A vision of systems and technology in a connected Europe

Giovanni De Micheli

May you live in interesting times !
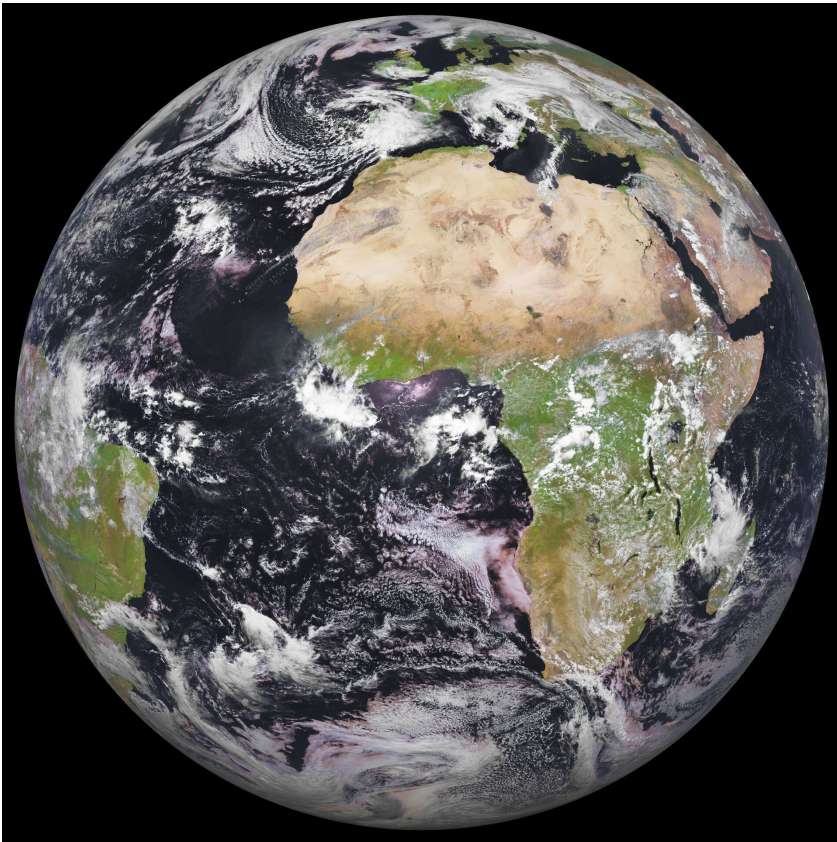
[P.A. Lorenzetti,1338]

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The challenge for this decade and beyond

# The challenge for this decade and beyond

- AI/ML and data-driven science require:
  - Large storage space
  - Large amount of energy for computation
- How do we rethink architectures, circuits and devices ?
  - To enable *edge devices* to use AI/ML
  - To curb the energy consumption
- Human/planetary dimension of AI/ML
  - Ethical questions

(c) Giovanni De Micheli

Migration is a planetary event

- Migration in 2020
  - 281M – 3.6% world population [Source UN IOM]
- Migration patterns
  - EU importing low-tech workers
  - EU exporting high-tech personnel
  - EU fluxes in 2022 – 7M in, 2.7 out [Source EU commission]
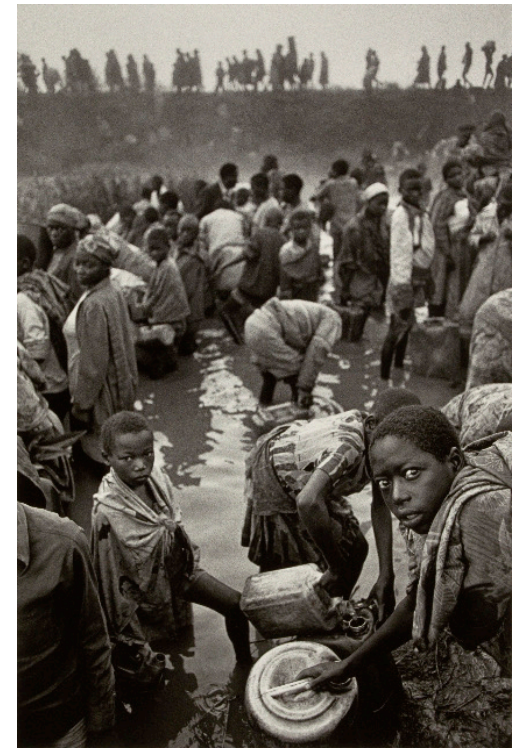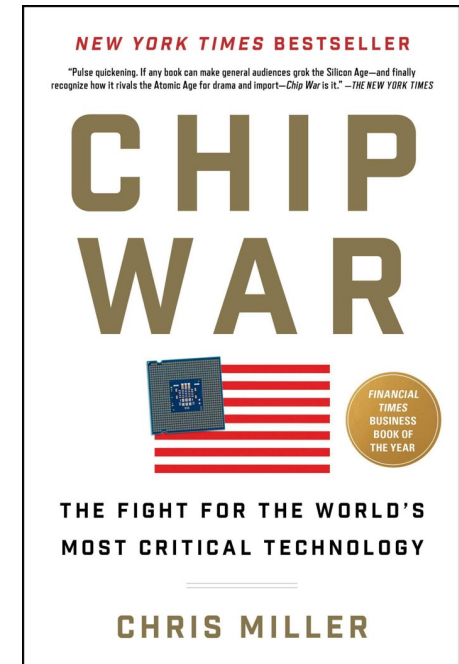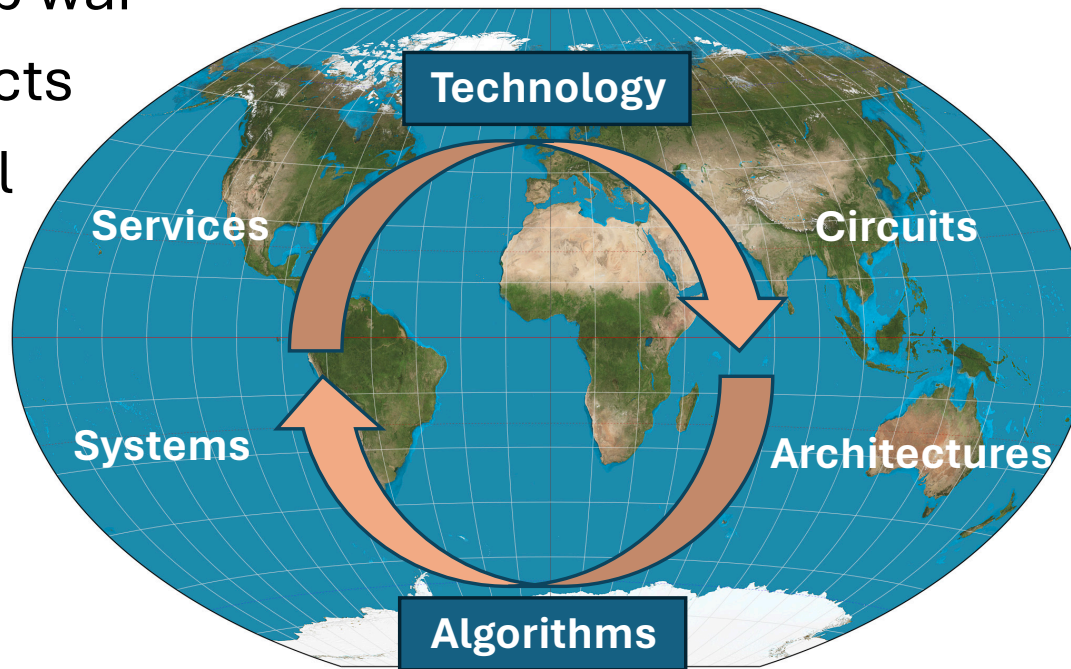
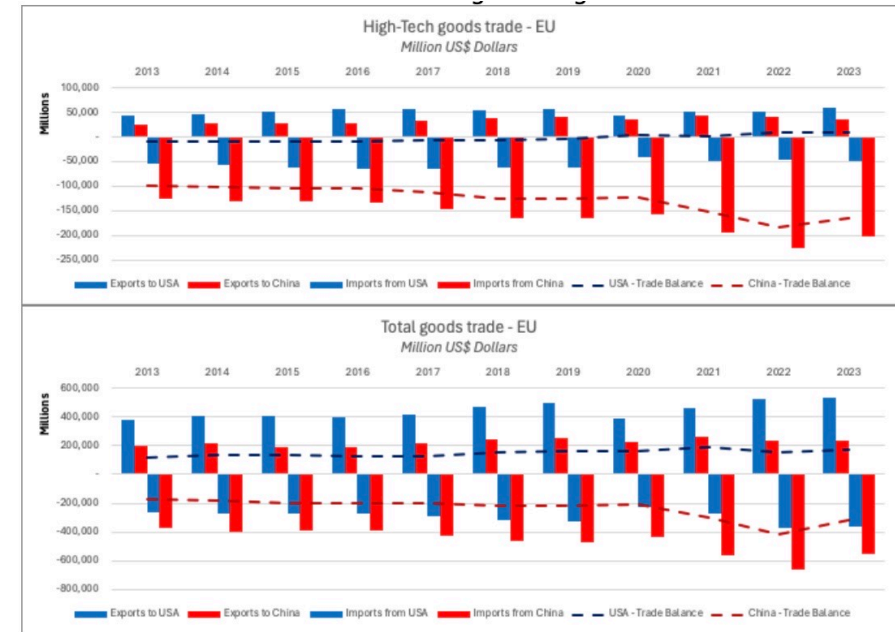[Source: S. Salgado]

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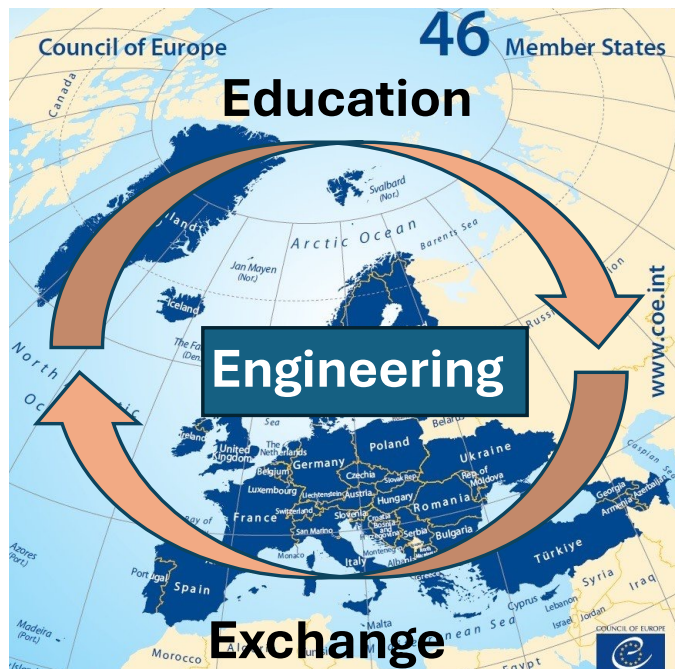
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Fragmentation of the world technological market

- US-China chip war
- Chip and AI acts
- Export control

Europe in a fragmented world

- Keep competitive in technology
- Form and retain key scientists/engineers
- Keep fruitful osmosis with rest of the world

[Source: UN Comtrade]

Key Point # 1

- European counties have diverse cultural origins and habits
  - Long and complex history

- Europe requires a critical mass to compete with US and China
  - Investments, market, menpower

- Europe should attract more scientists/engineers to work
  - Smart immigration
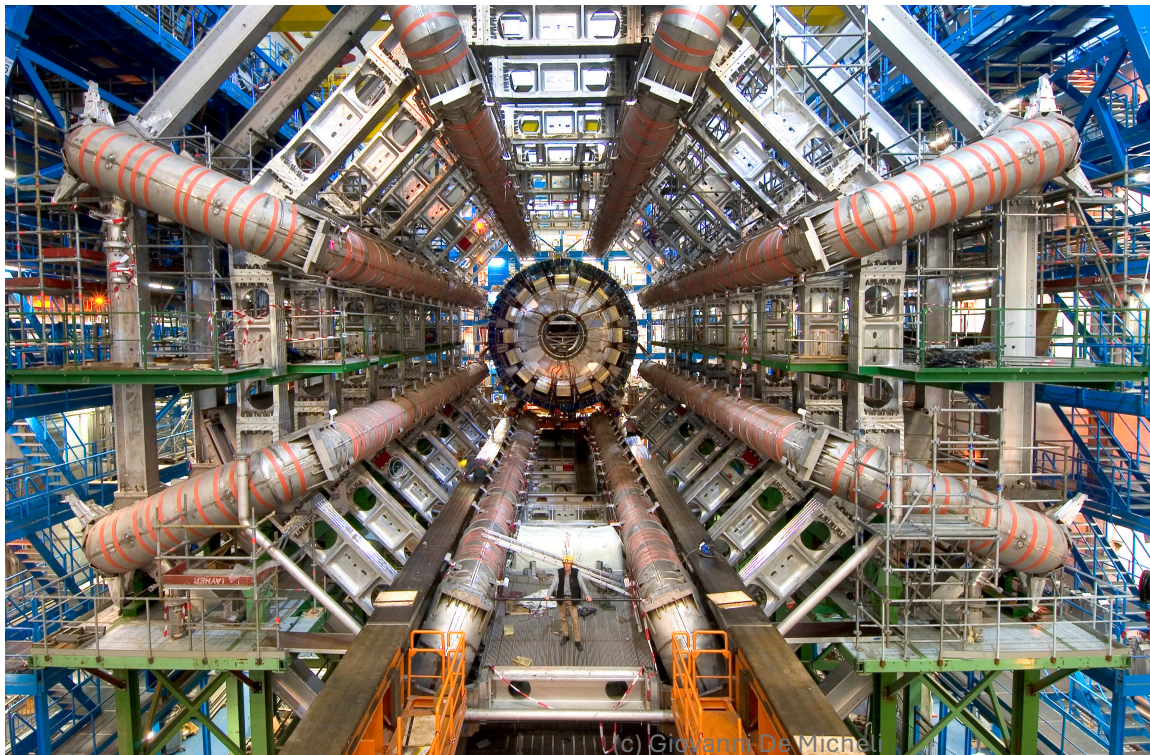
Europe is a cradle of technologies

- Strong coupling among art, culture and science

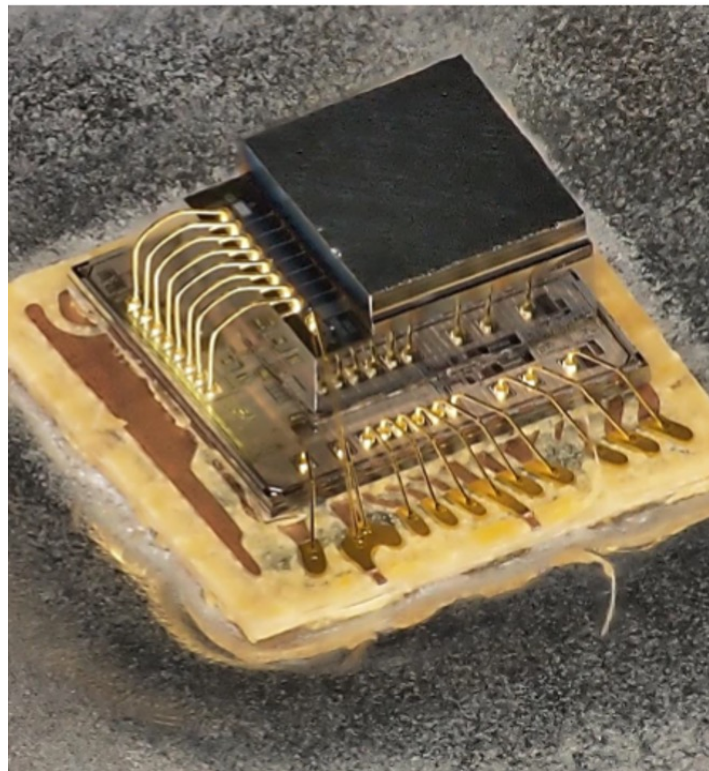[U. Boccioni, 1911]

Gems of Europe

- The ATLAS detector at CERN

Gems of Europe

- Intelligent sensor processing unit: edge AI in a sensor

[Courtesy: STMicroelectronics]

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Gems of Europe

- EUV litography enables nanometer CMOS fabrication

Gems of Europe

- Audi A8: a supercomputer on wheels

Gems of Europe

- EUTELSAT Quantum
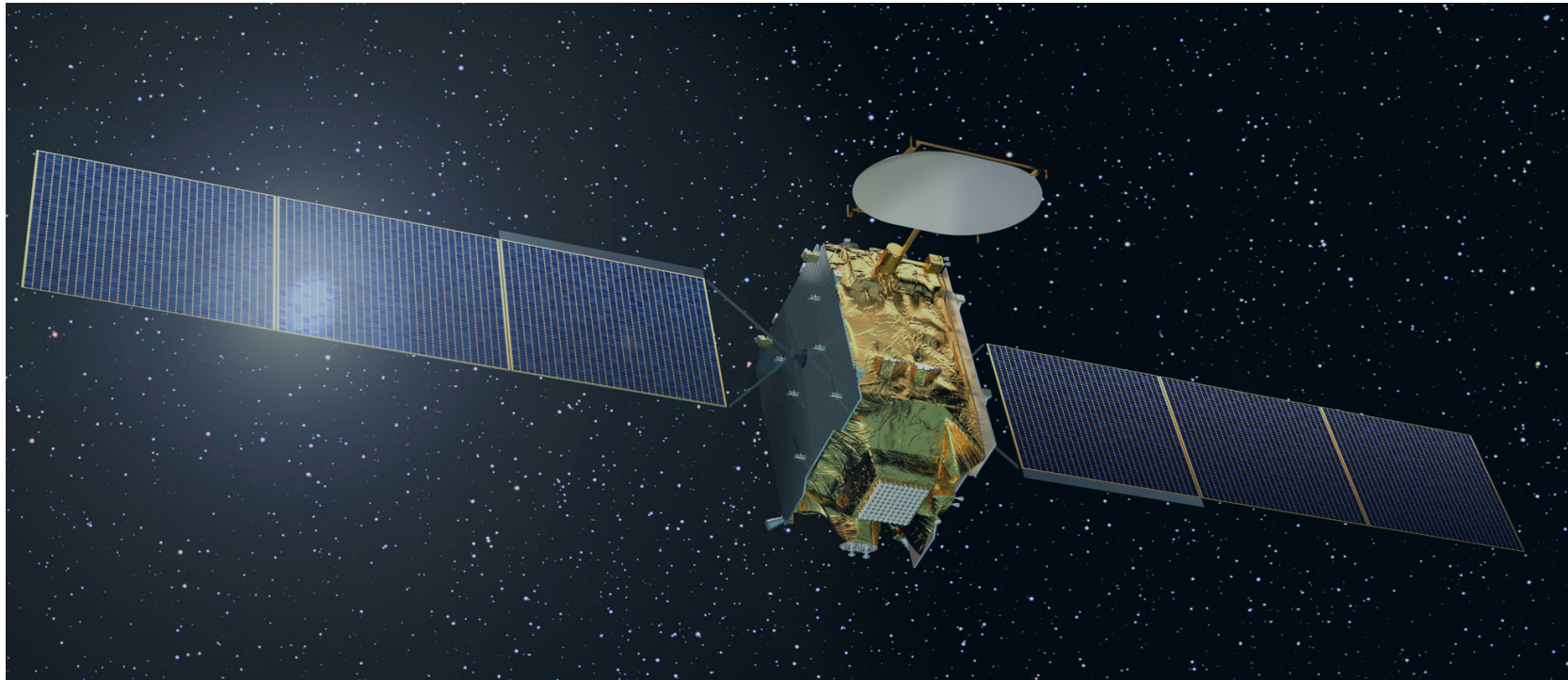
Where is the space for growth ?

- Systems versus components
  - Europe is strong in systems but needs components
  - Strong *value added* of systems and services
- Silicon versus hybrid
  - Si, GaN, SiC
  - There are more directions othen than downscaling silicon
- Ownership of the backbone of information society
  - From networks to ML/AI platforms and applications
- Smart, essential and frugal software
  - Commitment to green computation

Electronic systems industry

- There are plenty of opportunities for technical & market growth

  - Citius – Faster
    - Higher performance
  - Altius – Higher
    - 3-Dimensional
  - Fortius - Stronger
    - Do effort with less energy

Lausanne - CIO

There is plenty of space at the bottom

- Quantum computing accelerates computation
  - In some restricted but relevant domains
- Error tolerance and corrections
  - Evolution from NIQC to FTQC
- QC will be provided as a service
  - Will QC reach the workplace, home, edge?
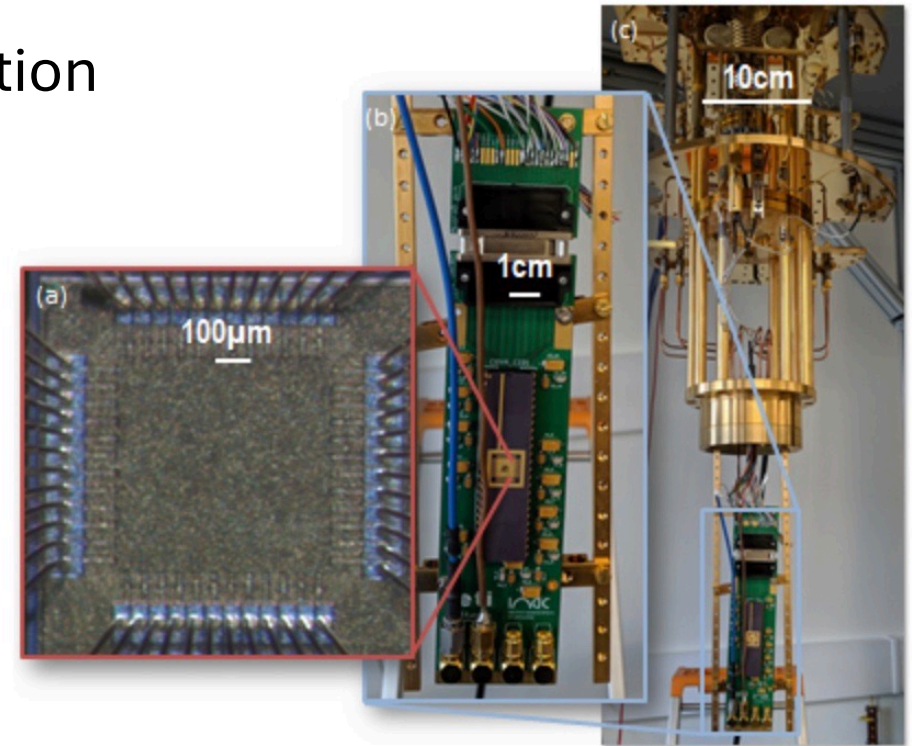
[Source: LETI]

Quantum computing

[P. Picasso]

- Two facets of quantum engineering:
- The physical world
  - Using matter to compute with *superposition* and *entanglement*
- The computational world
  - Designing and *compiling* algorithms into quantum circuits
- EDA can be instrumental for R&D in both domains
  - Advanced *physical design* and *quantum compilation*

There is plenty of space at the top

active **3D**

Current roadmap

active FEOL, passive BEOL

- finFET 2018-22
- GAA NSFET 2024-26
- FSFET 2028-30
- CFET 2032
- CFET 2034
- atomic CFET 2036
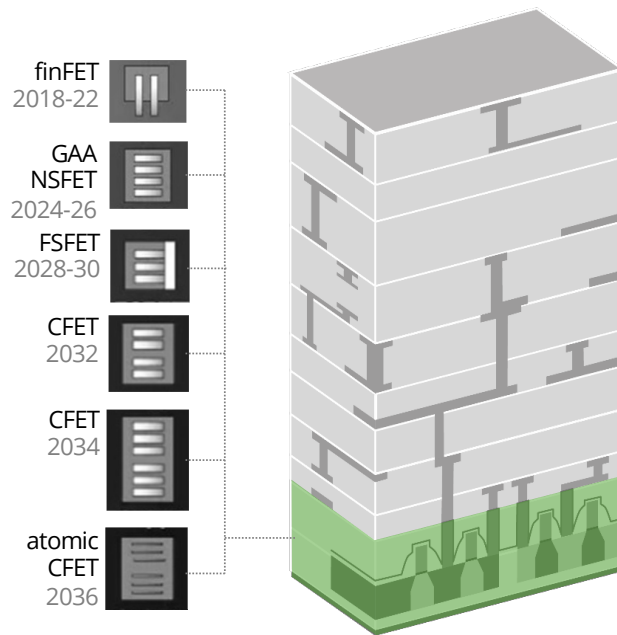
ABEOL Active 3D

active FEOL, active BEOL

- Devices integrated into **volume** BEOL

- **Scalable approach** by adding additional layers

- Can be combined with different base technologies

[TU Dresden and RWTH Aachen]

ABEOL

Perovskite FETs
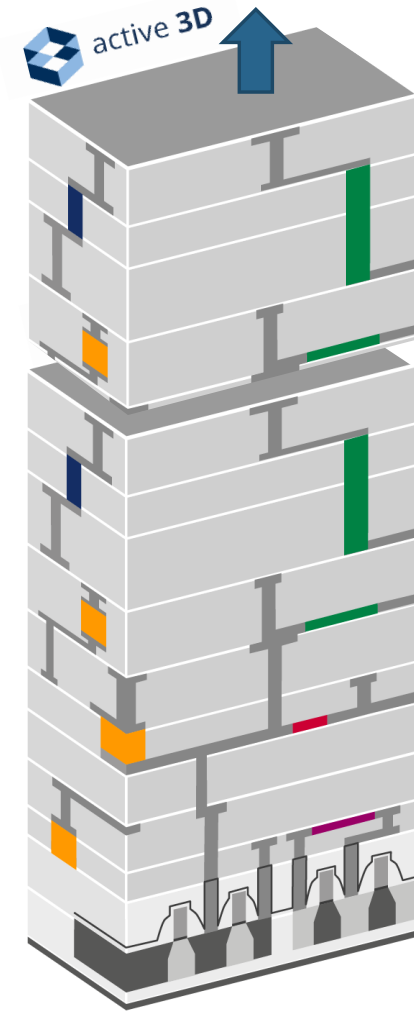
Vertical RFETs

Lateral RFETs

Racetrack Devices

Memristive Devices

BEOL 2D FETs

The N3EXT project

Interleaved logic & memory layers

Ultra-dense 3D

Dense memory

Efficient logic
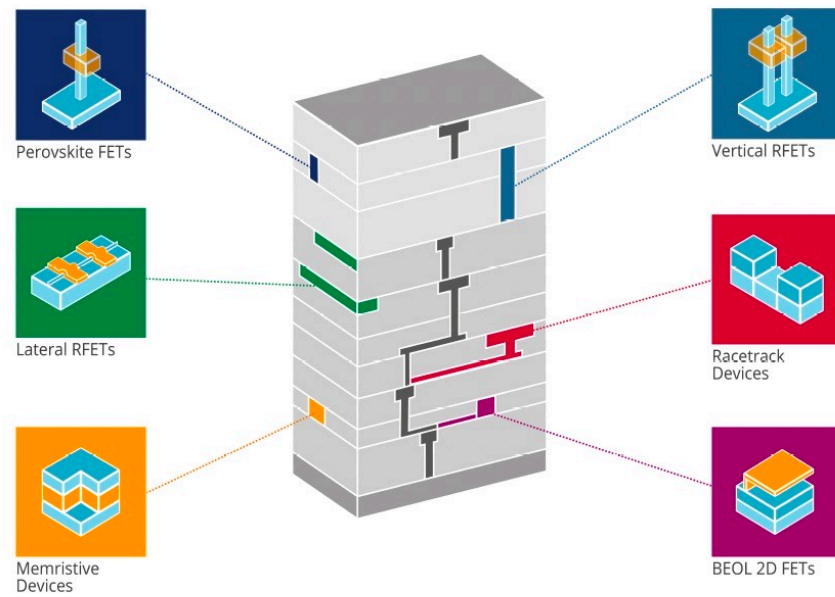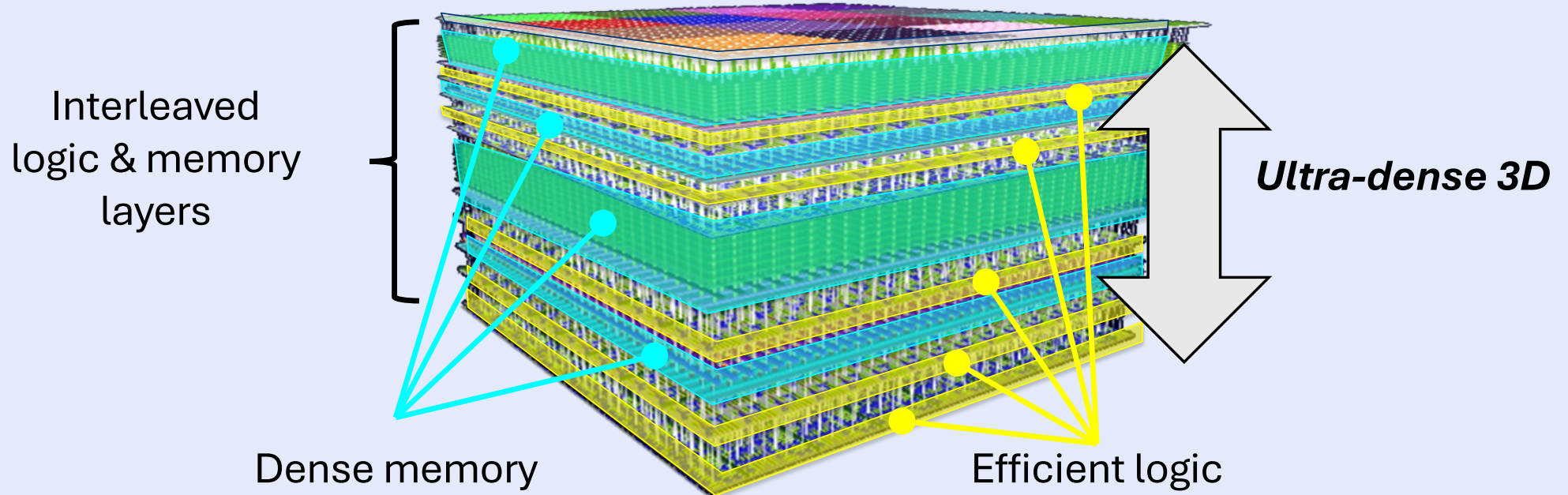
100× – 1,000× Energy Delay Product (EDP) benefits

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SKIN2DTRONICS

- Conformal electronics on any surface
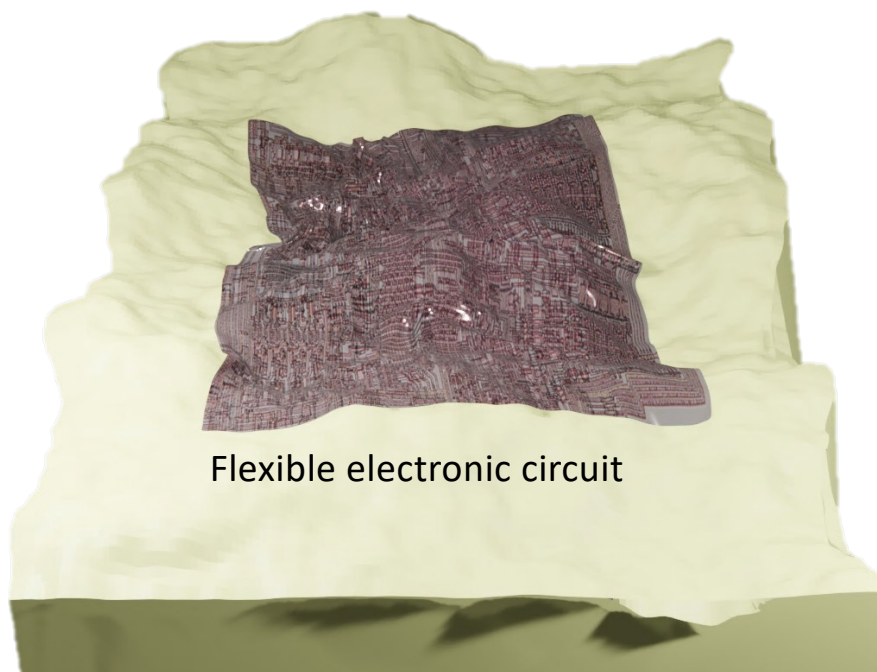
Flexible electronic circuit
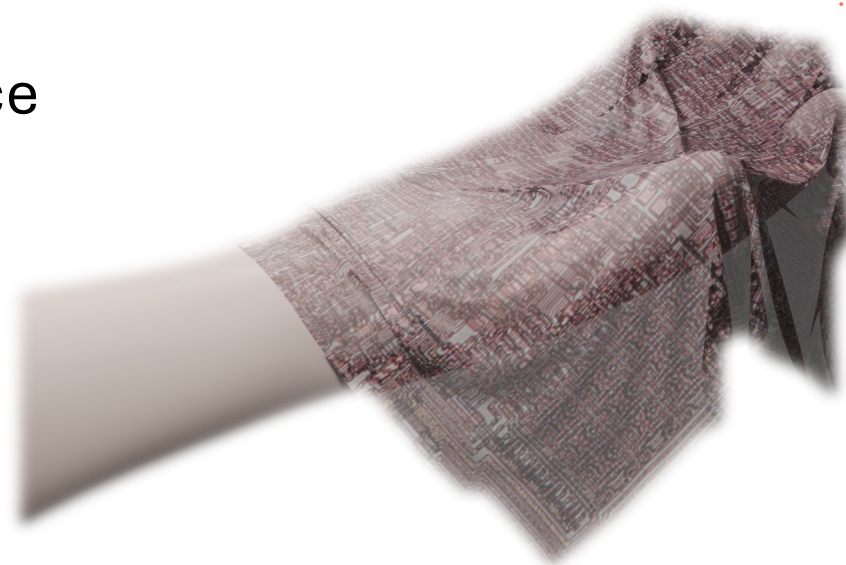
[SKIN2DTRONICS, led by Gianluca Fiori]

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There is plenty of space in the cold

Superconducting electronics

| Logic	Clock Freq. [GHz]	$E_{bit} / I_c\Phi_0$	Typical I_c [mA]	EDP [aJ·ps]	
CMOS	4	-	-	$\sim10^5$	
RSFQ [1]	50	19	150	120	Single-flux
eSFQ [2]	20	0.8	150	12	Single-flux
RQL [3]	10	0.33	150	10	Single-flux
LV-RSFQ [4]	20	3.5	150	54	
AQFP [5]	5	0.0083	50	0.086	Adiabatic
Quantum limit	-	-	-	5.3×10^{-5}	

[1] X. Peng et al., IEICE Trans. Electron. **E97.C**, 188 (2014).
[2] M. H. Volkmann et al., Supercond. Sci. Technol. **26**, 015002 (2013).
[3] Q. P. Herr et al., J. Appl. Phys. **109**, 103903 (2011).
[4] M. Tanaka et al., IEEE Trans. Appl. Supercond. **23**, 1701104 (2013).
[5] N. Takeuchi et al., Supercond. Sci. Technol. 28, 015003 (2015).

Superconducting electronics

47 GHz SFQ FFT Processor [Ke et al.,2021]

- Technology
  - No parasitic resistance at low temperature (4K)
  - Information by *quantized pulses* $\int V(t)dt = \phi_0 = h/2e = 2.07$ mv ps
- Design features
  - *Pulsed-logic computing paradigm* with *deep pipelines*
  - Ultrafast computation with small energy consumption
  - Many variants including adiabatic operation
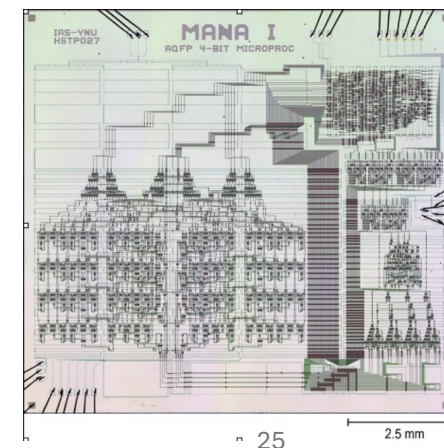
25 GHz 4-bit RISC [Ayala et a2.5l.,2021]

(c) Giovanni De Micheli

Superconducting electronics

Support for ultrafast acceleration
Enhancing AI/ML engines

Low-power operation
Limited by cooling technology

Bridge to Quantum Processors

Need for a new set of EDA tools

Acceleration of high performance computation

- A plurality of technologies to achieve **acceleration** of computation
  - Adapt computational flow to computational fabric
- Synthesis tools to realize accelerators on various platforms
  - AI techniques to search the design space (e.g., Synopsys 3DSO.ai)
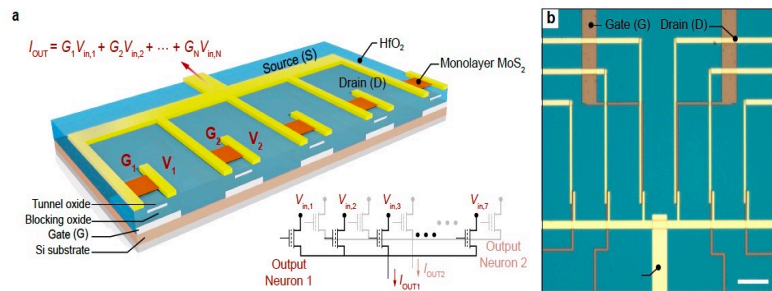
[Marega et al. ACS Nano 2022]

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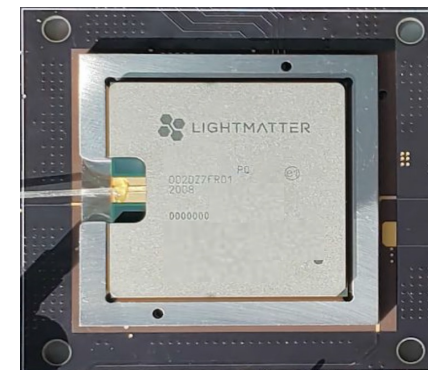
[Ramey, Hot Chips, 2020]

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There is not much space in the hot !

[S. Dali, Fire, Fire, Fire, 1971]

There is not much space in the hot !

- Thermodynamics of computing systems is the limiting factor
  - Reduce/recycle energy cost and heat dissipation of computation
  - Current roadblock for AI/ML and data centers
- The search for energy-efficient computing systems involves:
  - *Reversible* logic in quantum computing
  - *Adiabatic* computation in some superconducting families
- Computing systems are still very low in terms of efficiency
  - Heat and CO_2 generation per computational task

Circular thermodynamics in computing

- Heating bits
  - Use heat generated in water-cooled servers to produce electricty
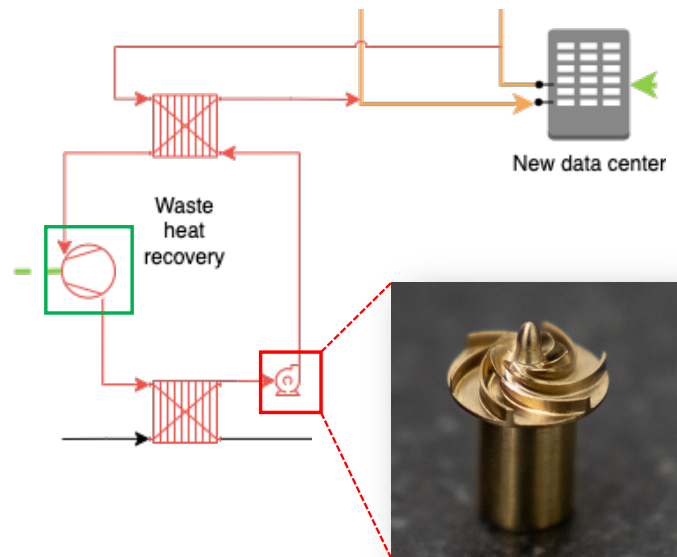
[Courtesy: M. Paolone, EPFL]

Circular thermodynamics in computing

- Infomaniak heats 6000 residential units in Geneva as of 2025
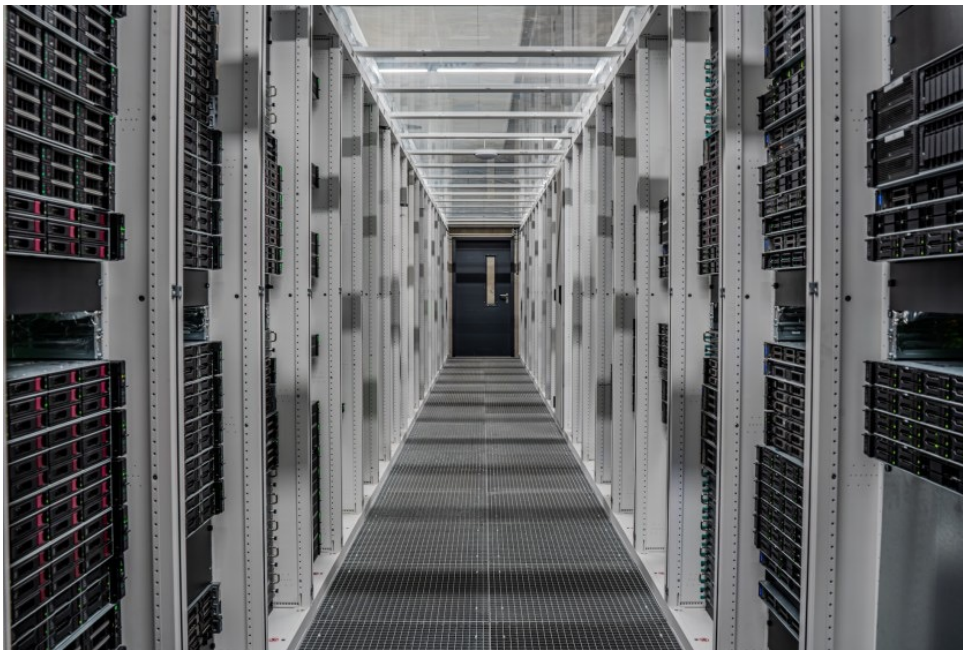
The Phoenix

- Mythical bird that is reborn from its ashes
- Exploit all leftovers of thermal cycles
- Circular energy economy

[Olha Darchuk]

Key Point # 2

- Edge to cloud integrated systems solutions
  - Balancing performance with energy cost

- Challenge is correctness and security
  - Protecting personal data and leveraging aggregate data

- Fully homorphic computing (FHE) is on the rise
  - Privacy has a performance cost but is important

How to realize the vision of a competitive Europe

(c) Giovanni De Micheli

[Paraolympic games closing, Paris 24]

How to realize the vision of a competitive Europe

- Realization of complex systems requires a multitude of skills
  - Leverage human capital

- Dominating societies need to be rich in culture and knowledge
  - Broad education is the key to technology growth

- Diversity and inclusion must wipe out differences
  - Cultural prejudices must be overcome

The future of higher education

Notable examples

Looking into the crystal ball

- It is difficult to make predictions, especially about the future [N.Bohr]
  - Indeed we live in a quantum world
  - Superposition of politics, economics, science and technology
  - Entangled decisions become observable only when system collapses
- We need directions in uncertain times
  - Our generation is responsible toward the younger one
  - Maintain peace and democracy
  - Save the environment
  - Infuse faith in a better future
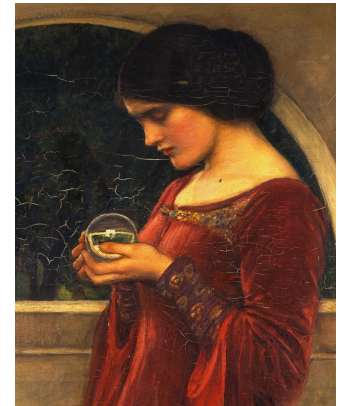
[J. Waterhouse, 1902]

Educate talents to support growth

- Design systems
  - Educate students to look at bigger picture and build prototypes
  - Strong collaborative effort and share capabilities
- Explore opportunities in nanoworld
  - Leverage strong experience in physics
  - Bring students early to the laboratory
- Use AI as specialized tools and not as commodities
  - Teach how to recognize origin of *corpora*
  - Use critical computational thinking

[Raffaello, 1509]

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Vision: I had a dream!
Information Tecnology

- Computing
  - Accessible and secure
  - Use open source platforms
- Software services and networks
  - Multicultural and freely available
  - Last mile connection
- Energy sources
  - Diverse, carbon free
  - Circular energy economy in all dimensions

[Courtesy of L. Benini, ETHZ]

Vision: I had a dream!
Applications of IT

- Transportation
  - From flying taxi to space
  - 3D transport with limited energy cost

- Medicine
  - From AI-based drug discovery to personalized medicine
  - Precision medicine and universal coverage

- Agriculture and manufacturing
  - Massive use of robots for heavy tasks
  - Preserve and enrich employment

Key Point # 3

- Advancements in engineering and technology require large efforts
    - Capital, people, skills, interaction

- Unity is required beyond provincial interests
    - Ownership of platforms, networks and software is crucial

- A unified smart energy grid is an enabler for a greener world
    - Energy generation, transport and storage

Conclusions

- The strongest European asset is the profound culture that defines and divides us
  - Diversity of culture is synonymous of richness
- Computing, communication and information technologies are continuously reinventing themselves
  - The planet Earth is just the limit to our imagination
- Education is the key to an evolving society
  - We are in the renaissance of circuits, systems and networks

Thank You

[Egylstadir, Iceland. Modern abstract art in nature]