

The AI revolution

How semiconductors
are fuelling innovation

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Semiconductors
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pushing each
other's envelope.”

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In an era where technology is advancing at an exponential pace, AI and semiconductors are both at points of inflection. The rapid evolution of AI — from generative models to agentic AI — has intensified the demand for increasingly sophisticated, efficient and specialized chips. At the same time, innovations in semiconductor design and fabrication are actively fuelling AI's capabilities, enabling breakthroughs that redefine the boundaries of artificial intelligence. This symbiotic growth is not just accelerating progress but also reshaping industries, economies and the very fabric of technological innovation.

As global data generation surges and AI's computational demands grow, the semiconductor industry faces both unprecedented opportunities and critical challenges — from supply chain vulnerabilities to the race for next-generation architectures like Gate-All-Around transistors and neuromorphic computing. Let us explore the intricate relationship between AI and semiconductors, unveiling the key trends, emerging breakthroughs and strategic imperatives that will shape the next decade of innovation.



The foundation of innovation

Semiconductor technologies have been the backbone of AI by providing the essential hardware needed to train on large data sets and perform inference. Innovations in semiconductor architecture — such as GPUs (Graphics Processing Units), TPUs (Tensor Processing Units) and NPUs (Neural Processing Units) — have been pivotal in advancing AI. These specialized processing units enhance AI capabilities by improving computational efficiency through massive parallelization, while reducing power consumption. AI, on the other hand, has inspired breakthrough research in semiconductor design and manufacturing beyond traditional limits, driving innovations in materials, processes and device architectures.

Continuous architectural innovation is crucial for driving AI forward. Improvements in process technology — such as smaller transistor sizes ('more-Moore') and newer transistor architectures like 'RibbonFet' and 'Gate All Around' have been supplemented by novel packaging methods (like chiplets and 3D stacking).

AI also serves as a catalyst for semiconductor advancements by prompting exploration into non-silicon materials and advanced fabrication techniques. The need for faster, more efficient data processing has accelerated research into 3D stacking, which boosts performance by integrating layers of circuitry. Additionally, memory innovation plays a critical role in managing AI's data-intensive operations. Next-generation memory technologies in form of HBM (High Bandwidth Memory) are rapidly evolving to reduce latency, increase throughput and ensure that semiconductor hardware can meet the data streaming demands of AI.

Breakthroughs beyond conventional architectures

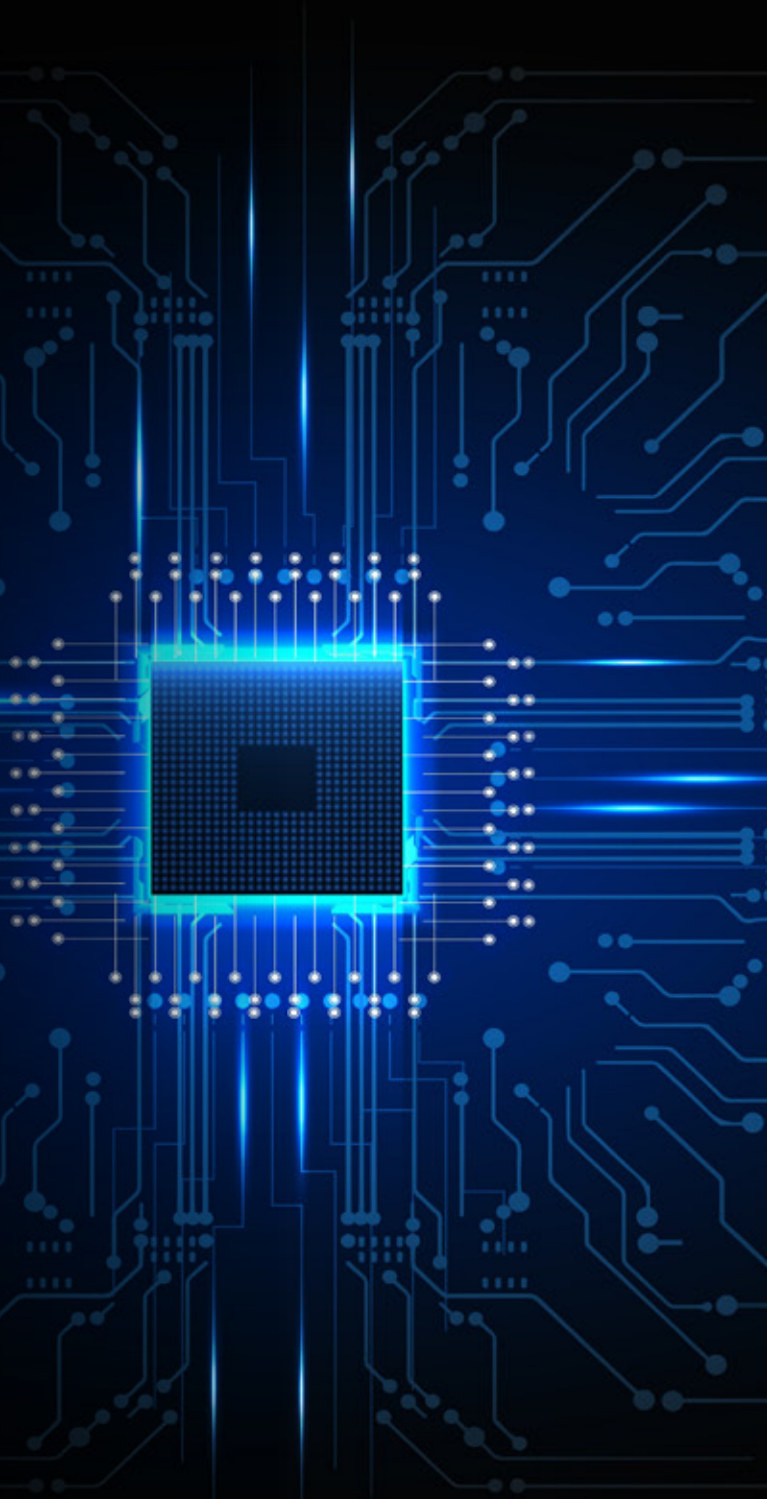
A central challenge in AI computing has traditionally been the 'von Neumann bottleneck,' where the separation of the processor and memory in traditional computing architectures creates data-transfer limitations that significantly impede performance. Today's breakthroughs in addressing this issue include neuromorphic computing and in-sensor or edge AI. Neuromorphic computing, inspired by the human brain's structure, employs spiking neural networks and parallel processing to

drastically cut power consumption. This technology is particularly advantageous for applications requiring rapid response times and high energy efficiency, such as real-time pattern recognition, robotics and prosthetics. Meanwhile, in-sensor or edge AI technology embeds AI capabilities directly into sensors, allowing for local data processing and real-time decision-making while minimizing energy use.

Challenges on the road ahead

The AI-semiconductor ecosystem, despite its vast potential, is confronted with significant challenges. As transistor sizes decrease to below the five-nanometer mark, the complexity of design and manufacturing escalates due to becoming exponentially more intricate.

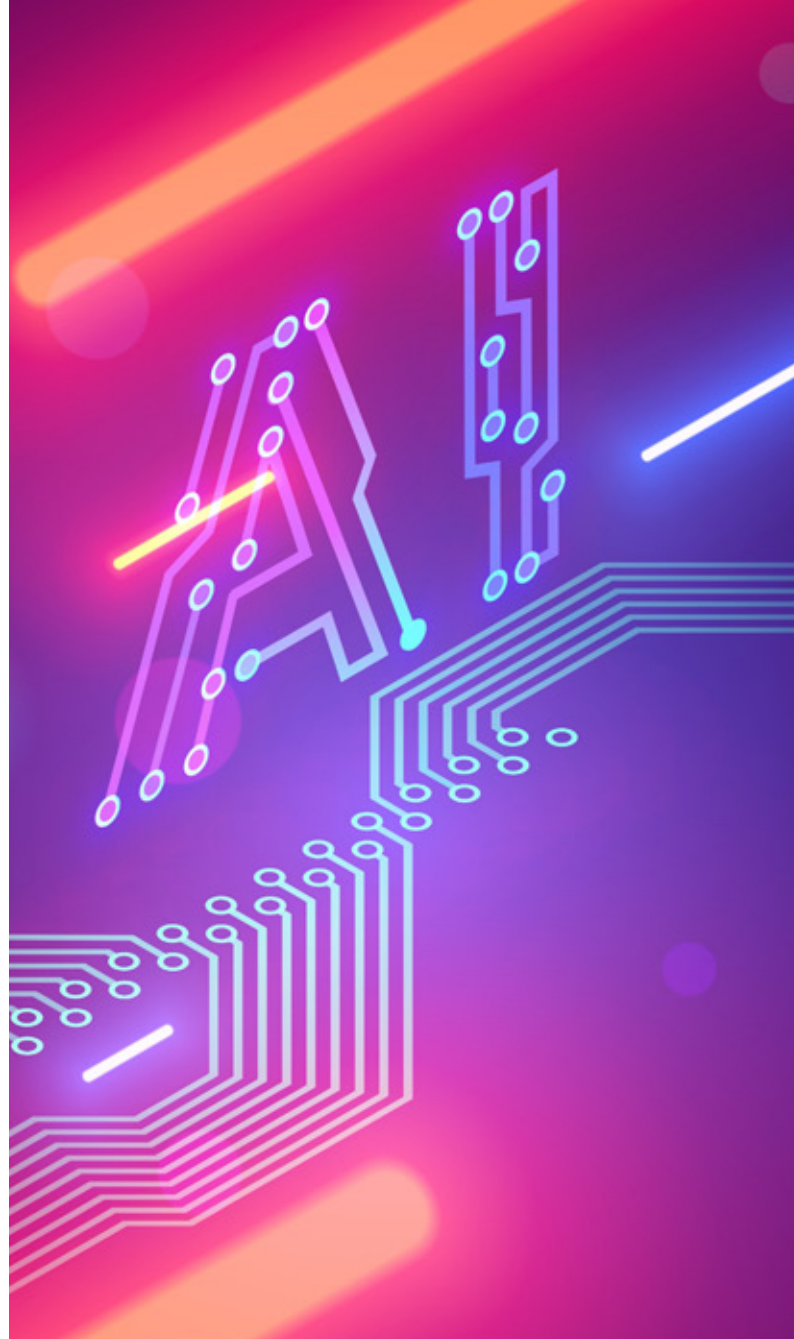
Even with AI-driven design tools, highly skilled engineers versed in semiconductor physics must refine the hardware. Designing a highly complex xPU needs with multi-GHz performance needs while keeping power in check needs engineers to explore and experiment with various optimization techniques – some of these optimization knobs may be working at cross-purposes. So, the chasm between 'turnaround time demand' for a chip and actual 'design cycle time' is growing. Hardware innovation alone is insufficient, as techniques like data pruning, quantization and model compression are necessary to fully realize the efficiency gains promised by cutting-edge semiconductors.



Opportunities on the horizon

Despite the challenges, the future of AI-semiconductor development brims with potential. The exploration of radical materials and architectures, such as moving beyond silicon to wide-bandgap materials or even quantum-inspired architectures, could redefine the limits of performance and power. As AI tasks increasingly migrate to edge devices – from autonomous vehicles to industrial IoT sensors – there is a growing demand for ultra-low-power solutions that support on-device intelligence, marking a significant shift towards energy-efficient Edge AI.

Additionally, the development of custom AI accelerators for sectors like healthcare, finance or consumer electronics promises hyper-optimized performance, potentially opening up new market segments and business models. Moreover, advancements in 3D stacking and chiplet designs offer modular, flexible systems through advanced packaging, enabling tailored AI solutions for unique workloads without the traditional fabrication costs.



Staying ahead of the curve

In a cutting-edge landscape where competition is fierce, merely improving on established technologies, such as replicating existing GPU or TPU models, is insufficient to secure a lead in this space. For companies and startups in the AI and semiconductor industries, the path forward involves embracing radical thinking by challenging conventional wisdom and exploring uncharted territories by evaluating non-traditional architectures, like neuromorphic computing or embedding AI directly into sensors to extend the boundaries of what is possible. Investing in skills and collaboration is also crucial, requiring the development of multidisciplinary teams capable of holistic hardware-software co-design and forging

partnerships across academia, startups and established semiconductor giants to drive deeper innovation. Furthermore, there is a need to focus on custom solutions by tailoring AI accelerators to specific workloads in various vertical markets, including autonomous robotics and personalized healthcare diagnostics. Planning for disruption is essential, with new materials and manufacturing processes on the horizon, as well as long-term R&D investments. It is important to keep sight of emerging paradigms – even if they lie outside the current mainstream – to stay ahead in the rapidly evolving tech landscape.

Who does the future belong to?

As we stand on the brink of a transformative era, AI is poised to drive revolutionary changes in semiconductor design and manufacturing, in packaging and system design and in software algorithms. Industry leaders like NVIDIA and Google have established formidable benchmarks, yet the future will favor those who dare to transcend incremental advancements. Cutting-edge developments such as chipset architectures and AI-embedded sensors are at the forefront of this shift, promising to redefine the technological landscape. For businesses and innovators, the stakes are high, encompassing not only significant opportunities but also intense competition and intricate challenges.

By boldly venturing beyond the familiar and investing robustly in talent and technology, forward-thinking entities can carve unique trajectories in this swiftly evolving field. As we contemplate the next monumental leap in technology, the synergy between AI and semiconductors emerges as one of the most dynamic and consequential domains of progress. For stakeholders in these sectors, the imperative is clear: innovate with courage, delve deep into understanding and gear up for a future where AI and semiconductors propel each other toward new pinnacles of technological prowess. The journey ahead is not merely about enhancing existing technologies but reimagining the realms of possibility.

Biswadeep Chatterjee has over 28 years of experience in the VLSI design industry, having worked on various projects and technologies.

He has held significant roles at Qualcomm and Intel, and currently leads the Physical Design capability unit at HCLTech. He is also passionate about teaching, conducting training courses and teaching VLSI CAD classes at premier institutes.

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