Quantum Materials for Energy Efficient Neuromorphic Computing (Q-MEEN-C)
EFRC Director: Ivan K. Schuller
Lead Institution: UCSD
Class: 2018 – 2026

Mission Statement*: To lay down the quantum-materials-based foundation for the development of an energy-efficient, fault-tolerant computer that is inspired and works like a brain ("neuromorphic").*

The digital and computational revolution of the last seven decades has propelled arguably one of the most important technological advances in history. The key breakthrough was the realization that a material such as Silicon features electronic properties that can be incorporated into a transistor, the basic building block of a von-Neumann computer. The current vertiginous development of storage density, computational power and cost is approaching the end due to unsustainable local high energy demand. The key future requirement of a reliable computation architecture, aside from being fault-tolerant, is to be energy efficient. The brain performs complicated computational tasks with high energy efficiency. The human brain serves as an inspiration to emulate this behavior using materials that can mimic dendrites, synapses, neurons, axons, and the network they comprise.

The original Q-MEEN-C approach included two materials-focused Thrusts: Charge and Spin. Since, in quantum materials, the two phenomena are strongly linked and can influence each other, we have reconfigured the project into 3 closely integrated materials-focused Thrusts **(Fig. 1)**. The principal nanoscale Quantum Materials (Thrust 1) will test and feedback the Neuromorphic Functionalities (Thrust 2) occurring at the mesoscale and use and modify the Emergent Phenomena (Thrust 3) which arise in macroscopic systems because of their coupling.

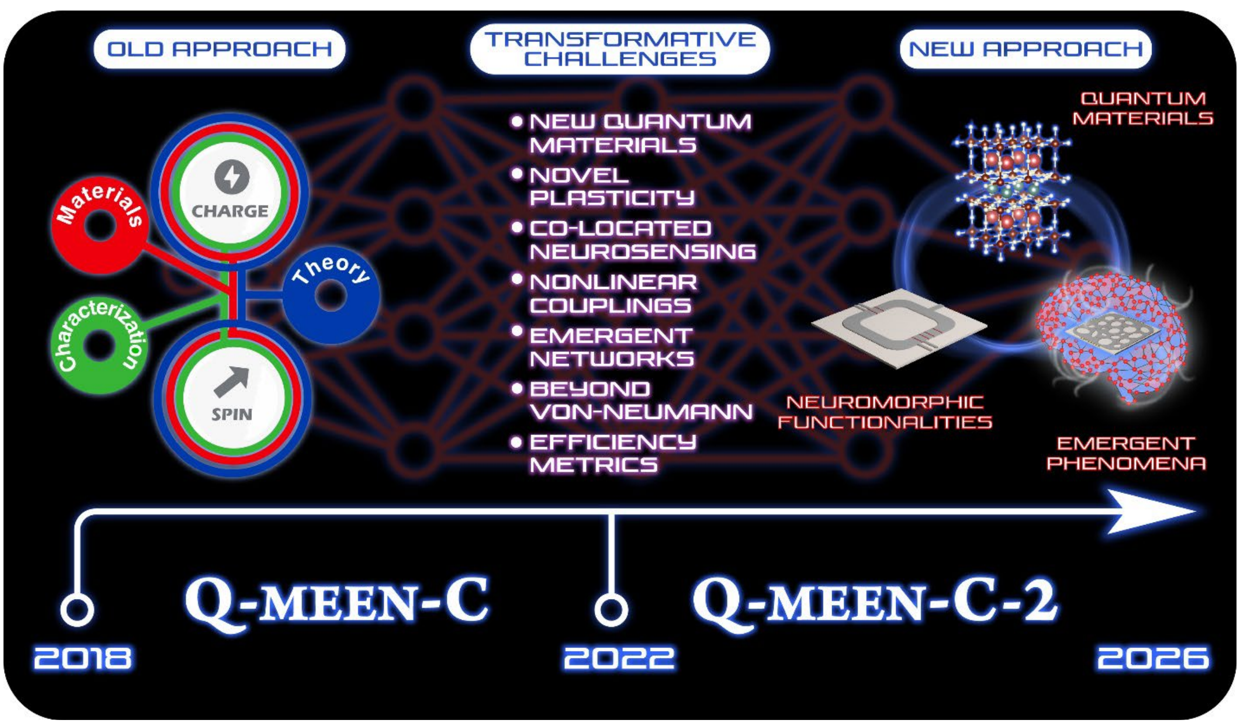

Figure 1: *Based on the accomplishments in the first 4 years with Spin and Charge thrusts, we identify 7 transformative challenges which lead to our newly structured, three-pronged approach.*

During the next 4 years Q-MEEN-C will synthesize promising new materials candidates, understand their microscopic and mesoscopic behavior due to naturally occurring and/or artificially imposed inhomogeneities, develop novel contactless connectivity using collective or frequency selective mesoscopic coupling, and develop new performance benchmarks for important materials properties. While the project is "materials-centric", its influence goes beyond the development and understanding of materials at the nanoscale to the meso- and macroscale properties.

This project is dedicated to fundamental research on materials that will mimic key properties of the brain, to develop a brain-inspired, "neuromorphic" computational paradigm. We will study aspects of materials at hierarchical length scales, from the microscopic to the macroscopic, in the same way that the brain itself is understood as an emergent phenomenon **(Fig. 2).** Central to our research is the realization that "quantum materials", which feature richer and more complex properties than conventional semiconductors, can offer emergent properties parallel to those of the brain.

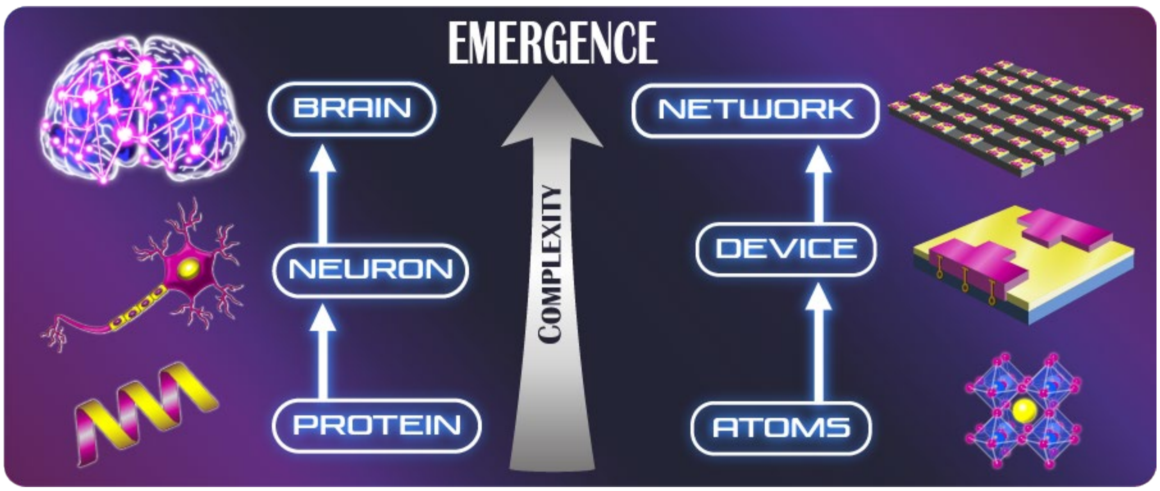

Figure 2: *We mimic the emergent complexity that makes the brain an efficient computer by harnessing the properties of quantum materials, approaching the problem at various length scales.*

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UC San Diego	Ivan K. Schuller (Director), Oleg Shpyrko, Alex Frañó, Robert Dynes, Eric Fullerton, Marcelo Rozenberg, Duygu Kuzum
UC Davis	Yayoi Takamura
UC Santa Barbara	Jonathan Schuller
NY University	Andrew Kent
Rutgers University	Shriram Ramanathan
University of Chicago	Giulia Galli
University of Illinois, Urbana-Champaign	Axel Hoffmann
CNRS, France	Julie Grollier
University of Tennessee, Knoxville	Katie Schumann
Brookhaven National Lab	Yimei Zhu

Contact: Ivan K. Schuller, Director, ischuller@ucsd.edu
858-534-2540, https://qmeenc.ucsd.edu/