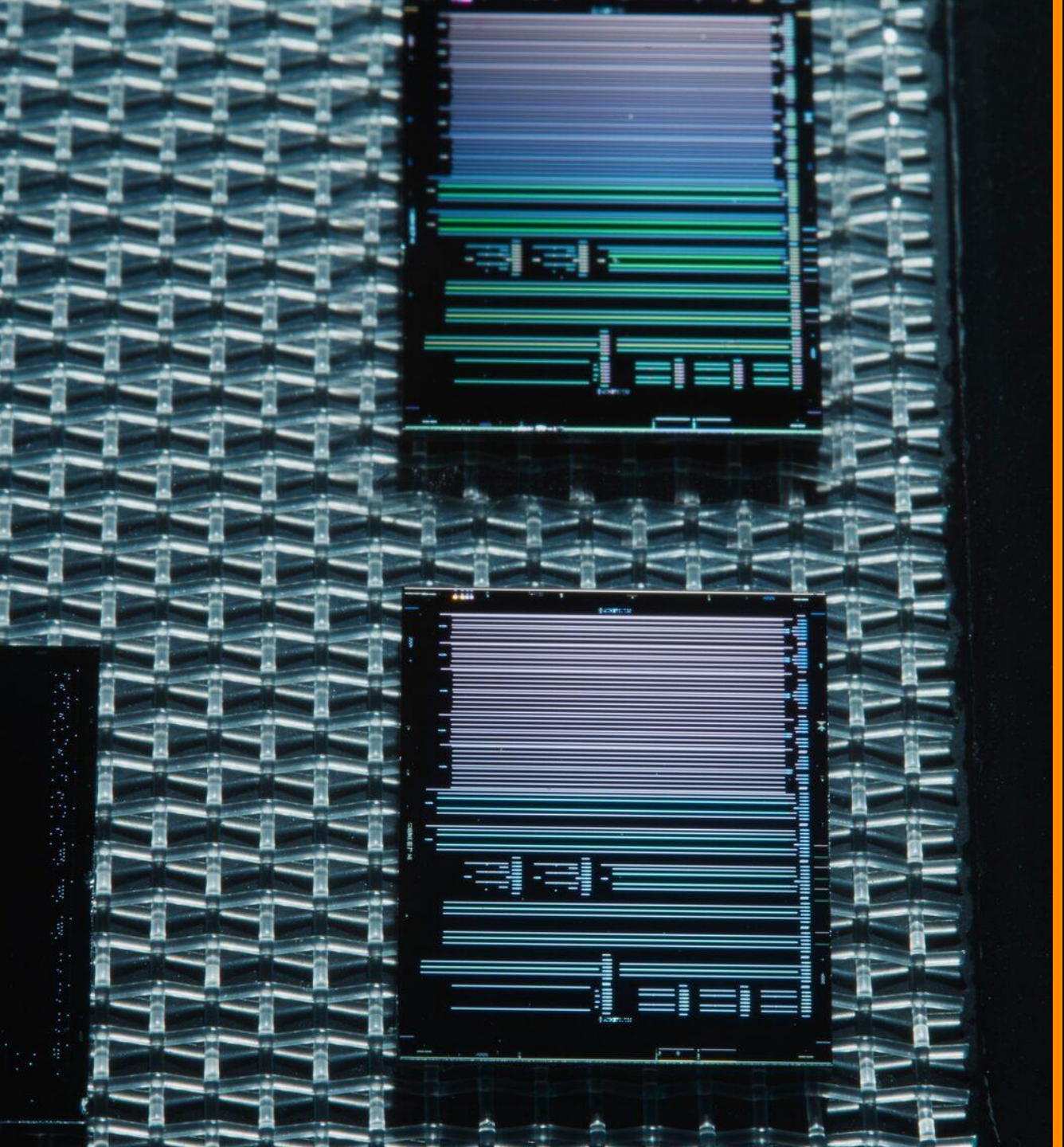


AKHETONICS

Optical Computing

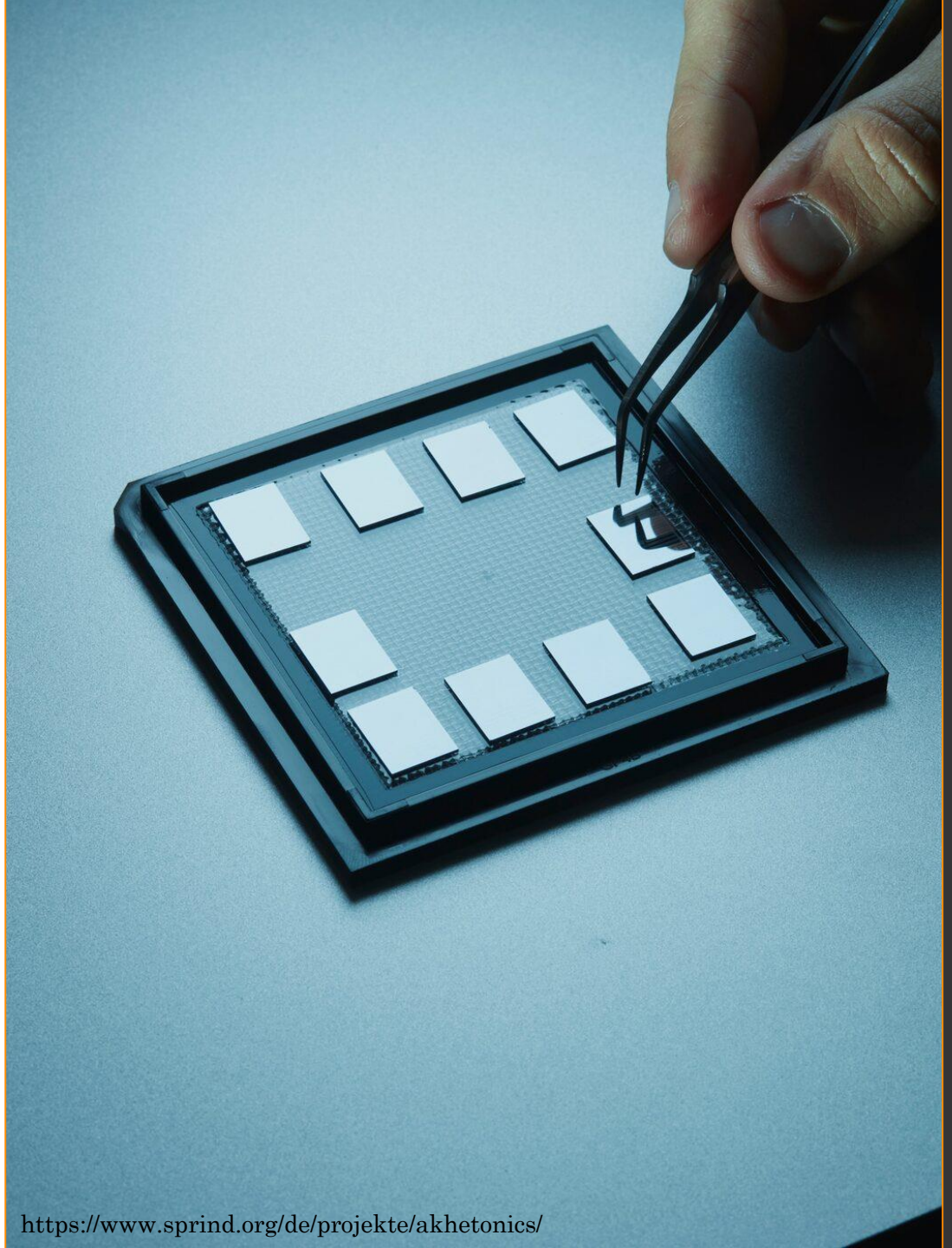
Towards All-Optical Data Centers

Who is AKHETONICS

- We are creating the world‘s first all-optical CPU.
- We are an interdisciplinary Team of 5.

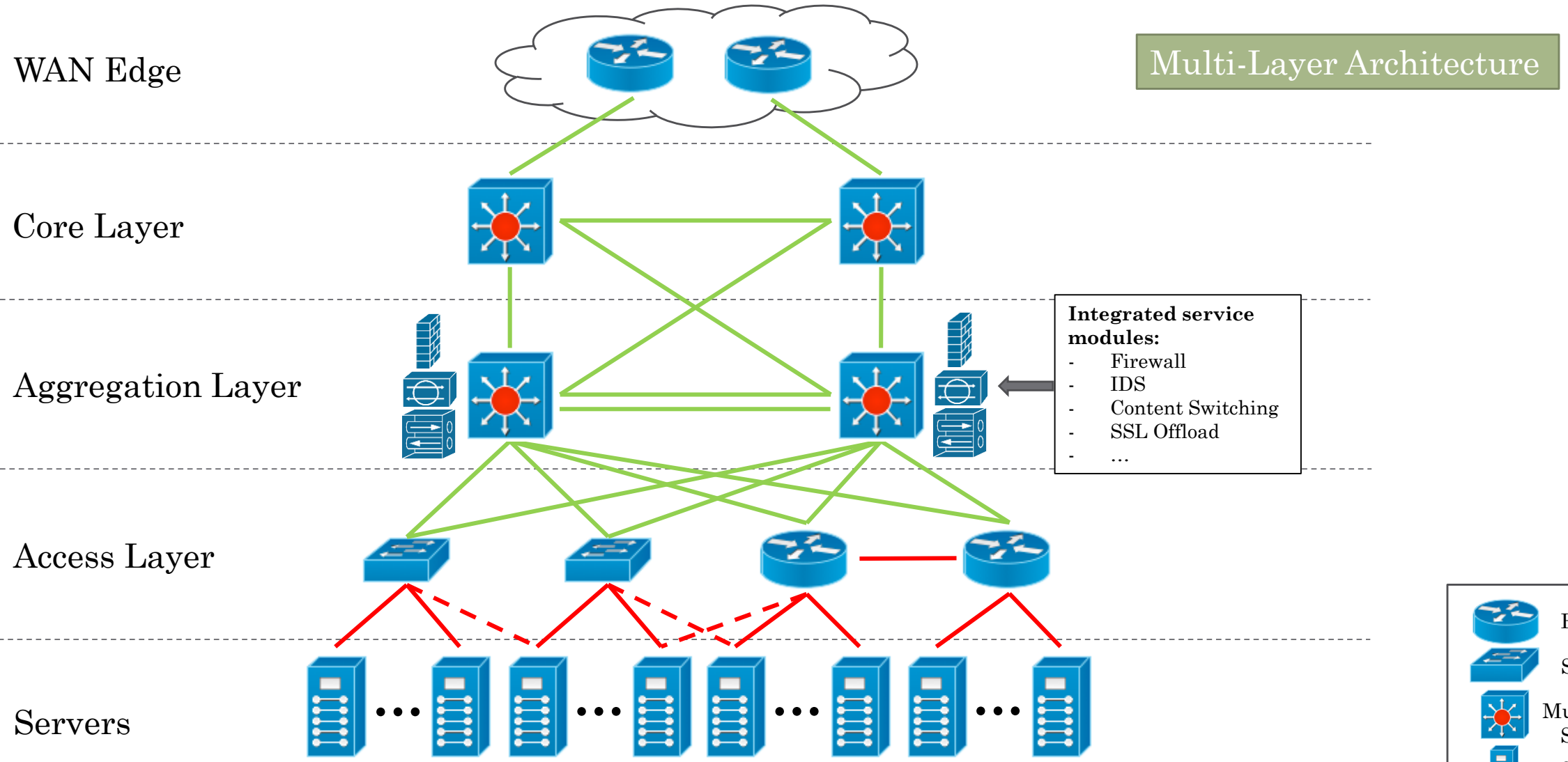
Michael Leonardo Alexander Felix Nicola

- We were founded in 2021 and are based in Berlin & Munich.
- We are supported by the SPRIN-D

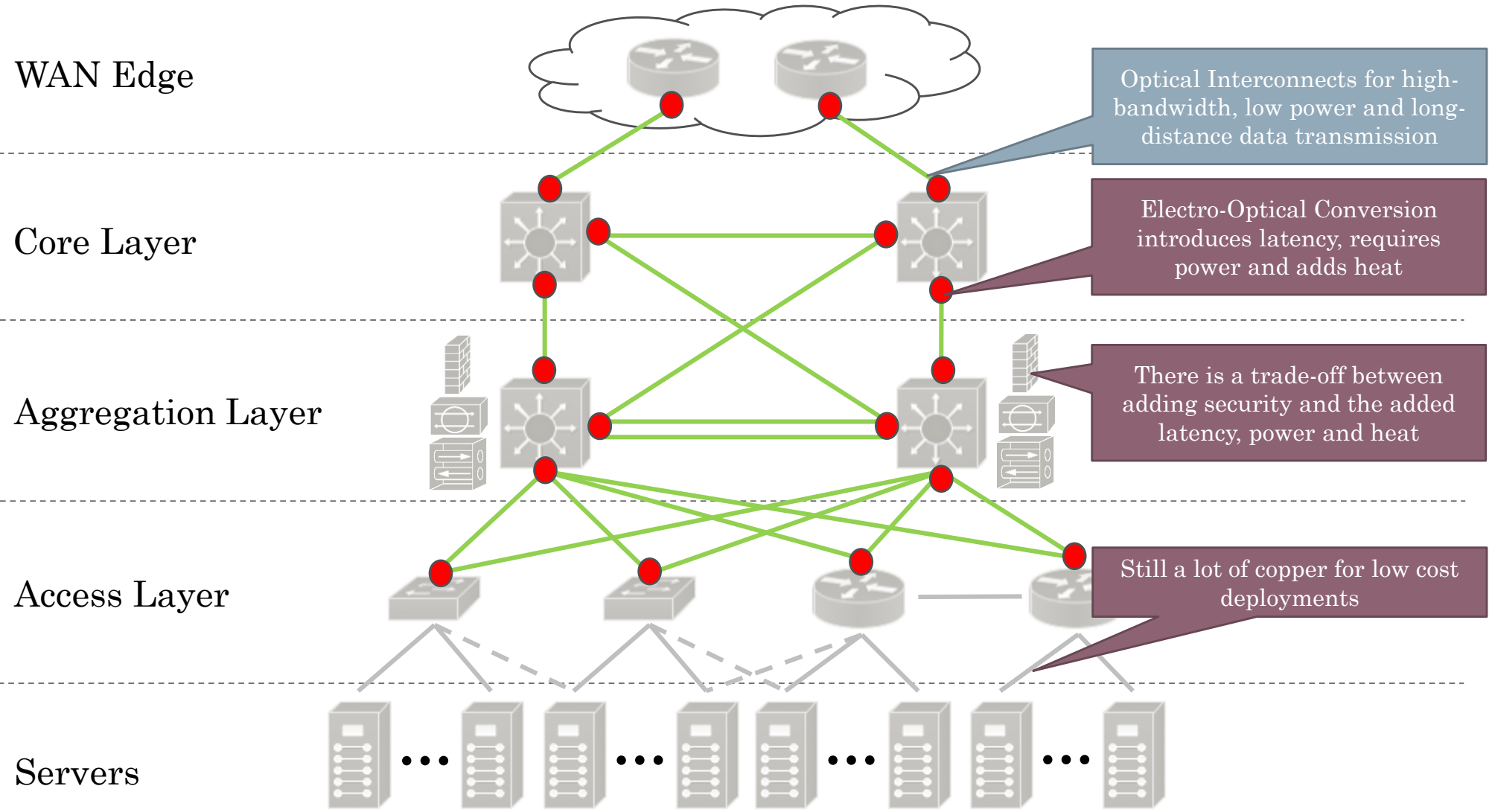


https://www.sprind.org/de/projekte/akhetonics/

Let‘s talk about Data Centers

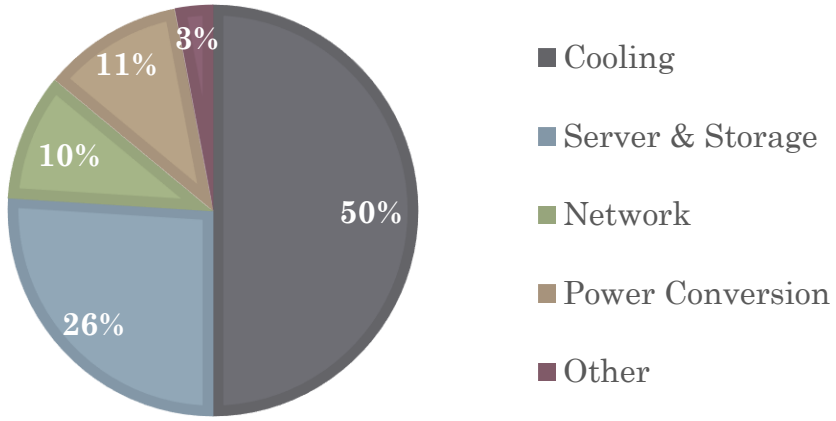


Optics in Data Centers

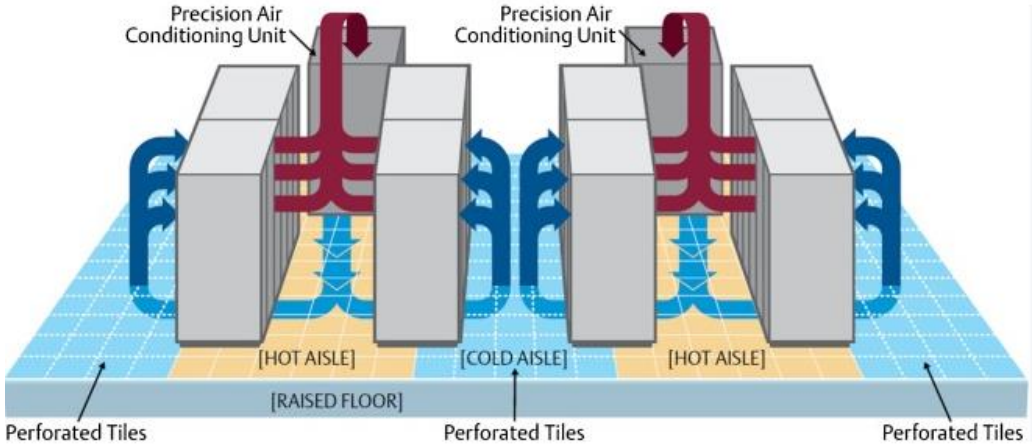


Problems

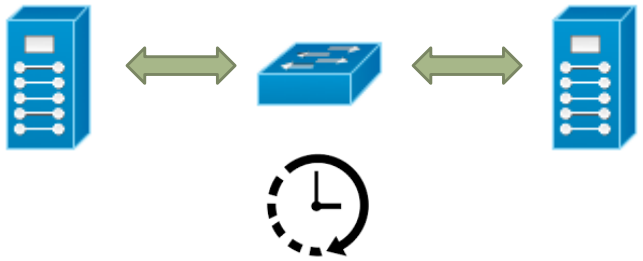
Power Consumption



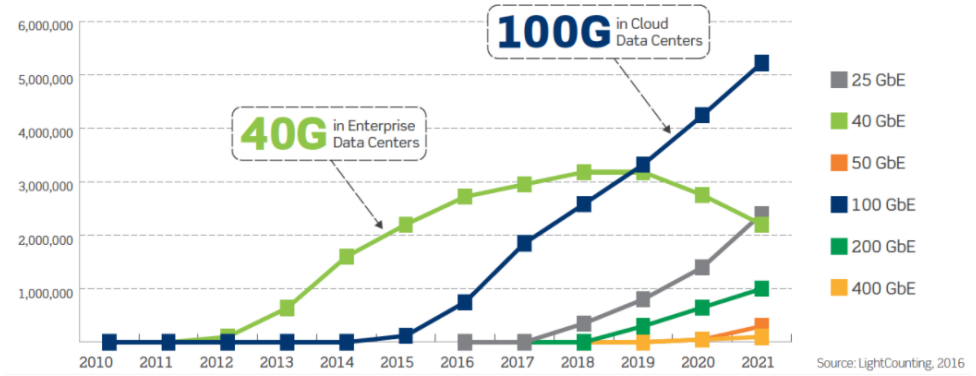
Heat Management



Latency & Performance



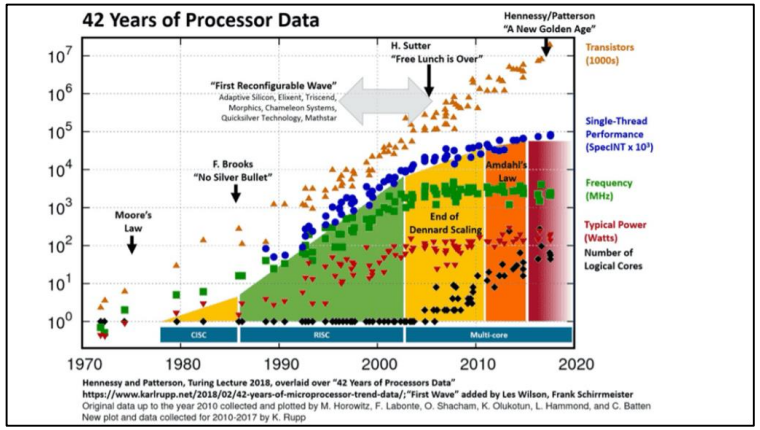
Bandwidth

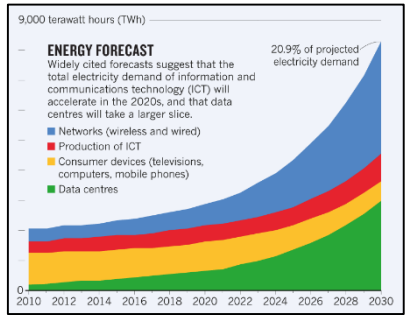


"Data Center Energy Consumption Modeling: A Survey", Dayarathna etal., 2016

"A review of thermal management and innovative cooling strategies for data center", Nadjahi etal., 2018

Current state of Electronics

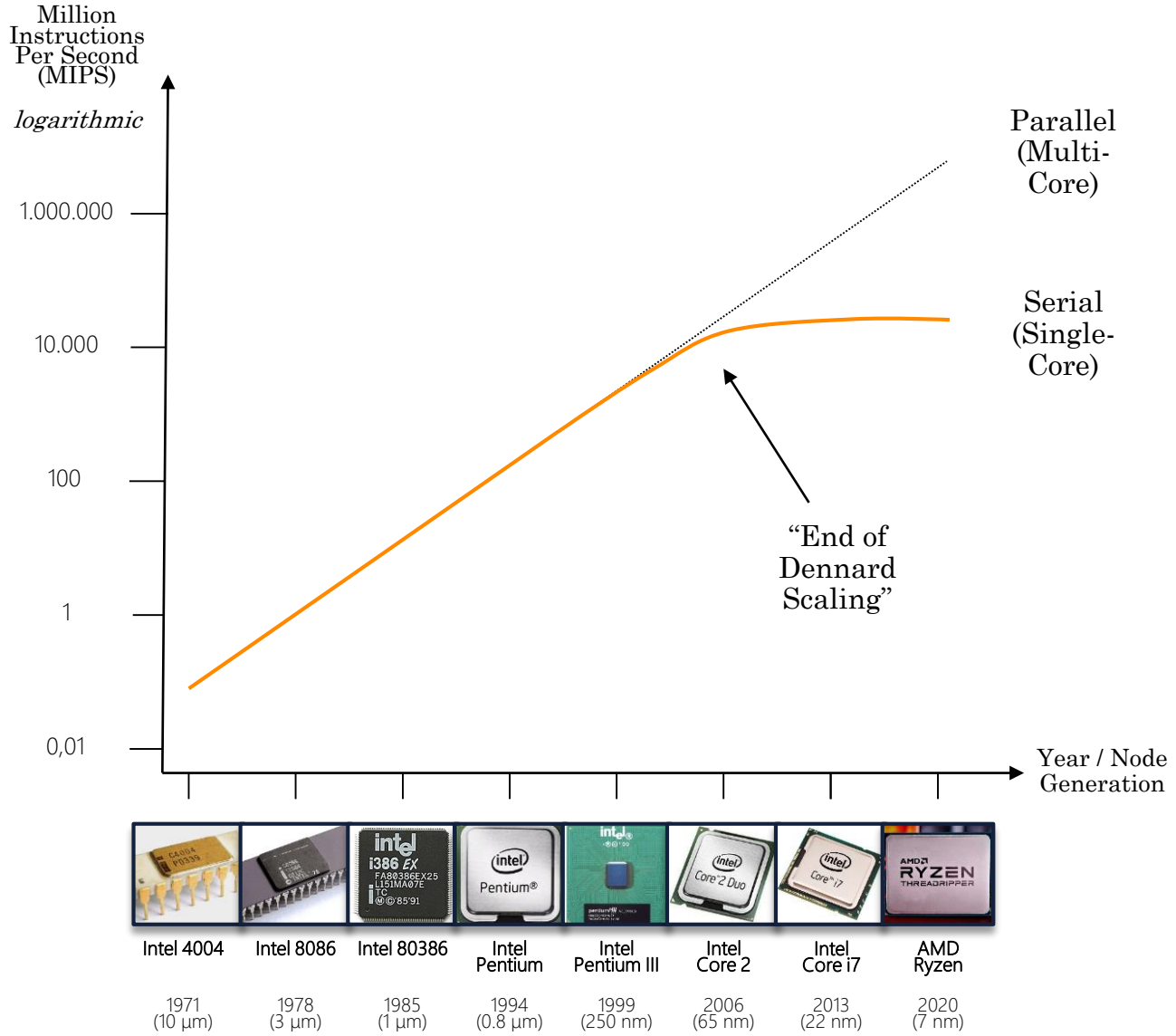




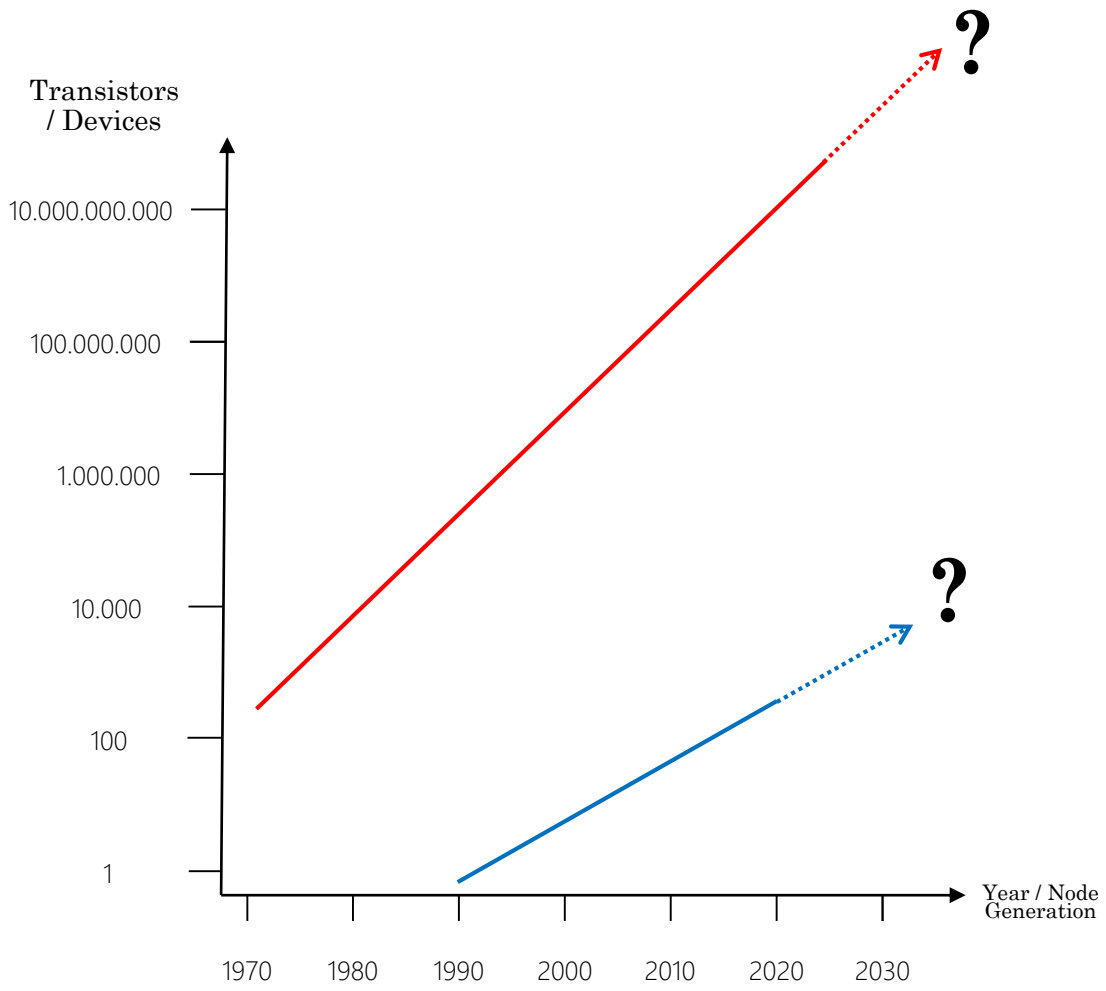
- **End of Dennard Scaling**
  Power use no longer goes down as transistor shrinks
- **Limit of Amdahl's Law**
  Performance increase by adding more resources greatly diminished
- **Limits of Moore's 1st/2nd Law**
  Cost of shrinking transistors grows exponentially, while benefits continue to shrink

↑ ***complexity***
↑ ***financial cost***
↑ ***environmental cost***
↑ ***power consumption***
↑ ***heat production***

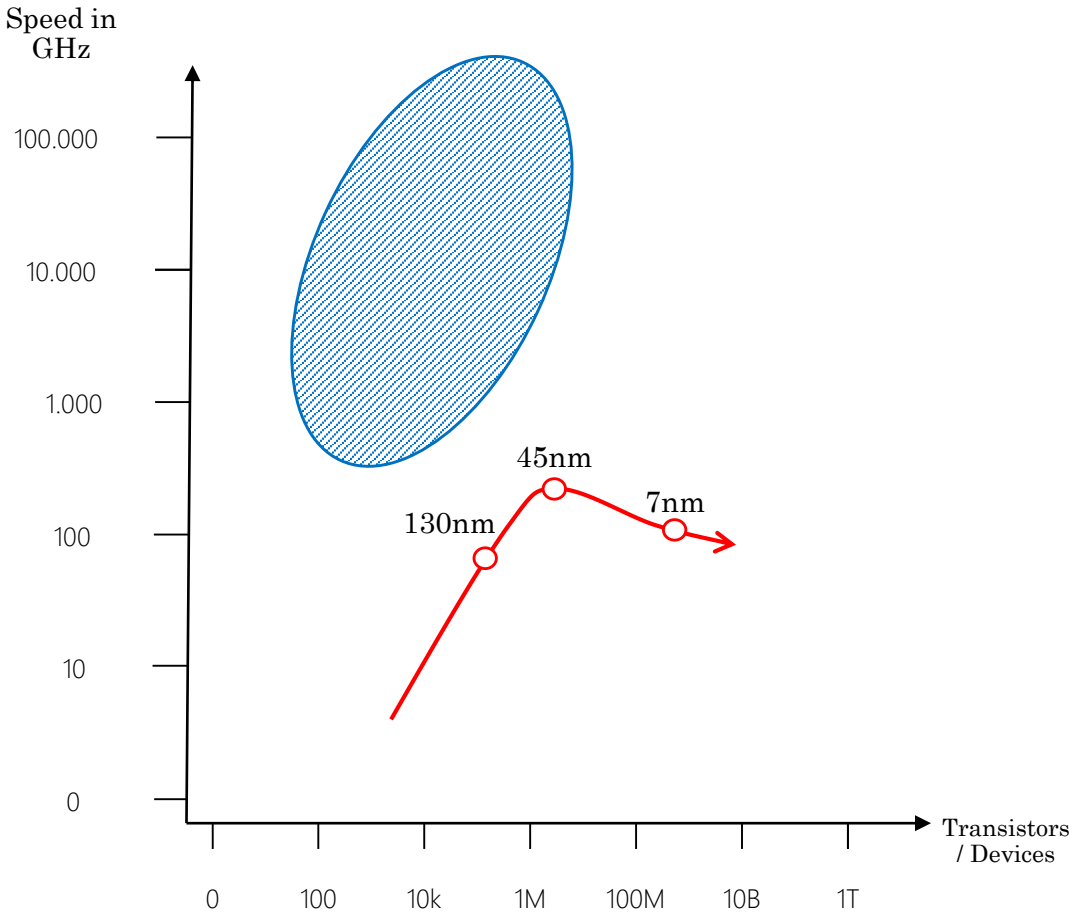
Good Old Electronics



Transistor / Device Count (Moore's Law in Photonics?)

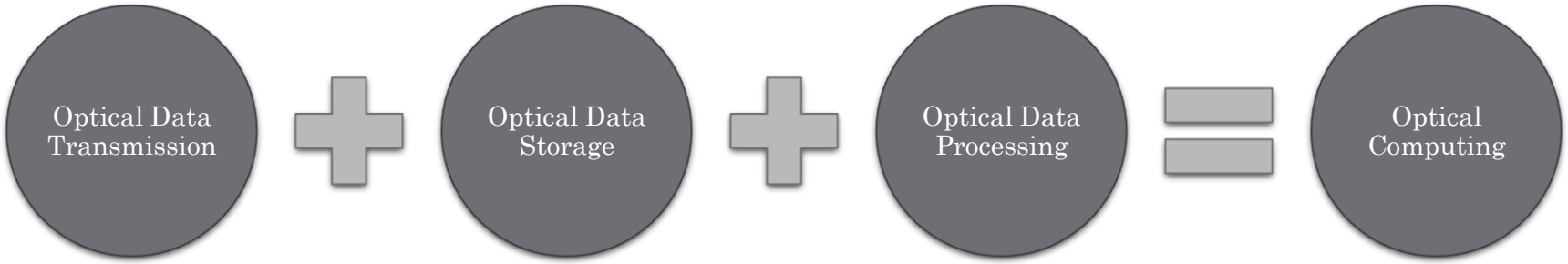


Max Transistor / Switch Speed vs. Density

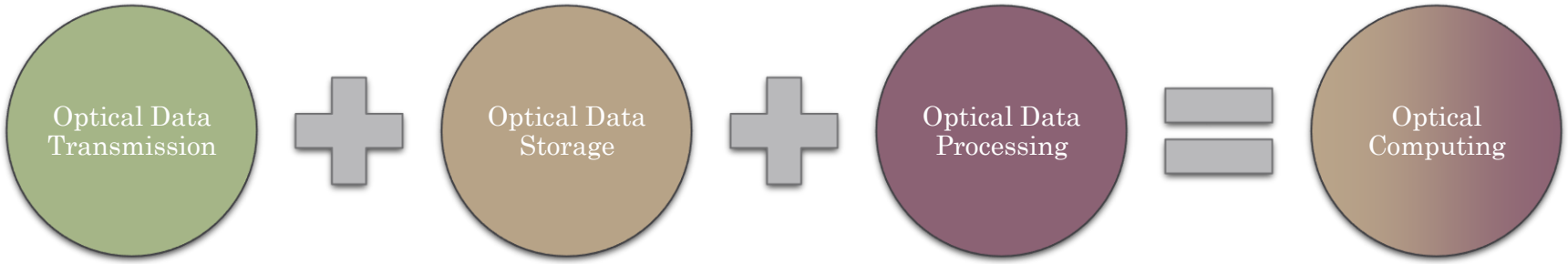


"Moore's Law in Photonics", M. Smit, J. van der Tol, M. Hill, 2011
"Terahertz Integrated Circuits and Systems for High-Speed Wireless Communications: Challenges and Design Perspectives", Payam Heydari, 2021

Optical Computing



Optical Computing



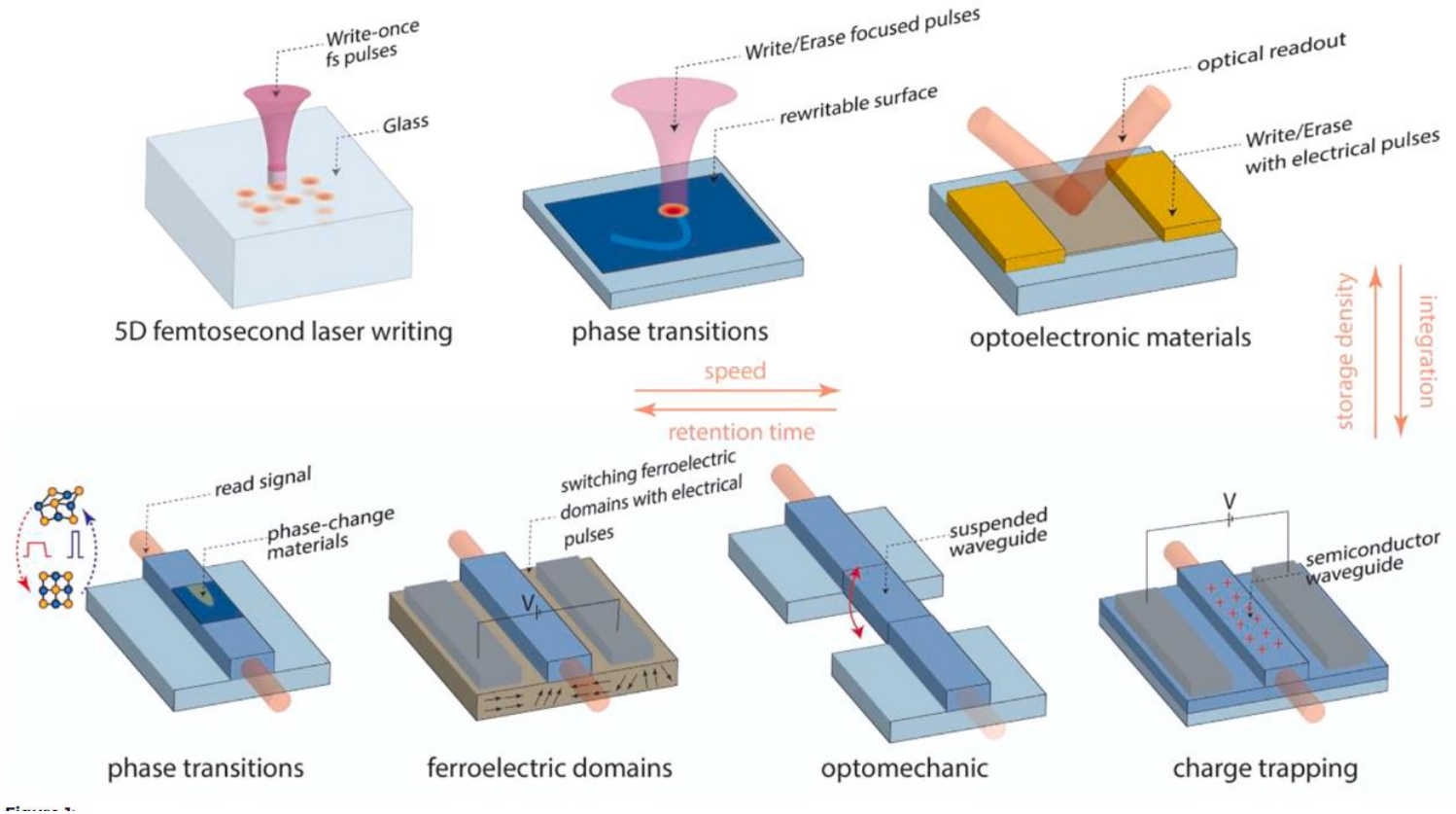
Well understood

Read-only memory is "easy",

Volatile memory still difficult

Focus of this talk

Overview of Optical Memory Technologies



"Photonic (computational) memories: tunable nanophotonics for data storage and computing", Lian etal., 2022

Data-Centers

The natural environment for Optical Computers.

→ Optically Interconnected

→ High Bandwidth

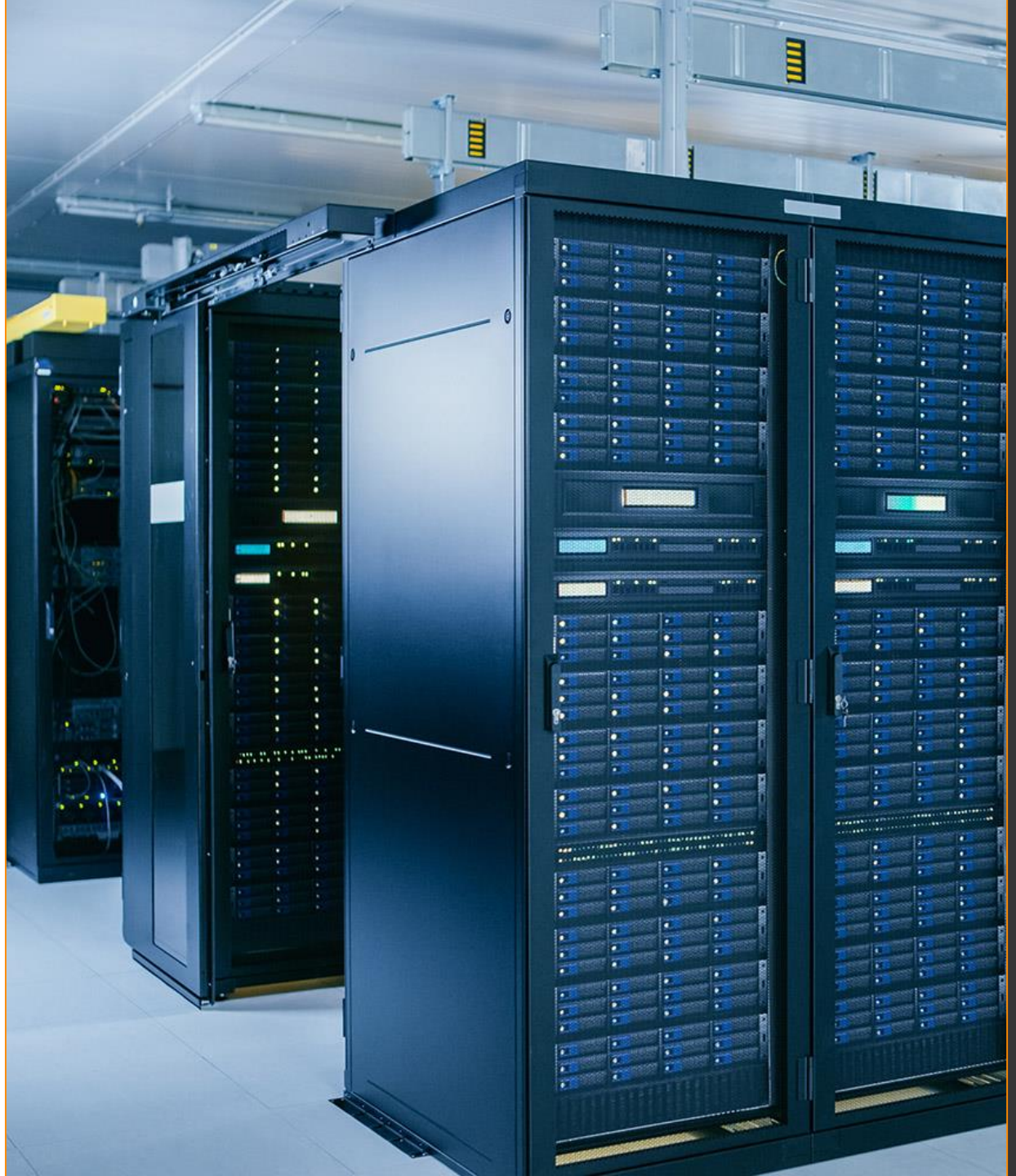
→ Low Power

→ Low Heat

→ Low Latency

For:

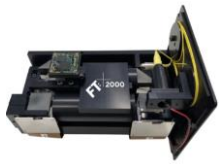
- All-Optical Routers / Switches / …
- All-Optical Firewalls / VPN / …
- All-Optical Servers / HPC / …



Current State of Optical Computing

Analog

Lightmatter



Optalysys

EnLight

LightOn

- Commercially available*
- **Electro-Optical Hybrids**
- Mostly linear systems
- Specific use-cases (matrix-vector multiplication)
- Current focus: AI Acceleration

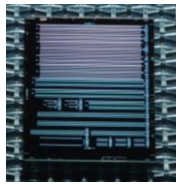
Quantum

QuiX Quantum

Xanadu

- Commercially available*
- **Electro-Optical Hybrids***
- Linear optical quantum computing

Digital



Akhetonics

Bell Labs

- In development
- **All-Optical**
- Non-linear optics / processing
- General-purpose

All those concepts can and should be combined for true all-optical data processing

Integrated non-linear photonics is ***the*** main challenge!

Nonlinear Optics

- Every nonlinearity has its advantages ***and*** disadvantages …
- And there are many to choose from / combine …

Optical-Optical Nonlinearities
parametric nonlinearities

$$\mathbf{P}(t) = \varepsilon_0 \left(\chi^{(1)}\mathbf{E}(t) + \chi^{(2)}\mathbf{E}^2(t) + \chi^{(3)}\mathbf{E}^3(t) + \ldots \right)$$

- Second-Harmonic Generation
- Pockels Effect
- Sum Frequency Generation
- …

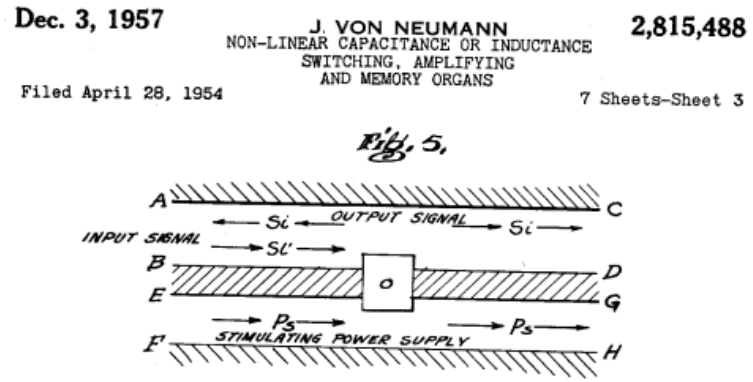
- Self-Phase Modulation
- Cross-Phase Modulation
- Other Optical Kerr Effects
- …

Electro/Thermo/…-Optical Nonlinearities
non-parametric nonlinearities

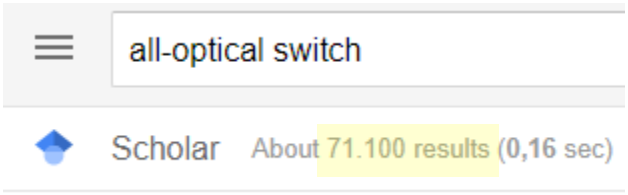
- Two Photon Absorption
- Raman Amplification
- Stimulated Raman Scattering
- …

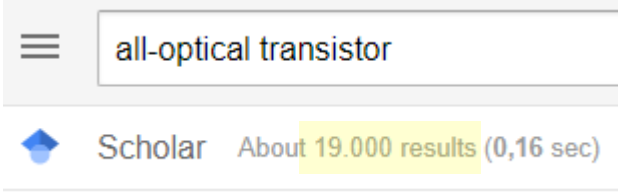
1000s of Optical Logic Gates

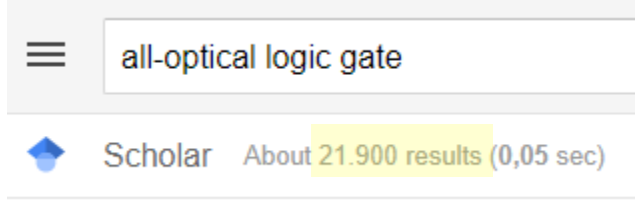
- First Patent from 1957 by John von Neumann.


Dec. 3, 1957 J. VON NEUMANN 2,815,488
NON-LINEAR CAPACITANCE OR INDUCTANCE SWITCHING, AMPLIFYING AND MEMORY ORGANS
Filed April 28, 1954 7 Sheets-Sheet 3
Fig. 5.

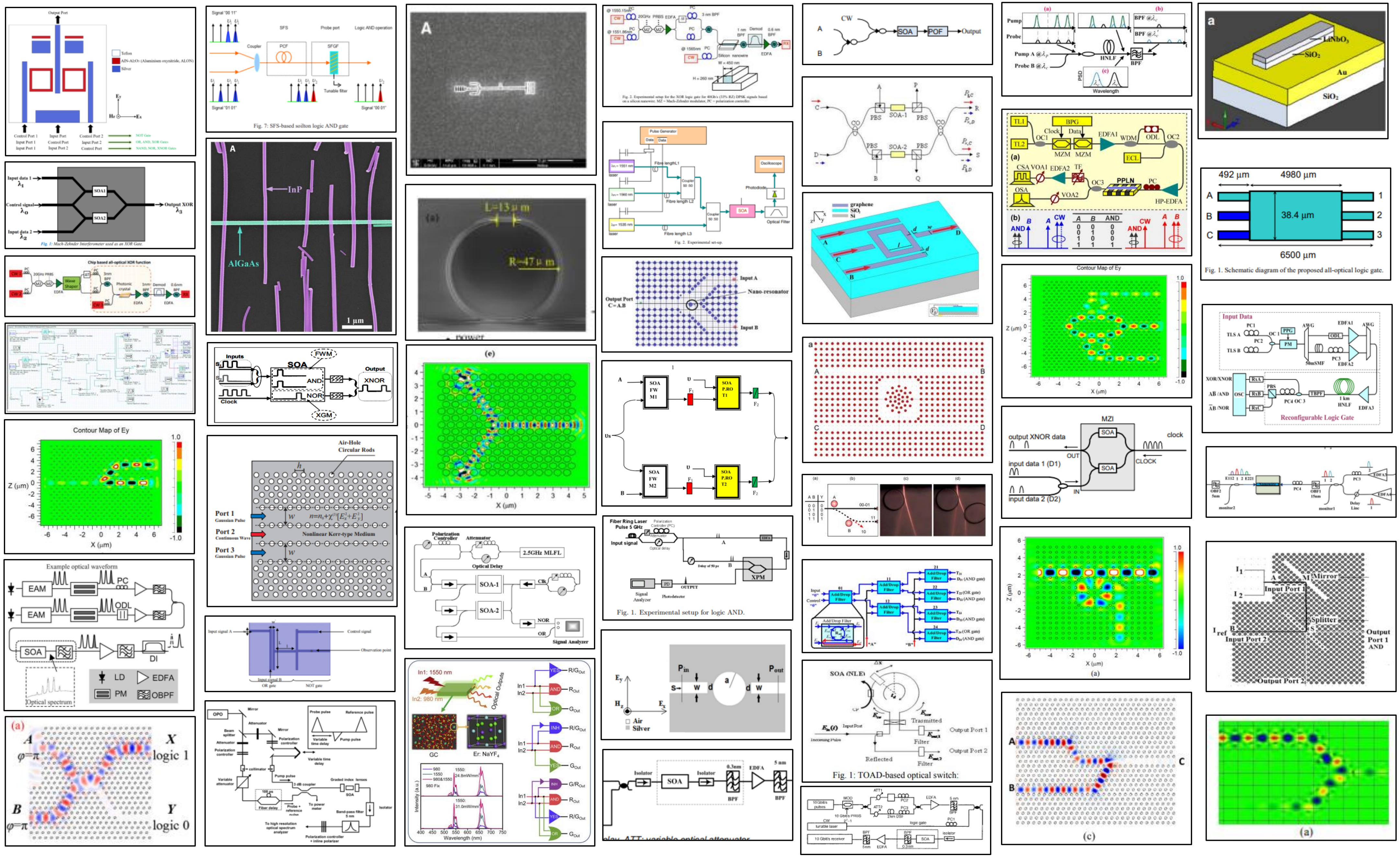
- A lot of academic research since then.







Just the first few pages of Google Scholar



AKHETONICS

November 17, 2022

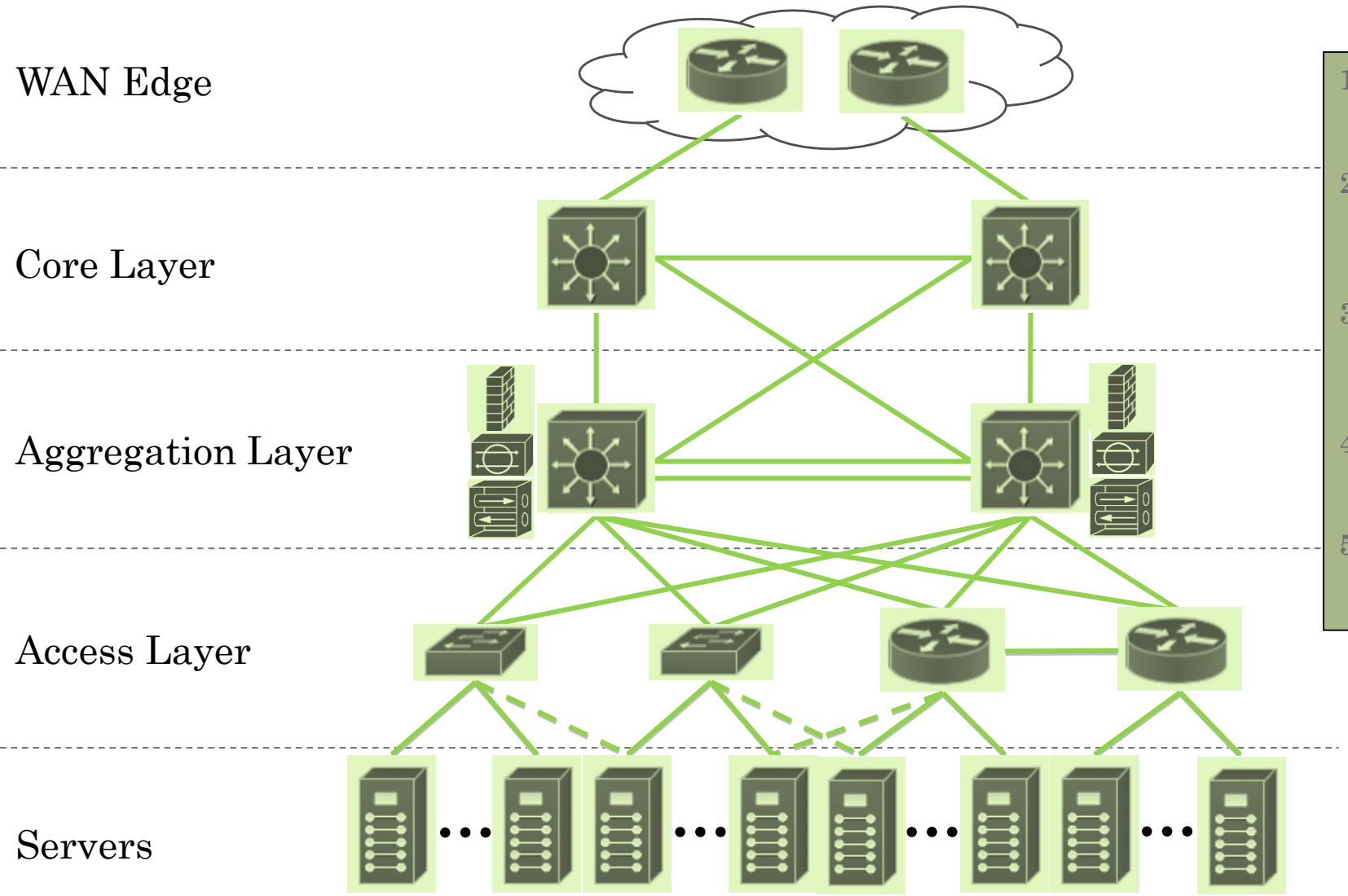
Criteria for Optical Logic Gates

Criteria	Description	
Cascadability	The output of one stage must be in the correct form to drive the input of the next stage.	Essential
Fan-out	The output of one stage must be sufficient to drive the inputs of at least two subsequent stages (fan-out or signal gain of at least two).	
Logic-level restoration	The quality of the logic signal is restored so that degradations in signal quality do not propagate through the system; that is, the signal is 'cleaned up' at each stage.	
Input/output isolation	We do not want signals reflected back into the output to behave as if they were input signals, as this makes system design very difficult.	
Absence of critical biasing	We do not want to have to set the operating point of each device to a high level of precision.	Optional
Logic level independent of loss	The logic level represented in a signal should not depend on transmission loss, as this loss can vary for different paths in a system.	

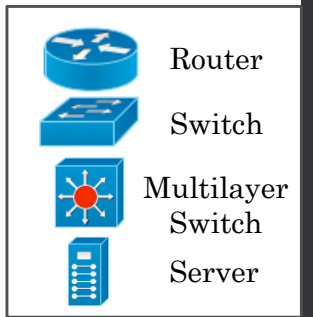
D. A. B. Miller. Device requirements for digital optical processing. SPIE Critical Reviews of Optical Science and Technology, CR35:68-76, 1990.

D. A. B. Miller. Are optical transistors the logical next step? Nature Photonics, 4:3-5, 2010.

Going All-Optical Step-by-Step



1. **Accelerators**
   AI, Simulation, …
2. **Encryption**
   VPNs, Encryption Modules, QKD, …
3. **Security**
   Firewall, IDS, DDoS Protection, …
4. **Networking**
   Routing, Switching, …
5. **General-Purpose**
   CPUs, xPUs, …



Takeaway

1 – Linear Optical Computing is already here.

2 – General-Purpose Digital Optical Computing is just around the corner.

3 – While all the components for a Digital Optical Computer are here, creating large circuits out of them is still hard!

It's one thing to have battery cells and motors,
the really hard part comes from engineering an entire car.

→ Exactly what we are solving at AKHETONICS.