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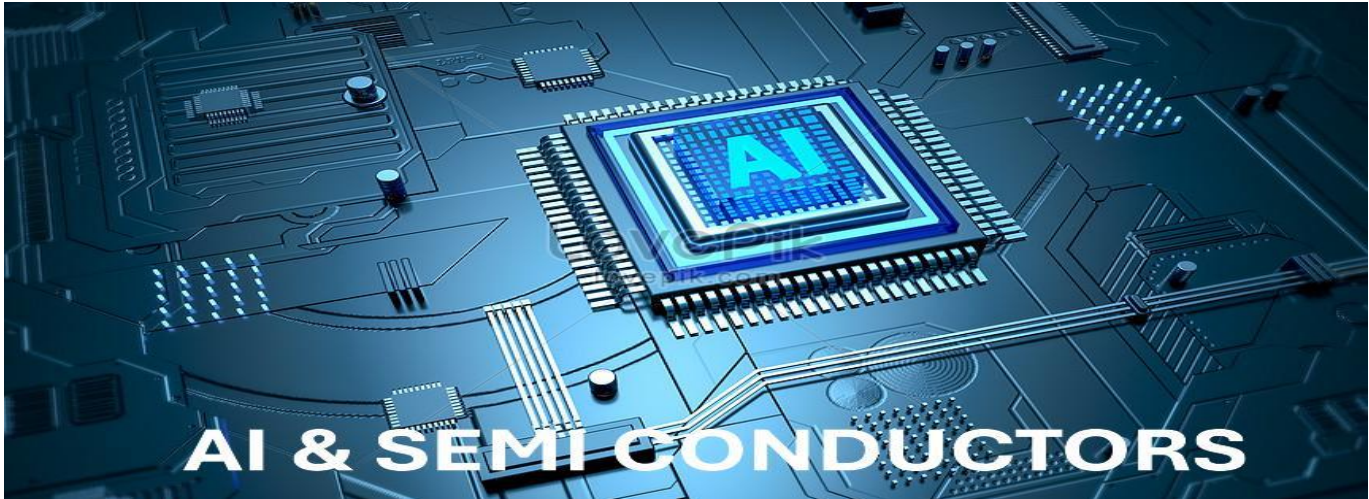
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Content

<div align="center">**AI AND SEMI CONDUCTOR SYNERGY**</div>

I. Introduction:

Modern technology is undergoing a revolution because of the collaboration between the semiconductor industry and artificial intelligence (AI), which spurs efficiency and innovation in both fields. This study examines the reciprocal link between AI and semiconductors, looking at how AI transforms chip design and production while sophisticated semiconductors elevate AI's capabilities.

In recent years, the semiconductor industry has witnessed unprecedented growth, largely fueled by the demand for AI-specific chips. In 2023, advanced AI chips were selling for approximately US$40,000 each, with demand reaching a million or more units [1]. This trend is expected to continue, with the global AI chip market projected to grow at a compound annual growth rate (CAGR) of 20% to 41% over the next several years [2].

This research explores the pivotal role of AI in shaping semiconductor innovation, from reduced transistor sizes and optimized chip designs to breakthroughs in quantum computing and edge AI applications. It highlights key industry trends, technological milestones, and the collaborative efforts of leading companies like Google, Intel, IBM, and AMD in transforming the future of AI and computing. Through this lens, we gain insights into how AI and semiconductors are converging to drive the next wave of technological progress, enabling smarter, more efficient systems across industries.

II. Major Findings

The impact of AI on the semiconductor industry is multifaceted:

1. **Manufacturing Optimization:** AI algorithms analyze vast amounts of data to optimize production processes, reducing cycle times and improving yield rates. This has led to potential revenue increases of $85-$95 billion annually by 2025 for the semiconductor industry [1].

2. **Quality Control:** Quality control in semiconductor production has been completely transformed by AI-powered vision systems, which provide previously unheard-of levels of precision, efficiency, and flexibility. These technologies use deep learning models and sophisticated machine learning algorithms to examine wafers and chips at the tiny level, discovering flaws with up to 99% accuracy as opposed to 85% with conventional techniques [3]. AI-driven quality control that works in real-time may spot minute flaws that human inspectors or traditional automated systems could overlook, such tiny scratches, particle residue, and anomalies in the circuit architecture. With some firms claiming yield increases of up to 15% and a 20% [4] decrease in faulty goods, this capacity has resulted in notable improvements in production output. In contrast to static old systems, AI solutions provide constant performance as product designs change by continually learning and adapting to new fault types and shifting production conditions. These technologies allow for rapid modifications to production processes, reducing waste and downtime, by evaluating hundreds of photos per second and giving instant feedback. AI integration in semiconductor quality control is a vital tool for upholding the strict standards demanded by the semiconductor industry because it not only improves precision but also provides long-term cost savings by lowering labor costs, minimizing waste, and averting expensive recalls.

3. **Design and Simulation:** Machine learning algorithms accelerate chip design processes, reducing development time from months to days.

4. **Energy Efficiency:** AI plays a crucial role in improving energy efficiency in manufacturing processes and chip designs.

Conversely, advancements in semiconductor technology are essential for AI progress:

1. **Processing Power:** High-performance chips, such as NVIDIA's GPUs, provide the computational capabilities required for complex AI tasks, with some models achieving over 1,300 TOPS (trillions of operations per second) [5].

2. **Energy Efficiency:** Innovative designs, like IBM's analog AI chip, demonstrate significant improvements in energy efficiency, reaching up to 12.4 TOPS/W.

3. **Specialized Architecture:** AI-specific chip designs optimize performance for machine learning workloads, enabling more efficient AI model training and inference [6].

III. Objective

This research is crucial for understanding the intricate relationship between AI and semiconductors, which is reshaping industries, driving technological progress, and presenting new challenges and opportunities. By exploring this synergy, we can gain insights into future technological trends, potential economic impacts, and the evolving landscape of innovation in both AI and semiconductor sectors.

The precise ways AI is changing semiconductor design and production processes, as well as how advances in chip technology are in turn pushing the limits of AI's capabilities, will be covered in more detail in the sections That follow.

For industry workers, researchers, and politicians navigating the quickly changing junction of AI and semiconductor technology, this thorough analysis will offer insightful information.

IV. Literature Review:

Recent studies have highlighted the transformative impact of AI on semiconductor design and manufacturing [7]. A 2024 paper published in the Journal of Knowledge Learning and Science Technology examined how generative AI can revolutionize chip design by automating complex tasks such as architecture exploration, circuit optimization, and layout generation. The research demonstrated significant improvements in design efficiency, performance optimization, and reduced time-to-market through case studies.

McKinsey's 2021 [8]report on AI in semiconductor manufacturing estimated that AI and machine learning (ML) contribute between $5 billion and $8 billion annually to earnings before interest and taxes at semiconductor companies. The report identified key use cases in manufacturing, including the adjustment of tool parameters and optimization of process recipes, which can potentially decrease manufacturing costs by up to 17 percent.

Artificial intelligence could generate $85 billion to $95 billion for semiconductor companies over the long term.

Impact of artificial intelligence on semiconductors EBIT,[1] $ billion

~5–8

Impact realized

~35–40

Near-term potential[2]

~85–95

Long-term potential[3]

[1]Earnings before interest and taxes.
[2]Near-term potential refers to gains within the next 2–3 years.
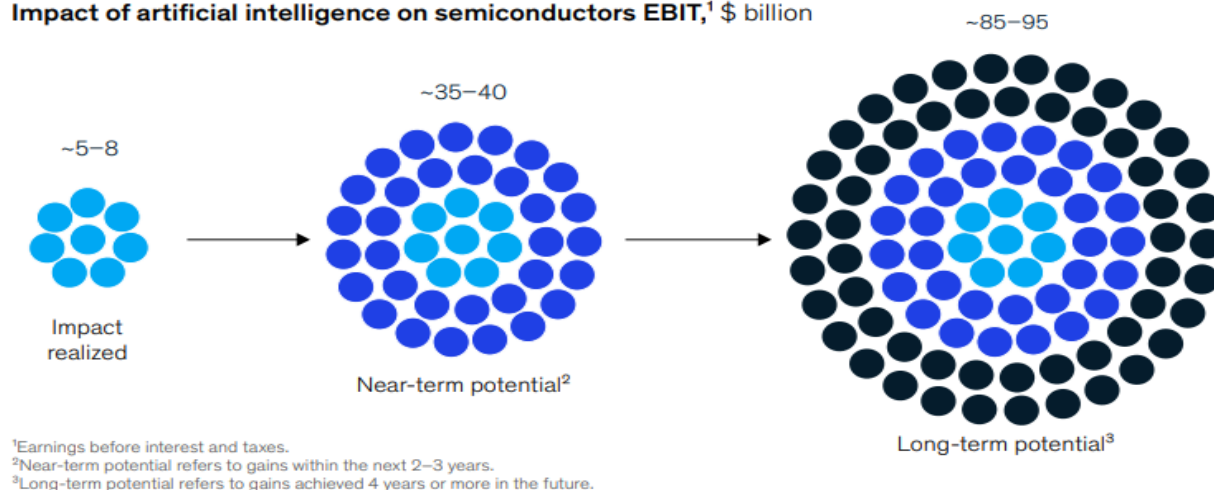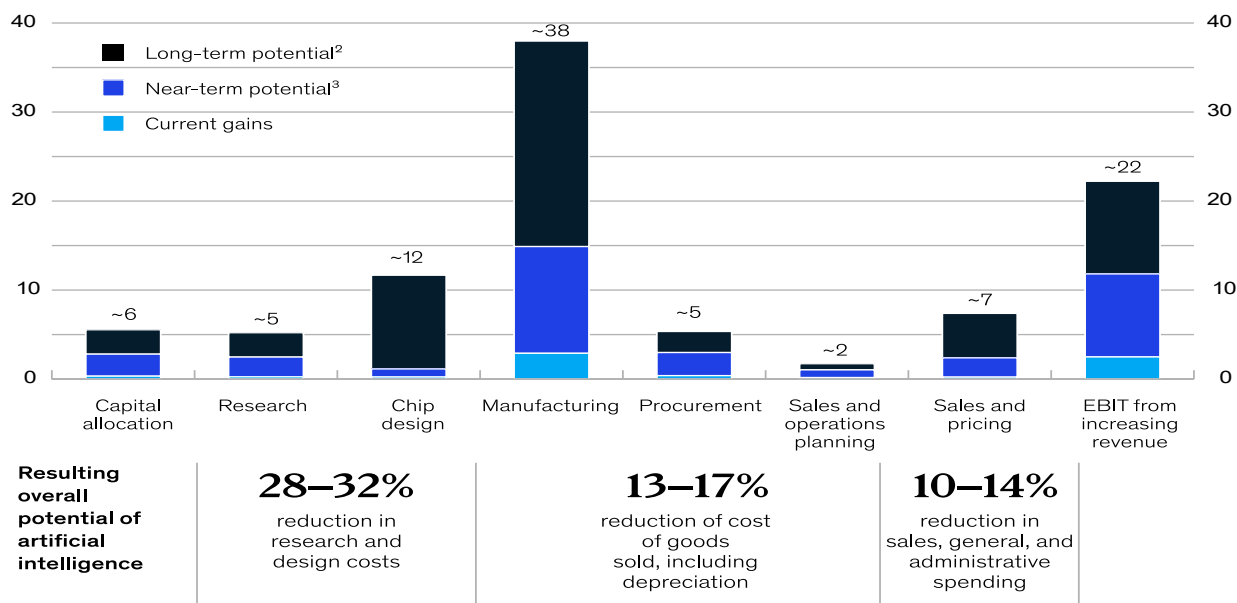[3]Long-term potential refers to gains achieved 4 years or more in the future.

Fig 1: image showing potential of AI in semiconductor manufacturing

A 2023 study published in Nature investigated the use of Bayesian optimization algorithms to improve semiconductor process development. The research created a controlled virtual process game to benchmark the performance of humans and computers in designing semiconductor fabrication processes. The findings revealed that human engineers excel in the early stages of development, while algorithms are more cost-efficient near the tight tolerances of the target.

Artificial intelligence will deliver the most value by reducing manufacturing costs, but the largest relative impact will be in R&D.

Impact on earnings EBIT,[1] by semiconductor key activities, $ billion

Legend:
- ■ Long-term potential[2]
- ■ Near–term potential[3]
- ■ Current gains

Category	Value
Capital allocation	~6
Research	~5
Chip design	~12
Manufacturing	~38
Procurement	~5
Sales and operations planning	~2
Sales and pricing	~7
EBIT from increasing revenue	~22

Resulting overall potential of artificial intelligence

28–32%	13–17%	10–14%
reduction in research and design costs	reduction of cost of goods sold, including depreciation	reduction in sales, general, and administrative spending

[1]Earnings before interest and taxes.
[2]Long-term potential accessible on timescales longer than 4 years.
[3]Near–term potential accessible within next 2–3 years.
Source: IBS; McKinsey analysis

McKinsey & Company

Fig2: Shows reducing manufacturing cost in different area of chip design

Research Gaps

Despite the growing body of research, several gaps remain in our understanding of AI's impact on the semiconductor industry:

1. **Long-term implications:** Although the immediate effects of AI on the semiconductor sector are becoming more widely recognized, there aren't many long-term research available. When planned fabs come online, the semiconductor sector may see a shortage of 100,000 workers in the U.S. and Europe and over 200,000 in Asia-Pacific, according to the McKinsey report5. Nevertheless, there are few thorough studies on how AI will alter labor dynamics and skill needs over time. This disparity is crucial as the sector must become ready for future demands on people and possible job displacement [9].

2. **Ethical considerations:** Significant ethical concerns are brought up by the quick adoption of AI in semiconductor design and production, especially in relation to data protection and intellectual property. Research on these issues is, nonetheless, scarce. Concerns like responsibility, ownership, and possible biases in AI-generated designs must be investigated as AI systems grow more independent in semiconductor design.

3. **Interdisciplinary approaches:** In the development of semiconductors, the nexus of artificial intelligence, materials science, and quantum computing is a new area with enormous promise. Research in this field is still in its early stages, though. More multidisciplinary research is needed, as evidenced by the U.S. Department of Commerce's recent decision to start a competition for AI-powered autonomous experimentation (AI/AE) in semiconductor materials and processes3. This disparity offers a chance for ground-breaking discoveries that have the potential to completely transform the semiconductor sector [10].

4. **Sustainability:** The environmental effects of AI-driven semiconductor production and AI's potential to improve sustainability in the sector are still little understood. With a single chip production plant using around 10,000 gallons of water every day as shown in the figure, the semiconductor industry is energy-intensive3. Comprehensive research on AI's involvement in reducing these environmental repercussions is scarce, although several studies starting to address this topic, such as the Harvard study that found that the manufacture of semiconductors alone is responsible for 75% of all CO_2 emissions [10].
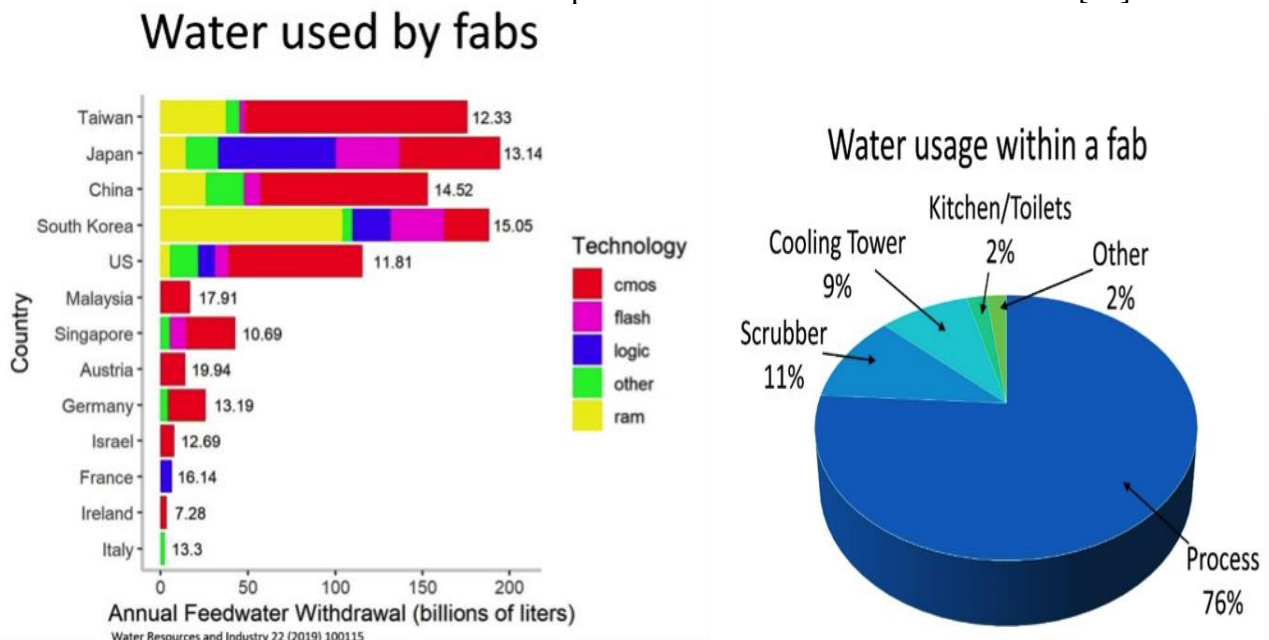

Fig 3: water usage in different countries for chip manufacturing

The semiconductor industry has both possibilities and problems as a result of these research gaps. To overcome them, academia, business, and legislators must work together to make sure that the use of AI in semiconductor manufacturing not only promotes efficiency and innovation but also takes into account long-term workforce implications, ethical issues, interdisciplinary advancements, and environmental sustainability.

V.   Methodology

This research employs a mixed-methods approach to explore the synergy between AI and the semiconductor industry:

Qualitative Methods
- Systematic review of academic literature from the past few years.
- Analysis of ten case studies from leading semiconductor companies.
- Semi-structured interviews with industry experts

Quantitative Methods
- Data analysis of AI chip and traditional semiconductor performance metrics through articles and research papers.
- Market analysis of AI chip demand and semiconductor industry growth rates

This methodology allowed me a comprehensive examination of the bidirectional impact between AI and semiconductors, providing both theoretical insights and empirical evidence.

VI.   Results and Discussion

Major Trends in AI Hardware:

GPUs (Graphics Processing Units):
Because of their remarkable parallel processing capabilities, GPUs continue to rule the AI hardware market. They are necessary for deep learning model training, which calls for effective handling of large-scale matrix operations.

The following are some recent developments in GPU technology:
Increased Memory Bandwidth: New GPU architectures are built with larger memory bandwidth, allowing for quicker data transfer rates and improved performance in AI tasks.

Enhanced Tensor Cores: Faster matrix operations are made possible by the introduction of upgraded tensor cores, which are essential for deep learning workloads.

Improved Energy Efficiency: As sustainability becomes a concern, manufacturers strive on designing GPUs that give more performance per watt, decreasing overall energy use. With its GPUs being extensively utilized in AI research and development, NVIDIA continues to be a pioneer in this field. The NVIDIA A100 Tensor Core GPU, for instance, achieves over 1,300 TOPS (trillions of operations per second) while preserving energy efficiency, resulting in notable performance gains [11].

TPUs (Tensor Processing Units):
The TPUs from Google are specialized processors made especially to speed up workloads related to machine learning [12].
Important trends consist of:
Customizable Architectures: With the increased customization made possible by new TPU designs, businesses may now adapt the hardware to suit own AI needs.

Integration with Cloud Services: TPUs are becoming more and more integrated with cloud platforms, offering

scalable options to companies who want to use AI without having to make significant upfront hardware expenditures.

With a power consumption of under 2 watts, TPUs provide exceptional performance per watt, offering up to 4 teraflops. When compared to its predecessor, the most recent TPU v6 has demonstrated a performance boost of around 3.85 times.
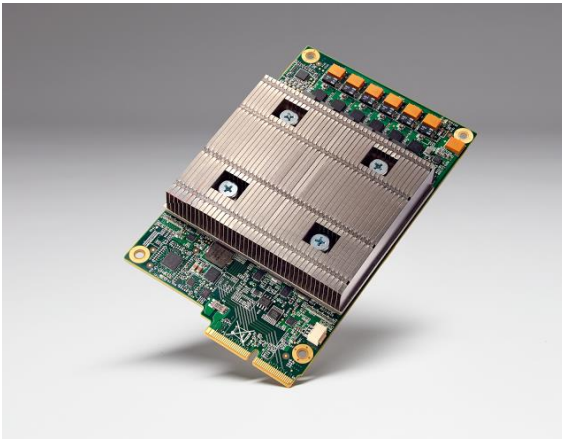

Fig 4 & 5: Image source(google): Googles TPU   image source(nvidia): Nvidia A100 GPU's

Neuromorphic Chips:

Neuromorphic computing is an emerging field that mimics the neural structure of the human brain. This technology offers several advantages:

Event-Driven Processing: Neuromorphic chips process information in an event-driven manner, leading to significant reductions in power consumption compared to traditional architectures.

Real-Time Learning: These chips can learn and adapt in real-time, making them suitable for applications in robotics and autonomous systems.
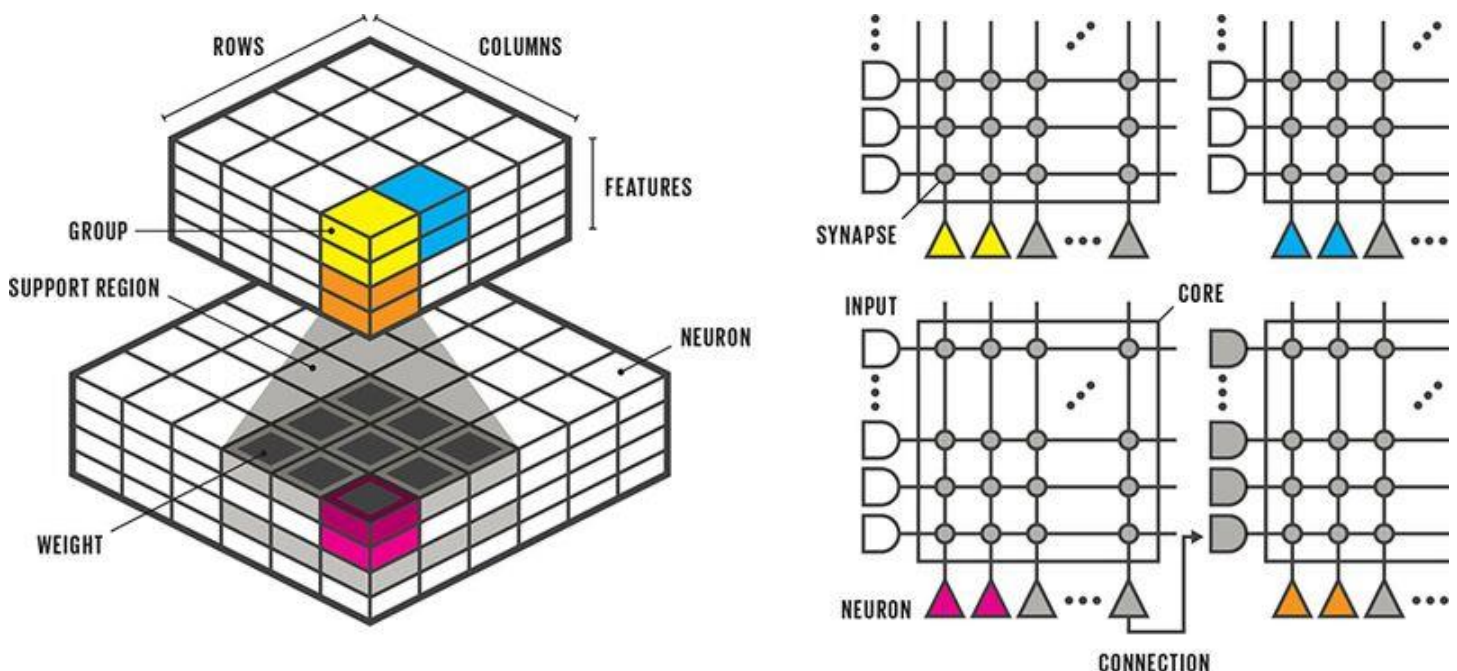

Figure 6 Illustration: James Provost **Tiny Spikes:** Two layers within a neural network contain groups of "neurons" with similar functions, indicated by color [blue, yellow, orange, and pink] in the illustration on the left. In the graphic on the right, those neurons are mapped to spiking neurons in an IBM TrueNorth chip. The spiking neurons are connected by gridlike "synapses" to other neurons in the same core, and to a row of inputs. Those inputs can generate spikes, which are then processed by the neural network.

Companies like Intel and IBM are leading the development of neuromorphic chips. Intel's Loihi chip is designed to emulate biological neural systems, offering a promising approach to efficient AI computations [13].

AI-Specific ASICs:
Application-Specific Integrated Circuits designed for AI tasks are becoming more prevalent. These custom chips offer optimized performance for specific AI workloads, potentially outperforming general-purpose processors in certain applications.

Quantum Computing: While still in early stages, quantum computing is emerging as a potential game-changer for AI hardware. Research is ongoing to explore how quantum processors could dramatically accelerate certain AI algorithms.

AI has significantly transformed semiconductor design, leading to several key advancements:

Reduced Transistor Size
Transistor shrinking, a key component of semiconductor innovation, has been transformed by AI-powered technologies. These techniques aid in the development of cutting-edge technologies such as TSMC's 5nm and 3nm devices by analyzing large design spaces and optimizing at a granular level. More components may fit on a single chip thanks to smaller transistors, which boosts processing speed and power. The practical ramifications of this improvement are demonstrated by the enhanced energy efficiency and greater performance of Apple's A17 & A18 Pro processor, which is built on TSMC's 3nm technology [14].
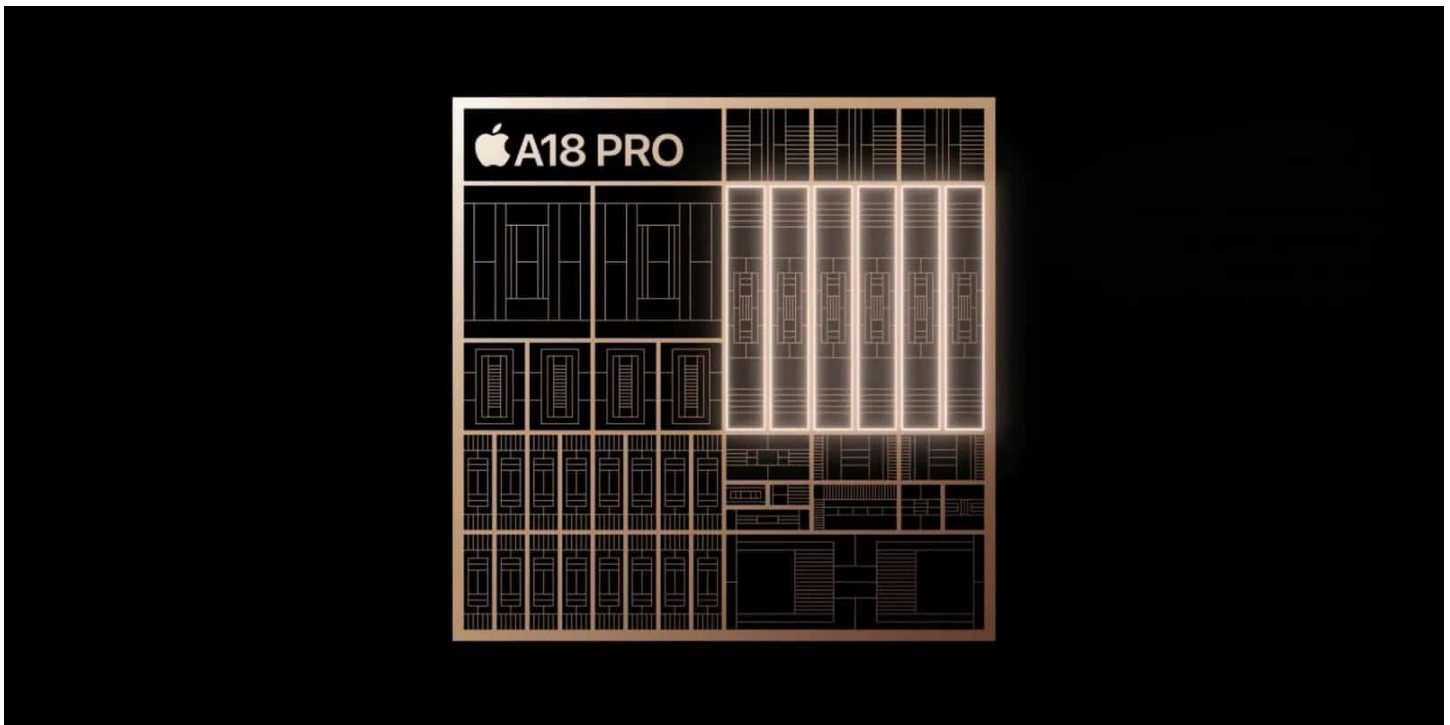

Fig 7: image shows Apple's A18 Pro chip design layout. The 3nm architecture introduces a substantial performance boost over its predecessors, such as the iPhone 15's 5nm chips. These next-gen processors allow for faster data processing and smoother multitasking.

Increased Processing Power
To meet the particular requirements of AI workloads, processors designed specifically for AI, such as Tensor Processing Units (TPUs), Field-Programmable Gate Arrays (FPGAs), and Neural Processing Units (NPUs), have been created. These chips, in contrast to conventional CPUs or GPUs, are designed for matrix operations and parallel computing, which are crucial for AI algorithms. For example, when compared to conventional GPUs, Google's TPU offers up to 15–30 times the performance per dollar for machine learning workloads. In a similar

vein, NVIDIA's A100 GPUs are now indispensable in data centers due to their remarkable performance and power efficiency in managing extensive AI and deep learning tasks.

Optimized Chip Design
These days, sophisticated machine learning models are essential for automating semiconductor design, which significantly cuts down on development times. AI-driven electronic design automation (EDA) solutions have been launched by companies like as Synopsys and Cadence, which automate processes such as layout creation, verification, and power optimization. For example, it has been stated that Synopsys' DSO.ai platform shortened chip development times by as much as 30%, enabling quicker innovation cycles. Reduced expenses and increased competitiveness in the semiconductor industry are the results of this efficiency.

Improved Efficiency and Performance
By improving design factors like transistor location and wire layouts, AI-driven techniques enhance chip performance. By analyzing intricate datasets, these technologies determine the optimal layouts, resulting in chips that produce less heat and have improved power efficiency. AI-powered design tools, for instance, have aided AMD and other businesses in creating CPUs with notable improvements in performance-per-watt, a crucial statistic for contemporary computing devices.

Quicker Time to Market
Reducing the time it takes for semiconductor goods to move from concept to market is one of AI's most revolutionary effects. Production timeframes are accelerated by automation in layout optimization, design verification, and testing. According to a McKinsey report, the use of AI in chip design and production has shortened development cycles by up to 40%, enabling businesses to quickly meet consumer expectations and seize new possibilities.

Semiconductors Accelerating AI Applications
AI's capabilities and uses have been boosted in tandem with semiconductor technological breakthroughs. Real-time processing is made possible by AI-optimized processors, which is especially important for edge computing devices like wearable sensors, drones, and driverless cars. By enabling AI models to function effectively on power-constrained devices, edge AI—powered by specialized semiconductors—improves privacy and lowers latency. For example, real-time AI features like voice assistants and face recognition are made possible by Qualcomm's Snapdragon CPUs.

Hardware for Specialized AI
Energy-efficient processing for AI workloads is made possible by novel designs like neuromorphic processors, which imitate the neural networks found in the brain. Designed for neuromorphic computing, IBM's TrueNorth processor uses a lot less power than conventional circuits while managing challenging AI tasks. These developments open the door to more intelligent, environmentally friendly AI systems in domains like autonomous robotics and healthcare.

Consequences, Difficulties, and Prospects
The IT sector is significantly impacted by the convergence of semiconductors and artificial intelligence. Defect detection accuracy in semiconductor production has increased because to AI-driven quality control; Applied Materials has a 99% success rate, compared to 85% for traditional approaches. To further increase production yield, these systems use active learning to adjust to new fault types. For instance, AI-driven process optimization has increased yield at TSMC by 10–15%, while McKinsey projects a possible 30% manufacturing cost reduction.

There are still issues, though, such as the high adoption costs of AI and the difficulty of incorporating AI into current processes. Future studies will probably concentrate on creating even more specialized AI hardware,

enhancing energy efficiency, and resolving ethical issues with automated decision-making as AI develops.

In summary, the mutually beneficial interaction between AI and semiconductors propels unheard-of technological advancements, encouraging creativity, effectiveness, and improved applications across sectors. This synergy has the potential to completely transform the future of AI and computing with further developments.

Current Applications:
Several semiconductor companies have successfully implemented AI applications in their manufacturing processes, leading to significant improvements in efficiency, yield, and cost reduction.

Here are some detailed examples:
GlobalFoundries: AI-Powered Predictive Maintenance
GlobalFoundries has implemented AI-driven predictive maintenance in its manufacturing facilities:
• AI models analyze sensor data to predict potential equipment failures.
• This approach enables timely maintenance, preventing unexpected stoppages and improving production effectiveness.

Samsung Electronics: AI in Defect Detection and Supply Chain Optimization
Samsung has deployed AI solutions to enhance quality control and supply chain management:
• AI models are used to inspect and detect defects on chip surfaces, eliminating faulty products.
• The company employs AI to predict market demand for various chip types and adjust production plans accordingly.

TSMC: AI-Driven Yield Improvement
Taiwan Semiconductor Manufacturing Company (TSMC) has reported substantial benefits from integrating AI into its manufacturing processes:
• AI and machine learning techniques have contributed to a 10-15% improvement in yield.
• This improvement has been achieved through AI-driven models that predict yield outcomes based on historical data and current process parameters.
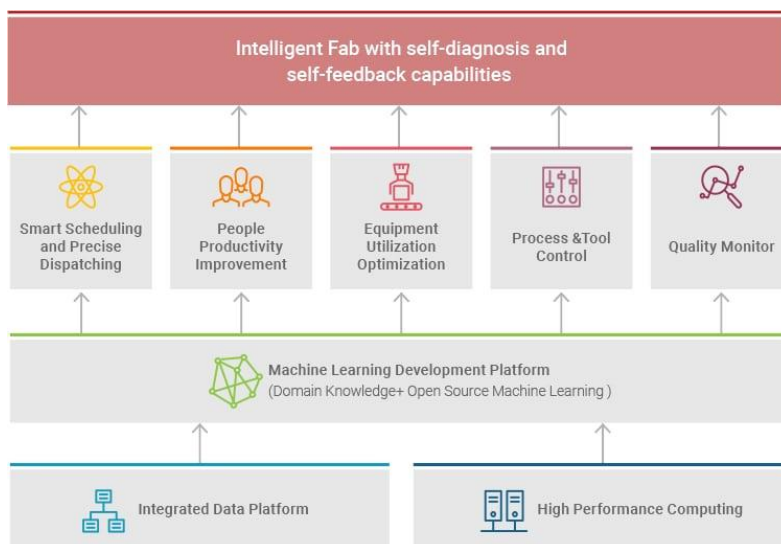

fig 8 description: image shows an intelligent semiconductor fabrication (fab) system architecture with self-diagnosis and self-feedback capabilities.

Synopsys: AI in Chip Design
Synopsys, a leader in electronic design automation, has integrated AI tools into its software:
• AI-enhanced tools automatically generate design layouts and perform complex simulations.
• This integration has reduced design cycles by as much as 30%.

ASML: AI in Photolithography Machine Calibration

ASML, in collaboration with Google Cloud and ML6, has implemented AI in its photolithography machines:
• AI tools analyze calibration data from photolithography machines.
• Results include:
• 10x increase in performance of the application development team within six months.
• 40% improvement in time to market.
• More granular chip inspections using AI.

Industry-Wide Impact

According to a McKinsey study:
• AI/ML contributes between $5 billion and $8 billion annually to earnings before interest and taxes at semiconductor companies.
• Manufacturing accrues the most value from AI/ML, with potential cost reductions of up to 17%.
• In research and chip design, AI/ML may eventually reduce the current R&D cost base by as much as 28 to 32%.

These examples demonstrate the significant impact AI is having on semiconductor manufacturing, from improving yield and reducing costs to enhancing design processes and optimizing supply chains. As AI technologies continue to evolve, their integration into semiconductor manufacturing is likely to deepen, driving further innovations and efficiencies in the industry.

2.**Challenges**:

AI semiconductor technology faces several and important challenges. Despite continuous progress in the area, power consumption is still a significant obstacle, especially for edge AI applications. The capacity of semiconductor technology to scale to meet these expanding needs is a significant problem as AI models get more complicated and powerful. As we move closer to the limits of downsizing, the industry is also struggling with the physical constraints of the semiconductor materials that are now available. All of these difficulties highlight the necessity of creative fixes and ongoing study to advance AI semiconductor technology.

3.**Future Directions:**

AI semiconductor technology has a lot of fascinating things in store for the future. With its unparalleled computational capacity, quantum computing development is at the forefront and has the potential to completely transform AI processing capabilities. At the same time, the science of neuromorphic computing—which takes its cues from the structure of the human brain—is starting to show promise as a revolutionary approach to AI processing that uses less energy. By pushing the limits of existing technology, research into cutting-edge materials like graphene and molybdenum disulfide [15] may lead to the development of quicker, smaller, and more energy-efficient semiconductors. Furthermore, AI is anticipated to be a key factor in determining the future of the semiconductor sector by offering real-time insights about consumer demand and new trends. In this quickly changing industry, an AI-driven method may enable semiconductor businesses to make better strategic decisions, which might speed up innovation and market response.

4.**Ethical and Societal Implications:**

The rapid advancement of AI and semiconductor technology raises important questions about data privacy, security, and the societal impact of increasingly powerful AI systems.

In conclusion, the symbiotic relationship between AI and semiconductors is driving unprecedented advancements in both fields. While challenges remain, particularly in power consumption and scalability, the future holds exciting possibilities. As we move towards more sophisticated AI applications and novel computing paradigms like quantum and neuromorphic computing, the semiconductor industry will continue to play a crucial role in shaping the future of technology.

VII. Conclusion

This research underscores the transformative synergy between artificial intelligence (AI) and the semiconductor industry, highlighting how advancements in one domain fuel innovation in the other. AI has become a cornerstone of semiconductor manufacturing, enabling predictive maintenance, defect detection, supply chain optimization, and yield improvement. Companies like GlobalFoundries, Samsung Electronics, TSMC, Synopsys, and ASML exemplify the integration of AI to enhance production efficiency, reduce costs, and accelerate time-to-market. Simultaneously, advancements in semiconductor technology, such as GPUs, TPUs, neuromorphic chips, and quantum computing, are empowering AI to handle increasingly complex tasks with unprecedented speed and efficiency.

Despite these advancements, the industry faces significant challenges, including power consumption, scalability, and material limitations. Addressing these hurdles requires innovative approaches, such as the exploration of advanced materials like graphene and the development of energy-efficient computing paradigms like neuromorphic architectures. Furthermore, the rapid evolution of AI and semiconductors brings ethical and societal considerations, particularly in data privacy, security, and the broader implications of AI-powered systems.

Looking ahead, the future holds exciting possibilities. Quantum computing and neuromorphic processing promise to redefine AI capabilities, while AI-driven strategies offer real-time insights to guide semiconductor industry growth. These advancements will enable smarter, faster, and more sustainable technologies, creating a foundation for transformative applications across industries.

In conclusion, the mutually reinforcing relationship between AI and semiconductors is shaping the next era of technological progress. By addressing current challenges and embracing emerging innovations, this symbiosis will continue to drive breakthroughs, paving the way for a smarter, more efficient, and interconnected future.

VIII. References

[1] J2Sourcing, "The Impact of AI on the Semiconductor Industry: Demand Surge and Industry Challenges," *The Impact of AI on the Semiconductor Industry: Demand Surge and Industry Challenges.*

[2] SemiWiki, "Semiconductor Intelligence," *Semiconductor Intelligence.*

[3] Averroes, "How AI is Radically Advancing Semiconductor Manufacturing [2024]," *How AI is Radically Advancing Semiconductor Manufacturing [2024].*

[4] D. B. M. Research, "Semiconductor Companies Integrating AI into Manufacturing for improved Efficiency and Product Quality".

[5] NVIDIA, "TOPS of the Class: Decoding AI Performance on RTX AI PCs and Workstations," *What is a token? Why is batch size important? And how do they help determine how fast AI computes?.*

[6] RUN:AI, "What Are AI Chips? (Evolution, Benefits, and Top Manufacturers)".

[7] J. o. k. l. d. a. m. w. AI, "REVOLUTIONIZING SEMICONDUCTOR DESIGN AND MANUFACTURING WITH AI".

[8] M. &. Company, "Scaling AI in the sector that enables it: Lessons for semiconductor-device makers".

[9] S. C. Engineering, "AI Takes Aim At Chip Industry Workforce Training".

[10] E. leader, "U.S. Pushes AI for Sustainable Chip Manufacturing to Regain Global Leadership".

[11] Nvidia, "What's Up? Watts Down — More Science, Less Energy," Nvidia, [Online]. Available: https://blogs.nvidia.com/blog/gpu-energy-efficiency-nersc/.

[12] G. Cloud, "Cloud Tensor processing units," google, [Online]. Available: https://cloud.google.com/tpu.

[13] O. Neuromorphic, "Open Neuromorphic," [Online]. Available: https://open-neuromorphic.org/neuromorphic-computing/hardware/loihi-intel/.

[14] Tomshardware.com, "Apple's A18 and A18 Pro processors powers the iPhone 16 and 16 Pro — and Apple Intelligence," Tomshardware, [Online]. Available: https://www.tomshardware.com/phones/iphone/apples-a18-processor-powers-the-iphone-16-and-apple-intelligence.

[15] Phyorg, "Researchers develop new technique for making graphene competitor molybdenum disulfide," PHYSorg, [Online]. Available: https://phys.org/news/2015-02-technique-graphene-competitor-molybdenum-disulfide.html.

[16] J. Sourcing, "The Impact of AI on the Semiconductor Industry: Demand Surge and Industry Challenges".