechanical switch/relay was probably first applied to the telegraph or ticker tape, enabling messages to be send over large distances with wires and batteries. The early telephone network became automated using this technology and by the second quarter of the 20th Century the automated telephone exchange was probably the most complex “device” made by man. Desk calculator developments had continued after Pascal and in due course became electrified with electric motors and relays. By the 1930s people were building very large calculators using relay technology particularly Dr Zeus in Germany. He used 35mm film perforated with instructions to control his Z computer/calculators and had it not been for WW2 intervening may well have become better known in his time. He had the same problem as everyone else in that his machines had no appreciable storage



EDSAC Replica Project

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Acoustic delay lines were adapted for use in early RADAR developments. They were used “open-ended” in clutter cancelling circuits. Those involved in early electronic computers still had the problem of lack of storage for their calculating engines (ENIAC) It was not until 1947 that John Mauchly applied for a patent for a memory device which involved recirculating acoustic (ultrasonic) signals in a delay line. If an acoustic pulse is injected in one end of a tube full of mercury and the emerging delayed signal at the other end is amplified and reshaped before reinjecting it, the pulse could be kept circulating “forever” or until the power was turned off. This topic could easily be another lecture so I must drop it here apart from saying that this is the technology EDSAC used.

Mercury Delay Lines

29/02/2016

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This picture shows Maurice Wilkes inspecting a “coffin” of 16 5ft long tubes of mercury. They were called “tanks” to avoid confusion with “vacuum tubes” which we now call thermionic valves or just valves. A bank of 16 tanks weighed over half a ton the weight being distributed roughly 50/50 between the mercury and the steel. The memory capacity was the equivalent of 1152 bytes. It took about 1.2mS for a pulse to complete the trip down the tank so if the piece of data you wanted had just been reinjected your circuit would have to wait 1.2mS before it came round again. This is the nature of dynamic serial memory.

21st Century Nickel Delay Line

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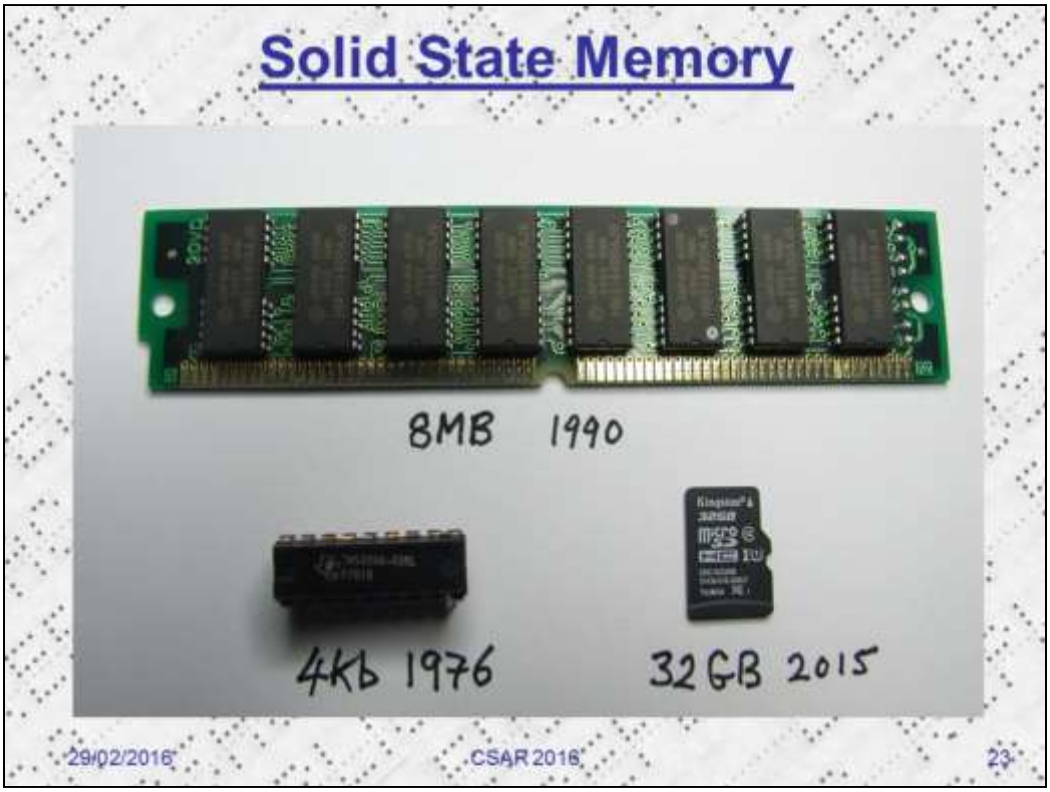
To finish up this section I want to introduce to you a metric for comparing the technologies we have been looking at in a common way. At one end we have brass, which had featured for some 2000 years and at the present time we deal with specs of silicon. Mass and storage capacity are the only things they have in common therefore I propose the SI unit of Byte per Kilogram to compare the technologies.

This is a 21st century prototype of the nickel delay line we will be using on EDSAC. Its performance is in line with what we know of the Ferranti nickel delay lines.

Core Store 32x32 bits

Kevin Murrell

This memory matrix is from a PDP 8, we think. Core memory was the most common main memory in computers until the dawn of the next generation of memories.



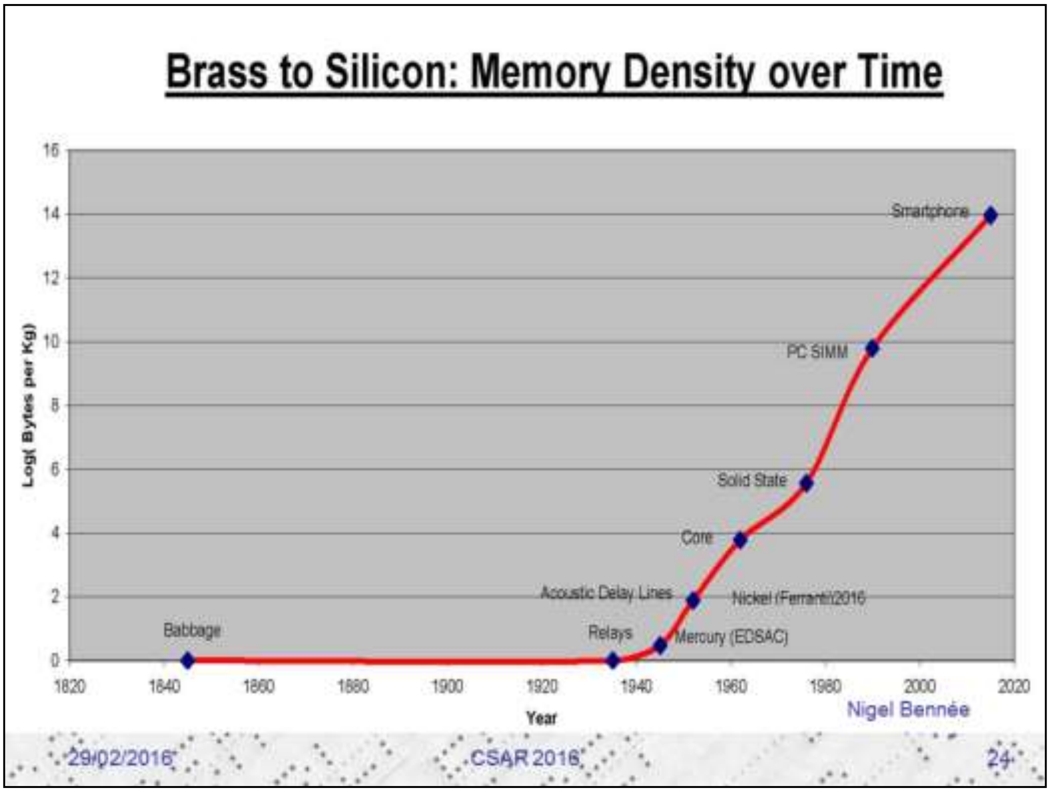
Solid State Memory

8MB 1990

4Kb 1976

32GB 2015

This is a selection of solid state memories starting with a 4096 bit chip from my first home built SWTP computer. The 8MB SIMM is from our first Elonex PC and finally the 32GB micro SD card which I fitted to my first smartphone last year.



Brass to Silicon: Memory Density over Time

Nigel Bennée

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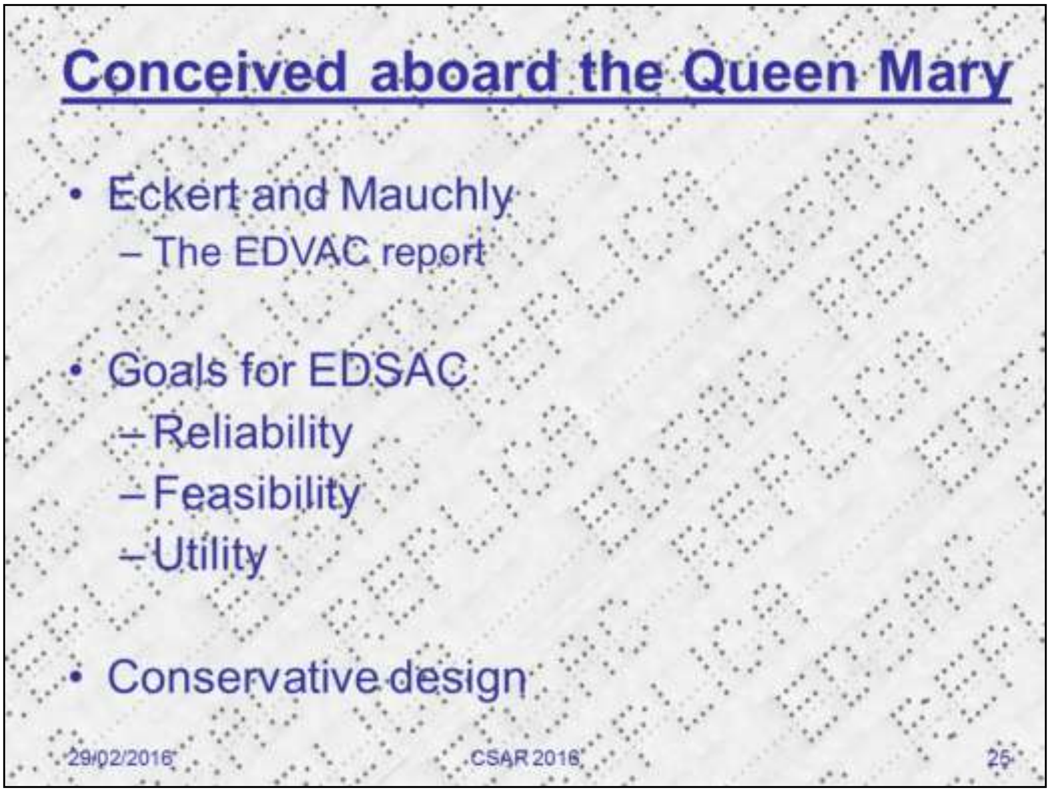
You will be unsurprised with this familiar shaped curve but what I wanted to illustrate is that EDSAC is at this turning point, another piece of evidence for it’s claim to be pivotal in the history of computing. Surprisingly Babbage’s brass registers, at the culmination of a 2000 year old technology and electromechanical relays at the beginning of the next, both only score slightly less than 1 byte per kilogram. Mercury delay lines move to a heady 3 bytes per kilogram and then we see an approximate 10 fold increase in density every 5 years. This is as near as dam it the same as the Moore’s law figure which doubles the number of transistors that can dance on the head of a pin every 18 months. So it appears that Moore’s Law could be reformulated and applied even before he proposed it. So much for the mandatory graph.



Conceived aboard the Queen Mary

- Eckert and Mauchly
  - The EDVAC report
- Goals for EDSAC
  - Reliability
  - Feasibility
  - Utility
- Conservative design

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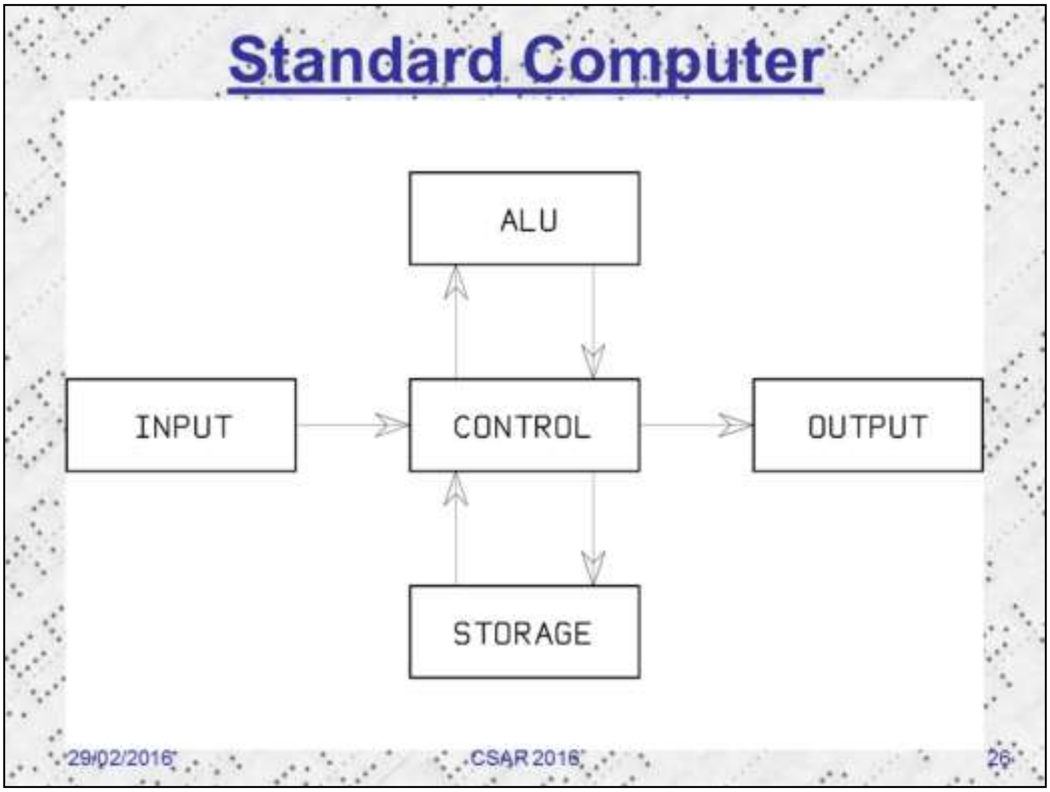
To return to the main story. Wilkes had seen a draft 1945 report on the proposed EDVAC computer and it was this that had prompted him to cross the pond to attend a Summer School in 1946. It was held at the Pennsylvania University Moore School of Electrical Engineering. It was given by Presper Eckert and John Mauchly. Wilkes also met John von Neumann who is credited with suggesting that data and program could share the same store. Wilkes was able to discuss the draft design for a stored program computer called EDVAC. It is common to call this type of computer architecture, where data and program share the same address space, von Neumann, as opposed to a Harvard architecture where program and data memory are kept apart. As an aside Babbage’s Analytical Engine is a Harvard Architecture.

- On his return trip on the Queen Mary Wilkes sketched out a design for a simple computer based on similar lines to EDVAC which he named EDSAC. Wilkes motivation was to design a reliable, buildable and first and foremost usable machine that would serve the computational needs of the University.
- He was very conservative in his design and did not push for the maximum performance from the technology available to him as he wanted reliability. Our experience during the reconstruction shows that trying to double the machine’s speed would have been unlikely to have achieved a stable, reliable machine and would have given us problems as well.



Standard Computer

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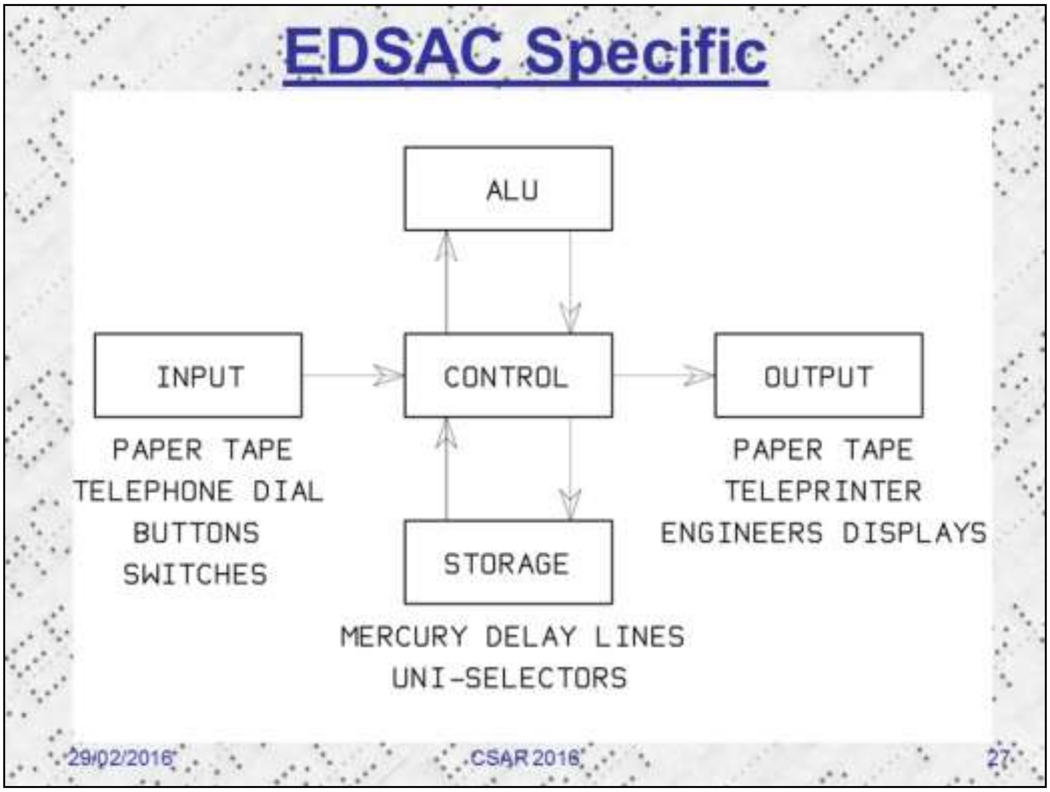
EDSAC has a simple computer architecture. It has all the normal main components that we would expect today for input, output, control, storage and Arithmetic Logic Unit for computation.



EDSAC Specific

ALU

INPUT

CONTROL

OUTPUT

PAPER TAPE
TELEPHONE DIAL
BUTTONS
SWITCHES

STORAGE

PAPER TAPE
TELEPRINTER
ENGINEERS DISPLAYS

MERCURY DELAY LINES
UNI-SELECTORS

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In the specific case of EDSAC these basic functions are implemented with 5 hole paper tape, teleprinter technology and mercury delay lines.

EDSAC Specification

- Serial Stored Program Digital Computer
- Clock Speed 0.5MHz
- Max. Instruction Rate ~6000 ips
- Average Instruction Rate ~600 ips
- Memory Size 1024 18 bit Words (2300B)
- One 72 bit Accumulator
- One 36 bit Multiplier
- 5 Hole paper tape and Teleprinter I/O

For completeness EDSAC’s specification is shown here.

HOW did we go about it?

- Andrew Herbert collected together a team of people old enough to know what a thermionic valve was.
- Chris Burton had already led the rebuilding of the “Manchester Baby” (SSEM)
- Alan Clarke had found sources of brand new 70 year old valves
- It was an irresistible challenge that kept a lot of people off the streets.

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So how did we go about replicating this icon? I have already described David Hartley’s trawl of the archives and I am sure he could give an interesting account of that. We had some funding so the next thing was to find a Project Manager. Fortunately Andrew Herbert had just retired from running Microsoft Research and rather than leave him to get bored watching daytime television he was asked to take the unpaid job. Luckily he accepted the challenge. Andrew collected together some likely people and the project was set up formally with a board of trustees and charity registration etc. at the end of 2011.

The Volunteers

- Teams of one or more focussed on specific parts of the machine
- Scattered all over the country
- Individual skills and resources
- 20+ people with a common purpose

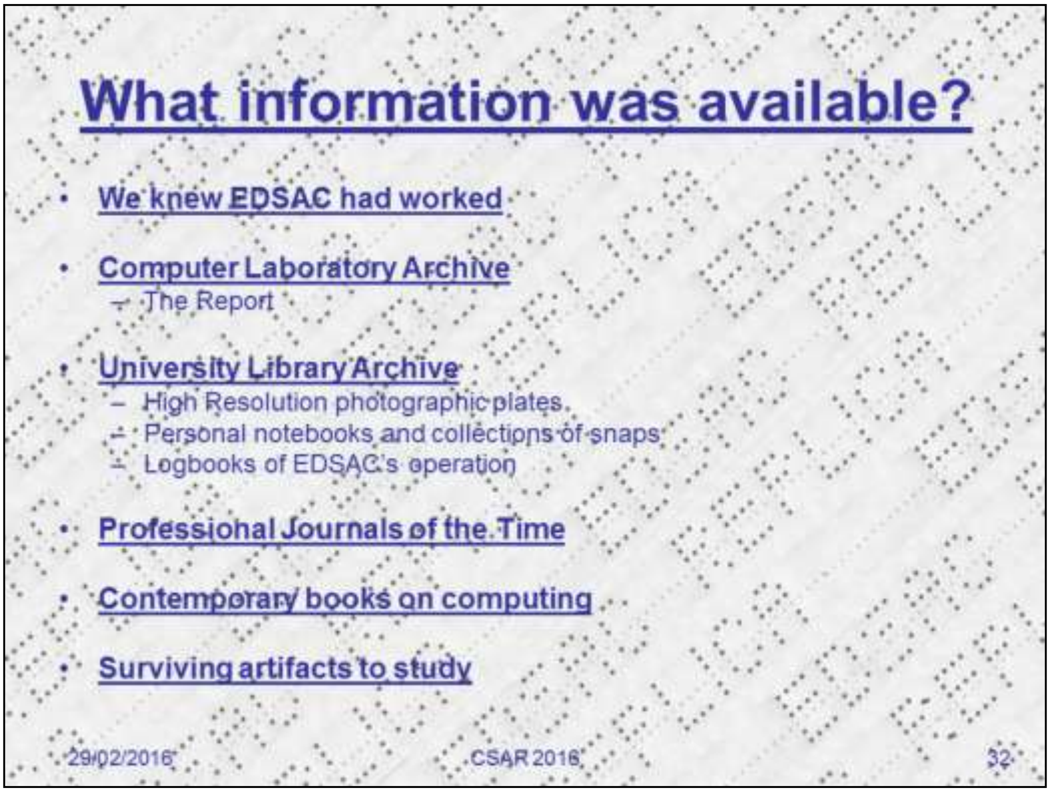
Some words

The Hardcore

Most of the team

This is our display at the National Museum of Computing at Bletchley Park.

Please note the two authentic lampshades, genuine 1940s



What information was available?

- We knew EDSAC had worked
- Computer Laboratory Archive
  - The Report
- University Library Archive
  - High Resolution photographic plates
  - Personal notebooks and collections of snaps
  - Logbooks of EDSAC's operation
- Professional Journals of the Time
- Contemporary books on computing
- Surviving artifacts to study

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So what did we know when we started? We knew firstly that EDSAC had worked once upon a time so why not again? From the documentation available to us and survivors that had actually worked on the machine we know that EDSAC was developed to a large extent on the hoof.

- This view is supported by the main reference document which we have which is “The Report” an internal document produced in May 1948 which describes both existing and intended components. It has several pencil changes on both text and logic diagrams. It is also an incomplete description of EDSAC but it does put over the intent of how it was envisioned to operate and the global features such as clock and digit pulses which are essential to its operation. It is the spirit of this document that the team try to follow.
- The University Library Archive was also a source of information as were the various papers submitted to professional journals on the subject.
- The earliest books on computing have also been instructive.
- Most important of all is the rare example of an actual EDSAC artefact.

Surviving EDSAC Artifact

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When EDSAC was unceremoniously scrapped it is rumoured that some of the 7ft racks were taken away to be used as bookshelves, the valves were saved for reuse, the mercury was sold (some say at a profit), and three Memory Regeneration Chassis were distributed to museums. The London Science Museum, the Computer History Museum in California and the Computer Laboratory, University of Cambridge each received one. We were allowed access to the Computer Laboratory’s one. It would be nice if we could do the archaeologist’s trick of digging up a big thigh bone and then reconstructing a full dinosaur but our reconstruction must work when it’s finished. But we were able to measure it up,(as no dimensioned drawings of any of EDSAC’s structure were contained in the surviving documents) and look at it’s circuits and even gently apply some volts.

* A set of CAD drawings was generated and by modern magic we made a copy. This chassis was naturally named Chassis 01 and is the most replicated chassis in the machine accounting for 43 of the 140 + chassis.

Surviving EDSAC Artifact

Cloned using CAD and CNC Technology

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From this single dimensioned chassis it was then relatively simple to determine the dimensions of the racks necessary to hold them. I should point out that this basic level of documentation was not available to us in the archives.

Metal Bending

Teversham Engineering CNC punch

First Replica Rack

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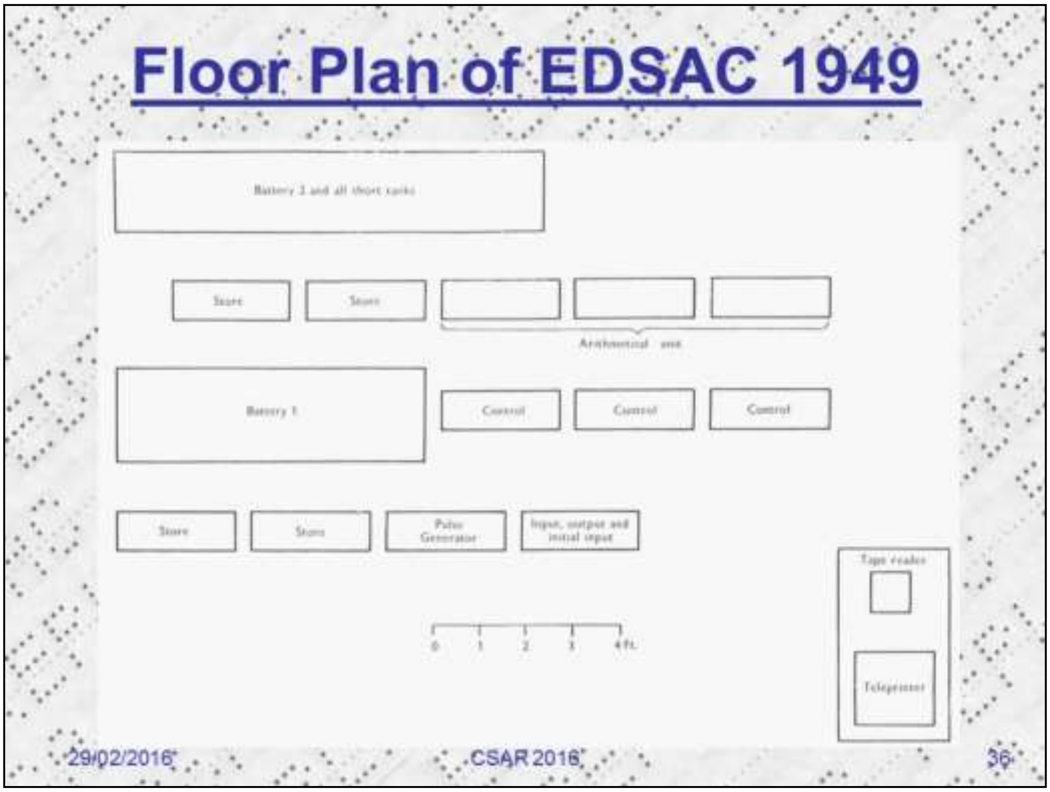
A local company, Teversham Engineering, has been very supportive of the project and with their equipment and skill rapidly turn our files into painted metal.

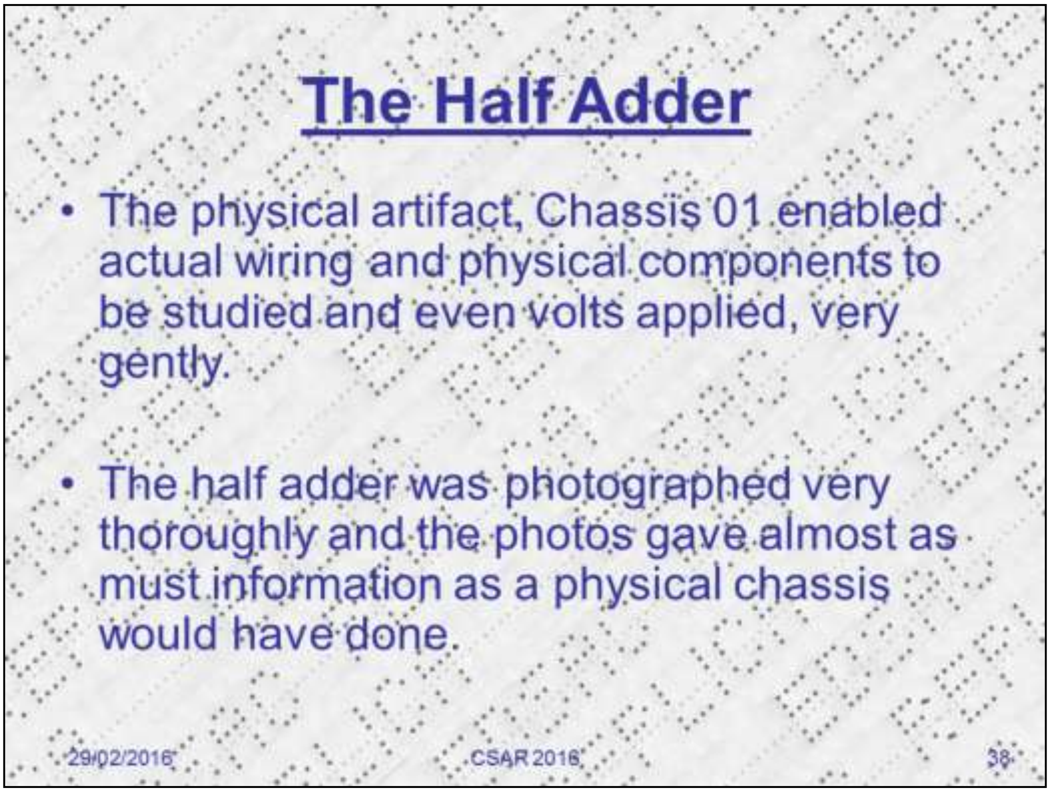


Floor Plan of EDSAC 1949

It was fortunate for us that Wilkes published an article on EDSAC in The Journal of Scientific Instruments in 1949 in which a dimensioned drawing of the layout of EDSAC appeared. Note the scale. This was incredibly useful as we now had a gross layout of major recognised functions and using an analogy, we were able to complete the edges of the jig saw puzzle.

The Outside Edges 2014

Don’t be deceived into thinking that the presence of chassis mounted on racks is a sign of progress, it is just that chassis are bulky and take up a lot of room so need to be stored somewhere when they are wired up. This photo is taken at the location in the National Museum of Computing where EDSAC now lives. Note the nice new wooden floor.



The Half Adder

- The physical artifact, Chassis 01 enabled actual wiring and physical components to be studied and even volts applied, very gently.
- The half adder was photographed very thoroughly and the photos gave almost as must information as a physical chassis would have done.

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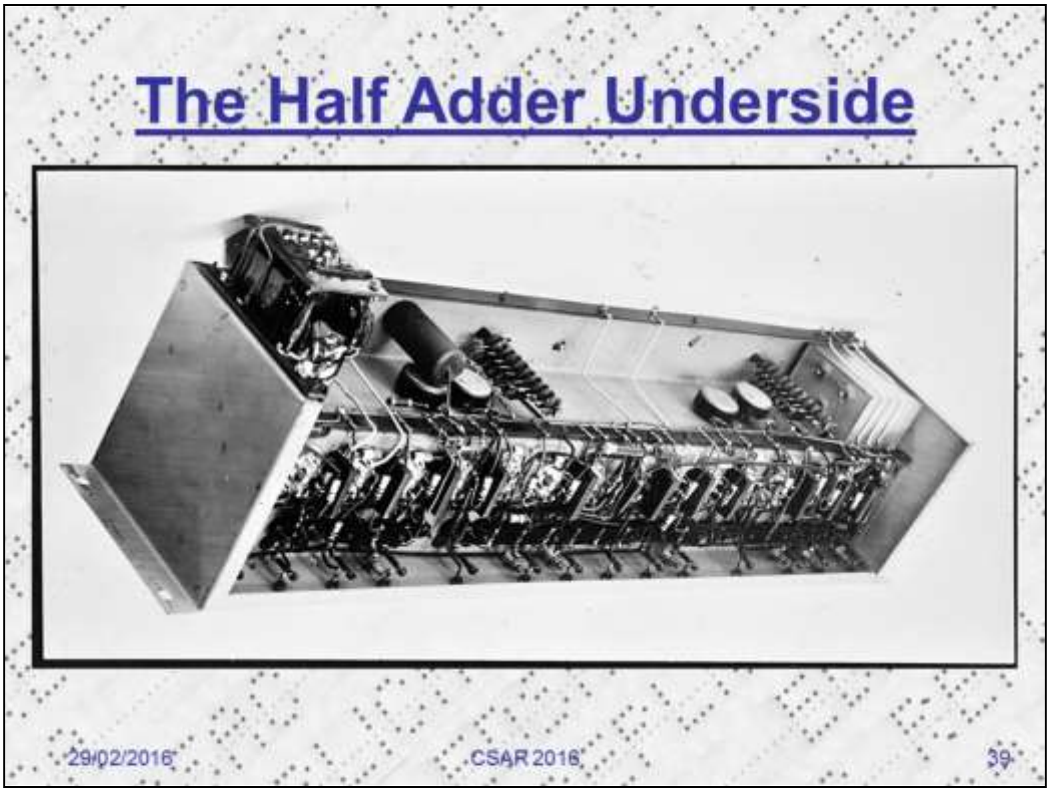
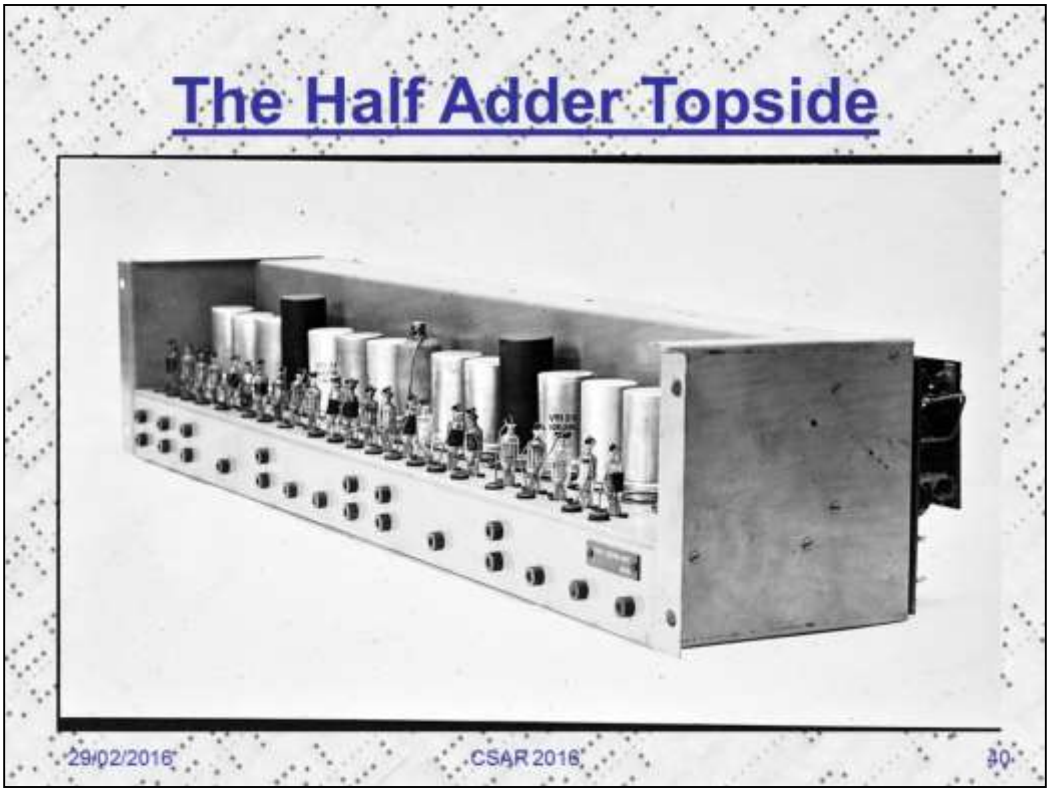
Chassis 01 was our only physical artefact but one other chassis type was photographed very thoroughly.

* The photographs of the Half Adder while not yielding a circuit diagram added additional pointers to how these chassis were originally assembled which in turn helped us keep our replications looking authentic.



The Half Adder Underside

Note tag strips and distributerd delay lines and cathode current monitors



The Half Adder Topside

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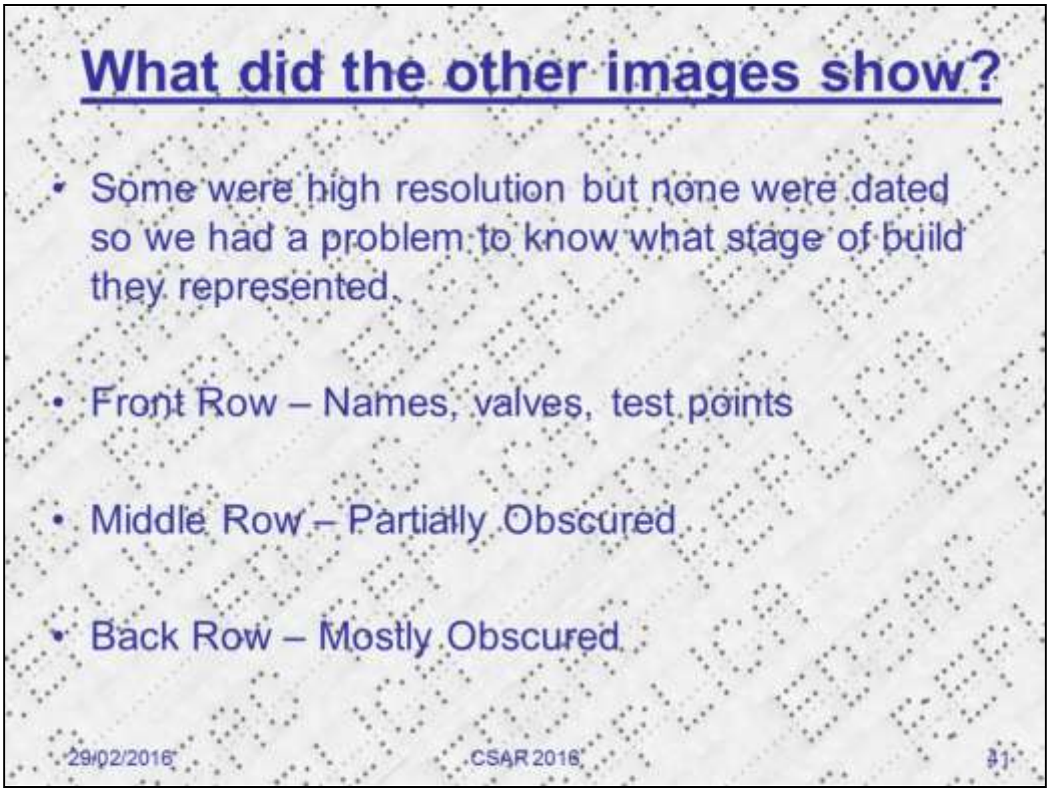
Chassis 07, as the Half Adder is numbered, occurs four times in the machine. With the exception of some selection logic for the memory tanks every other chassis in the machine is individual and different. There are over 70 different chassis types.



What did the other images show?

- Some were high resolution but none were dated so we had a problem to know what stage of build they represented.
- Front Row – Names, valves, test points
- Middle Row – Partially Obscured
- Back Row – Mostly Obscured

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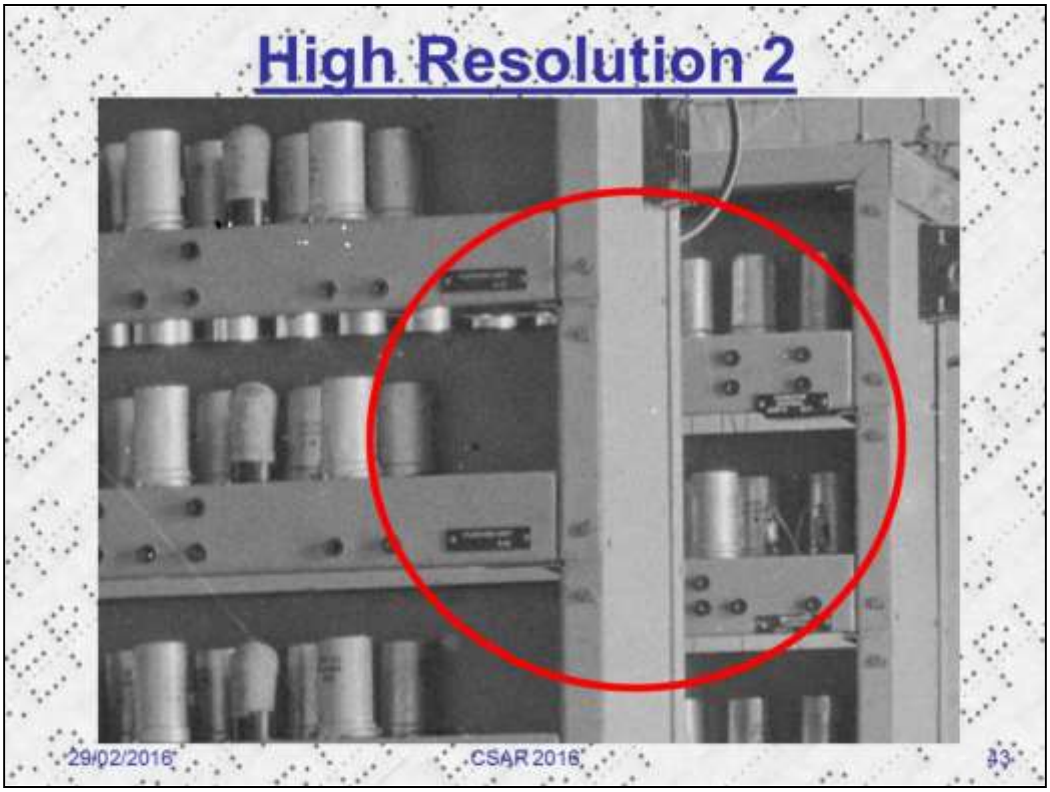
There were a lot of images in the archives. They varied from high resolution photographic glass plates to snapshots in personal albums. Unfortunately none of them was dated so we could not be sure what stage of the machine's construction any particular image represented. What they did show, quite clearly, particularly in the front and middle rows, was chassis labels and even some valve labels. The back row however was mostly obscured and will form the focus of the rest of this talk. It is also the part of the machine that I have done the most work and can therefore share it with you with confidence.

High Resolution 1

First let me show you the quality of a typical glass plate albeit initially of unknown date. Now we believe this image to have been taken prior to completion for reasons I will cover later. If you concentrate on the top right of the rear row and we zoom in.



High Resolution 2

Three valve types are visible in this image EF54, EB34 and EA50 as are four labels. If we zoom in further.

High Resolution 3

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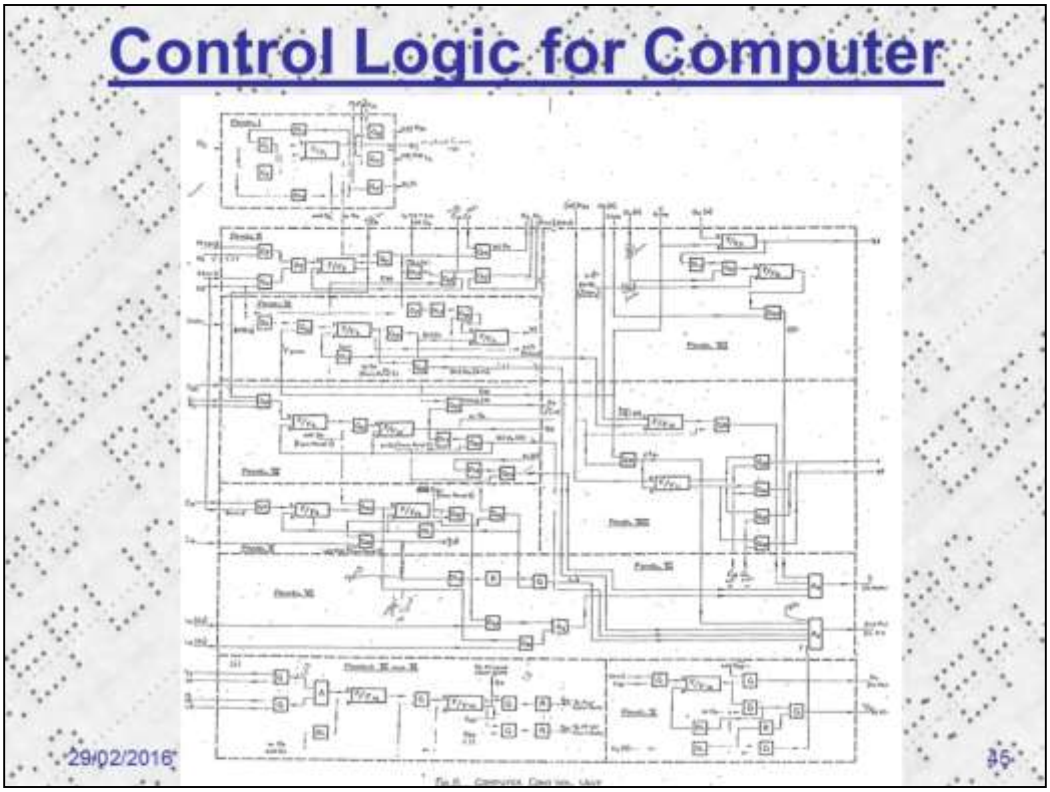
Not easy to read but if you know that there is a module called a Flashing Unit comprising of two flip flops you can “read” the left hand label “easily”. The right hand label says Computer Control.



Control Logic for Computer

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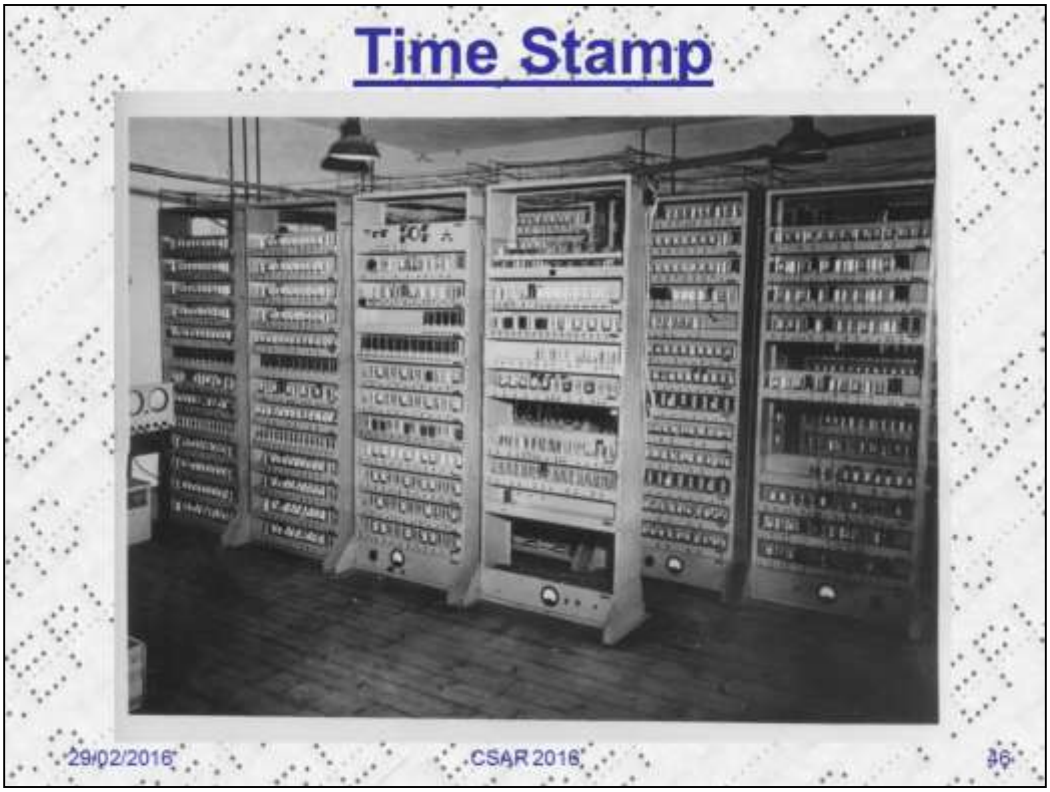
Now there are 11 logical blocks concerned with computer control mentioned in The Report so it would have been very nice if a little more information could have been included on the label. We can count 11 chassis but they are all called Computer Control. I was allowed to study the original plates under high magnification at the University Library but could gather no more information. We are right down at the grain size of the image and even my Photoshop expert son was unable to extract information that was not there.



Time Stamp

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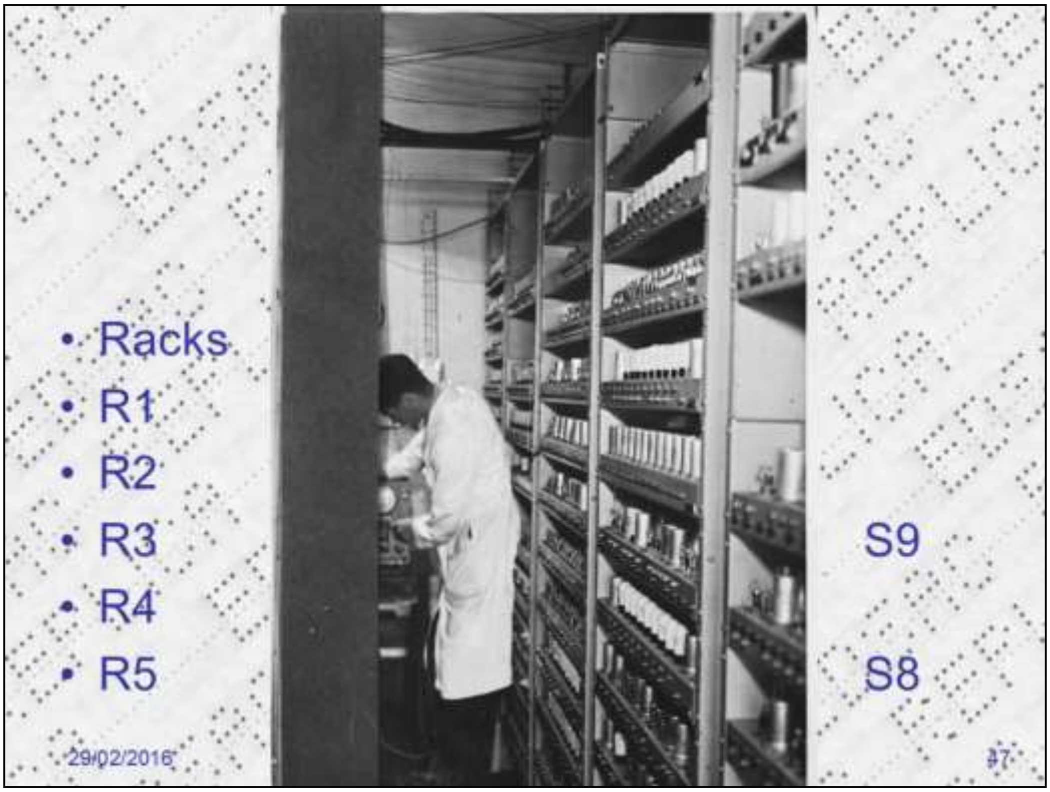
One of our team made a welcome discovery in a contemporary book “Automatic Digital Calculators” by Wilkes containing an image whose caption “Fig 2.1 A photograph of EDSAC taken shortly after its completion”. This gave us a time stamp and we were able to date many of the other images.



- Racks
- R1
- R2
- R3
- R4
- R5

S9

S8

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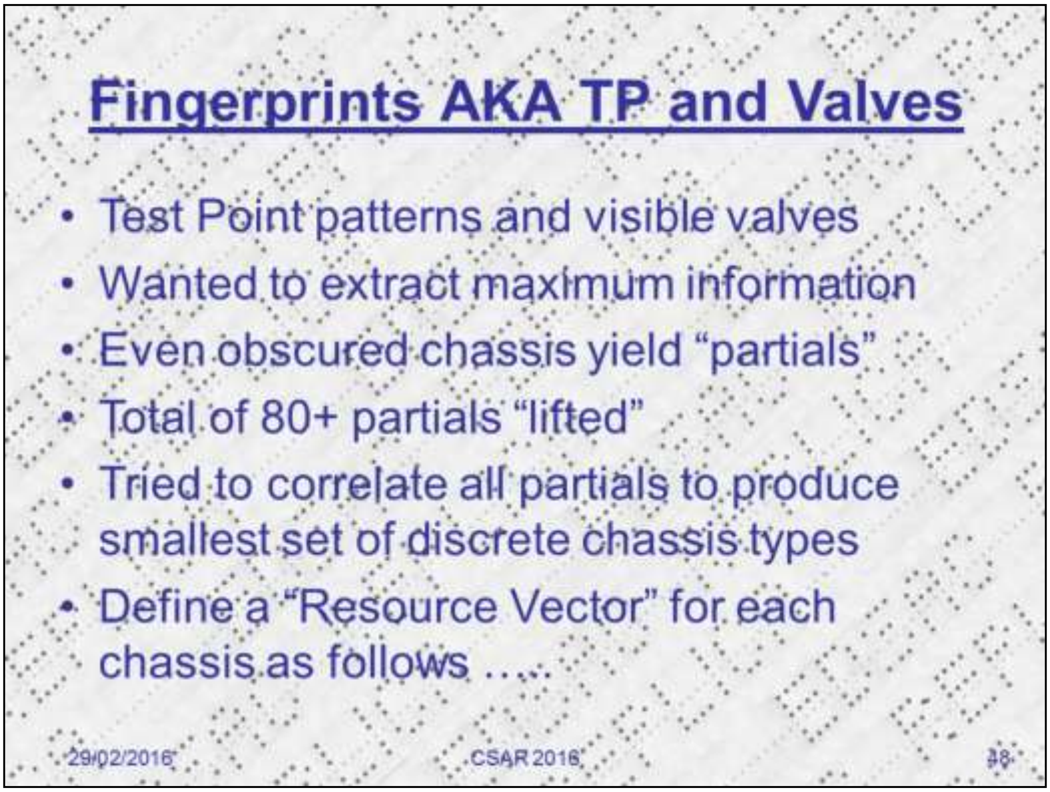
What was important for me was that it enabled the provenance of this image to be verified. This is the only image that shows any detail of the rear row which is pretty much obscured in all other images. This is the reference image for the layout of the three racks of the ALU but as you can see the nearest rack, R5, and the lower portions of R3 and R4 are still obscured.



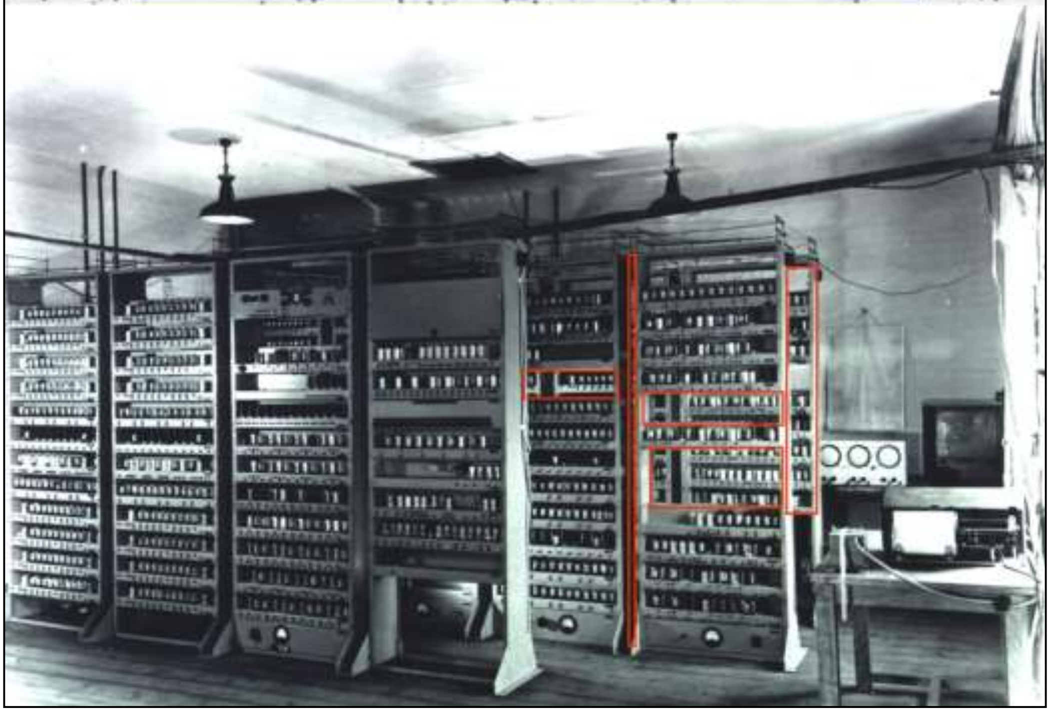
Fingerprints AKA TP and Valves

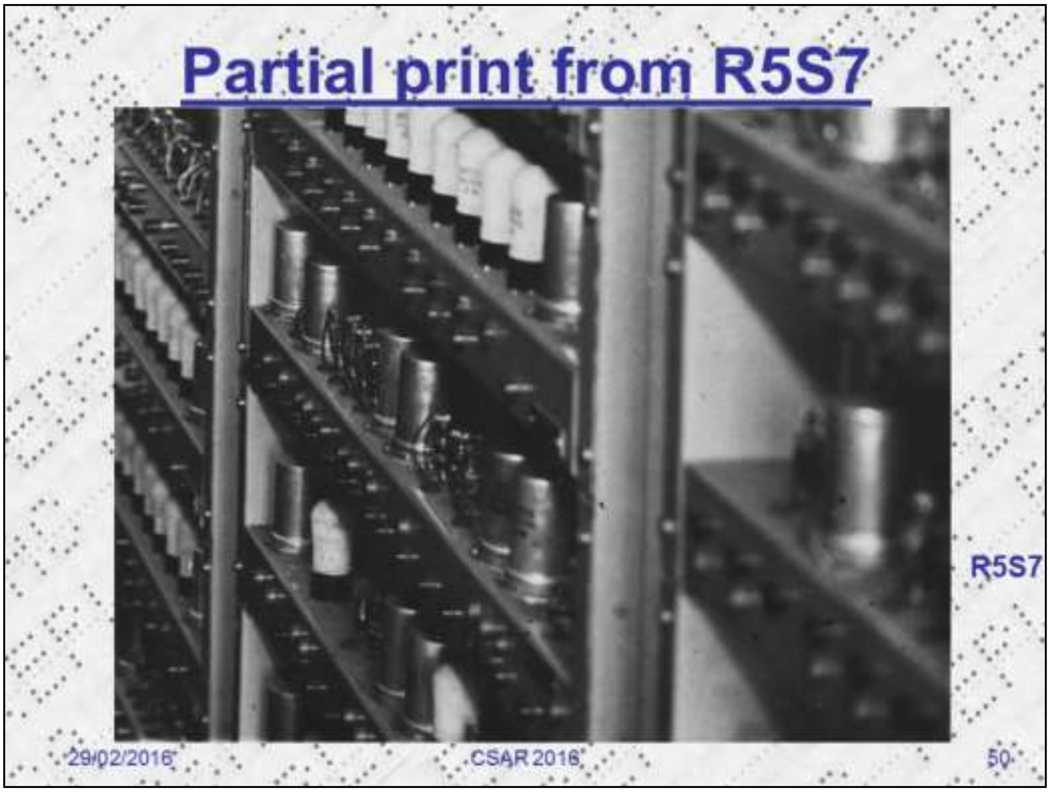
- Test Point patterns and visible valves
- Wanted to extract maximum information
- Even obscured chassis yield “partials”
- Total of 80+ partials “lifted”
- Tried to correlate all partials to produce smallest set of discrete chassis types
- Define a “Resource Vector” for each chassis as follows …..

I cannot possibly cover the entire process that has enabled us to get to where we are today but I will take you through the forensic approach taken to recreate one of the 32 chassis in the ALU.

Our first objective was to extract every last piece of information from the images we had. By this I mean that even a badly obstructed chassis image may have a few test points or tops of valves showing and these need to be recorded as a “partial”, a term used by fingerprint experts. I will only consider the three racks R3, R4 and R5 of the ALU. After about three months of eye strain, new glasses and headaches I collected over 80 distinct partials for the database. By a process of cross correlation all the fragments were merged until sufficient whole or almost whole chassis were generated to fill the slots on the racks R4 and R5.

Another image edsac.99.9



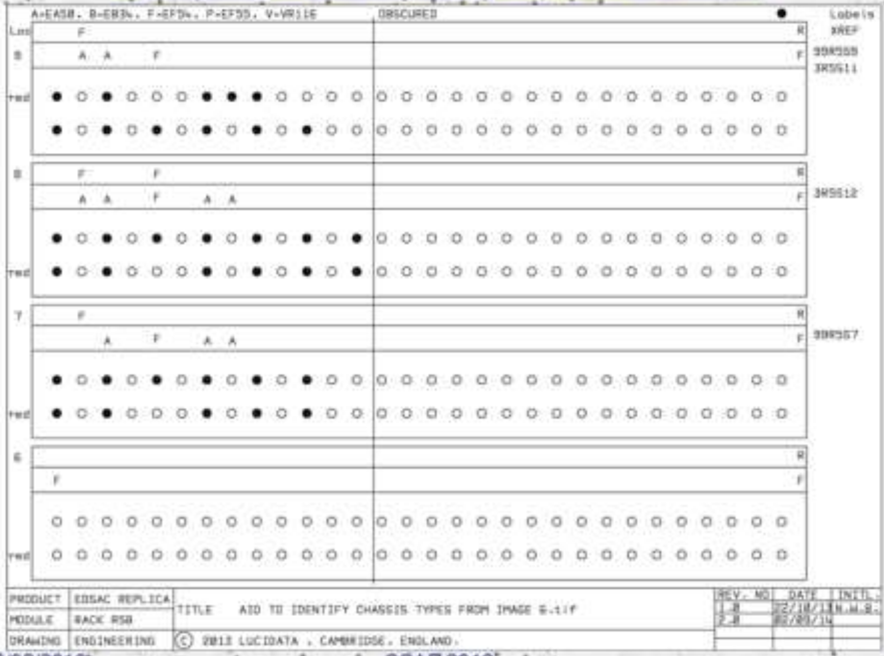


Partial print from R5S7

R5S7

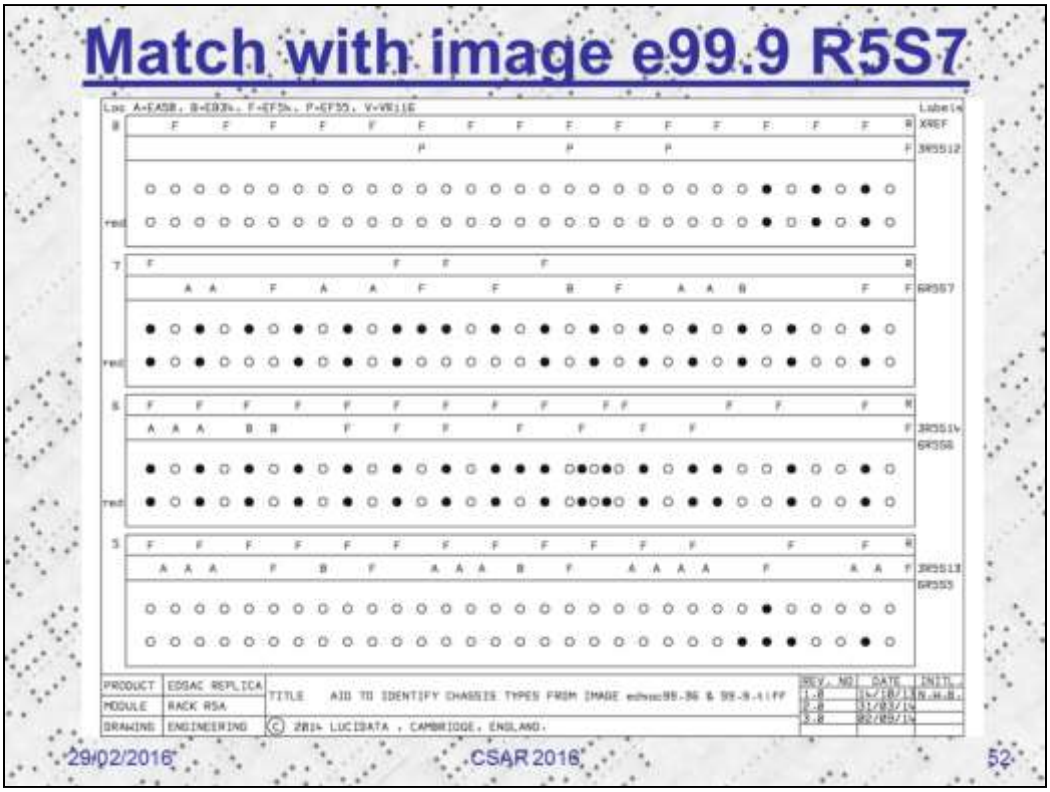
If you look at the bottom right hand side of this slide you will see the symbol R5S7. Simply Rack 5 Shelf 7.

Rack 5 Shelf 7 Partial



That partial is in the database of fragments. There are five different types of valve in this part of the machine and I have coded them with a single letter. There are not many visible here.

Match with image e99.9 R5S7



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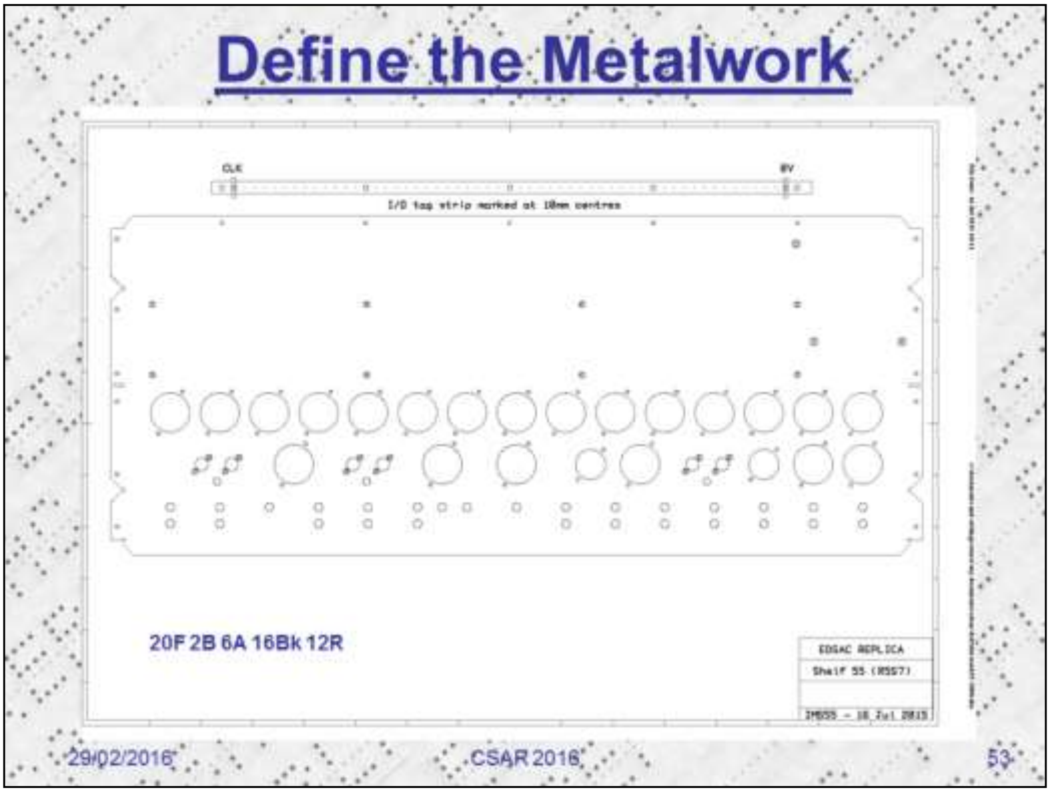
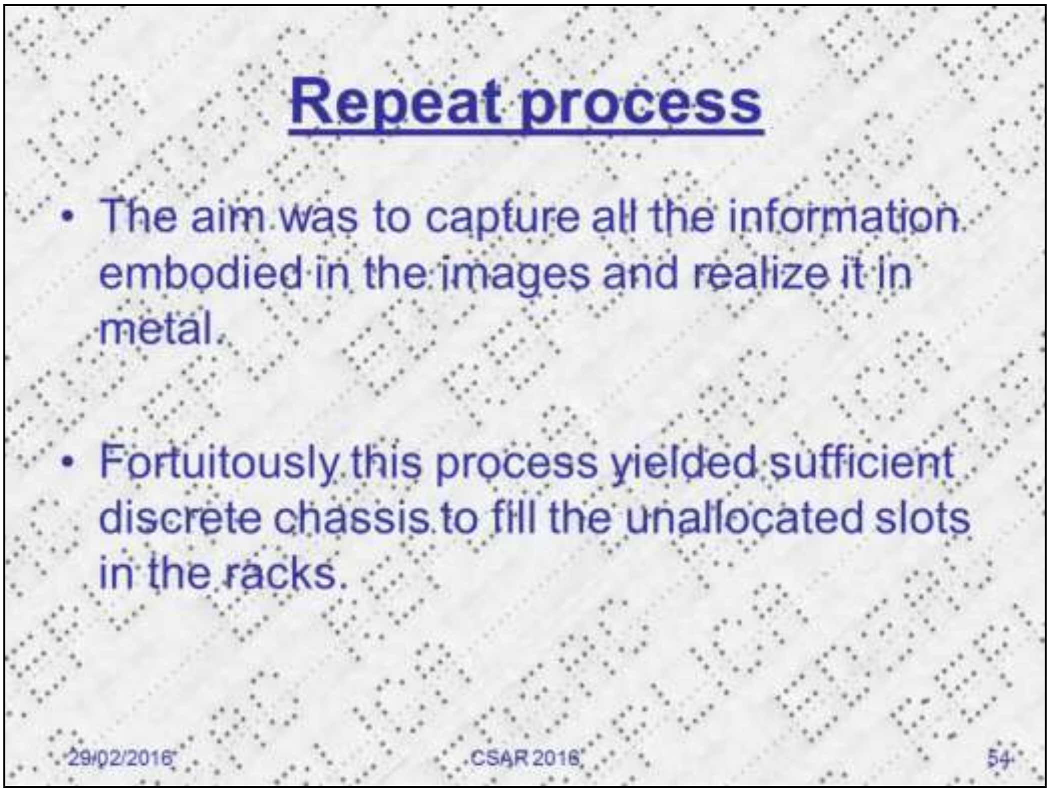
It matches a bigger fragment in another image which still does not show all the valves but shows all the test points. From what we have learnt about the allocation of test points to circuits we can make an informed guess about what valves might be out of sight.



Define the Metalwork

20F 2B 6A 16Bk 12R

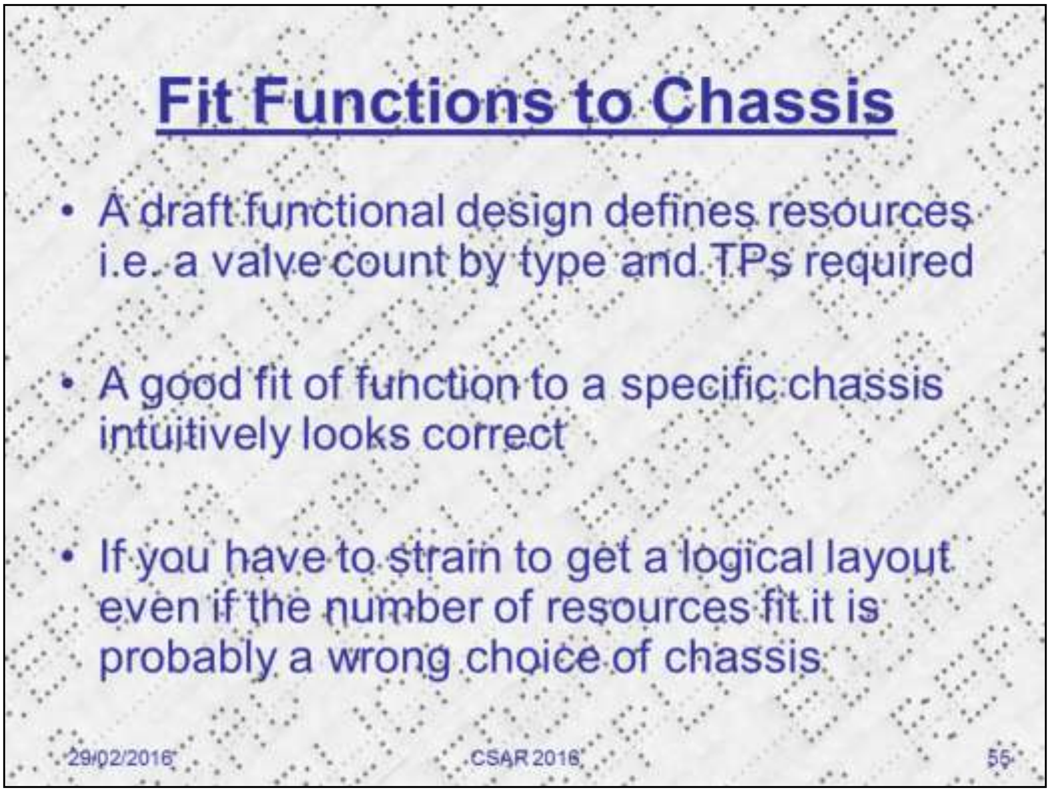
We have enough evidence to enable us to specify some metalwork based on this knowledge and generate a short descriptor (DNA fragment or Resource Vector) for the chassis which in this case has been given the number 55, literally the 55th chassis to be defined and punched out. For this chassis the resource vector is 21F, 2B, 6A,16Bk,12R. This same process was applied to all available data and the metalwork manufactured even though we did not know exactly what function each chassis would take on.



Repeat process

- The aim was to capture all the information embodied in the images and realize it in metal.
- Fortuitously this process yielded sufficient discrete chassis to fill the unallocated slots in the racks.

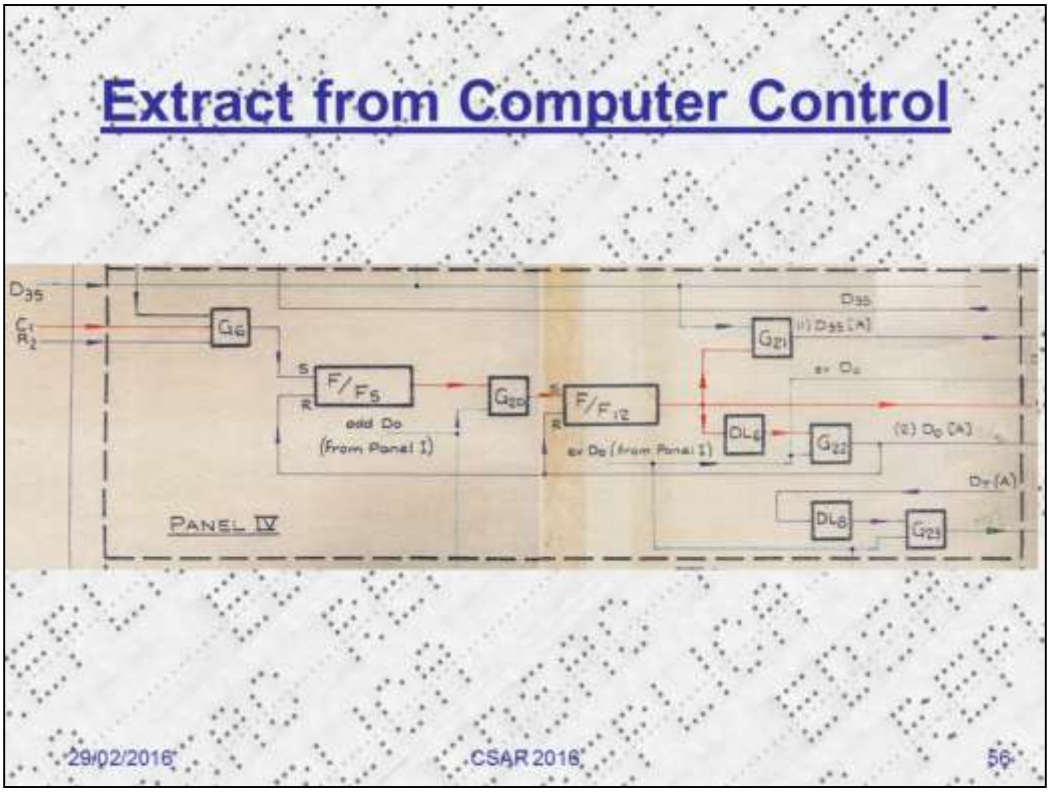
Repeat this process until all the pieces are in place.



Fit Functions to Chassis

- A draft functional design defines resources i.e. a valve count by type and TPs required
- A good fit of function to a specific chassis intuitively looks correct
- If you have to strain to get a logical layout even if the number of resources fit it is probably a wrong choice of chassis

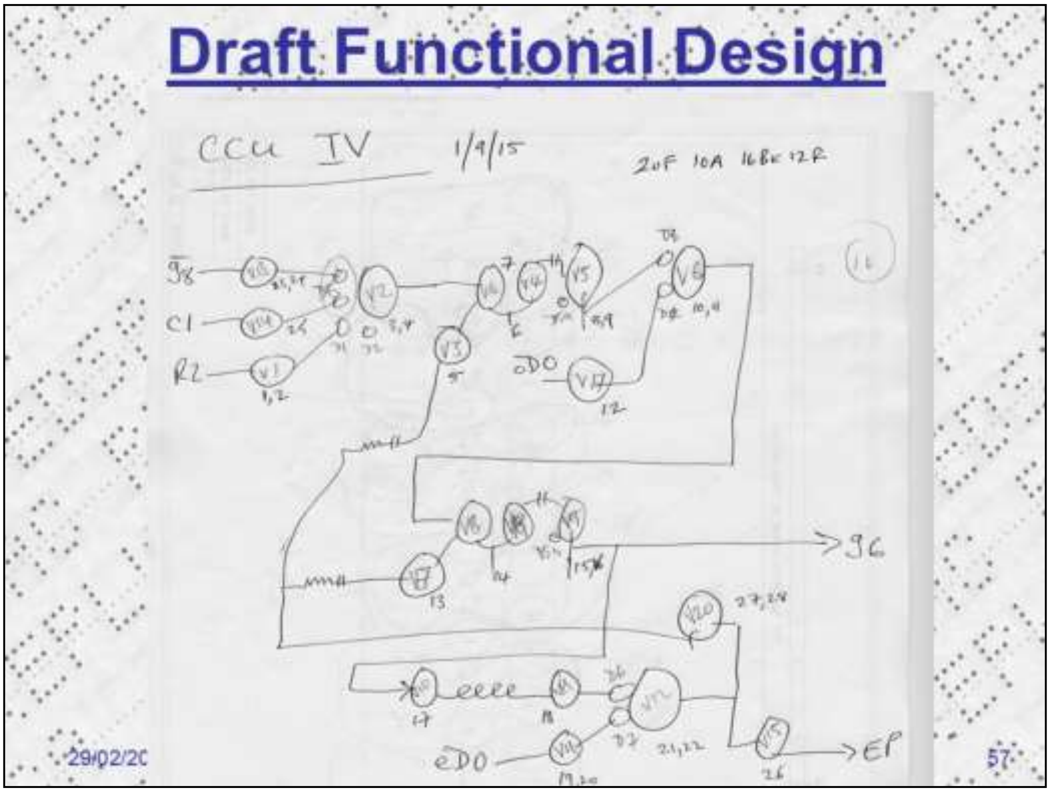
If we chose a logic block from the computer control section, in this case CCU IV, and make a sketch of how it might be implemented.



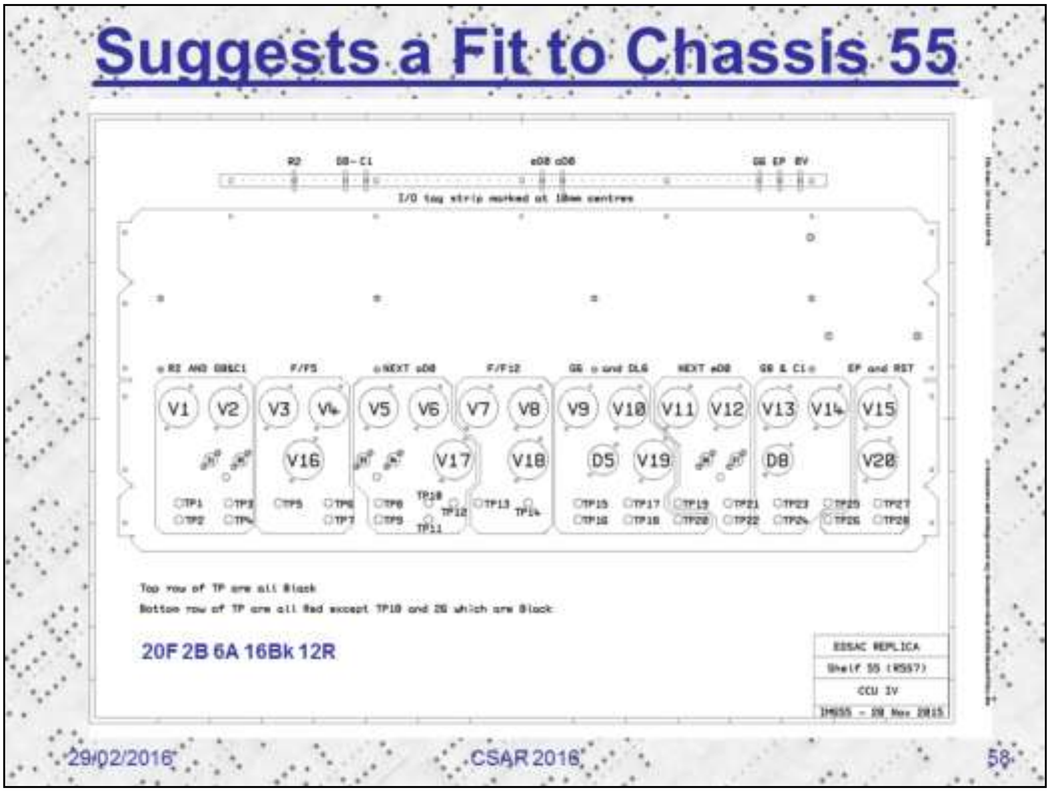
Extract from Computer Control

If we chose a logic block from the computer control section, in this case CCU IV, and make a sketch of how it might be implemented.

Draft Functional Design



Not up to the standard of Leonardo I know but sufficient to count valves and make a Requirement Vector which we can use to search our list of Resource Vectors.



Suggests a Fit to Chassis 55

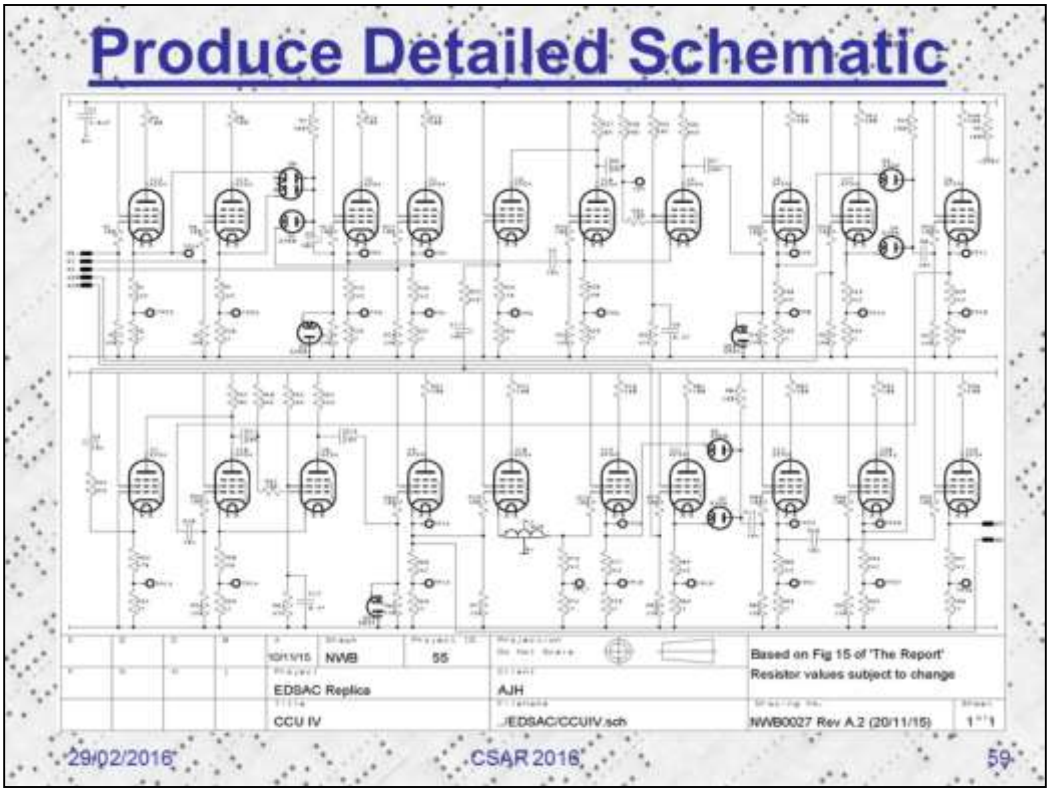
Top row of TP are all Black

Bottom row of TP are all Red except TP10 and 26 which are Black

20F 2B 6A 16Bk 12R

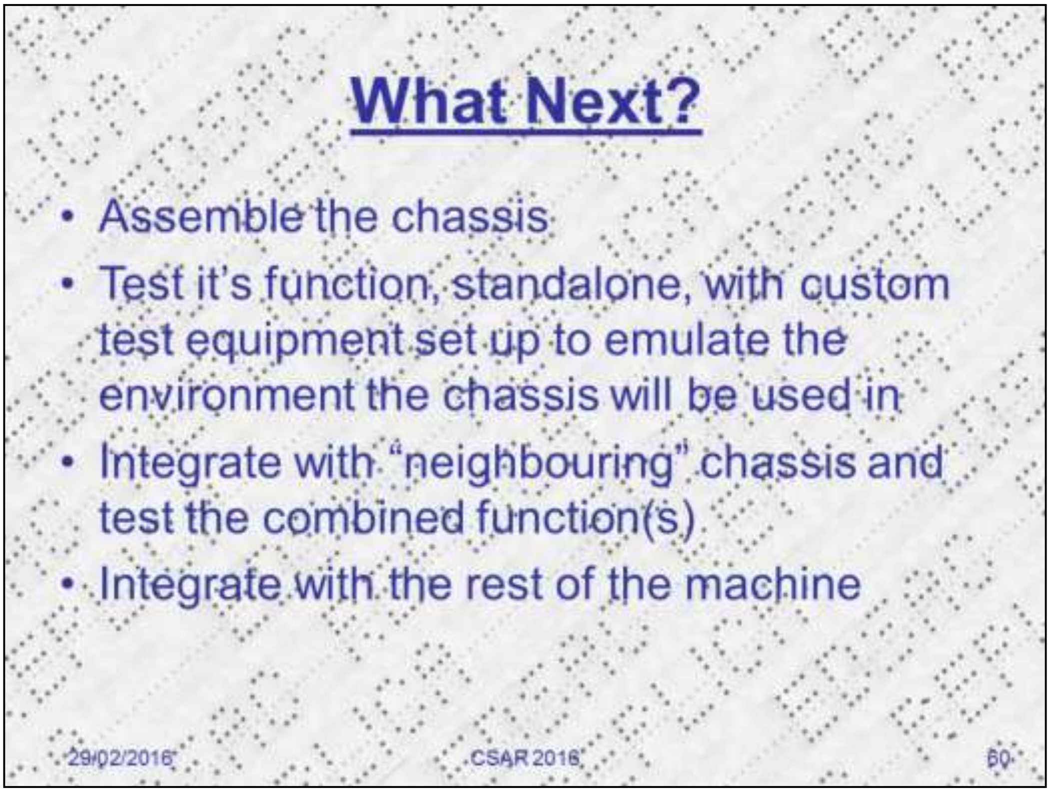
EDSAC REPLICA
Shelf 55 (R557)
CCU IV
IMG55 - 28 Nov 2015

Fortuitously the choice of chassis 55 seems to fit rather well without extreme effort being required to place the sub-modules. The sharp eyed among you will notice that the Resource Vectors are not the same. We said CCU IV needed 10A diode equivalents but the chassis 55 only has 6A. But it also has 2B which are double diodes so that’s equivalent to another 4A. Tick. Trust me. So now we want to implement it we need to make a neat schematic.



Produce Detailed Schematic

Here is an example of our documentation.



What Next?

- Assemble the chassis
- Test it's function, standalone, with custom test equipment set up to emulate the environment the chassis will be used in
- Integrate with "neighbouring" chassis and test the combined function(s)
- Integrate with the rest of the machine

All chassis are first tested stand alone using custom test equipment built with modern technology to exercise the chassis. Then the chassis is integrated with other already tested chassis and the combined sub-system exercised.

Repeat this process until all the pieces are in place.

Mercury – Hazchem

- A Decision was taken early on in the project that we would not use mercury to avoid problems with H&S and the high cost.
- We would still use acoustic delay lines but based on nickel/steel wire. This was a major piece of development work by Peter Linington
- The electrical interface is identical to that of a mercury delay line so no non-authentic modifications are required.
- Use of digital emulator for commissioning only

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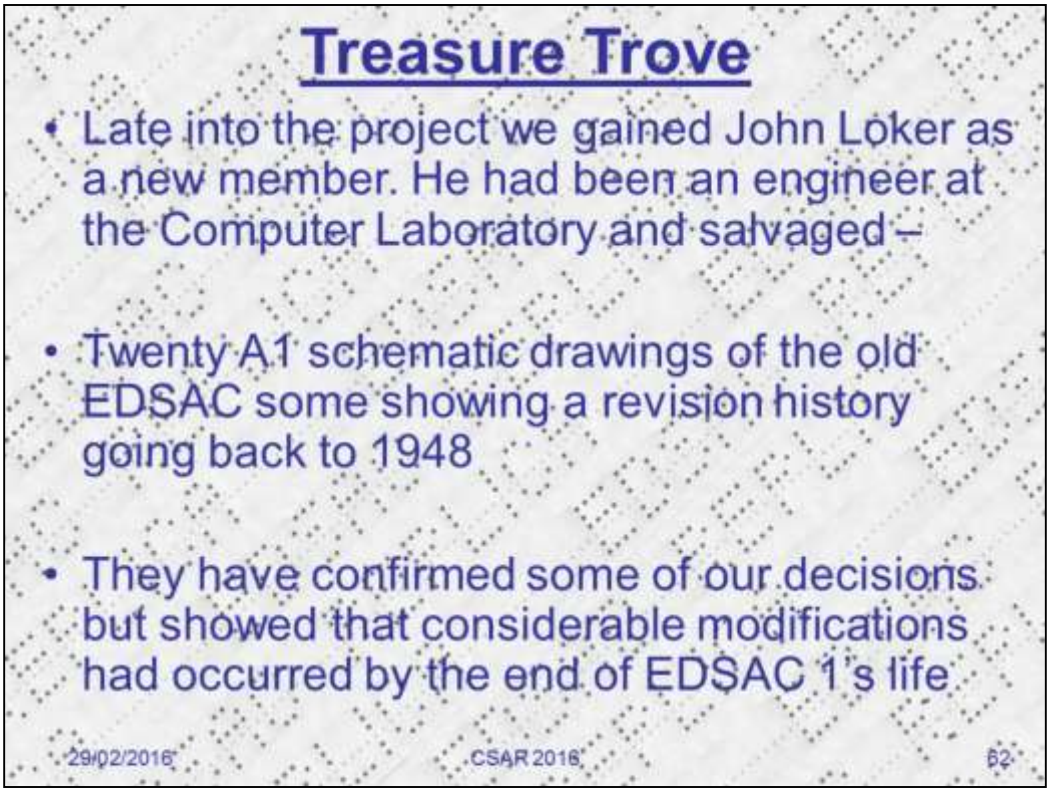
To finish off we took the decision at the project inception that we would not use mercury as the medium for the acoustic delay lines due to potential problems with using a hazardous substance in a public area and Health and Safety. It would also be very expensive as about 500Kg would be required. Instead Peter Linington has spent a considerable part of his time developing a wire based memory. This technology overlapped EDSAC’s life and was used by Ferranti in early machines prior to magnetic core technology so is of the proper era. The interfaces have been kept the same as if mercury tanks were used and we may at a later date substitute one of the short tanks for a mercury one so the public does not feel cheated and to show that it works. In the interim and to help all the developers to progress with their own work a small digital circuit was developed which connects inside Chassis 01 and emulates the external storage device. These emulators will be removed as acoustic delay tanks come on stream



Treasure Trove

- Late into the project we gained John Loker as a new member. He had been an engineer at the Computer Laboratory and salvaged –
- Twenty A1 schematic drawings of the old EDSAC some showing a revision history going back to 1948
- They have confirmed some of our decisions but showed that considerable modifications had occurred by the end of EDSAC 1's life

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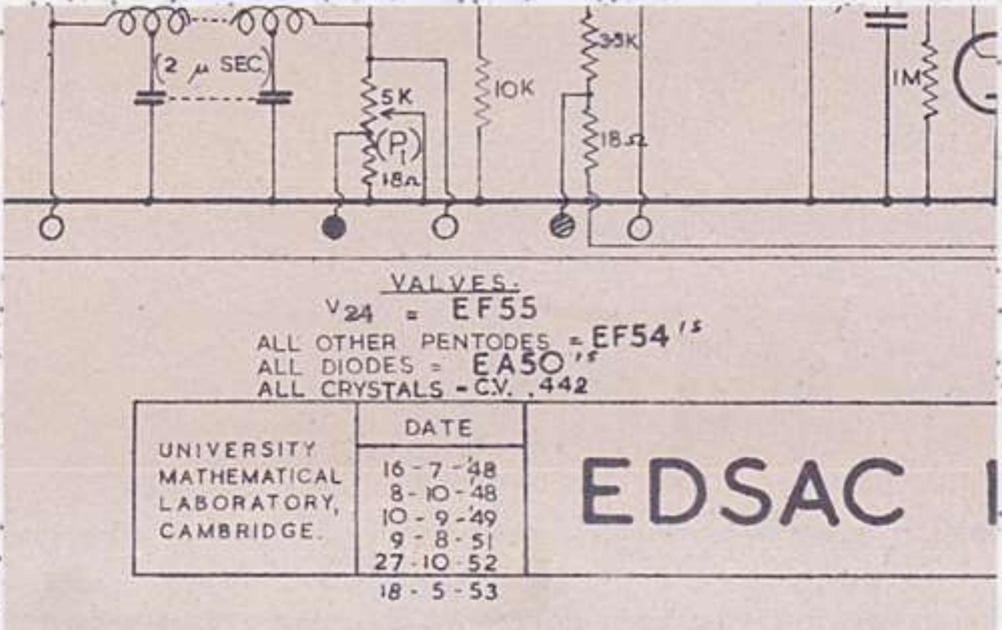
Another story that must be mentioned is the so called Treasure Trove of EDSAC schematics that was found by John Loker when he was clearing out some cupboards at the Computer Laboratory. They documented the machine at the end of it's life and we think they were probably prepared for the LEO engineers who were busy at that time. The drawings showed many divergences from the machine we are building but also supported many of the guesses we had made in our development.

Modification Record



VALVES.

V_{24} = EF55

ALL OTHER PENTODES = EF54's

ALL DIODES = EA50's

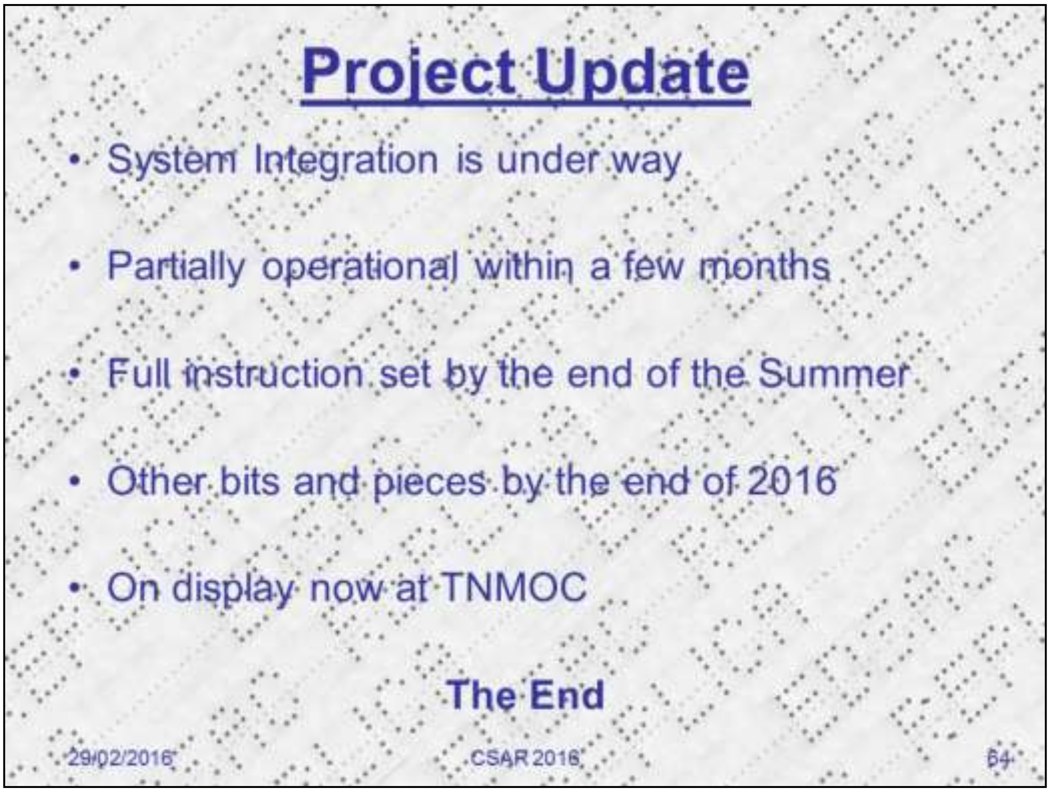
ALL CRYSTALS - C.V. 442

UNIVERSITY
MATHEMATICAL
LABORATORY,
CAMBRIDGE.

DATE

16 - 7 - 48
8 - 10 - 48
10 - 9 - 49
9 - 8 - 51
27 - 10 - 52
18 - 5 - 53

EDSAC



Project Update

- System Integration is under way
- Partially operational within a few months
- Full instruction set by the end of the Summer
- Other bits and pieces by the end of 2016
- On display now at TNMOC

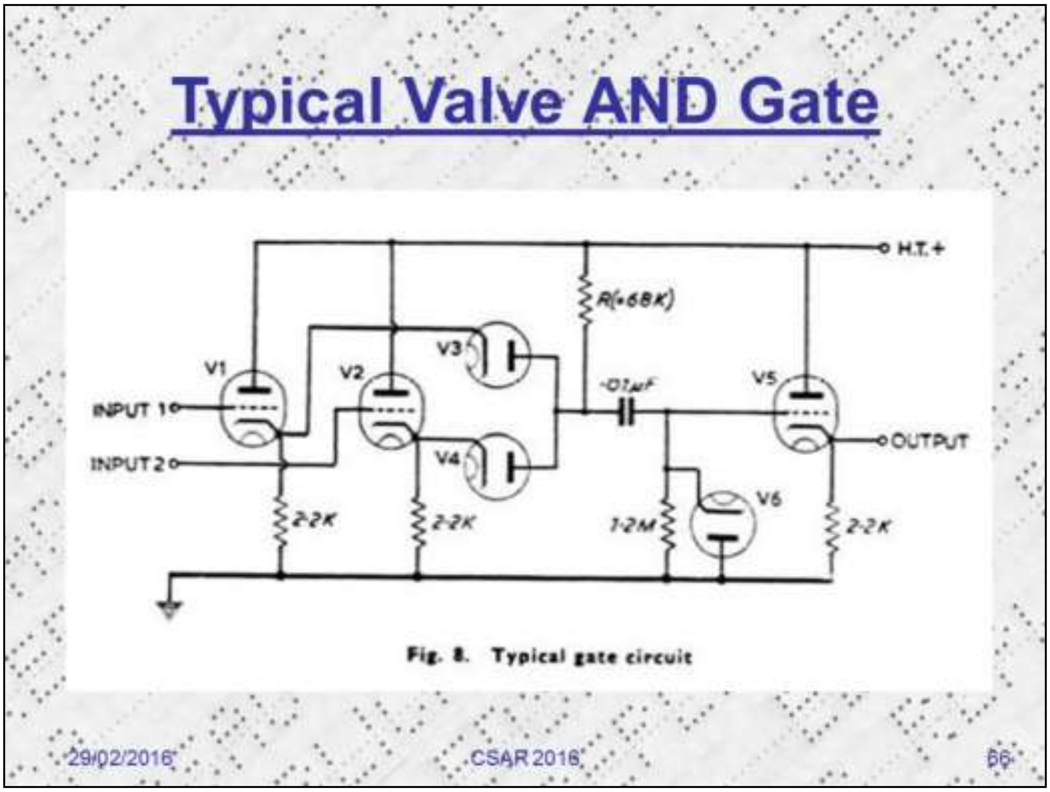
The End

This slide summarizes where we are.

URLs of Websites

- The EDSAC Replica Project
  - www.edsac.org
- The National Museum of Computing
  - www.tnmoc.org
- The Computer Conservation Society
  - www.computerconservationsociety.org
- The EDSAC Simulator
  - http://www.dcs.warwick.ac.uk/~edsac/

These websites contain a wealth of interesting stuff.



Typical Valve AND Gate

Fig. 8. Typical gate circuit

Regeneration Unit

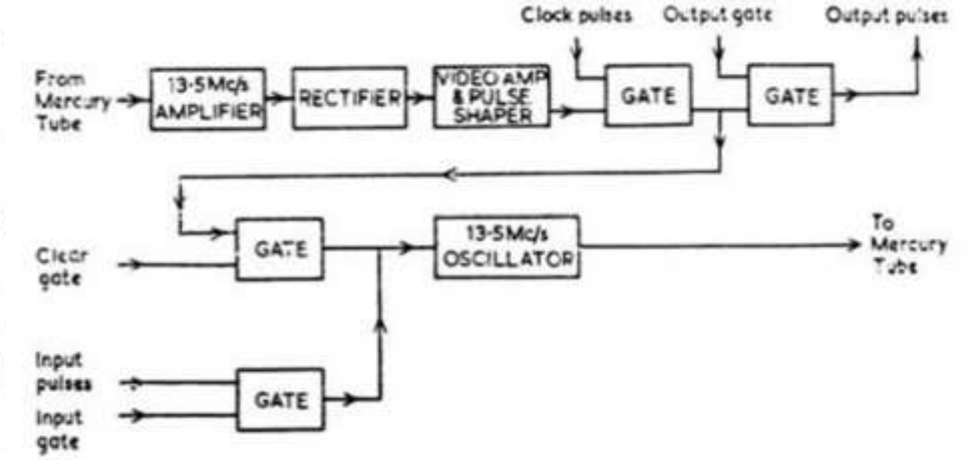


Fig. 3. Schematic diagram of memory unit