Bi-Fi: Just Like Your Doctor!

Shahin Farshchi
President
Vista Integrated Systems
www.visys.biz

Kiran Patel
Technology Evangelist
Sun Microsystems, Inc.
www.sun.com

Aleksey Pesterev
Research Assistant
UCLA EE: Microsystems Lab
UCLA BME: Neuroengineering Lab
www.judylab.org

TS-3683

This Session's Takeaway:

Learn how to leverage state-of-the-art, smart embedded system technologies for monitoring biological activity

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

Summary and References

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

Summary and References

Big Picture

Revolutionize health care as the way we know it!

- “Mobile and wireless devices will become prevalent in the clinical setting”
  - Gartner Dataquest
- Every bed in a hospital will be a “monitored bed”
  - Facilitates the inexpensive deployment of clinics in deprived or remote locations

Why Do Wireless Patient Monitoring?

The world ain't gettin' any younger

- Baby boomers are aging
  - There is a need for more personalized care
  - Preserve independence
- Pre-emptive method for fighting disease
- Facilitates superior care for patients with chronic disease
- Fuelled by the commoditization of bandwidth

Challenges

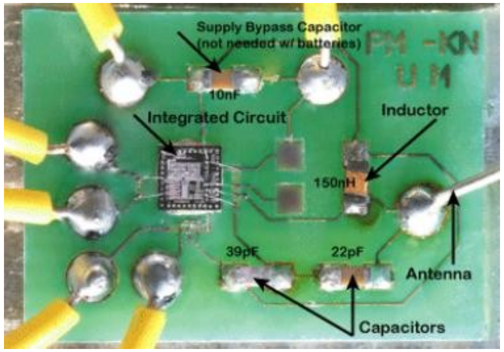
- Creating a low-cost, scalable technology
  - Upgradeable without costly system overhaul
  - Enable the system to advance with new technology
  - Avoid re-inventing the wheel (radio, processor, ADC, etc.)
- Versatile platform
  - Capable of acquiring various biological signals

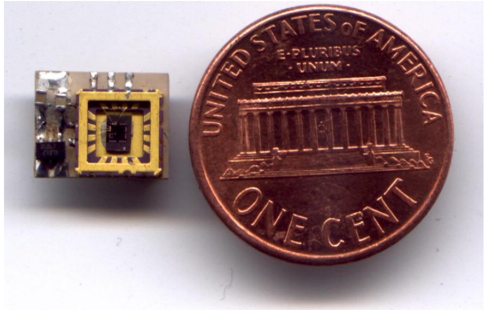
Challenges (Cont.)

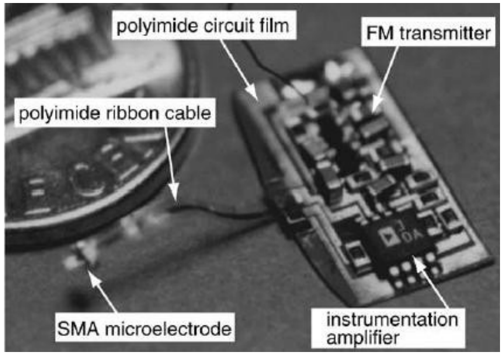
- Low-power
  - Day-long experiments
- Small size
  - Minimize potential discomfort
- Remotely programmable
  - Allowing the user to wirelessly switch sensing parameters

Existing Approaches

- Custom fabricate front-end amplifiers and transmitters
  - Extremely low power (several mW)
  - Short range
  - Normally not capable of bi-directional communication
  - Long development and turn-around times







Existing Approaches

- Commercial off-the-shelf PC-based systems
  - Large and power-hungry (at least 10s of watts)
  - Long range
  - Capable of bi-directional communication

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

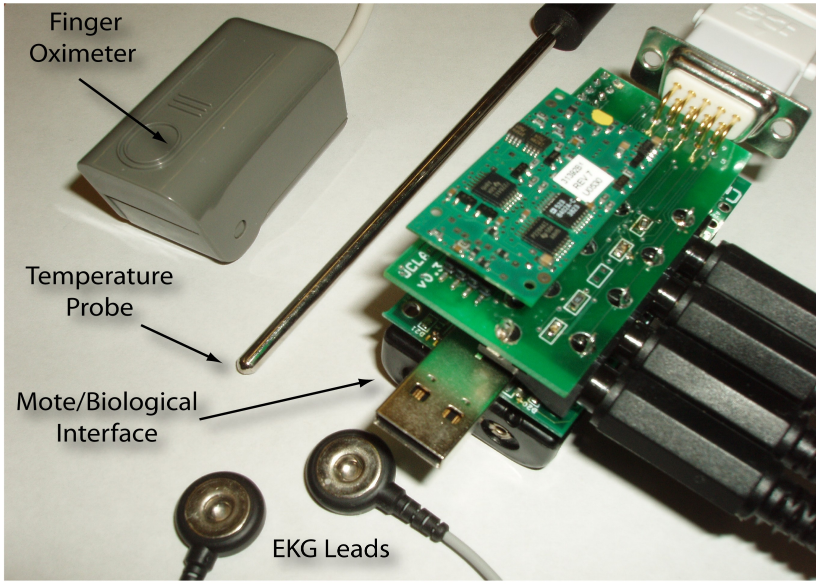
How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

Summary and References

What Is Bi-Fi?

- Bi-Fi is an embedded system architecture for:
  - Patient monitoring in hospitals
  - Out-patient care
  - Laboratory research
- Conceived at UCLA
- Leverages “Smart Dust” technologies

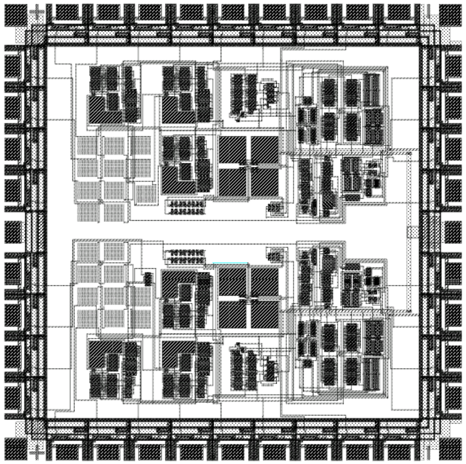


What Does Bi-Fi Do?

- Obtain high-rate biological data
  - Neural signals
  - Pulse oximetry
  - Electrocardiographs
- Interpret, filter, and transmit biosignals
  - Neural spike activity
  - Early warning
- Provides remote configuration
  - Real-time transmission
  - Event detection and characterization

Bi-Fi: Hardware-Level

- Circuits for interfacing biological systems with embedded sensors
- Signals of Interest
  - EKG, blood oxygen saturation, respiratory rate, neural spikes, and local field potentials



Bi-Fi: Embedded–System-Level

- Wireless-enabled processor modules (otherwise known as "motes") that collect, process, and communicate biological information
  - Require software framework for enabling flexible high-rate biological signal acquisition

Bi-Fi: Support Infrastructure

- A back-end network architecture for aggregating sensor readings and hosting them to client devices
  - Database server for archiving data
  - Client devices for browsing acquired data
    - PC-class devices
    - Personal data assistants
    - Mobile phones

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

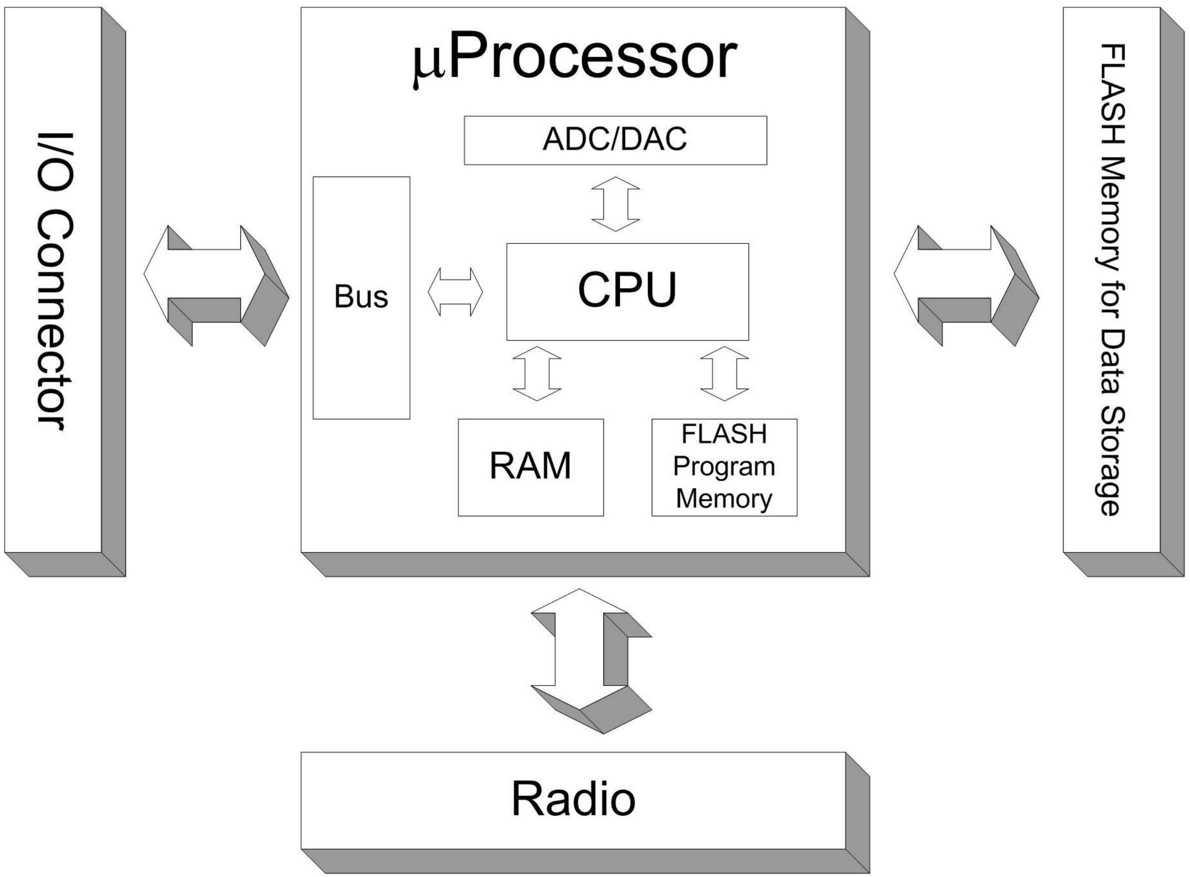
Summary and References

What Is a Mote?

Wireless-enabled processor module

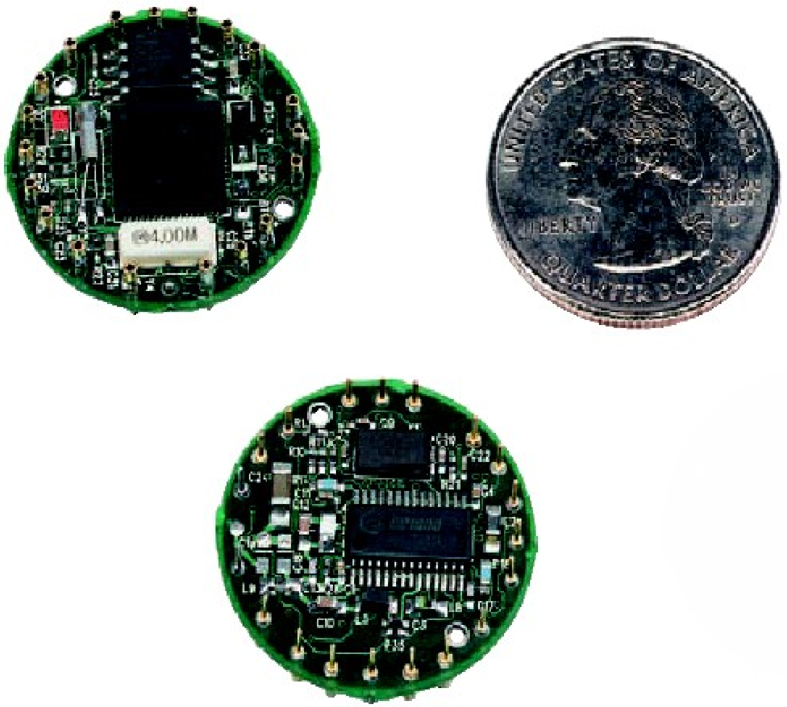
- A tiny computer with communications and storage capabilities
- Hardware-constrained
  - Requires a small-footprint operating system
- Bandwidth-constrained
  - Necessitates efficient signal processing methods
- Power-constrained
  - Requires power management algorithms

Mote Architecture



Atmel ATmega 128L-Based MICA

- TinyOS-based
- MICA2
  (900-MHz band)
- MICA2DOT
  (900-MHz band)
- MICAz
  (2.4-GHz ZigBee)



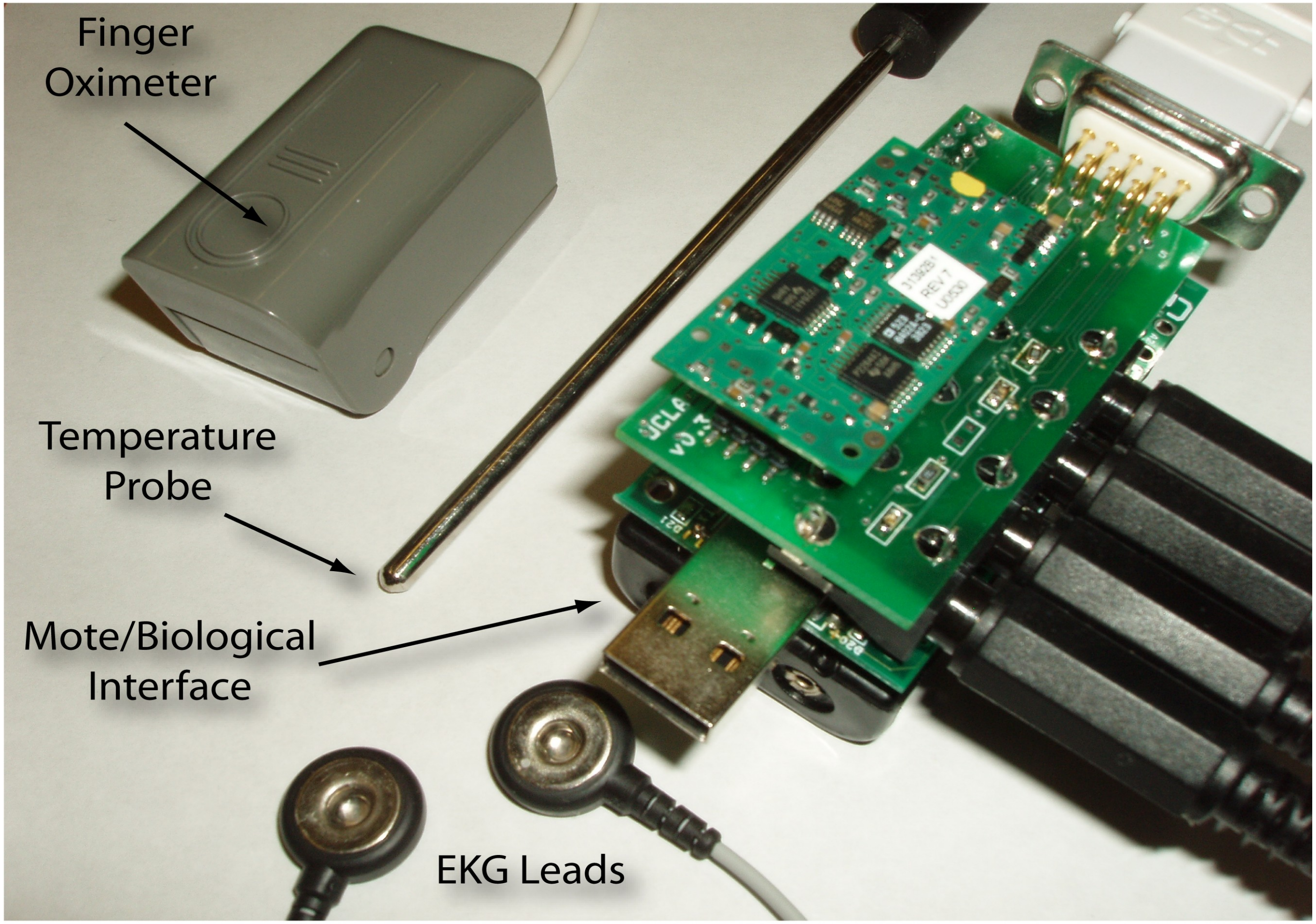
Limitations of MICA

- No DMA (for jitter-free data acquisition)
- Limited processing capability
- Limited memory (4 KB)

Texas Instruments MSP430-Based Telos

- TinyOS-based
- On-board DAC
- 2.4-GHz ZigBee
- Features DMA

Bi-Fi Mote



Finger
Oximeter
Temperature
Probe
Mote/Biological
Interface
EKG Leads

Bi-Fi Mote Requirements

- Flexible high-speed data collection
  - High-speed: 500 Hz to 5 KHz
  - Typical gather and transmit speeds (wireless)
    - MICA2: 1 KHz
    - MICAz: 5 KHz
    - TelosB: 4 KHz
- Processing power for filtering, compression
  - FFT, convolution, ADPCM, multiplication/SQRT
- Reliable wireless data transmission
  - ACK

Presentation Outline

Motivation

What Is Bi-Fi?

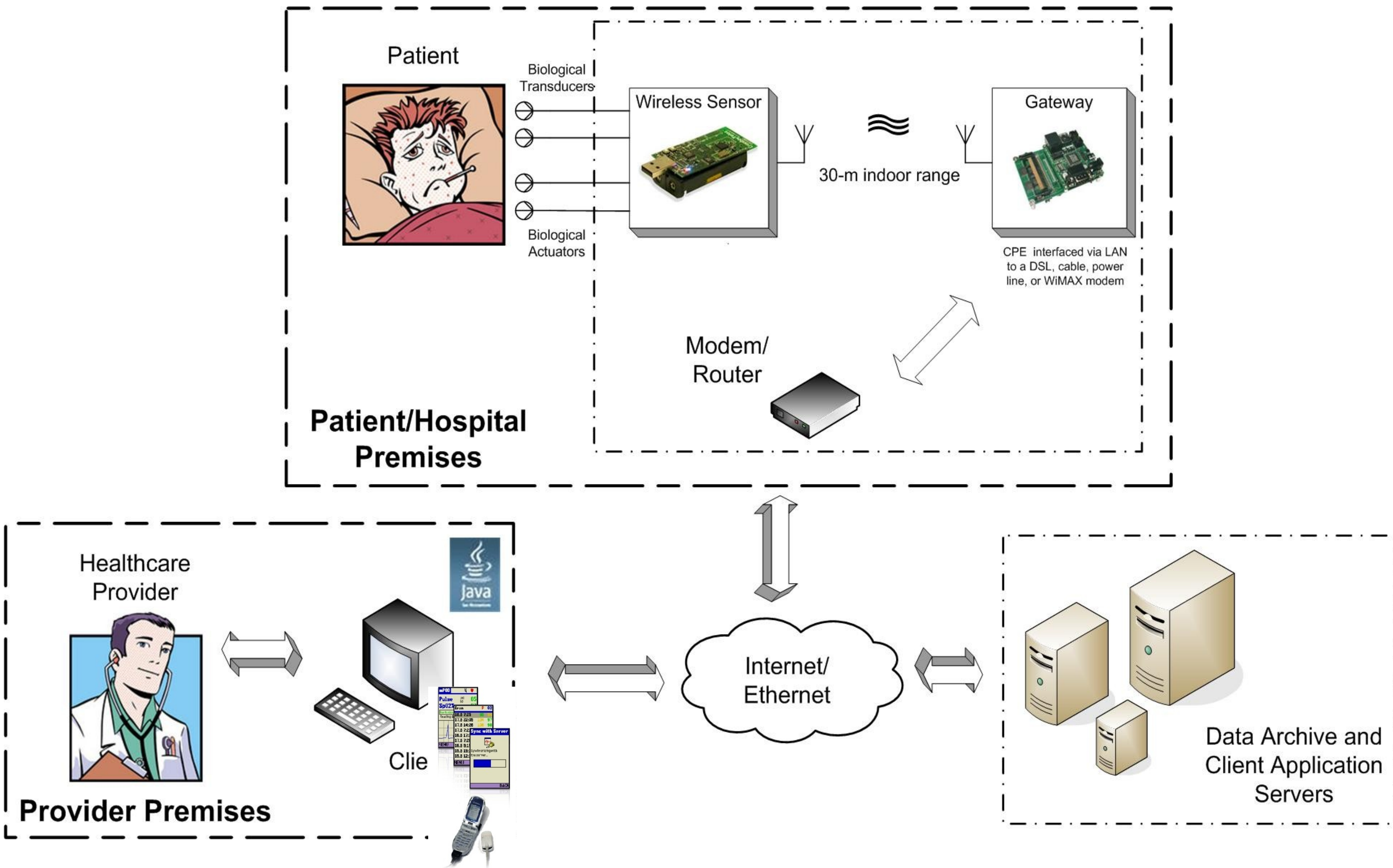
What Is a Bi-Fi Mote?

How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

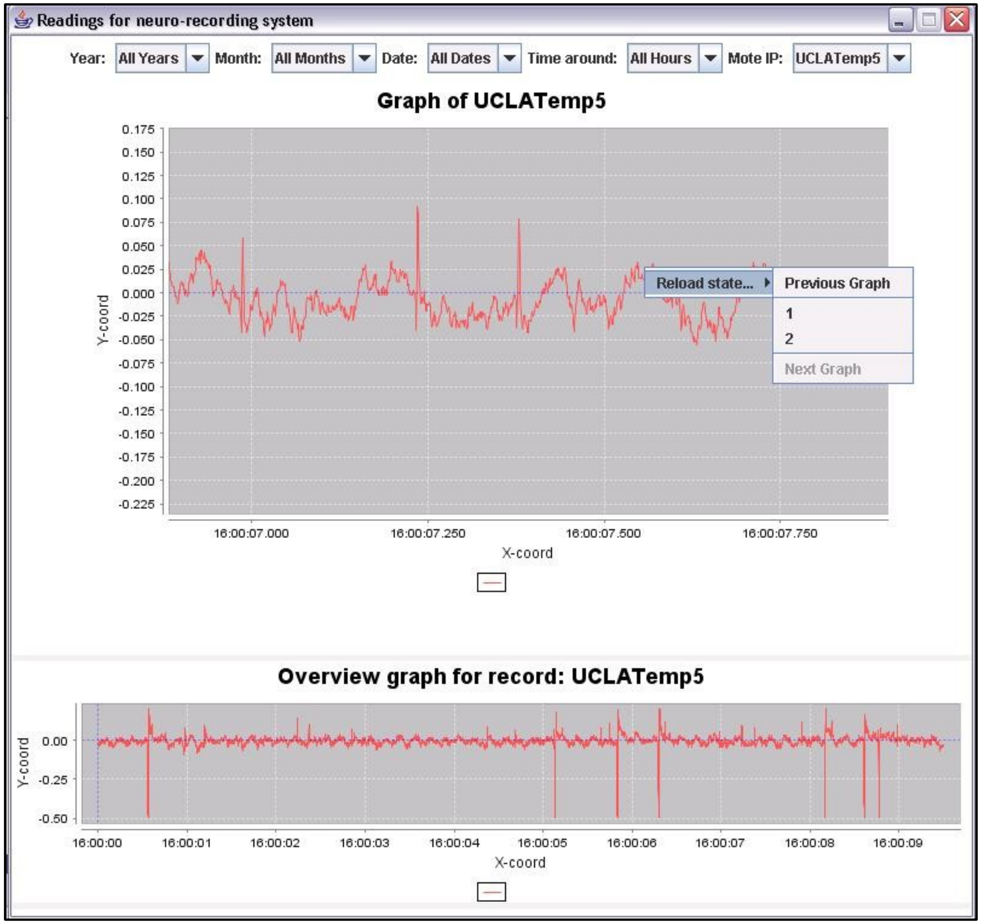
Summary and References

Bi-Fi System Architecture



Bi-Fi Java™ Technology-Based Desktop Client

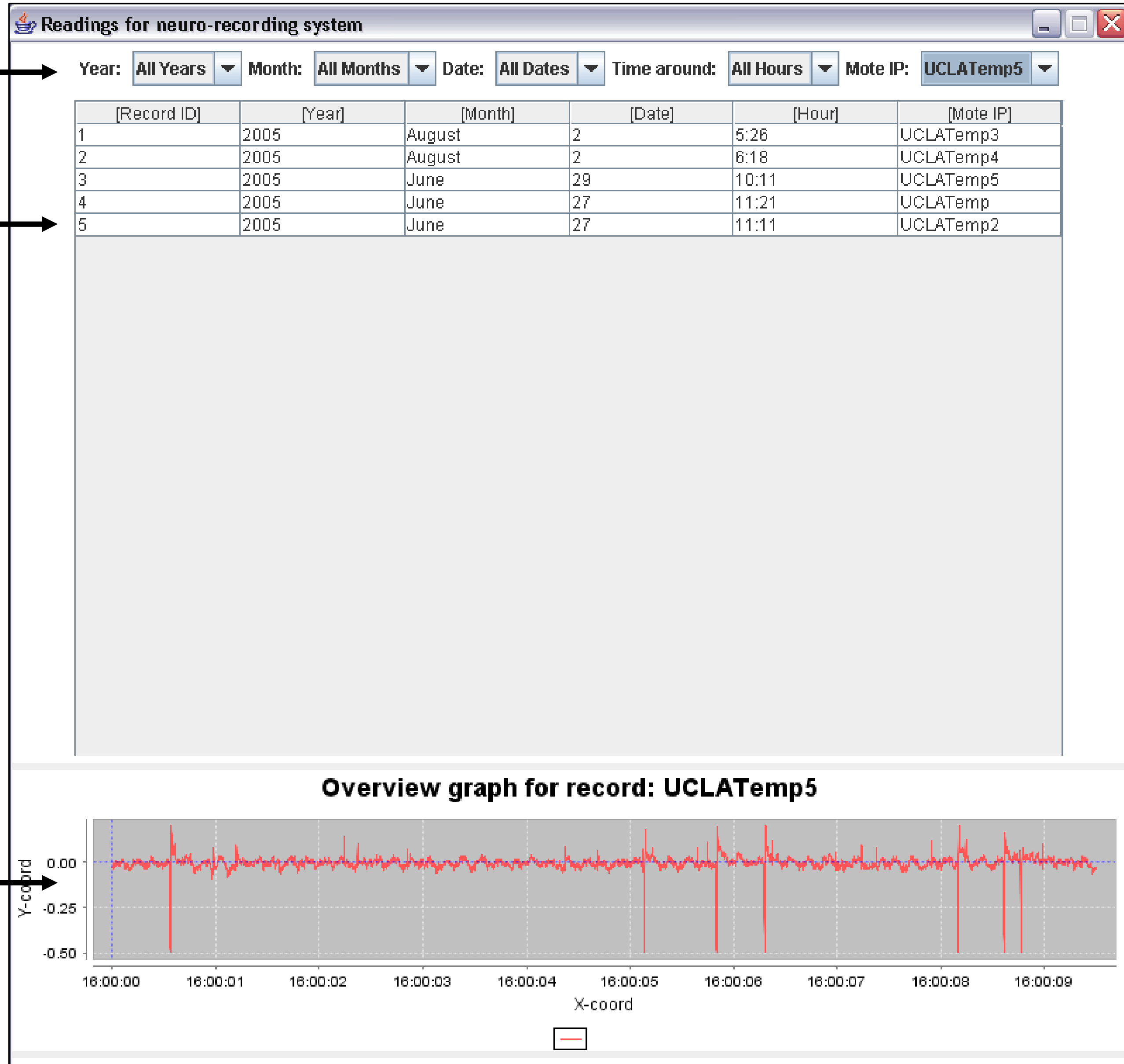
- Browses archived recordings
- JFreeChart-based

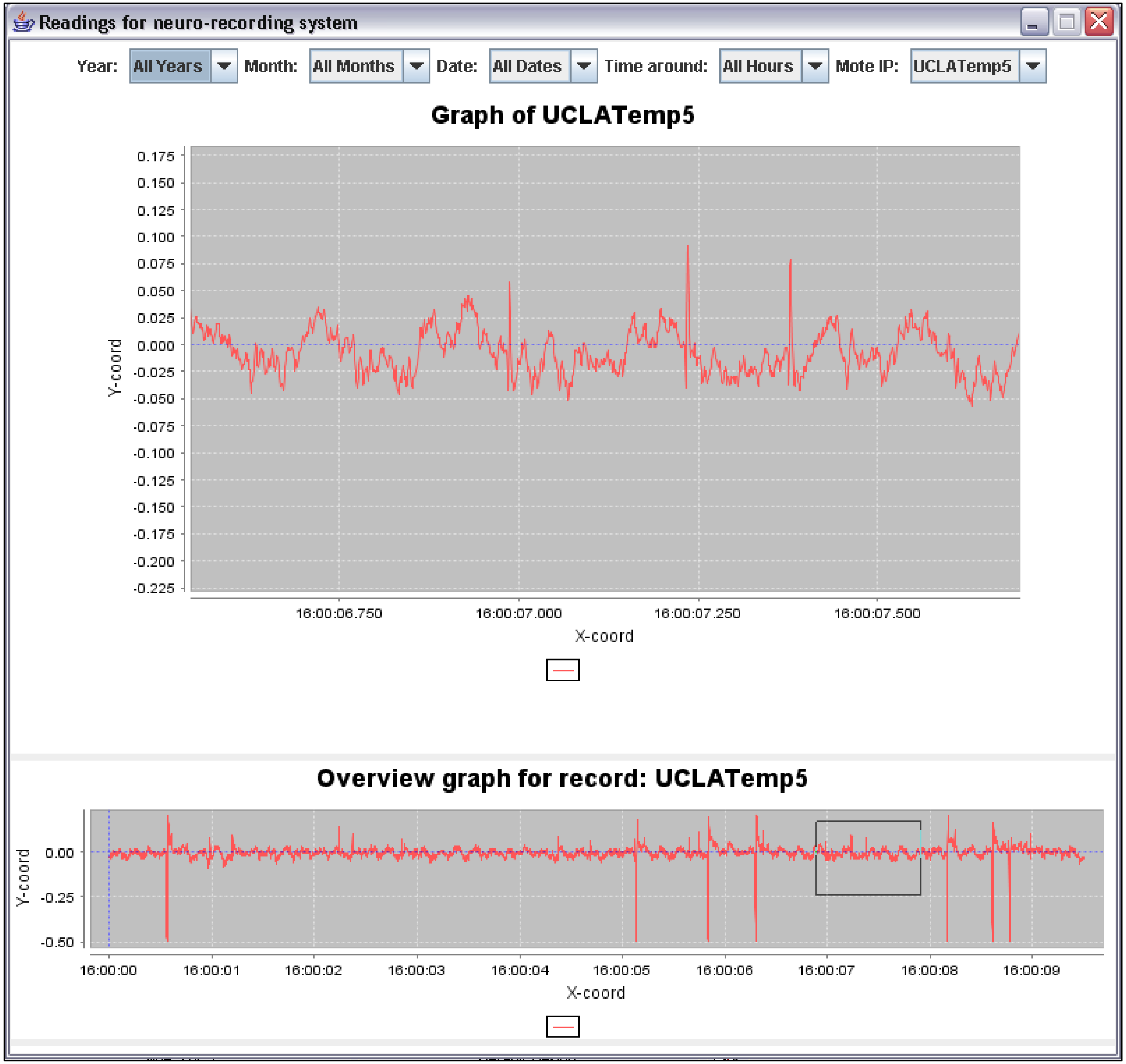


Drop-Down Menus Retrieved From the Database and Populated Based on User's Selection

Records with Matching Selection Criteria Are Listed in a Drop-Down Menu

An Overview of the Recorded Data Is Displayed for the Highlighted Item

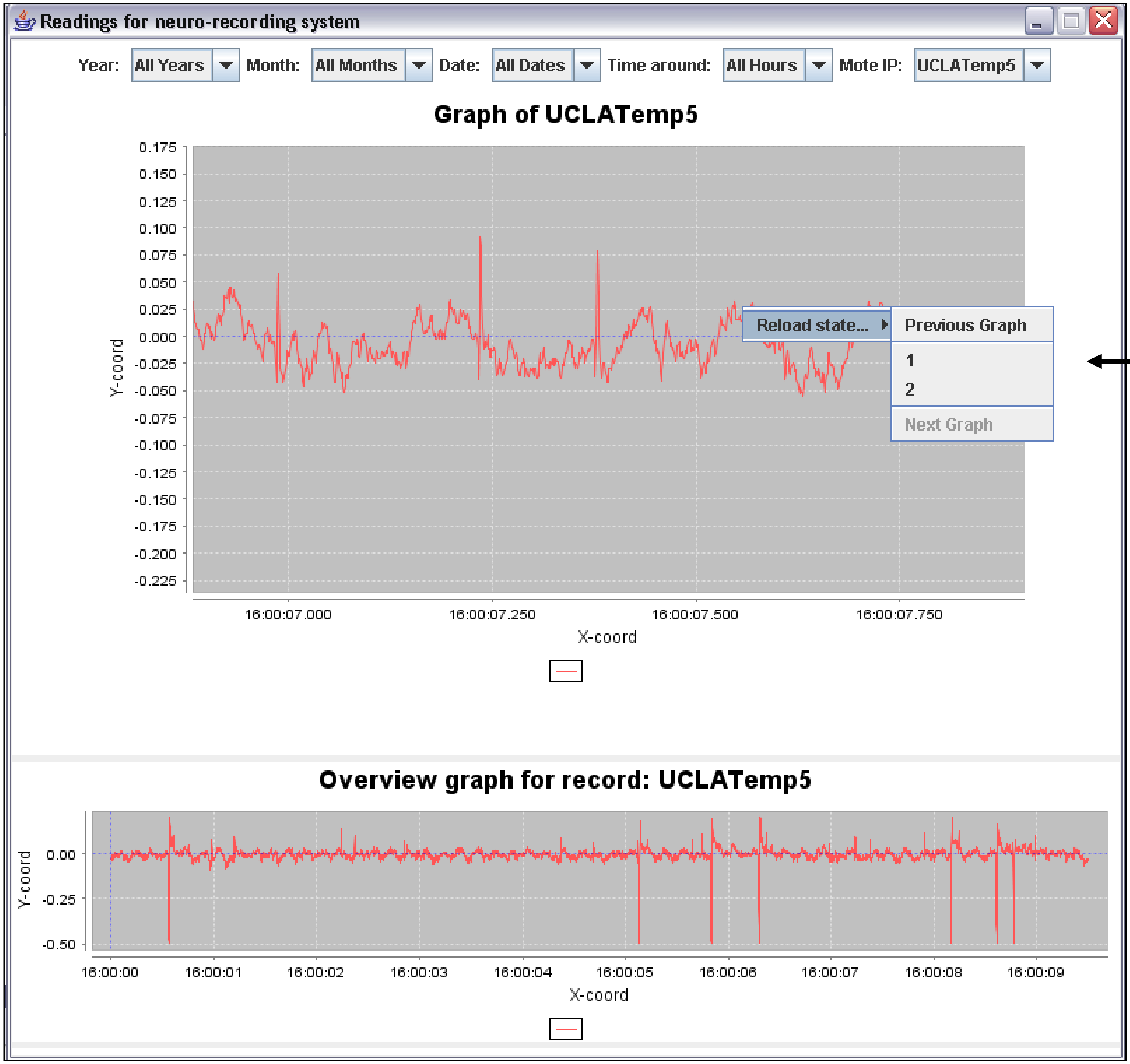




Graphs Are Re-Drawn By Selecting Another Dataset

Chosen Portion of the Waveform

A Box Can Be Drawn on a Portion of the Waveform That Is of Interest, Which Is Blown Up in the Box Above



Right Clicking on This Graph Enables Users to Navigate Any Previous Zoom State

Bi-Fi Java Technology-Based Mobile Client

- Java ME platform-based
- Bluetooth communication
- Platform-independent

Photo courtesy of Global Care Quest http://www.globalcarequest.com

What the Bi-Fi Mote Must Do

- Acquisition
  - Adjustable signal acquisition and resolution
- Analysis/filtering
  - Filter uninteresting data to reduce radio power consumption
- Compression
  - Lossy/lossless algorithms depending on congestion/number of motes

There Is a Need for a Modular Framework

- Deployed mote cannot be easily reprogrammed
  - Accept commands to restructure application
- Provide a method of changing where (not only how) data is processed
  - Back end much more powerful and knowledgeable

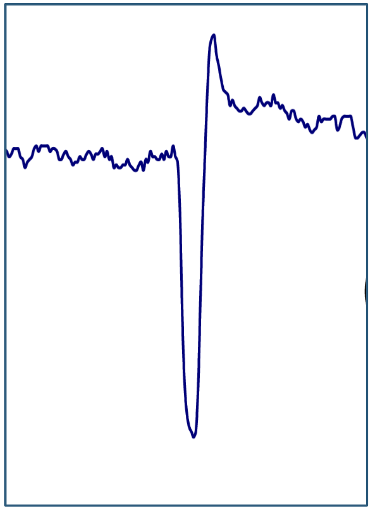
The VanGo Framework at Bi-Fi's Heart

Greenstein et al., UCLA CENS

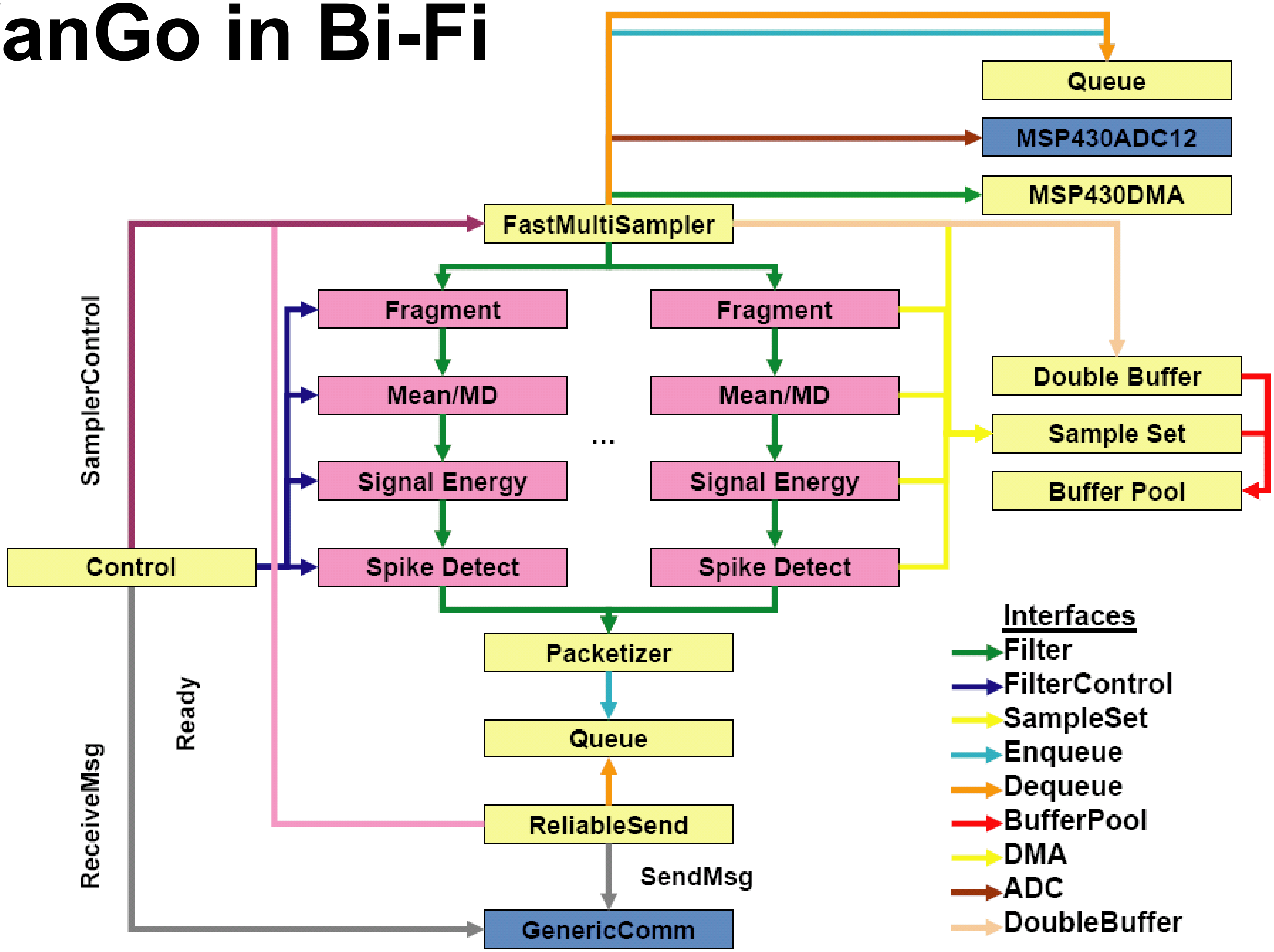
- Enables a mote to acquire, filter, and transmit biological data at data rates near hardware limits
- Written in NesC for TinyOS
- Modules shared between motes and PC-class devices
  - Sharing achieved by emulating a mote on a PC (EmStar)
  - Motes gather and send data
  - Archive server collects and hosts data while providing sensor configuration data

VanGo in Action

- High-rate biosignal acquisition
  - Collect waveforms at a rate of 4–8 kHz
  - Calculate the descriptive measurements:
    - Mean, mean deviation from mean, standard deviation
  - Detect spikes in the waveform
  - Filter data based on user's preferences
    - Send all waveform, spikes, summary (timestamp)

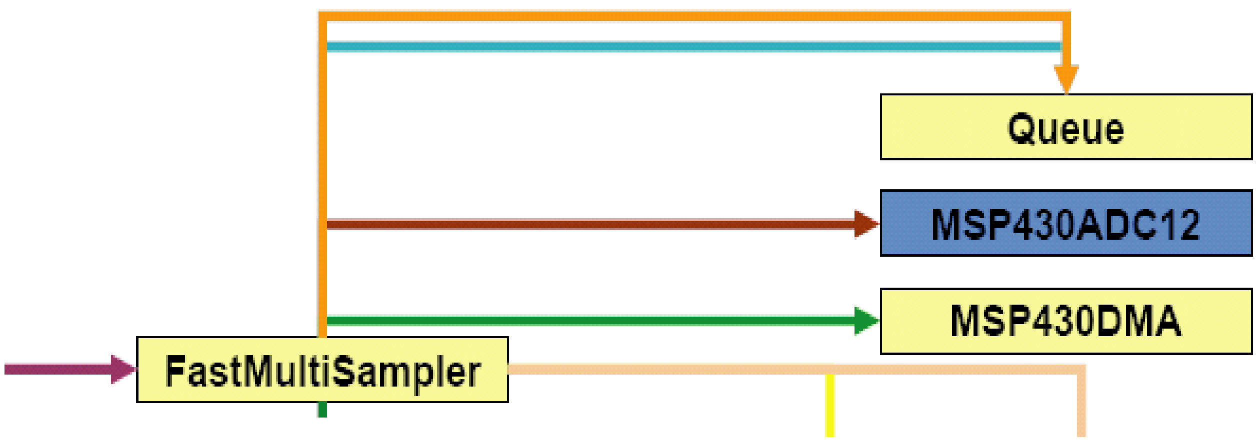


VanGo in Bi-Fi



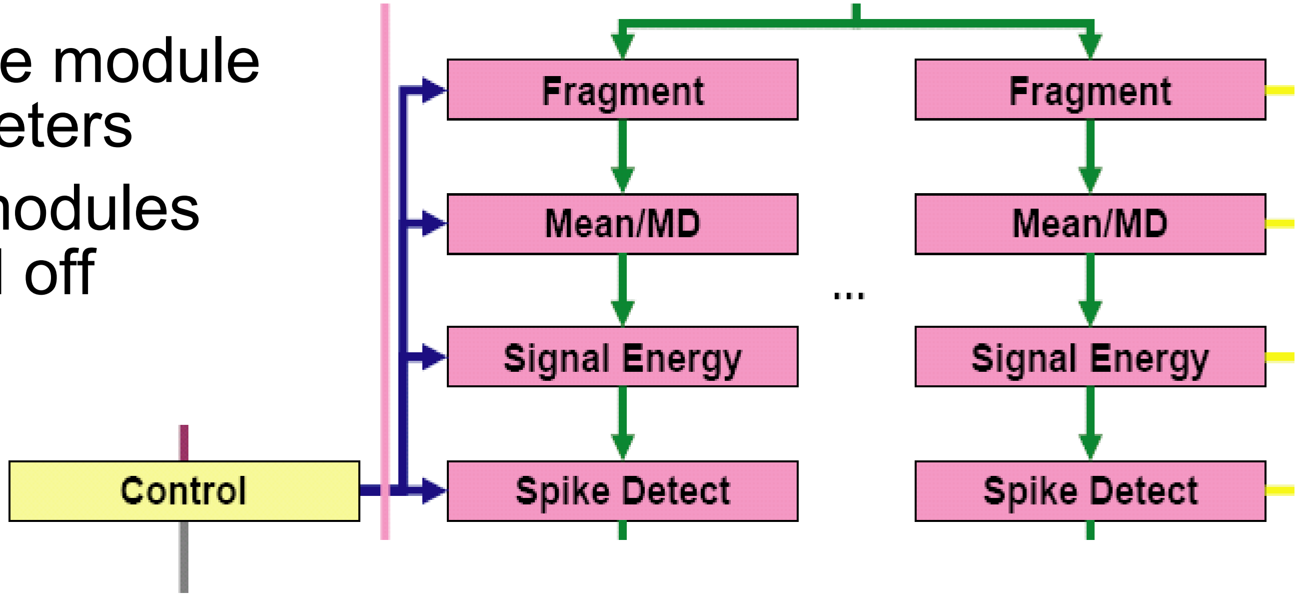
Data Generation

- VanGo acquires data via:
  - ADC (mote)
  - UART (mote/PC)
  - Network (PC)



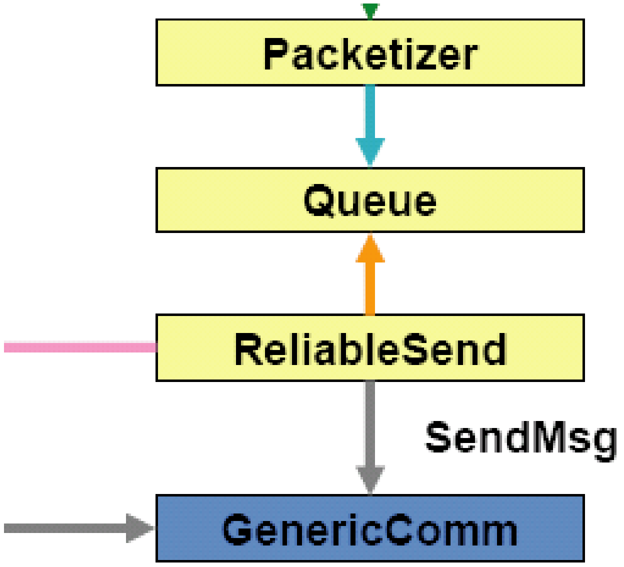
Data Processing

- Layers
- Control
  - Change module parameters
  - Turn modules on and off



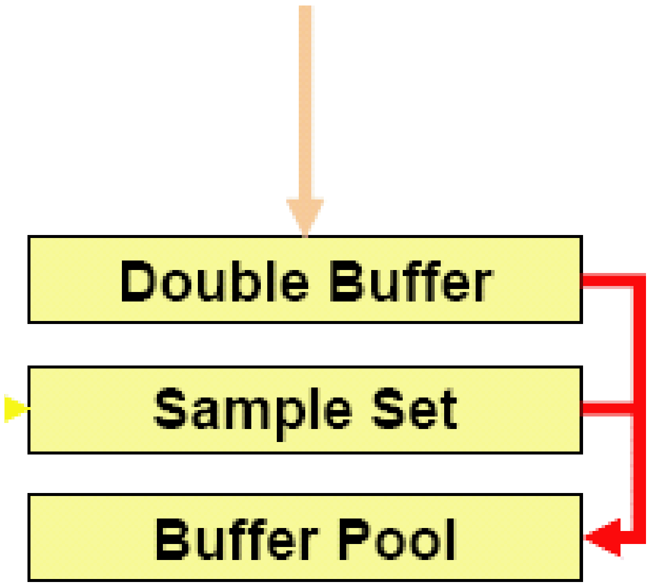
Terminating Data Path

- Forward data
  - Network
    - Serve clients
  - Radio
    - Control deployed motes
    - Send data to PC
- Clean up



Memory Management

- Application manages memory (not the OS)



Limitations of VanGo

- Written in NesC
  - Not a mainstream language
  - Steep learning curve
- New operating system (TinyOS)
- Gateway receiver runs in EmStar
  - Required for emulating mote code
  - PC code not very flexible
  - Large program footprint (~ 500 MB)
  - Linux-only

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

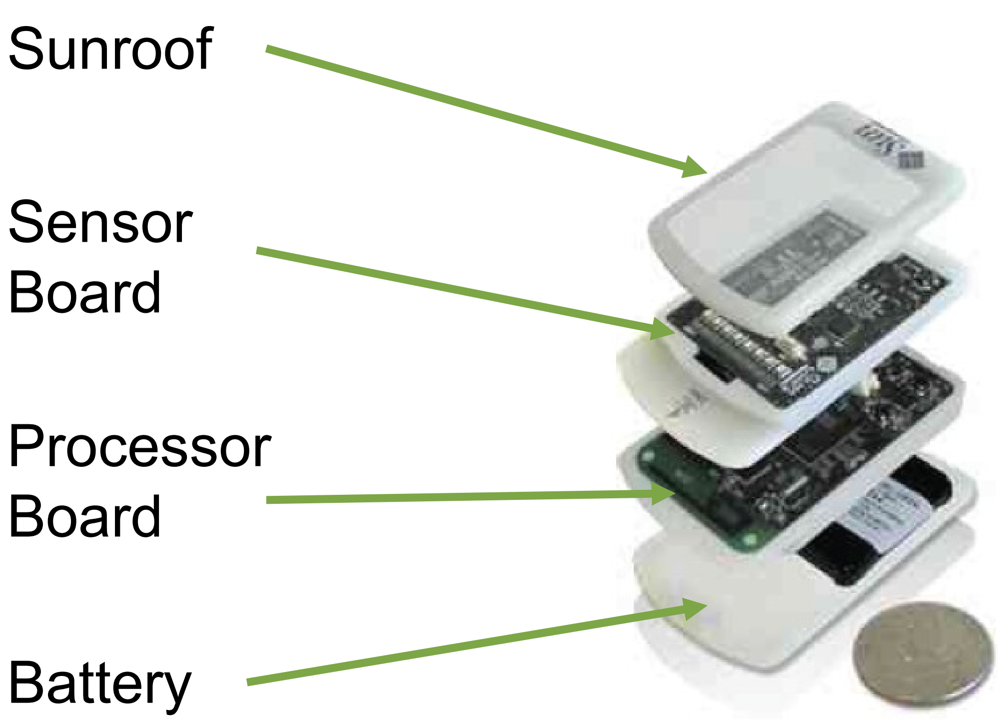
How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

Summary and References

Java Technology-enabled Sun SPOTs

Small Programmable Object Technology



Java Technology-enabled Sun SPOTs

- 32-bit Atmel ARM920T core @ 180 MHz
- 512 KB RAM, 4 MB Flash
- 802.15.4 transceiver
- Sensor board
  - Temperature, light, 3D-accelerometer
  - 8 tri-color LEDs
  - Six 10-bit ADCs
- Operates on a Java VM (Squawk)

Project Sun SPOT Squawk Java VM

- Designed for constrained devices
- Mainly written in Java code, tiny amount of C
- Runs on bare metal ARM without need for an OS
- Can also run on Solaris, Linux, Windows, MacOS
- Fully capable Java ME CLDC 1.1 Java VM
- Supports GC, threads, direct interrupts
- Runs multiple isolates in one VM

Leveraging the Flexibility of Java

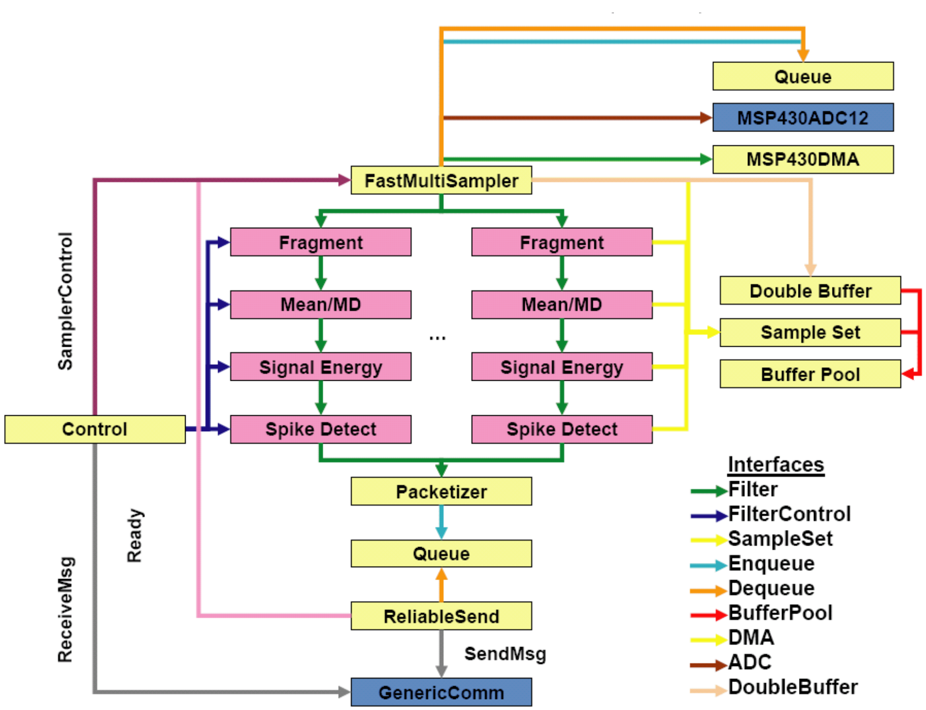
- Portability of code between generations of motes
  - Motes evolve on an ongoing basis
  - Framework will continue to work on any Java-enabled mote
- Portability of code between devices
  - Running mote application on the PC
  - Allows for a single framework that can run on both classes of devices
- Writing for a common virtual machine

Why Java Technology Beats NesC

- Much easier to use
- Process isolation
  - Running multiple programs
- Resource sharing
- Memory allocation
- Garbage collection
- Energy management

Future Work: VanGo in Java Technology

- The modular structure of VanGo leads itself easily to Java-based classes
- Derive filters using inheritance
  - Duplicate code in current framework
  - Space-limited devices



Filters in NesC

Example Module

```
module GateM {
   ...
   provides interface SingleFilter as Filter_p; // input sample set
   uses interface SingleFilter as Filter_u; // output sample set
   ...
}
implementation {
   command void Filter_p.put(sample_set_t* set) {
   ... } // code to process sample set
}
```

Example Configuration

```
FastSamplerC.Filter_u -> FragmentM.Filter_p;
FragmentM.Filter_u -> AverageM.Filter_p;
AverageM.Filter_u -> GateM.Filter_p;
GateM.Filter_u -> ZeroCrossingM.Filter_p;
ZeroCrossingM.Filter_u -> AdpcmM.Filter_p;
AdpcmM.Filter_u -> PacketizerM.Filter_p;
```

Filters in Java Technology

```
Interface Filter
{
     ...
     boolean run(SampleSet set);
     ...
}

public static void main(String[] arg)
{
     Filter[] filterList;
     ...
     filterList[i].run(set);
     ...
}
```

DEMO

The Bi-Fi System in Action

Presentation Outline

Motivation

What Is Bi-Fi?

What Is a Bi-Fi Mote?

How Does It Work?

Enhancing Bi-Fi with Project Sun SPOT

Summary and References

Summary

- Wireless biological monitoring is important
- Leveraging embedded systems technologies is the way to do it
- Bi-Fi proves that the concept is viable, but TinyOS has its limitations
- Java technology overcomes these limitations
- Sun SPOTs are the only Java technology-based motes available
- System can evolve to a wearable computer for enabling emotional-intelligent software

JavaOne℠ Conference Sessions

- Squawk: a Java™ VM for Wireless Sensor/Actuator Networks
  - TS-1598: 05/16/06, 3:15 pm
- Sun SPOT Bird-of-feather Session
  - BOF-0289: 05/16/06, 8:30 pm
- Simplified Development of Wireless Sensor and Actuator Applications Using Java™ Technology
  - HOL-7160: 05/17/06, 9:45 am
- Sun SPOT Pod

Acknowledgements

- National Science Foundation
  - NSF DBI Grant # 0456125
- Professor Jack W. Judy
  - http://www.ee.ucla.edu/~jjudy
- UCLA Microsensor, Microactuator, and Microsystem Laboratory
  - http://www.judylab.org
- VanGo at CENS
  - http://research.cens.ucla.edu

For More Information

- Vista Integrated Systems: http://www.visys.biz
- UCLA Judylab: http://www.judylab.org
- CENS: http://research.cens.ucla.edu
- Crossbow Technology: http://www.xbow.com
- Dust Networks: http://www.dust-inc.com
- Sun SPOT: http://sunspotworld.com

Publications

S. Farshchi, I. Mody, and J.W. Judy, “A TinyOS-Based Wireless Neural Interface,” *Proceedings of the 26th Annual Conference of the IEEE Engineering in Medicine and Biology Society*, September 1-5, 2004, San Francisco, CA, USA.

S. Farshchi, P. H. Nuyujukian, A. Pesterev, I. Mody, and J.W. Judy, “A TinyOS-Based Wireless Neural Sensing, Archiving and Hosting System,” *Proceedings of the 2nd International Conference IEEE Engineering in Medicine and Biology Society Conference on Neural Engineering*, March 16-19, 2005, Arlington, VA, USA.

S. Farshchi, P. H. Nuyujukian, A. Pesterev, I. Mody, and J.W. Judy, “A TinyOS-Enabled MICA2-Based Wireless Neural Interface,” To be published in the IEEE Transactions on Biomedical Engineering.

J. W. Judy, P. S. Motta, S. Farshchi, S. Badelt, and G. Fridman, “Technologies and Methods for Improving the Capability of Brain-Computer Interfaces,” *Proceedings of the 2005 Brain-Computer Interface Conference*, Rensselaerville, NY, June 14-19, 2005.

B. Greenstein, A. Pesterev, C. Mar, E. Kohler, J. W. Judy, S. Farshchi, and D. Estrin, "Collecting High-Rate Data Over Low-Rate Sensor Network Radios," University of California, Los Angeles Center for Embedded Networked Sensing Technical Report #55, [Online]. Available: http://research.cens.ucla.edu/pls/portal/url/item/05002645A3A05A96E0406180528D2EF9.

S. Farshchi, P. H. Nuyujukian, A. Pesterev, I. Mody, and J. W. Judy, “An Embedded System Architecture for Biosignal Recording,” IEEE Transactions on Information Technology in Biomedicine, submitted for publication.
S. Farshchi, A. Pesterev, W. Ho, and J. W. Judy, “Acquiring High-Rate Neural Spike Data with Hardware-Constrained Embedded Sensors,” Submitted to the 28th annual IEEE Engineering in Medicine and Biology Conference, September 1-5, 2006, New York, NY, USA.

S. Farshchi and J. W. Judy, “Low-Noise Amplifier Circuit for Embedded Electrophysiological Recording with Adjustable Gain and High-Pass Filtering,” Accepted for publication in the Proceedings of the 16th Biennial IEEE University Government Industry Microelectronics Symposium, June 25-June 28 2006, San Jose, CA, USA.

N. Fernando, S. Farshchi, P. H. Nuyujukian, A. Pesterev, I. Mody, and J. W. Judy, “An Embedded-Sensor-Based Wireless Neural Stimulation and Recording System,” Submitted to the 28th annual IEEE Engineering in Medicine and Biology Conference, September 1-5, 2006, New York, NY, USA.

Q&A

Bi-Fi: Just Like Your Doctor!

Shahin Farshchi
President
Vista Integrated Systems
www.visys.biz

Kiran Patel
Technology Evangelist
Sun Microsystems, Inc.
www.sun.com

Aleksey Pesterev
Research Assistant
UCLA EE: Microsystems Lab
UCLA BME: Neuroengineering Lab
www.judylab.org

TS-3683