Brain-Implantable Computing Platforms for Emerging Neuroscience Applications

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Motivation. The quality of life in modern society undeniably has been improved by the pervasive embedding of microelectronics into a vast array of everyday objects. The exponential scaling of semiconductor technologies has now opened the door to embedding microelectronics into biological systems, including the human body, which could revolutionize the practice of medicine and significantly augment human capabilities. While implanted electronic devices, such as pacemakers, insulin pumps, and cochlear implants, have been in use for many years, implantable microelectronic systems are now being used in increasingly sophisticated applications that interface with the brain.

Unfortunately, the microelectronics used even in leading-edge brain-implantable research efforts lag the state-of-the-art in computing and microelectronics by several generations, severely limiting their capabilities and acceptable deployment sites. The vast majority of bio-implanted devices, particularly brain-implanted devices, are merely conduits for data from the brain to external computation resources with little to no computation occurring in the implant. These limitations, rooted in the employed computing technologies, pose a significant barrier to profound breakthroughs in neuroscience.

BICP. An ambitious group of researchers from Carnegie Mellon University[1] and the University of Pittsburgh[2] recently have teamed up to pursue a first-of-its-kind multi-use **brain-implantable computing platform (BICP)**. Our BICP will be the first brain-implantable device to demonstrate significant computational resources within the implant itself, eschewing power-hungry wireless communication whenever possible. This dramatic increase in the computational capability of the implant will be a disruptive technology shift for neuroscience researchers.

The envisioned BICP is an implantable distributed computing system, consisting of millimeter-scale computational elements that wirelessly draw mWatt-range power and communicate wirelessly between both implanted elements and the outside environment. Figure 1 (top) offers a conceptualization of a BICP implanted below the skull, receiving power and communication via inductive coupling; Figure 1 (bottom) shows a block diagram of the platform, highlighting the major subsystems: power, communications, computation, and sensor/actuator interface. While a BICP appears at first blush to have a high-level organization common with many mobile embedded computing systems, its uniquely stringent requirements in power/energy, form-factor, and biocompatibility preclude direct application of existing low-power computing and microelectronics techniques.

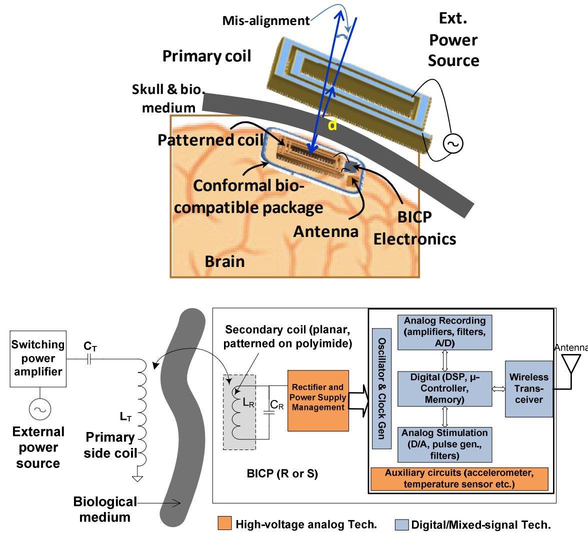

Figure 1: (top) Externally powered BICP Node and (bottom) BICP Node Architecture

In order to achieve the efficiency, performance, and form-factor needed for BICP, a highly interdisciplinary team is required to rethink completely the entire computer systems design stack, from application algorithms to implementation substrate. Some important objectives for this multi-use brain-implantable computing platform are

- Support for a wide range of neuroscience applications via a customizable platform architecture
- Highly energy efficient operation to fit within the severely constrained power envelope
- Sustainable wire-free delivery of mWatt-level power
- Minimal thermal effect on surrounding tissues
- Efficient wireless communication to external devices and to a distributed system of BICPs
- Cubic millimeter form-factor with biocompatible packaging for fully-enclosed implantation
- Secure and reliable operation over many years

Why is BICP interesting? Our growing understanding of human brain function has enabled neuroscientists to conceive of brain-implantable computational systems that could one day repair damaged portions of the brain or even enhance neural capabilities beyond our natural functions. In the neuroscience community, research and development of such applications are already well underway (e.g., deep-brain stimulation, brain-computer interface, and neuroprosthesis.) Research and development of such systems not only hold intrinsic scientific value, but more importantly offer tremendous societal and economic benefit. BICP poses some very formidable computing challenges, and the ASPLOS community is well positioned to contribute to this new computing discipline and to the advancement of neuroscience.

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[1] G. Fedder, J.C. Hoe, X. Li, K. Mai, J. Paramesh, and Y. Rabin
[2] A. Cheng, T. Cui, A. Schwartz, R. Sclabassi, M. Sun, D. Weber, and D. Whiting