**Midterm: Explore the Brain-Computer Hybrid - Cortical Labs CL1**

**Option A: Research Report**

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**I. Introduction**

As the field of artificial intelligence (AI) advances, it continues to take inspiration from one of the most complex and efficient systems known to science: the human brain. Despite the sophistication of artificial neural networks (ANNs), these silicon-based architectures often fall short in capturing the adaptability, learning efficiency, and energy-conscious operation of biological brains. Enter Cortical Labs' CL1, a revolutionary development in Synthetic Biological Intelligence (SBI). CL1 combines living neurons with silicon interfaces to create a hybrid system capable of learning, adaptation, and self-organization. This research report aims to explore how CL1 functions, what neuroscience principles underpin it, its real-world applications, and the ethical and technical challenges associated with it. In doing so, I will relate CL1 to fundamental course concepts such as Hebbian learning, Spike-Timing-Dependent Plasticity (STDP), network dynamics, and predictive coding, which are the terms that I have learned about in my course “Neuroscience as a model for AI” so far.

**II. Background: What is CL1?**

Cortical Labs, an Australian startup, has developed the CL1, which is widely considered the world’s first commercial biological computer (Data Center Dynamics, 2024). At its core, CL1 uses approximately 800,000 living neurons cultured from human stem cells, interfaced with a microelectrode array (MEA) that allows for bi-directional communication between biological tissue and electronic systems. These neurons are embedded in a closed-loop environment where they can receive input (such as from a video game like Pong) and produce output based on their learned behavior.

This system marks a turning point in SBI: rather than simulating brains with code, CL1 leverages the biological properties of neurons to carry out computation. According to Cortical Labs (2024), CL1 learns through environmental feedback, adjusting synaptic connections over time to perform specific tasks. This unique capability makes it not just a tool for AI research, but also a bridge to a deeper understanding of brain-like computation.

**III. Analysis and Discussion**

**1. The Neuroscience Behind It**

CL1 relies on foundational principles of neuroscience to achieve learning and computation. At the cellular level, neurons encode information using action potentials or spikes. These spikes transmit electrical signals across synapses, whose strength changes over time through plasticity mechanisms.

One of the key concepts we've studied in this course is Hebbian learning, which can be summarized as "cells that fire together, wire together." This principle is foundational to how CL1 adapts its behavior. When two neurons are activated in close temporal proximity, their synaptic connection strengthens, facilitating future activation patterns. This is especially relevant in CL1, where environmental inputs (like the movement of a Pong paddle) cause neurons to respond in patterned ways (BiopharmaTrend, 2024).

Closely related is Spike-Timing-Dependent Plasticity (STDP), a more nuanced form of Hebbian learning that takes the timing of spikes into account. If a presynaptic neuron fires just before a postsynaptic neuron, the connection is strengthened. If the order is reversed, it weakens. This bidirectional tuning of synaptic weights is present in the CL1’s learning loop and allows it to refine behavior in response to rewards or feedback, much like the brain's reward system (New Atlas, 2024).

Another key concept is self-organization. Unlike pre-programmed AI systems, the CL1 displays spontaneous activity among neurons. These neurons fire in patterns that aren’t directly caused by inputs, forming emergent behavior through their network dynamics. Over time, as we learned in class, such self-organization can give rise to complex behaviors like decision-making or pattern recognition. This is similar to how biological brains evolve specialized circuits through development and experience.

Moreover, CL1 raises interesting connections to predictive coding, a framework I’ve learned about in other assignments. Predictive coding proposes that the brain is constantly trying to minimize prediction errors between expected and received stimuli. CL1, by learning through closed-loop environmental feedback, implicitly participates in similar error-minimizing behavior. When it plays Pong, it improves by reducing the gap between the expected paddle placement and the outcome, mirroring the core logic of predictive processing.

**2. How It's Built**

CL1 is a hybrid system that blends biological and computational technologies. The central element is the microelectrode array (MEA) that serves as the interface. Electrodes stimulate the neurons and also record their activity. This closed-loop setup allows for two-way communication, where a digital simulation (e.g., Pong) can affect neuronal firing, and neuronal outputs can affect the simulation's feedback.

As outlined in the official Cortical Labs whitepaper, the neurons are grown in a controlled culture, supported by a fluidic system that provides nutrients and maintains temperature. Unlike static ANNs, this biological network is dynamic and continuously rewires itself based on stimuli, offering far more adaptability.

In terms of computational parallels, CL1 aligns most closely with reinforcement learning. Like reinforcement learning agents, CL1 optimizes its behavior through trial-and-error, receiving feedback from its environment (Medium, 2024). However, unlike traditional AI models that need massive datasets and pre-programmed algorithms, the CL1 operates with unsupervised learning principles, where emergent intelligence arises from interaction rather than explicit instruction.

Furthermore, the architecture is modular and potentially scalable. Cortical Labs has hinted at the possibility of linking multiple CL1 units in parallel, which could emulate specialized processing regions like those seen in mammalian brains. This suggests potential for hierarchical SBI systems modeled after the brain’s compartmentalized structure; vision, memory, motor control, etc., each handled by distinct neuron groups.

**3. Applications for CL1**

CL1's potential spans several transformative domains:

1. Drug Discovery and Neurological Research:

Since CL1 uses human-derived neurons, it provides a platform to test the impact of pharmacological agents on actual human neural tissue. This is particularly valuable in early-stage drug development and toxicity screening, reducing the reliance on animal models and improving relevance (PCWorld, 2024).

1. Disease Modeling:

Neurological conditions like Alzheimer’s, Parkinson’s, or epilepsy could be modeled using the CL1 by integrating neurons derived from patients. Researchers could then observe the progression and treatment response of diseases in real-time, opening up avenues for personalized medicine (BiopharmaTrend, 2024).

1. Adaptive Robotics:

CL1 could serve as an adaptive controller for robots. Since it learns through feedback and can self-organize, a robot powered by CL1 could respond more fluidly to dynamic environments. This could revolutionize fields like autonomous driving, prosthetic limbs, or even space exploration, where unpredictable settings demand real-time learning.

1. Creative AI:

Due to its unpredictable and emergent behaviors, CL1 could be a tool in generative art, music, or design. Unlike deterministic models, the biological element introduces stochastic creativity that can complement traditional creative AI (New Atlas, 2024).

**4. The Future of AI**

The development of CL1 signals a possible paradigm shift in how we build intelligent systems. One speculative but grounded vision is the formation of hybrid AI systems: a computational architecture combining silicon-based AI with biological processors. Each system type has complementary strengths. Silicon is fast, precise, and scalable; biology is adaptive, efficient, and capable of real-time learning without extensive training.

Another future direction lies in scaling SBI. Imagine linking multiple CL1 units together, forming a modular neural network akin to different brain regions working in concert. This could enhance distributed learning, memory capacity, and multitasking, approaching the complexity of mammalian brains.

When learning about predictive coding, I learned how the brain constantly generates hypotheses about incoming data and updates its models based on prediction errors. The CL1, embedded in closed-loop environments, inherently engages in such feedback cycles, making it a living example of predictive coding in action.

Also notable is the energy efficiency of CL1. Traditional data centers consume megawatts of energy to train large AI models. The CL1, in contrast, operates on under 1,000 watts per rack (El País, 2024), providing a sustainable path forward as AI becomes more integrated into our infrastructure.

**5. Challenges and Ethics**

a. Technical Challenges:

The longevity of neural cultures remains a bottleneck. Maintaining viable, contamination-free neurons for extended experiments is a delicate and resource-intensive process. These neuron cultures require highly specialized environments; precisely controlled temperature, humidity, nutrient supply, and pH levels, to survive and function effectively. Even slight deviations in these conditions can lead to reduced neural activity, degradation, or cell death. Moreover, as neurons age, their responsiveness and plasticity diminish, which limits the duration of experiments and long-term applications. Another major challenge is achieving consistency across different batches of neurons. Unlike standardized silicon chips, biological neurons are inherently variable due to genetic, epigenetic, and environmental factors during cultivation. This makes reproducibility a significant hurdle, especially in applications requiring reliability and stability. Unlike silicon-based AI, where behavior is predictable and scalable, biological networks exhibit a level of randomness that complicates debugging and benchmarking. Addressing these challenges will require advances in tissue engineering, automated monitoring, and perhaps bio-compatible materials to enhance culture longevity and stability (PCWorld, 2024).

b. Scalability:

Current versions of CL1 are limited in size and processing power. As of now, the number of neurons in each CL1 unit is constrained by the physical space on the microelectrode array, the ability to sustain cell viability over time, and the complexity of maintaining robust communication between neurons and electronic systems. Increasing the number of neurons while ensuring they remain healthy, responsive, and well-integrated with the digital interface presents a daunting technical challenge. Furthermore, biological systems are inherently variable; no two neuron cultures behave identically. This biological variability makes it difficult to scale up while maintaining uniformity in performance across multiple CL1 units. To create larger, more powerful SBI systems, researchers must develop more advanced scaffolding technologies and improve electrode sensitivity to accommodate denser neuron populations. Additionally, synchronization between units, similar to how different regions of the brain work in concert, would require highly sophisticated interface protocols and possibly the use of AI-driven calibration tools. All of these hurdles must be overcome to make the CL1 not just a powerful research tool, but a scalable platform for commercial and industrial use.

c. Ethical Considerations:

The use of human-derived neurons brings up significant ethical concerns that warrant deeper reflection. Although CL1 is far from sentient and does not possess consciousness, the use of living human cells introduces moral complexity. As these systems grow more complex and potentially approach higher forms of learning or memory storage, it is not unreasonable to imagine a future where questions about awareness or autonomy arise. We must consider where to draw the line in terms of sentience and moral responsibility. For instance, could prolonged stimulation of neuron cultures lead to forms of experience or suffering, however rudimentary? These are questions without clear answers, but ones we must proactively prepare for. This is where preemptive ethical frameworks come into play. Transparency in the source of the cells, consent for their use, long-term oversight, and interdisciplinary input from ethicists, neuroscientists, and policy makers will be crucial. Moreover, as society becomes increasingly aware of these technologies, ethical codes must evolve in parallel to address not only what we can do with SBI like the CL1 but also what we should do. Establishing principled guardrails now will help ensure responsible and humane innovation later.

d. Public Perception:

There is a “yuck” factor to biological machines. The idea of AI systems powered by lab-grown human neurons challenges long-held societal boundaries between life and machine, raising discomfort and even fear in the public imagination. Many people are uneasy with the notion of blending biology and computation, particularly when human cells are involved. Concerns about playing God, creating sentient entities, or exploiting biological materials can spark moral panic or resistance. These reactions are compounded by a general lack of understanding about how such systems actually work and what ethical safeguards are in place. Therefore, public education and transparent research practices are critical. Scientists and developers must communicate clearly about CL1’s purpose, its limitations, and its potential benefits to humanity. Media portrayals, classroom outreach, public forums, and regulatory oversight all play important roles in fostering informed acceptance. If the public perceives these technologies as mysterious or threatening, it could slow progress through regulatory pressure or lack of funding. Conversely, with thoughtful engagement, CL1 could become a celebrated example of responsible innovation at the intersection of biology and AI.

**IV. Conclusion**

In conclusion, Cortical Labs CL1 is a compelling example of how neuroscience and artificial intelligence can converge to create something novel. By integrating real, living neurons into computational frameworks, CL1 demonstrates the power of biological systems in solving complex problems. It reflects the core concepts we’ve explored in this class: Hebbian learning, STDP, network dynamics, and predictive coding, in an applied, tangible system.

But beyond the technical fascination, as a student deeply passionate about AI and neuroscience, I find the CL1 inspiring on a personal level. Learning about CL1 brought what I had learned in my class assignments to life. It made abstract ideas, like synaptic plasticity and self-organization, feel real and urgent. This is no longer science fiction; it’s happening now, and it demands that we, as the next generation of AI researchers, approach our field not just with technical expertise but with humanity, responsibility, and curiosity.

Working on this research report has changed how I think about intelligence. I used to see it as something purely computational: algorithms and data structures. But now, I see it as something organic, dynamic, and even poetic. Intelligence isn’t just about output or optimization; it’s about adapting, feeling, and surviving. CL1 embodies this beautifully.

As I go forward, I hope to be part of building systems that don't just mimic brains but learn from them; ethically, thoughtfully, and boldly. Whether through hybrid architecture, biomedical applications, or new paradigms of learning, the fusion of neuroscience and AI is going to shape our future in profound ways. The CL1 is only the beginning, and I can’t wait to see and maybe help build what comes next.

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