Part I

History and machines of cryptography

CHAPTER 14: MACHINES and HISTORY of CRYPTOGRAPHY

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PROLOGUE

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- **What to value more**? **Personal freedom?** or **the order and law?**

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- Third World War would be the war of informaticians (cryptographers and cryptanalysts).

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History is full of codes. They have decided the outcomes of battles and led to the deaths of kings and queens.

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- Around 1585 Matteo Argenti wrote a 135-pages book on cryptography that is considered as the highlight of the renaissance cryptography.

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- The method was redeveloped and published later by Prussian Friedrich Kassiski.

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- Till recently it was assumed that secret codebooks are necessary for secret communication.

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- It was the design of the telegraph and the need for *field ciphers* to be used in combat that ended the massive use of nomenclators and started a new history of cryptography dominated by polyalphabetic substitution cryptosystems.

OLD GOLDEN TIMES of CRYPTOGRAPHY

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  For example, each ambassador of (many) of the Italian states had a crypto-secretary.

EXAMPLES of “UNBREAKABLE CODES”

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- BEALE CODE, published in 1885, should contain encryption of the place where a treasury worth of 20 million of dolars is hidden.

BEALE CODE

- In 1885 a paper was made public that contains three pages of codes that should describe a place where a treasury has been hidden that is worth of 50 millions of dollars and what to do with it.
- Many people spent a lot of time, some their whole life, to decode it.
- One page was decoded using an article about American Independence.
- The key part, describing exactly the place the treasury was hidden has not been decrypted yet.

BEALE CODE - 1 PAGE

When, in the course of human events, it becomes 10 necessary for one people to dissolve the political bands which 20 have connected them with another, and to assume among the 30 powers of the earth, the separate and equal station to 40 which the laws of nature and of nature's God entitle 50 them, a decent respect to the opinions of mankind requires 60 that they should declare the causes which impel them to 70 the separation.

We hold these truths to be self-evident, 80 that all men are created equal, that they are endowed 90 by their Creator with certain inalienable rights, that among these 100 are life, liberty and the pursuit of happiness; That to 110 secure these rights, governments are instituted among men, deriving their 120 just powers from the consent of the governed; That whenever 130 any form of government becomes destructive of these ends, it 140 is the right of the people to alter or to 150 abolish it, and to institute a new government, laying its 160 foundation on such principles and organizing its powers in such 170 form, as to them shall seem most likely to effect 180 their safety and happiness. Prudence, indeed, will dictate that governments 190 long established should not be changed for light and transient 200 causes; and accordingly all experience hath shewn, that mankind are 210 more disposed to suffer, while evils are sufferable, than to 220 right themselves by abolishing the forms to which they are 230 accustomed.

But when a long train of abuses and usurpations, 240 pursuing invariably the same object evinces a design to reduce them 250 under absolute despotism, it is their right, it is their 260 duty, to throw off such government, and to provide new 270 Guards for their future security. Such has been the patient 280 sufferance of these Colonies; and such is now the necessity 290 which constrains them to alter their former systems of government. 300 The history of the present King of Great Britain is 310 a history of repeated injuries and usurpations, all having in 320 direct object the establishment of an absolute tyranny over these 330 States. To prove this, let facts be submitted to a 340 candid world.

Figure 24 The first three paragraphs of the Declaration of Independence, with every tenth word numbered. This is the key for deciphering the second Beale cipher.

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For example, BLACK CHAMBER in Vienna used to encrypt about 100 letters daily.

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- Allan Turing (helped to brake ENIGMA, designed BOMBS, developed a technique to determine positions of German submarines).

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- Allan Turing (helped to brake ENIGMA, designed BOMBS, developed a technique to determine positions of German submarines).
- John Nash (Nobel price for game theory and economics)

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- To achieve this progress has required formalization of some basic notions of science - such as randomness, knowledge, in-distinguishibility and proof.

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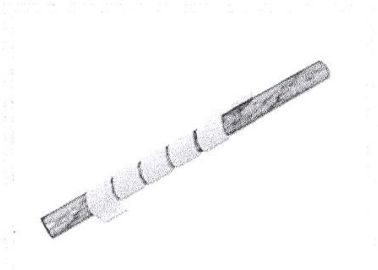
- The break into system JN-25 led to the US-victory in the Battle of Midway.
- US Army group managed to break the highest security Japanese cryptosystem called *PURPLE* even before beginning of WW2.

HISTORY of CRYPTOGRAPHIC MACHINES

FIRST KNOWN DEVICES - SCYTALE

- Spartans used transposition cipher device called scytale . It was a wooden stick around which a strip of parchment (pergament), or leather or papyrus was spirally wrapped, layer upon layer. The plaintext was written on the parchment lengthwise down the staff. Then the parchment was unwrapped and sent. Text on parchment had no sense until it was re-wrapped around a stick of equal diameter. (One use of the scytale was documented to be used around 475 BC).



A Scytale, an early device for encryption.

ENCRYPTION DISCS

Leon Battista Alberti (1401-1472) developed an encryption disc to be used for polymorphic substitution.
They were used for several centuries to speed up the use of CAESAR cryptosystem.

Encryption disks could also be called **scramblers**.

JEFFERSON's WHEEL

For an interested reader, [Ka] contains a description of the wheel in Jefferson's own words.

Jefferson's wheel consists of a cylinder mounted on an axis. 26 straight lines, parallel to the axis and at equal distances from each other, are drawn on the cylinder. The cylinder is then cut into 10 smaller cylinders of equal height. The smaller cylinders are referred to as *disks*. Thus, we have 10 disks free to rotate independently about the common axis. Moreover, each of the disks is divided into 26 boxes of equal size on its circumference. On each disk, the 26 boxes are now filled with the 26 letters of the English alphabet. The order of the letters is chosen arbitrarily and varies from disk to disk.

A particular Jefferson wheel is depicted in Fig. 1.7. The same wheel will be used in Example 1.7, where also the individual disks are described in detail, that is, also the parts not visible in the figure.

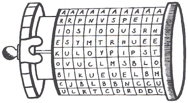


Fig. 1.7

It should be added that Jefferson used 36 disks. We have chosen the smaller number 10, for clarity of presentation.

Both the sender and the receiver possess identical wheels, that is, the cyclic order of the letters is the same on each disk. To encrypt an English plaintext, the sender first divides it into blocks of 10 letters each. A block is encrypted by first rotating the disks in such a way that the block can be read from one of the 26 letter sequences parallel to the axis, and then choosing any of the 25 remaining letter sequences as the cryptotext.

To decrypt, the legal receiver rotates the disks of the Jefferson wheel in such a way that the cryptotext can be read from one of the 26 letter sequences. The plaintext then appears as one of the 25 remaining letter sequences. It will be obvious which one: with an extremely high probability, only one of the letter sequences can be a part of a meaningful English text. Thus, it is not necessary to agree in advance how many lines in the wheel will be advanced in the encryption process. It can be any number between 1 and 25, and the number can vary from block to block.

The situation is slightly different if the plaintext is "nonsense." Then the encryption distance in the wheel must be agreed upon in advance. For instance, if the encryption distance is 3 then the plaintext AAAAAAAAAA will be encrypted as ESYMTRHUEE according to the wheel of Fig. 1.7.

CRYPTOGRAPHY of the FIRST WORLD WAR

BEGINNING of FIRST WORLD WAR

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- **A** 6×6 **blackboard filled with 26 letters and 10 digits**. It was used for the first encoding similarly as at the Playright cryptosystem.

	A	D	F	G	V	X
A	8	p	3	d	1	n
D	i	t	4	0	a	h
t	7	k	b	c	5	z
G	j	u	6	w	g	m
V	x	s	v	i	r	2
X	g	e	y	0	1	q

plaintext **attack at 10 pm**

is encrypted: **DV DD DD DV FG FO DV DD AY XG AD GX**

- **A short permutation**, say of m elements. It was used for writing first cryptotext into rows of length m, then permuting columns and writing final cryptotext row by row.

M	A	R	K
D	V	D	D
D	D	D	V
G	G	F	D
D	V	D	D
A	V	X	G
A	D	G	X

A	K	M	R
V	D	D	D
D	V	D	D
G	D	F	F
V	D	D	D
V	G	A	X
D	X	A	G

First important ADFGVX message was cracked by French G. Painvin, on **June 2, 1918**.

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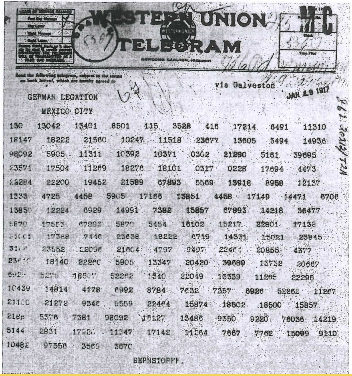
- Several other codebooks were captured in years 1918-1919.

ZIMMERMAN TELEGRAM

ralty's cipher bureau, named after the office in which it was initially housed. Room 40 was a strange mixture of linguists, classical scholars and puzzle addicts, capable of the most ingenious feats of cryptanalysis. For example, the Reverend Montgomery, a gifted translator of German theological works, had deciphered a secret message hidden in a postcard addressed to Sir Henry Jones, 184 King's Road, Tighnabruaich, Scotland.


WESTERN UNION TELEGRAM

via Galveston

JAN 19 1917

GERMAN LEGATION

MEXICO CITY

130 13042 13401 8501 115 3528 416 17214 6491 11310
18147 18222 21560 10247 11518 23677 13605 3494 14936
98092 5905 11311 10392 10371 0302 21290 5161 39695
23571 17504 11269 18276 18101 0317 0228 17694 4473
22284 22200 19452 21589 67893 5569 13918 8958 12137
1333 4725 4458 5905 17166 13851 4458 17149 14471 6706
13850 12224 6929 14991 7382 15857 67893 14218 36477
5870 17553 67893 5870 5454 16102 15217 22801 17138
21001 17388 7446 23638 18222 6719 14331 15021 23845
3156 23552 22096 21604 4797 9497 22464 20855 4377
23610 18140 22260 5905 13347 20420 39689 13732 20667
6929 5275 18507 52262 1340 22049 13339 11265 22295
10439 14814 4178 6992 8784 7632 7357 6926 52262 11267
21100 21272 9346 9559 22464 15874 18502 18500 15857
2188 5376 7381 98092 16127 13486 9350 9220 76036 14219
5144 2831 17920 11347 17142 11264 7667 7762 15099 9110
10482 97556 3569 3670

BERNSTORFF.

ZIMMERMAN TELEGRAM - STORY

- The most important contribution of Room 40 was decryption of so called "Zimmerman telegram.'
- It was a telegram sent on January 17, 2017 from the German Foreign Office via Washington to its ambassador in Mexico.
- In the telegram German Foreign Minister Arthur Zimmerman offered to Mexico United States territories of Arizona, New Mexico, and Texas as an enticement to join the war as a German ally.
- Motto of telegram was "Make war together and then make peace together". Germans also promised Mexico "Generous financial support".
- This telegram convinced president Roosevelt, who believed in negotiations with Germany, that it is necessary to declare the war to Germany, what then happened on 6 April 1917.
- Mexican president did not accept German's proposal because he consider their claim about financial support as empty and a war with very strong US as very dangerous for Mexico.

CRYPTOGRAPHY of the SECOND WORLD WAR

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- Between June 1940 and June 1941 Allies lost an average 50 big ships each month and about 50 000 seamen died during that period.

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- In spite of all these enormous loses about 99% of all ships sailing to and from the British Isles did so safely.

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- The battle of Atlantic lasted 5 years, 8 months and 5 days.

STORY of ENIGMA

ENIGMA – its PRINCIPLES

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Main components of the Enigma cryptomachine:

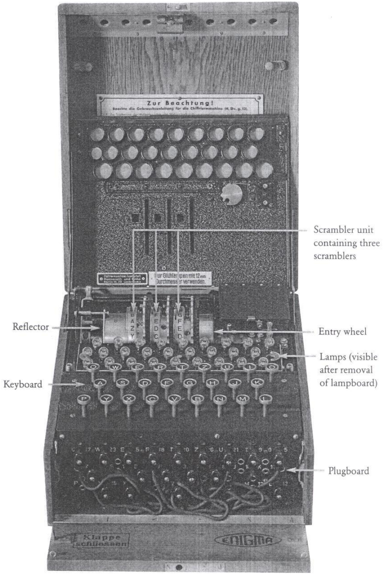
- **Keyboard**
- n **scramblers (rotors)**, $n \geq 3$. At each position a scrambler could implement a CAESAR cryptosystem. After encoding one letter it moved one position. After making full completion, next scrambler was moved one position.
- **Reflector** - to allow to use the same technique for encryption and description.
- **Plugboard** – to realize several transpositions of letters
- **Lampboard**

Number of keys with three scramblers:

- Scramblers orientations 26^3 settings.
- Scrambler arrangements $3! = 6$
- Plugboard settings: 100 391 791 500

Total number of keys is $\approx 10^{16}$.

About 30 000 Enigma machines have been produced.


Scrambler unit containing three scramblers
Reflector
Entry wheel
Lamps (visible after removal of lampboard)
Keyboard
Plugboard
Zur Beachtung!
ENIGMA

IMPACT of ONE SCRAMBLER

The following picture shows how one moving scrambler causes that the same letter - "B" in this time, may be differently encoded if several times is encoded.

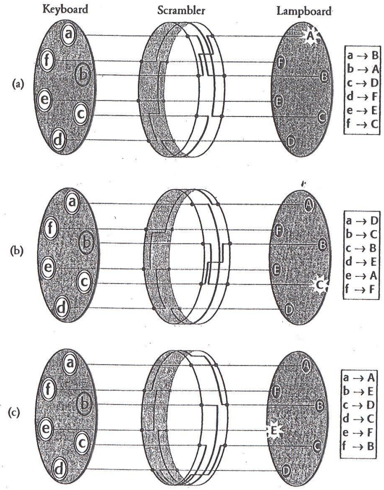
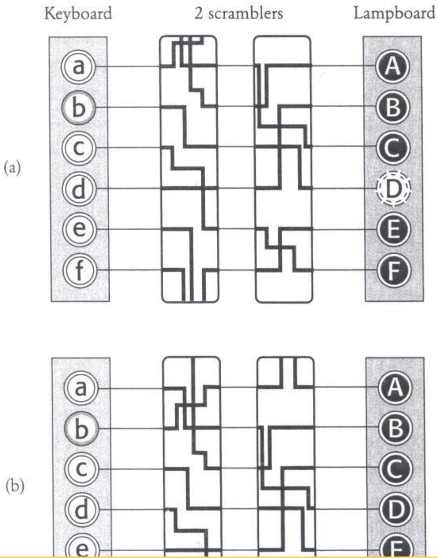


Figure 34 Every time a letter is typed into the keyboard and encrypted, the scrambler rotates by one place, thus changing how each letter is potentially encrypted. In (a) the scrambler encrypts b as A, but in (b) the new scrambler orientation encrypts b as C. In (c), after rotating one more place, the scrambler encrypts b as E. After encrypting four more letters, and rotating four more places, the scrambler returns to its original orientation.

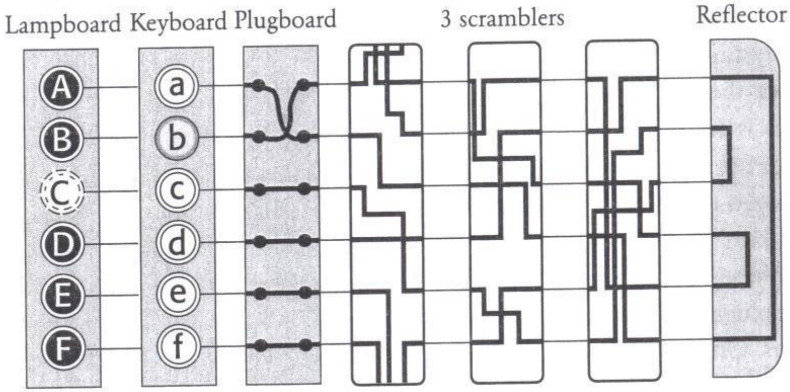
IMPACTS of two SCRAMBLERS

The following picture shows how two moving scramblers cause that the same letter - "B" in this time - may be differently encoded if it is several times encoded.



ENIGMA STRUCTURE in case of THREE SCRAMBLERS

The following picture shows basic structure of ENIGMA with lampboard, keyboard, plugboard,three scramblers and reflector.



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- Allies were able to get (from destroyed submarines and ships) some codebooks.

DAY-KEYS versus MESSAGE-KEYS I

Day-key components:

Plugboard setting: A-L, P-R, T-D, B-W, K-F, D-Y
Scrambler orientation: Q - C - W
Scramblers ordering: 2 - 3 - 1

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Example: PGHPGH –> KIVBJE
Message key PGH is encoded as KIVBJE

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Cycles

$A \rightarrow F \rightarrow W \rightarrow A$

$B \rightarrow Q \rightarrow Z \rightarrow K \rightarrow V \rightarrow E \rightarrow L \rightarrow R \rightarrow I \rightarrow B$

$C \rightarrow H \rightarrow G \rightarrow O \rightarrow Y \rightarrow D \rightarrow P \rightarrow C$

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Later they mechanized this decryption process using machines called *bombs*.

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- To find the plugboard setting Rajewski did first decoding without paying any attention to plugboard connections.

Example if the cryptotext was decrypted as

$$alliveinBerlin$$

this suggested that the transposition

$$L - -R$$

was used.

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STORY of BLETCHEY PARK

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- The most difficult problem and most important task was to break navy ENIGMA. (In 1940 and 1941 Allies used to lose about 50 ships per moths that were sink by German submarines.)
- Sophisticated techniques were used to make sure that Germans do not realize that their "unbreakable ENIGMA" was broken.
- Main techniques used were: brains, technology, intelligence, luck.

WORK in BLETCHEY PARK

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Cottage where early work on decoding ENIGMA was performed. The windows on the top open to Turing's room.

Hut 1, bellow, was the first one to be constructed.

PROBLEMS and MAIN SUCCESSES of BLETCHEY PARK

- Main German encryption systems ENIGMA and LORENZ were virtually unbreakable if properly used.
- It was poor operational procedures and sloppy operator behaviours that allowed the GX&CS cryptanalysts to find ways to read them.
- Main problem for Bletchey Park codebreakers came when German introduced four-rotor ENIGMA. This change stopped their ability to decode German messages from February to December, 1942.
- Prior to the Normandy landings on the D-Day in June 1944, the Allies knew locations of all but two of the German 58 divisions on the Western front.

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Success of WW2 cryptanalysis was therefore due to a proper combination of art, science and technology.

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- Had this happened the enemy would undoubtedly introduced changes in its encryption policy/equipment.
- Such changes could have enormous impacts on decryption capabilities.
- For that reason there was a separation between groups doing decryption and groups sending out intelligence received from messages.

TURING's ROLE in BLETCHEY PARK

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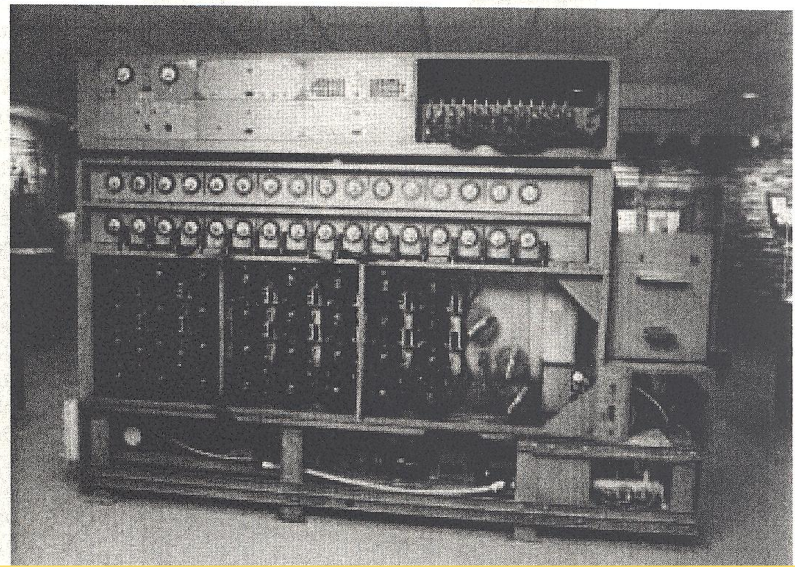
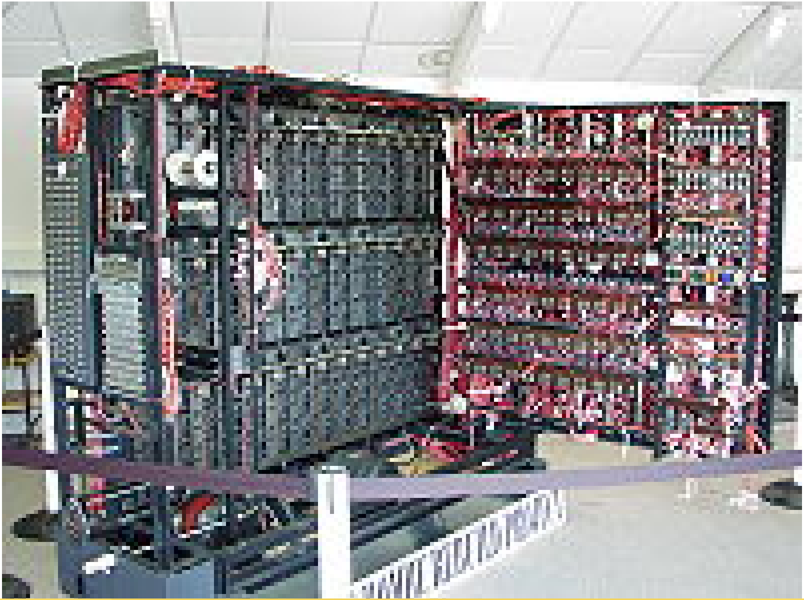
- Germans then added one scrambler to ENIGMA and for four months British were not able to decrypt their messages. In August and Septemeber 1942 German were able to sink 47 ships.
- In order to quantify quality of guesses he developed a measure of it called "ban" - and defined it as the smallest change in weight of evidence that is directly perceptible to human intuition. One ban represented odds of 10 to 1 in favour of a guess. Normally Turing worked also with decibans and centibans - smaller units.

BOMBS -PHOTO FROM WAR TIMES



BOMBS - RECONSTRUCTION - VIEW FROM BACK

The back of the rebuilt **Bombe**.



LORENZ SZ40 and COLOSSUS

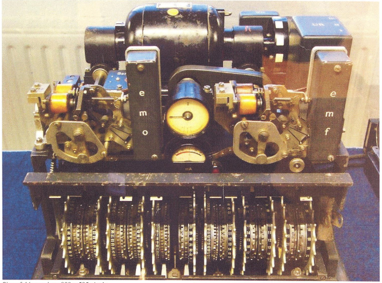
LORENZ SZ40

- Lorenz SZ40 was an electromechanical encryption machine, far more complicated than Enigma that was used to encrypt telegraphic messages between German High Command and their army commands in Europe.

Image:Lorenz-SZ42-2.jpg

From Wikipedia, the free encyclopedia

- Image
- File history
- File links



Size of this preview: 800 × 595 pixels
Full resolution (1,141 × 848 pixels, file size: 146 KB, MIME type: image/jpeg)

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A Lorenz SZ42 cipher machine on display at Bletchley Park museum.

- To encrypt a message with Lorenz, the 5-bit plaintext symbols were combined with a stream of key characters.

LORENZ SZ40 I

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DECRYPTION of LORENZ CIPHER

- Bill Tutte developed so called double-delta method to find wheel start positions of Lorenz when producing encryption of some message..
- Tutte's method was, however, much too much computationally demanding.
- Mathematician Max Newman came with idea how to automate some parts of the process for finding the settings used for each message.
- Based on Newmann's idea a machine was built and named **Heath Robinson**.
- Main difficulty with using this machine was that two paper tapes had to be kept in synchrony at 1,000 characters per second.

COLLOSUS TECHNICAL DETAILS

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- Colossus was used in Bletchey Park during WW2 to help in the cryptanalysis of the Lorenz cipher.

COLLOSUS TECHNICAL DETAILS

- Colossus was the world's first electronic, digital, fixed-program, single purpose computer with variable coefficients.
- Colossus used vacuum tubes to perform Boolean operations and calculations.
- Colossus was used in Bletchey Park during WW2 to help in the cryptanalysis of the Lorenz cipher.
- Colossus was used to find possible Lorenz key settings rather than to decrypt particular cryptotexts.
- The cryptotext was read at the high speed from a paper tape and the other stream was generated internally as a simulation of outcomes of the Lorenz machine
- If the count for the setting was above a certain threshold it would be sent as an output to an electric typewriter.

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- The χ wheels stepped regularly with each symbol that was encrypted; ψ wheels stepped irregularly; under the control of motor wheels μ.

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- Initially Colosus was used to work out the start positions of χ wheels, but later also to determine the wheel breaking.

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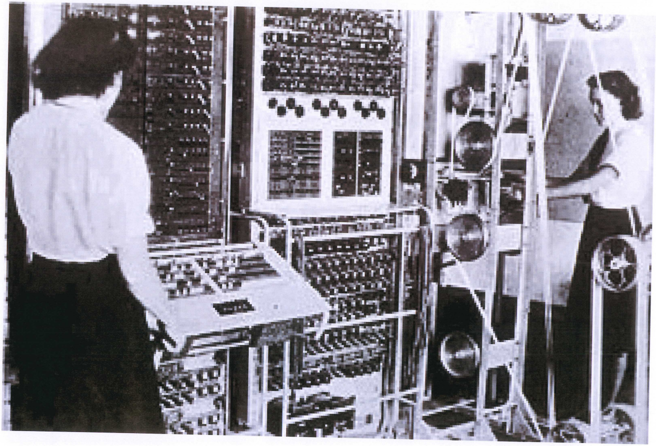
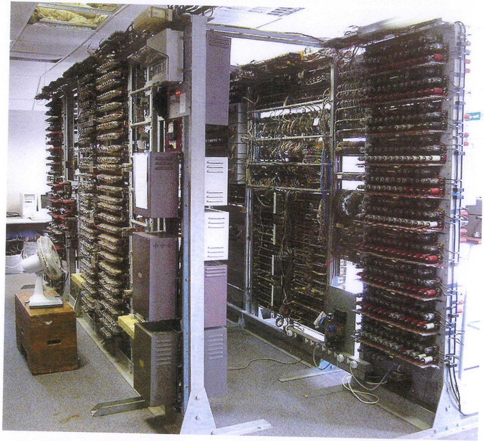
- Ten Colossus computers were in use by the end of the war.
- Programming of Colossus was achieved by a combination of telephone jack-plugs, cords and switches.
- After the WW2 Colossus computers were destroyed, at the order from Churchill. Moreover, Tommy Flowers was ordered to destroy also blueprints of Colossus and he did so on 8 June 1945 (!?!?!?!?!?!?!)

COLOSSUS PHOTO



COLOSSUS PHOTO from BACK



COLOSSUS - DETAILS

- Each of ten Colossi was 2.3 m high, about 14 m long and occupied one room.
- Colossus reduced the time to break Lorenz messages from weeks to hours.
- Colossus was built just in time for the deciphering of messages which gave vital information prior to D-Day of 2WW. They showed that Hitler swallowed the deception campaign about the area of landing of Allies.
- By the end of 2WW 63 millions of characters of top secret German messages were decrypted
- In 1994 attempts started to redesign Colossus for a museum. A functioning replica was completed in 2007 and is on display at the *National museum of computing*

COLOSSUS - COMMENTS

- Collosus was not "Turing complete" - it was not a general purpose (universal) computer.
- At that time it was not realized that "Turing completeness" is of large importance.
- To set up Colossus for a new task the operators had to set up plugs and switches to alter wiring.

STORY of ENCRYPTION MACHINES

- British were able to break ENIGMA only because it was used with various unproper restrictions and because it was used for stereotypical messages that resulted in "cribs".
- US crypto analysts were also successful in breaking Japanese encryption machine called Purple.
- On the other hand, encryption machines "Typex" used by British army and air force, and machine SIGABA used by US army have never been broken during second world war.
- However, all these machines could not really been used in such fighting as on Pacific islands in jungles.
- A new ingenious idea was to use Navajo Indians for communication because no Japanese could understand it.

NAVAJO CODE

- One of the most useful encryption ideas during WW2 was to assign to American army units Navajo Indians who a given message first translated to the Navajo language and then transmitted using the usual radio waves.
- Main problem with this idea was how to deal with words that had no equivalent in Navajo languages.
- This way of transmitting messages secretly was 100% successful.
- More than 800 Navajo Indians served this way successfully in American Army.

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- Rivest, Shamir and Adleman, from MIT, started to work on this problem in 1976.
- Rivest and Shamir spent a year coming up with new ideas and Adleman spent a year shooting them down.
- In April 1977 they spent a holiday evening drinking quite a bit of wine.
  At night Rivest could not sleep, mediated and all of sudden got an idea. In the morning the paper about RSA was practically written down.

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- This discovery was, however, too early and GCHQ kept it secret and they disclosed their discovery only after RSA has been shown very successful.

ATTACKS on RSA

RSA can be seen as absolutely secure. However, this does not mean that under special circumstances some special attacks can not be successful. Two of such attacks are:

- The first attack succeeds in case the decryption exponent is not large enough. **Theorem** (Wiener, 1990) Let $n = pq$, where p and q are primes such that $q < p < 2q$ and let (n, e) be such that $de \equiv 1(\mathrm{mod}\,\phi(n))$. If $d < \frac{1}{3}n^{1/4}$. then there is an efficient procedure for computing d.
- **Timing attack** P. Kocher (1995) showed that it is possible to discover the decryption exponent by carefully counting the computation times for a series of decryptions. Basic idea: Suppose that Eve is able to observes times Bob needs to decrypt several cryptotext s. Knowing cryptotext and times needed for their decryption, it is possible to determine decryption exponent.

PRETTY GOOD PRIVACY

In 1991 Phill Zimmerman developed and released PGP (Pretty Good Privacy) and by that he made use of the RSA cryptosystem very friendly and easy and, consequently, by that he made strong cryptography widely available.

Starting February 1993 Zimmerman was for three years a subject of FBI and Grand Jury investigations, being accused of illegal exporting arms (strong cryptography tools).

William Cowell, Deputy Director of NSA said: "If all personal computers in the world – approximately 200 millions – were to be put to work on a single PGP encrypted message, it would take an average an estimated 12 million times the age of universe to break a single message".

Heated discussion whether strong cryptography should be allowed keep going on. September 11 attack brought another dimension into the problem.

Even in 2004 former FBI director in his Congress inquiry asked for a new law against public use of encryptions.

HISTORY of QUANTUM CRYPTOGRAPHY

- Around 1970 Stephen J. Wiesner developed, but did not published, the concept of quantum secret money.
- In 1984 Charles Bennett and Gilles Brassard published BB84 protocol.
- In 1989 Bennett at all made first cryptography experiment with photon transmission of photons at the distance 32 cm
- In 1990 unconditional security of the BB84 protocol has been shown.
- In 1991 Eckert published his entanglement based protocol E91 for unconditionally secure generation of classical shared key,
- In 1993 Bennett et al. developed the protocol for quantum teleportation.
- In 1995 quantum key generation using optical cable for distance 22.5 km was demonstrated
- In 1997 it was shown that unconditionally secure quantum bit commitment is impossible.
- In 1998 quantum teleportation was experimentally confirmed.
- In 2004 an open air absolutely secure photon transmission for the distance 27 km was shown, from one Alp's peak to another.
- In 2008 an open air absolutely secure photon transmission was demonstrated for distance 147km on Canary Islands.

EPILOGUE

CRYPTOGRAPHY TOOLS as WEAPONS

- **Military success of Allies during World War II was partly due to great outcomes of cryptanalysts.**
- **Because of that cryptography was highly estimated during the Cold War and cryptography was considered as a war weapon in many countries, especially in USA. As a consequence cryptography production, products, use and export were regulated in the corresponding way as for other arms.**

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- Because of that, it has not much sense to teach about current standards - they will likely be replaced by new ones in few years.
- Beautiful and deep mathematics is usually needed to create safe cryptographic systems - any tools that work are fine for breaking cryptosystems.