Manufacturing *In-Vitro* Living Neural Computing Chips for Efficient AI Learning and Computation

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Blue Sky Idea: In this idea, I put forward the question on whether living synthetically engineered biological hardware and software can be combined to work together linking the best of what a biological brain and a silicon chip can offer. For decades, we have deployed AI based deep neural network algorithms *'in-silico'* – i.e. on silicon chips. But what if we could deploy engineered deep neural network algorithms 'in-vitro' or even more far-fetched deployed 'in-vivo'. Such a neo-cortex system will comprise at its core synthetic neural cells in engineered three-dimensional architectures packed together with biomaterials that provide the engineered living 'brain' with both cognitive and computational capability in unparalleled power efficiencies.

Just as microfabrication and nanofabrication processes have transformed computing, tools available from synthetic biology, bioprinting, biomaterials and computational tools can help realize computing within living matter. The push towards alternate forms of computing beyond silicon is not new - Neuromorphic computing has paved the way to utilize materials that can compute but this field still rely on non-living materials. This blue sky idea is to design, fabricate, produce, test and apply living neural computing cores that mimic the human brain but with the advantages of current silicon based computing. Such multiplexed capability would enable better data efficiency, lower energy consumption and task adaptability that would surpass current software driven AI algorithms. This is mainly because neural cells and the tissue that arise from them if organized and trained to perform specific sets of tasks, would be far more efficient than silicon based chips.

To create viable cognitive manufacturing machines with neural computing chips, solutions would require convergent thinking from fields as diverse as synthetic biology, cellular engineering, gene-editing, systems biology, machine learning, biomaterials and three-dimensional biomanufacturing processes to help realize such neural computing chips. Applications of such neural computing chips can include manufacturing machines and robots that are trained to be made 'self-aware', machines that quickly adapt to changing environments, robots that determine almost instantaneously on how to grasp 3D objects, machines that are able to recollect past process parameters when faced with heavily customized order requests etc.

Scientific Challenges: The core innovation that must happen among others is to engineer synapses between neurons organized in three-dimensions similar to the neocortex in the brain which would then have the ability to perform logic, memory, long term storage and learning tasks. But to encourage synapse formation, we must gene-edit cells with customized DNA to form super-human like neural tissue, encourage organization of neural cells through fabricated three-dimensional micro-environments, and train neural cells to form connections with other neurons to ultimately form a self-organized neo-cortex like 3D architecture. We may already have the some basic science foundations in synthetic biology and cellular engineering to design such neural architectures. We currently lack the manufacturing process science to build such 3D neural chips. Once formed, a challenge would be to train this hybrid 3D computing platform to receive specific inputs and generate outputs necessary to perform cognitive tasks for the application domain it is placed under. Natural research questions to ask are - How would such living-structures continue to train while in a manufacturing operation, how would more neurons connect and disconnect with other neurons to codify experiences and create new learning modalities necessary to perform in the future.

Manufacturing Research Vision: To design, build and mass produce a functional and commercially viable living neurocomputer, we must study: 1) Cellular biomanufacturing that can generate massive quantities of genetically edited cells with desired DNA characteristics made available at production scale through biofoundries; 2) These living raw materials must be combined with engineered materials to create neural 3D microchips, with high levels of automation catered to producing living products economically and reliably; 3) Once integrated with manufacturing machines, there is the opportunity to device entirely new algorithms that can take advantage of the neural compute architecture within living matter for real-time manufacturing applications.