# AI in Context: AI Foundations 1920s–1950s

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Fall 2025 - Lecture 2 of 4

# Reminder of Lecture 1

## The Birth of Quantifying Intelligence

- Spearman's g-factor (1904) and its legacy
- PCA and dimensionality reduction
- AI benchmarks and leaderboard culture
- Critical analysis of quantification

Available here

# Lecture 2: AI Foundations (1920s-1950s)

## Today's Outline

- **Intellectual preconditions**·
  - Logic and axiomatics
  - Neuroscience discoveries
  - Computation before computers
- **WWII's transformative impact**
  - Computation, intelligence, and "intelligence"
- **The birth of AI 1.0**

# Part 1: Intellectual Preconditions

# 1900s: Math/Logic as Pinnacle of Scientific Thought

## David Hilbert (1862-1943)

- **Hilbert Program**: Complete, consistent foundation for all mathematics through **axioms**
- Formalize all mathematics using finite set of axioms and logical rules
- Foundation for Turing, von Neumann, and others on **computability** and **automata**

**Reference**: Alma Steingart's "Axiomatics: Mathematical Thought and High Modernism" (2023)

# 1900s: Math/Logic as Pinnacle of Scientific Thought

## Whitehead/Russell: *Principia Mathematica* (1910-1913)

- Derive all mathematical truths from logical axioms
- Academic dominance of mathematics and logic
- Seen as the highest form of intellectual inquiry

# The Quest for Completeness

## 1+1=2 in Principia Mathematica (1910) (~360 pages)

$*54{\cdot}43.\quad \vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

*Dem.*

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

$[*51{\cdot}231] \qquad \equiv . \iota`x \cap \iota`y = \Lambda .$

$[*13{\cdot}12] \qquad \equiv . \alpha \cap \beta = \Lambda \qquad (1)$

$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \qquad (2)$

$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash .$ Prop

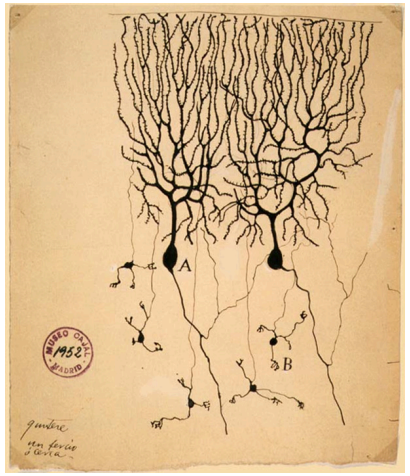
From this proposition it will follow, when arithmetical addition has been defined, that $1 + 1 = 2$.

# 1936–1950: The Concept of Computation

## Turing's Universal Machine (1936, Age 24)

- Machines capable of performing any computation that can be formally described
- Responded in the negative to Hilbert's challenge
- "there can be no one definite method capable of deciding whether or not a given mathematical statement is provable" (cf. Gödel 1931) -- Hodges

# Meanwhile: Discovery of Neurons



# Meanwhile: Discovery of Neurons

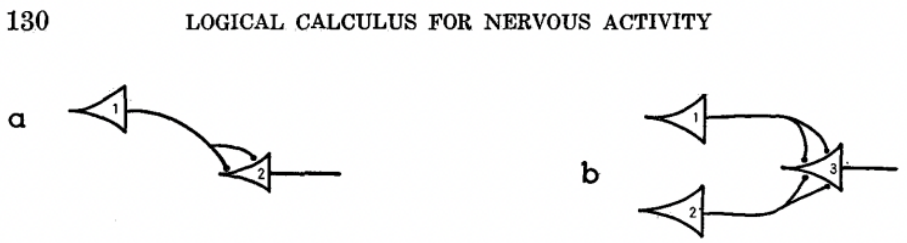
## Santiago Ramón y Cajal (1906 Nobel Prize)

- Pioneered understanding of neural structure
- Brain as network of interconnected units
- Foundation for computational models of mind

# 1943: The Birth of Artificial Neural Networks

## McCulloch & Pitts: "A Logical Calculus..."

- ...of the Ideas Immanent in Nervous Activity"
- Inspired by Neurons+Turing Machines
- Proposal: Neurons as binary logic units: a mathematical model of brain computation

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# Turing Impact Pre WWII: McCullough & Pitts 1943

> *"One more thing is to be remarked in conclusion. It is easily shown: first, that every net, if furnished with a tape, scanners connected to afferents, and suitable efferents to perform the necessary motor-operations, can compute only such numbers as can a Turing machine;*

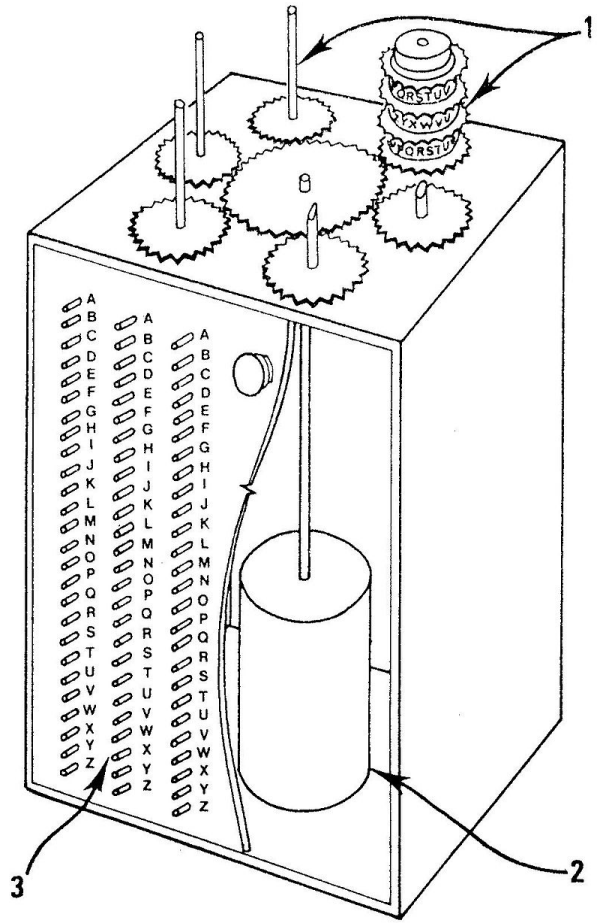
> *"[ANNs afford] a psychological justification of the Turing definition of computability and its equivalents, Church's λ-definability and Kleene's primitive recursiveness...*

> *If any number can be computed by an organism, it is computable by these definitions, and conversely."*

# Part 2: WWII Changes Everything

**The war accelerates:**

- Computational needs
- Cryptography advances
- Information theory
- Early computers



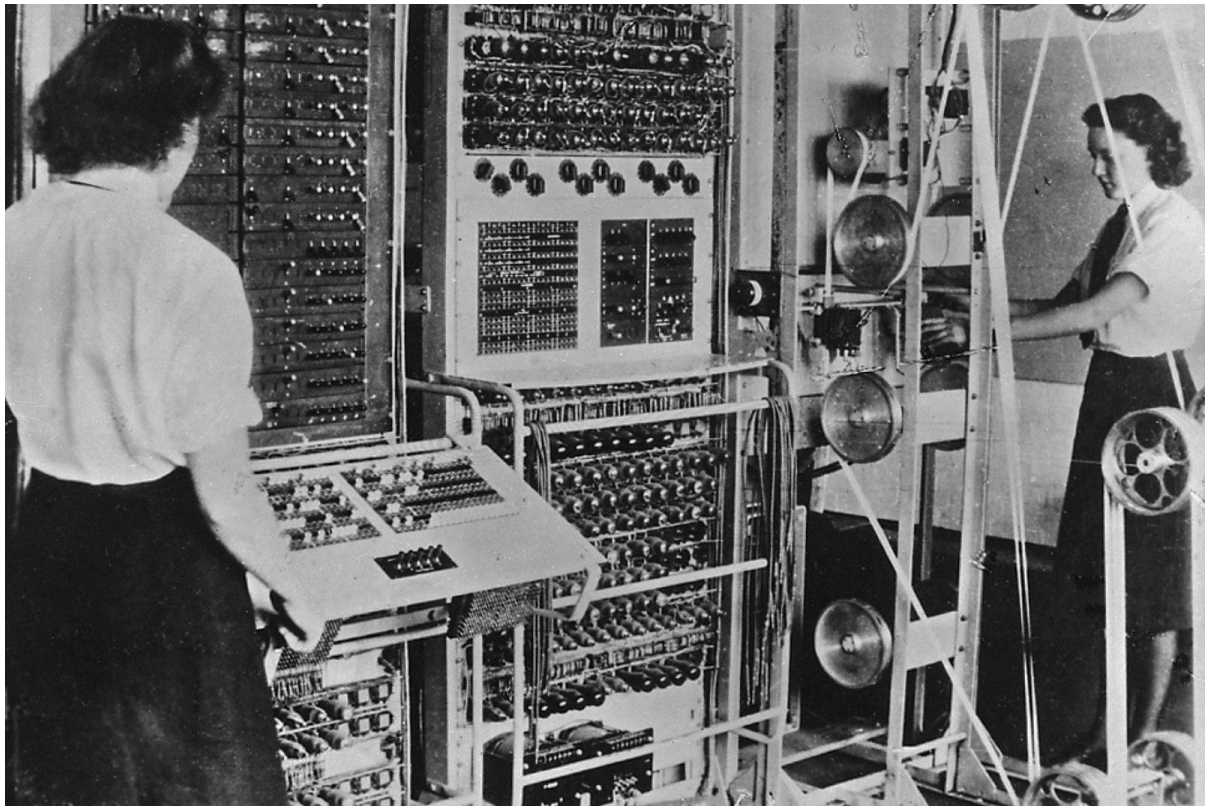

*8. Bomba kryptologiczna*

(dla przejrzystości ukazano
w górnej części bomby
tylko jeden zestaw
wirników szyfrujących)

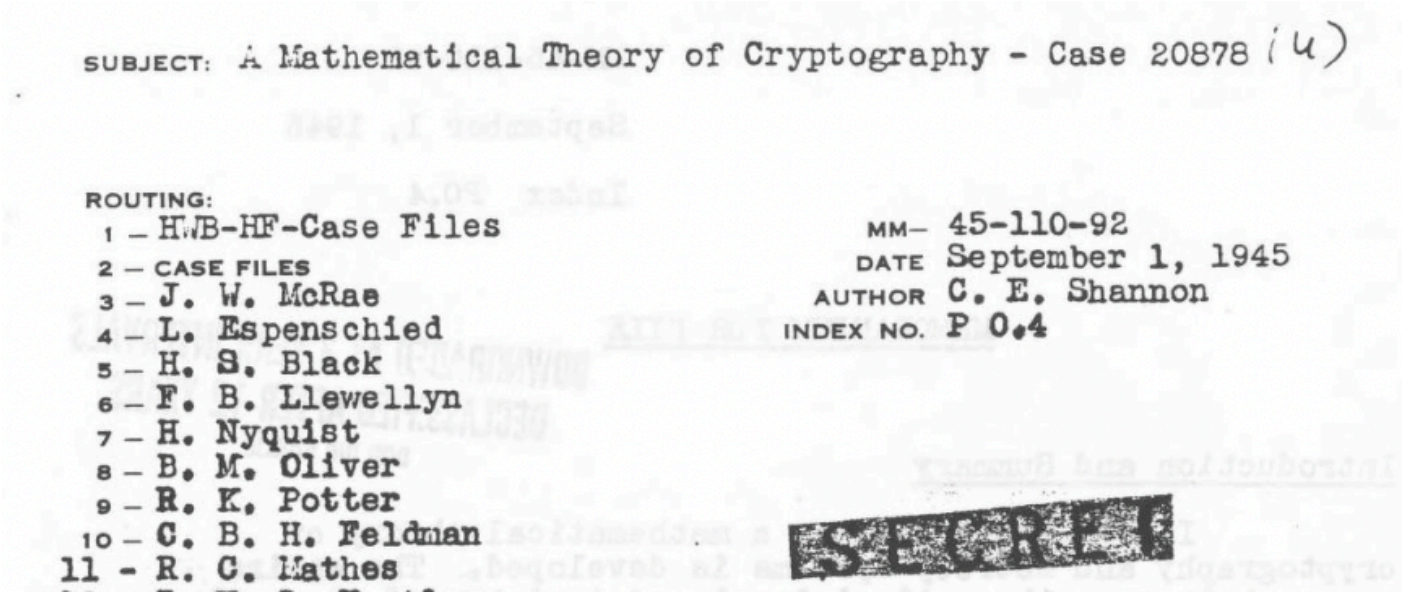
1. wirniki,
2. silnik elektryczny,
3. przełączniki

# WWII: codebreaking & labor

# WWII: computation & labor



# WWII: information theory



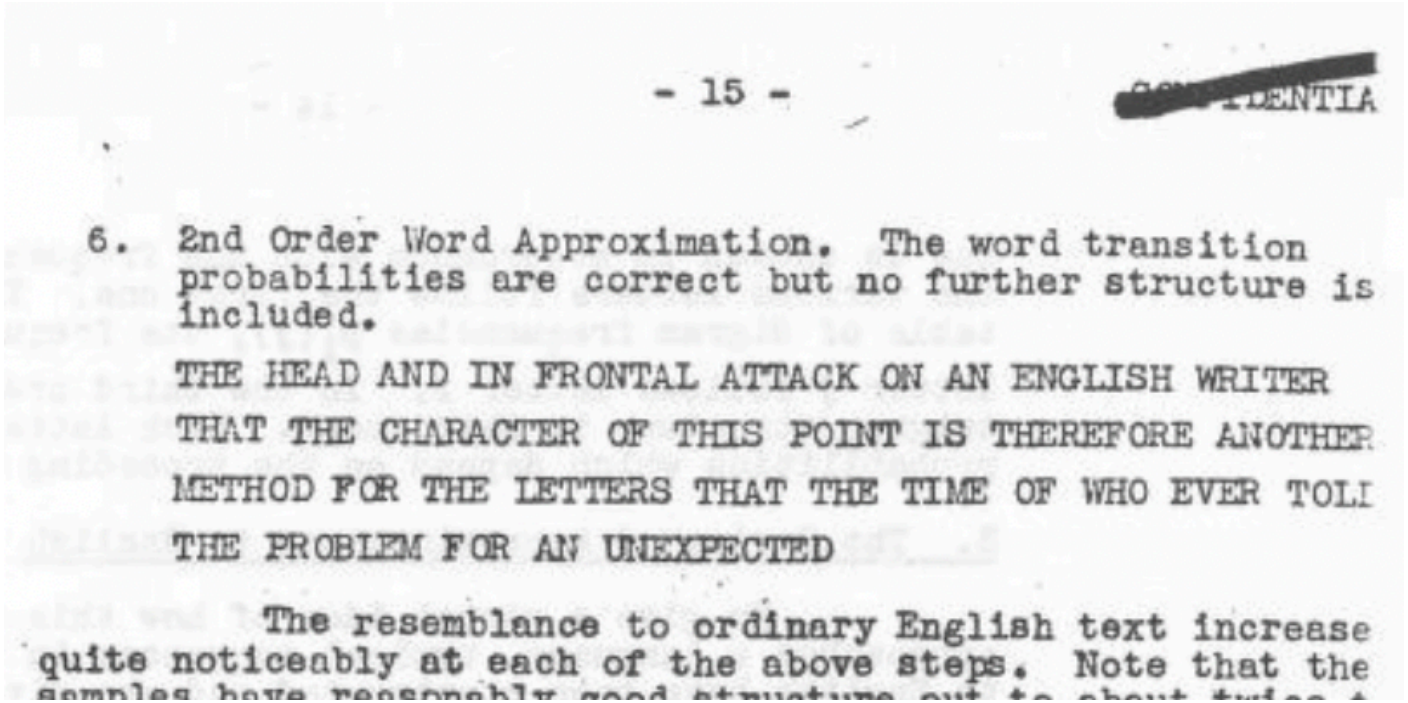
SUBJECT: A Mathematical Theory of Cryptography - Case 20878 (4)

ROUTING:
1 – HWB-HF-Case Files
2 – CASE FILES
3 – J. W. McRae
4 – L. Espenschied
5 – H. S. Black
6 – F. B. Llewellyn
7 – H. Nyquist
8 – B. M. Oliver
9 – R. K. Potter
10 – C. B. H. Feldman
11 - R. C. Mathes

MM– 45-110-92
DATE September 1, 1945
AUTHOR C. E. Shannon
INDEX NO. P 0.4

SECRET

# WWII: information theory & language models



- 15 -

[redacted]DENTIA

6. 2nd Order Word Approximation. The word transition probabilities are correct but no further structure is included.

THE HEAD AND IN FRONTAL ATTACK ON AN ENGLISH WRITER

THAT THE CHARACTER OF THIS POINT IS THEREFORE ANOTHER

METHOD FOR THE LETTERS THAT THE TIME OF WHO EVER TOLI

THE PROBLEM FOR AN UNEXPECTED

The resemblance to ordinary English text increase quite noticeably at each of the above steps. Note that the samples have reasonably good structure out to about twice t

# Part 3: Post-War Foundations

# Turing's 1948 Paper and 1950 "Imitation Game"

## Turing's 1948 Paper

- Suggested building machines that simulate brain functions
- Introduced the idea of learning machines
- Introduced the imitation game

## 1950: "Imitation Game" (Turing Test)

- The challenge of defining intelligence in terms of machine behavior

# AMT48: Intelligence as an Emotional Concept

> *"INTELLIGENCE AS AN EMOTIONAL CONCEPT*

> *The extent to which we regard something as behaving in an intelligent manner is determined as much by our own state of mind and training as by the properties of the object under consideration."*

- Intelligence is partly in the eye of the beholder

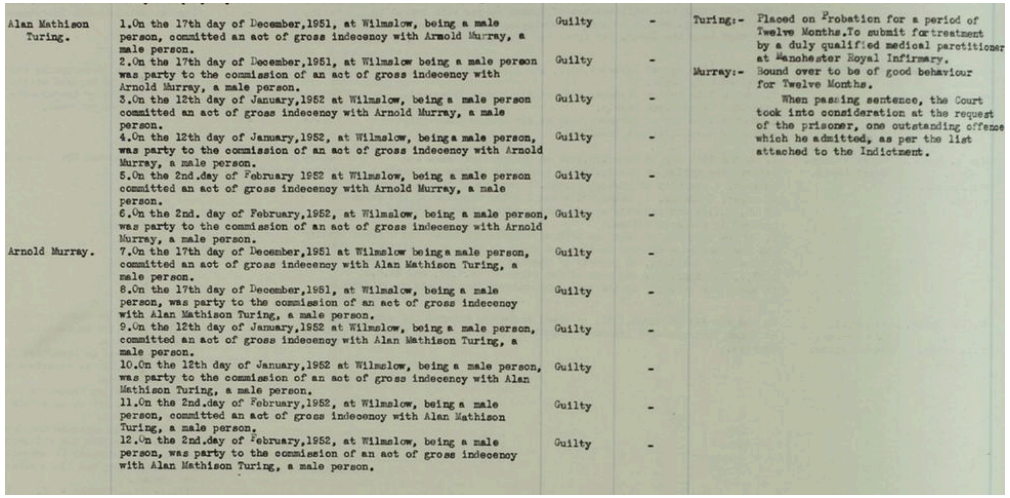
# T'50 after WWII: Imitation Game

## The Game Setup

- **Three people**: A man (A), a woman (B), and an interrogator (C)
- **Interrogator's goal**: Determine which is the man and which is the woman
- **Question**: What happens when a machine takes the part of A?

> *"Can machines think?" → "Can machines simulate human conversation?"*

# Imitation Game and Turing's Personal Life



| | | | | |
|---|---|---|---|---|
| Alan Mathison Turing. | 1.On the 17th day of December,1951, at Wilmslow, being a male person, committed an act of gross indecency with Armold Murray, a male person. | Guilty | - | Turing:- Placed on Probation for a period of Twelve Months.To submit for treatment by a duly qualified medical paretitioner at Manchester Royal Infirmary. |
| | 2.On the 17th day of December,1951, at Wilmslow being a male person was party to the commission of an act of gross indecency with Arnold Murray, a male person. | Guilty | - | Murray:- Bound over to be of good behaviour for Twelve Months. |
| | 3.On the 12th day of January,1952 at Wilmslow, being a male person committed an act of gross indecency with Arnold Murray, a male person. | Guilty | - | When passing sentence, the Court took into consideration at the request of the prisoner, one outstanding offence which he admitted, as per the list attached to the Indictment. |
| | 4.On the 12th day of January,1952, at Wilmslow, being a male person, was party to the commission of an act of gross indecency with Arnold Murray, a male person. | Guilty | - | |
| | 5.On the 2nd.day of February 1952 at Wilmslow, being a male person committed an act of gross indecency with Arnold Murray, a male person. | Guilty | - | |
| | 6.On the 2nd. day of February,1952, at Wilmslow, being a male person, was party to the commission of an act of gross indecency with Arnold Murray, a male person. | Guilty | - | |
| Arnold Murray. | 7.On the 17th day of December,1951 at Wilmslow being a male person, committed an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |
| | 8.On the 17th day of December,1951, at Wilmslow, being a male person, was party to the commission of an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |
| | 9.On the 12th day of January,1952 at Wilmslow, being a male person, committed an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |
| | 10.On the 12th day of January,1952 at Wilmslow, being a male person, was party to the commission of an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |
| | 11.On the 2nd.day of February,1952, at Wilmslow, being a male person, committed an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |
| | 12.On the 2nd.day of February,1952, at Wilmslow, being a male person, was party to the commission of an act of gross indecency with Alan Mathison Turing, a male person. | Guilty | - | |

*Guilty under 1885 legislation, AMT died 7 June 1954, age 41, law repealed 1967; PM apology '09; Royal pardon '12*

## Imitation Game/"Turing Test" (2014)

- **Gendered nature** replaced by human/bot in lore
- **Historical accuracy**: "Most of the rest of this film isn't [true]...shoe-horning the incredible complexity of the Enigma machine and cryptography in general was never going to be easy. But this film just rips the historical records to shreds"

*From Information is Beautiful (blog)*

# Turing 1950: "Intelligence" Operationalized

> *"We now ask the question, 'What will happen when a machine takes the part of A in this game?' Will the interrogator decide wrongly as often when the game is played like this as he does when the game is played between a man and a woman? These questions replace our original, 'Can machines think?'"*

> *"May not machines carry out something which ought to be described as thinking but which is very different from what a man does? This objection is a very strong one, but at least we can say that if, nevertheless, a machine can be constructed to play the imitation game satisfactorily, we need not be troubled by this objection."*

**How does this compare to Spearman?**

# Turing 1950: Prescient Objections

## Memory and Storage

> *"The criticism that a machine cannot have much diversity of behaviour is just a way of saying that it cannot have much storage capacity. Until fairly recently a storage capacity of even a thousand digits was very rare."*

**Hidden/tacit knowledge**: Massive computational data analysis at Bletchley

# Turing and Computation: The Manchester Machine

> *"The reader must accept it as a fact that digital computers can be constructed, and indeed have been constructed, according to the principles we have described, and that they can in fact mimic the actions of a human computer very closely."*

# Turing 1950: Prescient Objections

## The Nine Objections

1. **The Theological Objection** (soul)
2. **The 'Heads in the Sand' Objection** (too terrible to be true)
3. **The Mathematical Objection** (cf., logic)
4. **The Argument from Consciousness** ("sonnet")
5. **Arguments from Various Disabilities**

# Arguments from Various Disabilities

> *"...Be kind, resourceful, beautiful, friendly, have initiative, have a sense of humour, tell right from wrong, make mistakes, fall in love, enjoy strawberries and cream, make some one fall in love with it, learn from experience, use words properly, be the subject of its own thought, have as much diversity of behaviour as a man, do something really new"*

**More objections:**

6. **Lady Lovelace's Objection** (cannot create)
7. **Argument from Continuity in the Nervous System** ($x'$ vs $x_t$)
8. **The Argument from Informality of Behavior** (fragility of rules)
9. **The Argument from Extra-Sensory Perception** (!)

*Whole essays/subfields discussing some of these objections*

# Turing and Learning, Sec 7

> *"a machine undoubtedly can be its own subject matter. It may be used to help in making up its own programmes, or to predict the effect of alterations in its own structure. By observing the results of its own behaviour it can modify its own programmes so as to achieve some purpose more effectively. These are possibilities of the near future, rather than Utopian dreams."*

**Two Paths to Intelligence:**

1. "Just program it" (Simon's approach)
2. Machine learning (Turing's vision)

# Turing Impact: UK

## Influenced UK "Machine Intelligence" Researchers

**Christopher Strachey** wrote programs to:

- **Play checkers** (1951, before Arthur Samuel at IBM coins "machine learning" to play checkers in 1959)
- **Write love poems** (try it at home! www.gingerbeardman.com/loveletter)

# Tangent: How to Generate Poems Without Data?

Try this at home!

# Turing Impact: "Toy" AI

## Chess vs NLP

**Both are done by humans, but Chess is a game:**

- **Mechanized**
- **Abstracted**

**Key insight**: Getting mechanical devices to imitate human intelligence first succeeds in arenas when humans have allowed themselves to behave like machines (e.g., with algorithmic rules of production or games like chess)

# "AI" Named and Branded

## Dartmouth 1956

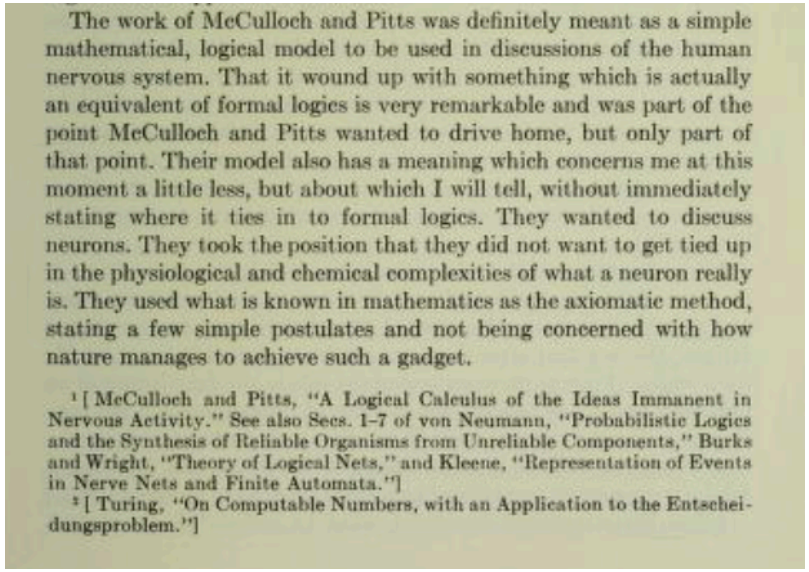
# The Dartmouth Conference (1956)

## 4. Shannon and the Rise of Automata Theory

**Automata Theory in the 1940s-1950s:**

- **John von Neumann's Self-Reproducing Automata (1948)**: Early ideas about machines that could replicate themselves
- **State of Automata Theory (1945-1955)**: Automata as abstract machines, a way to model systems through states and transitions

# Impact on and of JvN



The work of McCulloch and Pitts was definitely meant as a simple mathematical, logical model to be used in discussions of the human nervous system. That it wound up with something which is actually an equivalent of formal logics is very remarkable and was part of the point McCulloch and Pitts wanted to drive home, but only part of that point. Their model also has a meaning which concerns me at this moment a little less, but about which I will tell, without immediately stating where it ties in to formal logics. They wanted to discuss neurons. They took the position that they did not want to get tied up in the physiological and chemical complexities of what a neuron really is. They used what is known in mathematics as the axiomatic method, stating a few simple postulates and not being concerned with how nature manages to achieve such a gadget.

[1] [ McCulloch and Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity." See also Secs. 1–7 of von Neumann, "Probabilistic Logics and the Synthesis of Reliable Organisms from Unreliable Components," Burks and Wright, "Theory of Logical Nets," and Kleene, "Representation of Events in Nerve Nets and Finite Automata."]

[2] [ Turing, "On Computable Numbers, with an Application to the Entscheidungsproblem."]

# 6. McCarthy, Dartmouth, and the Shift After 1956

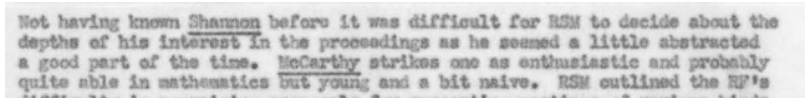
Post-Dartmouth Conference where logic and symbolic AI became the "high road," and data-driven approaches (seen as heuristic or mechanical) were the "low road."

# McCarthy (b. 1927), Dartmouth/MIT

- **PhD Princeton (Mathematics)**: PDE
- **@Bell** (along w/Minsky) under Shannon 1953
- **Interest in logic**
- **LISP & GOFAI**
- **DARPA largess**, esp via J.C.R. Licklider and IPTO (of 'Internet' fame) & "Machine-Aided Cognition" (MAC)
- **"raised as a Communist but eventually became a conservative Republican"**
- **NB**: D'56 team all militarily funded directly or indirectly

# D'56: NB Shannon's Level of Commitment

- **D'56 funded by RF** (Weaver hand-off)


Not having known Shannon before it was difficult for RSM to decide about the depths of his interest in the proceedings as he seemed a little abstracted a good part of the time. McCarthy strikes one as enthusiastic and probably quite able in mathematics but young and a bit naive. RSM outlined the RF's

- **Rockefeller Foundation** asked to add other organizers. They added Minsky and Rochester, "chief designer of IBM's (NSA-funded) 701"

# D'56: 7 Prescient Goals

1. **"Automatic Computers"** (programming languages)
2. **"How Can a Computer be Programmed to Use a Language"** (natural language processing)
3. **"Neuron Nets"** (neural nets and deep learning)
4. **"Theory of the Size of a Calculation"** (computational complexity)
5. **"Self-improvement"** (machine learning)
6. **"Abstractions"** (feature engineering)
7. **"Randomness and Creativity"** (Monte Carlo and stochastic learning)

**NB**: no 1 "method", just an aspiration

# Historical Context on This Aspiration

## Not a New Aspiration

**Longstanding dreams of machines as servants or partners:**

- **Engineering "robots"** (1923) to do work we don't want (since Hephaestus robots)
- **Understanding ourselves/humanity/intelligence** by creating/engineering artificial intelligences and/or as partners/mates (since Ovid's Pygmalion)

**NB**: both *literary* and *engineering* (since Vaucanson's 18th c duck) aspiration

# D'56: Outcome?

> *"anybody who was there was pretty stubborn about pursuing the ideas that he had before he came, nor was there, as far as I could see, any real exchange of ideas" -- JCM from Pamela McCorduck, 2004*

> *"Newell and Simon seemed...to be addressing psychologists...Minsky wasn't...necessarily convinced that human and artificial intelligence needed to resemble each other. This last was a very strong theme in AI research in the early years." -- McCorduck*

# D'56: "Brains"?

## Two Approaches

**Brain modelers** -- how thought *embodied*

**Mind modelers** -- how thought doesn't require *body* (cf. the "U" in AMT's UTM 1936, of which JCM was well-aware)

> *"The physical machine became little more than an arbitrary vehicle for the interactions of pure information." -- Paul Edwards, "The Closed World"*

# D'56: Split on Methods

- **Simon**
- **JCM**
- **Learning** (next week)

**One vision**: AI means to "take symbolic information as input, manipulate it according to a set of formal rules, and in so doing can solve problems...

> *"After the 1956 workshop, this became the dominant approach...most notably, human intelligence was the central exemplar around which early automation attempts were oriented." -- Stephanie Dick*

# GOFAI, 1956-1973

> *"programmed instructions operating on formal symbolic representations... From the mid 1950s to the mid 1980s, it was the dominant (though not the only) approach in AI." -- Margaret A. Boden, GOFAI*

# Knowledge Acquisition Bottleneck

> *"the central problem facing knowledge engineering today, the bottleneck of knowledge acquisition." – Lenat, 1983*

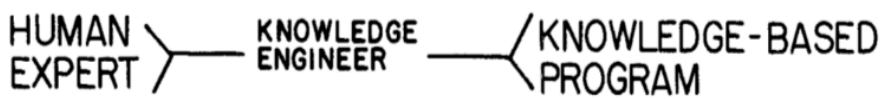



**Figure 9-1:** The bottleneck of knowledge acquisition is *transfer of expertise*. This comprises *(i)* the expert's difficulty in articulating what he knows, and *(ii)* the impedance mismatch between the concepts and vocabulary of the expert and the knowledge engineer.

# Why No Data?

## Logic as the High Road

- **Logic ruled** over data-driven approaches
- **Promise**: Formal reasoning and symbolic logic for understanding computation

# In GOFAI, Knowledge >> Data

> *"In this approach, 'knowledge engineers' would interview human experts, observe their problem-solving practices, and so on, in hopes of eliciting and making explicit what they knew such that it could be encoded for automated use (Feigenbaum, 1977, p. 4). Expert systems offered a different explanation of human intelligence, and their own theory of knowledge, revealing that both were moving targets in this early research." -- SD2019*

# GOFAI Fundings

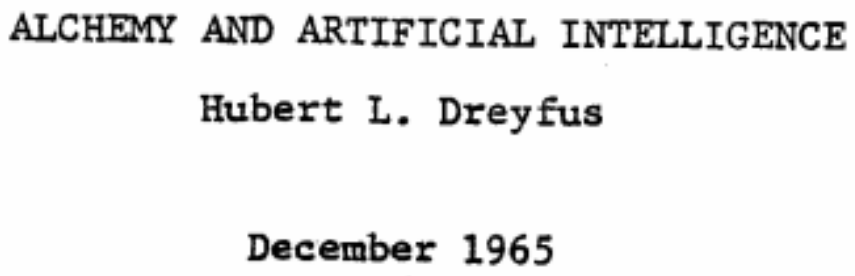
- **AF**: Simon
- **ONR**: Simon
- **DARPA**: JCM
- **NSA via IBM**: ML

# GOFAI Claims

> *"Within ten years, they claimed,*

- a computer would be world chess champion,
- a computer would compose aesthetically valuable music,
- a computer would discover and prove an important unknown mathematical theorem, and
- most psychological theories would take the form of computer programs."

*See also: Strong/AGI vs Weak/narrow AI*



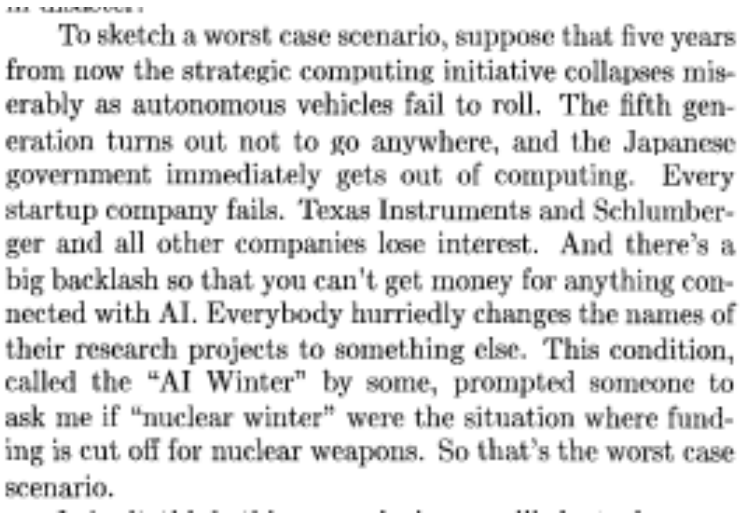
ALCHEMY AND ARTIFICIAL INTELLIGENCE

Hubert L. Dreyfus

December 1965

# 1st AI Winter

*quoting Drew Mcdermott, AAAI 1984



To sketch a worst case scenario, suppose that five years from now the strategic computing initiative collapses miserably as autonomous vehicles fail to roll. The fifth generation turns out not to go anywhere, and the Japanese government immediately gets out of computing. Every startup company fails. Texas Instruments and Schlumberger and all other companies lose interest. And there's a big backlash so that you can't get money for anything connected with AI. Everybody hurriedly changes the names of their research projects to something else. This condition, called the "AI Winter" by some, prompted someone to ask me if "nuclear winter" were the situation where funding is cut off for nuclear weapons. So that's the worst case scenario.

# Lighthill 1973

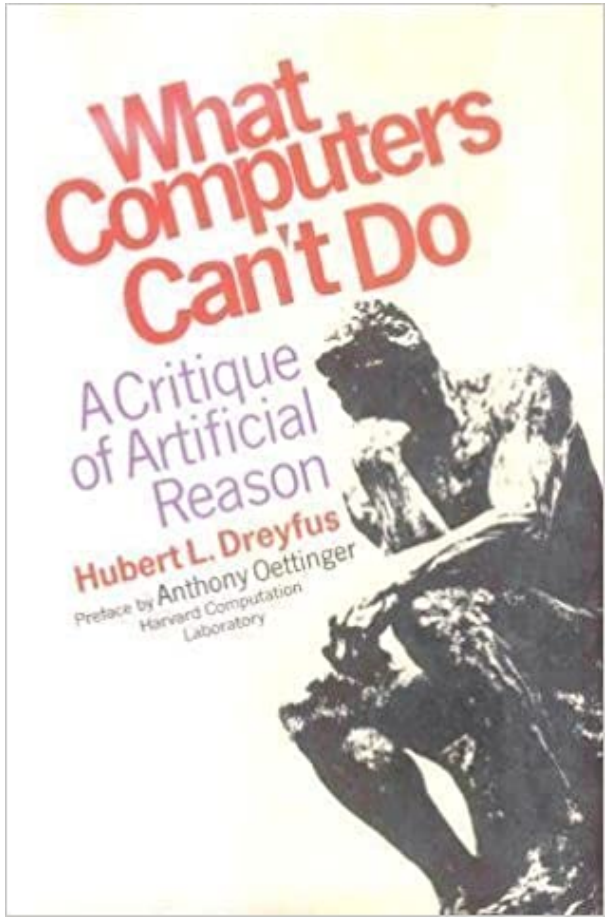
## Lighthill Report

> *"Some very interesting researches have been carried out to develop general problem-solving programs, and such work can be of research interest to psychologists, but the performance of these programs on actual problems has always been disappointing. Students of all this work have generally concluded that it is unrealistic to expect highly generalised systems that can handle a large knowledge base effectively in a learning or self-organising mode to be developed in the 20th century." (13)*

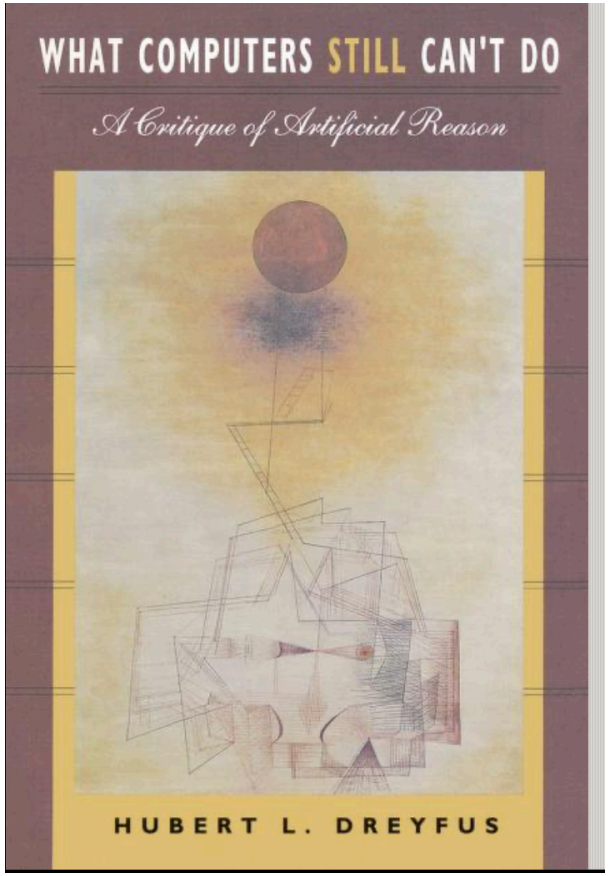
# In US, Similar Pushback (1/3)

- **1961-01-17**: Eisenhower's "military–industrial complex"
- **1965 Dreyfus'** ***Alchemy and AI*** (then books, '72,'79,'86,'92)

# Dreyfus 1972



# Dreyfus 1992



# In US, Similar Pushbacks (2/3)

- **1966**: ALPAC report by Pierce (Bell)

# In Machine Translation: ALPAC 1964-1966

> *"The Department of Defense, the National Science Foundation, and the Central Intelligence Agency have supported projects in the automatic processing of foreign languages for about a decade; these have been primarily projects in mechanical translation.*

> *"there is no immediate or predictable prospect of useful machine translation."*

# In US, Similar Pushbacks (3/3)

- **1969**: Minsky on (limits of) "Perceptrons"
- **1969**: Mansfield Amendment & DOD: applied only, not basic
- **1973 DARPA "American Study Group" review**, etc. but...

# Ok But *Was* There a Winter?

## Norvig's View: From Book (1995,2003,2009,2020)

> *"Overall, the AI industry boomed from a few million dollars in 1980 to billions of dollars in 1988, including hundreds of companies building expert systems, vision systems, robots, and software and hardware specialized for these purposes. Soon after that came a period called the 'AI winter,' in which many companies fell by the wayside as they failed to deliver on extravagant promises. It turned out to be difficult to build and maintain expert systems for complex domains, in part because the reasoning methods used by the systems broke down in the face of uncertainty and in part because the systems could not learn from experience."*

# Norvig's View: Personal Communication

> *"I'm a winter skeptic as well. I haven't seen good data.*

> *"there was a winter in the sense that over time not everyone automatically got a job at MIT or Stanford or Bell Labs, but everyone got good jobs throughout.*

> *"So essentially, we define the winter as the death of specific companies, not a widespread drop in students or professionals, and blame the decline on ...nd not enough ML. The timing is not quite right, as there were reports of winter before 1988, but that's the date we found a revenue number for. Later, we describe the current boom that has taken the industry to trillions of dollars."*

# Ok But *Was* There a Winter? (Continued)

- **Japan** Fifth generation computer (1982-1992, 400M 1992USD)
- **IPTO** Strategic Computing Initiative, 1B USD though S. Amarel and J. Schwartz cut back
- **Shift to VC $$**

# More on SCI's Organization 1983

- "machine vision would serve the autonomous land vehicle;
- natural language processing would support the battle management project;
- speech understanding would link to both battle management and the pilot's associate; and
- expert systems would underpin each of these applications."

-- Emma Salisbury, 2020-05-22

# Machine Learning as AI Subaltern

- **Remember**: "computers" in 1956 were v. different (and limited)
- **1950s**: Setting goals (but also: Sputnik, ARPA)
  - "In effect, ARPA reincarnated the World War II OSRD." --Edwards
- **1960s**: Transformative funding, shakey victories
- **1970s**: "winter" (cancellation of certain high-visibility projects)
- **1980s**: Data curious AI researchers challenge rules
- **As late as 1990s**: It was believed that *rules* were the road
- **As late as mid 2000s**: domain expertise valued even for predictive performance
- **2010s**: Shatter this via "deep nets", an echo of ANN's from 1943
- "Overwhelmingly, machine learning systems are oriented towards one specific task: to make accurate predictions." -- SD2019

# What About Data?

- **Next week**: The attempts to keep data alive, esp w.r.t. ANN
- **At the time though...**
  - Simon on Learning
  - Minsky on Perceptrons (a la Rosenblatt)
  - Langley on "history" of ML in 1983

# Meanwhile... Other Impacts of WWII

- **Next week**: "big data" in the 1970s / mil-computational complex
- **Later week**: 'Pattern Recognition' becomes 'Learning' becomes 'AI 2.0'

# Looking Ahead

## Next Week Preview

**Lecture 3: "The End of Rules, The Dawn of Data"**

- Data disputes and the Perceptron story
- Rules and rule-rot
- The making of big data
- Preconditions for learning

## Questions?