Local neuromorphic computing with emerging nanodevices for real-time high-resolution therapy of cardiac fibrillation

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Current cardiac implants rely on low-resolution sensing, necessitating high-energy therapies for ventricular fibrillation. However, this approach is traumatic for patients. High-resolution cardiac mapping could enable precise detection of life-threatening abnormalities and low-energy therapy, but real-time data processing requires advanced algorithms. New types of hardware, based on memristor nanodevices, could implement such algorithms efficiently and compactly. This study proposes a closed-loop memristor-based cellular neural network system for detecting abnormal wavefronts and enabling localized, low-energy therapies for ventricular fibrillation. A memristor-mappable cellular neural network was developed to detect wavefronts and wavebreaks in cardiac signals (Fig. 1). We tested it using arrhythmia data captured in-vitro from human hearts rejected for transplantation. This approach achieved >96% accuracy, 92% precision, 99% specificity, and 93% sensitivity in wavefront detection[1]. An analog chiplet implementation using memristors as templates is also proposed for experimental demonstration[2]. The algorithm was integrated with OpenCARP, a cardiac simulation platform. The simulations employed cardiac tissue models and termination pulses of varying strengths, durations, and locations based on detected waveforms to refine intervention strategies for rotor termination and energy-efficient therapy. Plus, it enabled optimized electrode placement guided by detected wavefronts and thus supported local low-energy stimulation to restore normal cardiac rhythm. Simulations demonstrated successful wavefront detection and effective arrhythmia interventions, including rotor splitting and collision. These findings highlight the potential for spatially distributed systems based on emerging nanodevices for closed-loop sensing, computing, and low-energy therapy with precise timing and localization.

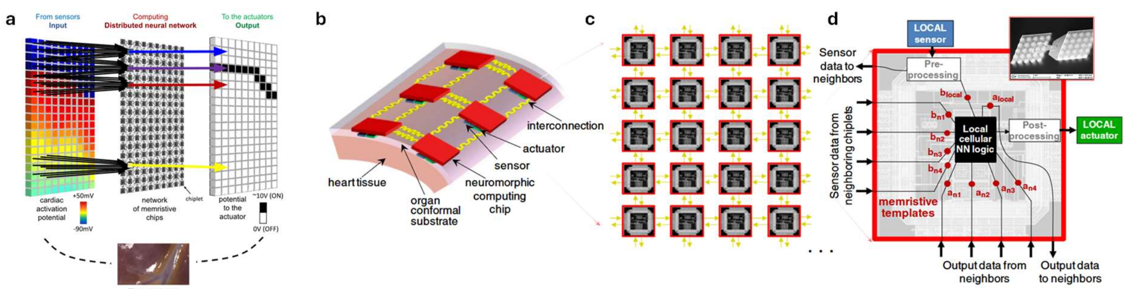

Figure 1 Proposed distributed computing for abnormal cardiac wavefront determination: (a) closed-loop sensing-computing-actuation suitable for an (b) organ-conformal platform with a (c) distributed network of neuromorphic computing chips with interconnections that enable the inputs and outputs signals to be shared between neighbours; d) schematic of the functionality of a neuromorphic chip that has a core local cellular neural network-state circuit which determines the output to the actuator based on a set of programmable templates implemented using memristor nanodevices (representative device shown in inset), the inputs from the local and neighbouring sensors and the outputs of the local and neighbouring chip.

References:

[1] Yang, Z., Zhang, L., Aras, K., Efimov, I. R., Adam, G. C. *Advanced Intelligent Systems* **2022**, 4(8), 2200032.
[2] Adam, G. C., & Efimov, I. R., **2023**. *U.S. Patent No. 11,701,002*. U.S. Patent and Trademark Office.