Analog VLSI and Biological Systems Group

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Introduction
The aim of biologically inspired electronics is to emulate biology in building ultra low power, real-time, compact systems from an analog circuit engineer's or physicist's point of view. Such systems are useful as smart sensors. They are also useful in biomedical applications where the low power and biomimetic capabilities are particularly advantageous. Biologically inspired systems yield insights into how biology works via engineering synthesis that would be very hard to attain via scientific analysis. Work in the group focuses on three projects, the low-power bionic ear project, the time-based hybrid computing project, and the analog VLSI vision systems project.

Low-Power Bionic Ear

Sponsors
David and Lucille Packard Foundation Fellowship, under contract number 2001-19533

Project Staff
Michael Baker, Timothy Lu, Christopher Salthouse, Ji-Jon Sit, Lorenzo Turicchia, Serhii Zhak, Professor Sarpeshkar

The aim of this project involves designing an ultra low power analog cochlear-implant processor that can improve the performance of digital processors by more than an order of magnitude, even allowing for the Moore's law scaling of digital technology. The project also explores the use of an analog silicon cochlea, which maps the biophysics of the inner ear to a chip, as the basis for a cochlear-implant processor. The silicon cochlea has the potential to revolutionize patient's speech recognition in noise, a key limiting factor today, while performing 100's of MFLOPS of computation with a mW of power. It is straightforward to extend the circuits of this project to create low-power speech recognition front ends.

Time-Based Hybrid Computing

Sponsors
Office of Naval Research, under contract number N00014-00-1-0244; David and Lucille Packard Foundation Fellowship, under contract number 2001-19533; Office of Naval Research, under contract number N00014-02-1-0434

Project Staff
Micah O'Halloran, Alex Mevay, Heemin Yang, Professor Sarpeshkar

This project attempts to combine the best of analog and digital computation to compute more efficiently than would be possible in either paradigm of computation: The analog advantages of low power and good technology exploitation are combined with digital advantages of divide-andconquer processing, signal restoration, and programmability. The project uses time as a signal variable rather than voltage or current to compute in a fashion that is not purely analog or digital. It takes inspiration from the duality of analog pulse-time and digital pulse-count signal representations of the brain's neurons. It is being applied to create ultra-low-power time-based analog-to-digital converters, analog memories, novel control architectures, and programmable sensory data processors.

Analog VLSI Vision Systems

Sponsors
Defense Advanced Research Projects Agency, through Office of Naval Research grant number N00014-99-1-0438, to California Institute of Technology, UNDER SUBCONTRACT NUMBER 1007021; Office of Naval Research, under contract number N00014-02-1-0434

Project Staff
Maziar Tavakoli-Dastjerdi, Micah O'Halloran, Professor Sarpeshkar

This project maps the distributed-feedback loops of biological photoreceptors to create low power high-performance photoreceptors. These photoreceptors are used in analog VLSI visual motion sensors. Such motion sensors are inspired by correlation circuits in houseflies and are important in robotic, security camera, and tracking applications.

Publications

Journal Articles Published:

Crone, B.K., A. Dodabalapur, R. Sarpeshkar, A. Gelperin, H.E. Katz, and Z. Bao, "Organic Oscillator and Adaptive Amplifier Circuits for Chemical Vapor Sensing", Journal of Applied Physics, June 2002.

M. O'Halloran and R. Sarpeshkar, "Scalable Hybrid Computation with Spikes", Neural Computation, Vol. 14, No. 9, September 2002.

C. Salthouse and R. Sarpeshkar, "A Practical Micropower Programmable Bandpass Filter for Use in Bionic Ears", IEEE Journal of Solid State Circuits, Vol. 38, No. 1, pp. 63-70, 2003.

M. Tavakoli and R. Sarpeshkar, "An Offset-Cancelling Low-Noise Lock-in Architecture for Capacitive Sensing", in press, IEEE Journal of Solid State Circuits, expected publication date 2/1/2003.

Submitted for Publication:

L. Turicchia and R. Sarpeshkar, "A Bio-Inspired Companding Strategy for Spectral Enhancement", submitted to IEEE Transactions on Speech and Audio Processing.

M. Baker, M. O'Halloran, and R. Sarpeshkar, "Low-Power High PSRR Current-Mode Microphone Preamplifier", submitted to IEEE Journal of Solid-State Circuits.

A. MeVay and R. Sarpeshkar, "Predictive Comparators with Adaptive Control", submitted to IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing.

M. Baker, S. Zhak, and R. Sarpeshkar, "A Low Power Wide Dynamic Range Envelope Detector", submitted to IEEE Journal of Solid State Circuits.

Books/Chapters in Books

R. Sarpeshkar, "The Silicon Cochlea", in *Sensors and Sensing in Biology and Engineering*, F. G. Barth, editor, in press.

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Accepted Conference Papers

L. Turicchia and R. Sarpeshkar, "The Silicon Cochlea: From Biology to Bionics", Proceedings of The Biophysics of the Cochlea: Molecules to Models Conference, Titisee, Black Forest, Germany, 27 July to 1 August 2002.

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M. O'Halloran and R. Sarpeshkar, "A Low Open-Loop Gain High-PSRR Micropower CMOS Amplifier for Mixed-Signal Applications", Proceedings of the IEEE International Symposium on Circuits and Systems, Vol. 2, pp. 424-427, Scottsdale, Arizona, May 2002.

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T. Lu, M. Baker, C. Salthouse, J. J Sit, S. Zhak, and R.Sarpeshkar, "A Micropower Analog VLSI Processing Channel for Bionic Ears and Speech Recognition Front Ends", accepted paper, IEEE Symposium on Circuits and Systems, Bangkok, Thailand, 2003.

R. Sarpeshkar and M. Baker, "A Micropower Envelope Detector for Audio Applications", accepted paper, IEEE Symposium on Circuits and Systems, Bangkok, Thailand, 2003.

Theses

Good, Daniel, *Design of a Low Power Capacitive Sensor for a Micromachined Accelerometer*, Master of Engineering thesis, Department of Electrical Engineering and Computer Science, MIT, 2002.

O'Halloran, Micah, *A Clock Based Analog Memory Element for Integrated Circuits*, Master of Science thesis, Department of Electrical Engineering and Computer Science, MIT, 2002.

Sit, Ji-Jon, *A Low Power Analog Logarithmic Map Circuit with Offset and Temperature Compensation for use in Bionic Ears*, Master of Science thesis, Department of Electrical Engineering and Computer Science, MIT, 2002.

Mevay, Alex C. H., *Predictive Comparators with Adaptive Control*, Master of Engineering thesis, Department of Electrical Engineering and Computer Science, MIT, 2002.