

TECHNOBYTE 2K24

Annual Edition



BEYOND SILICON:

We examine the Gallium Nitride (GaN) transistors revolutionizing power delivery.

THE END OF MOORE'S LAW:

What happens to the industry when CPUs stop getting smaller?

ENGINEER'S GUIDE:

Top 5 low-power microcontrollers for your next IoT IoT project.

BEYOND REALITY

The next generation of sensory VR is here. Are we ready to leave the physical world behind?

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VISION OF THE DEPARTMENT

To achieve excellent standards in technical education and engage research in the field of Electronics and Communication Engineering creating employable and innovative professionals who can excel in global challenges

MISSION OF THE DEPARTMENT

- 1) To practice innovative teaching and learning practices in Electronics and Communication domain with effective curriculum enhancement and Industry collaboration.
- 2) To inspire creative enquiry and innovation in students through excellent training programs and projects for professional skills.
- 3) To imbibe a sense of team work, ethics combined with social responsibility in students.

Chairman



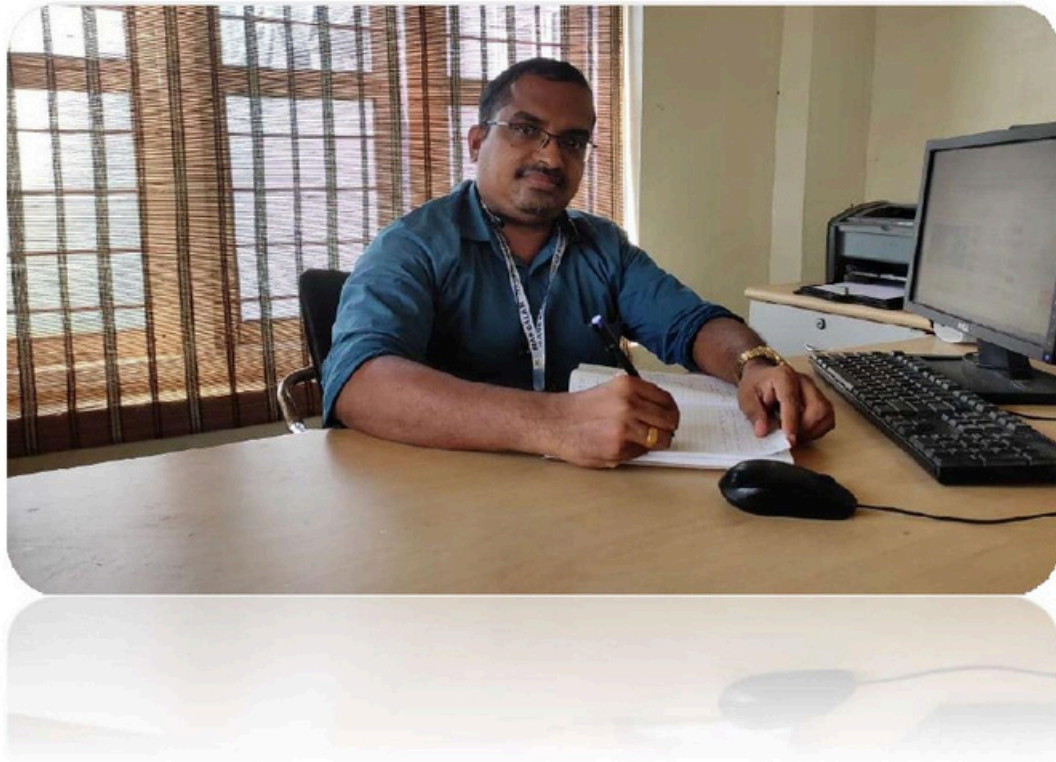
Pursuing your passions makes you more interesting, and interesting people are enchanting.

Principal

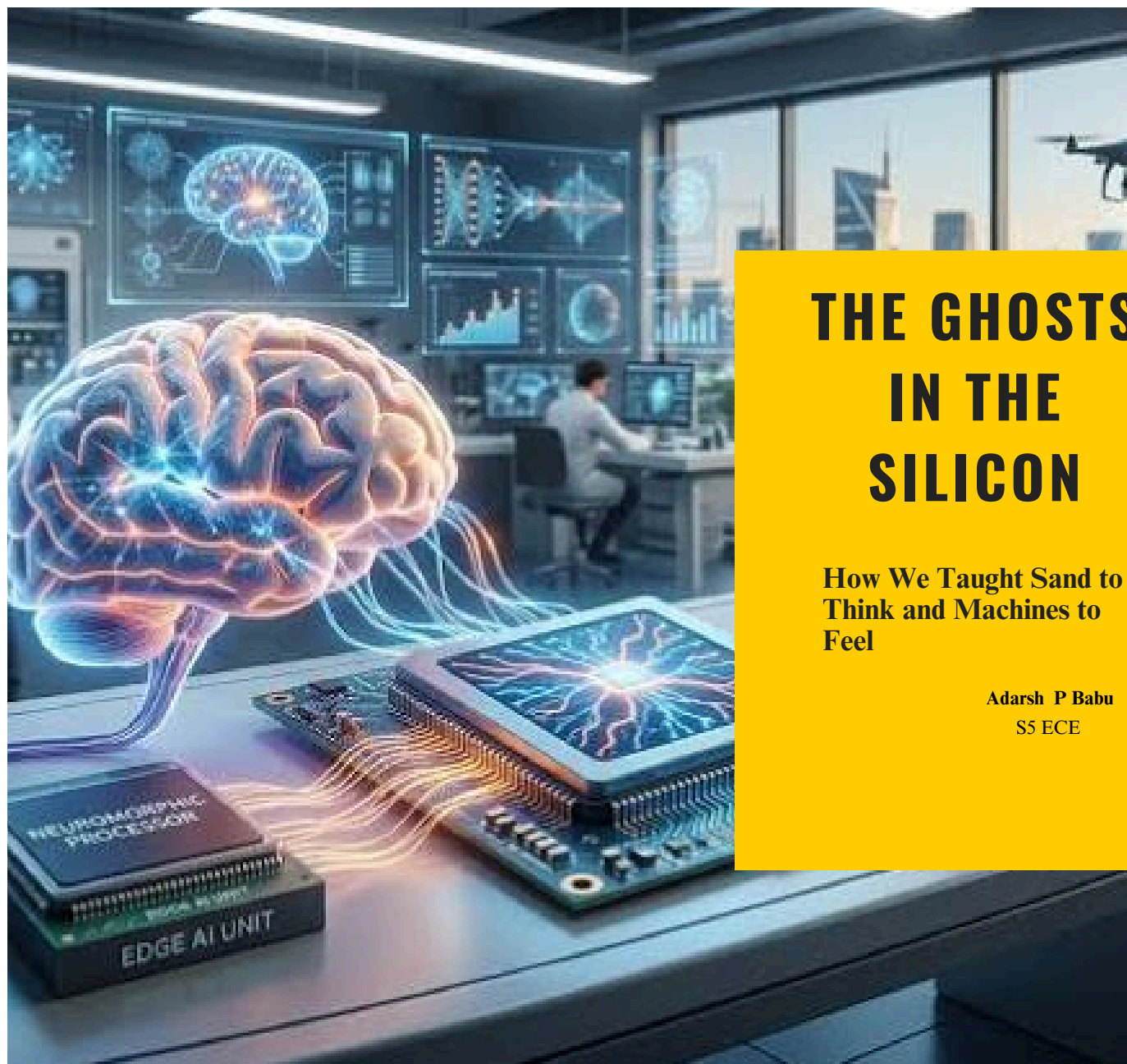


Desire is the key to motivation, but it's determination and commitment to an unrelenting pursuit of your goal - a commitment to excellence - that will enable you to attain the success.

HEAD OF THE DEPARTMENT



The Department of Electronics and Communication Engineering at Mangalam College of Engineering, established in 2002, is committed to academic excellence, innovation, and research. The department offers undergraduate and postgraduate programs in VLSI and Embedded Systems, supported by experienced faculty. Through internships, projects, workshops, seminars, and industry collaborations, students gain practical knowledge and stay updated with the latest technologies. The department also encourages cultural, sports, and extracurricular activities, nurturing skilled, innovative, and socially responsible professionals.



THE GHOSTS IN THE SILICON

**How We Taught Sand to
Think and Machines to
Feel**

Adarsh P Babu
S5 ECE

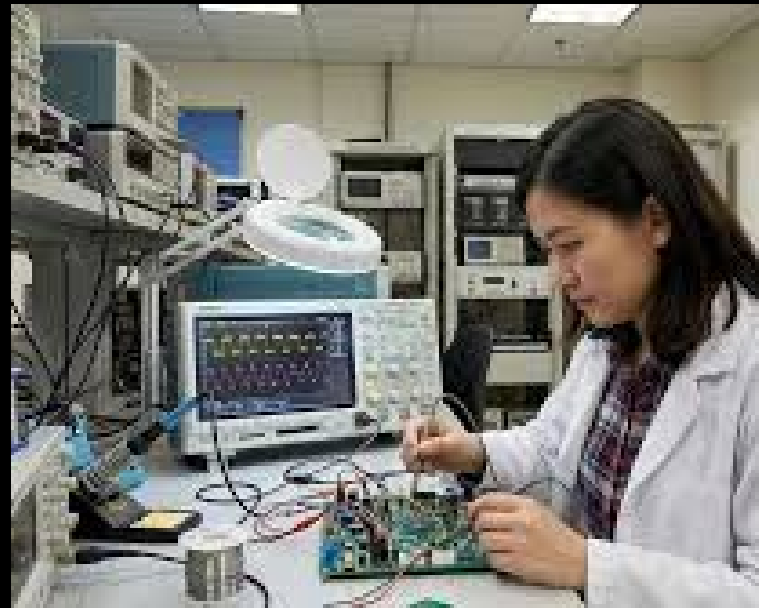
in a basement laboratory humming with the low, steady drone of cooling fans, a third-year engineering student watches a hand close around a delicate glass beaker. The hand is not human. It is a skeletal assembly of matte-black carbon fiber, exposed silver servos, and a labyrinth of microscopic wiring. But the grace with which it moves—the minute hesitation before contact, the precise calibration of force that holds the glass without shattering it—feels entirely organic. This is not merely a mechanical trick. What is happening in this room is a profound act of translation

. In the span of a few milliseconds, a cascade of electrons has rushed through a silicon maze, triggering a sequence of algorithmic decisions that interpret spatial data, calculate friction coefficients, and actuate physical motors. The hand doesn't just move; it understands its environment. We are witnessing the maturation of engineering intelligence: the invisible choreography between the physical reality of electronics and the abstract logic of computing.

For decades, we treated these as separate disciplines. Electrical engineers built the bodies; computer scientists wrote the minds. Today, those boundaries have evaporated. To build the modern world—a world of autonomous vehicles, adaptive energy grids, and synthetic limbs—requires a mind that can traverse the boundary between hardware and software without breaking stride.

PART I: THE ALCHEMY OF SAND

Before a machine can learn, before it can recognize a human face or balance a drone in a gale, it requires a physical substrate. It is easy to forget, in our era of cloud computing and wireless omnipresence, that the digital world is profoundly physical. It is made of rock, metal, and light



At the core of every smart system is a microprocessor—a city of microscopic switches etched into a flake of silicon. We have taken the second most abundant element in the Earth's crust, purified it, and carved it into architectures so dense they defy human comprehension. A modern System on a Chip (SoC) might contain upwards of 50 billion transistors, each acting as a microscopic floodgate, permitting or blocking the flow of electrons to represent a binary one or zero.

"We have taken the second most abundant element in the Earth's crust, purified it, and carved it into architectures so dense they defy human comprehension. The digital world is profoundly physical"

But the sheer scale of miniaturization has pushed electronics to the very edge of classical physics. "When you are building transistors that are only a few dozen atoms wide, you are no longer just an electrical engineer; you are a quantum traffic cop," says Dr. Aris Thorne, a leading researcher in semiconductor physics. "Electrons begin to misbehave. They tunnel through barriers. The heat generated by billions of switches firing billions of times a second threatens to melt the very substrate they live on"

This is where the genius of modern hardware engineering shines. It is not just about making things smaller; it is about architecture. Engineers design multi-core processors, specialized neural processing units (NPUs), and graphic processing units (GPUs) that divide and conquer tasks. They build hardware specifically optimized to handle the brutal mathematics of machine learning. The silicon is no longer a blank slate; it is physically sculpted to anticipate the kind of thoughts it will be asked to think.

* * *

PART II: THE GHOST IN THE MACHINE

If the silicon is the brain tissue, software is the consciousness. For a long time, the relationship between hardware and software was strictly dictatorial. Human programmers wrote exhaustive lists of rigid, IF-THEN rules, and the processor executed them blindly. A machine was "smart" only insofar as a human had anticipated every possible scenario it might encounter. But the physical world is messy. It is full of shadows, unpredictable weather, and human irrationality. You cannot write a traditional IFTHEN program to drive a car through a busy intersection, because the permutations of variables are virtually infinite.



To solve this, computing had to evolve from instruction to inference. Enter machine learning and neural networks. Instead of writing rules, software engineers now design architectures that allow systems to learn from data. They feed a network millions of images of stop signs, under every conceivable lighting condition, until the system develops its own internal, mathematical representation of "stop signness." This transition demands a staggering amount of computational brute force. "The algorithms we use today—deep learning, transformer models—are conceptually elegant, but mathematically violent," notes Elena Rostova, a senior architect of autonomous systems.



PART III: THE DIGITAL NERVE ENDINGS

A brain in a jar, no matter how powerful, is deaf, dumb, and blind. For a system to be truly smart, it must interact with the analog chaos of the physical world. It needs nerve endings. This is the domain of embedded systems and sensors—the unsung heroes of engineering intelligence. We have engineered MicroElectro-Mechanical Systems (MEMS) that act as the eyes, ears, and inner ears of our machines. The accelerometer in a smartphone, which detects orientation, relies on a microscopic physical mass suspended on microscopic silicon springs. When the phone moves, the mass shifts, altering the electrical capacitance, which the processor translates into a digital understanding of gravity.

"They require billions of matrix multiplications. If we tried to run today's AI on the processors of a decade ago, it would be like trying to drain the ocean with a teaspoon. The software is only as smart as the hardware allows it to be." This symbiotic relationship is the defining characteristic of modern engineering. Software developers must deeply understand the memory bandwidth and thermal limits of the hardware. Hardware engineers must anticipate the evolving demands of software frameworks. The ghost and the machine are inextricably linked.

* * *

"A brain in a jar, no matter how powerful, is deaf, dumb, and blind. For a system to be truly smart, it must interact with the analog chaos of the physical world."

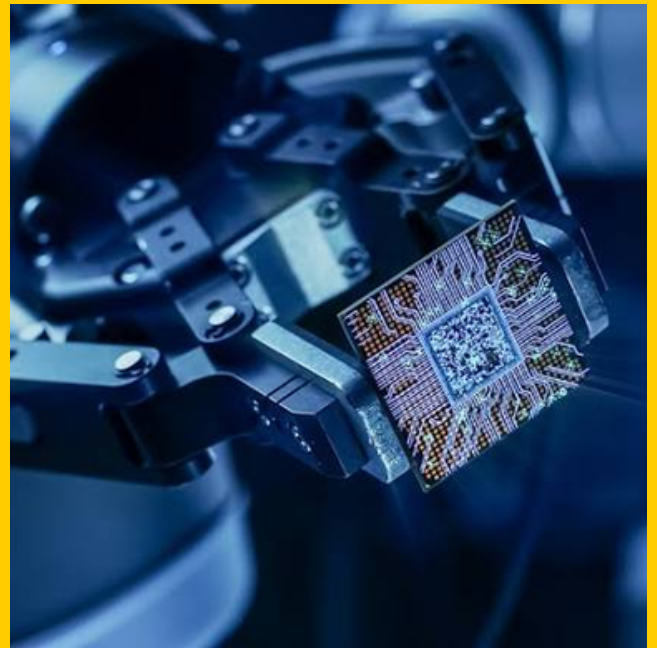
Consider the autonomous drone. As it navigates a dense forest, it is subjected to a torrent of analog noise: sudden wind gusts, blinding shafts of sunlight, the physical inertia of its own frame. Its sensors—LiDAR bouncing lasers off tree trunks, gyroscopes feeling the tilt, cameras parsing shadows—pull in millions of data points a second. The true magic happens at the interface. Analog-to-Digital Converters (ADCs) must capture this messy, continuous reality and slice it into discrete digital value

The processor must filter the noise, run the data through its trained neural networks, calculate a response, and send digital commands to the actuators—the motors that spin the propellers. And it must do all of this in a fraction of a heartbeat, thousands of times a minute, continuously correcting its own physical state against its digital intent..

* * *

PART IV: THE BUILDERS OF THE NEXT ERA

For the students sitting in lecture halls today, and the professors guiding them, the implications of this cyber-physical convergence are staggering. The silos of the 20th century are obsolete.



“When I was in school, you picked a lane,” says Dr. Marcus Vance, a professor of cybernetics and a pioneer in adaptive robotics. “You were a circuits person, or you were a code person. Today, if you build a beautiful circuit but don’t understand the machine learning framework that will run on it, your circuit is useless. If you write brilliant code but don’t understand the latency of the sensors feeding it data, your robot crashes into a wall.”

“Today, if you build a beautiful circuit but don’t understand the machine learning framework that will run on it, your circuit is useless.”

The modern engineering curriculum is rapidly adapting to this reality. Students are learning to view systems holistically. They are designing custom PCBs (Printed Circuit Boards) in the morning and training neural networks in the afternoon. They are learning that optimization is not just a software problem, but a physical one—that an inefficient algorithm drains a battery just as surely as a short circuit. This is the ultimate promise of engineering intelligence: the synthesis of disciplines. We are no longer just building tools; we are building systems that perceive, adapt, and act

* * *

THE "SO WHAT?": A LINGERING THOUGHT

To study engineering today is to inherit the most complex toolkit in human history. We are currently laying the digital nervous system of the 21st century over the physical skeleton of the 20th. Every smart grid that balances renewable energy loads, every diagnostic machine that catches a tumor a doctor missed, and every prosthetic limb that allows a user to feel the texture of an apple relies on this fragile, beautiful bridge between silicon and code. But with this immense capability comes an equally immense responsibility. Intelligence, whether biological or engineered, is a lever that magnifies intent. A smart system will optimize exactly for

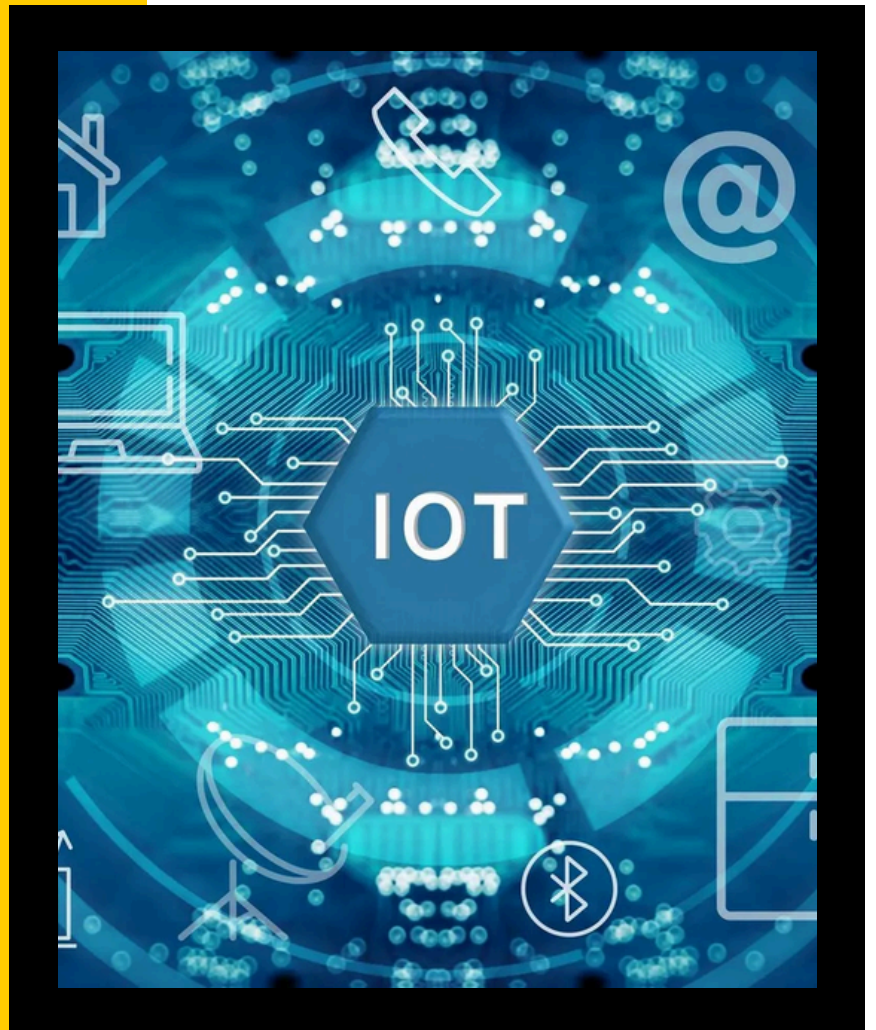
the variables it is programmed to value. If the engineers who build these systems do not possess a deep ethical understanding of the physical world they are intervening in, the precision of the hardware and the speed of the software will only help us make mistakes faster. The students working in the labs today— watching carbon-fiber hands close around glass beakers—are not just learning how to make things work. They are deciding how the future will behave. They are the ones who must ensure that as we teach sand to think and machines to feel, we do not lose our own humanity in the translation. The ghosts we put into the silicon are, ultimately, reflections of ourselves



THE INTERNET OF EVERYTHING

When devices start talking to each other, the network escapes the screen and becomes the environment

Ayana Antony
S7 ECE



For decades, the internet was a place we visited—a destination behind a glowing screen. Today, it is escaping the glass. As everyday objects, civic infrastructure, and human routines begin to communicate autonomously, we are no longer just users of a network. We are becoming inhabitants of a global nervous system

THE "SO WHAT?": A LINGERING THOUGHT

You know the drill. You open an app to turn on your smart lights. You open a different app to adjust the thermostat. Your smartwatch buzzes to tell you to stand up, but it doesn't tell your desk to automatically raise to a standing position

We have surrounded ourselves with "smart" devices, but they are all fiercely independent, trapped in their own isolated ecosystems. This is the Internet of Things (IoT)—a slightly underwhelming era where devices can connect to a distant server, but rarely to each other. They are solitary nodes shouting into the void of a centralized cloud. And frankly, it requires too much human micromanagement. That is changing. Engineers are building the Internet of Everything (IoE). It is the evolutionary leap from a world of isolated "things" to an integrated web where things, people, processes, and data interact in real-time, without human mediation. The devices aren't just talking to the cloud anymore; they are turning around and talking to each other

OKAY BUT WHAT ACTUALLY IS IT?

Picture a modern shipping port. A decade ago, human operators directed cranes, truck drivers waited in miles-long queues with paper manifests, and dispatchers guessed at optimal routes. Today, when an automated cargo ship is still fifty miles offshore, its onboard navigation systems are already whispering to the port's autonomous cranes. They negotiate docking times based on tidal data, local wind speeds, and the real-time GPS locations of the automated guided vehicles waiting on the asphalt. The containers themselves possess environmental sensors, continuously transmitting their internal temperatures to algorithms that prioritize the offloading of perishable goods



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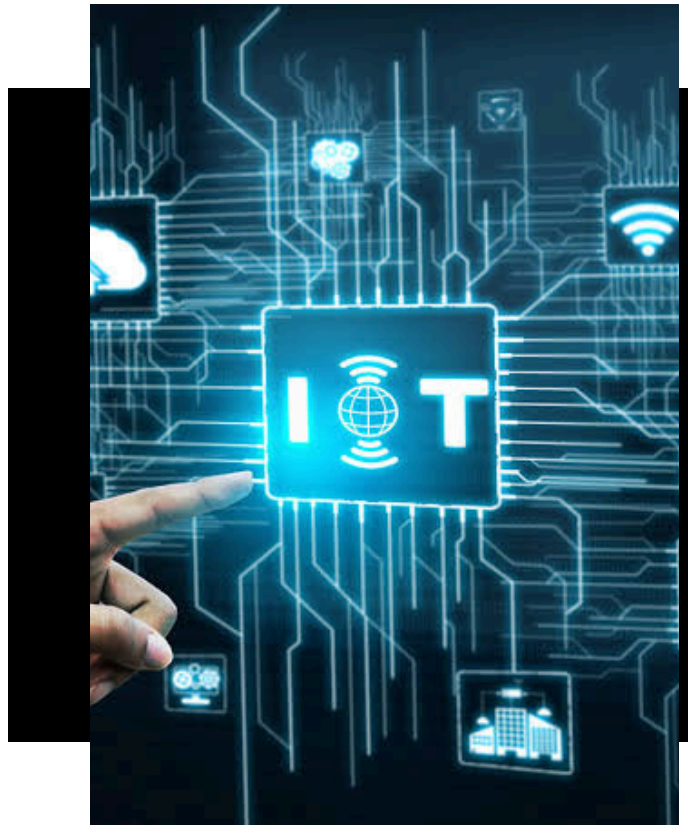
WAIT, WHY DO WE SUDDENLY NEED THIS?

The shift from IoT to IoE is being driven by pure physics and necessity. Two main reasons:

- The cloud is too slow. If a self-driving car has to ask a server in Virginia whether it should brake for a stray dog in Seattle, the latency will cause a crash. The intelligence must be smeared across the physical world, embedded in the tires, the concrete, and the streetlights
- New networks demand smarter environments. 5G and incoming 6G

networks use higher frequencies to carry massive amounts of data. But these higher-frequency waves travel in much straighter lines and get blocked easily [cite: 5]. A millimeterwave 5G signal can get seriously weakened by a pane of glass [cite: 5]. To make the IoE function, engineers are rethinking physical infrastructure, creating technologies like Reconfigurable Intelligent Surfaces (RIS) that act as smart mirrors, deliberately • • ECS DEPARTMENT MAGAZINE 2redirecting wireless signals around corners and dead zones so devices can maintain constant communication .

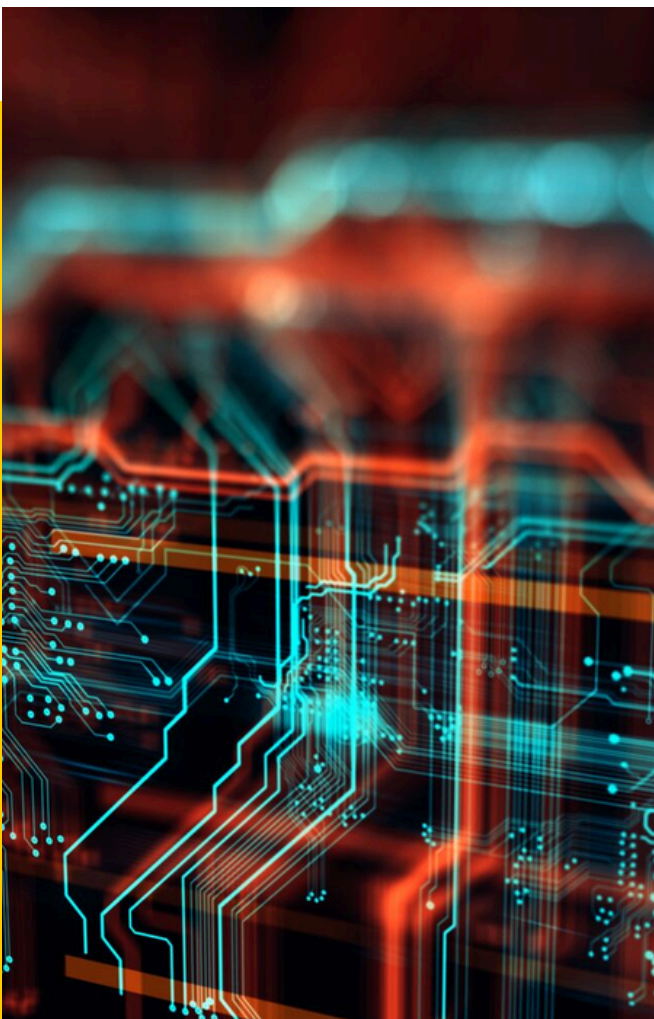
We spent the last twenty years teaching machines how to speak to us. The next twenty years will be defined by what machines say when they turn around and speak to each other."



WHAT CAN YOU ACTUALLY DO WITH THIS?

Here is where it gets genuinely useful—and kind of wild to imagine

- Autonomous intersections: Traffic lights are replaced by negotiation algorithms. Cars communicate their speed, trajectory, and passenger urgency directly to each other, seamlessly merging and crossing intersections without stopping, parting like a school of fish
- Hyper-responsive power grids: When a neighborhood's demand for electricity spikes, the smart grid doesn't just spin up a coal plant. It talks to thousands of local smart thermostats and electric vehicles, negotiating a tiny, imperceptible 1-degree drop in AC or a 3-minute pause in car charging to instantly balance the load





- Smart agriculture: Drone swarms fly over sprawling fields, processing images locally to identify crop blight plant by plant. They communicate instantly with ground-based robotic sprayers to deliver micro-doses of pesticide only to the affected leaves, rather than crop-dusting the entire farm

THE GENUINELY COOL PART: YOU ARE A NODE

In the IoE, a human being is not an external operator clicking a mouse; we are environmental variables. Our biometrics, our movement patterns, and our schedules are data points that the machines respond to. When you walk into a room, the building senses the thermal load of your body, crossreferences your calendar to see how long you plan to stay, and adjusts the airflow and lighting accordingly

You do not ask the room to make you comfortable. The room observes you, communicates with its own subsystems, and anticipates your biological needs before you consciously register a chill

OKAY, SO WHAT'S THE CATCH?

Nothing this connected is without risk. We are building a highly coupled system. "In a loosely coupled system, if your internet goes down, you can't watch Netflix," explains Dr. Amina El-Sayed, a cybersecurity researcher focusing on autonomous infrastructure. "In a highly coupled IoE environment, if a malicious actor injects a false data packet into a city's traffic sensor mesh, they don't just cause a digital glitch. They physically crash autonomous trucks or destabilize the power grid."

Furthermore, there is the interoperability nightmare. For the IoE to function, a sensor built by Siemens must perfectly interpret a data packet from an Apple wearable, relayed through a Cisco router. Getting fiercely competitive corporations to agree on a universal, opensource language is a political challenge just as much as an engineering one.

WHY THIS MATTERS ESPECIALLY FOR US

College campuses are essentially miniature smart cities. They have their own power grids, complex transit systems, densely packed populations, and highly variable schedules. This makes universities the ultimate testbeds for the Internet of Everything. When a lecture hall fills with three hundred students, the ambient temperature and CO2 levels spike rapidly. Instead of waiting for a manual

thermostat adjustment, campus IoE systems can monitor the sudden influx of MAC addresses connecting to the local Wi-Fi router, predict the thermal load, and preemptively trigger the HVAC system before the room even gets stuffy. You are living inside the prototype

WHERE'S THIS ALL GOING?

The ultimate goal of the IoE is invisibility. We are moving toward a state of "ambient intelligence



In the future, you won't pull a device out of your pocket to check the internet. The internet will be baked into the drywall, the pavement, and the fabric of your clothes. The world will be programmed to react to our subconscious biology before we even form a conscious thought

For the engineers and designers sitting in college lecture halls today, this is the ultimate design challenge. You are not just building tools; you are building an ecology

THE TAKEAWAY

We spent the first half-century of computing forcing humans to learn the language of machines

We stared into screens, typed commands, and adapted our workflows to suit the silicon. The Internet of Everything reverses the dynamic. As the devices around us begin to talk to each other, they are finally learning the language of the physical world. The network is no longer a destination. It is the air we breathe

* * *



THE INVISIBLE SYMPHONY: HOW AI IS TEACHING THE AIRWAVES TO THINK

AI IN WIRELESS COMMUNICATION

Eswar Aravind

S3 ECE

stand in the center of a crowded college football stadium on a crisp Saturday afternoon, right after a game-winning touchdown, and look around. You will see seventy thousand people cheering, throwing their hands in the air, and, almost in unison, pulling out their smartphones to text, post, or stream the moment to the world.

To the human eye, the scene is one of pure, joyful chaos. But to a radio frequency (RF) engineer, the real chaos is entirely invisible.

In that exact moment, the air above the stadium is choked with electromagnetic radiation. Millions of data packets are colliding, bouncing off concrete bleachers, refracting through human bodies, and desperately fighting for a sliver of the radio spectrum. Cell towers on the stadium's rim are screaming instructions, trying to coordinate the massive traffic jam of signals.

It is a miracle of modern engineering that your video uploads at all. But behind the scenes, the cellular network is redlining.

For the past century, we have treated the wireless spectrum like a vast, empty highway. We kept building faster cars (from 1G to 5G) and adding more lanes (higher frequencies). But we are finally running out of invisible real estate. The physics of radio waves—governed by Shannon-Hartley's theorem—dictate a hard mathematical limit to how much data you can squeeze into a specific frequency band. As we race toward a future of autonomous vehicles, drone swarms, and remote robotic surgery, the old way of managing wireless traffic through rigid, human-written algorithms is breaking down

To survive the next decade, the network cannot just be fast. It must become conscious. This is the dawn of the AI-native network. In laboratories and telecom hubs across the globe, engineers are stripping away decades of traditional mathematical formulas and replacing them with neural networks. They are moving artificial intelligence out of the cloud and injecting it directly into the physical airwaves, teaching our cell towers not just to transmit, but to learn, adapt, and predict

THE LIMITS OF HUMAN MATHEMATICS

To understand why AI is necessary, you have to understand how staggeringly complex wireless communication has become.

In the era of 3G and early 4G, your phone was essentially a sophisticated walkie-talkie. It talked to a cell tower, and the tower talked back. The math required to filter out background noise and decode your voice was complex, but it was static. Engineers wrote elegant, rigid equations to handle signal interference, baked those formulas into silicon chips, and shipped them out. With 5G and the upcoming 6G, that static architecture collapses. Modern cell towers use a technology called Massive MIMO (Multiple-Input Multiple-Output). Instead of a single antenna broadcasting in all directions like a lighthouse, a modern tower is a grid of hundreds of microscopic antennas. These antennas use a technique called "beamforming" to shoot targeted, laser-like beams of data directly to your moving phone, bouncing the signal off buildings and cars to bypass obstacles

"We are no longer broadcasting data; we are choreographing it. The environment is changing milliseconds at a time, and human mathematics simply cannot calculate the choreography fast enough."

Imagine trying to play a game of billiards," explains Dr. Julian Vance, a former lead systems architect at a major telecommunications firm, now directing a wireless research lab at an Ivy League university.

"But the pool table is on a ship in a hurricane, the balls are multiplying every second, and the pockets are moving. That is what a 5G network looks like in a dense urban environment."

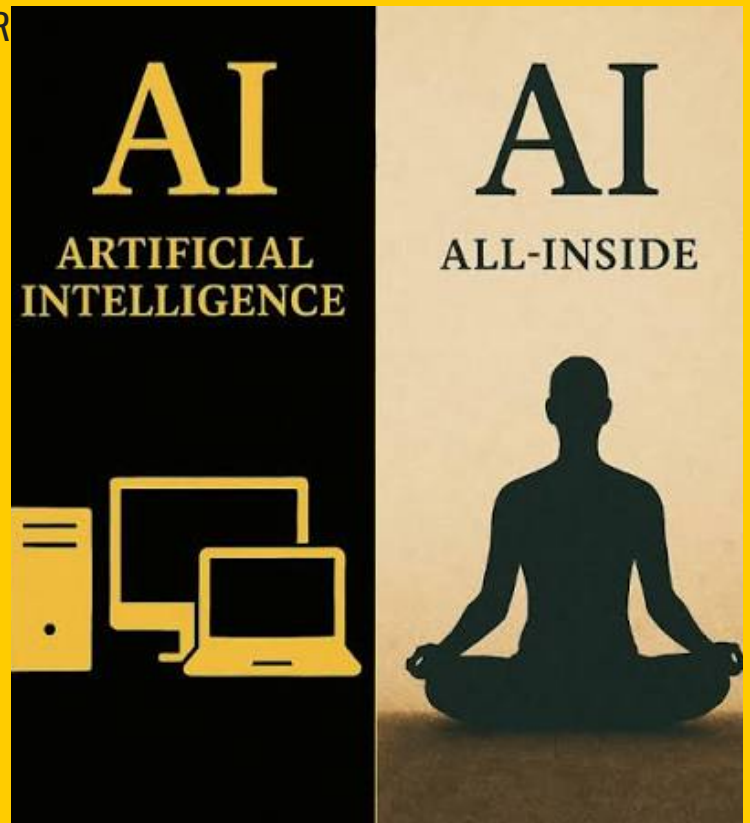
When a network relies on human-written heuristics—rules of thumb programmed by engineers—it assumes the environment is predictable. But a city is not predictable. A sudden rainstorm alters how radio waves travel. A passing double-decker bus blocks a millimeter-wave signal. Even a crowd of people walking through a plaza absorbs enough RF energy to drop a connection. Traditional networks react to these changes after they happen, causing latency. An AI-driven network, however, doesn't wait. It predicts.

COGNITIVE RADIO AND THE NEURAL RECEIVER

The first major leap in this revolution is happening at the very edge of the network, in something called the "physical layer."

For decades, the transmitter (your phone) and the receiver (the cell tower) communicated using standardized, pre-agreed-upon alphabets of radio signals. But researchers are now deploying Deep Learning to create "neural receivers

"We are teaching the physical infrastructure of the internet to perceive the physical world. The airwaves are no longer just a medium; they are a sensory organ"



Even more radical is the concept of Cognitive Radio. An AI-enabled radio doesn't just sit on a designated frequency band; it actively scans the electromagnetic spectrum, learning its environment. If it notices that a local television frequency is unused on Thursday afternoons, it can dynamically borrow that spectrum to transmit your 4K video, then seamlessly hop back to a cellular frequency milliseconds before the TV station begins broadcasting again. It is digital spectral gymnastics, executed faster than the blink of an eye.

THE SELF-HEALING NETWORK

Beyond the physical layer, AI is transforming the macro-architecture of the internet.

Modern cellular networks are so vast that when something breaks, diagnosing the problem is like finding a needle in a continent-sized haystack. A fiber optic cable is accidentally severed by a construction crew in Chicago; a software update causes a glitch in a router in Atlanta; a sudden surge of smartphone usage overloads a tower in Manhattan. In traditional systems, alarms flash in a central control room, and human operators scramble to reroute traffic.

Enter "Zero-Touch Network and Service Management".

AI models are being trained on the entire historical telemetry of global networks

They can monitor billions of data points in real-time—temperature spikes in servers, microfluctuations in signal latency, shifting weather patterns. By recognizing subtle anomalies that precede a failure, the AI can predict a localized network collapse before it happens.

We are building networks with an immune system," Dr. Vance notes. "If a node is about to fail, the AI senses the degradation, automatically reroutes the traffic, isolates the dying hardware, and sends a work order to a technician. To the end-user streaming a movie, the network never blinked

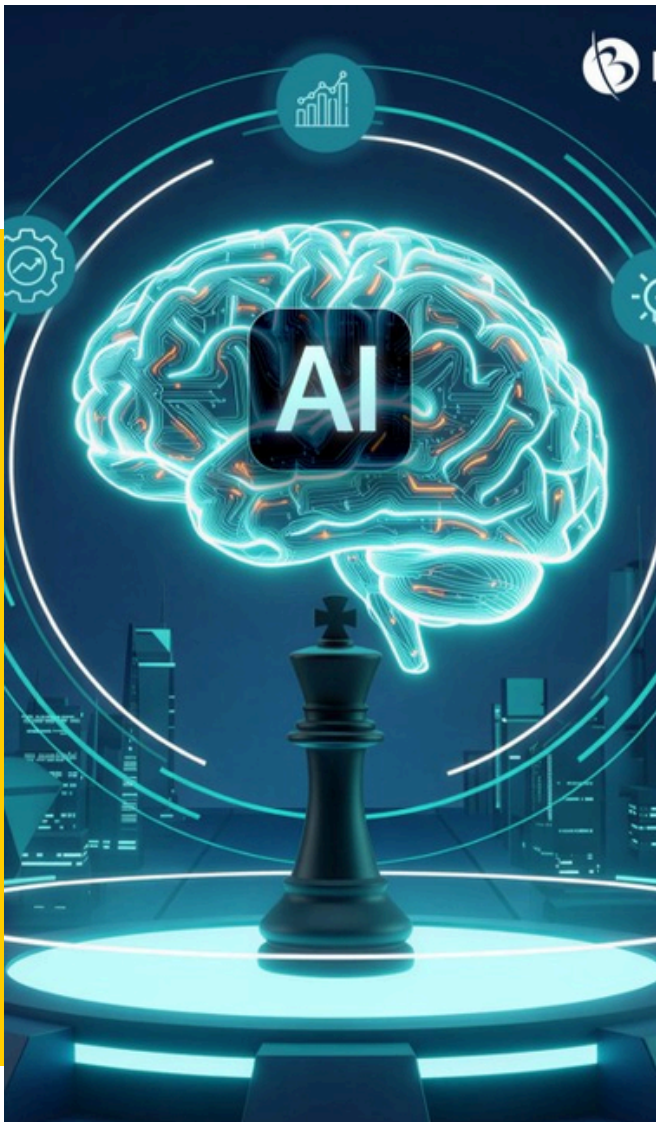
This capability becomes existential as we move toward 6G. We are entering an era of "network slicing," where a single physical network is sliced into multiple virtual networks. An autonomous vehicle on the highway requires a slice of the network with ultra-low latency; if its signal drops for even twenty milliseconds, a fatal crash could occur. Meanwhile, a smart-refrigerator downloading a firmware update can tolerate high latency but needs massive bandwidth. AI is the only mechanism capable of dynamically rationing these invisible resources in real-time, ensuring the car gets its data instantaneously while the refrigerator waits its turn

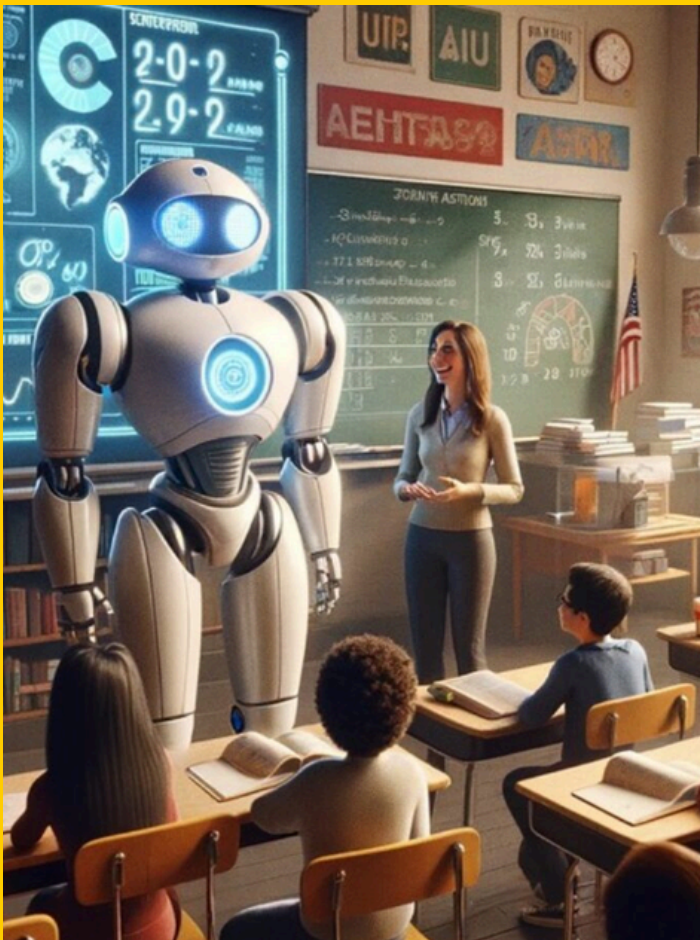
"We are entering an era where connectivity is a matter of life and death. An autonomous vehicle cannot wait for a human engineer to reboot a router. The network must heal itself in the time it takes a car to travel a single inch."

THE "SO WHAT?": A NERVOUS SYSTEM FOR THE PLANET

It is easy to look at the telecom industry—with its acronyms, spectrum auctions, and cell tower aesthetics—as purely utilitarian plumbing. We expect the Wi-Fi to work, and we only notice the cellular network when the bars drop to zero.

But the integration of Artificial Intelligence into wireless communication represents a profound philosophical shift in how humanity interacts with its environment





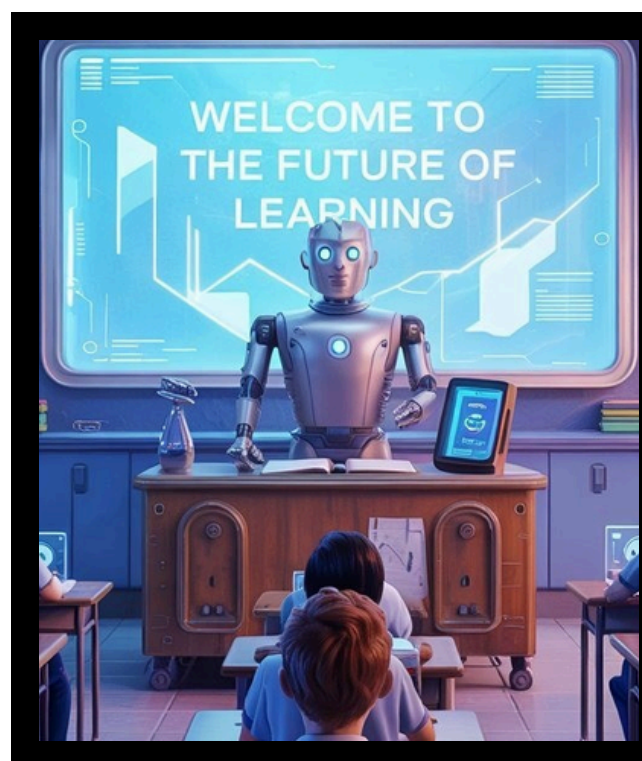
Imagine a campus where the buildings themselves adjust the wireless network based on the flow of students between classes. Imagine disaster zones where swarms of drones instantly negotiate a makeshift, high-speed cellular network to guide rescue workers, the AI mapping the wreckage through the very radio waves it uses to communicate.

We are no longer simply building a communication grid. We are constructing a planetary nervous system. It is a system that can feel the hum of the city, anticipate the needs of its inhabitants, and seamlessly bridge the gap between human intent and digital execution.

The next time you stand in a crowded stadium and hit "send" on a photo, take a moment to look up. The air above you isn't empty. It is a brilliant, invisible, and hyperintelligent symphony, calculating a billion probabilities a second, just to keep you connected to the world.

For the first time in history, the space around us is becoming intelligent. The electromagnetic spectrum, a natural resource that has existed since the Big Bang, is being taught to perceive, adapt, and learn. As we push toward the 2030s and the rollout of 6G, the lines between computation and communication will blur completely

"The ultimate promise of AI in wireless technology is invisibility. The technology will become so perfectly adapted to our needs that we will stop thinking of it as infrastructure, and start experiencing it as the air we breathe."



EDGE AI: THE NEW ELECTRONIC FRONTIER

How intelligence is moving out of the cloud and into chips, sensors, robots, vehicles—and the next generation of electronic devices

Gopika Mohan
S7 ECE



EDGE AI IS CHANGING WHAT ELECTRONIC DEVICES CAN DO. For decades, most electronic systems mainly sensed, transmitted or displayed information. Now, small processors can increasingly analyse signals and make useful decisions close to where the data is generated. A camera can identify an object, a vibration sensor can detect abnormal machine behaviour and a wearable can recognise unusual patterns without sending every piece of information to a distant cloud server

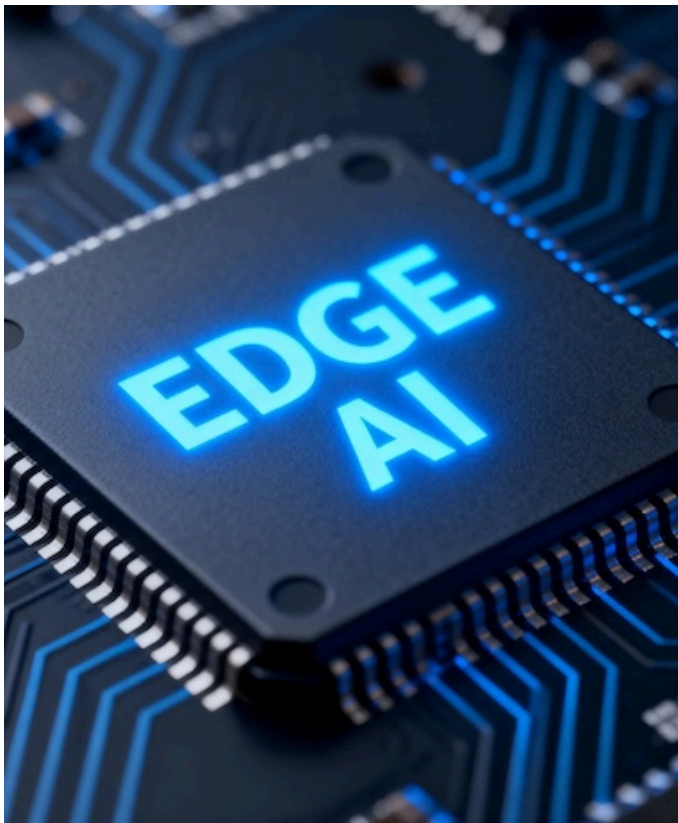
FROM CLOUD INTELLIGENCE TO LOCAL INTELLIGENCE

Traditional AI systems often follow a long path: a sensor collects data, the data travels through the internet to a cloud server, the AI model processes it, and the result returns to the device. Edge AI moves part of this intelligence closer to the source of the data. The architecture can become much simpler: Sensor → Local Processor → Decision

This does not mean the cloud disappears. Cloud systems remain useful for large-scale model training, storage, software updates and complex analysis. However, immediate decisions can happen locally. This is important when a network is slow, unavailable or unnecessary. A factory machine may need to react within milliseconds, while a drone may have to continue operating even when connectivity becomes unreliable.

THE TINY PROCESSOR BECOMES INTELLIGENT

One of the most important developments behind Edge AI is the ability to run machine-learning models on small and energy-efficient processors. A washing machine, agricultural sensor or battery-powered monitor does not need a data-centre-sized computer. Instead, engineers are exploring TinyML and on-device AI for microcontrollers and other constrained hardware



These devices have limited memory and processing power, so the model must be carefully designed. Engineers reduce unnecessary calculations, use lower-precision numbers, minimise memory movement and optimise the complete system. The goal is not to place the biggest possible model inside a device. The goal is to create intelligence that is small enough to be useful in the real world.

An intelligent sensor therefore does more than report a measurement. A microphone can recognise a sound pattern. An accelerometer can recognise a fall. A camera can detect an object. A vibration sensor can identify a possible fault. The device begins to answer not only “What did I measure?” but also “What does this measurement mean?”

"The future electronic device may no longer simply sense the world. It may interpret it."

WHY EDGE AI MATTERS: SPEED, PRIVACY AND EFFICIENCY

Latency is one of the strongest reasons for moving intelligence closer to the device. An autonomous vehicle, robot or industrial system cannot always wait for information to travel across the internet and return. When the processor is already near the sensor, the system can potentially respond faster. In the physical world, every millisecond can matter

Local processing can also reduce the amount of information that must leave a device. A smart camera may analyse its scene locally and transmit only important events instead of continuously uploading every frame. A wearable device may process sensor information before communicating selected results. Local processing does not automatically guarantee privacy or security, but it creates the possibility of making information useful without always transmitting the raw data.

Efficiency is another major challenge. AI computation requires energy, while sensors, memory and wireless communication also consume power. A successful Edge AI device therefore requires system-level optimisation. The sensor may remain asleep until an event occurs, a small model may filter data before a larger model is activated, and the wireless radio may stay off when there is nothing important to send



ELECTRONICS AND AI COME TOGETHER

Edge AI is bringing together fields that were often studied separately. AI requires algorithms and data, but those algorithms must eventually run on physical hardware. A larger model may require more memory. More calculations may consume more energy. Higher precision may require more hardware resources. Poor sensor signals can limit the accuracy of an AI system.

This creates a new type of engineering environment. Modern electronic systems may combine a CPU, GPU, NPU, DSP, FPGA and specialised accelerator. Each component can perform the task it handles most efficiently. A low-power processor may monitor a sensor continuously, while a more powerful accelerator becomes active only when necessary.

Research is also exploring new ways of computing. Neuromorphic systems investigate brain-inspired concepts such as event-driven processing and sparse communication. Event-based cameras generate information mainly when brightness changes rather than continuously producing complete frames. Other researchers are studying analog and mixed-signal AI, advanced memory and photonic computing



The result is a broad shift in electronics. The future chip may be defined not only by the number of transistors it contains, but also by how efficiently processors, memory, sensors and specialised hardware work together

EDGE AI ENTERS THE PHYSICAL WORLD

Robotics is a natural environment for Edge AI because robots must sense, interpret and act in real time. A robot may combine information from cameras, microphones and motion sensors, then make a local decision without depending completely on the cloud. The same principle is important for drones, industrial machines and autonomous systems

In factories, Edge AI can support predictive maintenance. A system can learn what normal machine behaviour looks like and detect unusual patterns before a major failure occurs. In agriculture, intelligent sensors can observe soil, temperature, humidity and crop conditions while transmitting only important information. In healthcare, wearable and portable devices can analyse signals locally and act as an intelligent monitoring layer.

These applications show why Edge AI is more than simply making AI smaller. Intelligence is becoming closer to the physical systems that produce data. The sensor, processor, network and actuator are increasingly becoming parts of one connected decision-making system

THE NEXT FRONTIER

The cloud will remain an essential part of modern computing. Large-scale training and analytics require powerful infrastructure. Edge AI does not replace the cloud; instead, it changes how work can be divided. Urgent, private or simple tasks can happen on the device. Intermediate processing can happen nearby. Massive computation can remain in the cloud. For electronics students, this convergence creates an important opportunity. Strong foundations in analog and digital electronics, semiconductor basics, microcontrollers, sensors, signal processing and communication remain essential. At the same time, skills in embedded programming, Python, C/C++ and machine learning are becoming increasingly valuable



“The physical world has deadlines. Edge AI is an attempt to give artificial intelligence the ability to meet them.”

Edge AI is a quiet but important change in the history of electronics. Electronic devices are beginning to move beyond simply measuring the world. They are beginning to interpret it. The future may belong not only to the largest computers in distant data centres, but also to the small processors inside the devices we use every day—closer to the signal, closer to the sensor and closer to the decision



CAN WALLS CONTROL WI-FI?

Meet the “smart surfaces” engineers are using to fix dead zones — by literally reprogramming the walls around you

Ajmal Al Hameed
S3 ECE

THE PROBLEM WE ALL KNOW TOO WELL

You know the spot. Maybe it's the stairwell, maybe it's that one corner of the library, maybe it's your dorm room that's just far enough from the router. You watch your phone go from full bars to “LTE” to nothing, and you sigh and walk somewhere else.

For decades, the fix for this has basically been: add more routers, add more towers, and hope for the best. Nobody ever thought to fix the wall. It was just... a wall. An obstacle. Something signals had to fight their way around.

That's changing. Researchers are now building walls that can actually help steer wireless signals around a room — on purpose, in real time, like a mirror that knows exactly where you're standing and angles itself to bounce light straight at you.

It's called a Reconfigurable Intelligent Surface, or RIS for short. And yes, it's as cool as it sounds.

OKAY BUT WHAT ACTUALLY IS IT?

Picture a flat panel — could be the size of a picture frame, could cover an entire building wall — covered in thousands of tiny electronic elements. Each one is way smaller than the wavelength of the signal it's dealing with. Individually, each element does basically nothing.

But when you control thousands of them together, using software, something interesting happens: you can make the whole panel act like a smart mirror for radio waves. its life

Instead of a signal randomly bouncing off a wall and scattering everywhere (which is what a normal wall does), the RIS panel can grab that signal and deliberately redirect it — straight down a corridor, around a corner, into a dead zone that's never had good signal in its life.

A simple way to think about it

**"A normal wall reflects signal by accident.
An RIS wall reflects signal on purpose."**

Researchers have already tested this in real buildings — office lobbies, hallways, multi-floor spaces — and the results are wild. In some non-line-of-sight dead spots, adding a single RIS panel improved signal strength by up to 40 dB. For context, that's not a small tweak — that's roughly the difference between “no signal at all” and “full bars

WAIT, WHY DO WE SUDDENLY NEED THIS?

Good question. Walls have always messed with signal — why is this only a big deal now? Two reasons:

- 5G (and future 6G) uses higher frequencies. Higher frequency = more data, which is great. But higher-frequency waves travel in much straighter lines and get blocked way more easily. A 4G signal shrugs off a wall. A millimeter-wave 5G signal can get seriously weakened by a pane of glass or even someone's hand wrapped around their phone. Suddenly, the physical environment matters a lot more than it used to.
- It finally became cheap enough to actually build. The core idea for reconfigurable reflecting surfaces has technically been around since the early 2000s. Nobody cared much — it was a cool trick with no real use case.

It wasn't until around 2018–2019, when 5G's line-of-sight problems became impossible to ignore, that engineers dusted off the idea and it exploded into one of the hottest research topics in wireless communications. It's now considered one of the leading candidate technologies for 6G



WHAT CAN YOU ACTUALLY DO WITH THIS?

Here's where it gets genuinely useful — and kind of fun to imagine:

- Fixing dead zones in buildings — that stairwell, that corner office, that basement lab — without installing a whole new router or antenna. Just a passive panel on the wall or ceiling redirecting signal that's already there.
- Fixing corridor turns — signal travels great down a straight hallway and then just dies at the corner, because radio waves don't bend around sharp edges on their own. A panel at the junction can catch it and throw it around the corner

- Fixing “urban canyon” problems — ever lose signal walking between tall buildings downtown? Same issue, bigger scale. Cities are testing RIS panels on building facades and even streetlights to redirect signal into shadowed areas a tower can't reach.
- Stadiums and malls — packed with people (who are basically walking water balloons that absorb radio waves really well). RIS panels built into ceiling tiles or decorative wall panels can quietly boost coverage without adding visible antenna clutter

The common thread: instead of solving coverage problems by adding more transmitters, you solve them by making the environment itself smarter.



THE GENUINELY COOL PART: WALLS THAT BLOCK EAVESDROPPING

Here's a fun one. Radio signals broadcast outward in all directions — that's just how they work. Which means, in theory, anyone with a receiver sitting in that broadcast pattern could intercept your data. This is why we rely so heavily on encryption.

But an RIS panel can do something clever: shape the signal so it only forms a strong, coherent, readable version exactly at your device's location. Everywhere else in the room, the same transmission arrives as scrambled, mostly useless noise — not because it's encrypted, but because of pure geometry. The eavesdropper just isn't standing in the one spot where all the reflected copies of the signal line up correctly



“It's security through physics instead of math.”

Still early-stage research, but it's a genuinely different way to think about wireless privacy

Okay, so what's the catch?

Nothing this convenient comes free. A few real challenges:

- It's passive, not magic. Most RIS panels redirect signal — they don't create new signal out of nothing. If the signal is already too weak to begin with, the panel can't rescue it. It's a booster, not a replacement for actual infrastructure
- Controlling thousands of tiny elements in real time is hard .Figuring out the perfect

configuration for a room full of people who keep moving around is a legitimately difficult computing problem, and a lot of current research is really about the software that decides how to configure the panel, not the hardware itself.

- Who installs it? Who pays for it? A cell tower is clearly the phone company's responsibility. A wall panel embedded in a mall ceiling that's helping a specific carrier's signal reach customers... whose job is that? These are boring-sounding questions, but they're actually slowing things down more than the engineering is

Why this matters especially for us

Campuses are basically the perfect (worst) case study for this problem: old buildings never designed with wireless in mind, next to glass-heavy new buildings that reflect signal unpredictably, lecture halls that fill with hundreds of phones the second class starts, and dorms where running new cable through century-old walls is either impossible or absurdly expensive.

That's exactly why several university engineering departments have started running their own RIS pilots — in libraries, lecture halls, dorm hallways — both as a research platform and as a genuine attempt to fix their own Wi-Fi dead zones

“The tech is literally being tested in the same kind of rooms that have been failing students’ Wi-Fi for years, by the people who feel it the most.”

WHERE'S THIS ALL GOING?

A few directions researchers are already chasing:

- Walls that sense, not just steer. If a panel already has to model how signals bounce around a room to redirect them properly, it can use that same info to detect that someone walked into the room — no camera needed. Think smart occupancy detection, or even GPS-level indoor positioning in places where GPS never works.
- Self-powered panels. Some designs are experimenting with panels that harvest their own operating power directly from the radio waves passing through them — no power cable required

- Building materials that come with this built in. The long-term dream floating around research circles: glass, drywall, and wall panels that ship from the factory with basic reconfigurable radio behavior already baked in — not an upgrade you add later, just a normal property of the material



THE TAKEAWAY

We've spent all of human architecture treating walls as passive — their entire job is to just stay where they are and not move. RIS is one of the first serious attempts to give a wall an actual job to do with the invisible signals passing through your space every second

It's not going to replace routers and cell towers anytime soon. But next time you walk somewhere and your phone signal randomly jumps from one bar to five for no obvious reason... the wall might have just done something on purpose



THE ANATOMY OF THE ARTIFICIAL

When Machines Learn to Breathe

Blesson Biju
S5 ECE

in the subterranean basement of a university robotics lab, a machine is waking up. It does not whir, clank, or grind. It hisses, softly, like a sleeping diver drawing breath.

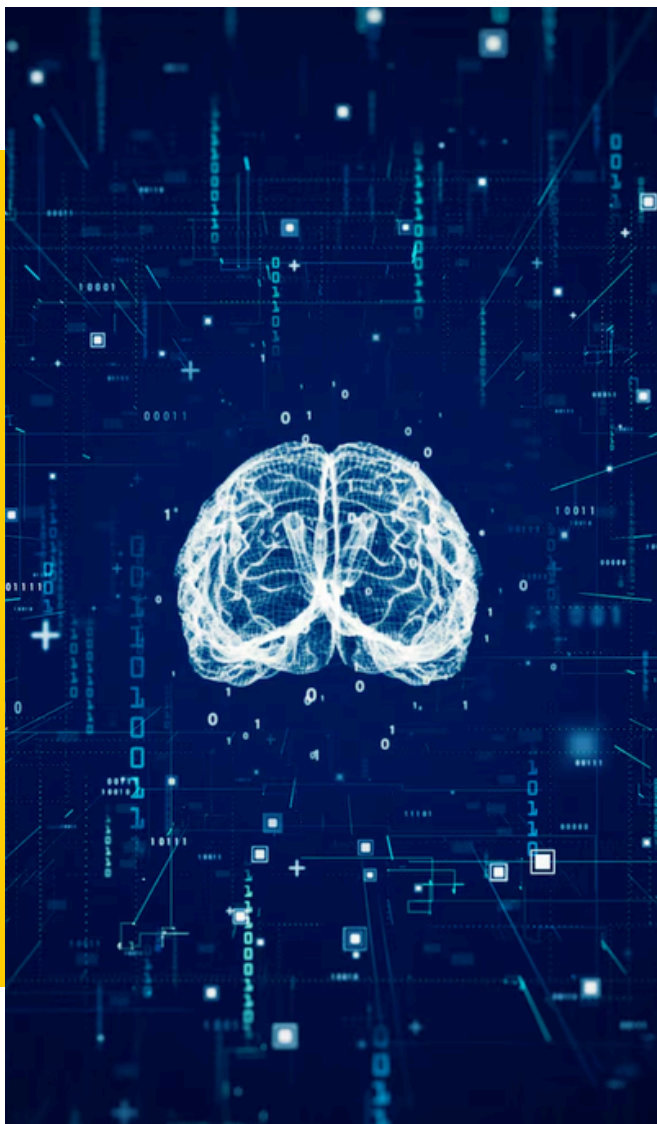
„Resting on a sterile steel table is a translucent, four-legged entity cast from synthetic silicone. It looks less like a product of engineering and more like a translucent starfish dredged from a silicon sea. A researcher turns a valve. Compressed air rushes through microscopic, vein-like channels embedded within the elastomer body. The creature’s front appendages swell and curl, gripping the table’s edge with a delicate, uncanny grace, pulling its squishy bulk forward

This is not the metallic terminator of science fiction, nor the bolted-down robotic arm of a Detroit assembly line. This is the vanguard of soft robotics—a radical, biologically inspired discipline that is ripping up the century-old rulebook of mechanical engineering. For generations, we built machines to conquer the physical world through rigid force. Now, engineers are looking to the octopus, the caterpillar, and the human heart, realizing that the future of machinery isn't forged in titanium. It is molded in rubber, driven by fluid, and built to yield

CHAPTER 1: THE CURSE OF THE RIGID

To understand why robotics is going soft, we must first understand why it was born hard.

Since the industrial revolution, human engineering has been defined by rigid kinematics. We built out of steel, iron, and eventually carbon fiber because our primary goal was precision and heavy labor. Traditional robots are assemblies of rigid links connected by discrete joints, driven by electrical motors. They are exceptional at doing the same exact movement ten thousandtimes a millimeter-perfect precision—whether that is welding a car chassis or placing a microchip on a motherboard



But rigid robots harbor a fatal flaw: they are fundamentally terrified of chaos.

A traditional robotic arm requires a mathematically perfect, structured environment. If a human steps into its programmed path, or if the object it is supposed to pick up is slightly deformed, the rigid robot fails—often catastrophically. "We spent sixty years building robots that exist in cages," says Dr. Aris Thorne, a simulated composite of leading biomechanical researchers. "We locked them away on factory floors because if they bumped into a human, the human would break. We created a world of machines that lacked a fundamental biological trait: compliance

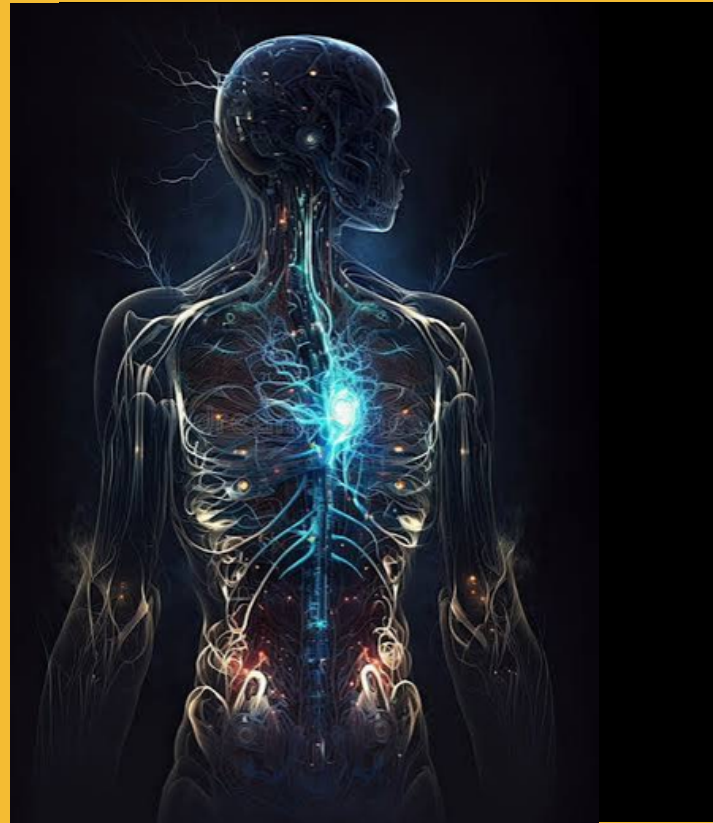
In physics and engineering, "compliance" is the ability of a material or mechanism to yield to an external force without breaking. A tree branch swaying in the wind is compliant; a glass rod is not. The human hand, with its padded flesh, articulating cartilage, and flexible tendons, is a masterpiece of compliance. If we want robots to enter our homes, care for our elderly, or operate inside our bodies, they cannot be made of unyielding metal. They must become squish

"We spent sixty years building robots that exist in cages. We created a world of machines that lacked a fundamental biological trait: compliance."

CHAPTER II: THE MATERIALS REVOLUTION

The transition from rigid gears to continuum mechanics requires entirely new materials. Soft robotics is less about traditional computer science and more about advanced chemistry and materials science.

The most common actuators (the components that make a robot move) in this new field are Pneumatic Artificial Muscles (PAMs) and Fluidic Elastomer Actuators (FEAs). Instead of using a motor to turn a gear, engineers cast silicone or rubber with intricately designed internal chambers. When air or water is pumped into these chambers, the material expands. By varying the thickness of the silicone walls—making one side thicker than the other—the expansion forces the structure to bend, twist, or curl in highly predictable ways



But pneumatics are only the beginning. Researchers are experimenting with Shape-Memory Alloys (SMAs), wires made from materials like Nitinol that can be bent out of shape when cool, but snap back to their original, programmed shape when an electric current heats them. They act exactly like synthetic muscle fibers, contracting silently and smoothly.

Then there are Electroactive Polymers (EAPs), often dubbed "artificial muscles." These are plastics that change their size or shape when stimulated by an electric field. Imagine a robot that doesn't need an air compressor, but simply twitches and flexes in response to electrical impulses, much like the nervous system fires a human bicep



This materials revolution is redefining the university curriculum. Engineering students are no longer just coding pathfinding algorithms or calculating the torque of a servo; they are mixing polymers, studying fluid dynamics, and dissecting the biomechanics of cephalopods to understand how an octopus can squeeze its entire body through a hole the size of a coin.

CHAPTER III: THE HEALING TOUCH

The most profound implications of soft robotics are unfolding not on factory floors, but in operating rooms and rehabilitation clinics.

Consider the limitations of modern surgical tools. Even the most advanced robotic surgery systems, like the Da Vinci, rely on rigid, rod-like instruments

They are marvels of engineering, but they still struggle to navigate the tortuous, winding pathways of the human body—like the deep branches of the lungs or the winding human intestine.

Enter the soft robotic endoscope. Modeled after the movement of a caterpillar or an inchworm, these tethered robots are made of soft polymers that can expand and contract to gently inch their way through delicate biological tubes. If they press against the wall of a colon or a blood vessel, their soft exterior yields, dramatically reducing the risk of puncturing the tissue.

Beyond surgery, soft robotics is revolutionizing physical therapy and human augmentation. For stroke survivors who have lost motor control, traditional exoskeletons have historically been bulky, heavy, Iron-Man-style suits that are exhausting to wear and visually alienating. Soft exosuits, however, look and feel more like high-tech athletic wear.

Constructed from advanced textiles and integrated with pneumatic actuators and artificial tendons, these suits wrap comfortably around the calf or thigh. As the wearer attempts to take a step, sensors detect the subtle electrical activity in their muscles, and the suit subtly tightens, providing a gentle, assistive pull that perfectly mimics the body's natural biomechanics. It is human-machine integration that doesn't erase the humanity of the user

“If we want robots to enter our homes, care for our elderly, or operate inside our bodies, they cannot be made of unyielding metal. They must become squishy.”

CHAPTER IV: NAVIGATING THE ABYSS

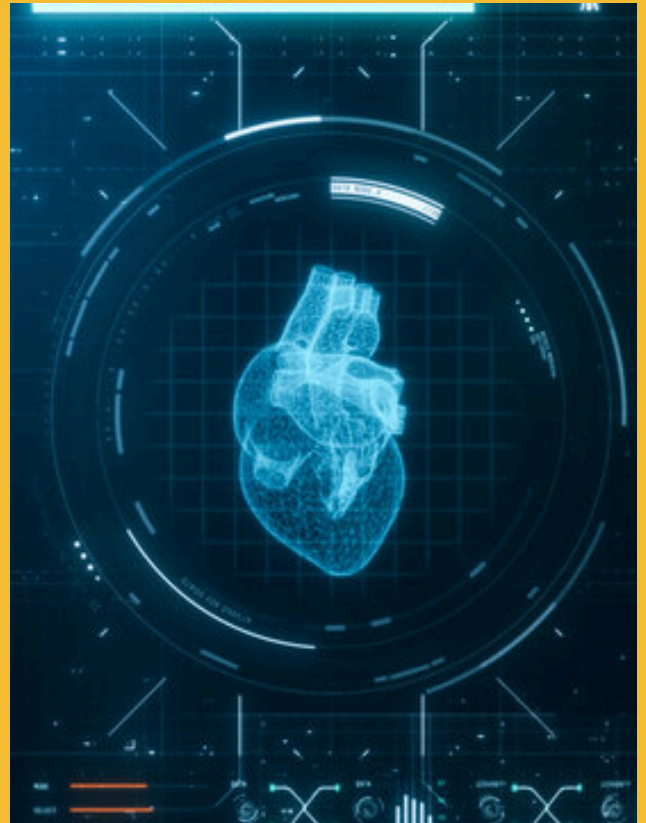
Outside the human body, the pliability of soft robots allows them to survive in environments that would crush or trap their rigid ancestors.

In search-and-rescue operations following an earthquake, sending a heavy, metal robot into the unstable rubble of a collapsed building is incredibly dangerous; the robot's weight and rigid structure can easily trigger a secondary collapse. A soft robot, however, can squeeze through jagged, irregular crevices, deflating itself to pass under concrete slabs and re-inflating to lift debris or deliver oxygen tubes to trapped survivors

This same principle is taking soft robots to the least hospitable place on Earth: the Marianas Trench.

At a depth of nearly 36,000 feet, the pressure of the ocean is roughly 1,000 times greater than at sea level. Traditional deep-sea submersibles require incredibly thick, heavy titanium pressure hulls to protect their electronics and motors from being obliterated. Yet, deep-sea creatures like the snailfish survive there with gelatinous bodies and no rigid skeleton.

Inspired by this, engineers have recently developed soft robotic submersibles cast entirely in silicone, with their delicate electronic components distributed throughout the soft body rather than housed in a single rigid core. Because the silicone is already solid and incompressible, the



crushing pressure of the deep ocean simply passes through it without damaging the robot, allowing these artificial manta rays to swim gracefully through the abyss.

THE "SO WHAT?": THE PHILOSOPHY OF YIELDING

The rise of soft robotics is more than just a technological milestone; it represents a profound philosophical shift in how humanity relates to the world it builds.

Since the dawn of the Industrial Age, our approach to technology has been one of dominance. We built machines that were louder, harder, and stronger than nature. We poured concrete over the earth to give our rigid cars a smooth surface.

We forced the organic world to adapt to our artificial geometry

Soft robotics reverses this dynamic. It suggests a future where technology yields to nature, where machines are designed to exist in harmony with the fragile, chaotic, and beautiful unstructured environments of human life. It blurs the line between the artificial and the biological, asking us to redefine what it means for a machine to be "alive."

As we watch a silicone starfish breathe in a laboratory, we are not just witnessing the future of engineering.

We are watching the machine age grow up, step out of its rigid cage, and finally learn how to touch the world without breaking it.

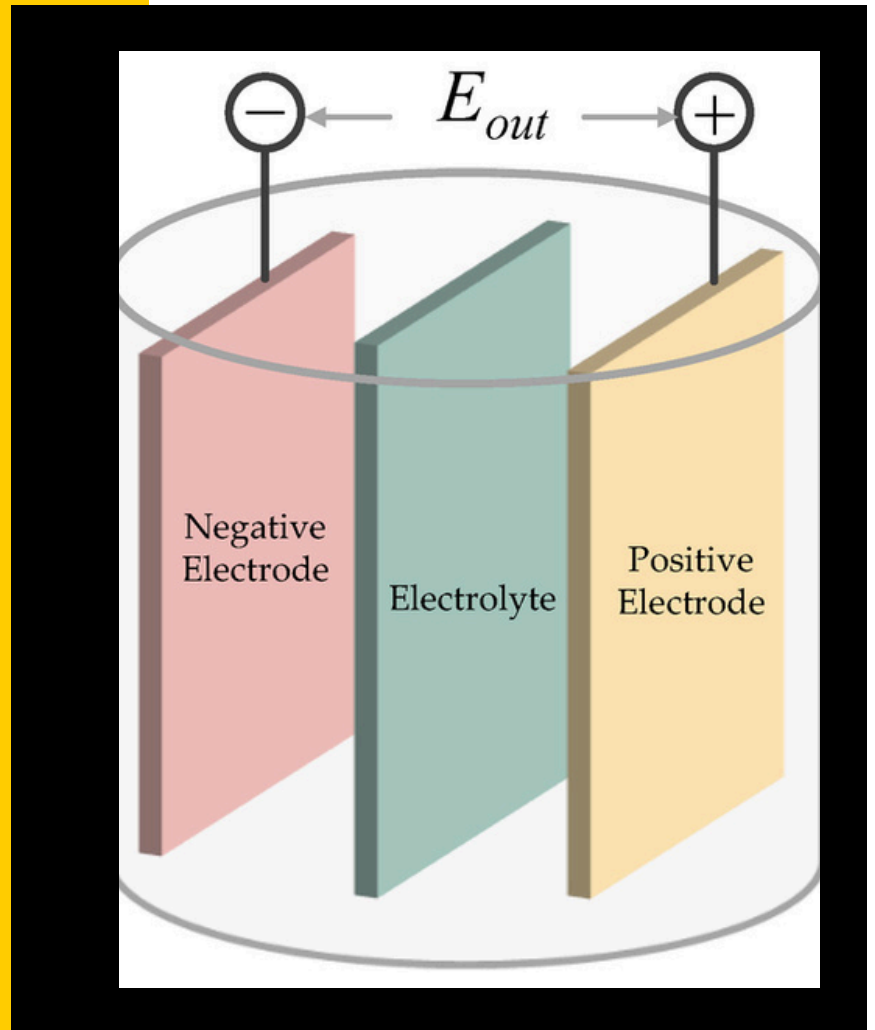
"Since the dawn of the Industrial Age, our approach to technology has been one of dominance... Soft robotics reverses this dynamic, suggesting a future where technology yields to nature."



THE POST-BATTERY PARADIGM

Science & Technology
Feature

Jisha Giji
S7 ECE



HOW AMBIENT ENERGY HARVESTING COULD CHANGE THE DESIGN OF CONNECTED DEVICES

The Internet of Things is expanding into places where ordinary computers cannot easily go. Sensors are being placed in bridges, factories, farms, buildings, medical equipment, and remote ecosystems. Many of these devices need to measure temperature, pressure, motion, light, vibration, or chemical conditions and communicate their findings with little human attention

That creates a difficult practical problem. A sensor may be inexpensive and physically small, but its battery still has to be manufactured, installed, monitored, replaced, and eventually discarded

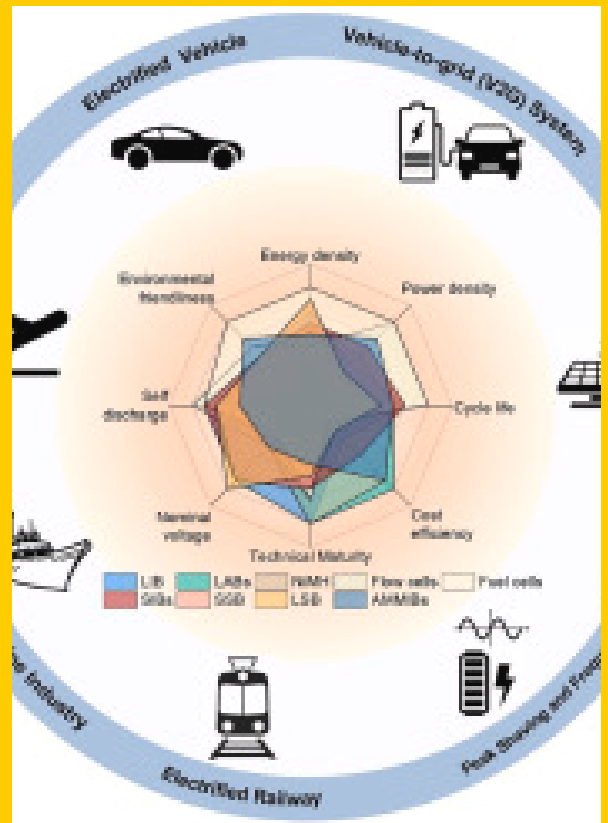
Replacing one battery is manageable. Replacing batteries in thousands or millions of remote devices is a continuing logistical burden.

Researchers are therefore developing ambient energy harvesting: the conversion of naturally available energy—such as light, vibration, heat, or radio-frequency radiation—into the small amounts of electricity required by an electronic system. The goal is not to power every device with a room lamp or a passing radio signal. The goal is to design devices that use very little energy and wake up when their environment provides enough of it

Researchers are therefore developing ambient energy harvesting: the conversion of naturally available energy—such as light, vibration, heat, or radio-frequency radiation—into the small amounts of electricity required by an electronic system. The goal is not to power every device with a room lamp or a passing radio signal. The goal is to design devices that use very little energy and wake up when their environment provides enough of it

WHY BATTERIES BECOME DIFFICULT AT SCALE

Batteries remain essential for phones, laptops, vehicles, medical devices, and countless other products. They provide a useful combination of energy density, portability, and predictable output. They are not, however, maintenance-free or infinitely durable.



Electrochemical cells age through chemical and mechanical changes, and their useful life depends on temperature, charge cycles, current demand, storage conditions, and the design of the device.

In a large sensor network, the difficulty is often maintenance rather than energy capacity. A sensor attached to a bridge or buried in soil may be difficult to reach. A device inside industrial machinery may require a shutdown before it can be serviced. A network deployed across a forest, ocean, or agricultural field may contain locations where regular battery replacement is expensive or unsafe.

Batteryless design addresses this problem by changing the system's assumptions.

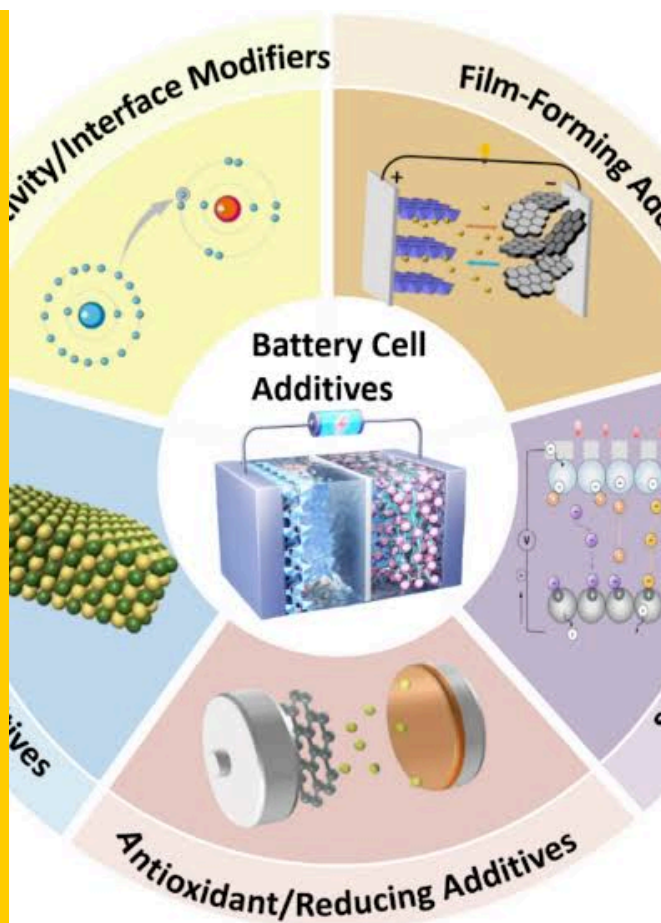
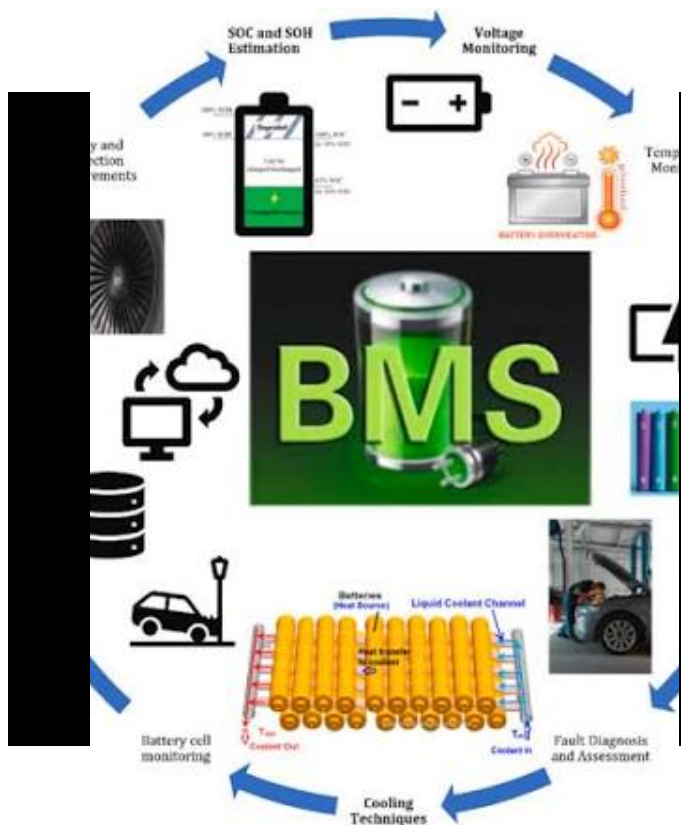
Instead of expecting a continuous supply of stored energy, the device is designed around the energy that is actually available. A small solar cell may support a sensor during daylight. A vibration harvester may operate when a machine is running. A thermal generator may use a temperature difference. An RF harvester may collect energy from nearby transmitters, although the available power usually decreases rapidly with distance.

The result is not unlimited operation. It is maintenance reduction through energy-aware engineering

COMPUTING WHEN POWER COMES AND GOES

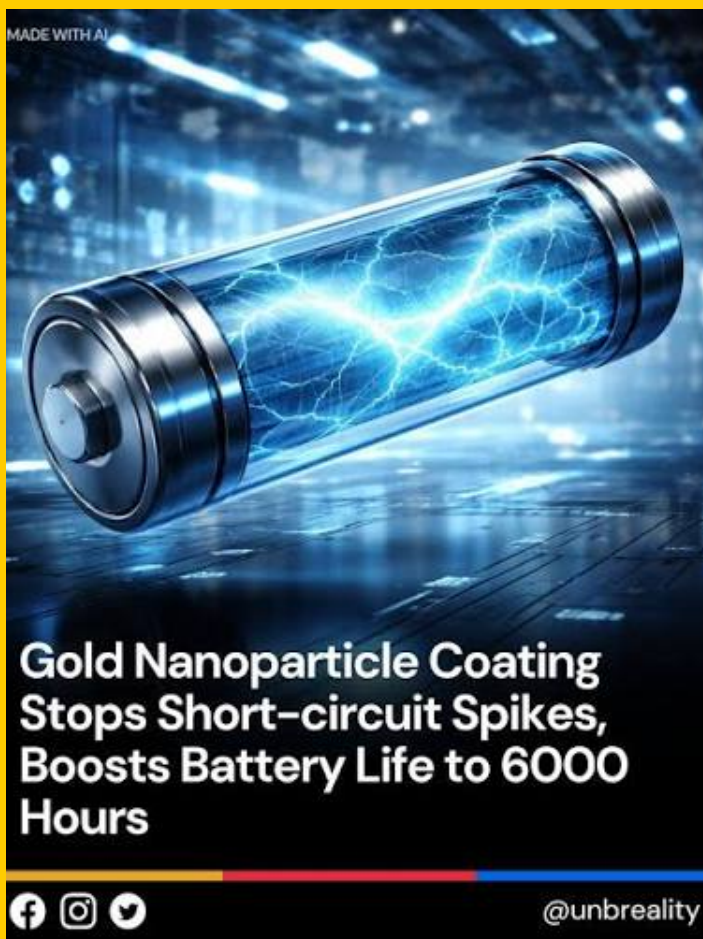
The central challenge of a batteryless device is intermittency. Sunlight changes, machinery stops, people move, and radio signals fluctuate. A conventional computer assumes that power will remain available while its processor is executing instructions and while its memory is holding data. An intermittent computer cannot make that assumption.

Intermittent computing treats power loss as normal operating condition. A microcontroller may wake up, measure a sensor, perform a small calculation, save a result, and transmit only when sufficient energy has accumulated. If the voltage begins to fall, the system can save its progress before shutting down. When energy returns, the device resumes from a known checkpoint instead of starting the entire task again



Non-volatile memories such as FRAM and MRAM are useful in this context because they can retain information without continuous power. However, no single memory technology solves every problem. Designers must consider endurance, speed, energy consumption, cost, storage capacity, and how frequently the system may lose power.

Software is just as important as hardware. Tasks must be divided into units that can safely pause. Checkpoints must be written in a way that prevents corrupted state. Sensor readings and messages may need sequence numbers so that a device can recover after an interrupted transmission. The result is a different programming model: the system is designed not for uninterrupted execution, but for progress across many short windows of available energy



THE GENUINELY COCOMMUNICATING WITHOUT A POWER-HUNGRY TRANSMITTER PART: YOU ARE A NODE

Communication can consume a significant share of a tiny device's energy budget. Generating a radio signal normally requires oscillators, amplifiers, frequency control, and other active circuitry. A batteryless sensor may not have enough stored energy to run these components continuously.

Ambient backscatter offers a different approach. Instead of generating its own carrier wave, a device changes how it reflects existing radio-frequency signals. By switching its electrical impedance, the device can alternate between absorbing and reflecting a small amount of the surrounding signal.

receiver detects those changes and reconstructs the encoded information.

The University of Washington's original ambient-backscatter research described the technique as a way for battery-free devices to use existing television and cellular transmissions as both an energy source and a communication medium. ¹ The approach does not provide the same data rate or range as a conventional Wi-Fi access point. Its appeal is that a simple device can send small amounts of telemetry without operating a full radio transmitter.

As with all energy-harvesting systems, the environment determines the result. The distance from the RF source, the orientation of the antenna, interference, the receiver's sensitivity, and the time available for harvesting all matter. Ambient backscatter is best suited to small messages and carefully designed deployments rather than high-bandwidth communication.

WHERE BATTERYLESS SYSTEMS COULD BE USEFUL

The most promising applications are those in which the device collects small amounts of data over a long period and where maintenance is difficult. Structural-health sensors could monitor strain or vibration in bridges, towers, railways, or industrial equipment. A batteryless node does not need to transmit continuously; it may wake when a vibration pattern suggests an unusual event and then report a compact alert. Environmental monitoring is another strong use case. Solar-powered nodes can measure soil moisture, temperature, water quality, or animal activity in places where routine visits are costly. A network may combine local energy harvesting with low-power mesh communication so that each device forwards only the information that matters

Medical applications require particularly careful distinction between possibilities and current practice. External energy transfer, including approaches based on ultrasound or electromagnetic fields, is being studied for some implantable and wearable systems. These techniques may reduce the need for frequent procedures in selected applications, but they must meet demanding requirements for safety, reliability, biocompatibility, and clinical approval. A batteryless implant is not automatically safer than a battery-powered one

THE LIMITS OF A POST-BATTERY WORLD

The phrase “post-battery” can be misleading. Ambient harvesting does not eliminate the need for energy storage in every system. A small capacitor, rechargeable microbattery, or other storage element may still be needed to accumulate energy between harvest events.

Many devices will also continue to use conventional batteries when they need high power, long periods of operation without harvesting, or predictable performance.

Energy harvesting has limits of scale as well. A tiny sensor may operate on microwatts or milliwatts, while a wireless transmitter, motor, display, or artificial-intelligence accelerator may need far more. Designers must reduce the workload before they can expect a small harvester to support it. This is why batteryless systems often emphasize local filtering, event detection, compressed messages, and low-power hardware. The environmental benefits also depend on the complete life cycle of the device. A batteryless sensor may reduce replacement waste, but it still contains semiconductors, packaging, wires, antennas, and other materials. Responsible design includes repairability, recovery, recycling, and the ecological effects of deploying large numbers of electronic devices.

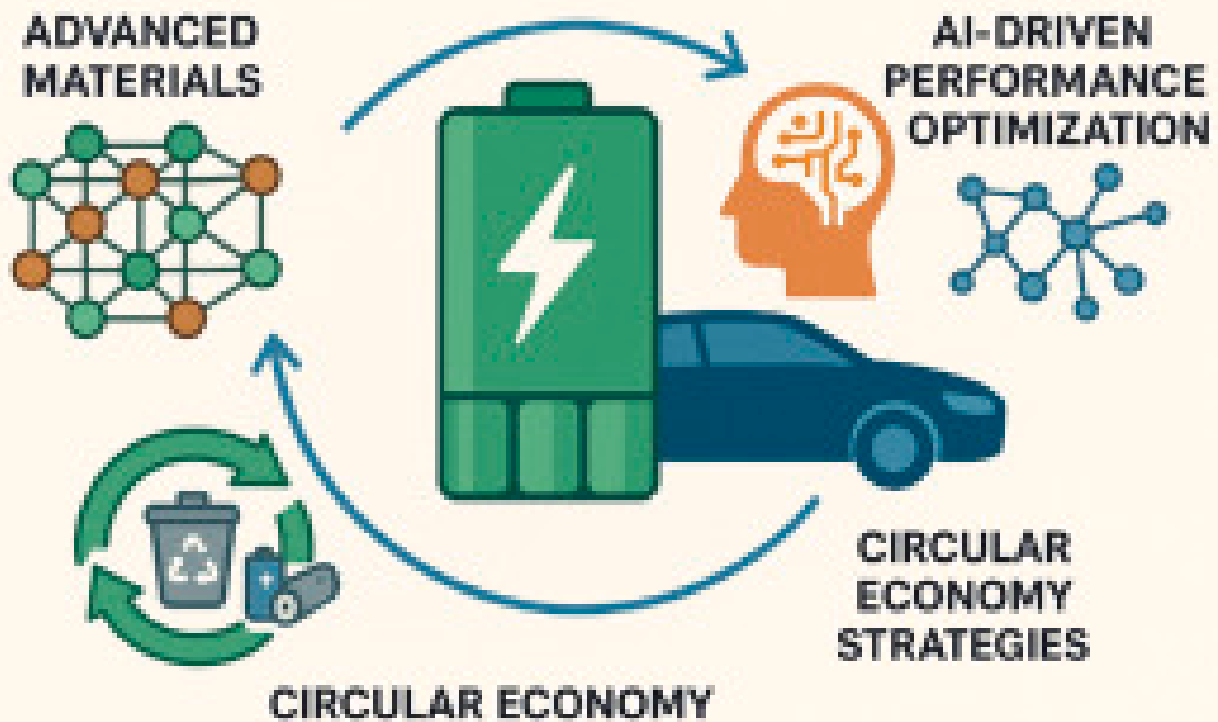


WHAT STUDENTS NEED TO LEARN

Ambient-powered computing brings together subjects that are often taught separately. Students need to understand circuits and semiconductor devices, but they also need knowledge of electromagnetic fields, materials, embedded software, wireless protocols, control systems, data management, and environmental measurement.

The most important design habit is to begin with an energy budget. How much energy is available? How often does it arrive? How much can be stored? What is the minimum useful task? How much energy does sensing consume compared with computation and communication? These questions may determine the architecture before a processor or sensor is selected.

NEXT-GENERATION LITHIUM-ION BATTERIES FOR ELECTRIC VEHICLES



COMPUTING DESIGNED FOR SCARCITY

Ambient energy harvesting is not a promise that electronics will operate without limits. It is a design philosophy for places where energy is small, intermittent, and expensive to maintain. The technology asks engineers to replace assumptions of abundance with careful decisions about timing, storage, computation, and communication.

The result could be a new generation of devices that are quieter, smaller, and less dependent on scheduled battery replacement. Some may live inside infrastructure, some in fields and forests, and some on the human body.

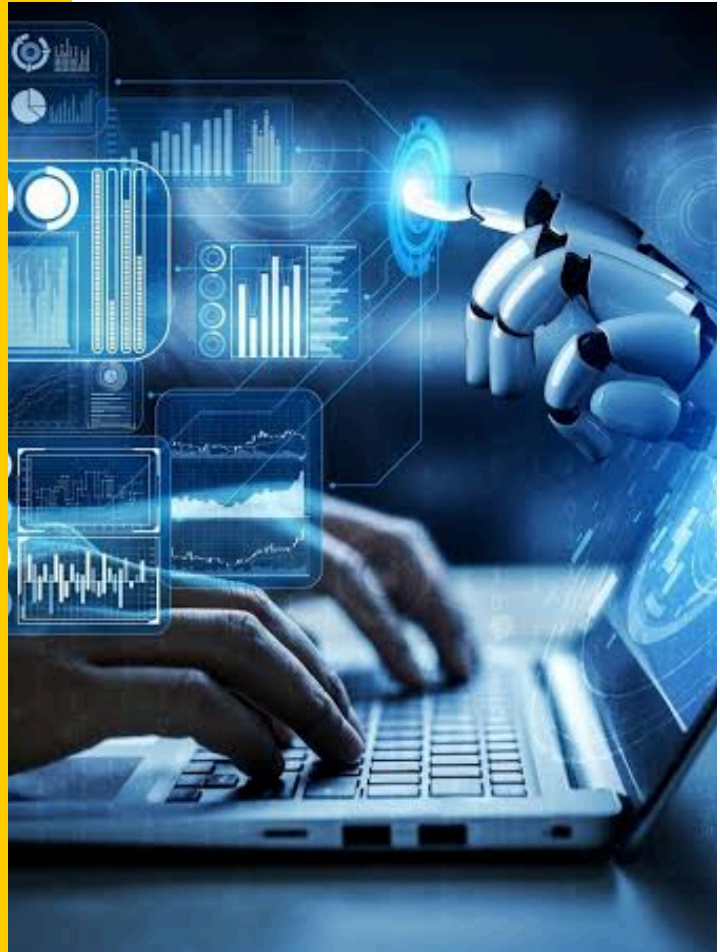
They will not perform every task a laptop can perform. They will perform a narrower task, repeatedly and efficiently, using whatever energy their surroundings provide.

The post-battery future is therefore not a future without batteries. It is a future in which many devices no longer need to depend on a battery alone.

THE CRUCIBLE OF CODE

The next era of computing will not be defined by one miraculous machine, but by the convergence of many kinds of machines

Meenakshi Mohan
S3 ECE



For most of the history of modern computing, progress followed a familiar pattern. Transistors became smaller, processors became faster, networks became wider, and more software moved into the cloud. That pattern has not disappeared, but it is no longer enough to describe the direction of research.

Today, engineers are exploring several paths at once: three-dimensional transistor structures, specialized materials, optical connections, biological neural tissue, faulttolerant quantum systems, and intelligent devices that process data close to where it is collected. These technologies are at different stages of development. Some are already entering commercial products; others remain experimental. What connects them is a common question: How can computation continue to become more capable without simply repeating the old strategy of putting more conventional silicon in the same place?

BEYOND FLAT SILICON

Moore's Law is often described as a prediction that the number of transistors on an integrated circuit doubles roughly every two years. More precisely, it is an observation about the historical pace of semiconductor development, not a physical law. Maintaining that pace has become increasingly difficult as engineers work at extremely small dimensions and face problems involving leakage, variability, power density, manufacturing complexity, and cost.

Jenny Smith
Year 7 Co-ordinator

The response has been architectural rather than purely numerical. Instead of shrinking a conventional planar transistor indefinitely, researchers have developed structures that improve control over the flow of current. Gate-all-around nanosheet transistors surround the conducting channel more completely than earlier designs, helping the gate control the device at smaller dimensions. Research roadmaps are also exploring complementary field-effect transistors, or CFETs, which stack n-type and p-type devices vertically to make more efficient use of chip area.

These approaches do not abolish the difficulties of scaling. They move the engineering challenge into new areas: advanced fabrication, heat removal, electrical contacts, process variation, and the difficulty of manufacturing three-dimensional structures reliably at high volume.

Another route is to change the material or the way information moves. Gallium nitride and silicon carbide are examples of wide-bandgap semiconductors used especially in power electronics, where their properties can support efficient switching, higher operating temperatures, or smaller power-conversion systems.



Photonic interconnects take a different approach by using light to move information between parts of a computing system. Optical links can offer high bandwidth and may reduce some electrical communication bottlenecks, but they still require energy-efficient lasers or modulators, detectors, packaging, and control electronics.

The lesson is important: the future of semiconductor progress will not come from one universal replacement for silicon. It will come from combining devices, materials, packaging methods, and communication technologies for particular tasks.

WHEN BIOLOGY BECOMES PART OF THE COMPUTER

A second research frontier is exploring whether living neural tissue can participate in computation. Scientists can grow three-dimensional brain organoids from human stem-cell-derived cultures. These organoids are not complete brains and should not be described as miniature human minds. They are laboratory models that reproduce some cellular and molecular features of neural development.



Researchers are investigating whether organoids connected to microelectrode arrays can receive stimulation, produce measurable electrical activity, and adapt to patterns of input. A 2023 review described this emerging field as organoid intelligence and discussed the development of three-dimensional microelectrode interfaces, bioengineering platforms, and ethical frameworks for studying biological computing.

The limitations are equally significant. Organoids require carefully controlled culture conditions, nutrients, monitoring, and ethical oversight. Their activity is difficult to interpret, and their size and organization differ substantially from a functioning brain. Claims that biological systems will soon deliver general-purpose intelligence at a fraction of the energy cost of silicon should therefore be treated as research hypotheses, not established engineering results.

QUANTUM COMPUTING AND THE COST OF RELIABILITY

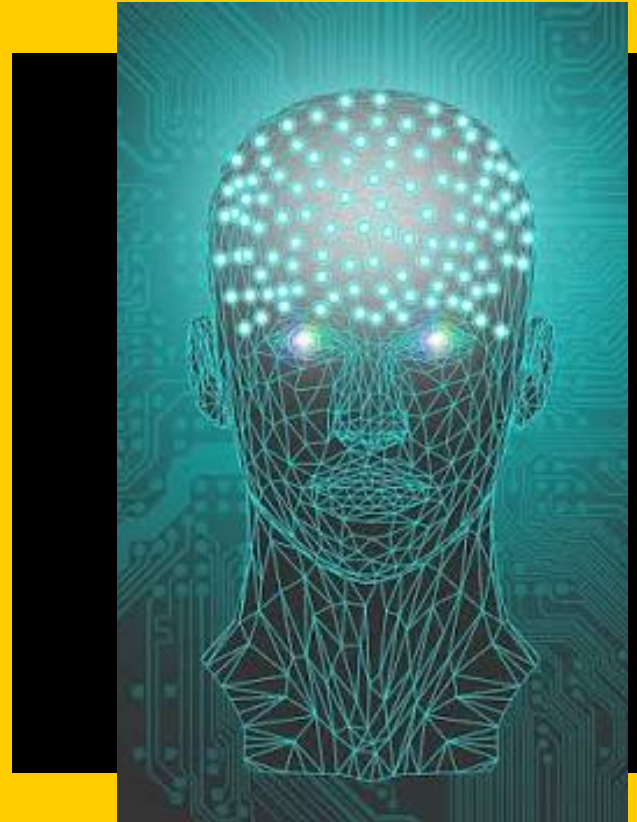
Quantum computing uses physical systems that can exhibit superposition and entanglement. The basic information unit is the qubit, but a qubit is not simply a faster version of a classical bit. Quantum algorithms are designed for particular mathematical structures, and a quantum computer is not expected to outperform a classical computer at every task.

The central engineering problem is reliability. Qubits are sensitive to noise, imperfect control, unwanted interactions, and environmental disturbances

In superconducting systems, the processor is operated inside a dilution refrigerator at temperatures close to absolute zero. Other platforms use trapped ions, neutral atoms, photons, or different physical mechanisms, each with its own advantages and challenges

. One of the most important ideas in the field is quantum error correction. A logical qubit stores information across multiple physical qubits so that errors can be detected and, under suitable conditions, corrected. This redundancy is expensive: a useful logical qubit may require many physical components, along with complex control and measurement systems.

That is why the phrase “fault-tolerant quantum computer” describes a long-term engineering objective rather than a finished product. Future machines may help with selected problems in chemistry, materials science, optimization, and cryptography, but the timing and scale of those benefits remain active research questions.



It is more accurate to say that quantum computing could provide advantages for particular problems than to promise that it will solve every difficult computation in minutes.

INTELLIGENCE AT THE EDGE

Not every important computing advance will happen in a supercomputer or a laboratory refrigerator. Increasingly, computation is moving toward the edge of the network: cameras, vehicles, industrial machines, agricultural equipment, buildings, and environmental sensors.

Sending every raw measurement to a distant cloud can consume bandwidth, increase latency, and create privacy concerns. Edge systems process at least part of the information close to its source. A transport system might analyze traffic locally before sending only alerts and summaries to a central service. An agricultural sensor might identify crop stress without continuously uploading every image. A building-monitoring system might detect unusual vibration patterns before a human engineer examines the structure.

Edge computing does not eliminate the cloud. It redistributes work among sensors, gateways, local servers, and centralized data centres. The best arrangement depends on the application's need for speed, connectivity, energy efficiency, privacy, and long-term storage.

NIST research on edge systems has emphasized the importance of privacy methods for continuous streams of sensor data.

This distributed model also changes the meaning of a “computer.” A computer may no longer be a single box with a screen and keyboard. It may be a network of small processors embedded in roads, machines, farms, medical devices, and public infrastructure.

THE UNIVERSITY AS A CONVERGENCE ZONE

These developments are changing what it means to study computing. A student working on a new processor may need knowledge of materials science, device physics, packaging, thermal engineering, and compiler design.



A researcher studying organoid intelligence may combine cell biology, electrophysiology, microfabrication, machine learning, and ethics. A quantum-computing project may require physics, mathematics, cryogenic engineering, control systems, and cybersecurity.

The boundaries between disciplines remain useful because they organize knowledge. But the most difficult problems increasingly occur at those boundaries. A future engineer may need to understand not only whether a system works, but also how much energy it consumes, what data it collects, how it fails, who controls it, and who may be affected by its decisions.

That is why ethics should not be treated as a final paragraph added after the engineering is complete. Biological computing raises questions about consent, moral status, and the responsible use of living tissue. Quantum advances affect cryptography and the security of stored information. Autonomous edge systems may make decisions in environments where mistakes can affect safety, access, or livelihoods. Responsible research requires these issues to be considered during design, testing, and deployment

A FUTURE BUILT FROM MANY SUBSTRATES

The next stage of computing is not a single dramatic transition from “old computers” to “new computers.” It is a gradual reorganization of where computation happens and what it is made from.



Silicon will remain central, but it will be joined by optical connections, new transistor geometries, specialized power materials, biological interfaces, quantum devices, and distributed edge nodes. Each approach has a different strength. Advanced transistors aim to improve density and efficiency. Photonics targets communication bottlenecks. Biological systems offer new models of adaptation.



Quantum processors explore a different computational framework. Edge devices bring intelligence closer to the physical world. The most important skill for students entering this field may therefore be neither memorizing one technology nor predicting one winner. It will be learning how to compare systems honestly, understand their limits, and combine them responsibly.

The future of computing will be built not from one material, one algorithm, or one discipline, but from a carefully designed conversation among all of them.



THE GHOST IN THE FREQUENCIES

How AI and Radar are Teaching Architecture to See

Vidhu Mohan
S7 ECE

In a windowless, subterranean laboratory buried beneath a university engineering building, a machine is watching a woman breathe.

There is no light in the room, save for the blue glow of a computer monitor. There are no cameras mounted in the corners, no optical lenses focused on her chest, and no thermal sensors reading her body heat. She stands completely still in the dark. Across the room, a device no larger than a deck of cards sits on a tripod. It emits no sound and captures no photons. Yet, on the computer screen, a perfect, real-time, three-dimensional skeletal model replicates her exact posture. As she inhales, the ribcage of the digital skeleton expands. The machine knows the precise cadence of her heartbeat

This is not a parlor trick; it is the vanguard of integrated sensing. By flooding the room with invisible, high-frequency millimeter waves and using advanced artificial intelligence to interpret the chaotic echoes that bounce back, researchers are teaching machines to perceive the physical world without capturing a single pixel of light.

For a century, our technological vision has been chained to the camera—a flawed, fragile mimicry of the human eye. But the era of optical dominance is fracturing. We are entering a new paradigm of machine perception, where the built environment does not need to look at us to know exactly what we are doing.

We are teaching our technology to see like bats, and in the process, we are fundamentally rewriting the future of privacy, healthcare, and surveillance.

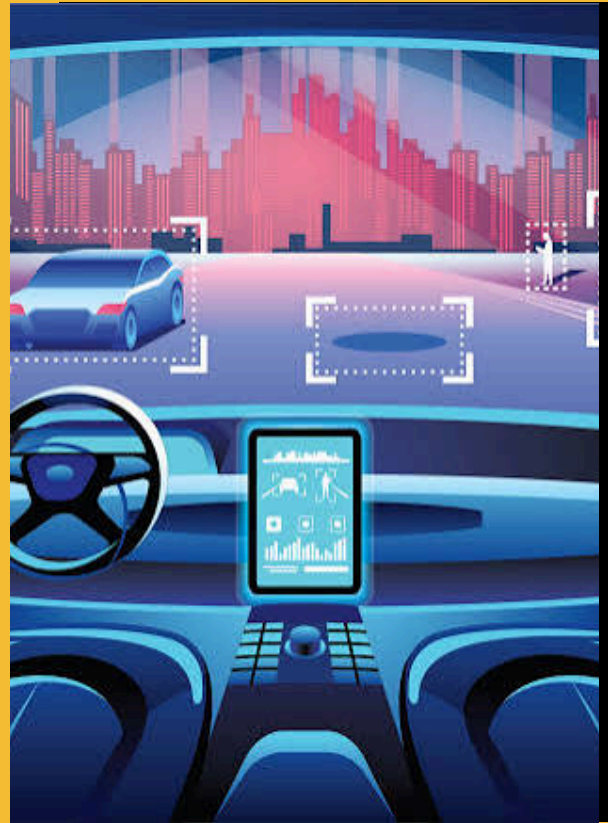
CHAPTER I: THE TYRANNY OF THE LENS

To understand the magnitude of this shift, we must first understand the limitations of the lens. Since the invention of the camera obscura, human engineering has obsessed over capturing light. The modern digital camera—whether it is mounted on a self-driving car, a drone, or the bezel of your smartphone—operates on this exact same prehistoric principle. It requires a light source to bounce photons off an object, which then pass through a curved piece of glass to hit a sensor.

But optical vision is inherently fragile.

If a self-driving car turns a corner into the blinding glare of a setting sun, its cameras are blinded. If a dense fog rolls into a shipping port, optical sensors become entirely useless. Most importantly, cameras suffer from the fatal flaw of occlusion: they cannot see through walls, clothing, or even a sheet of paper.

Beyond its physical limitations, the camera has become the ultimate instrument of privacy invasion. As the Internet of Things (IoT) demands more environmental awareness to make our homes and cities "smart," the default solution has been to blanket our living spaces with optical lenses.



“We reached a terrifying inflection point where providing better healthcare to an elderly person meant placing a high-definition camera in their bathroom,” explains Dr. Aris Thorne, a simulated composite of leading researchers in computational radio frequencies. “It was a dystopian trade-off. We realized that if we wanted machines to be deeply integrated into our intimate spaces, we had to invent a way for them to understand context without ever seeing our faces.”

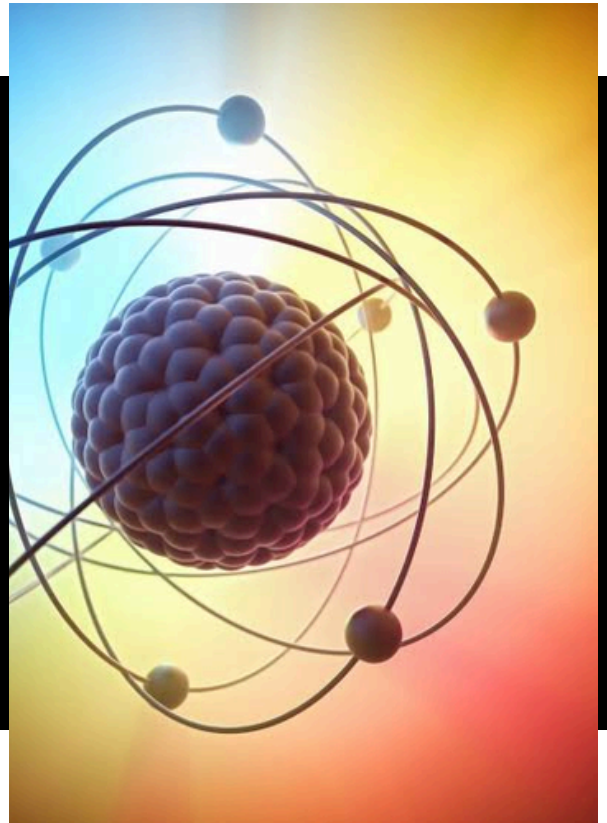
The solution was not to build a better camera. It was to abandon light entirely.

“We reached a terrifying inflection point where providing better healthcare to an elderly person meant placing a high-definition camera in their bathroom.”

CHAPTER II: THE PHYSICS OF THE UNSEEN BOUNCE

The alternative to light has been surrounding us all along. Our modern world is an invisible, chaotic ocean of electromagnetic waves—from the Wi-Fi routers broadcasting internet to our laptops, to the cellular towers pinging our phones, to the radio stations transmitting music.

Historically, we have only used these radio frequencies (RF) to carry data. But every time an RF wave travels through a room, it interacts with the physical objects inside it. When a Wi-Fi signal hits a wall, some of it passes through, and some of it bounces back



When it hits a human body— which is essentially a giant bag of saltwater—the wave is absorbed, scattered, and altered in highly specific ways.

Integrated sensing leverages two primary branches of this physics.

- **Millimeter-Wave (mmWave) Radar:** Unlike traditional weather radar, which uses massive dishes to bounce low-frequency radio waves off clouds miles away, mmWave radar uses very high frequencies (typically between 60 and 77 GHz) over very short distances. These waves are microscopic. Because of their tiny size, they are incredibly sensitive to micro-movements.



CHAPTER III: THE BRAIN BEHIND THE ECHO

If radar has existed since World War II, why are we only now using it to track heartbeats and map human skeletons? The answer lies in the explosive, parallel evolution of Artificial Intelligence.

For decades, the problem with radar was the "noise." If you emit a radar pulse in a standard living room, the wave doesn't just bounce off the person standing in the middle. It bounces off the ceiling, the television, the metallic edge of a coffee table, and the glass of a window. Some waves bounce off the person, hit the wall, hit the ceiling, and then return to the sensor. This is known as "multipath interference," and to a traditional computer, it looks like meaningless, chaotic static.

"Trying to see a human being in raw radar data is like trying to identify a specific drop of water in a hurricane," says Dr. Elena Rostova, a simulated pioneer in the field.

When a mmWave bounces off a human chest, the millimeter-scale displacement of the skin caused by a heartbeat alters the frequency of the returning wave—a phenomenon known as the Doppler effect.

- **Ambient Wi-Fi Sensing:** This is perhaps the most magical, and unsettling, frontier. You do not even need dedicated radar emitters. By simply analyzing the standard Wi-Fi signals bouncing between the router in your living room and your smartphone, engineers can map the environment. As you walk across the room, you disturb the invisible electromagnetic field of the Wi-Fi. By measuring these disruptions—specifically looking at the Channel State Information (CSI)—systems can detect if someone has fallen down, if they are typing on a keyboard, or if they are simply breathing in their sleep.

This is where deep learning enters the narrative. Over the past five years, researchers began feeding massive datasets of this chaotic RF static into neural networks, pairing the radar data with optical video feeds. The AI was given a simple task: look at the camera feed to see where the human joints are, and then look at the chaotic radar static and find the hidden patterns that match those joints.

After millions of iterations, the AI learned to filter out the noise of the walls, the furniture, and the multipath bounces. It learned the specific, microscopic radar signature of a human hand waving, a knee bending, or a lung expanding. Today, once the neural network is fully trained, the optical camera is entirely removed.

The AI can now hallucinate a perfect 3D skeleton from nothing but the invisible echoes.

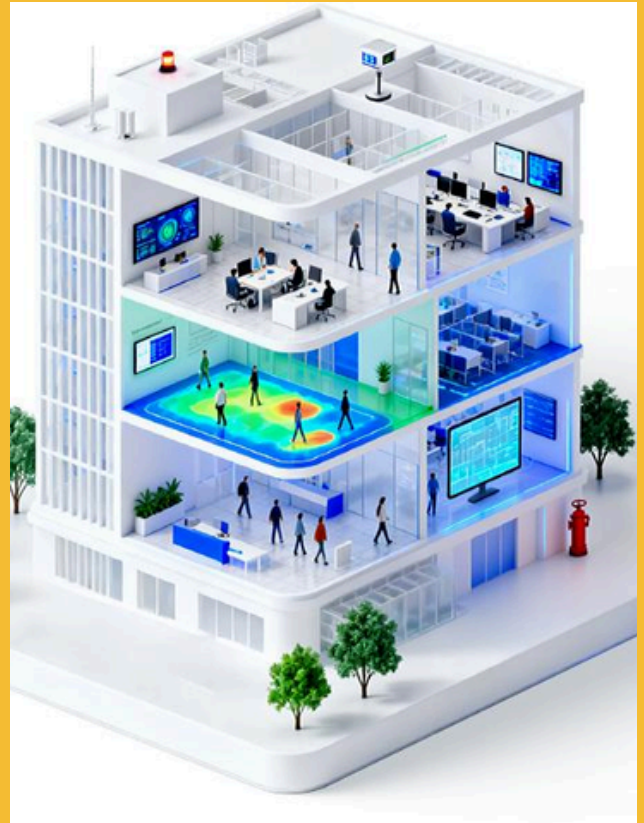
“Trying to see a human being in raw radar data is like trying to identify a specific drop of water in a hurricane.”

CHAPTER IV: THE ARCHITECTURE OF EMPATHY (AND SURVEILLANCE)

The implications of seeing without cameras are poised to fundamentally rewrite the curriculum of modern engineering and computer networking.

In healthcare, the applications are profound and immediately life-saving. In senior care facilities, optical cameras are massive privacy violations, while wearable panic buttons are frequently forgotten or taken off during showers—the place where falls are most likely to occur. A mmWave radar sensor placed behind the drywall of a bathroom can monitor a patient 24/7. It cannot see the color of their skin, their state of undress, or their identity. But if the physical mass of the patient rapidly descends to the floor, the AI instantly recognizes the signature of a fall and alerts the nurses' station.

In automotive engineering, integrated sensing is replacing optical cameras for in-cabin monitoring. A radar hidden in the dashboard can easily "see" through a thick winter coat to monitor the subtle breathing patterns of a driver,



detecting the onset of micro-sleep or a medical emergency before the driver's eyes even close. It can detect if a child has been left under a blanket in the backseat, sensing their tiny heartbeats even if they are entirely hidden from view.

However, a technology that can see through walls and detect a heartbeat from across the room is inherently a double-edged sword

We are building a world where the very walls of our homes, offices, and universities act as omniscient sensors. If a standard Wi-Fi router can be upgraded via a firmware patch to detect the emotional states of the people in the room based on their respiration rates, who owns that data? If an authoritarian government deploys Wi-Fi sensing in a public square, they do not need facial recognition cameras to know exactly how many people are gathered in a windowless basement, or what their precise physical movements are.

The legal frameworks of the 20th century are entirely unprepared for the physics of the 21st. Our privacy laws are largely based on the concept of a "reasonable expectation of privacy" behind closed doors. But what does a closed door mean to a machine that sees in radio waves?

“Our privacy laws are largely based on the concept of a 'reasonable expectation of privacy' behind closed doors. But what does a closed door mean to a machine that sees in radio waves.”

THE "SO WHAT?": YIELDING TO THE INVISIBLE

The transition from optical cameras to integrated RF sensing represents a profound philosophical pivot.

For centuries, our definition of "surveillance" and "awareness" has been intrinsically tied to the eye. We believed that to understand the world, we had to capture its light, freeze it, and analyze it.

As we move forward, the built environment will no longer watch us with cold, glass lenses. Instead, architecture will become deeply, invisibly sentient. Our smart homes and intelligent classrooms will not look at us; they will feel our presence, sensing the displacement of the air, the rhythm of our pulses, and the geometry of our movements.

Technology is finally learning to close its eyes, realizing that in the dark, the echoes tell a far more honest story.





THE SKY IS NOW A NETWORK

How a swarm of washing-machine-sized satellites quietly rewired the meaning of “online” — and what it costs us to get there

Elsa Jose
S5 ECE

There is a particular kind of dark that only exists far from a city. Not the movie-theater dark of a blackout, but a dark with texture — a sky so unobstructed by light pollution that the Milky Way looks less like a smear and more like a structure, something you could almost reach up and touch.

It’s the kind of dark you find in the high plains of Mongolia, in the fjords of northern Norway, in a fishing village on the edge of the Pacific where the nearest fiber-optic cable is a two-day boat ride away. It’s also, increasingly, a dark with traffic in it. If you watch that sky patiently enough on a clear evening, you will eventually see a line of lights moving in disciplined, silent formation — not a shooting star, not a plane, but a train of satellites, evenly spaced, gliding from horizon to horizon in about four minutes.

A decade ago, this sight would have puzzled even a seasoned astronomer. Today, students post videos of it with the caption “Starlink train” and move on with their evening, the way an earlier generation might have shrugged at a contrail. What’s happening in that dark sky is one of the most consequential and least understood infrastructure projects of our time: the migration of the internet’s last mile into orbit. Not “the internet” in the abstract sense we usually mean when we say a satellite “provides internet” — but literally, physically, several thousand refrigerator-sized machines orbiting the Earth roughly seventeen times a day, each one a piece of telecommunications equipment doing a job that used to require a cable in the ground or a tower on a hill.

This is the story of how that happened, why it took sixty years longer than the man who first proposed it expected, and why the ordinary act of loading a webpage on a boat, a mountain, or a battlefield has quietly become one of the more contested pieces of real estate — or rather, orbit-estate — on the planet.

I. THE MAN WHO SAW IT COMING, AND GOT THE TIMELINE WRONG

In October 1945, a young Royal Air Force radar instructor named Arthur C. Clarke — a few years away from writing *2001: A Space Odyssey*, currently paying his bills with a technical magazine subscription — published a short paper in *Wireless World* titled “Extra-Terrestrial Relays.” In it, he laid out, with the calm precision of someone doing homework rather than prophecy, the mathematics of a satellite parked exactly 35,786 kilometers above the equator. At that altitude, a satellite’s orbital period matches Earth’s rotation exactly. It doesn’t cross the sky. It hangs there, motionless relative to the ground, forever — a fixed point you could aim a dish at once and never adjust again.

Clarke understood immediately what this meant: three such satellites, spaced evenly around the globe, could relay a signal to almost the entire populated Earth. He’d essentially invented the geostationary communications satellite on a napkin, twelve years before Sputnik even reached orbit and twenty-two years before the first one, Intelsat I, actually did the job he’d described.



For the next half-century, “satellite internet” and “geostationary satellite” were functionally the same phrase. And it was a compromise everyone quietly hated. A signal traveling to geostationary orbit and back covers roughly 144,000 kilometers round-trip — a bit under half a light-second — which sounds trivial until you’re on a video call and every sentence arrives with a diplomatic half-second of hesitation, like talking to someone over a bad long-distance line to another continent.

For email, that latency is invisible. For a Zoom class, a video game, or a stock trade, it’s crippling. There was, on paper, an obvious fix: fly the satellites lower. Low Earth orbit — a band starting a few hundred kilometers up, where the International Space Station also lives — cuts that round-trip distance from 144,000 kilometers to under 1,000. Latency drops from roughly 600 milliseconds to something closer to 20 or 30, competitive with a decent home cable connection.

The problem was coverage. A satellite in LEO isn't parked over your head — it's moving at nearly 7.5 kilometers per second, and it crosses your local sky in minutes before disappearing over the horizon. To provide continuous coverage anywhere on Earth, you don't need three satellites. You need thousands, handing a connection off between one another like a bucket brigade, faster than you can notice the handoff happened. Someone tried this in the 1990s. It was called Iridium, and it is one of the great, expensive, honorable failures of the dot-com era — a constellation of 66 satellites, a billion-dollar-plus engineering triumph, that filed for bankruptcy in 1999 less than a year after launching commercial service, undone by handsets the size of a brick, a price tag

north of three dollars a minute, and a fatal miscalculation about how fast terrestrial cell networks would spread. Iridium was right about the physics and catastrophically wrong about the economics. It became a cautionary tale told in business schools for twenty years: don't build the megaconstellation, the numbers don't work.

“Iridium was right about the physics and catastrophically wrong about the economics — the megaconstellation that proved a good idea can still arrive at the wrong price.”

THE BORING REASON THIS BECAME POSSIBLE: A ROCKET THAT LANDS

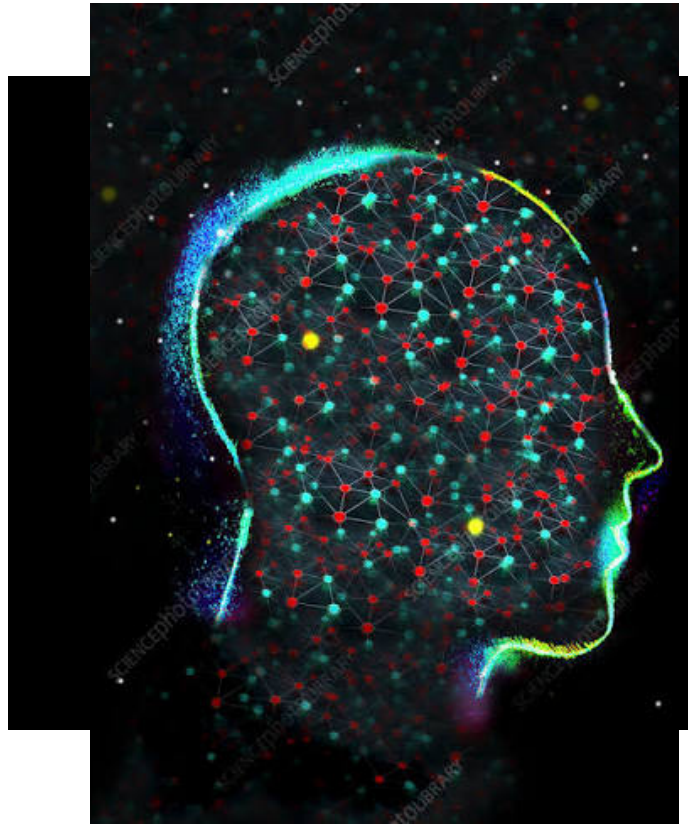
Ask an aerospace engineer why low-Earth-orbit internet suddenly makes financial sense after decades of failure, and you will not get a story about a breakthrough in radio science.

You will get a story about a rocket booster landing itself on a floating platform in the ocean.

For the entire history of spaceflight before 2015, every rocket stage that carried a payload to orbit was thrown away — dropped into the sea, burned up, used exactly once, at a manufacturing cost that had to be repaid entirely by that single flight. It's the equivalent of building a 747, flying it from New York to London, and then bulldozing it into the Atlantic. Under those economics, launching thousands of satellites was never going to pencil out, no matter how clever the constellation design.



Reusability changed the unit economics of the entire industry, not gradually but by roughly an order of magnitude. A first-stage booster that can fly ten, twenty, or more times amortizes its cost across every one of those flights. Combine that with satellites redesigned from scratch to be manufactured on an assembly line — flat-packed, standardized, built by the hundreds rather than handcrafted by the dozen the way geostationary satellites always had been — and the economics of a LEO megaconstellation flip from absurd to merely audacious.



“People think the hard part is the satellite,” a systems engineer who spent years designing smallsat buses told me. “The hard part was always getting a hundred of them into orbit for the price it used to cost to launch one. Once launch got cheap and frequent, the constraint moved. It stopped being ‘can we build this’ and became ‘how fast can we build this.’” That shift — from a scarcity problem to a manufacturing problem — is the entire hidden engine of the LEO satellite internet boom. It’s also why the current era doesn’t have one player, but a genuine, fast-moving field of them, each betting on a slightly different architecture, a different orbital shell, a different business model, and increasingly, a different flag.

III. THE RACE, BY THE NUMBERS

It's worth pausing on scale, because the scale is genuinely disorienting if you haven't been tracking it. At the start of 2019, humanity had fewer than 2,000 active satellites of any kind, doing everything from weather forecasting to spying to GPS. One company's broadband constellation alone now exceeds that entire historical total several times over — well past ten thousand active satellites in orbit, accounting for a majority of everything humans currently operate above the atmosphere. It reached ten million paying subscribers across more than a hundred countries only a handful of years after its first commercial customer got online. That company is not alone, and being first has not meant being uncontested.



A rival built by an e-commerce giant has taken a different architectural bet — fewer, more capable satellites spread across three orbital shells, laser links forming a mesh in the sky so data can hop satellite-to-satellite rather than always routing down to a ground station, and a promised top speed meant to outpace the market leader. It is years and thousands of satellites behind schedule relative to its own original ambitions, a reminder that “we have the money and the plan” is a necessary but insufficient condition for getting metal into orbit on time.

THE SELF-HEALING NETWORK

Beyond the physical layer, AI is transforming the macro-architecture of the internet.

Meanwhile, an older constellation — built originally as a business connectivity play, then rescued from bankruptcy by a national government's direct investment, a striking event in itself — has staked out the market for maritime, aviation, and enterprise customers who need reliability more than they need bragging rights about speed. And on the other side of the geopolitical ledger, two Chinese state-backed constellations are climbing toward orbit on a similar timetable, driven by a calculation that has nothing to do with rural broadband economics and everything to do with a country deciding it does not want its communications infrastructure, or its future battlefield connectivity, dependent on a network another nation's regulator can switch off

This is the part that tends to surprise people outside the industry: satellite internet, which sounds like a consumer convenience story, is increasingly a national security story. A network that can blanket a warzone, a disputed border, or a disaster zone with connectivity independent of local ground infrastructure is not just a telecom asset. It's strategic infrastructure, and every government capable of building or buying one has started treating it that way. When a conflict knocked out ground-based communications in one Eastern European country in the early 2020s, satellite terminals shipped in within days became a documented, publicly discussed factor in how that country's military and civilians stayed connected — the first time a commercial LEO constellation demonstrably shaped the course of an active war, and a case study that every defense ministry on Earth has since read closely.

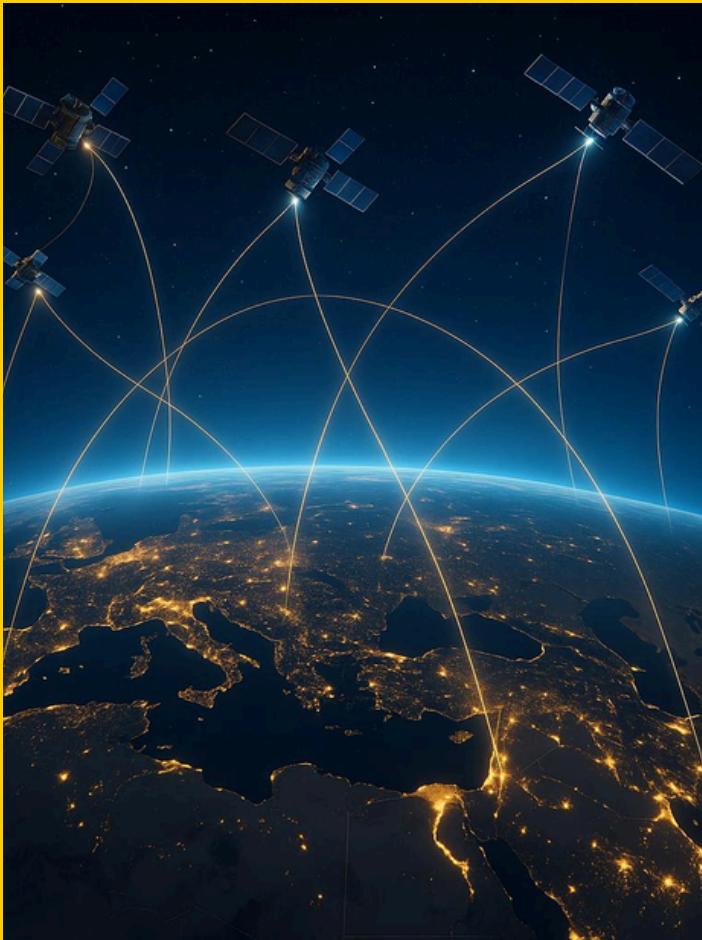


“Satellite internet, which sounds like a consumer convenience story, is increasingly a national security story.”

IV. WHAT IT ACTUALLY FEELS LIKE TO BE UNDER THE NET

Numbers are one register for this story. Here's another. Imagine a two-room schoolhouse serving a scattering of ranching families spread across several hundred square miles — the kind of place where the nearest town with a stoplight is ninety minutes away, and where, until recently, “internet class” meant a single donated laptop, a data plan measured in painful gigabytes, and a teacher who had learned to plan lessons around the hours when the connection was least likely to drop.

For decades, this was simply the ceiling. Rural connectivity has always been an economics problem before it was a technology problem: running fiber to a farmhouse eleven miles from the nearest exchange costs a phone company roughly the same amount whether that farmhouse has one customer or a thousand behind it, and no publicly traded telecom is going to run that math and come out enthusiastic. Government subsidy programs have chipped away at the gap for decades, one grant cycle at a time, without ever closing it, because the underlying economics never changed. A dish the size of a large pizza box, aimed at open sky and requiring no permission from any local utility, changes that calculation entirely. It doesn't care how far you are from an exchange. It cares whether you can see the Sky



“The thing nobody prepared me for,” a rural high school teacher told me, describing the year her classroom went from a single shared laptop to a functioning broadband connection, “was how much of teaching I’d quietly given up on without noticing. Video field trips. Real-time collaboration with a class in another state. Kids submitting work the night before instead of driving into town to use the library Wi-Fi. It wasn’t that we were behind — it’s that we’d stopped imagining what wasn’t behind would look like.”

That reframing — from “internet access” as a binary switch to internet quality as something rural communities could finally take for granted the way urban ones always did — is probably the single most significant social effect of this technology, and the one least likely to make headlines, because “kid does homework on time” is not a viral story. It is, however, the actual point.

The same logic scales up to entire industries that have historically operated in connectivity blackout by default: commercial shipping, where a vessel mid-ocean has traditionally had internet access measured in kilobits and priced like caviar; commercial aviation, where the in-flight Wi-Fi that used to buffer on a single email attachment is being replaced, fleet by fleet, with connections fast enough for a video call at 35,000 feet; disaster response teams who, after a hurricane or earthquake takes out cell towers and fiber trunks alike, can now have a functioning internet connection back online within hours by unboxing a terminal and pointing it at the sky, rather than waiting weeks for line crews to rebuild physical infrastructure that may not even survive the next storm.

“We have put a working, revisable, occasionally malfunctioning piece of civilization up there among the stars, and it is now part of what a person looking up on a clear night is actually looking at, whether they know it or not.”

CHAPTER IV: NAVIGATING THE ABYSS

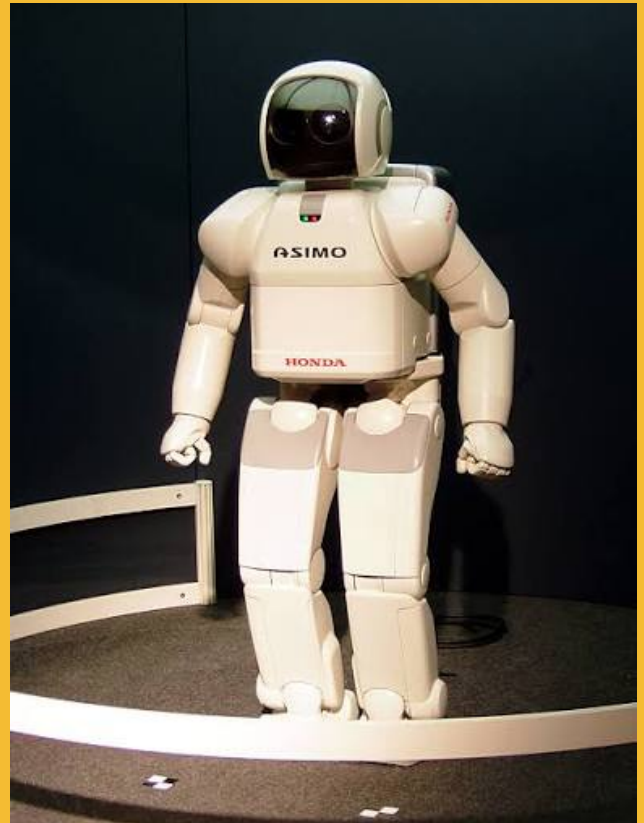
Outside the human body, the pliability of soft robots allows them to survive in environments that would crush or trap their rigid ancestors.

In search-and-rescue operations following an earthquake, sending a heavy, metal robot into the unstable rubble of a collapsed building is incredibly dangerous; the robot's weight and rigid structure can easily trigger a secondary collapse. A soft robot, however, can squeeze through jagged, irregular crevices, deflating itself to pass under concrete slabs and re-inflating to lift debris or deliver oxygen tubes to trapped survivors

This same principle is taking soft robots to the least hospitable place on Earth: the Marianas Trench.

At a depth of nearly 36,000 feet, the pressure of the ocean is roughly 1,000 times greater than at sea level. Traditional deep-sea submersibles require incredibly thick, heavy titanium pressure hulls to protect their electronics and motors from being obliterated. Yet, deep-sea creatures like the snailfish survive there with gelatinous bodies and no rigid skeleton.

Inspired by this, engineers have recently developed soft robotic submersibles cast entirely in silicone, with their delicate electronic components distributed throughout the soft body rather than housed in a single rigid core. Because the silicone is already solid and incompressible, the



crushing pressure of the deep ocean simply passes through it without damaging the robot, allowing these artificial manta rays to swim gracefully through the abyss.

THE "SO WHAT?": THE PHILOSOPHY OF YIELDING

The rise of soft robotics is more than just a technological milestone; it represents a profound philosophical shift in how humanity relates to the world it builds.

Since the dawn of the Industrial Age, our approach to technology has been one of dominance. We built machines that were louder, harder, and stronger than nature. We poured concrete over the earth to give our rigid cars a smooth surface.



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TECHNOBYTE

“where **dreams**
take shape, and
futures
take flight”

INSPIRE IMBIBE
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