

# Beyond Common Computing

ICCS2023 Jochen Viehoff

Very short history of microchips

The power of Moore's Law

Alternative computing

Analog computer, qubits, memristors, hybrid, DNA, neuromorphic

Summary and discussion

We are not prepared for the end of Moore's Law

David Rotman MIT Tech Review February 2023



Connection Machine 2 / 5

Lattice Gauge Theory / Quantum Field Theory

Lattice size:  $16 \times 16 \times 16 \times 32$

CM5: fastest computer 1993 1024 cores 131 Gflops peak



Heinz Nixdorf (1925 - 1986)

German computer pioneer and entrepreneur

Teach computing at school

Collect IT artifacts for a museum



Heinz Nixdorf MuseumsForum

Paderborn Germany

## Facts & Numbers

- 5,000 years - A “short” history of information technology
- 6,000 m<sup>2</sup> exhibition space / 2.500 guided tours p.a.
- Student labs / kids’ lab
- Library and archive
- 7 conference rooms / 700 m<sup>2</sup> auditorium with 400 seats
- 42 employees
- Educational programs
- Cafeteria and restaurant with 240 seats
- 1000 events p.a.
- 120,000 - 140,000 visitors p.a.

Claude Shannon (1916 - 2001)

A Symbolic Analysis of Relay and Switching Circuits, MIT (1937)

Information theory (1948): new “digital drug“

ALL information should be digitally encoded!





First transistor demo: Bell Labs December 1947

John Bardeen, Walter Brattain, William Shockley

Summer 1957

Texas Instruments: Jack Kilby's first "integrated circuit"

A microscopic view of a silicon chip, showing a complex network of yellow and blue circuitry on a dark blue substrate. The circuitry consists of various rectangular and circular patterns, likely representing different components and connections of the chip. The overall appearance is that of a highly detailed and intricate microchip.

1959 First silicon chip for mass production

Robert Noyce Fairchild Semiconductors



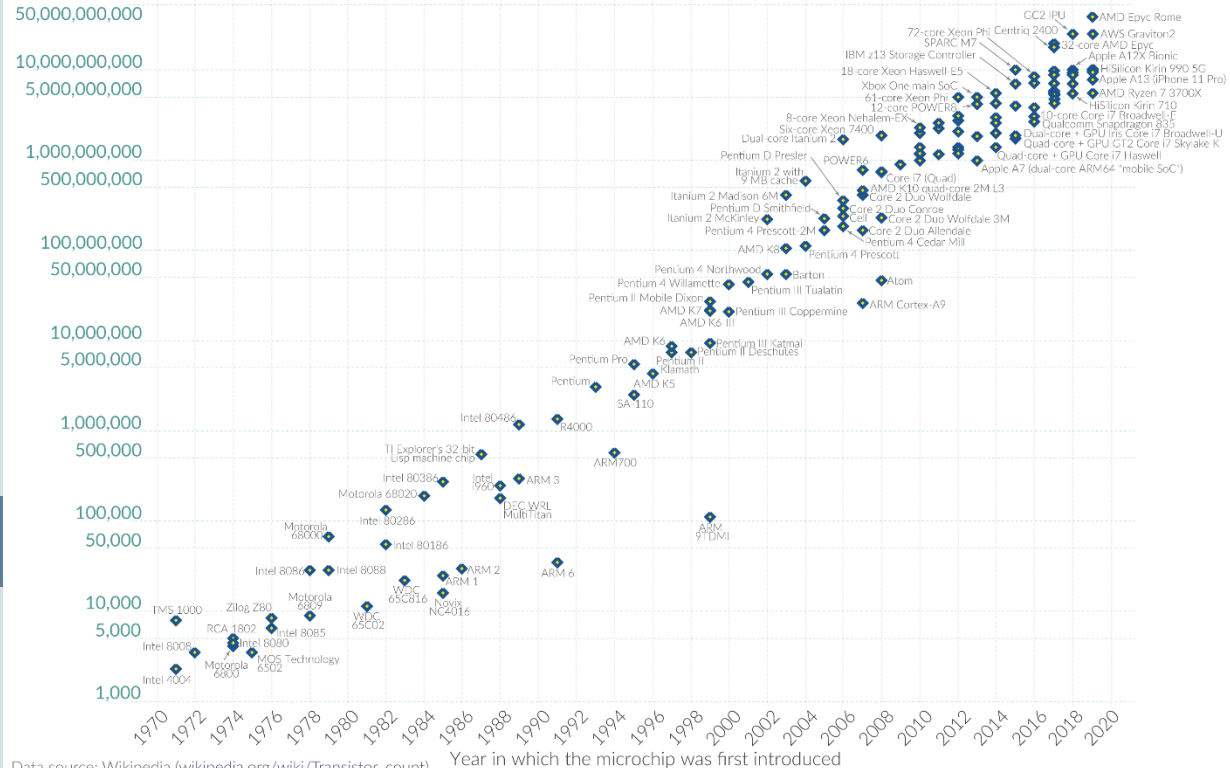
Gordon Moore INTEL

#Transistors double every 12/24 month (1965/1975)

# Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

## Transistor count



Data source: Wikipedia ([wikipedia.org/wiki/Transistor\\_count](https://wikipedia.org/wiki/Transistor_count))  
 OurWorldInData.org – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the authors Hannah Ritchie and Max Roser.

# Moore's Law 1965 - ... ?

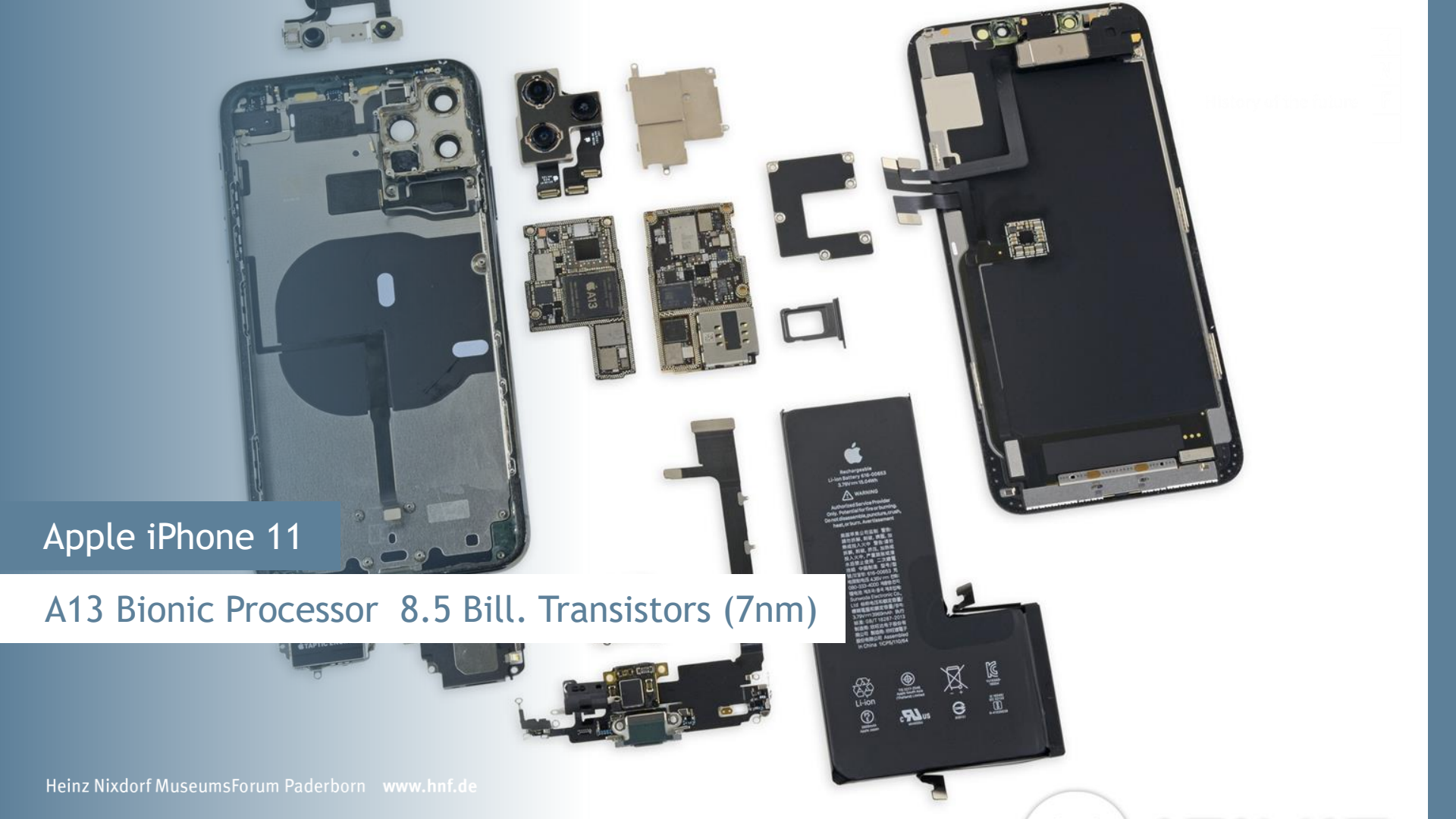


ENIAC - first electronic “computer“

1946 energy consumption 175kW

17,500 electronic vacuum tubes

Hand wired programs “room size“



Apple iPhone 11

A13 Bionic Processor 8.5 Bill. Transistors (7nm)



Apple iPhone 11 with ENIAC tubes

Power consumption 175GW ( 17 Nuclear Power Plants)



# Global annual internet traffic

Tracking Clean Energy Progress

History of the future



1997

2007

2017

2022

Amount of data produced daily (2023): 329 Million Terabytes

Videos account for over half of the internet traffic

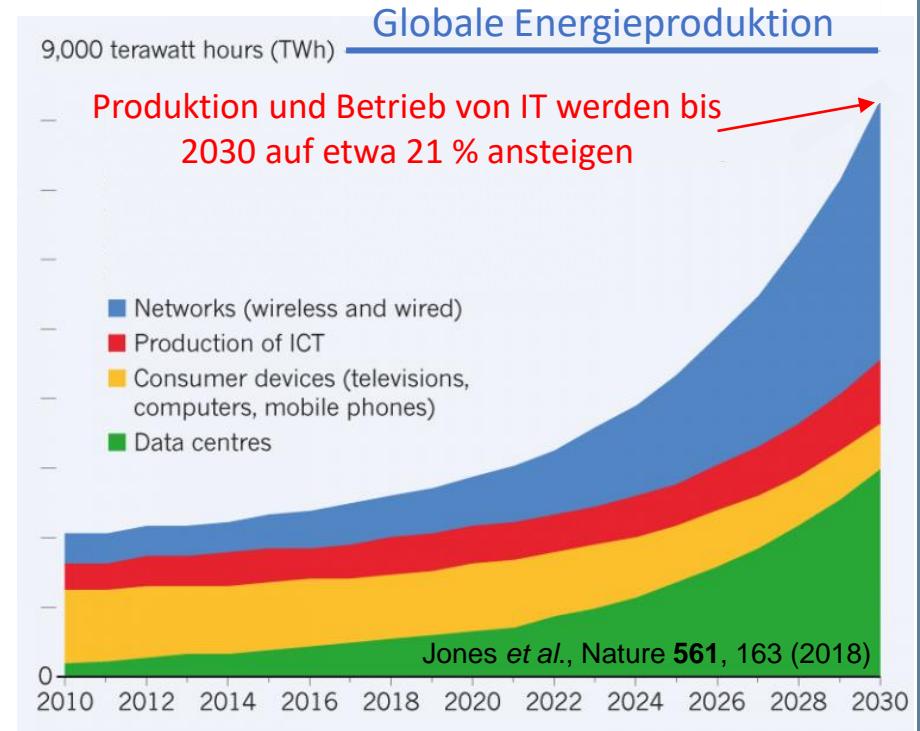
TB	terabyte	$10^{12}$ bytes
PB	petabyte	$10^{15}$ bytes
EB	exabyte	$10^{18}$ bytes
ZB	zettabyte	$10^{21}$ bytes
YB	yottabyte	$10^{24}$ bytes

Prof. Martin Ziegler (2021 HNF talk)

70 Bill. kWh per year to run the internet

2022: daily 5 bill. people online

2022: > 7,500 data centers worldwide

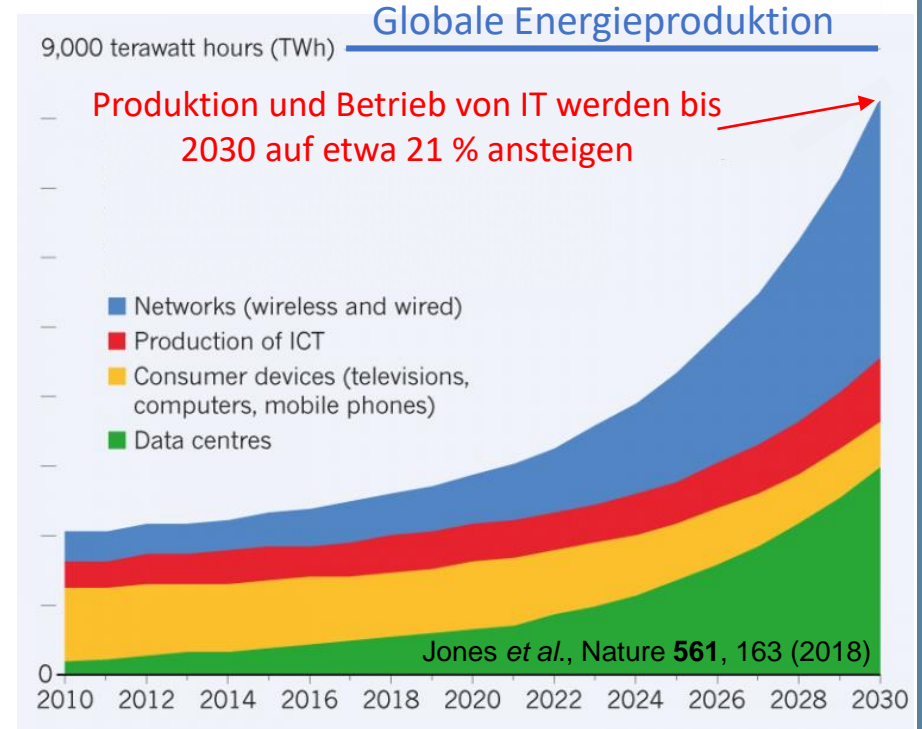


Landauer-Limit (1961)

Bit-operation  $> 3 * 10^{-21}$  Joule

2037 Total energy production

worldwide needed for ICT sector

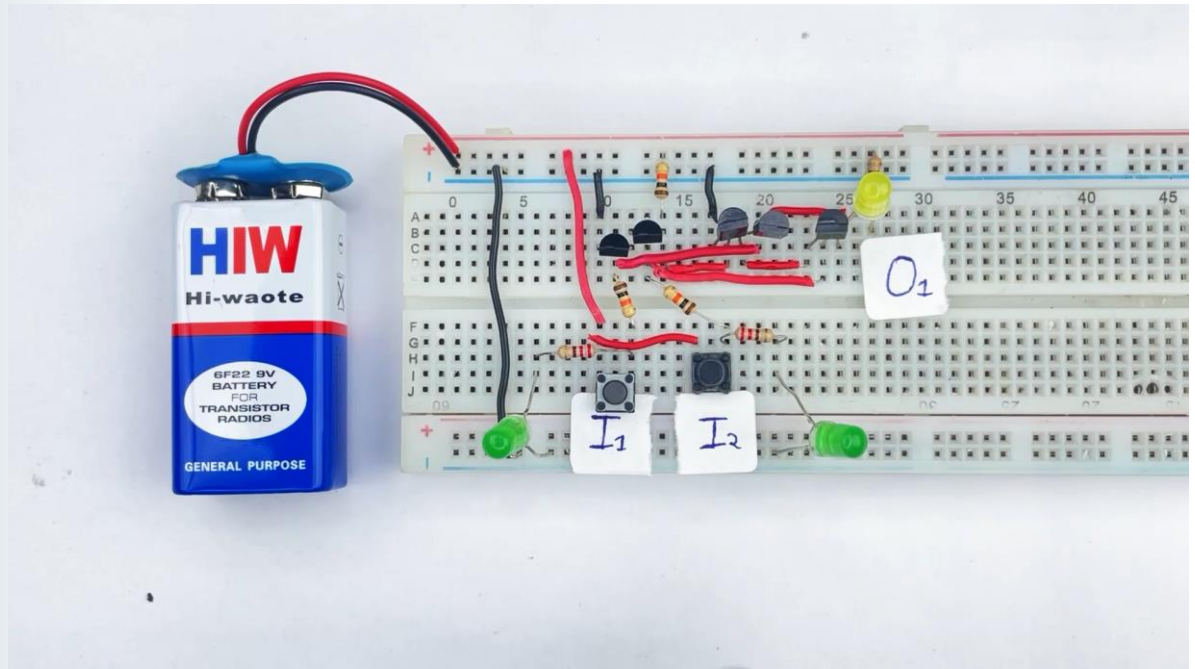


We are not prepared for the end of Moore's Law

David Rotman MIT Tech Review February 2023

## Boolean Math: XOR ( $\oplus$ )

X	Y	$X \oplus Y$
0	0	0
0	1	1
1	0	1
1	1	0

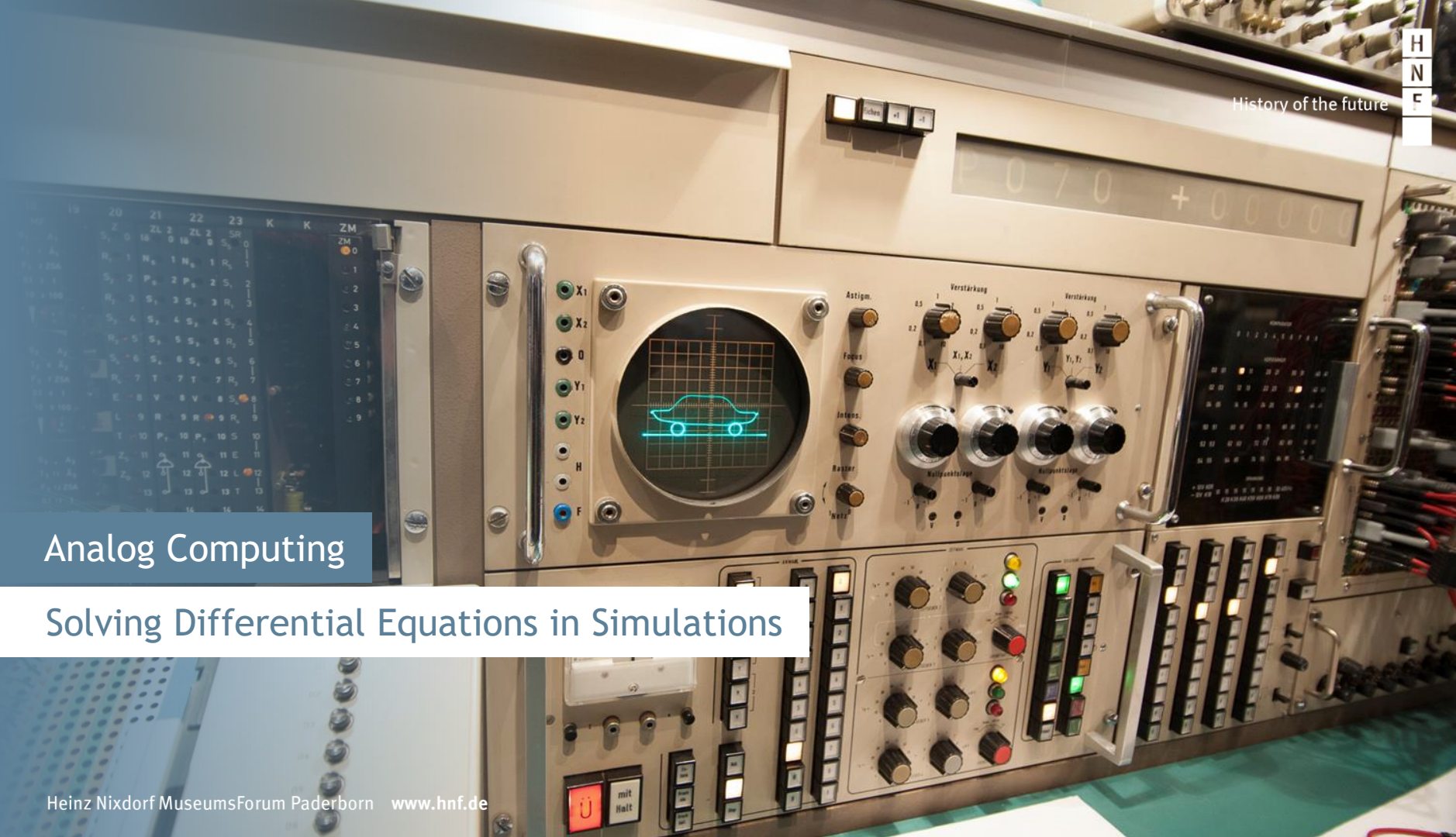


Logic gates: core elements for digital computers

XOR gate with 5 transistors

## 1. Alternative: Analog Computing

Solving Differential Equations with analog circuits



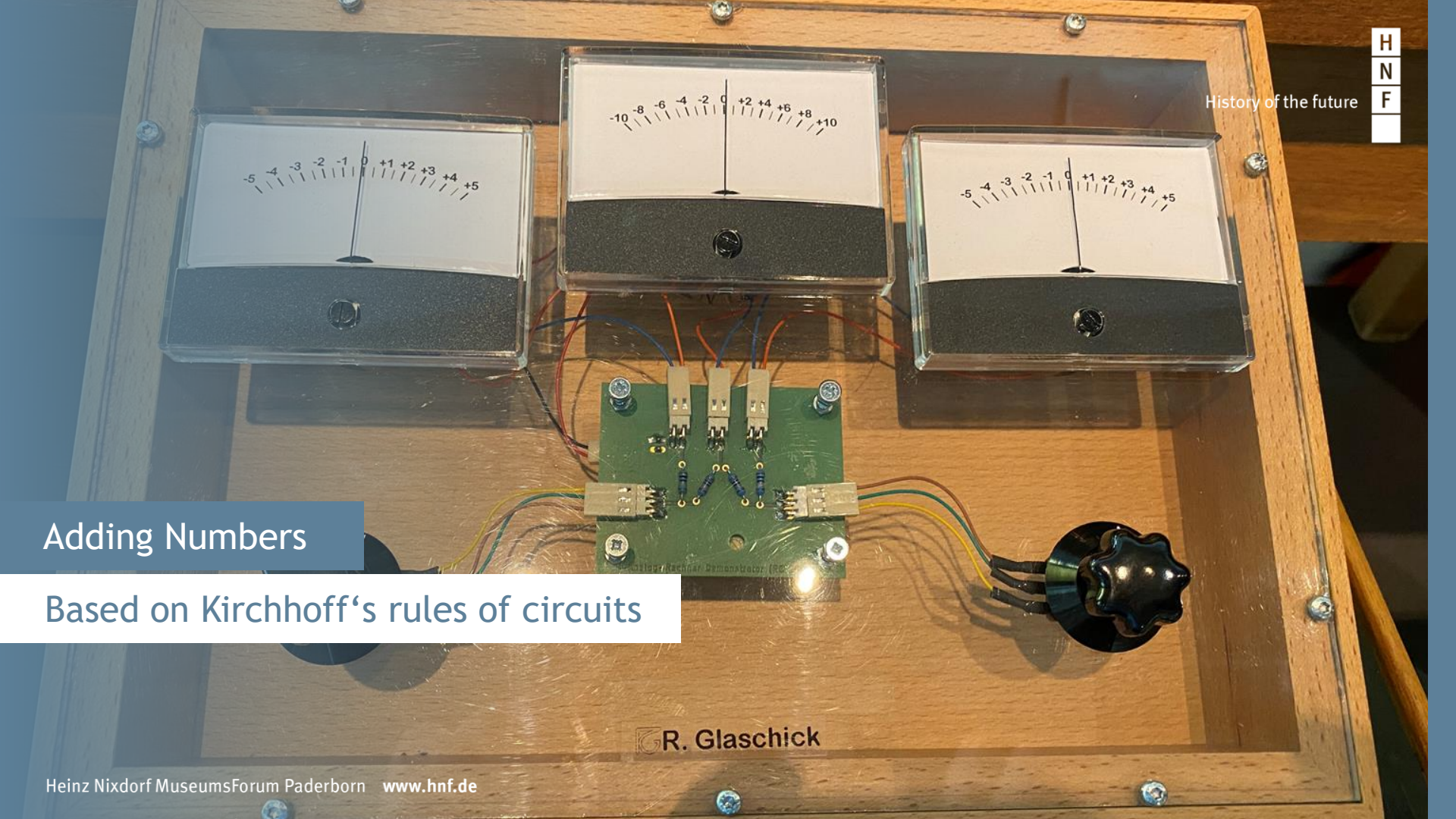
Analog Computing

Solving Differential Equations in Simulations

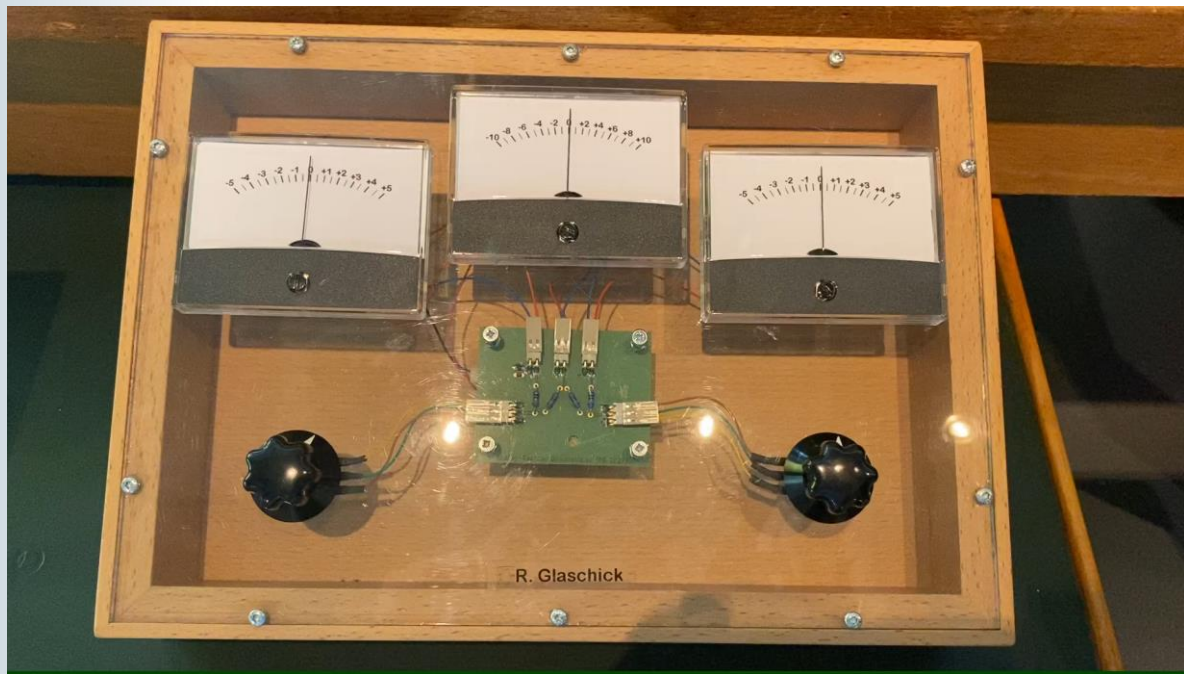
## Adding Numbers

Based on Kirchhoff's rules of circuits

R. Glaschick





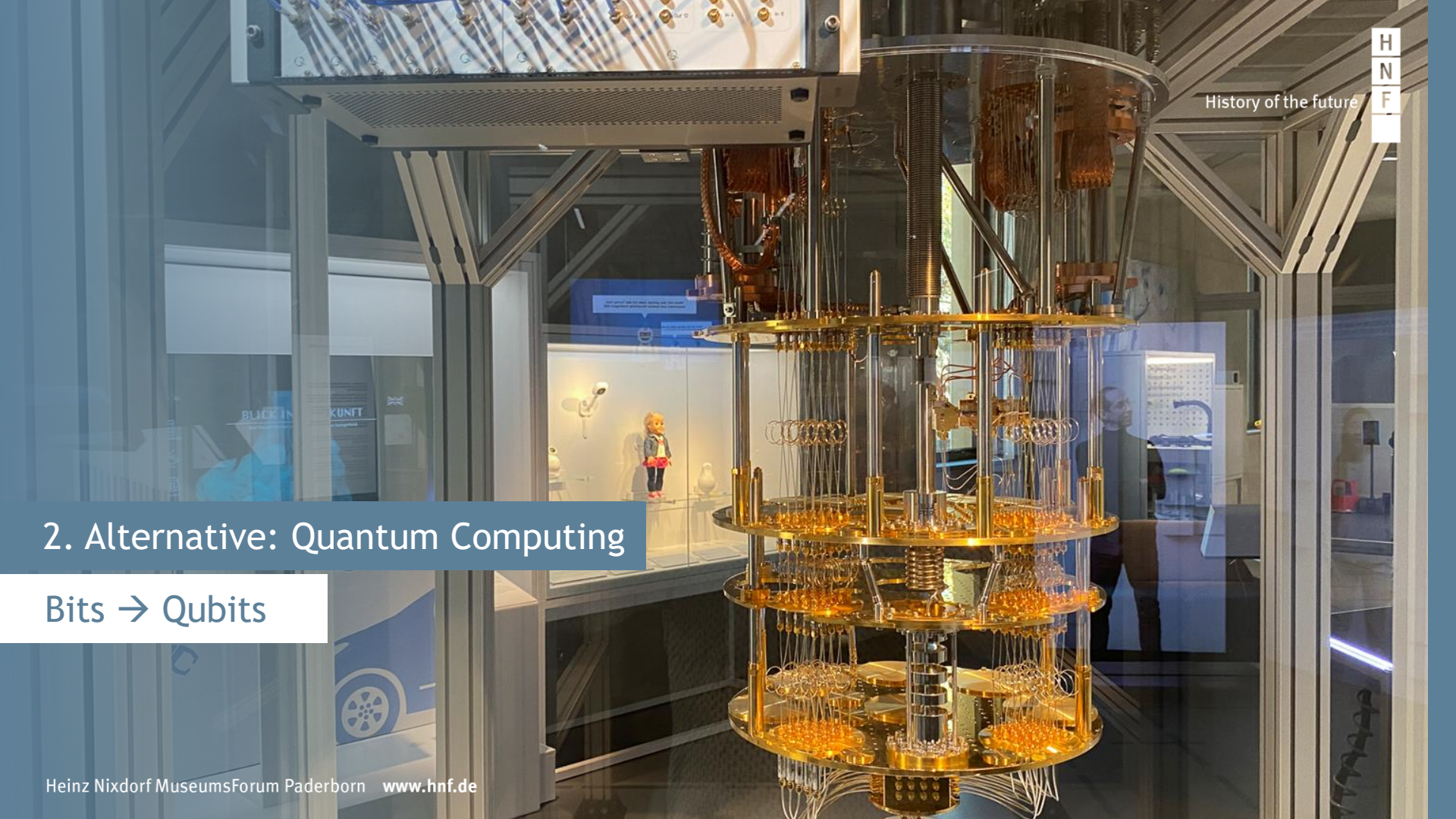


## Adding Numbers

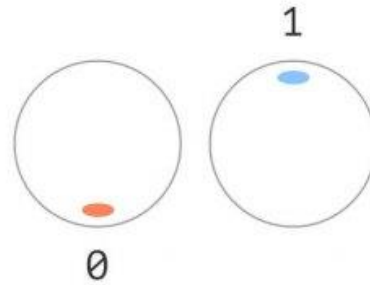
Based on Kirchhoff's rules of circuits

## 2. Alternative: Quantum Computing

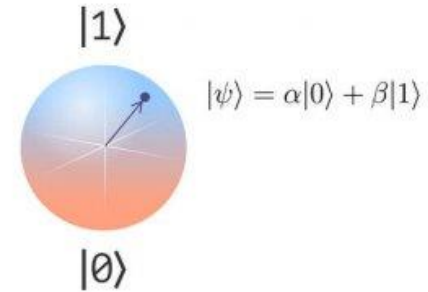
Bits → Qubits



Bit



Qubit

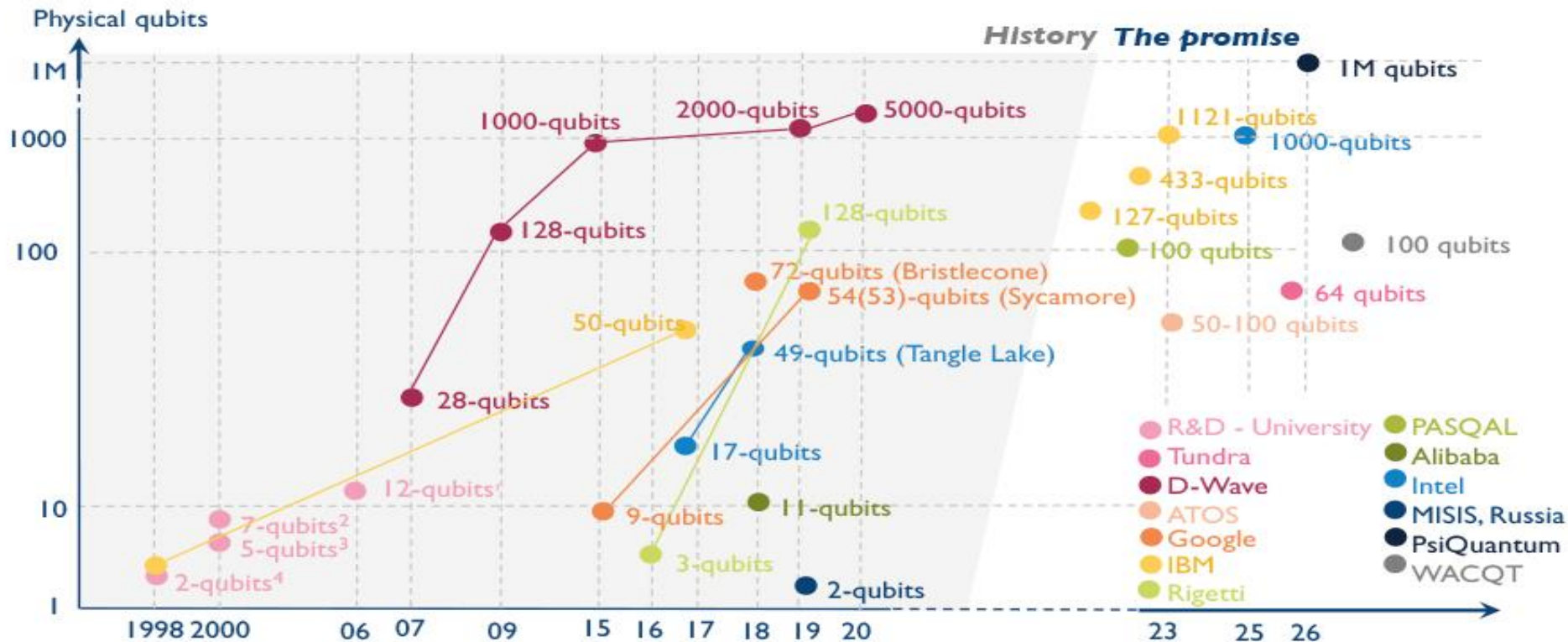


Complex problem solver

Cryptography, drug research, material sciences, machine learning

# 1998-2026 Physical qubit roadmap for quantum computer

(Source: Quantum Technologies 2021, Yole Développement, June 2021)



<sup>1</sup> (Institute for Quantum Computing, Perimeter Institute for Theoretical Physics, MIT)

<sup>2</sup> (Los Alamos National lab)

<sup>3</sup> (TU Munich)

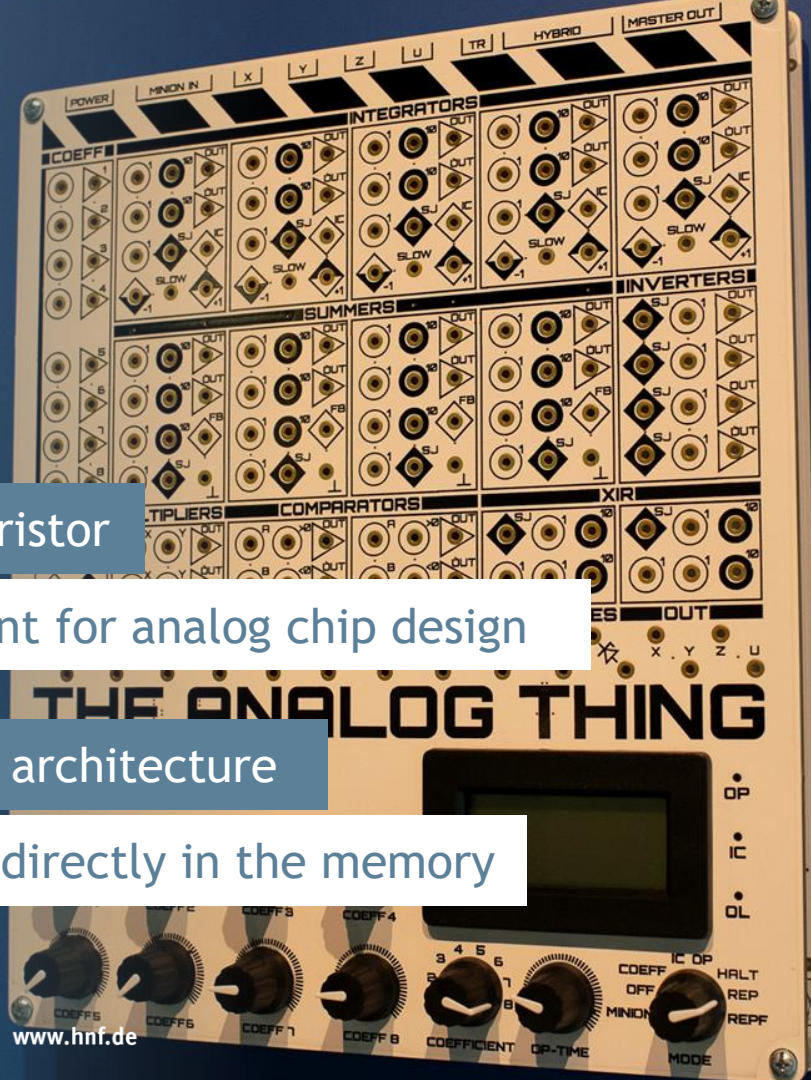
<sup>4</sup> (Oxford University, IBM, UC Berkeley, Stanford, MIT)

### 3. Alternative: Memristor

Electronic component for analog chip design

Avoid von-Neumann architecture

Do the calculations directly in the memory



History of the future

Dieser einfach zu programmieren und  
soll einer größeren Zielgruppe  
computern ermöglichen und so die  
breiter bekannt machen.  
Der Rechner ist wesentlich kleiner  
1970er Jahre, aber (bis auf die fehl  
ähnlich leistungsfähig. Für größer  
mehrere THATs zusammengeschal

*This easy-to-use, open-source and  
to provide a larger target group w  
computers and thus make the adv  
more widely known.  
The computer is much smaller th  
of the 1970s, but (except for the n  
similarly powerful. For larger con  
THATs can be interconnected.*

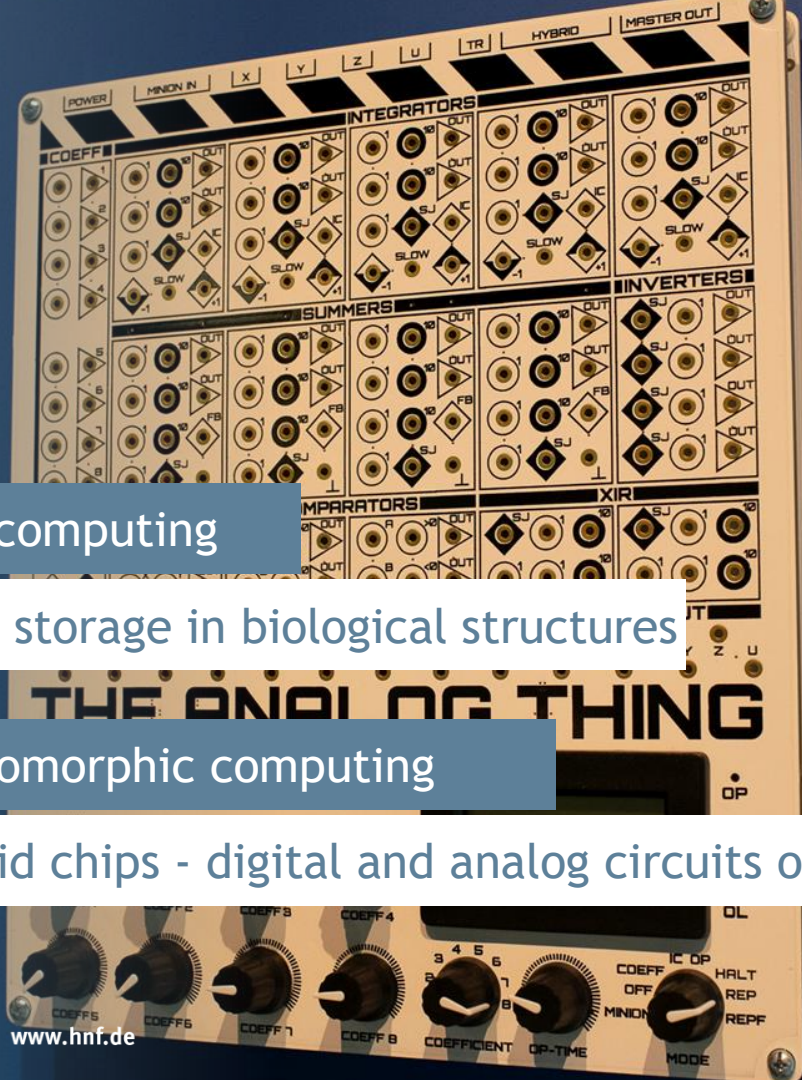
- Merkmale / Features:
- 900 g Gewicht / Weight
  - 1 ‰ Genauigkeit / Accuracy
  - 9 Summierer und Integrier
  - 2 Multiplizierer (Gilbert-Ze
  - 8 Koeffizientenpotentiome
  - 0 Funktionsgeneratoren /

#### 4. Alternative: DNA computing

Data processing and storage in biological structures

#### 5. Alternative: neuromorphic computing

6. Alternative: hybrid chips - digital and analog circuits on silicon chips



The Analog Thing  
anabrid GmbH | 2022

History of the future

Dieser einfach zu bedienende Rechner soll einer größeren Zielgruppe von Computern ermöglichen und so die breiter bekannt machen. Der Rechner ist wesentlich kleiner als die Rechner der 1970er Jahre, aber (bis auf die fehlende Multiplizierfunktion) ähnlich leistungsfähig. Für größere Rechner können mehrere THATs zusammengeschaltet werden.

*This easy-to-use, open-source analog computer is intended to provide a larger target group with a simple-to-use computer and thus make the advantage of analog computers more widely known. The computer is much smaller than the computers of the 1970s, but (except for the missing multiplier function) similarly powerful. For larger computers, several THATs can be interconnected.*

Merkmale / Features:  
900 g Gewicht / Weight  
hohe Genauigkeit / Accuracy  
Multiplizierer (Gilbert-Zelle)  
8 Koeffizientenpotentiometer  
10 Funktionsgeneratoren /

Are we prepared for a digital world without Moore's law?

Can we learn from nature how to build more energy efficient computers?

Is transistor-based binary information processing holistic enough?

R. Feynman: The quantum world can only be simulated with quantum computers

Research on alternative computing is making rapid progress

Enjoy ICCS2023

Please visit Paderborn and the HNF soon