The History and Technology of the Enigma Cipher Machine

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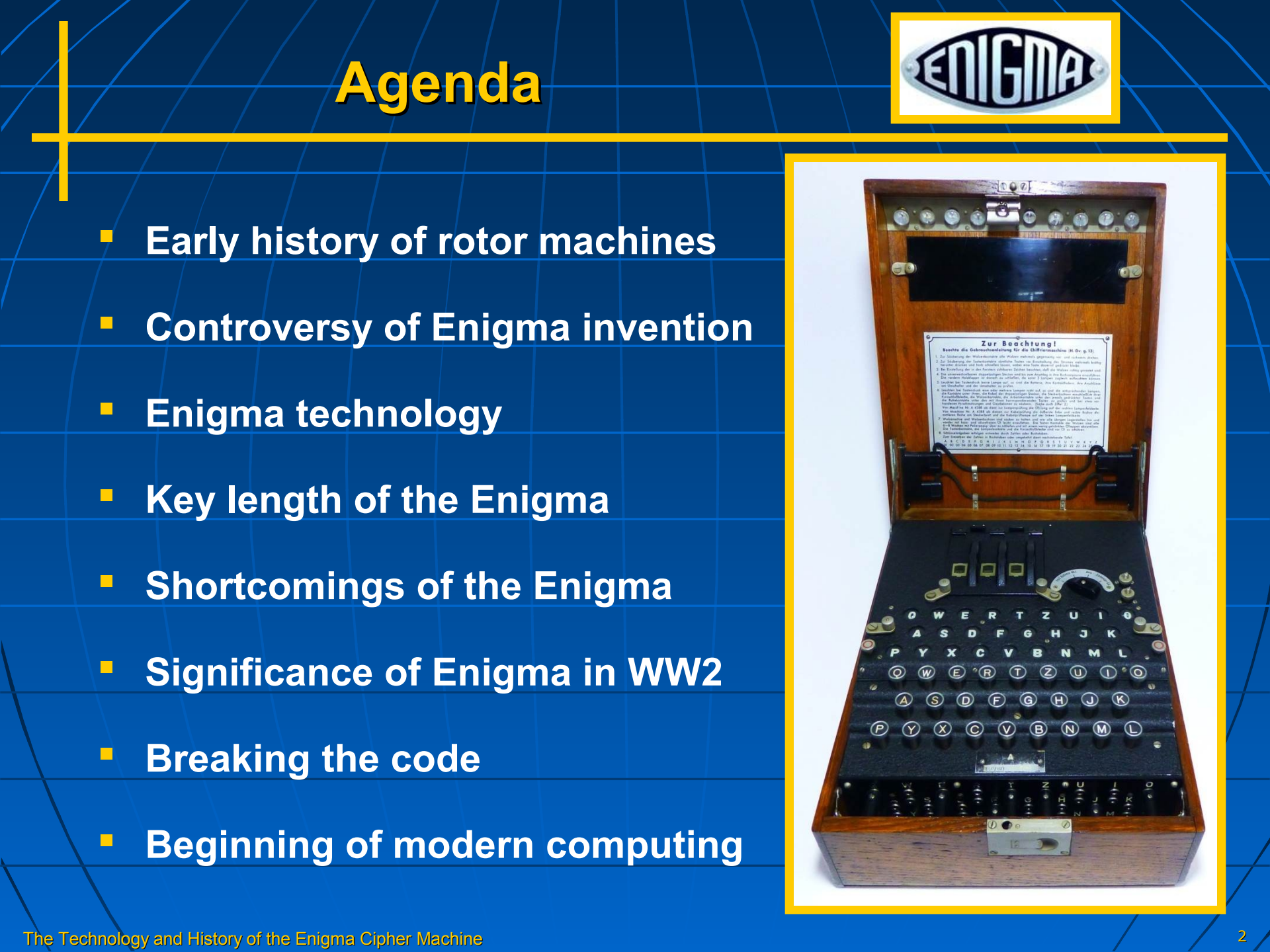
Agenda



- Early history of rotor machines
- Controversy of Enigma invention
- Enigma technology
- Key length of the Enigma
- Shortcomings of the Enigma
- Significance of Enigma in WW2
- Breaking the code
- Beginning of modern computing

WW1 - Radio made most ciphers obsolete

- Proliferation of radios in WW1 highlighted the need for a new cipher technology
- Many ciphers had shortcomings when 100's of messages are captured using the same key
- Cipher technology was manual and error-prone

Confederate
Vigenère Wheel

1888 Code Book

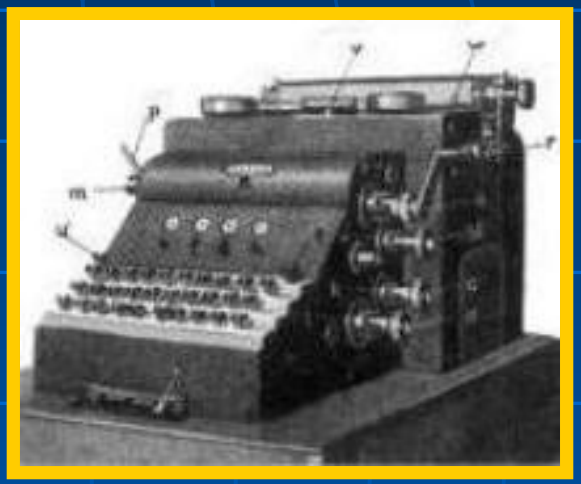
Questions. SHIPPING. Fop.

No.	SENTENCES.	No. of Cipher Word.	No.	Cipher.	No. of Sentence.
3139	What vessel did you ship by ?.....	.....	3139	Foppish	.....
3140	When, how, and by what route shipped ?...	.....	3140	Forage	.....
3141	When and how were bills of lading forwarded ?.....	.....	3141	Forbade	.....
3142	When can you ship ?.....	.....	3142	Forbear	.....
3143	When will a sailing vessel clear for——?....	.....	3143	Forbid	.....
3144	When will you ship ?.....	.....	3144	Forbidden ..	.....
3145	Which did you ship ?.....	.....	3145	Fordable ...	.....
3146	Who are the consignees ?.....	.....	3146	Forego	.....
3147	Will a few days delay in shipping make any difference to you ?.....	.....	3147	Foreseed. ...	.....
3148	Will you receive consignment of——?.....	.....	3148	Forelock ...	.....
3149	Ship	.....	3149	Foremost ...	.....
3150	Ship additional.....	.....	3150	Forest	.....

Invention of Rotor-Based Cipher Machines

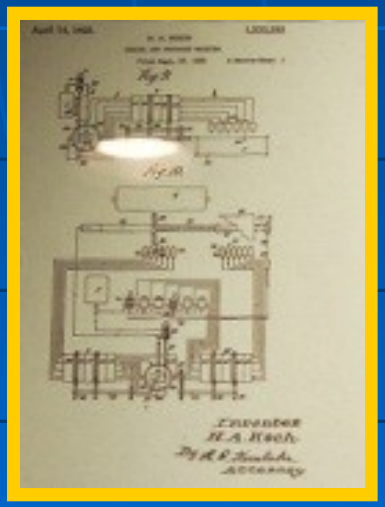
- Enigma was one of four cipher machines with electro-mechanical rotors invented in 4 different countries between 1917-1919

Edward Hebern USA 1917



Arthur Scherbius Germany 1918

Hugo Koch Holland 1919



Arvid Damm Sweden 1919

Enigma Invention

Arthur Scherbius
Germany

Hugo Koch
Holland

- German Navy bought Enigma in 1926, Army in 1928
- In 1927, Enigma inventor Scherbius curiously bought the rights to Koch's patent, paid 600 Dutch guilders (~$350)
- Scherbius had the earlier and almost identical patent
- Koch died in 1928
- Scherbius died in 1929 in a horse carriage accident, not knowing the role his invention would have in history

Enigma Technology

- Typewriter style cipher machine was a major advance in ease of use and cryptologic strength
- Innovation was the electro-mechanical rotors to encipher / decipher messages
- Pressing a key causes the rotors to turn, giving a new cipher algorithm for each letter in a message
- Electric pathway goes from keyboard–> plugboard–> rotors–> reflector–> rotors –> plugboard, then it lights up a bulb
- There is no printing capability, so the message must be written down

Keyboard

- QWERTZ keyboard with only 26 letters - no numbers, space bar, etc.
- Pressing key first rotates 1 to 3 rotors then lights up a bulb
- Each letter is encrypted 7 to 9 times, the key changes for each letter
- Note the serial # plate below the “V”

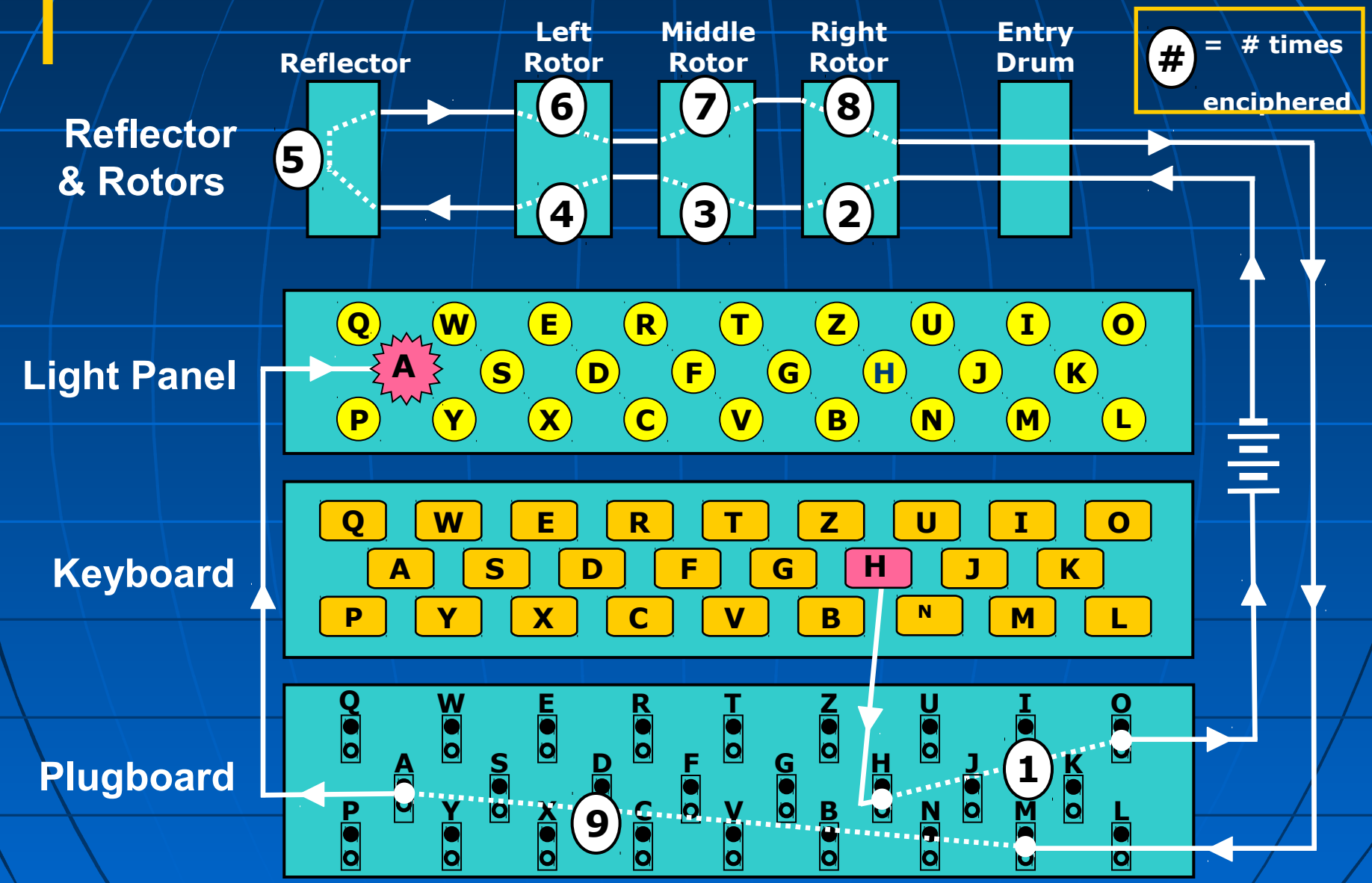
Plugboard

- German military added the plugboard to commercial Enigma in 1930, greatly increasing cryptologic strength
- In WW2, Germans always used 10 cables, switching 20 of 26 letters instead of varying # of cables from 0-13
- Reduced key length by a factor of 4, but simplified operations

Light Bulb Panel

- Keyboard, plugboard and light panel all follow QWERTZ format
- Only method of output - no printing capability
- Small light bulbs light up a letter, which must be written down
- Latches hold plastic filter for use in sunlight
- Operated by 4.5 volt battery or transformer from 220V plug

Wiring Diagram



Key Length of the Enigma

- Enigma has theoretical maximum number of settings (or keys) of 3×10^{114}, far more than the number of atoms in the universe (10^{80})
- Germans accepted operational tradeoffs which reduced the key length to the still astronomical number of 10^{23}
- A key length of 10^{23} is equivalent to a 77 bit key, better than the 56 bit DES standard of 1976-2002
- A key length of 10^{23} means 100,000 operators, each checking one key setting every second would take twice the age of the universe to break the code

Nazi Procedures for the Enigma

- Daily keys (settings for rotors and plugboard cables) were sent in a code book each month (longer for U-boats)
- Using the daily key, operators first sent a new key, then the text of the message in this new key – nullifying letter frequency analysis
- The new key specified the 3 rotor positions, and was sent TWICE
- Some operators used the same keys for each message, such as girlfriends initials, giving clues to solve the code
- Polish code-breakers exploited this shortcoming until 1939, when the Nazis sent the key only once

Using Enigma in the field

German Secrets of the Enigma

- Notice anything unusual about this Enigma?

Enlargement of Enigma from previous slide

Another Nazi propaganda picture of Enigma

- White cover over the plugboard
- Germans wanted to keep secret the military addition of a plugboard
- Even German allies, Italy and Japan, received Enigma machines without the plugboard

British Effort in Breaking the Code

- In 1939, UK began a major decoding effort in Bletchley Park, employing 11,000 people
- Effort led by Alan Turing, who built the Bombe - 36 Enigmas in series to check settings

Bletchley Park Mansion

- Many settings were manually eliminated and only the remaining settings checked by the Bombe – brute force wouldn't work
- Army and Luftwaffe messages were routinely decoded, the Naval Enigma was the greatest challenge
- British only acted on intelligence that could be uncovered from traditional sources (spies, direction finding, radar, traffic analysis)

U-Boat Peril

- Before the US entered the war, U-boats decimated Allied shipping, sinking about 60 ships per month
- U-boats roamed freely throughout Atlantic, forming "wolfpacks" to efficiently destroy convoys of supply ships for the UK
- Nazi strategy was to blockade the UK, expecting a quick surrender
- Naval Enigma was initially the same as the Army, but later more complex versions were used with more rigorous procedures
- Naval Enigma messages were completely secure until May, 1941

> *"The only thing that ever really frightened me during the war was the U-boat peril."*
>
> - Winston Churchill

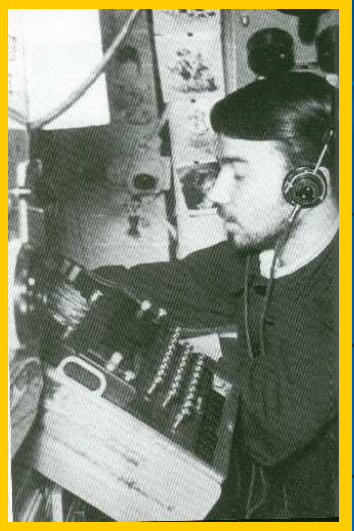
U-Boat

U-110

Sinking of U-110

- The first U-boat boarded and code books recovered was from U-110 in May 1941
- Captain died scuttling U-boat
- U-110 was sunk by British so Germans didn't realize their codes were compromised
- This single act was the turning point in the Battle of the Atlantic

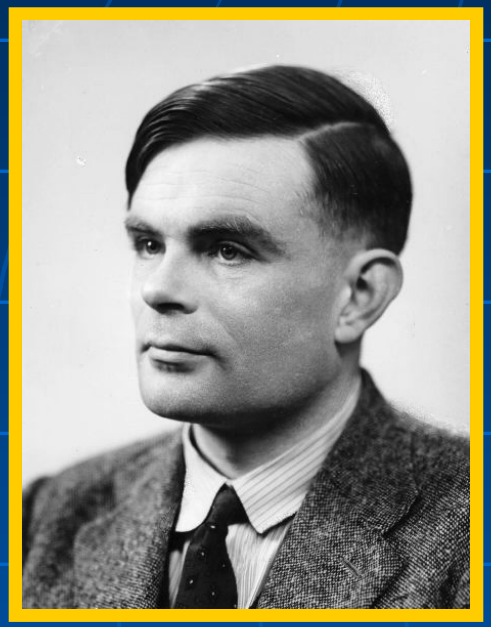
Captain of U-110
Fritz Julius Lemp



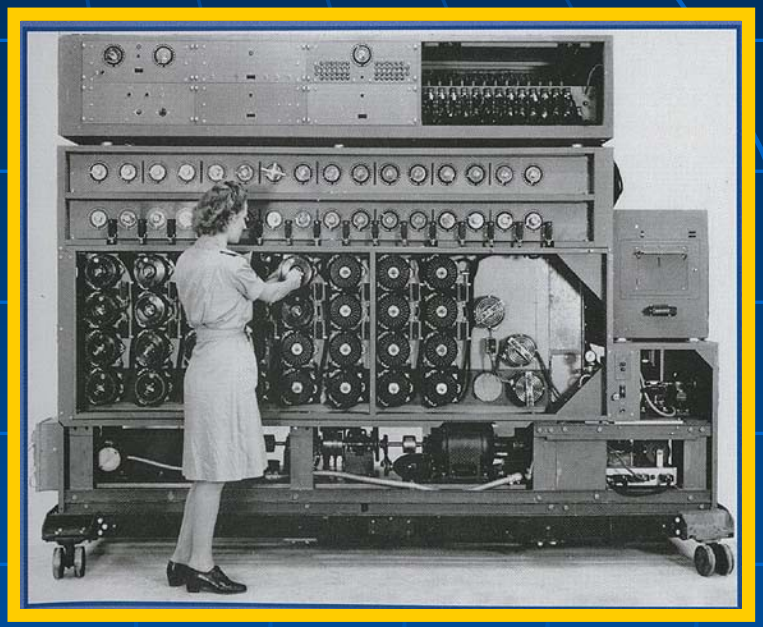
Enigma operator in U-110

HMS Bulldog – British destroyer captured U-110

Bombe – the Beginning of Computing



Alan Turing: Father of Computing



US Bombe

- Polish cryptoanalysts named their electro-mechanical codebreaker the Bomba for an ice cream treat, British called it a Bombe
- 210 Bombes were built in the UK, all were destroyed after WW2
- US employed NCR to build a faster version of the Bombe to decode the 4 rotor naval Enigma – 121 were built
- By the end of the war, the naval code was deciphered within 12 hours and the rest of the day's messages were read in real time

Battle of the Atlantic

US bombing of U-117 – Aug. 1943

- After breaking the Naval Enigma code, British selectively protected some ships
- British knew when U-boats would surface for supplies, so they pretended to "accidentally" find and destroy them
- In 1942, a 4th rotor was added to the Naval Enigma and 8 rotors were issued instead of 5 - making it more difficult to decipher
- It was discovered that unarmed weather trawlers carried the Enigma and codes, an easy target for additional code books
- Early U-boat success turned to failure, 725 of 1155 U-boats and 82% of 35,000 sailors never returned from sea
- Some estimate breaking the Enigma shortened WW2 by 2 years

Enigma After WW2

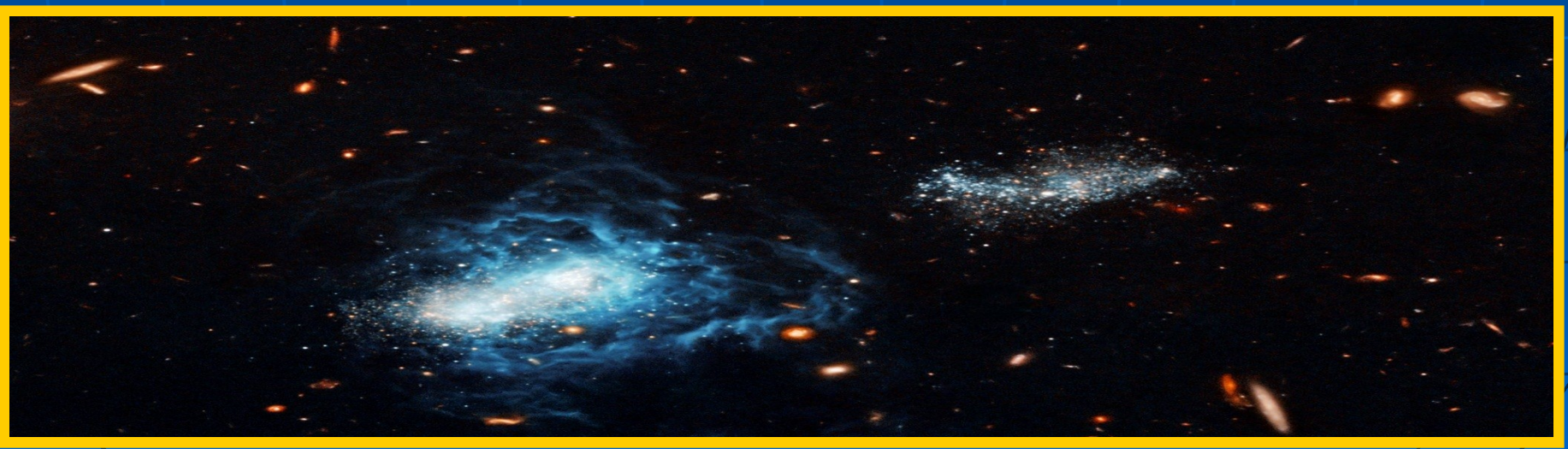
- Code-breaking success was not revealed until 1974, despite 11,000 people working on the effort in Bletchley Park, plus thousands more in the US
- US and UK encouraged use of Enigmas by other countries, including allies, reading their secrets for 3 decades
- Some Bombes were not destroyed, to decipher messages from countries still using Enigmas
- About 40,000 German Enigmas were manufactured, most were destroyed during or just after the war
- Today, fewer than 300 Enigmas are known to exist, up to 200 more are suspected to be in hidden collections
- Record prices at auction:
  - $269K for a 3-rotor Enigma at Bonhams on 4/13/15
  - $365K for a 4-rotor Enigma at Christies on 10/21/15

Rotor Settings

- The internal wiring of each rotor could be constructed in 26! different combinations. Since 3 rotors are used, the number of combinations when selecting 3 rotors out of 26! are:
  - 26! X (26!-1) X (26!-2) = 65,592,937,459,144, 468,297,405,473,480,371,753,615,896,841,298, 988,710,328,553,805,190,043,271,168,000,000
- Each of the 3 rotors could initially be set to any letter:
  - 26 X 26 X 26 = 17,576
- The right-most rotor advances one letter after each key is pressed, the second and third rotors advance one letter after a full revolution of the rotor to its right. The setting for the notch to enable this was also changeable to any letter of the alphabet:
  - 26 X 26 = 676 (Note: notch on left-most rotor has no effect)

Total Theoretical Number of Settings

- The total theoretical number of Enigma settings is thus the product of the 5 items on the previous 3 slides, or…
  - 3,283,883,513,796,974,198,700,882,069,882,752,878, 379,955,261,095,623,685,444,055,315,226,006,433,615, 627,409,666,933,182,371,154,802,769,920,000,000,000
  - Or 3.28×10^{114}
- This number is far greater than the total number of atoms in the observable universe (10^{80})



- THANK YOU !
- ANY QUERY?