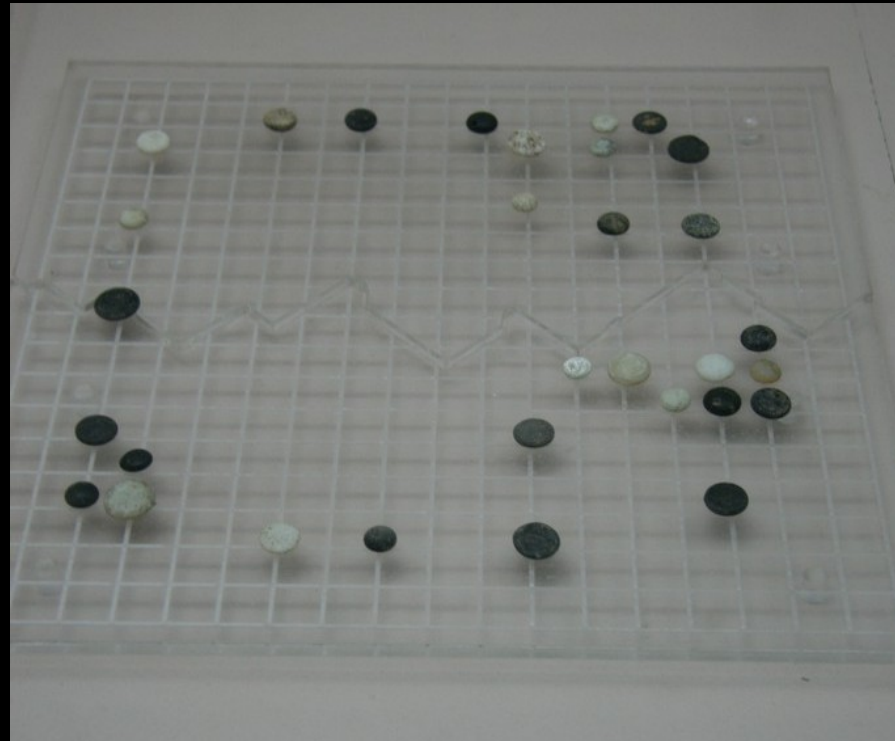


Computer modeling of physical phenomena



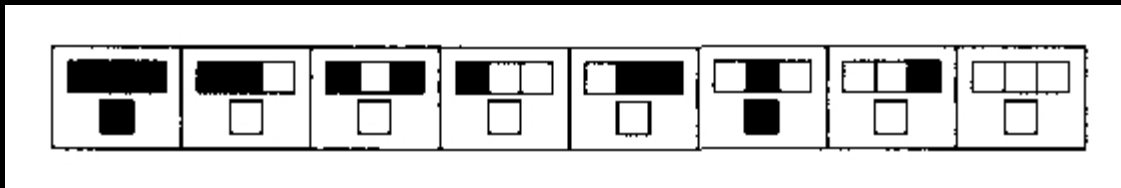
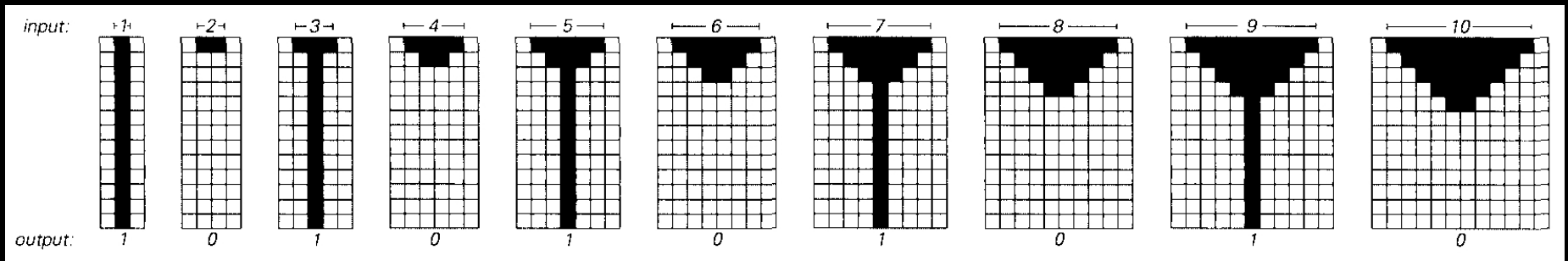
Lecture II CA - part 2

Automata as calculators

initial state – input

final state - output

An example – parity checking by the automaton 132:



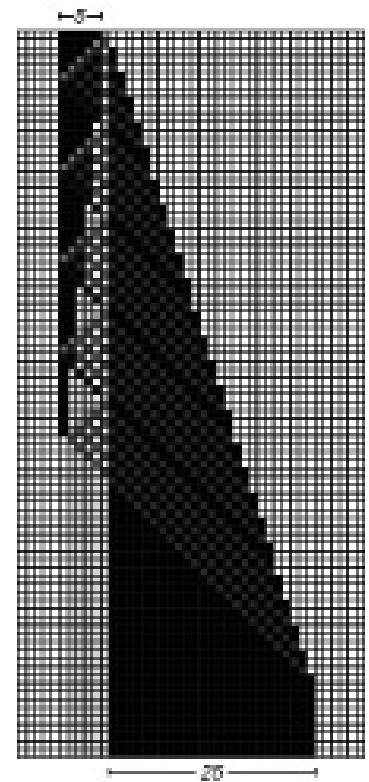
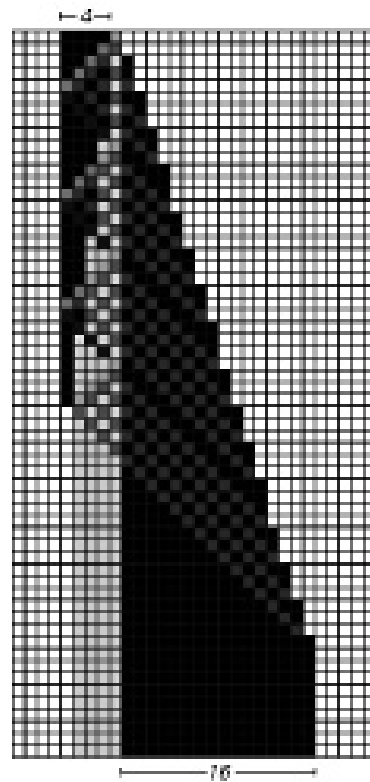
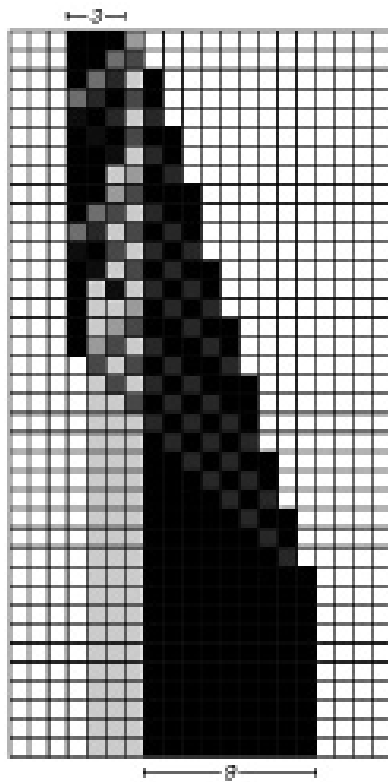
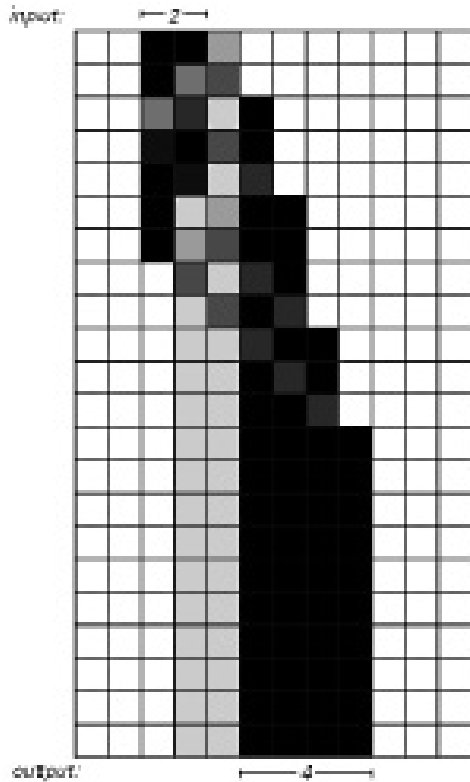
Squaring...

2

3

4

5

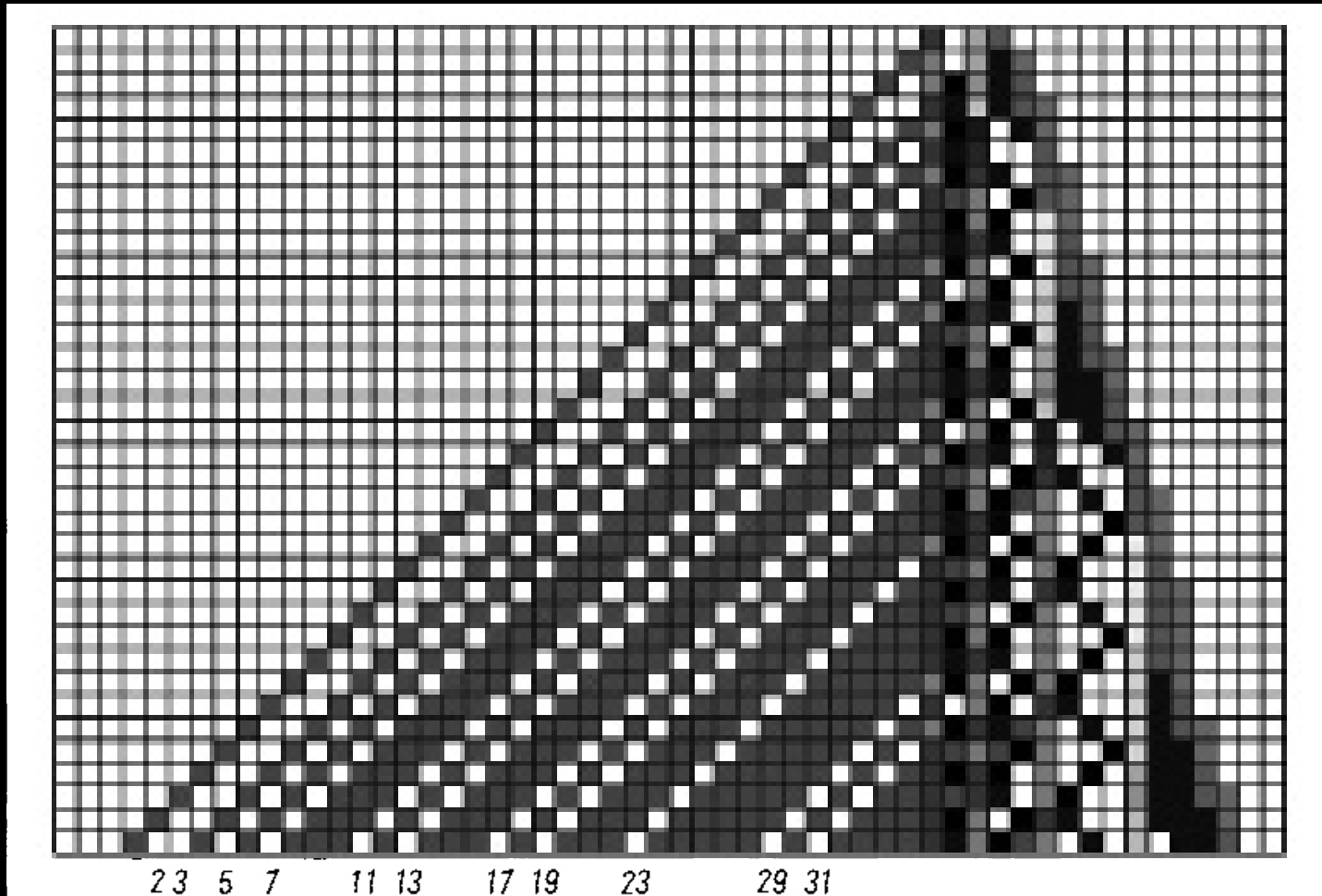


4

9...

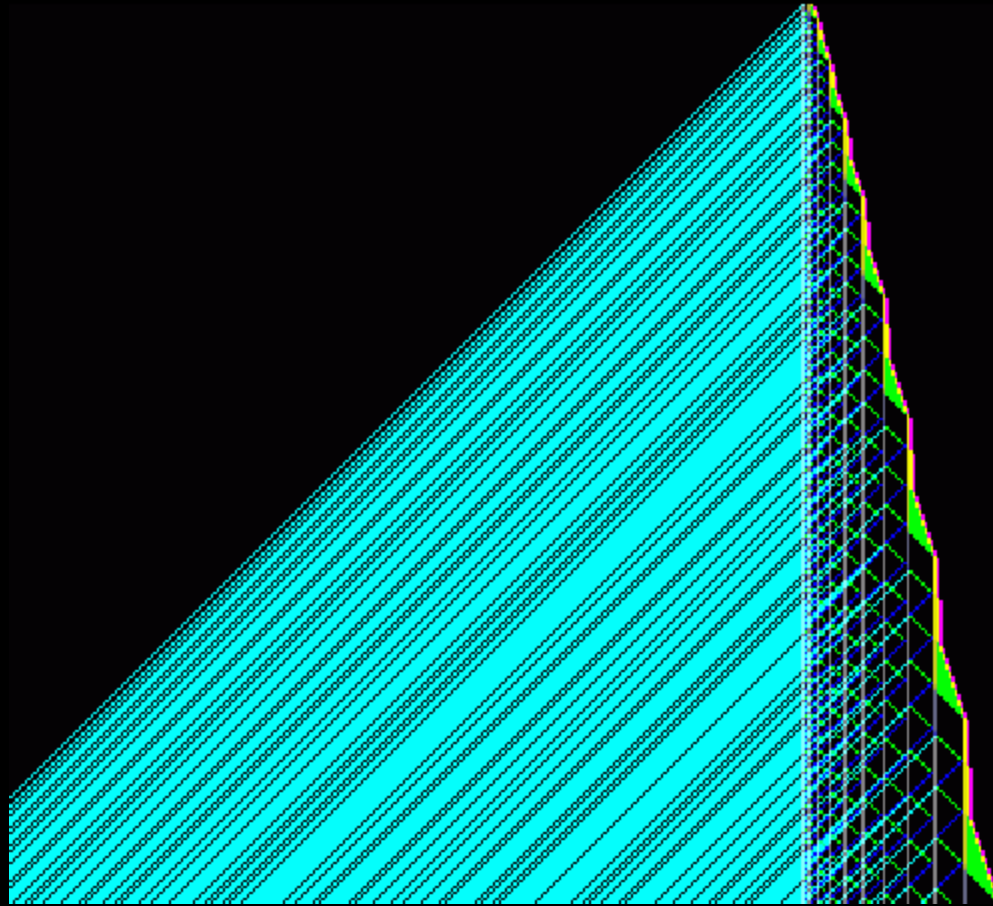
(8 state automaton)

Calculator of prime numbers



up to 31...

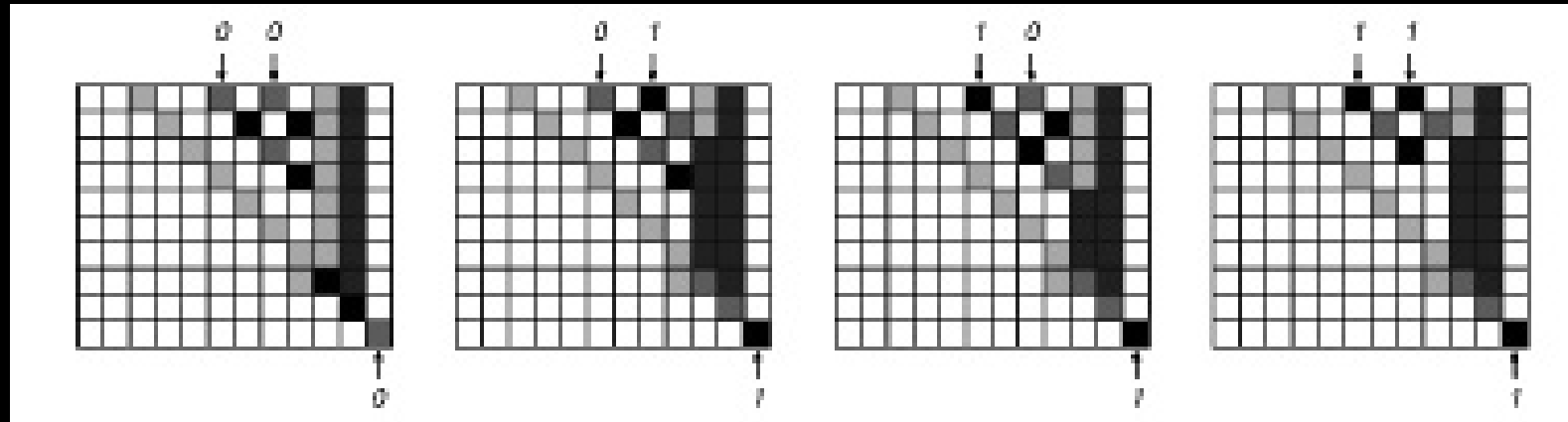
Calculator of prime numbers



.. and up to 821

Logical operations

OR:



rules (they work also for other logical operations):



Universal computer?

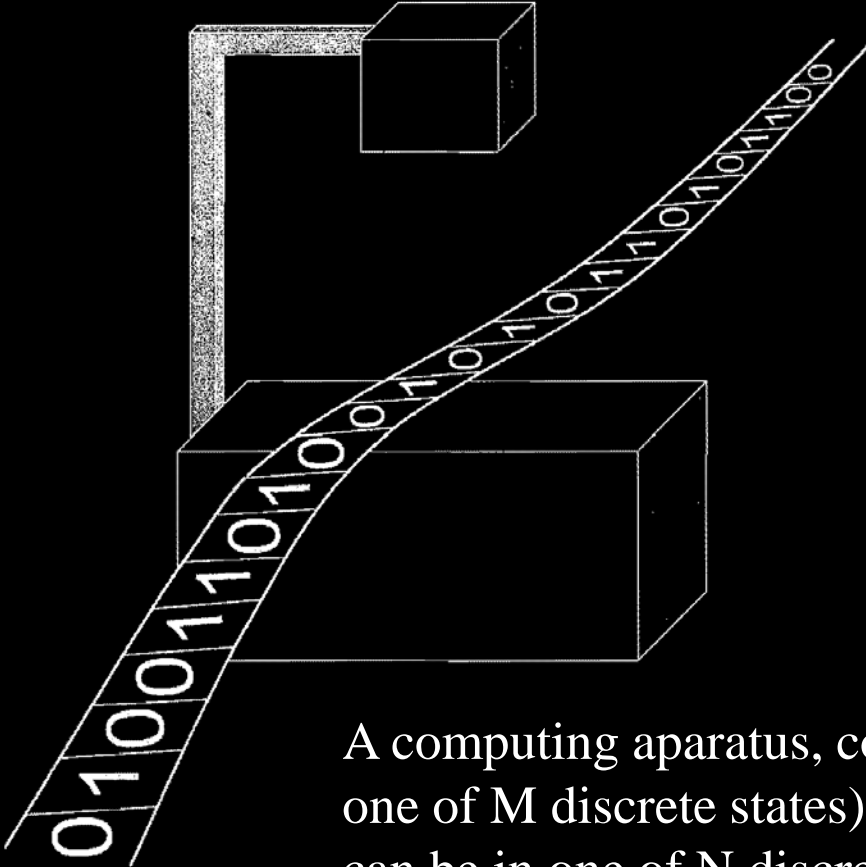
In the above examples we have used different automata for different tasks/computations



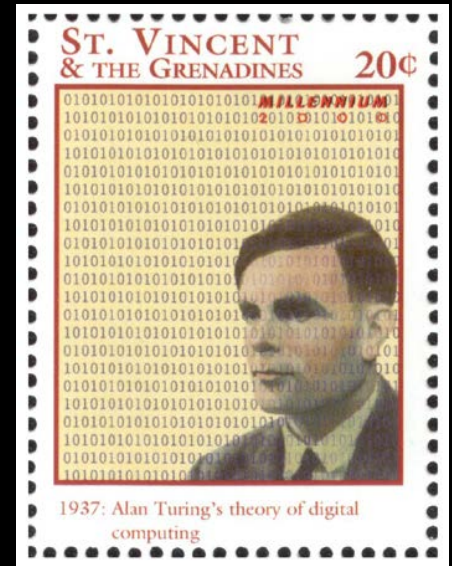
Can one have
a universal automaton
„that can do everything”?

Univerzální kuchyňský robot / Kompaktný kuchynský robot
Uniweralny robot kuchenny / Multipurpose Food Processor

Turing Machine



A computing apparatus, consisting of a head (which can be in one of M discrete states) and a tape divided into cells which can be in one of N discrete states (e.g. 0/1) Depending on the combination of the head state and the cell state the machine writes a new value on the tape, changes its state, and can also move the tape to the right or to the left.



Halting problem

Determine whether a Turing machine with a given code will stop after a finite number of moves or continue forever

Example:

```
x:=x0
repeat
  if x is even then
    x := x/2
  else
    x := 3*x + 1
until x = 1
```

Collatz problem



27, 82, 41, 124, 62, 31, 94, 47, 142, 71, 214,
107, 322, 161, 484, 242, 121, 364, 182, 91,
274, 137, 412, 206, 103, 310, 155, 466, 233,
700, 350, 175, 526, 263, 790, 395, 1186, 593,
1780, 890, 445, 1336, 668, 334, 167, 502, 251,
754, 377, 1132, 566, 283, 850, 425, 1276, 638,
319, 958, 479, 1438, 719, 2158, 1079, 3238,
1619, 4858, 2429, 7288, 3644, 1822, 911,
2734, 1367, 4102, 2051, 6154, 3077, 9232,
4616, 2308, 1154, 577, 1732, 866, 433, 1300,
650, 325, 976, 488, 244, 122, 61, 184, 92, 46,
23, 70, 35, 106, 53, 160, 80, 40, 20, 10, 5, 16,
8, 4, 2, 1

Church and Turing have shown that the halting problem is, in general, undecidable, which means that there is no general algorithm able to decide whether other algorithms will stop all possible program-input pairs

Halting problem (2)

- we are given as an input the code of a program P and a test input x.
- we want to know whether P, on input x, halts or not
- suppose that there were an algorithm A that correctly solves the Halting Program.
- now write a new program, called T, that, on input a program P, does the following:

T (program P)

- run A to determine whether P halts when given input P
- if P halts on input P, then run forever
- else, halt

- T receives as an input the code of a program P. It uses the algorithm A to determine whether the program P when given its own code as an input halts or not.
- If P halts when given its own code, T enters an infinite loop; if P does not halt when given its own code, T stops.
- What happens if T is given its own code as an input?
- T halts if and only if it does not halt  contradiction!

Universal Turing machine

a Turing machine, which is capable of emulating the workings of any other Turing machine, using it one can compute „everything” – by means of a long enough code....



"It is possible to invent a single machine which can be used to compute any computable sequence. If this machine U is supplied with a tape on the beginning of which is written the action table of some computing machine M , then U will compute the same sequence as M "

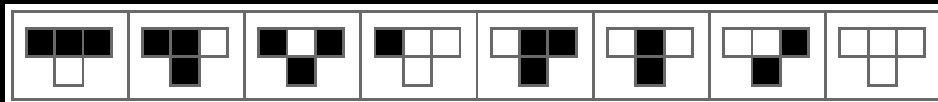
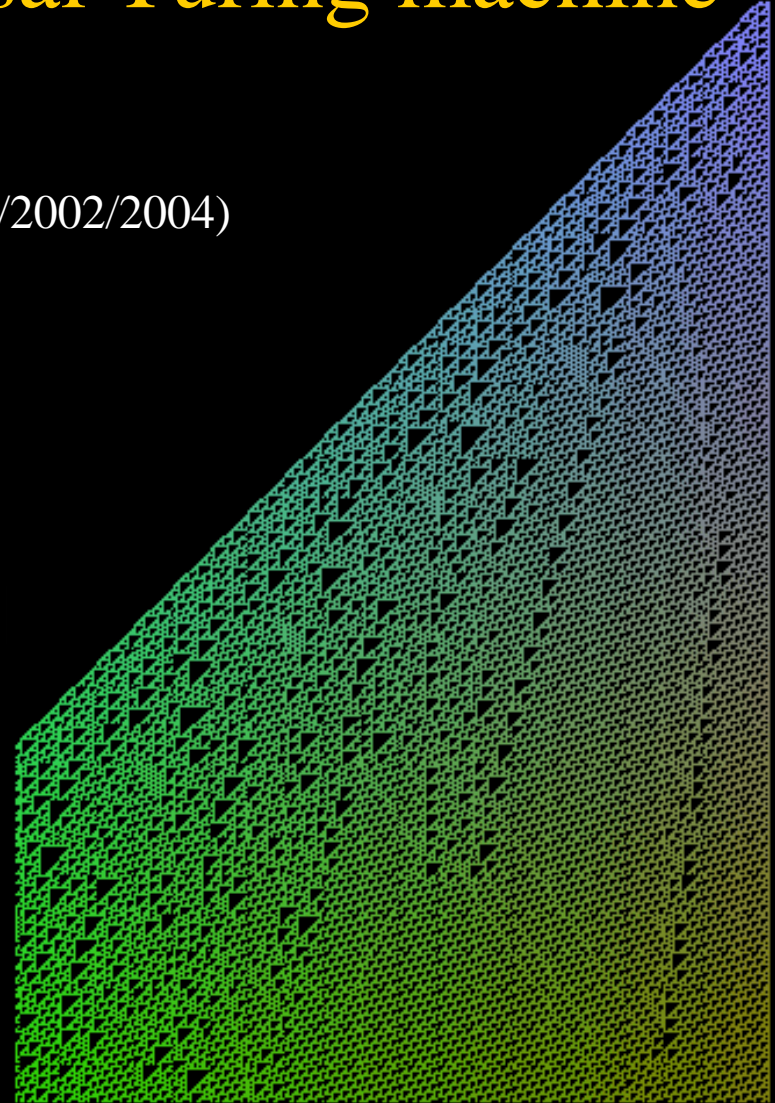
Turing, 1936

Automaton 110 is a universal Turing machine

Matthew Cook & Stephen Wolfram (1985/1994/1998/2002/2004)



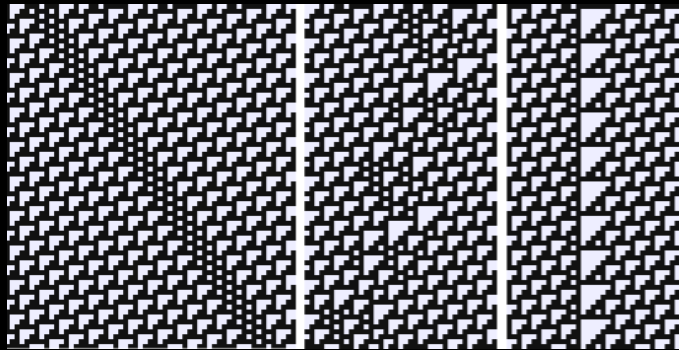
<http://web.mit.edu/cfox/www/knitting/f.html>



110 rule with 11011 seed

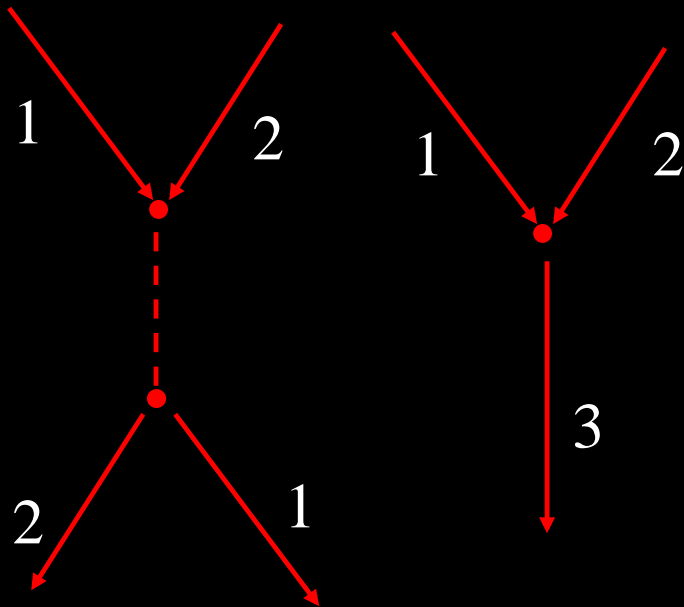
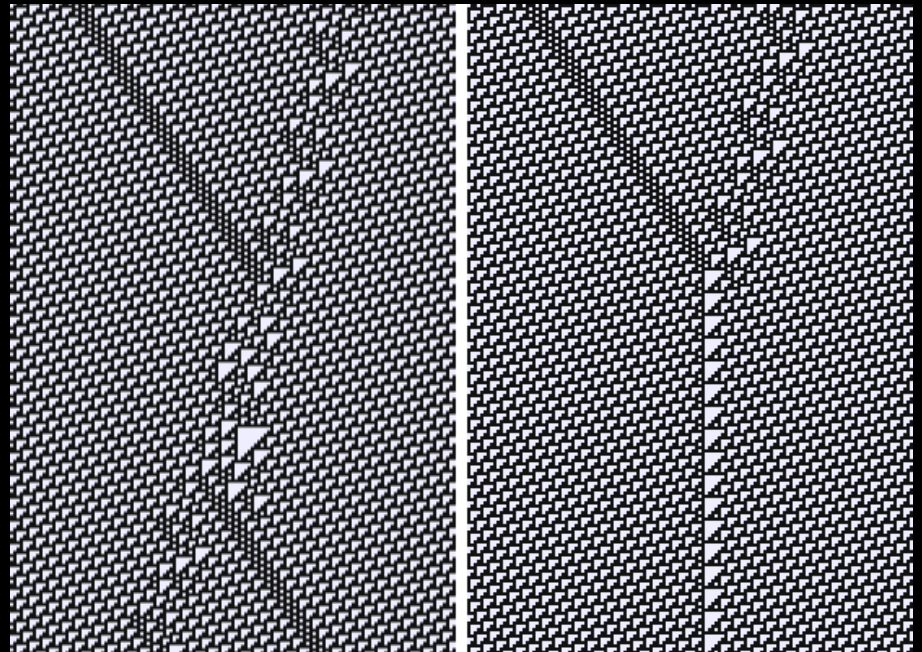
Gliders

the computations crucial for Turing machine emulation are based on the interactions between these structures



type 1 type 2 type 3

interaction:



The meaning of universality

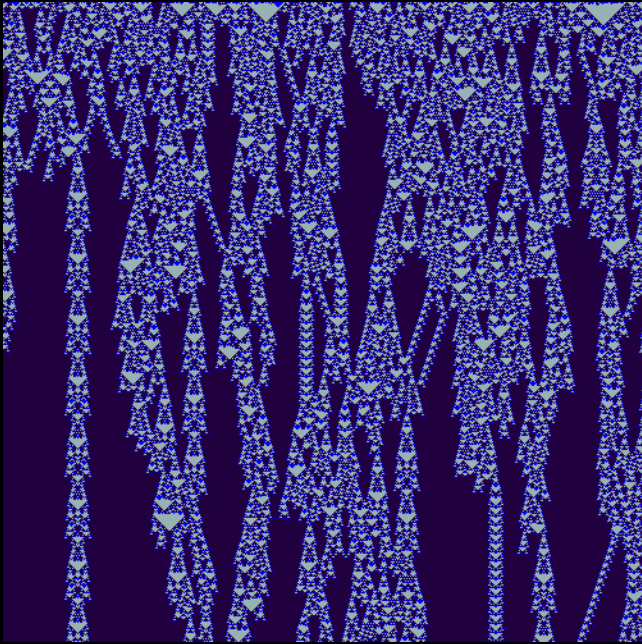
(according to Wolframa)

- universal systems are capable of emulating all other systems, no matter how complex their behavior is
- once the universality threshold has been reached, what one finds is that adding complexity to the underlying rules does not lead to any perceptible increase in the overall complexity of the behavior produced.
- the universality threshold can be reached even by the systems with very simple rules (110 automaton, Game of Life etc)

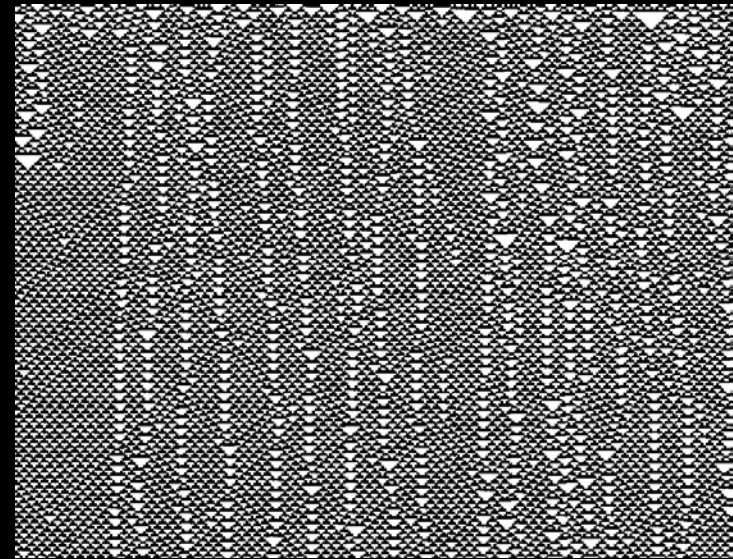
Life in life



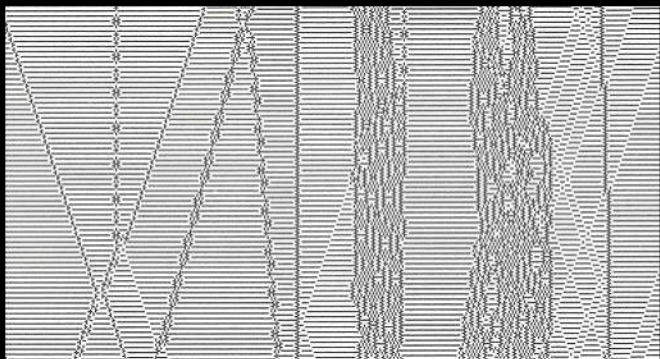
Other examples of class IV automata



1815 (three-state, additive)



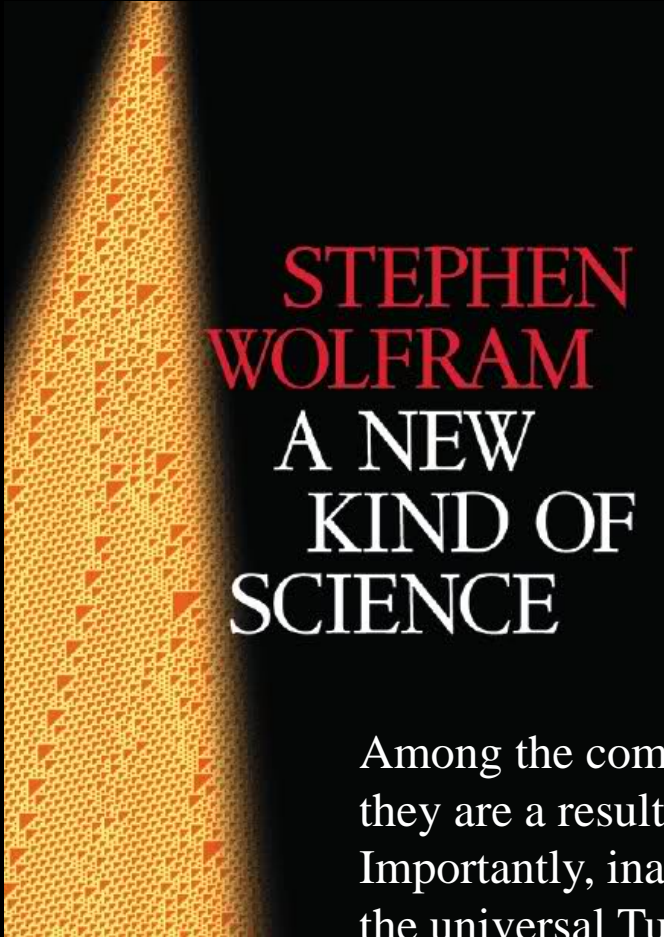
54



37R

are also thought to be universal Turing machines (but no proof so far)

A new kind of science?



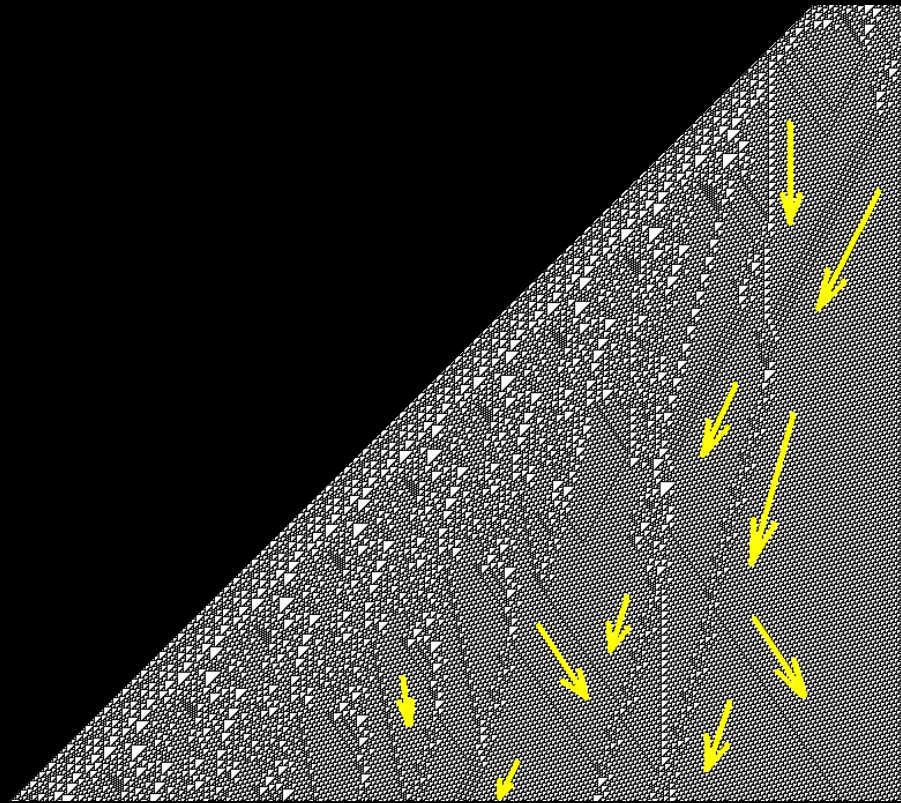
STEPHEN
WOLFRAM
A NEW
KIND OF
SCIENCE



Stephen Wolfram

Among the complex systems one comes across the ones which— although they are a result of application of simple rules – remain unpredictable. Importantly, inability of prediction of their evolution can be – similarly to the universal Turing machine halting problem – a fundamental property of those systems. Wolfram calls such systems **computationally irreducible** and claims that only the algorithms (and not equations) are useful for the description of their behaviour

Incomplete physics?



Hurray! It seems that I've discovered a Unified Theory of Glider Interaction

But there is this strange 3-glider collision effect that evades the theory...

Ah, perhaps we will need to add the ϕ^{10} term to our expansion....

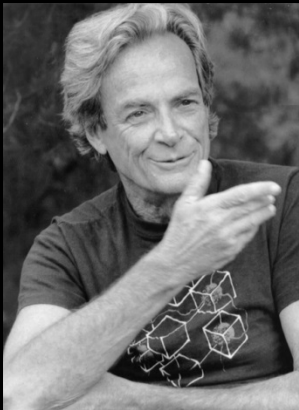
No full description of the dynamics ever possible (as it would solve the Turing halting problem)!

Universe = four lines of code?



Edward Fredkin

„Universe is a computer and information is more fundamental than energy or matter”



Richard Feynman

„So I have often made the hypothesis that ultimately physics will not require a mathematical statement, that in the end the machinery will be revealed, and the laws will turn out to be simple, like the chequerboard with all its apparent complexities”



Konrad Zuse

"Rechnender Raum,, 1967

„Universe constitutes one, big, never-ending computation...”

Universe = four lines of code?



How long do you envision this rule of the universe to be?"

"I'm guessing it's really very short."

"Like how long?"

"I don't know. In Mathematica, for example, perhaps three, four lines of code."

"Four lines of code?"

"That's what I'm guessing. (...) We're looking at a handful of lines of code."

"So it's not like Windows?"

"No. It's not like Windows. It's going to be something small, I think"

Stephen Wolfram,
interview, 2002

Consciousness = four lines of code?



Marvin Minsky

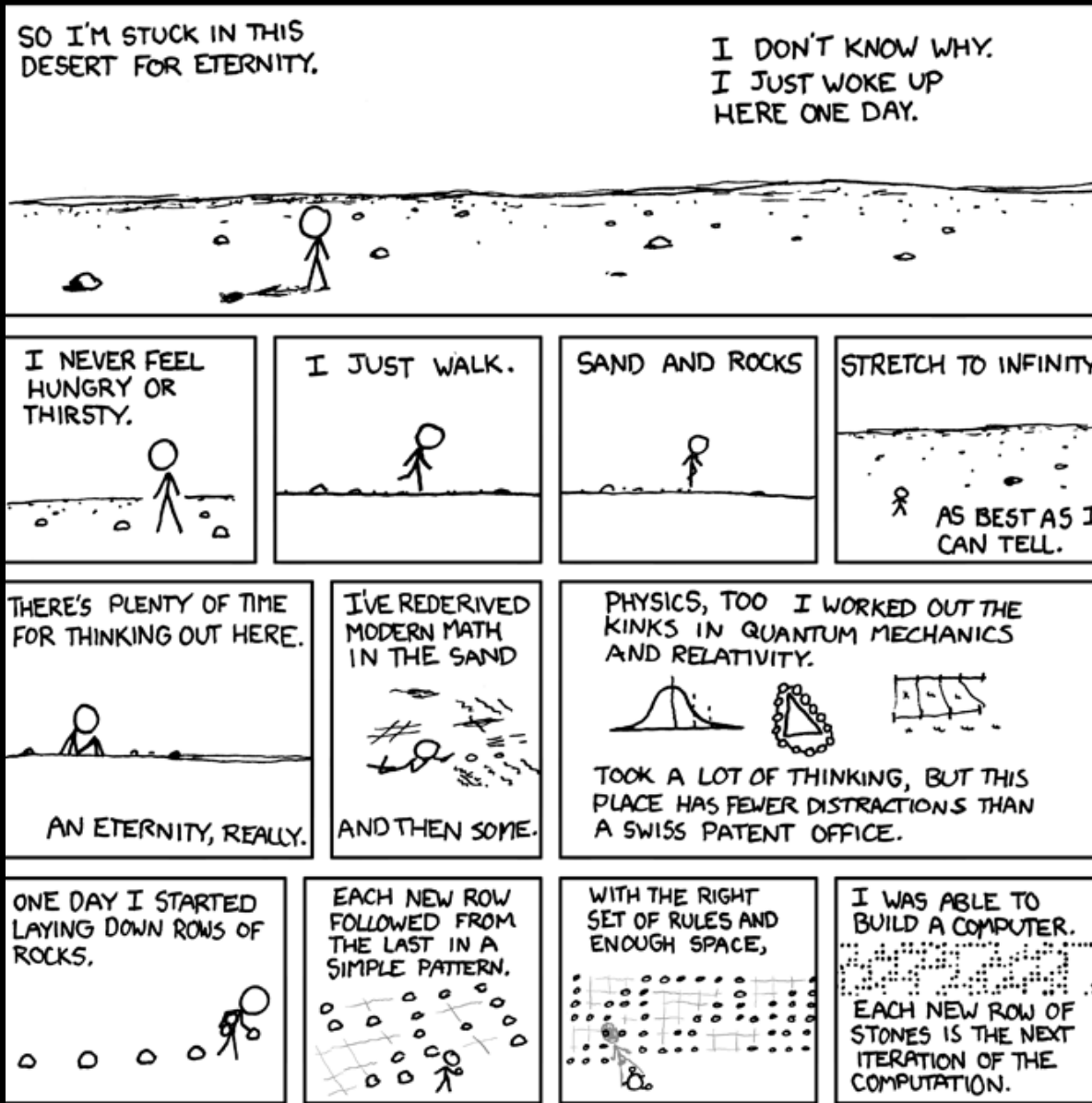
„What is commonly attributed to consciousness is mythical. In fact, some machines are potentially more conscious than are people”



Roger Penrose

„Conscious mind cannot work like a computer, even though much of what is actual involved in mental activity can do so”

A long time ago in a galaxy far, far away....



A long time ago in a galaxy far, far away....

