# Microsystem Scaling

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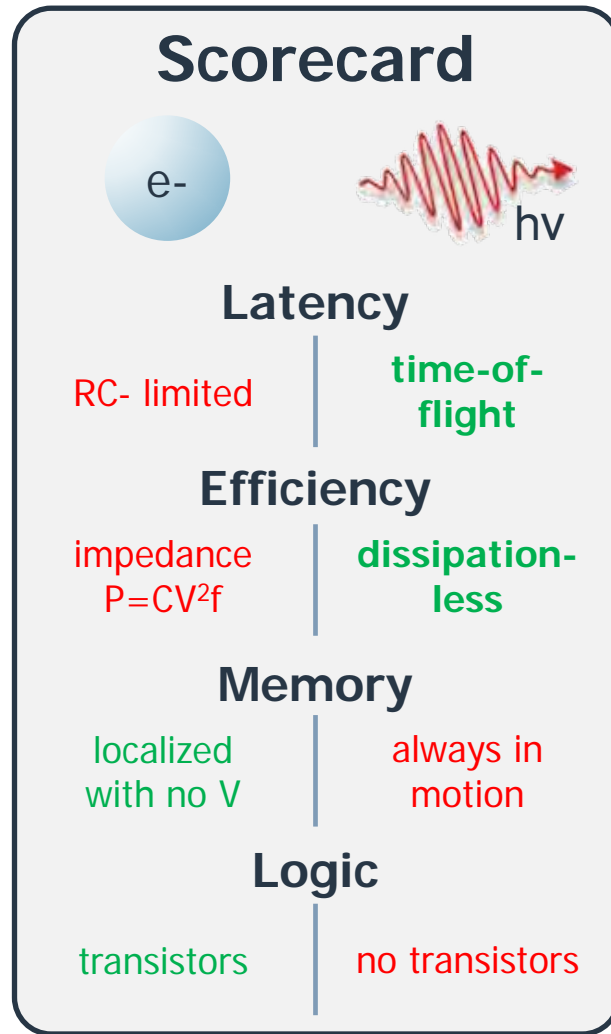
July 24, 2025

# Leveraging Light for Sophisticated Processing



**Very Large-scale Photonic Integrated (VLPI) circuits are enabled with:**

- **Advanced integrated photonics platforms**

- **Co-designed natively-optical algorithms and architectures**

- **Automated design tools**

Scorecard

e-   hv

**Latency**

RC- limited | time-of-flight

**Efficiency**

impedance $P=CV^2f$ | dissipation-less

**Memory**

localized with no V | always in motion

**Logic**

transistors | no transistors

**Computation by propagation**
**Nearly energy-free and fast**

**No general-purpose computing**
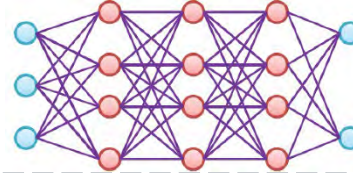**Not a replacement for digital electronics**

**Photonics-enabled Systems**

**Complex circuits**
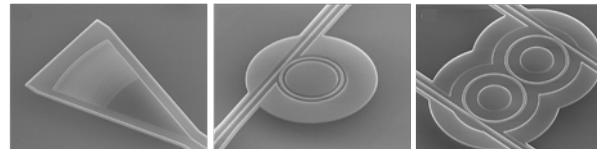(100-thousands to millions)
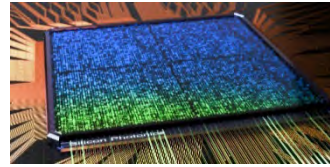
**Functional blocks**
(hundreds to thousands)

**Simple circuits**
(less than 50 components)

**Complex components**
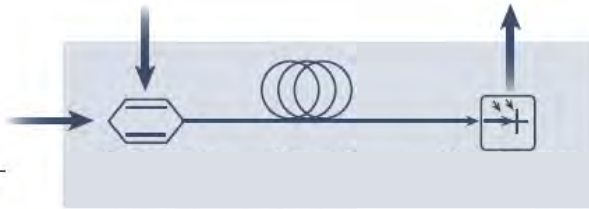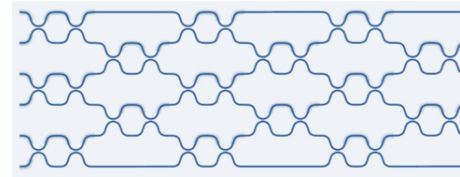(made of a few basic comp)

**Basic components**

**Technology of tomorrow?**

**Technology of today**

**Image credits:** Myles Marshall/Columbia Engineering, Intel, TSMC, 5G Technology World, Wiley Online Library, D. Xu, Engineering 46, 2025, H. Shu, Nature 605, 2022
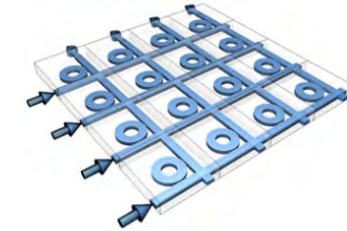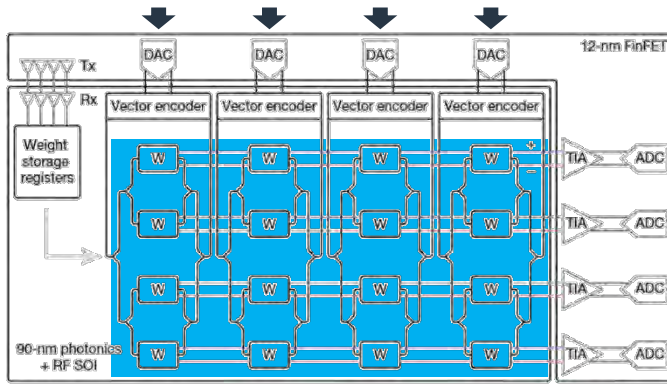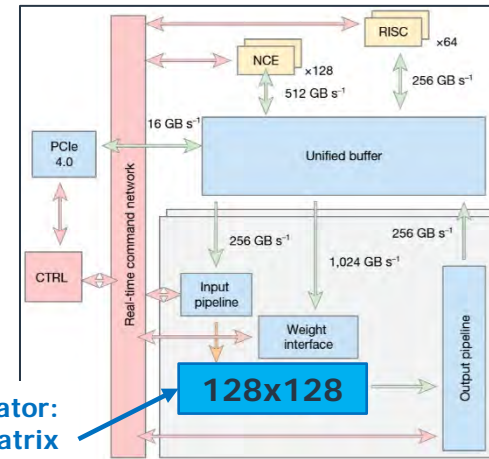
**Transceivers**

**AI-accelerators**

**Switches**

**Electrical: millisecond latency**

**Photonics: picosecond latency**

**Photonic accelerator: vector-matrix multiplication**

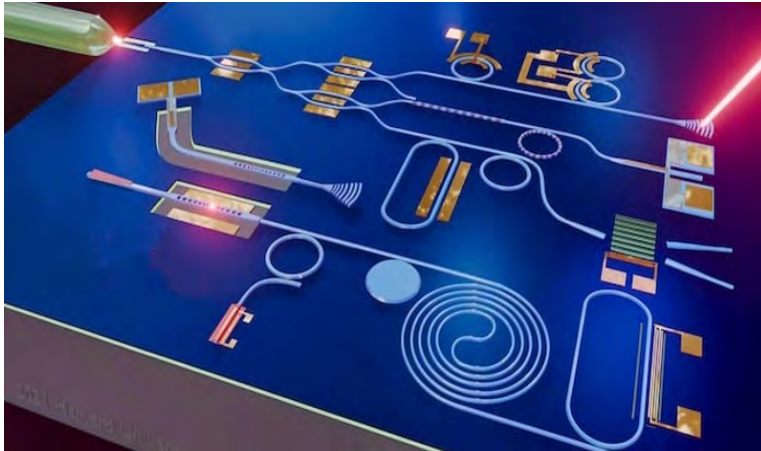**System architecture dominated by electronics:**
- 128 x 128 elements
- 1.6 W optical power
- Picosecond latency
- 25-billion transistors
- 78 W overhead
- Millisecond latency

Lightmatter, "Universal photonic artificial intelligence acceleration" *Nature* (April 2025)

**Electronics overhead dominates when photonic circuits are limited to isolated functions.**
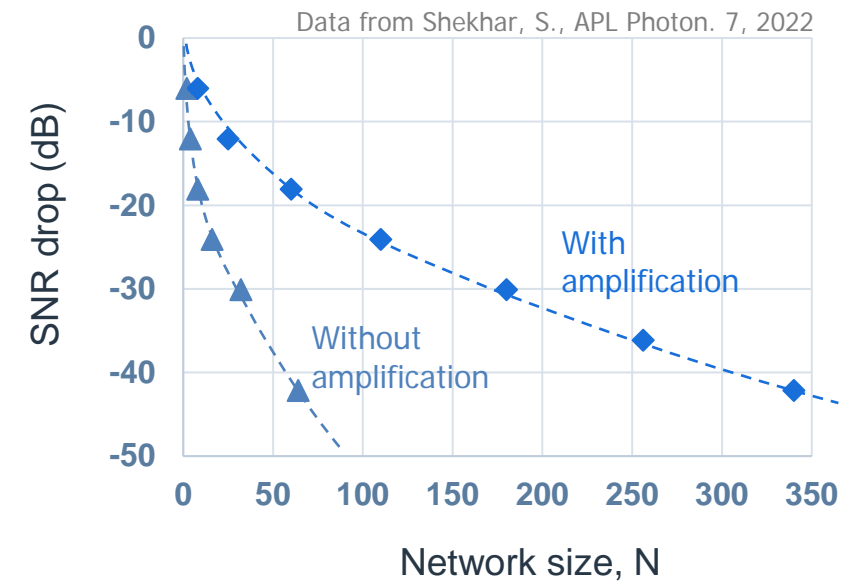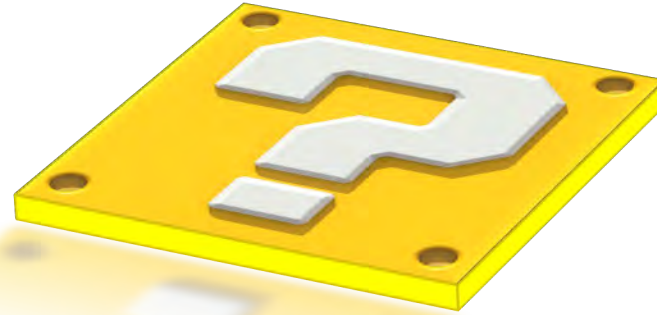
## Discrete and unique devices



M. Loncar *et al*, Advances in Optics and Photonics, 2021

## SNR Degradation vs Network Size



Data from Shekhar, S., APL Photon. 7, 2022

**With amplification**

**Without amplification**

Network size, N

SNR drop (dB)

**Innovation focused on device performance instead of circuit-enabled functionality**
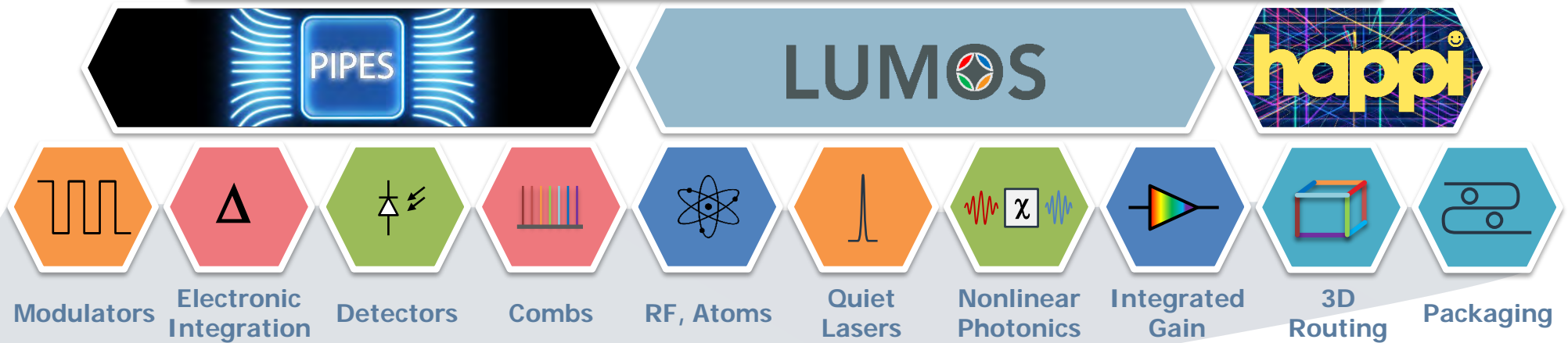
**Optical signal attenuation and accumulated noise severely limit the size of photonic circuits**

Scaling Complexity: VLPI Photonics

PIPES

LUMOS

happi

| Modulators | Electronic Integration | Detectors | Combs | RF, Atoms | Quiet Lasers | Nonlinear Photonics | Integrated Gain | 3D Routing | Packaging |

**Photonics Toolbox**

www.darpa.mil