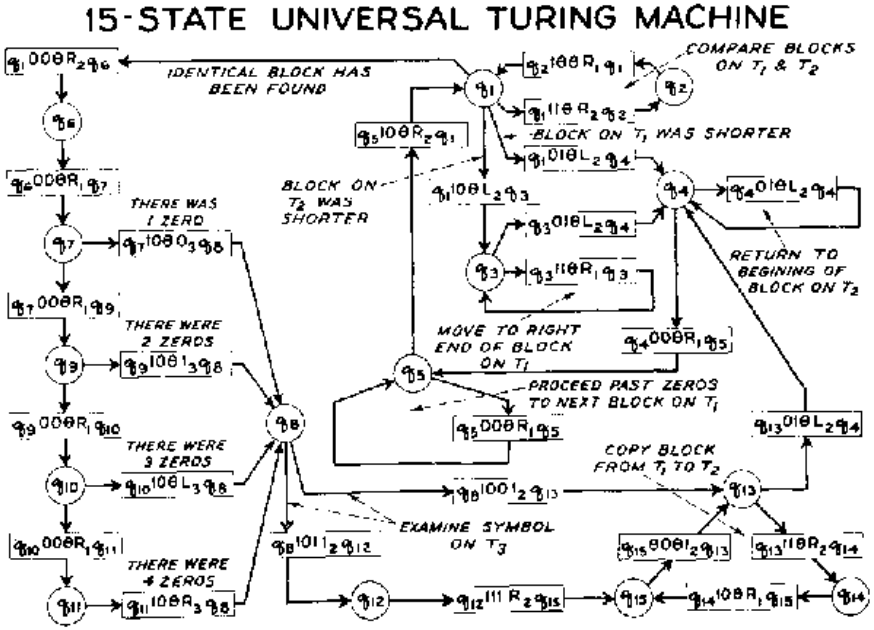
A short history of small machines

"This operation is so simple that it becomes laborious to apply" (Lehmer, 1933)



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Introduction

Topic? Translation/transmutation of 'logical minimalism' into computer engineering

Motivation Computer science as neither purely theoretical nor practical – If we want to understand what CS is, then we need to investigate how logic and engineering practices 'interact'

⇒ **Research in progress!!**

Introduction

- Tradition of Logical minimalism?
- Logicians/mathematicians as computer scientists avant la lettre – Curry, Turing and ACE
- in the 50s!

  Automata studies

  ZEBRA, Minima and other 'small' machines
- Discussion

Tradition of logical minimalism?

In § 2 we apply our results to the problem of reducing the number of primitive logical constants.†

§ 1. *Postulate-Set for Boolean Algebras.*

We assume:

I. A class K,

II. A binary K-rule of combination $|$,

III. The following properties of K and $|$:

1. There are at least two distinct K-elements.
2. Whenever a and b are K-elements, $a \mid b$ is a K-element.

$$Def. \quad a' = a \mid a.$$

3. Whenever a and the indicated combinations of a are K-elements,

$$(a')' = a.$$

4. Whenever a, b, and the indicated combinations of a and b are K-elements,

$$a \mid (b \mid b') = a'.$$

5. Whenever a, b, c, and the indicated combinations of a, b, and c are K-elements,

$$(a \mid (b \mid c))' = (b' \mid a) \mid (c' \mid a).$$

For convenience, $a \mid b$ may be read a *per* b.

Classification of Postulates 1–5.

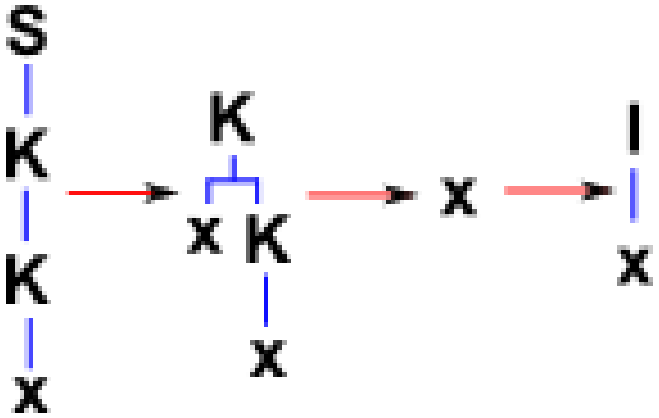
Postulate 1 is an existence-postulate. Postulate 2, which demands that the K-rule of combination $|$ shall be K-closed ‡ is a *K-closing* postulate

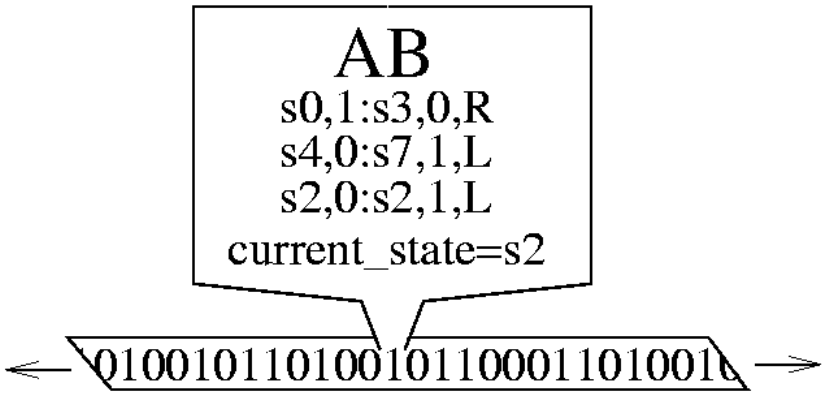
Tradition of logical minimalism?

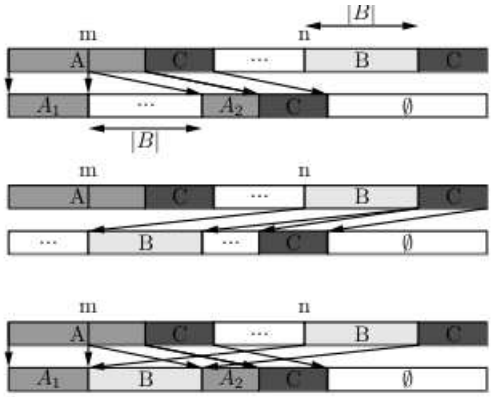
- Beginning 20th century: Search for formal simplicity in context of 'mathematical logic' (logical minimalism)
- Two obvious (related) lines of research:
  - to find smallest set of logical primitive (e.g. Sheffer stroke | (NAND))
  - Reduce or simplify existing axiom systems (e.g. Nicod)
- 'Logic in the 20s' (Post, Schönfinkel)

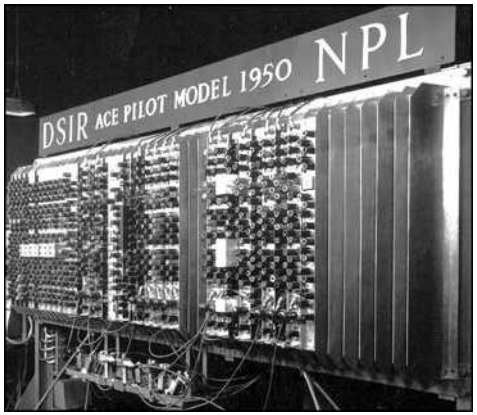
  > "We are led to the idea [...] of attempting to eliminate by suitable reduction the remaining fundamental notions, those of proposition, propositional function, and variable. [T]o examine this possibility more closely [...]it would be valuable not only from the methodological point of view [...] but also from a certain philosophical, or, if you wish, aesthetic point of view. For a variable in a proposition of logic is, after all, nothing but a token that characterizes certain argument places and operators as belonging together; thus it has the status of a mere auxiliary notion that is really inappropriate to the constant, "eternal" essence of the propositions of logic. It seems to me remarkable [that this] can be done by a reduction to three fundamental signs" (Schönfinkel, 1924)

Logicians/mathematicians as computer scientists avant la lettre









Logicians as computer scientists avant la lettre – Curry and Turing

⇒ **Idea of fixing simplest building blocks of logic and human reasoning....**

- Curry, 1942: "On the other hand, [...] there is [the problem of] simplification; one can seek to find systems based upon processes of greater and greater primitiveness [...] In fact we are concerned with constructing systems of an extremely rudimentary character, which analyse processes ordinarily taken for granted."
- Turing, 1936: "Let us imagine the operations performed by the computer to be split up into "simple operations" which are so elementary that it is not easy to imagine them further divided."

⇒ "Minimal" requirement/conditions for computing a number (Gandy, Sieg, Soare)

Logicians as computer scientists avant la lettre

⇒ **.... transmuted to 'real' machines**

- Turing and ACE (Davis, Hodges)
  - Design of a machine
  - "His priorities were a large, fast memory, and then a hardware system that would be as *simple as possible*. His side was always that anything in the way of refinement or convenience for the user, could be performed by thought and not by machinery, by instructions and not by hardware. In his philosophy it was almost an extravagance to supply addition and multiplication facilities as hardware, since in principle they could be replaced by instructions applying only the most primitive logical operations of OR, AND and NOT." (Hodges, 1983)
  - "*[W]e have often simplified the circuit at the expense of the code*" (Turing, 1947)

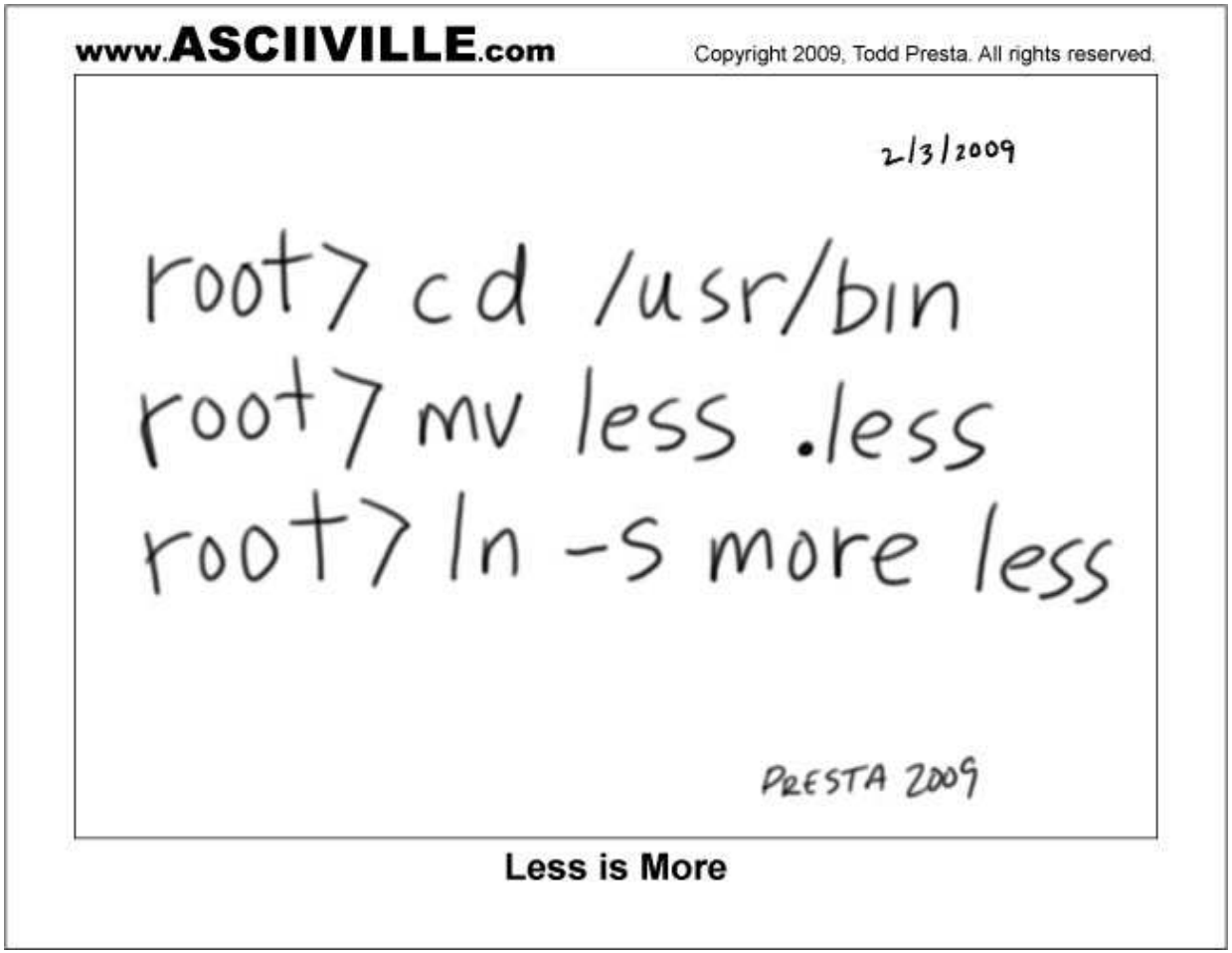
Logicians as computer scientists avant la lettre

⇒ .... transmuted to 'real' machines

- Curry and ENIAC (De Mol, Carlé and Bullynck, 2010)
  - Experience with a real machine
  - Von Neumann and Goldstine have pointed out that [we] should not use the technique of program composition to make the simpler sorts of programs, – these would be programmed directly [...] Nevertheless, there are three reasons for pushing the technique clear back to formation of the simplest possible programs from the basic programs, viz.: (1) Experience in logic and in mathematics shows that an insight into principles is often best obtained by a consideration of cases too simple for practical use [...] (2) It is quite possible that the technique of program composition can completely replace the elaborate methods of Goldstine and von Neumann [...] (3) The technique of program composition can be mechanized; if it should prove desirable to set up programs [...] by machinery, presumably this may be done by analyzing them clear down to the basic programs
  - "Now the possibility of making such [arithmetic] programs without using auxiliary memory is a great advantage to the programmer. Therefore, it is recommended that, if it is not practical to design the machine so as to allow these additional orders [the 26 original basic orders], then a position in the memory should be permanently set aside for making the

reductions contemplated." (Curry, 1950)

Less is more in the 50s



Less is More

Less is more in the Fifties

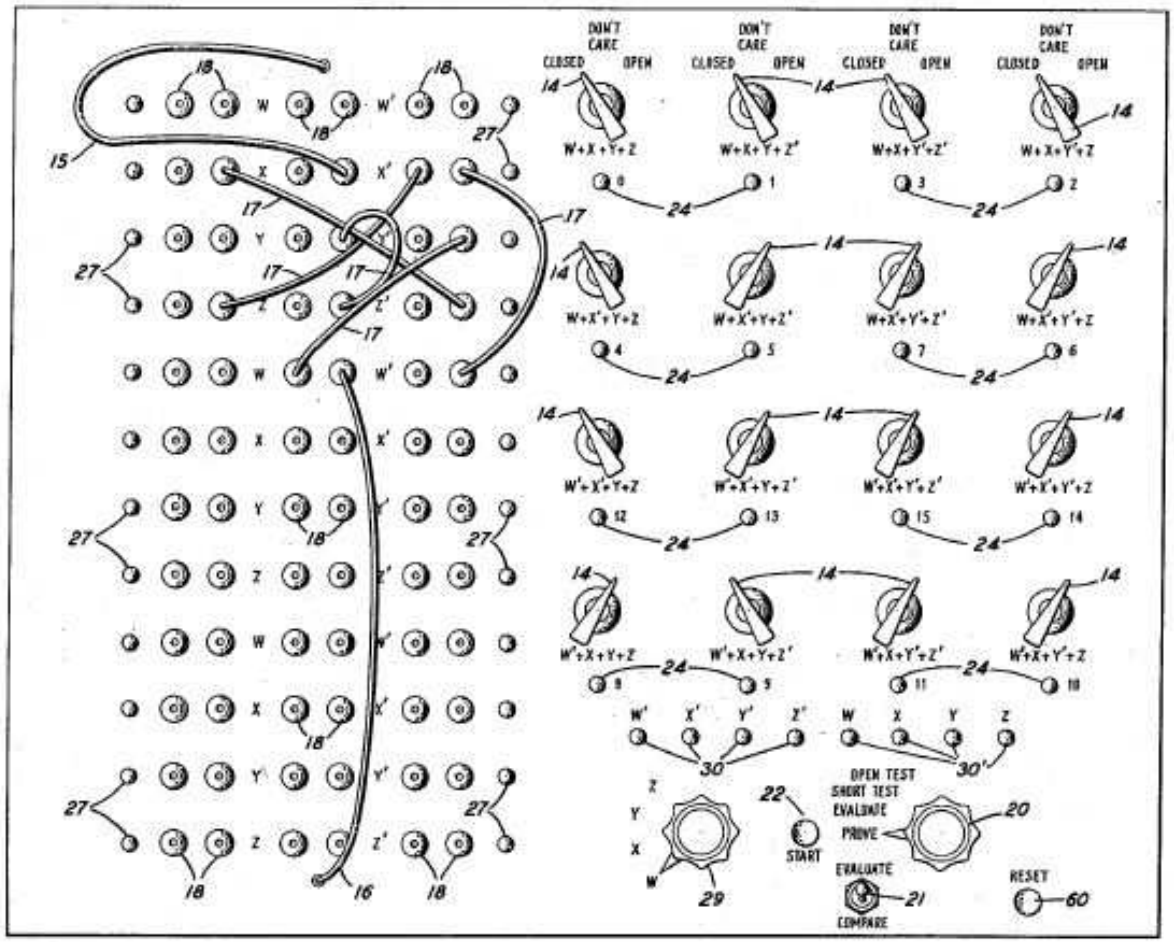
'Automata studies' 'tradition' (I) – a rapprochement between theory and practice

⇒ *Indirect influence of 'logical minimalism' – 'adapt' logical work to more practical contexts*

- **Theoreticians with an interest in real machines (Hao Wang, Martin Davis, Marvin Minsky)**: "The principal purpose of this paper is to offer a theory which is closely related to Turing's but is more economical in the basic operations. [...] Turing's theory of computable functions antedated but has not much influenced the extensive actual construction of digital computers. These two aspects of theory and practice have been developed almost entirely independently of each other. [...] One is often inclined whether a rapprochement might not produce some good effect. This paper will [...] be of use to those who wish to compare and connect the two approaches." (Wang, 1957)
- Development of theoretical model rooted in Turing machines but more adapted to 'real' computer (register machines)

⇒ Root for research on small machines (M. Margenstern, Y. Rogozhin, D. Woods, T. Neary, etc – See Neary and Woods, 2012 for a recent overview)

Less is more in the 50s: Moore and Shannon's circuit analyzer to find minimal circuits



Less is more in the Fifties

'Automata studies' 'tradition' (II) – a rapprochement between theory and practice

⇒ *Indirect influence of 'logical minimalism' – 'adapt' logical work to more practical contexts*

- **Engineers convinced of significance logic (Edward F. Moore, Claude E. Shannon)**:

⇒ Tradition of logical circuitry

- Sensitive to materiality: "[s]ince holes in punched tape cannot be erased once they are punched, in order to make a machine using punched tape capable of imitating the behavior of an ordinary Turing machine which has this erasing property the coding of the description of the machine would have to be in a more complicated fashion [...] It should be mentioned [...] that the properties of the tapes assumed in Turing machines are very much like the properties attained by magnetic tapes, which have erasability, reversibility, and the ability to use the same reading head for either reading or writing. **If a tape mechanism were available which had the properties assumed and which could be connected directly to relay circuits, it would be possible to build a working model of this machine using perhaps twenty or twenty-five relays.**
  "[This result shows] *that very complicated logical processes can be done using a fairly small number of mechanical or electrical components, provided*

large amounts of memory are available. With present speeds and costs of components, it would not be economically feasible to use such a machine to perform complicated operations because of the extreme slowness and fairly large amount of memory required."

$\Rightarrow$ Use of a model to investigate certain issues in actual computing machines

Less is more in the Fifties

Simple digital computers: Zebra, (Minima) and TX-0

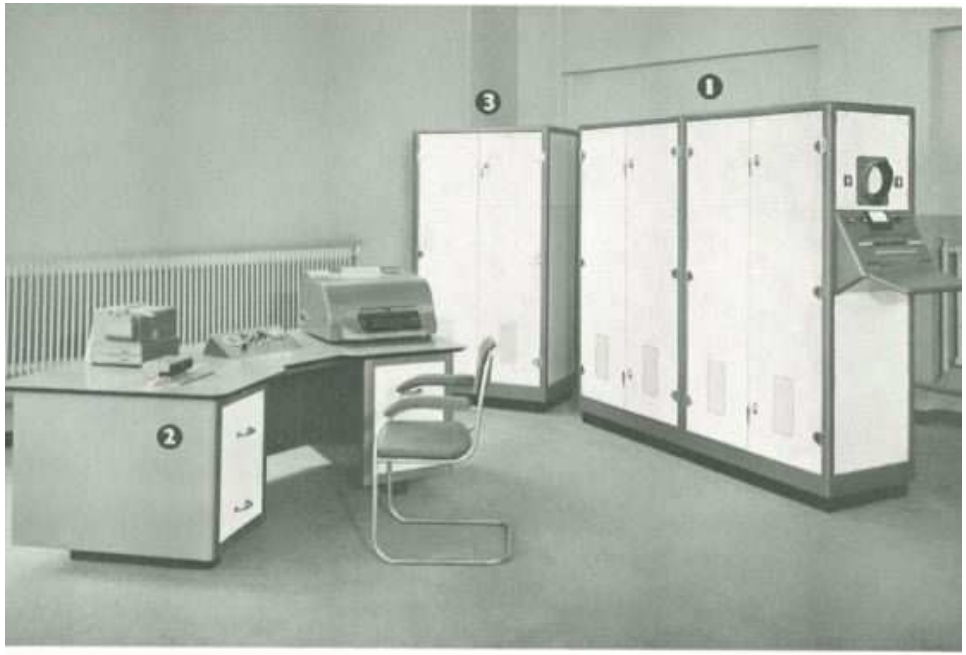
⇒ *Indirect influence or 're-invention' of 'logical minimalism' – building "small" computers*

⇒ *At best superficial references to logical work, more important is Wilkes' microprogramming*

⇒ Mostly as 'experimental' models that are inspiration for more commercial models

- Van der Poel's ZERO ("*not meant as a practical computer, but only serves the purpose of gaining experience*") and ZEBRA:
  ⇒ "The main idea of the [Zebra] machine is to economise as far as possible on the number of components by simplifying the logical structure. For example, multiplication and division are not built in but must be programmed."
  ⇒ "In this article will be described the logical principles of an electronic digital computer which has been simplified to the utmost practical limit at the sacrifice of speed."
  ⇒ "Complexity of the circuits has been exchanged for capacity of memory.

Less is more in the 50s: Van der Poel's ZEBRA (Stantec version)



description

Stantec-Zebra is made up of three items of equipment as illustrated.

1 **The Computer Cubicles**

These contain the Store, Arithmetic and Control Units and also incorporate Monitor and Test equipment.

2 **The Control Desk**

On this are mounted the Input and Output Equipments and the Operating Controls.

3 **The Power Cubicle**

In this the Power Supply Units and the Master Pulse Generators are equipped.

Less is more in the Fifties

Simple digital computers: Zebra, (Minima) and TX-0

- Poesch and Fromme's Minima – inspired by ZEBRA design
  "For the study of programming and for education in questions of programming we have thought of a model of a machine that has a very simple instruction code so that one can learn it fast, but also can do anything that occurs as complex operations in a modern computer"
  Practical concerns (again): "This machine could execute all instructions (also conditionals), but if one would realize it, the operation time would be too long."
  Z22 (1955) as "*outgrowth*" of the Minima, which was designed after "*discussions on the problem of the smallest meaningful program-controlled computer*" during which also the UTM was discussed but considered "*useless*" "*practically speaking*"
- Clarke's TX-0 – again, an experimental machine preparing the way for PDP series.
  ⇒ Crash course for engineers at Lincoln lab on "the logical structure of digital computers" – part on Turing machines (Moore's machine!) and part on Boolean algebra and circuit design (with ref. to Sheffer's stroke as the sole building block for circuits) ⇒ Part of discussions *"about the various possible minimal machines"* that could be designed

"Well, all right, let's build the smallest thing we can think of," and designed the TX-0, which was very primitively structured and quite small, quite simple - small for the day. Not physically small - it took lots of space; it still took a room." – only four instructions!

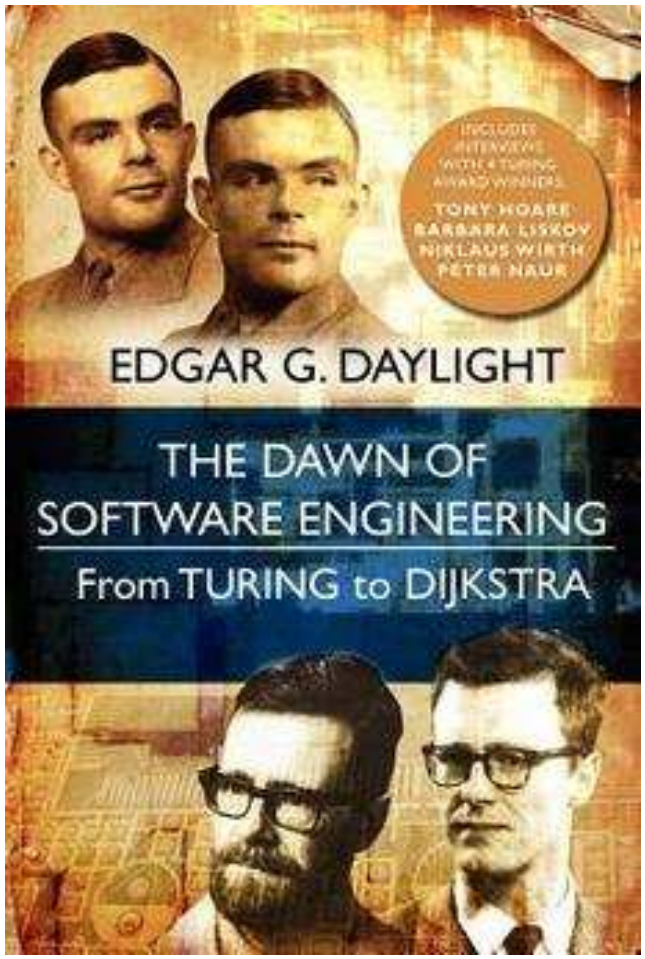
Less is more in the 50s: TX-0

Discussion

- Logical minimalism: From Schönfinkel "philosophical"/aesthetic point of view to a philosophy to think about limits and possibilities of aspects of real machines – building of "experimental machines and models
- Transmutation of LM affected by the physical and intellectual conditions of engineering practices (issues of speed, memory, money etc)
- Logical minimalism as one of many 'methods' to think about engineering and programming issues (e.g. what is the minimal number of relays needed to build a general-purpose computer and what are the costs of this minimality?)

$\Rightarrow$ 'Small' computers as experimental test cases for commercially viable computers (Minima/Z22, TX-0/PDP-1)

$\Rightarrow$ Computer science – meeting point between many different practices, heuristics and theoretical developments: here, logic and engineering – investigate how they interact and how they are mutually changed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