Cortical Labs CL1:

The First Commercial Biological Computer Research Report

Neuroscience as Model for AI ITAI-4374

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Introduction

Cortical Labs' CL1 is heralded as the world's first commercial biological computer powered by living human neurons integrated with silicon chips (Cuthbertson, 2025). Launched in early 2025, the CL1 system represents a breakthrough in Synthetic Biological Intelligence (SBI) – a new form of computing that merges biological neural networks with traditional hardware (Toohey, 2025). Unlike conventional artificial intelligence (AI) running on silicon alone, the CL1 leverages real neuronal cells as computing elements, promising learning and adaptability more akin to a brain than a machine (Cortical Labs, 2025). This report provides a comprehensive overview of the Cortical Labs CL1 system. It will introduce the scientific background in neuroscience that makes such a system possible, describe the CL1's architecture, and discuss its significance. In particular, the discussion will compare CL1's living neural networks to traditional AI, outline potential applications, explore the future of SBI technology, and consider the challenges and ethical questions that arise when computing and biology intersect. The goal is to understand how CL1 works and what implications this "brain-based" computer has for the future of computing and artificial intelligence.

Background: Neuroscience Foundations

The CL1 builds on foundational neuroscience insights into how networks of neurons process information. Neurons are the fundamental cells of the brain, capable of forming complex circuits that learn and adapt through changing connection strengths (synaptic plasticity). For decades, researchers have sought to harness this natural computing power. Brain-computer interfaces and neuromorphic engineering attempted to mimic neural behavior in silicon chips, but CL1 takes a more direct approach: using actual biological neurons for computation (Worley & Hartung, 2023).

This approach is informed by theories such as Karl Friston's free-energy principle, which models how neural systems adapt to minimize surprise in their environment (Friston, 2010). Such theories suggest that living neural networks inherently self-organize and learn through feedback, a principle that CL1's design exploits (Kagan et al., 2022; Friston, 2010).

A key precursor to CL1 was research demonstrating that live neuron networks in vitro can exhibit learning when embedded in simulated environments. In a landmark experiment, Kagan et al. (2022) grew about 800,000 cortical neurons from human and rodent cells on a high-density electrode array and connected them to a simple computer game (Pong). In this "DishBrain" system, the neurons received electronic stimuli representing the game's context and, in turn, their neural firing controlled the paddle in the Pong game (Kagan et al., 2022). Remarkably, the neural culture learned to play a simplified Pong within minutes – an example of goal-directed learning emerging spontaneously from a biological neural network when given sensory feedback (Kagan et al., 2022). The researchers attributed this rapid learning to the neurons' inherent adaptive algorithms shaped by evolution, potentially aligned with active inference models (Kagan et al., 2022). This experiment provided a proof-of-concept that live neurons can serve as a computational substrate, exhibiting learning and even hints of sentience or awareness of the game-world state (Kagan et al., 2022). It also underscored the importance of a closed-loop system: only when the neurons could both receive input and affect the environment (feedback) did learning occur, consistent with how brains learn via interaction (Kagan et al., 2022). These neuroscience foundations – plasticity, feedback-based learning, and theoretical frameworks of brain function – set the stage for the development of Cortical Labs' CL1 system.

System Architecture of the CL1

The CL1 biological computer is essentially a “brain in a box”, in the words of Cortical Labs scientists (Cuthbertson, 2025). Each CL1 unit contains living neural tissue integrated with traditional computing hardware in a self-contained life-support environment. Real human neurons (approximately 800,000 per unit) are cultured from stem cells and grown on a proprietary silicon chip that contains a dense grid of micro-electrodes (Toohey, 2025). These electrodes serve as the interface, capable of both stimulating the neurons and reading their electrical activity in real time (Cortical Labs, 2025). The neurons sit in a nutrient-rich solution within the device, which keeps them alive and functional. The CL1’s chamber is equipped with pumps to circulate nutrients, maintain proper gas exchange (oxygen/CO_2 levels), and regulate temperature – effectively imitating a miniature incubator for brain cells (Toohey, 2025; Cuthbertson, 2025). This internal life-support system is robust enough to keep the neurons alive for up to six months at a time (Cuthbertson, 2025).

Central to the CL1’s operation is Cortical Labs’ Biological Intelligence Operating System (biOS) – specialized software that creates a simulated environment for the neurons (Cortical Labs, 2025). The biOS can be thought of as a virtual world or game in which the neurons are “embodied.” It streams information to the neuronal network via the electrode interface, representing sensory inputs or feedback from whatever task or simulation is running (TechRadar reports the company describing it as sending information about the neurons’ environment directly to them) (Williams, 2025). In response, the neurons’ firing patterns (their “output”) are captured by the electrodes and fed back into the simulation or external task. This closed-loop interaction means the neurons and software continually influence each other. For example, if the CL1 is tasked with controlling a virtual paddle in a game, the biOS translates the game state into stimuli the neurons receive; the neurons' electrical responses then move the paddle, and the consequences of that movement are fed back to the neurons as new stimuli. In essence, the neurons function as a living processor, with the biOS acting as an interpreter between biological activity and digital computing tasks (Cortical Labs, 2025; Williams, 2025).

The hardware design reflects a modular, plug-and-play architecture. The CL1 device is self-contained – all necessary computing, recording, and life-support components are built in, requiring no external supercomputer to function (Cortical Labs, 2025). The unit includes USB and other I/O ports to connect peripherals such as cameras, sensors, or actuators, allowing the CL1's neural network to interface with external devices for experiments (Cortical Labs, 2025). A touchscreen on the device provides local controls and visualization of the network's status and data in real time (Cortical Labs, 2025). CL1 units are also networked to the Cortical Cloud, enabling users to access them remotely. The company offers a cloud-based "Wetware-as-a-Service (WaaS)" model, meaning researchers can run experiments on a CL1 via the internet without having the physical device, similar to cloud computing but with living neurons as the resource (Worley & Hartung, 2023; Toohey, 2025). For those who purchase a CL1 (at roughly $35,000 each), multiple units can be stacked together. In fact, Cortical Labs is reportedly constructing a server rack of 30 CL1 units (containing 30 separate neuronal networks) to scale up the available biological computing power (Williams, 2025). Notably, an entire rack of 30 CL1 biocomputers consumes on the order of only 850–1000 watts of power – about the same as a single modern high-end PC or a few lightbulbs – which is a fraction of the energy that an equivalent amount of conventional AI computing would require (Toohey, 2025).

Overall, the CL1's architecture elegantly fuses wetware and hardware: living neurons ("wetware"), the electrode array and support electronics ("hardware"), and the biOS bridging them with the digital realm (software). This synergy creates a platform where biological neural computation can be harnessed for real-world computing tasks in ways never before possible outside of a laboratory setting.

Discussion

Comparison to Traditional AI

Cortical Labs' CL1 invites comparisons with conventional artificial intelligence systems that run on purely silicon-based hardware. The most striking difference is how learning is achieved. Traditional AI, such as deep neural networks, relies on algorithms executed on silicon chips (CPUs, GPUs, or specialized AI accelerators). These algorithms often require enormous datasets and iterative training cycles to adjust weighted connections – an attempt to emulate synaptic learning in software. By contrast, the CL1's living neural network inherently learns from experience in real time, through the natural synaptic plasticity of the cultured neurons (Cortical Labs, 2025). The neurons in CL1 reconfigure their connections as a result of stimuli and feedback, essentially programming themselves in response to the environment (Cortical Labs, 2025). As the company puts it, "the neuron is self-programming, infinitely flexible, and the result of four billion years of evolution. What digital AI models spend tremendous resources trying to emulate, we begin with" (Cortical Labs, 2025). This means CL1 does not need to be "trained" in the same data-intensive way an AI model does; learning emerges more organically and quickly from the system's interactions (Kagan et al., 2022). For example, while a reinforcement learning AI might take many thousands of trials to learn a game like Pong, the DishBrain neurons learned an approximation of it within minutes when provided the right feedback loops (Kagan et al., 2022).

Another major difference is energy efficiency. The human brain famously operates on roughly 20 watts of power, far outperforming current supercomputers in terms of energy per computation. Similarly, SBI systems like CL1 use significantly less power than conventional AI hardware. Each CL1 unit runs at low power (its internal systems and neurons require minimal energy), and even a 30-unit CL1 cluster uses under 1 kW, which is orders of magnitude less energy than a comparable AI datacenter performing complex tasks (Toohey, 2025). This advantage comes from the fact that biological neurons are extremely efficient at information processing; they combine memory and computation in the same elements (synapses), unlike computers which expend energy shuttling data between memory and processor (Worley & Hartung, 2023). Cortical Labs claims that their neural systems require not only less energy but also far less data to learn: they can potentially generalize from small datasets or even single experiences, whereas traditional AI often demands big data (Cortical Labs, 2025). This makes CL1 an enticing prospect for achieving AI-like capabilities in scenarios where data or power are limited.

However, there are also important contrasts and current limitations. Traditional silicon AI is fast, precise, and highly reliable for well-defined tasks, whereas biological neural networks like in CL1 may be slower and noisier in their computations. Neurons operate on the scale of milliseconds (spike timing), which is much slower than a modern CPU's nanosecond operations. For many tasks, CL1's real-time learning capability is impressive, but it may not yet match the raw speed or complex logic processing of a dedicated digital processor. Additionally, reproducibility can differ: if you reset a silicon AI model with the same weights, it will behave identically, but a biological system might show variability each run because of the stochastic nature of biology. The CL1's neurons might also drift in behavior over time as they develop or degenerate, requiring careful calibration or periodic replacement (Cuthbertson, 2025). Moreover, while traditional AI can scale by simply adding more chips or running on cloud servers, scaling SBI means growing more neurons and managing live cultures, which is a different kind of challenge. Cortical Labs' approach to stackable units and cloud-accessible wetware is an attempt to solve this, but the field is in its infancy. As of 2025, CL1's neural networks are relatively small (hundreds of thousands of neurons) compared to even a mouse brain. They are not about to run a word processor or do arithmetic faster than your laptop; rather, their strengths lie in pattern recognition, adaptation, and possibly forming novel solutions in ill-defined environments – areas where human brains excel and AI often struggles. In summary, CL1's living AI offers human-like adaptability and efficiency, whereas traditional AI offers speed, scale, and consistency. The two approaches may be complementary: one can imagine hybrid systems where biological processors handle certain tasks and silicon others, each playing to their strengths (Worley & Hartung, 2023). The advent of CL1 suggests a new computing paradigm that could push beyond the limits currently faced by silicon-based AI (Candanosa, 2023).

Applications and Use Cases

As an entirely new type of computing platform, the CL1 opens up a range of potential applications. Cortical Labs envisions its technology being used first and foremost in scientific and medical research (Chong, as cited in Williams, 2025). Because the CL1 allows researchers to experiment directly with live human neural circuits, it could serve as a test-bed for neuroscience and pharmacology that is more ethically acceptable and relevant than animal testing. For instance, labs could use CL1 to study how neurons respond to certain drugs or stimuli, enabling advanced drug discovery, toxicity testing, and disease modeling on human neural tissue without needing to experiment on live animals or patients (Prada, 2025; Toohey, 2025). The CL1's human neurons might exhibit disease-like patterns if modified (e.g., neurons with genetic markers for Alzheimer's disease could be studied in the CL1 environment), offering a novel way to investigate neurological conditions and potential treatments in a controlled setting. This capability aligns with a broader movement toward reducing animal experimentation – Cortical Labs has highlighted that SBI could be an "ethically superior alternative to animal testing" while providing more directly translatable insights from human cells (Cortical Labs, 2025).

Another key application area is artificial intelligence and robotics. The CL1's neural network can serve as an AI controller for machines, effectively acting as a brain for a robot or autonomous system. Because it can learn from sensory inputs in real time, a CL1 unit connected to robotic sensors and actuators could learn to perform tasks in a dynamic environment, potentially yielding more flexible or creative behaviors than a pre-programmed AI (Toohey, 2025). For example, a robotic arm guided by a CL1 might learn to adapt its grip based on tactile feedback in a way that's difficult to hand-code. Cortical Labs has suggested that "robotic intelligence development" is a target use case – the CL1 could allow unlimited personalization of robot behavior by training each neural culture on specific tasks or preferences (Toohey, 2025). Similarly, CL1 could be used in controlling drones or autonomous vehicles, where on-the-fly learning and low power consumption are advantageous. However, these applications will require significant development to move from experimental demonstrations to reliable deployment. Early adopters will likely be research institutions exploring what SBI can do.

In the realm of pure computing, CL1 might be used to solve problems that are computationally complex for traditional algorithms but more naturally handled by brain-like networks. These include pattern recognition, anomaly detection, or multi-modal sensor integration tasks. A CL1 might excel at tasks where generalization from few examples is needed, or where the rules aren't well-defined enough to write a traditional algorithm. For instance, one could imagine using a CL1 to detect subtle patterns in financial markets or weather data that defy straightforward modeling. Such ideas remain speculative but tantalizing.

Importantly, Cortical Labs is making CL1 accessible through the Cortical Cloud platform, meaning that even organizations without a wetlab can utilize the technology (Worley & Hartung, 2023). By renting time on CL1 units remotely, data scientists or developers could incorporate a "neural chip" into their projects much as they would use a cloud GPU. This democratization of SBI could spur creative applications across fields. We might see experimental art installations driven by CL1 neural responses, or educational tools where students can interact with a live neural network in real-time via a computer interface. Over time, as the technology matures, one can envision hybrid systems – for example, conventional computers using CL1 modules as co-processors for certain tasks (much like GPUs accelerate graphics, a living neural processor might accelerate adaptive control or AI reasoning tasks).

In summary, the initial applications of CL1 will focus on research, biomedical innovation, and specialized AI tasks. Drug testing and brain science could gain a powerful tool through CL1's human-relevant neural platform. Robotics and AI could explore new architectures by incorporating living networks that learn on the fly. And by providing cloud access, Cortical Labs aims to catalyze a broad community of users to discover novel use cases. The full spectrum of applications will become clearer as developers experiment with this radically different form of computing in the coming years.

Future of SBI and Biological Computing

The launch of CL1 is a significant milestone in the nascent field of Synthetic Biological Intelligence (SBI), but it is likely just the beginning of a new era of biocomputing. In the near term (the next few years), Cortical Labs and others will work on scaling up and refining this technology. The concept of a "biological neural network server stack" composed of many CL1 unit's hints at how SBI might scale: by networking multiple live neural modules together to tackle more complex tasks (Williams, 2025). By the end of 2025, Cortical Labs plans to have multiple 30-unit stacks available via its cloud, effectively creating a biological cloud computing service (Williams, 2025). If successful, this could provide a significant amount of living neural computational capacity accessible to researchers globally, perhaps solving problems cooperatively or handling multiple experiments in parallel. The modular nature of CL1 (being stackable and interchangeable) suggests that larger "brain-like" systems could be built by simply adding more units, similar to how supercomputers scale out with more processors. However, coordinating multiple living networks to work together on one problem is uncharted territory – it raises questions akin to networking multiple brains. Research will be needed on how to best harness a cluster of neuronal cultures: should they be interconnected so neurons can communicate across units, or used in a divide-and-conquer approach where each unit handles a part of a problem, and a computer coordinates the results? These are open questions for the future of SBI.

Looking further ahead, the field will likely explore more advanced forms of biological neural networks, such as 3D brain organoids as computing units. The CL1 uses neurons grown in a 2D layer on a chip; the logical progression is to use 3D structures (often called organoids or "mini-brains") that can contain millions of neurons in a more brain-like architecture. In early 2023, a group of scientists led by Johns Hopkins University outlined their vision for "organoid intelligence

(OI)," which would involve complex 3D cultures of brain cells integrated with electronics to achieve cognitive computing capabilities far beyond current AI (Candanosa, 2023; Worley & Hartung, 2023). These researchers argue that organoid-based computers could in the future be faster, more efficient, and more powerful than silicon-based computers by virtue of having complexity and plasticity approaching that of animal brains (Candanosa, 2023). The CL1 can be seen as a practical first step on this long path – it demonstrates core principles (like coupling neurons with simulations) in a simpler 2D format. Achieving organoid intelligence will require advances in growing standardized, large organoids, as well as read/write interfaces possibly in three dimensions, and sophisticated training protocols (Worley & Hartung, 2023). Over the next decade, we can expect increasing convergence of tissue engineering, neuroscience, and computer science to push SBI forward. Companies and academic labs might develop larger "brain-on-a-chip" systems, and perhaps even begin to tackle tasks like speech recognition or decision-making with these systems.

Another important aspect of SBI's future is how it will integrate with traditional computing. It is unlikely that biological computers will simply replace silicon; rather, hybrid architectures could emerge. For instance, one might have a conventional computer that offloads certain tasks to a biological module (just as some current AI systems might use both classical algorithms and neural networks in tandem). Conversely, biological computers might use digital systems to handle memory storage or exact arithmetic while they concentrate on learning and inference. This hybrid approach could leverage the strengths of each technology.

In terms of potential, one cannot ignore the ultimate question: could SBI ever approach human-level intelligence or consciousness? While CL1 is far from that scenario – its neural networks are tiny compared to a human brain and operate in very controlled simulated worlds – the trajectory of scaling up neural systems is conceptually one path toward general intelligence. Some futurists speculate that if we can grow and sustain billions of neurons and interconnect them appropriately, we might have a machine with cognitive capacities rivalling a small animal's brain, and eventually, perhaps, a human. Whether that is truly achievable or practical remains to be seen; it may be that there are diminishing returns or insurmountable complexity barriers long before reaching that scale. Nonetheless, the future of SBI promises to expand our computing toolbox beyond anything we've had: computers that partially think like brains. Even if they don't become full "artificial minds," they could transform areas like adaptive control systems, real-time learning bots, and complex simulations of brain activity for research.

Challenges and Ethical Considerations

With the power of merging living neurons and machines comes a host of challenges and ethical questions. One immediate challenge is technical reliability and reproducibility. Biological components are inherently variable: no two batches of neurons are identical, and their activity can be influenced by slight differences in the culture environment. This means that ensuring a CL1 gives consistent results or behaves predictably over time is difficult. The neurons might spontaneously reorganize or develop in ways that aren't fully controllable, potentially leading to drift in performance (Cuthbertson, 2025). Cortical Labs has addressed some of this by creating a stable environment (temperature, nutrients, etc.) and limiting the lifespan of a given culture (they suggest replacing or resetting the neurons after ~6 months) (Cuthbertson, 2025). Even so, users of CL1 will need to treat these systems more like living lab specimens than like deterministic machines. They may require frequent calibration, oversight by neurobiologists, and redundancy (having multiple runs or units to ensure results are robust).

Another challenge is scalability and manufacturing. Growing high-quality neural cultures and integrating them with chips is as much a biotech process as a manufacturing one. If demand for SBI grows, there could be constraints on how many neuron cultures can be prepared (sourcing stem cells, lab facilities, etc.), and each unit needs careful handling to set up. This is unlike mass-producing identical silicon chips. Cortical Labs' commercialization of CL1 is itself a significant effort in scaling the manufacturing of such hybrid devices. As technology evolves, automating the cultivation of neurons and perhaps cryopreserving networks for distribution are tasks that engineers will need to solve to make SBI widely available.

The most profound questions surrounding CL1 and successors, however, are ethical. We must consider the moral status of using living human neurons as computational units. While these cells have no surrounding architecture to generate consciousness in the way a brain does, the research by Kagan et al. (2022) provocatively suggested that even in a dish, neurons can exhibit a rudimentary form of sentience – they respond to stimuli and seek to predict their environment in order to minimize surprise, which is a basic cognitive drive. This raises a question: could a sufficiently advanced CL1 (or future organoid computer) develop some level of awareness or the capacity to suffer? The Independent reported that Cortical Labs is aware of these concerns and claims to have instituted "guardrails… to address ethical concerns relating to consciousness and sentience," though details were not provided (Cuthbertson, 2025). These guardrails might include limiting the complexity of stimuli, ensuring the neural network's experiences remain simple (so as not to inadvertently create a sensation of pain or distress), or periodically resetting networks before they grow too complex. There is currently no consensus on when a network of neurons becomes a sentient mind – it is a spectrum and a topic of philosophical and scientific debate. Ethicists have begun discussing frameworks for "organoid ethics" or "neuromorphic ethics" to guide this field

(Worley & Hartung, 2023). It has been proposed, for example, that if neural computers start to exhibit learning akin to animals, they might need oversight like animal research protocols (Worley & Hartung, 2023). The Baltimore Declaration on OI in 2023 emphasized developing the technology in an ethically responsible manner, highlighting the need for interdisciplinary dialogue on these issues (Worley & Hartung, 2023).

Privacy and consent are another facet of ethics. The neurons used in CL1 are derived from human cells (often from induced pluripotent stem cells). Donors of such cells might raise questions about whether their cells could eventually be part of a "thinking" system and what that means for personal identity or rights. This is largely uncharted territory legally. Additionally, if SBI systems become widespread, there's the sci-fi sounding concern of misuse: could someone effectively create a network that is trained in a harmful way (for example, to feel constant negative stimulation) and is that equivalent to creating suffering? While far-fetched at this stage, these considerations mean there must be transparency and possibly regulation in how biological computing experiments are conducted.

On the positive side, one ethical advantage of SBI like CL1 is the reduction in use of live animals for research. If a CL1 can model certain brain responses, it might replace experiments on rodents for drug testing or neuroscience, aligning with the 3Rs (Replace, Reduce, Refine animal use) in research ethics (Candanosa, 2023). This is a strong ethical driver for some of the scientists in organoid intelligence – they see it as a way to get better data (from human cells) without harming animals (Worley & Hartung, 2023).

Finally, there is the public perception and "yuck factor" to navigate. The idea of a computer made of human brain cells can sound unsettling, as media reactions have shown (Prada, 2025). It forces us to rethink the boundary between technology and life. Clear communication will be important to help society understand the purpose and safeguards of SBI. As with any powerful technology, building public trust through responsible innovation is crucial. Cortical Labs' approach so far has been to engage openly (they published their Pong experiment in a peer-reviewed journal and discuss their work publicly), which is a good start.

In conclusion, the challenges ahead are both practical and philosophical. Researchers and engineers will need to improve the stability and scale of SBI systems like CL1, while ethicists, regulators, and society at large grapple with the implications of machines that blur the line between alive and machine. The CL1 has sparked these conversations in a tangible way, which is a necessary step as we progress into this new frontier.

Conclusion

Cortical Labs' CL1 system marks a pivotal moment in the convergence of biology and computing. By successfully integrating living human neurons with silicon chips and making this technology commercially accessible, CL1 demonstrates that biological computing is no longer confined to theory or laboratory experiments – it is here and now. This report has reviewed how CL1 operates and why it represents such a breakthrough. Grounded in decades of neuroscience research on how neural networks learn and build with a sophisticated closed-loop architecture (the biOS) that allows neurons to interact with virtual environments, the CL1 bridges the gap between organic brains and traditional computers. In doing so, it achieves capabilities like real-time learning and remarkable energy efficiency that challenge our conventional approaches to artificial intelligence.

The implications of CL1 and future SBI systems are far-reaching. In the short term, we can expect advancements in research methods, with CL1 enabling new experiments in neuroscience, drug discovery, and AI development. In the longer term, as the technology scales, it could transform industries – from creating more life-like AI for robotics to inspiring new computing architectures that fuse wetware and hardware. We may witness the advent of cloud services offering “neurons on demand,” and perhaps even the development of organoid-based computers pushing towards levels of complexity previously unimaginable in machines. Each of these steps will bring us closer to computing systems that learn, adapt, and perhaps even think in ways more similar to living brains than to today’s algorithms.

At the same time, CL1 urges caution and humility. It reminds us that intelligence in the natural world comes with qualities of sentience and autonomy that we are only beginning to understand. As we build machines with living components, we must carefully consider ethics and governance to ensure that we use this power responsibly. The excitement around the CL1 – its bold vision of “Actual Intelligence” beyond artificial – must be balanced with rigorous oversight and continued dialogue between scientists, ethicists, and the public.

In summary, the Cortical Labs CL1 is a milestone that showcases both the promise and the challenges of Synthetic Biological Intelligence. It is a first step towards computers that are not just analogous to brains but literally made of brain matter. This fusion of silicon and neurons opens a new chapter in computing history. The CL1’s debut invites us to think beyond silicon and envision a future where our most advanced “machines” are, in some part, alive. The journey of SBI is just beginning, and CL1 has set the stage for innovations to come – an exciting frontier where computing is reimagined through the lens of biology.

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