Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DKRZ
DEUTSCHES
KLIMARECHENZENTRUM

The Exponential Promise of High Performance Computing

Prof. Dr. Thomas Ludwig

German Climate Computing Centre Hamburg
Universität Hamburg – Department of Informatics – Scientific Computing

Alexis-Claude Clairaut (1713-1765)

Decides in 1757 to recompute the trajectory of Halley´s comet and improve the calculation

He partitions the computation between two friends

- Joseph-Jérôme Le Français de Lalande
- Nicole-Reine Étable de la Brière Lepaute

Mathematical Modelling / Numerical Simulation

The task: compute the three body problem for Saturn, Jupiter, and Halley´s Comet

Algorithm:

- Treat Jupiter and Saturn like hands of a clock around their common center, the sun
- Compute trajectories for a free flight of 1-2 degrees
- Compute velocity vectors according to their relative position and the position in relation to the sun
- The comet is an additional hand which flies in opposite direction on an elliptical trajectory
- The comet´s orbit is computed according to the mass attraction of the two big planets

First Parallel Computing

- The three persons work together from 1757 on in the Palais Luxembourg at one table
  - Work from morning to night
- Lalande and Lepaute treat the three body problem iteratively and move Saturn and Jupiter by 1-2 degrees around the sun
- They work together and hand over the results to Clairaut
- Clairaut computes the trajectory of the comet
- Clairaut checks all calculations for errors

Modell Validation

November 14th, 1757: results are presented to the Académie des Sciences

- Predicted appearance at April 15th, 1758
- Comet appears March 13th, 1758

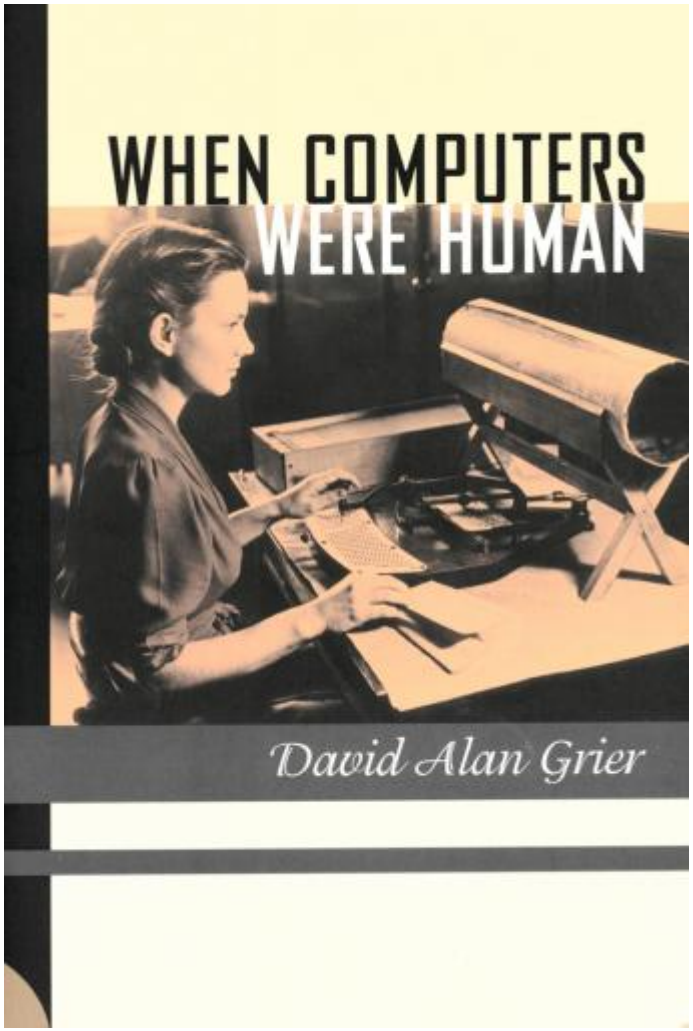
Clairaut was the **FIRST to divide mathematical labour** and has shown that lengthy computations can be divided into efficiently parallel computable parts

The Profession of the Computer

When Computers were human

David Alan Grier, 2005

The history of a profession



The Profession of the Computer...

The profession existed from the beginning of the 19th century until the end of the second world war

- The term was presumably already used in the 17th century

Major computation efforts

- Trajectories for celestial bodies (ephemerides)
- Nautical almanacs for the marine
- Tables for artillery missiles

Parallel human computers

- Computing offices / Computing laboratories
- 5-150 computers work together

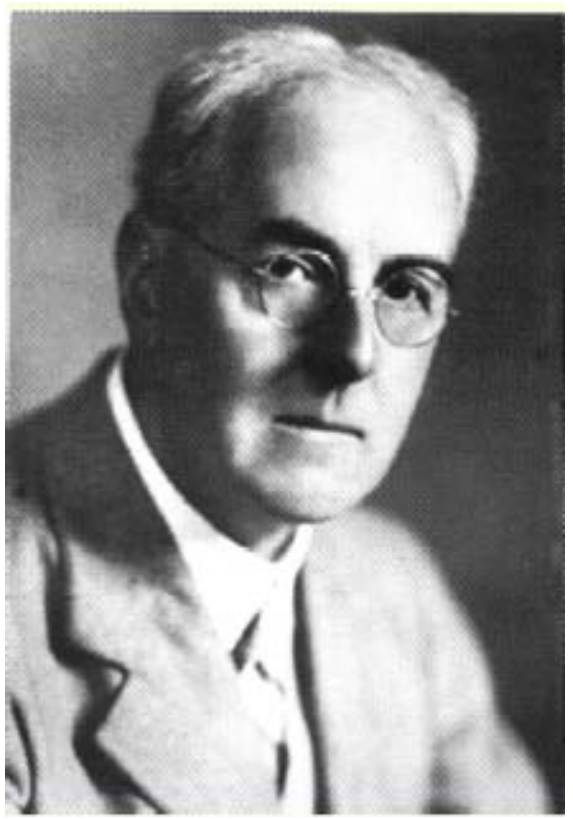
The Profession of the Computer...

Human FLOPS

- How many FLOPS makes a human computer?
- Test: compute 0.283765 x 0.847102 and stop the time
- Roughly estimated: 1 FLOP per 1.5 minutes
  - 0.01 FLOPS

Lewis Fry Richardson (1881-1953)

- Weather recordings since 1870
- In 1904 Vilhelm Bjerknes asks for a numerical weather prediction, because the evolution of weather follows physical principles
  - However, he cannot show a practical way
- In 1916 Richardson writes his book *Weather Prediction by Arithmetical Finite Differences*

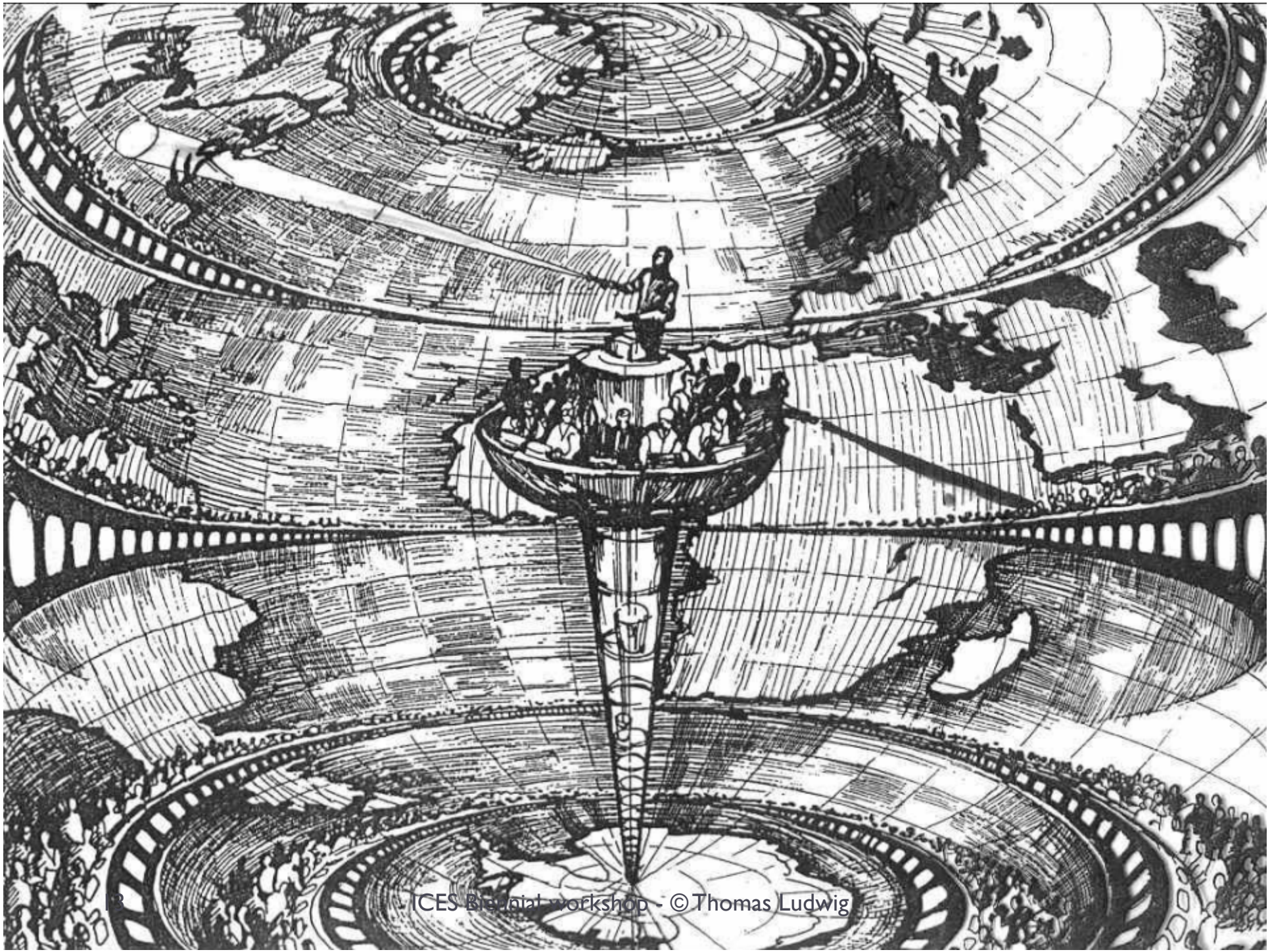


Richardson´s Vision

Perhaps some day in the dim future it will be possible to advance computations faster than the weather advances and at a cost less than the saving to mankind due to the information gained (WPNP)

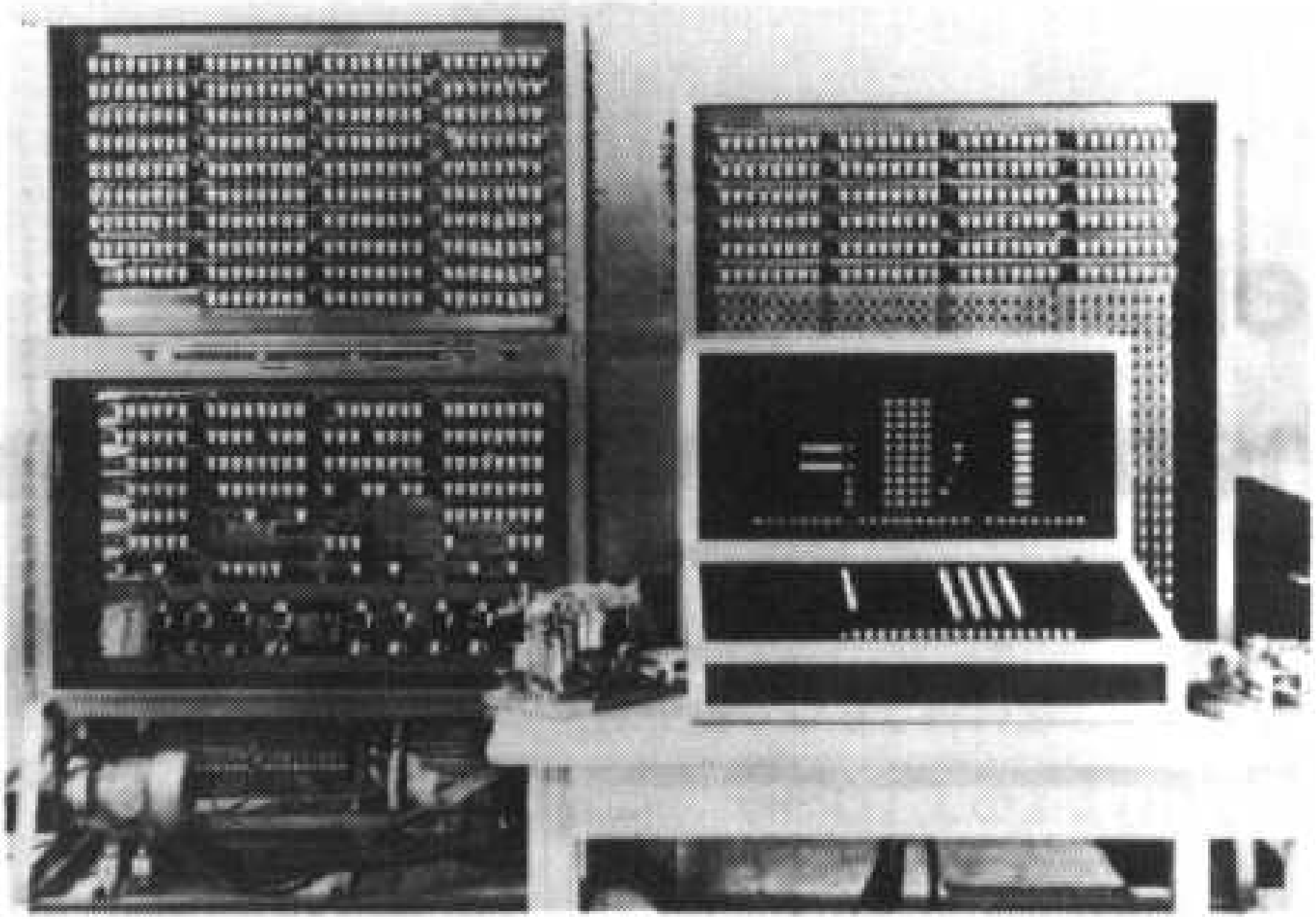
Richardson´s *Forecast Factory*

- He develops differential equations for temperature, humidity, pressure, etc.
- Divides the globe in 2,000 sections, where in each one the variables shall be computed in 3 hours
- He estimates to need 32 computers per section to keep the time requirement
  - (first real-time computing ☺)
- In total he needs 64,000 computers (640 FLOPS)



Konrad Zuse´s Z3

- In 1941 Konrad Zuse produces the first (electromechanical) programmable computer in the world: Z3
  - Its predecessor Z1 is called *mechanical brain*
- 2000 relais, 5-10 Hz clock rate
- Computational performance 0.3 Flops
  - equals 30 human computers



The TOP500 List

Web site www.top500.org

- Hans Meuer (Universität Mannheim)
- Jack Dongarra (Univ. Tennessee, Knoxville)
- Erich Strohmeier (NERSC/LBNL)
- Horst Simon (NERSC/LBNL)

Two updates per year

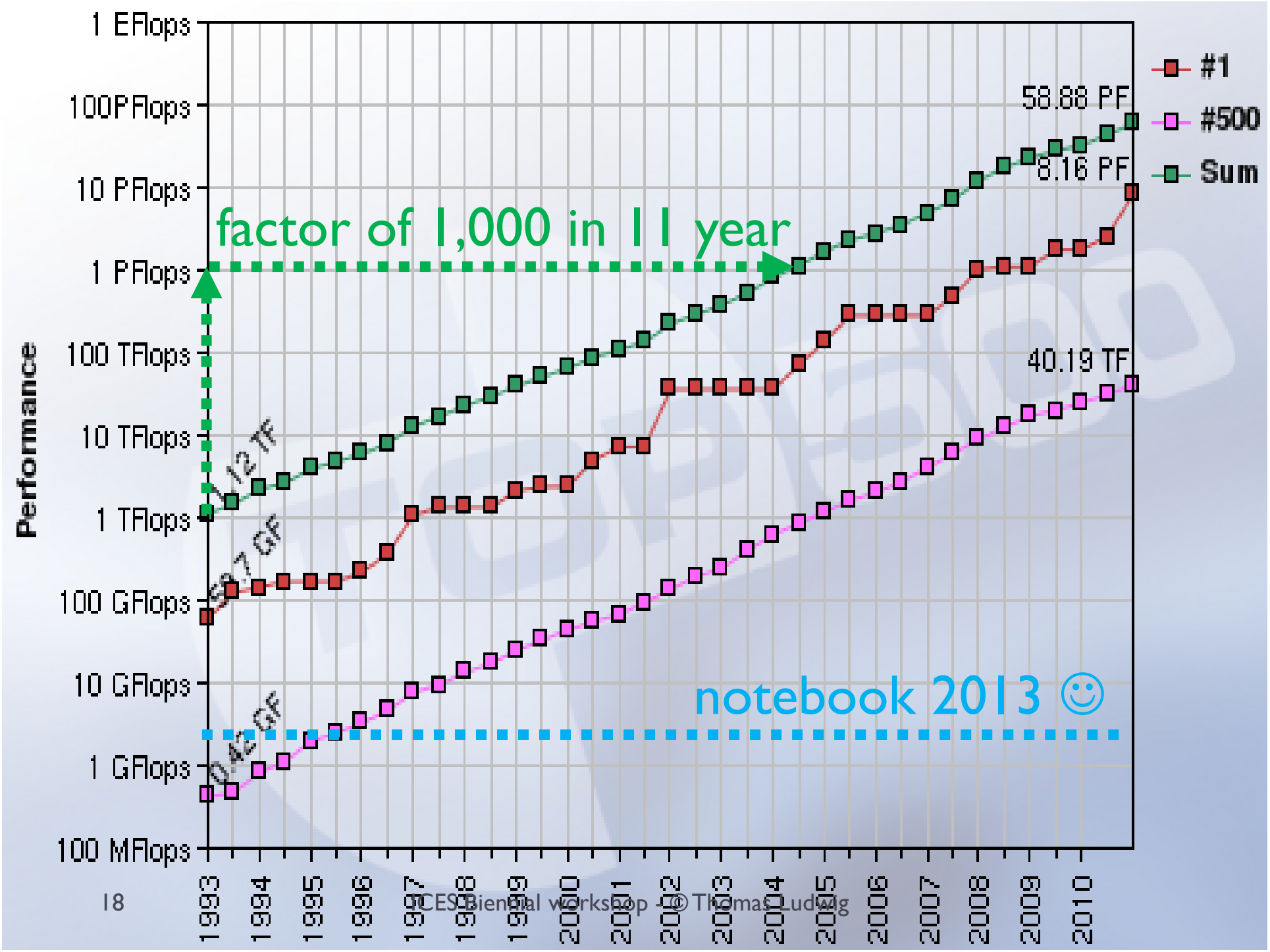
- Juni: International Supercomputing Conference Germany
- November: Supercomputing Conference USA

Based on LINPACK benchmark

The Top 5 Computers from June 2013

34 PFLOPS = 34.000.000.000.000.000 vs. 0.01 FLOPS for a human computer

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	National University of Defense Technology China	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	3120000	33862.7	54902.4	17808
2	DOE/SC/Oak Ridge National Laboratory United States	**Titan** - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560640	17590.0	27112.5	8209
3	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1572864	17173.2	20132.7	7890
4	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705024	10510.0	11280.4	12660
5	DOE/SC/Argonne National Laboratory United States	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786432	8586.6	10066.3	3945


1 EFlops
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10 PFlops
1 PFlops
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Sum
58.88 PF
8.16 PF
40.19 TF
1.12 TF
59.7 GF
0.42 GF
factor of 1,000 in 11 year
notebook 2013 ☺

Performance Increase

Moore´s Law

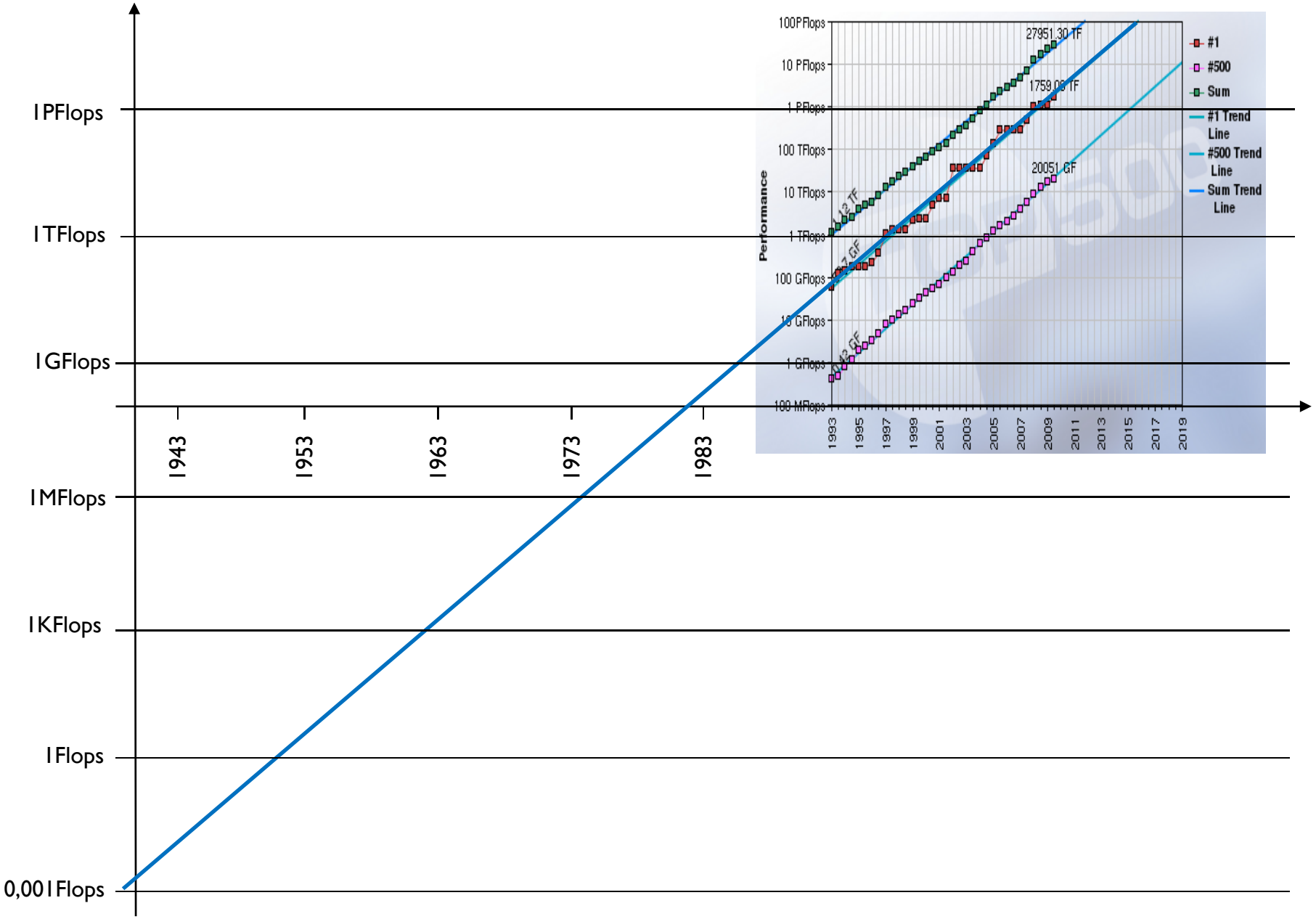
„Doubling of transistors every 18 months“

Corresponds to a doubling of performance

Jun93 to Jun13: 20 years = 13.3 x 18 months

factor $2^{13.3} \approx 10{,}000$

Total performance:	1 TFLOPS – 223.000 TFLOPS (x 223,000)
Performance #1:	60 GFLOPS – 33,862 TFLOPS (x 564,366)
Performance #500:	0.4 GFLOPS – 96,600 GFLOPS (x 241,500)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1759,09 TF
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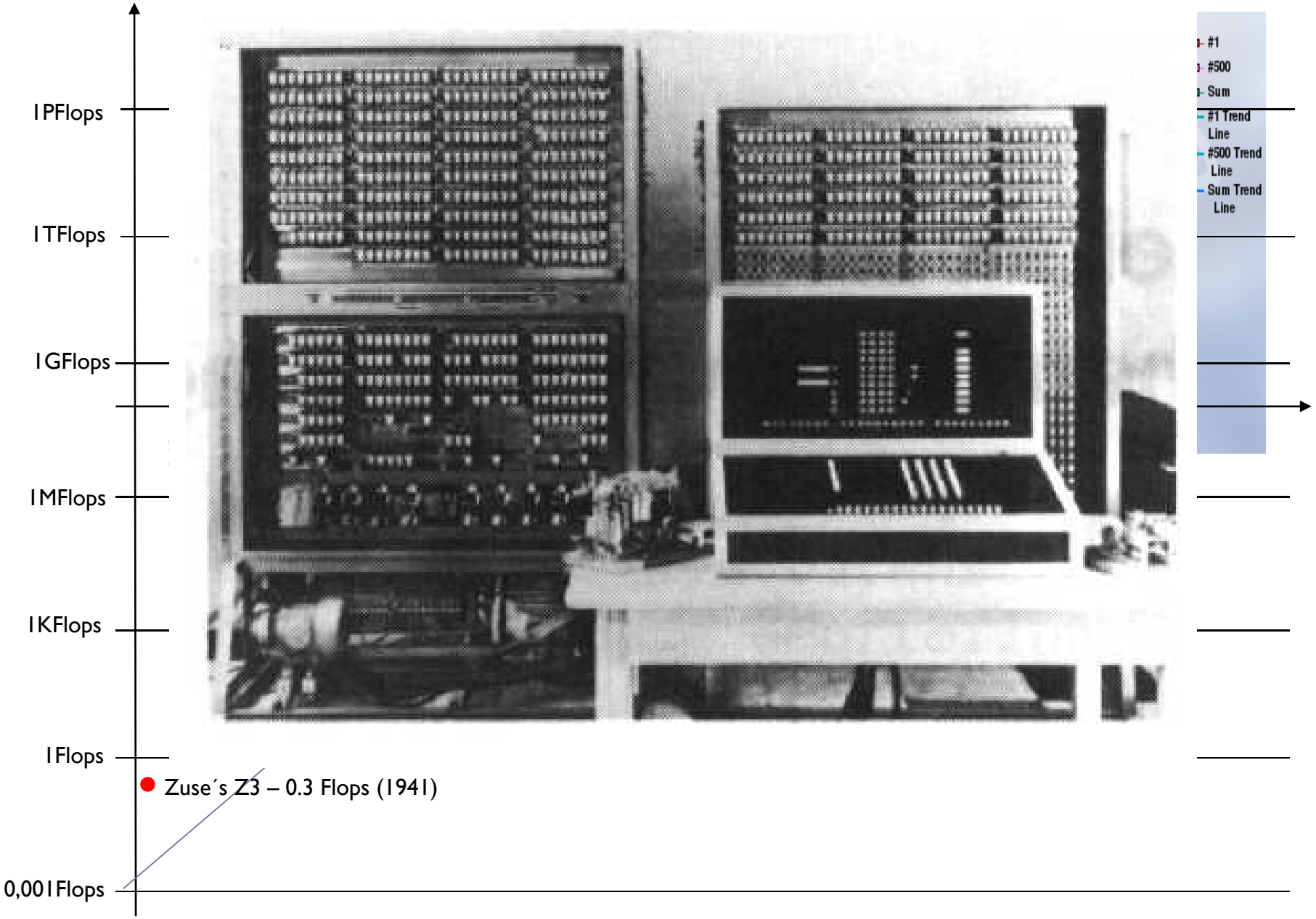
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Zuse´s Z3 – 0.3 Flops (1941)
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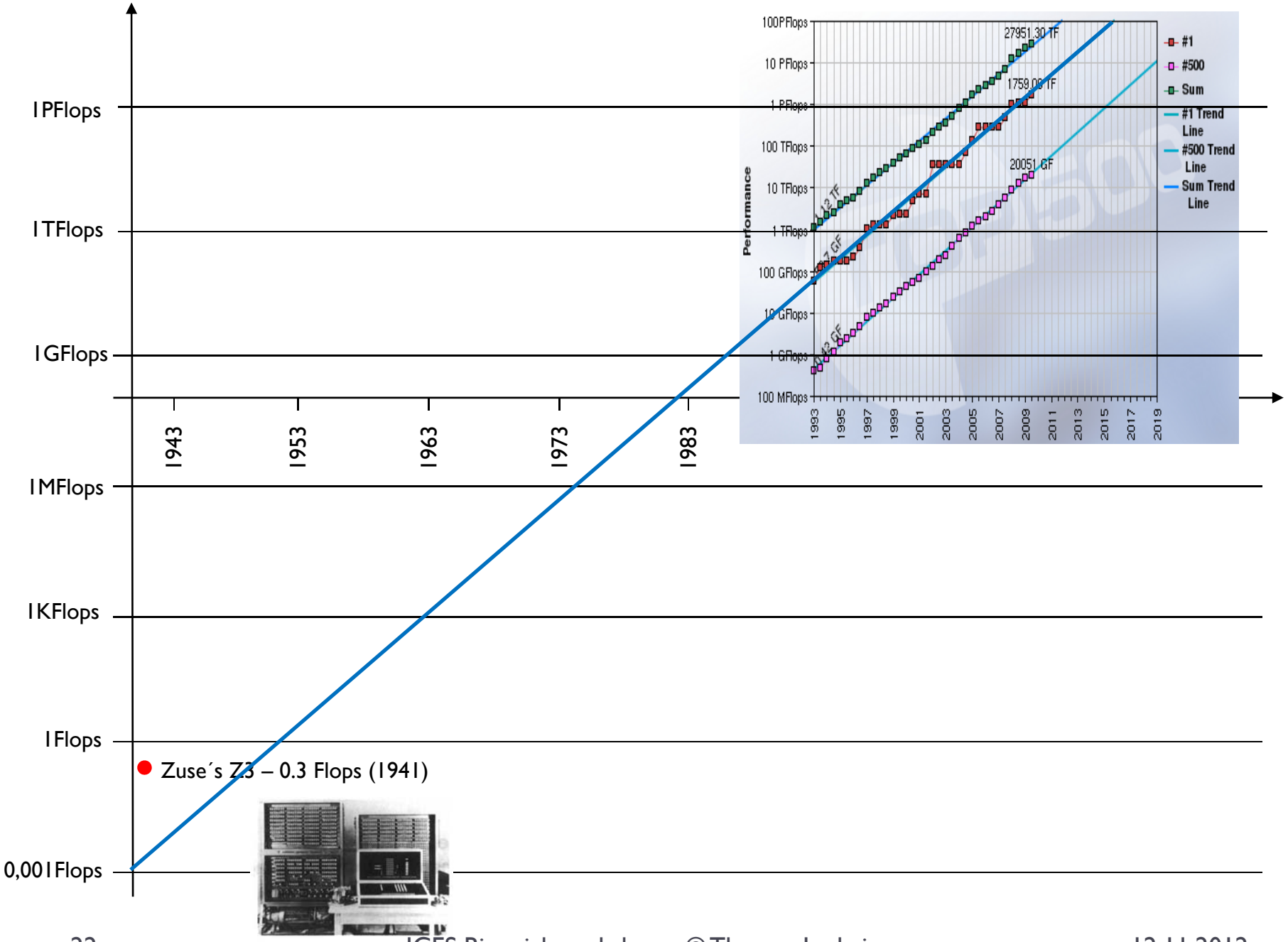
#500 Trend Line
Sum Trend Line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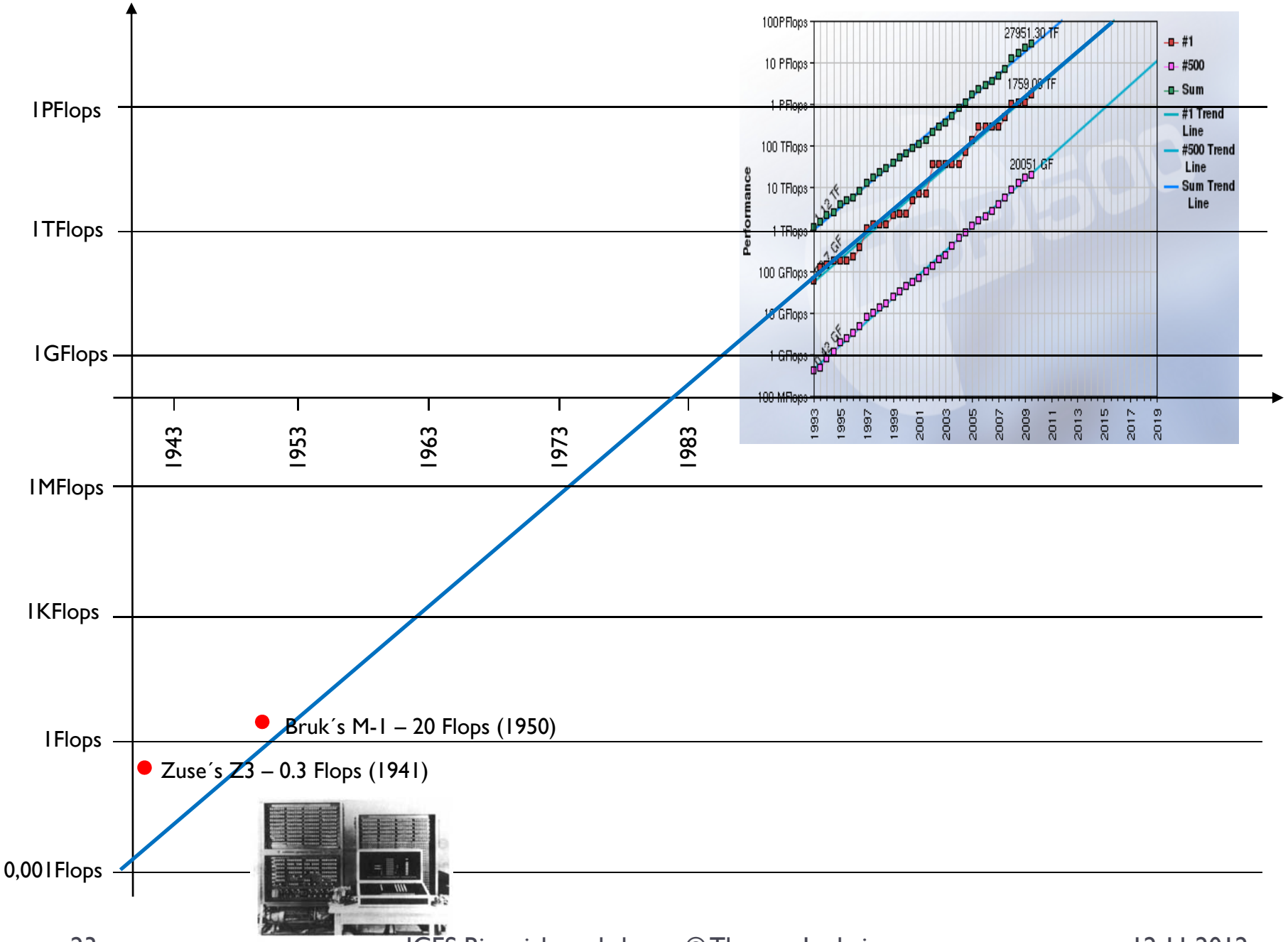
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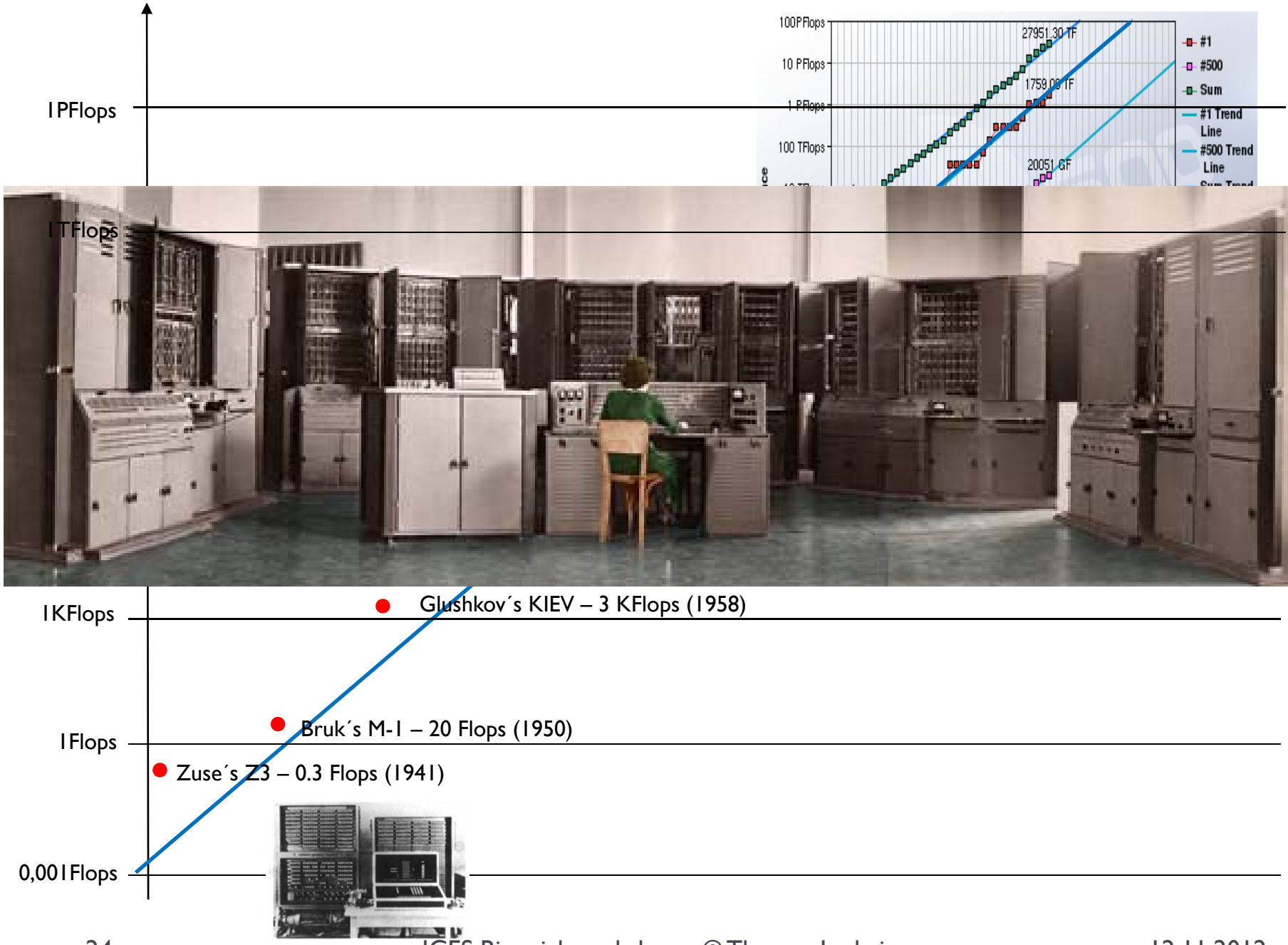
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Bruk´s M-1 – 20 Flops (1950)
Zuse´s Z3 – 0.3 Flops (1941)
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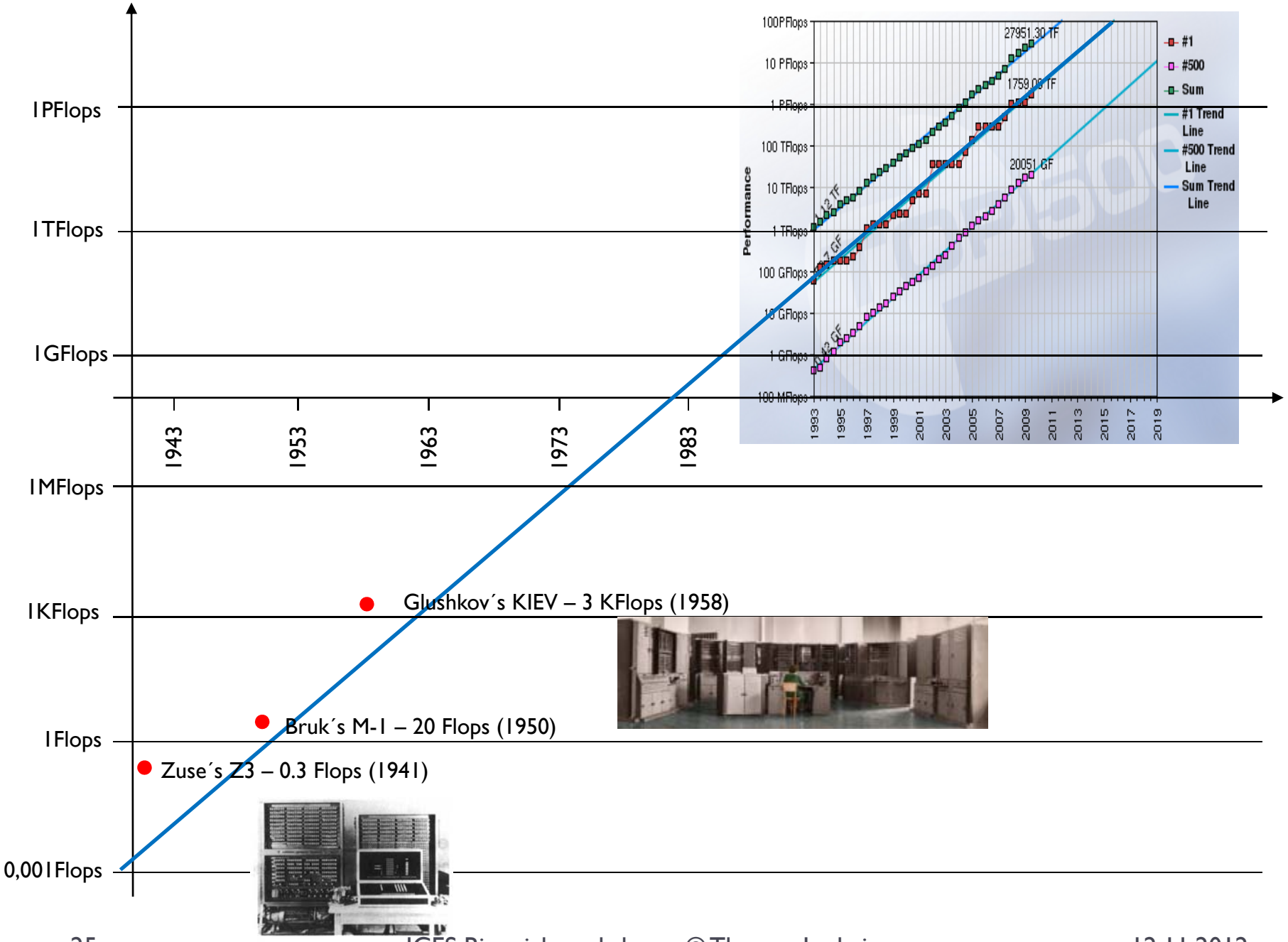
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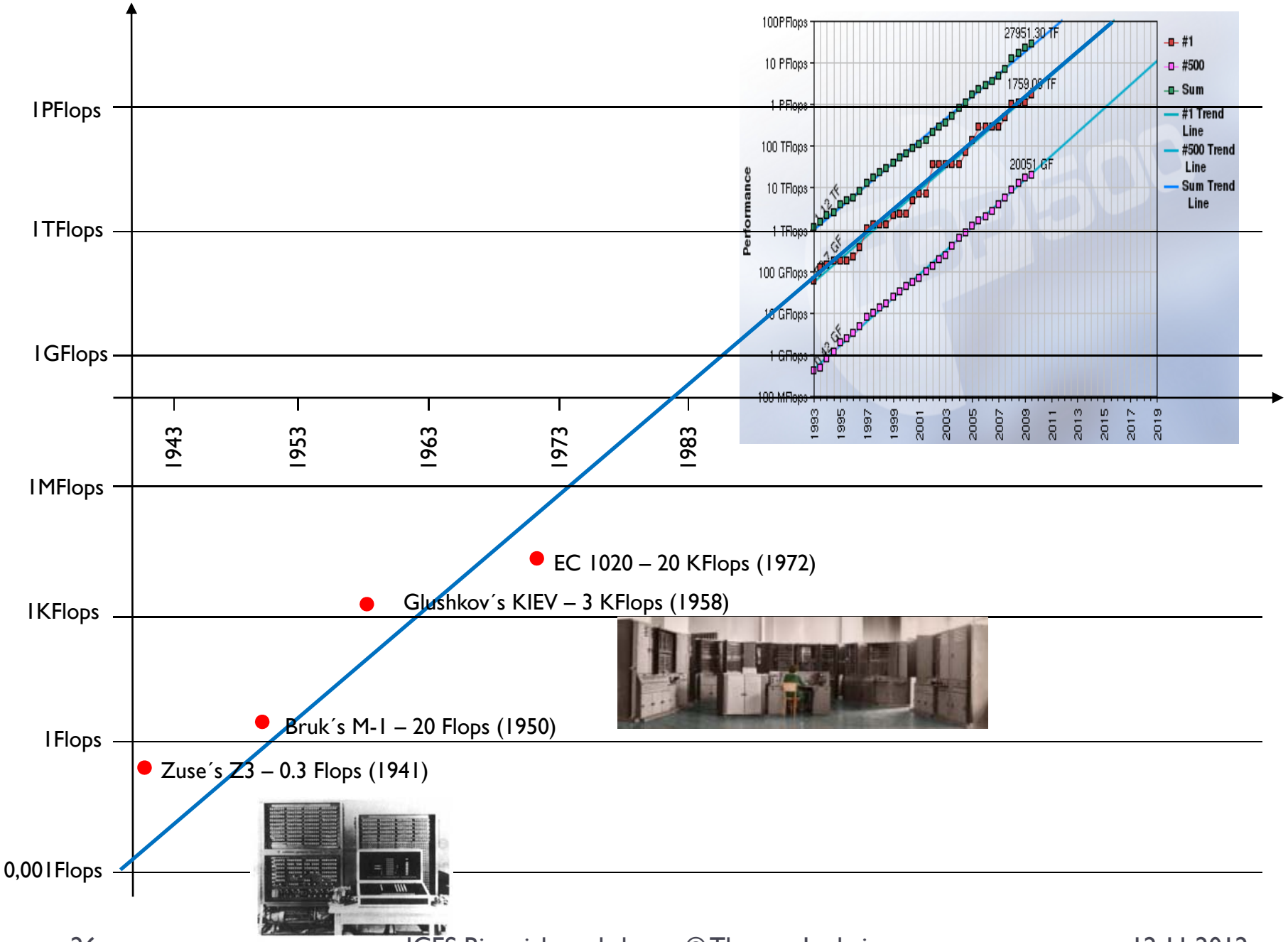
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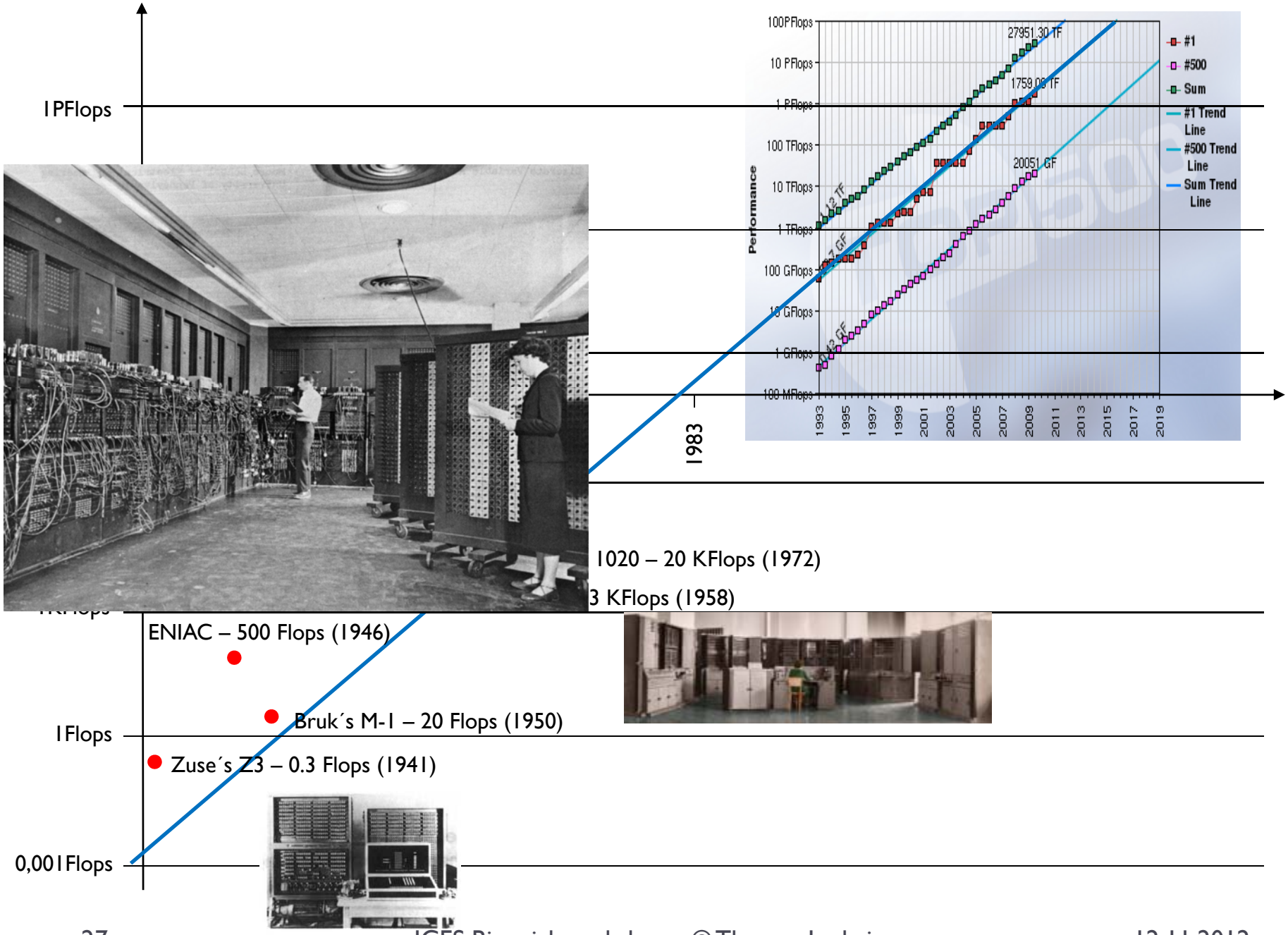
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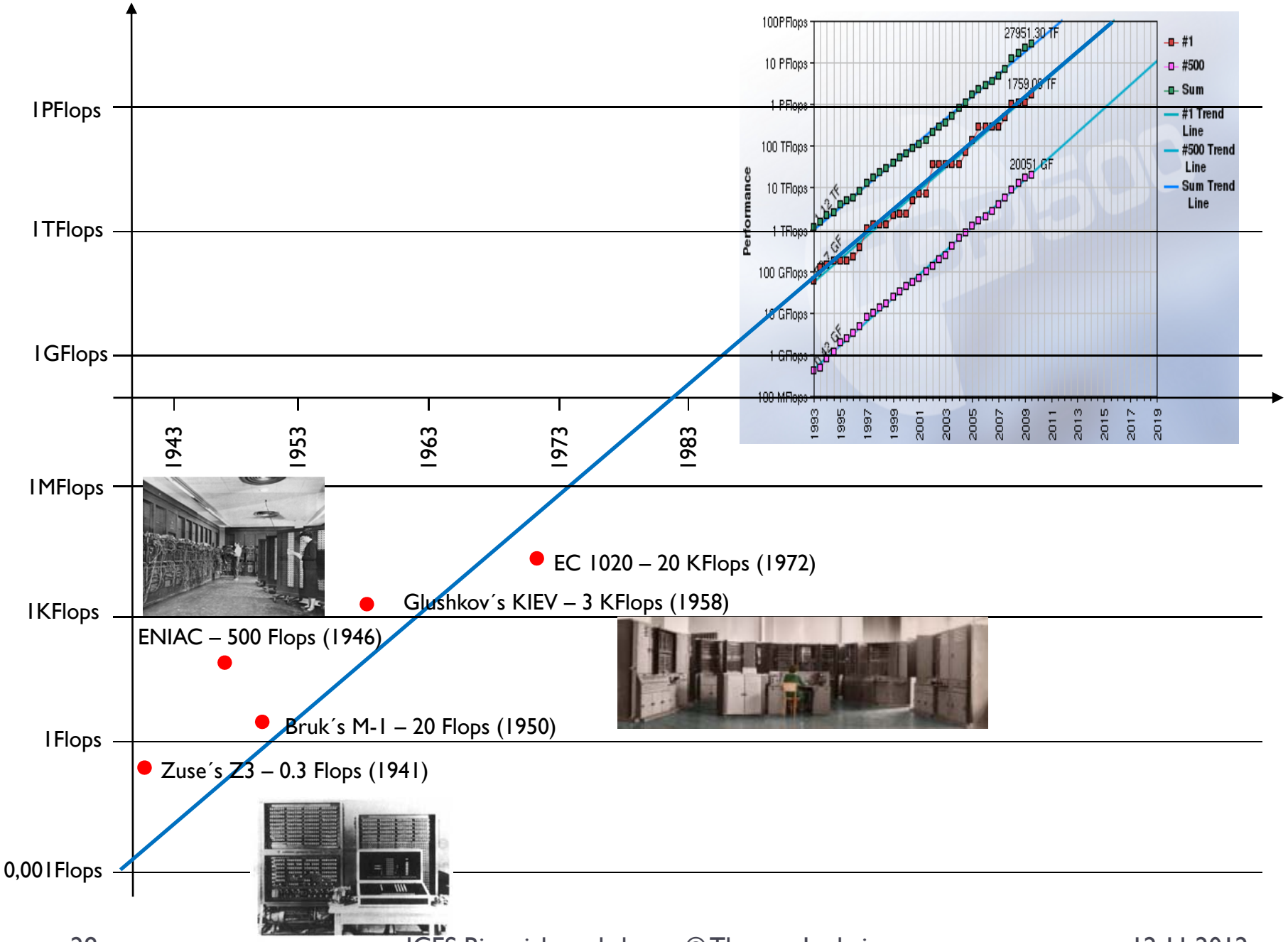
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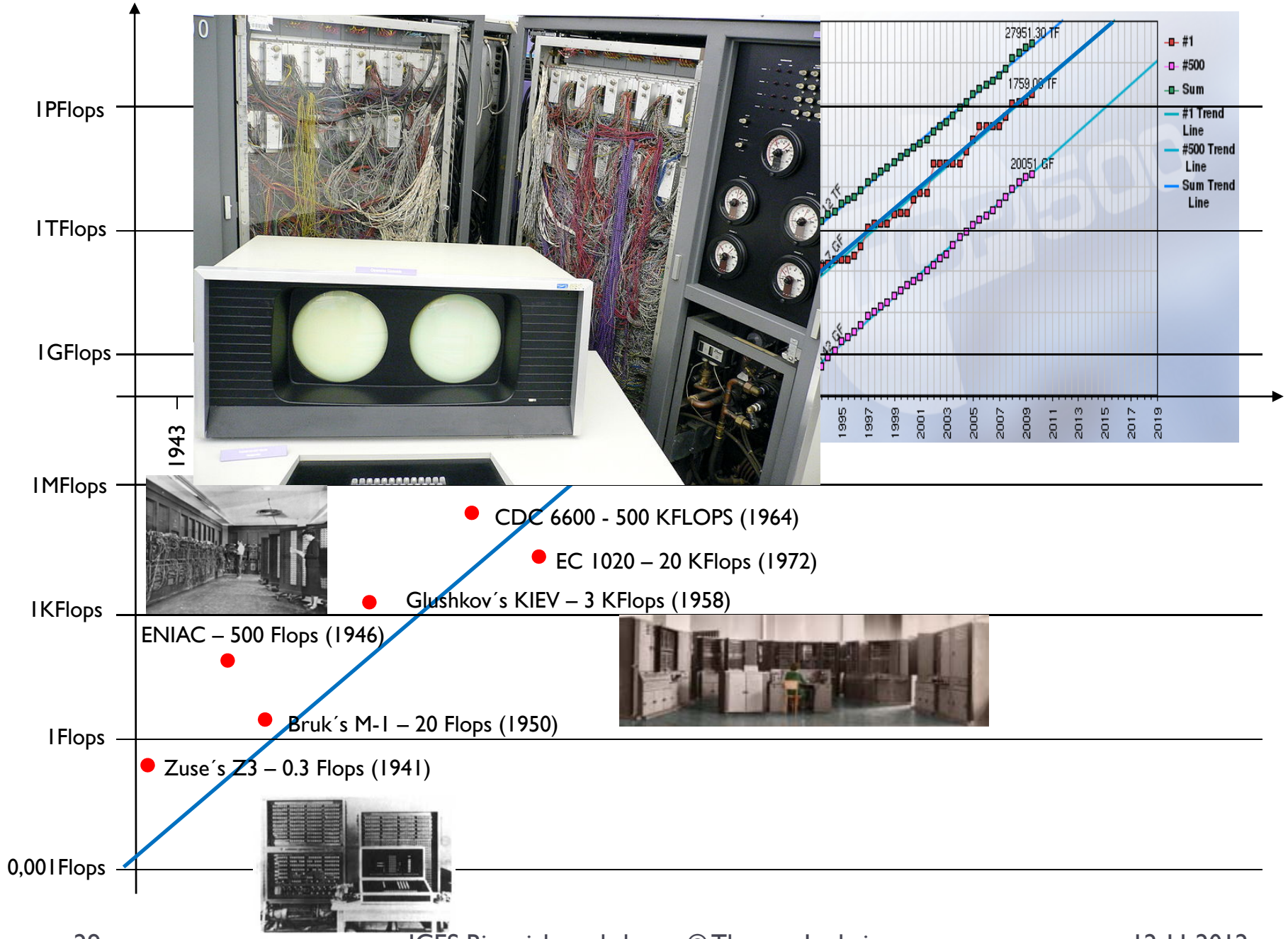
EC 1020 – 20 KFlops (1972)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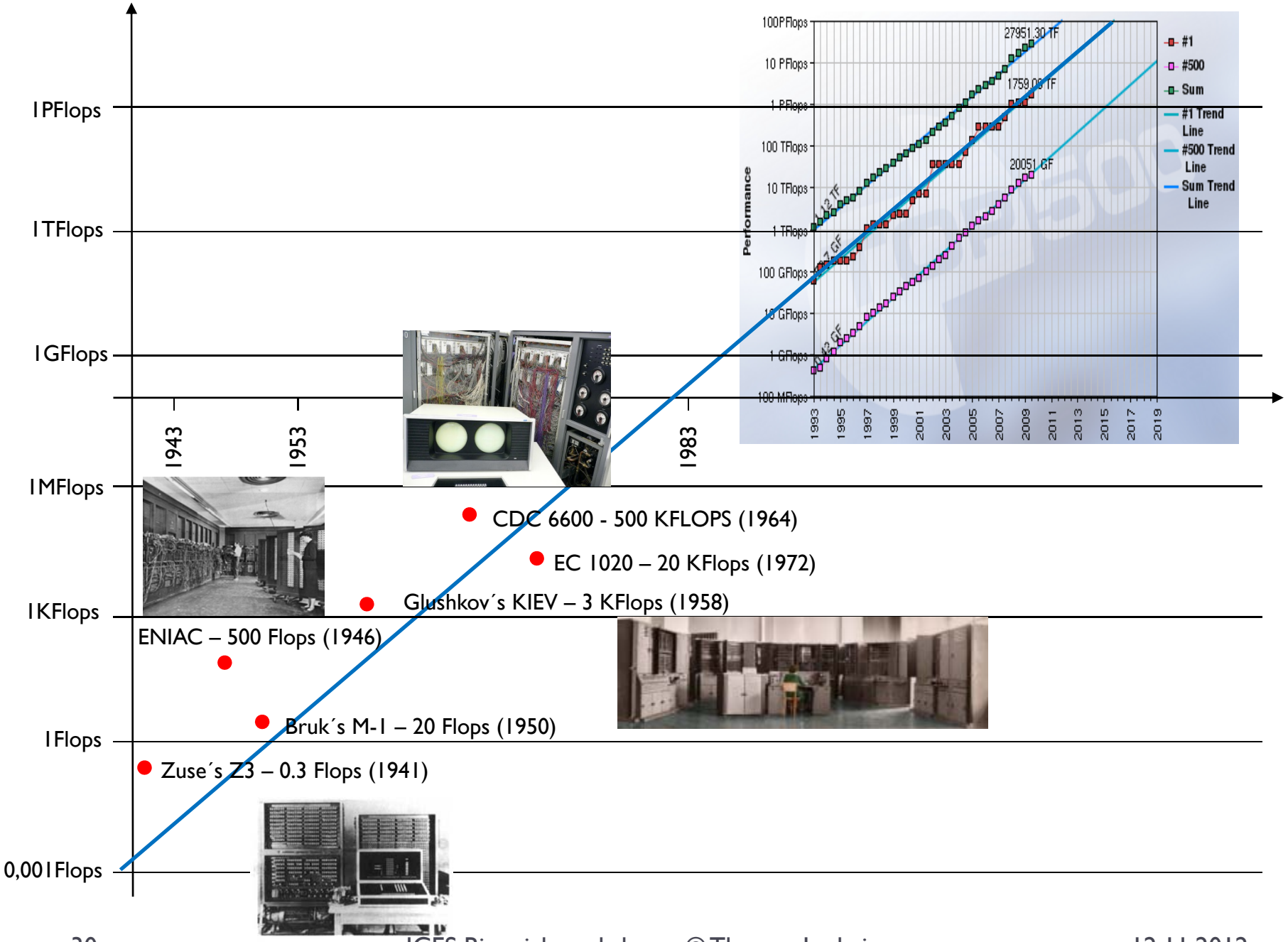
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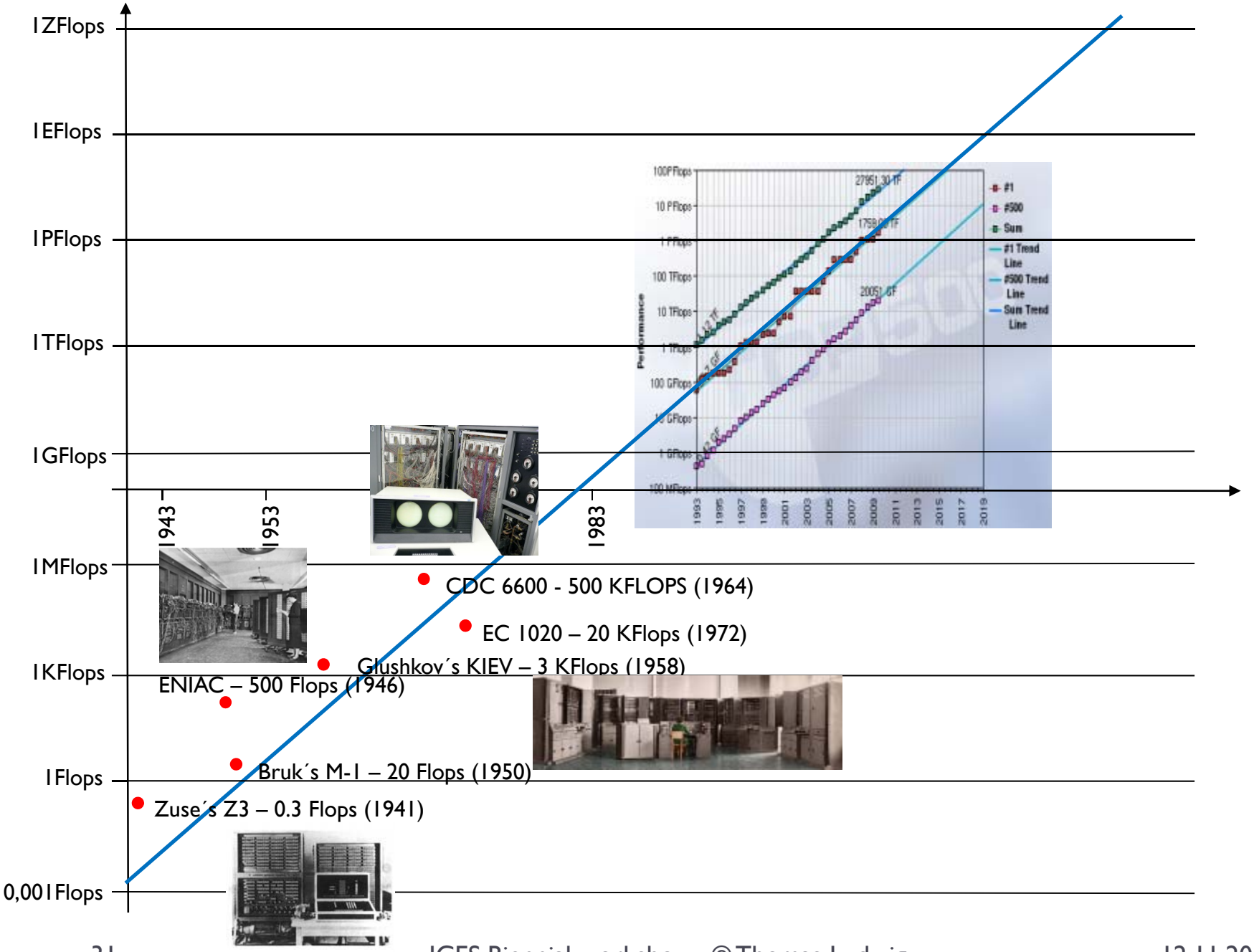
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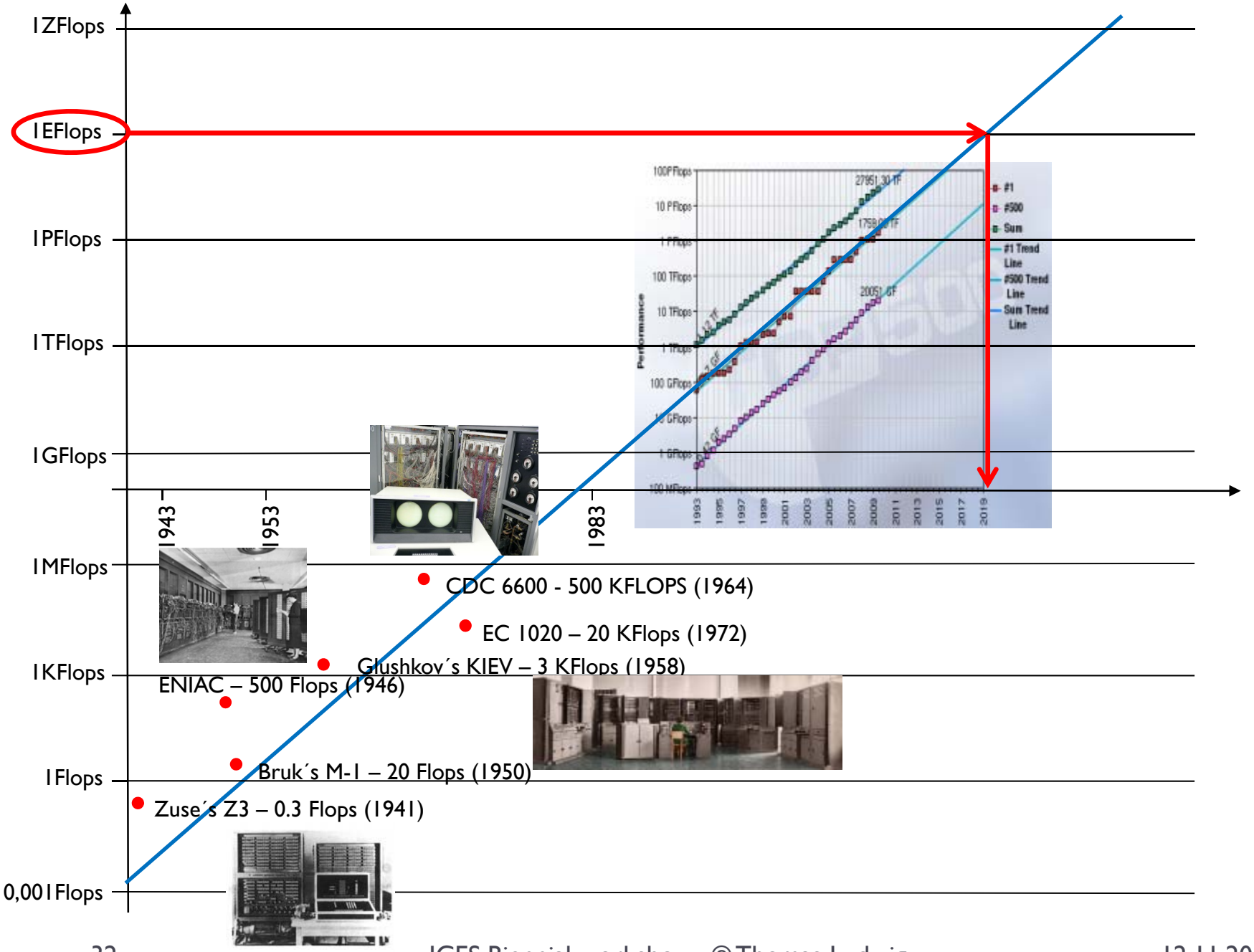
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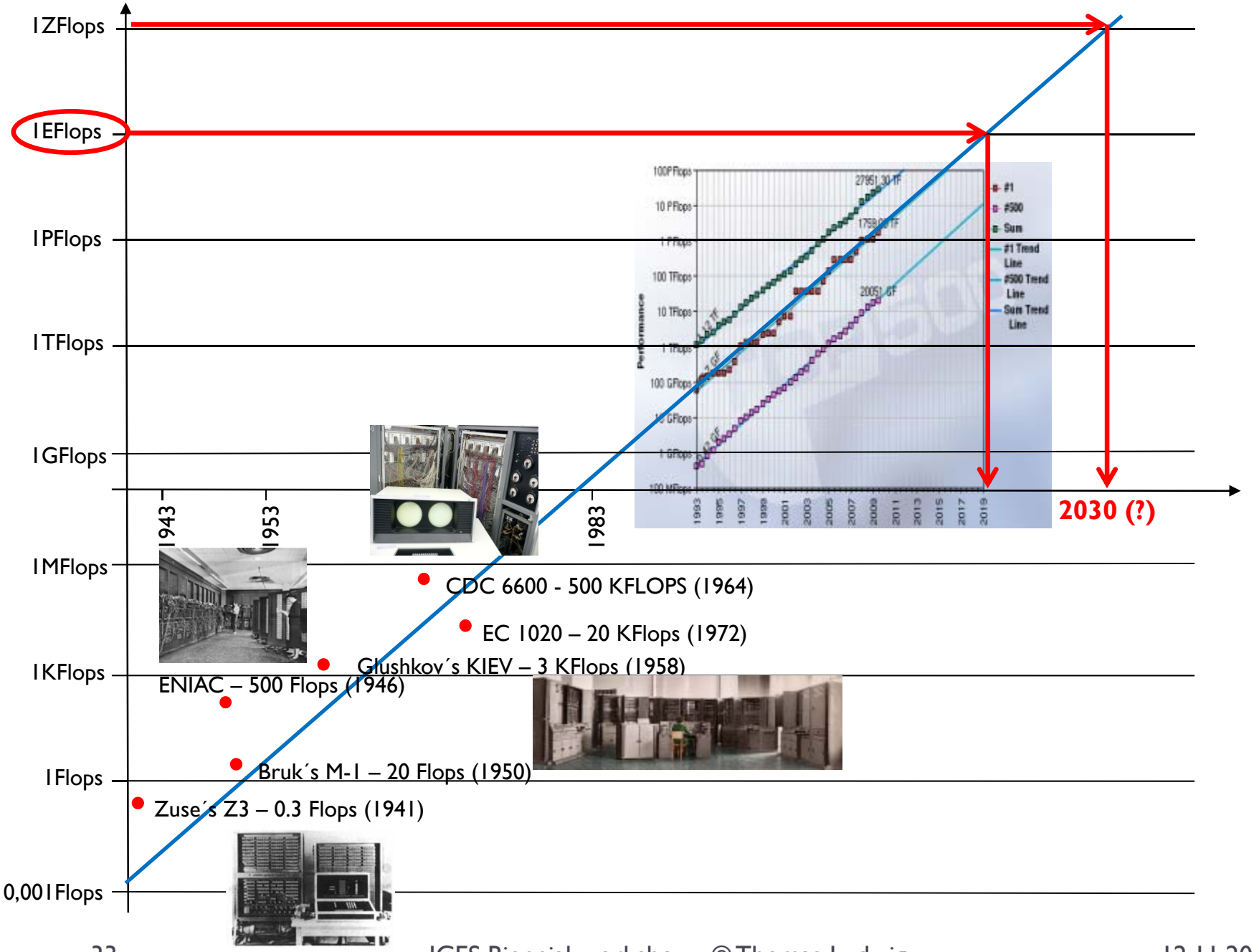
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CDC 6600 - 500 KFLOPS (1964)
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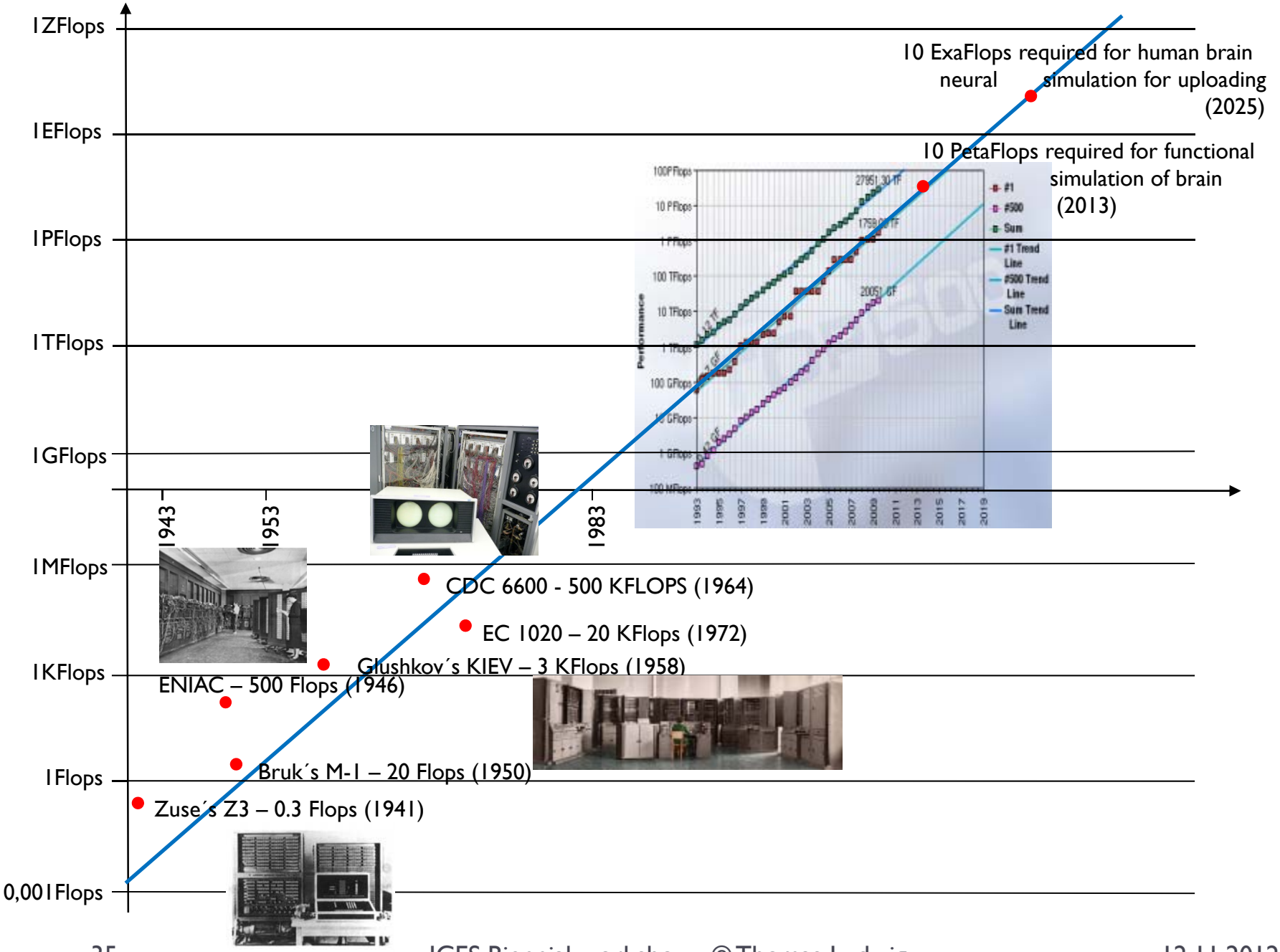
Post-Exascale Hardware

Current technology

- Based on semiconductor
- Transistors since 1952, diodes since ca. 1900

Future technologies

- Carbon nanotubes
- Biocomputers
- Quantum computers
- Higgs Boson computers ☺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10 ExaFlops required for human brain neural simulation for uploading (2025)
10 PetaFlops required for functional simulation of brain (2013)
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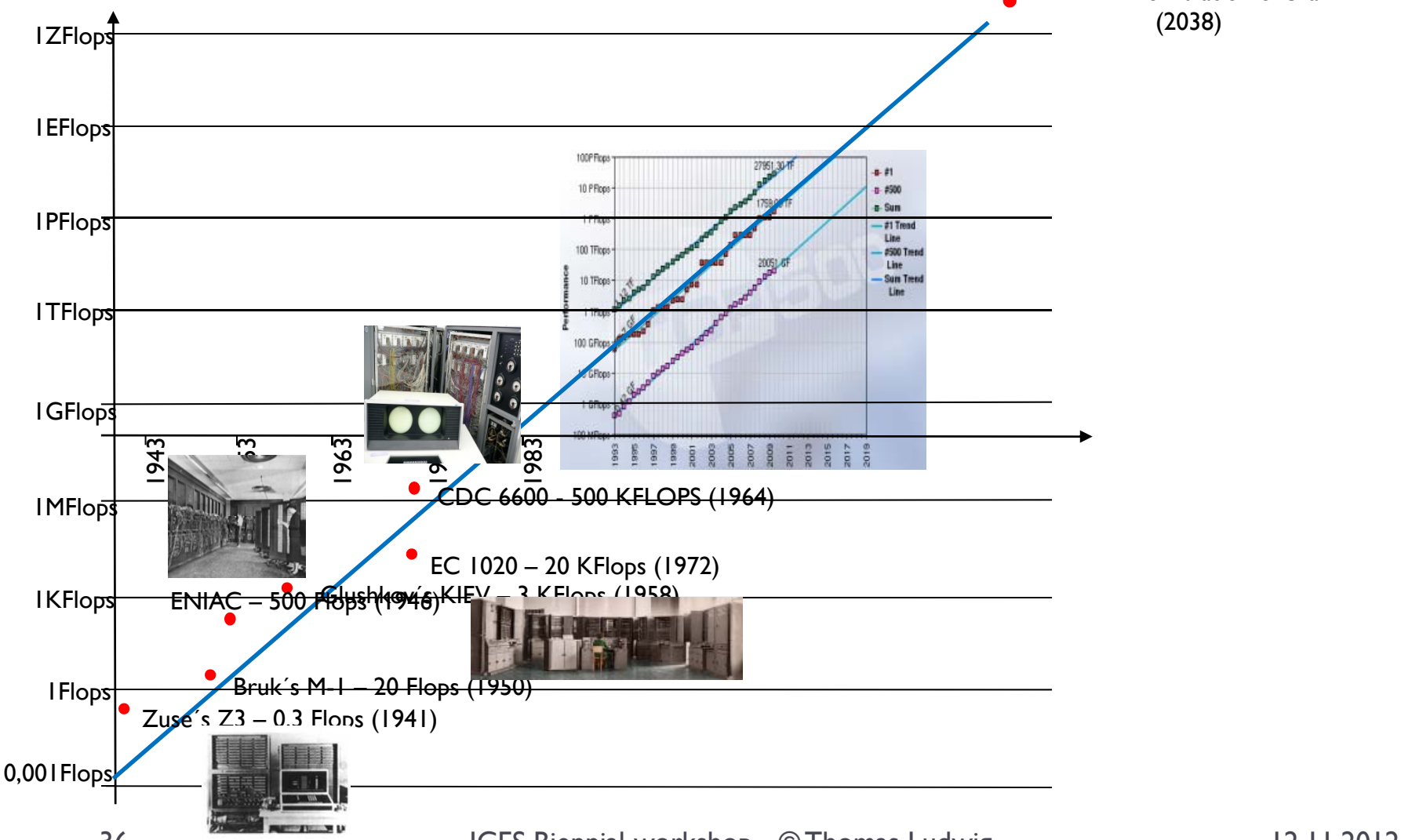
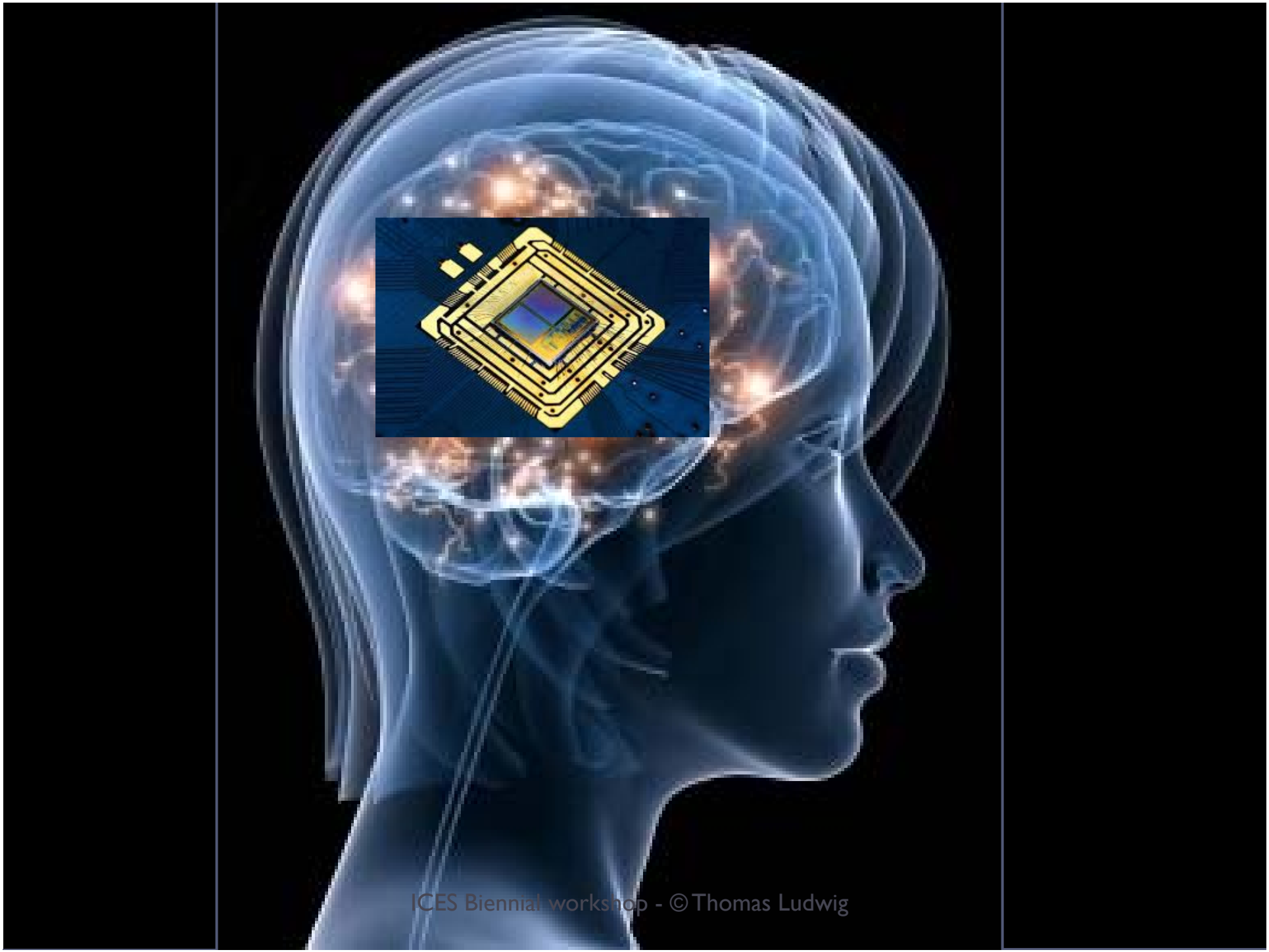
Better add 25 years and factor 1,000,000 compute power





Technological Singularity

The technological singularity is the theoretical emergence of greater-than-human superintelligence through technological means. (Wikipedia)

Mentioned first by John von Neumann in 1958

Ray Kurzweil predicts it for 2045