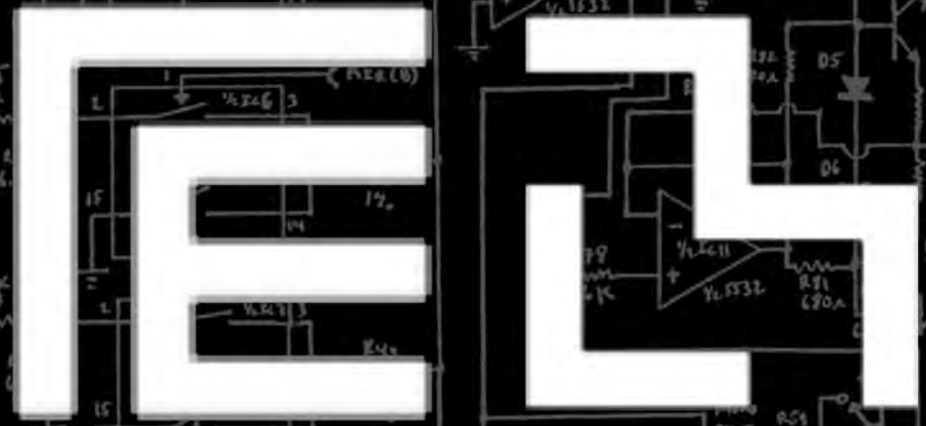
How We Will Connect To Our Networked Future in a Post-IoT World



Prof. Joe Paradiso
Responsive Environments Group
MIT Media Lab
http://resenv.media.mit.edu

1969

- First Manned Lunar Landing
- Birth of the Internet
- UNIX Launched
- SIGGRAPH Starts
- CDC 7600 Introduced
- DEC PDP-11 Introduced
- Minsky & Papert publish *Perceptrons*
- Start of Prog Rock!

2069 (my optimistic view)

- We will know how common life is throughout the universe
  - I think we're alone…
- Some people will live on the moon
  - But we don't know if or what kind of humans will go deeper into space
- We will have moved totally away from carbon-based fuels
  - Renewables, Fusion, Safe/scalable Fission…
- We will have figured out how to adjust carbon in the atmosphere and/or master geoengineering in the interim
- New computational substrates will become established
  - VLSI silicon doesn't scale any more, Power constraints, etc.
  - Smart memory, optical, organic, quantum…
- Programming them will be very different
  - More akin to optimization, etc.
- Direct neural interfaces will start to move out of prosthetic niches
  - What is wired vs what is grown?
  - New forms of artistic expression that go beyond physical perception
- Deep AI will be established, but will be benevolent…
  - This is in its best interest and it will be good at manipulating us

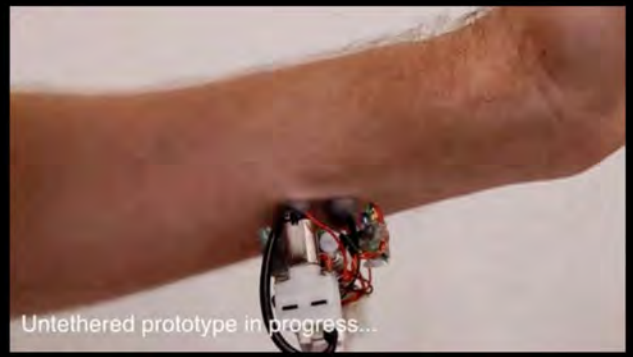
Enroute to 2069…

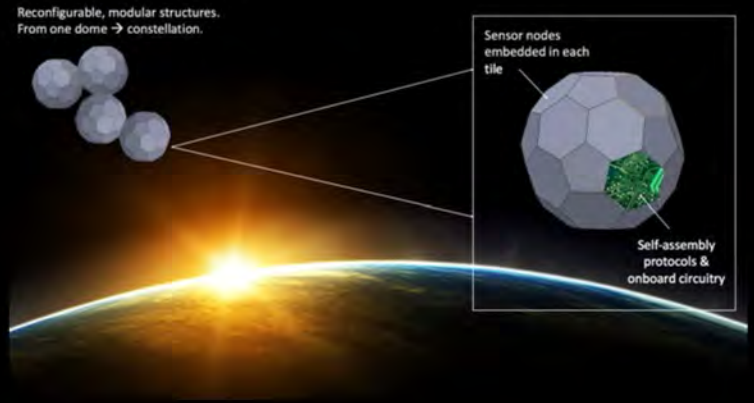
- Social media is stillborn at mob mentality
  - We need to anneal to achieve collective intelligence
- Interfaces to information become wearable and precognitive
  - Our effective ‘brains’ move outside our skulls
  - We can all ‘see’ a different reality, not just believe it
- How will we control access to our attention?
- Where does ‘self’ stop and ‘other’ begin?
- How will human presence generalize?

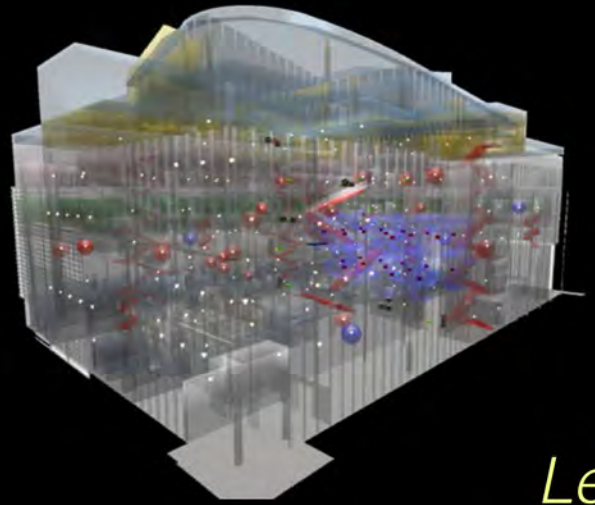
Topics

- A bit about the Media Lab and Me
- Sound and audio
- Smart buildings
- Wearables
- Smart tools
- Sensate materials
- Generalization of presence, sensory augmentation

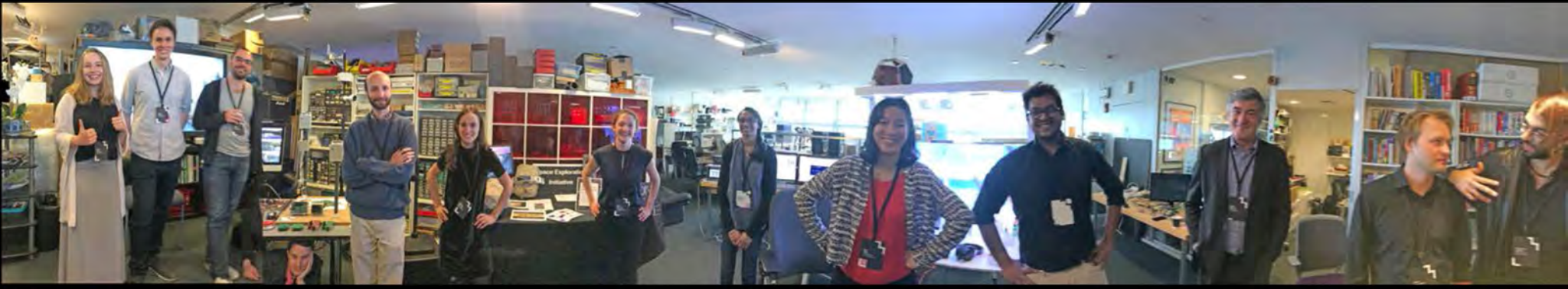
People, Buildings, Landscapes, Oceans, Space







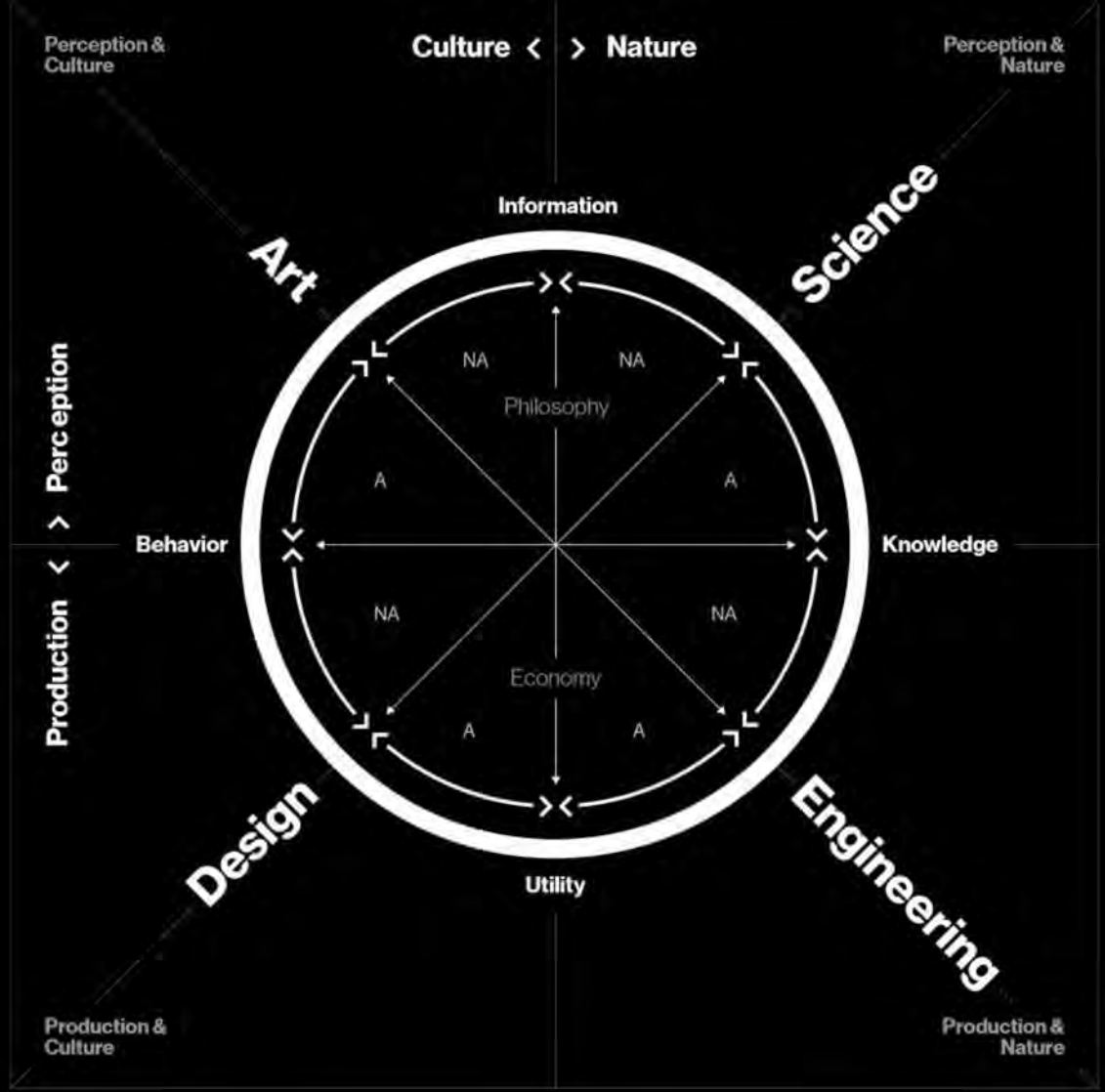
Leveraging sensing at scale




TRIAD
responsive
environments
Open House

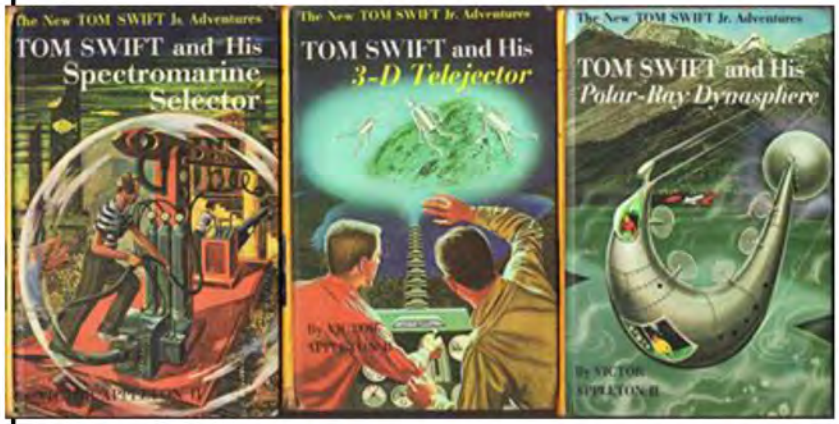
The MIT Media Lab is an "antidisciplinary" research lab driven by the passion and curiosity of its students and faculty. Lab researchers look beyond the obvious to pose the questions not yet asked.

25 Groups researching radical HCI, Augmented Reality, Computational Photography, Sensors, IoT, Brain Interfaces, Implantable Electronics, Genetics, Robotic Prosthetics, Smart Cities, Future of Music, Social Media & Networks…


Perception & Culture
Culture < > Nature
Perception & Nature
Information
Art
Science
Perception < > Production
Behavior
Knowledge
NA
NA
Philosophy
A
A
NA
NA
Economy
A
A
Design
Engineering
Utility
Production & Culture
Production & Nature

A Historical Perspective

My Role Model



…to experimental high-energy physics

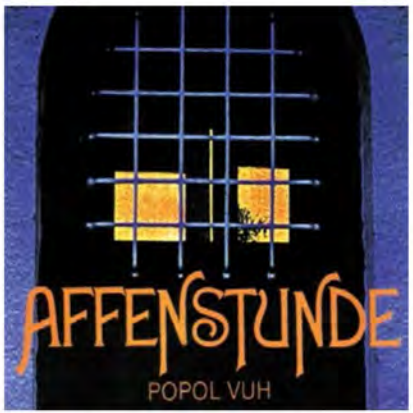
PhD at CERN with Ulrich Becker and Sam Ting (MIT LNS) 1981

The (original) 'Berlin' Sound (with Linz offshoot)

Tangerine Dream - 1974

Klaus Schulze - 1975

Eela Craig - 1971

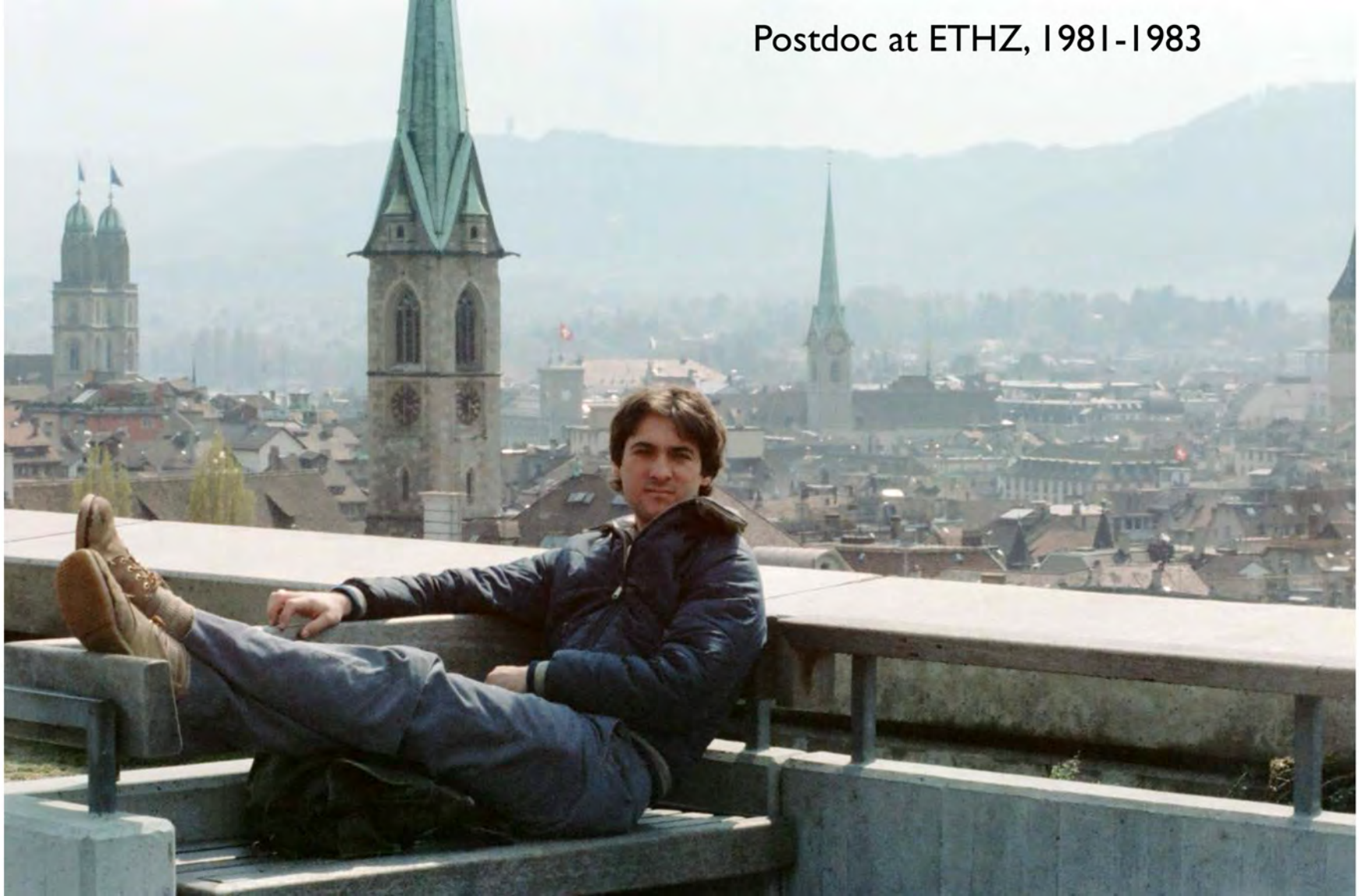


Popol Vuh - 1972

Conrad Schnitzler - 1974

Eberhard Schoener - 1973

1975 (in my parents' basement)



Postdoc at ETHZ, 1981-1983

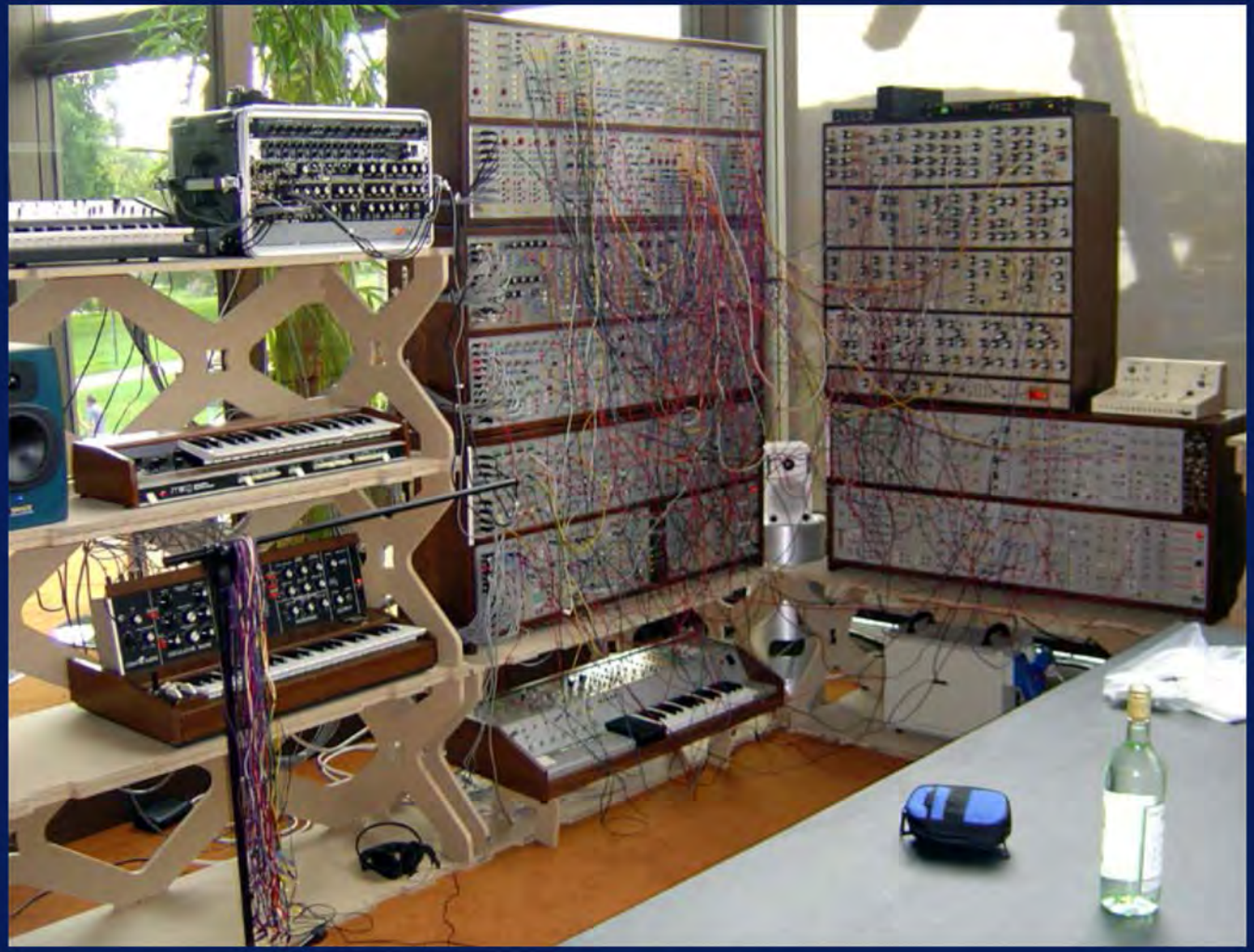
The Zurich Modules - Nov., 1983

In Cabinets - mid 1980's USA

Newton living room - 1986

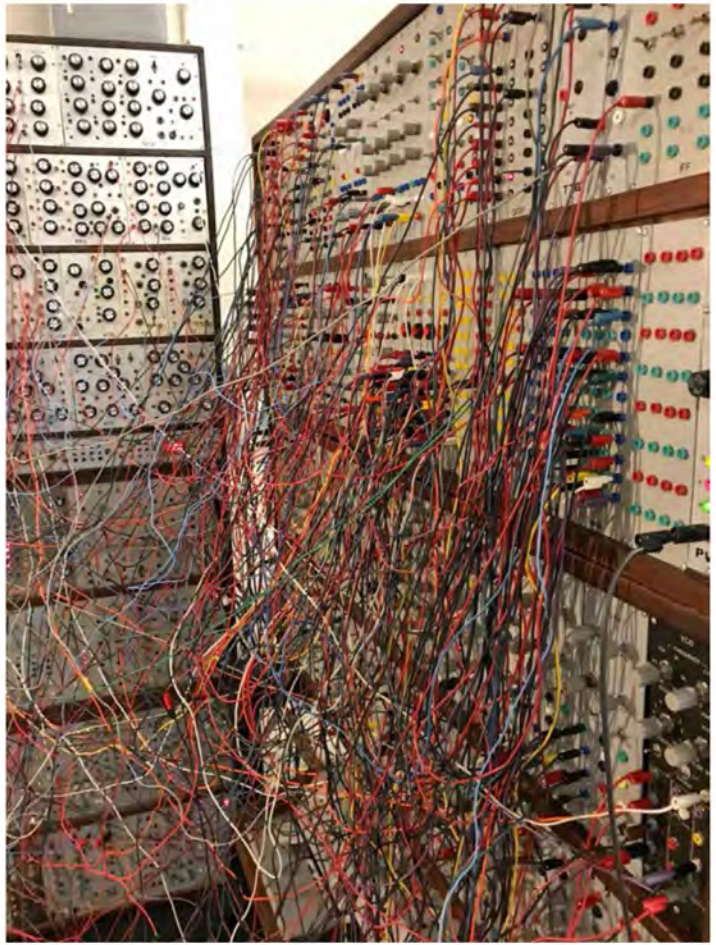
With Gerfried and Horst at Ars Electronica 2016

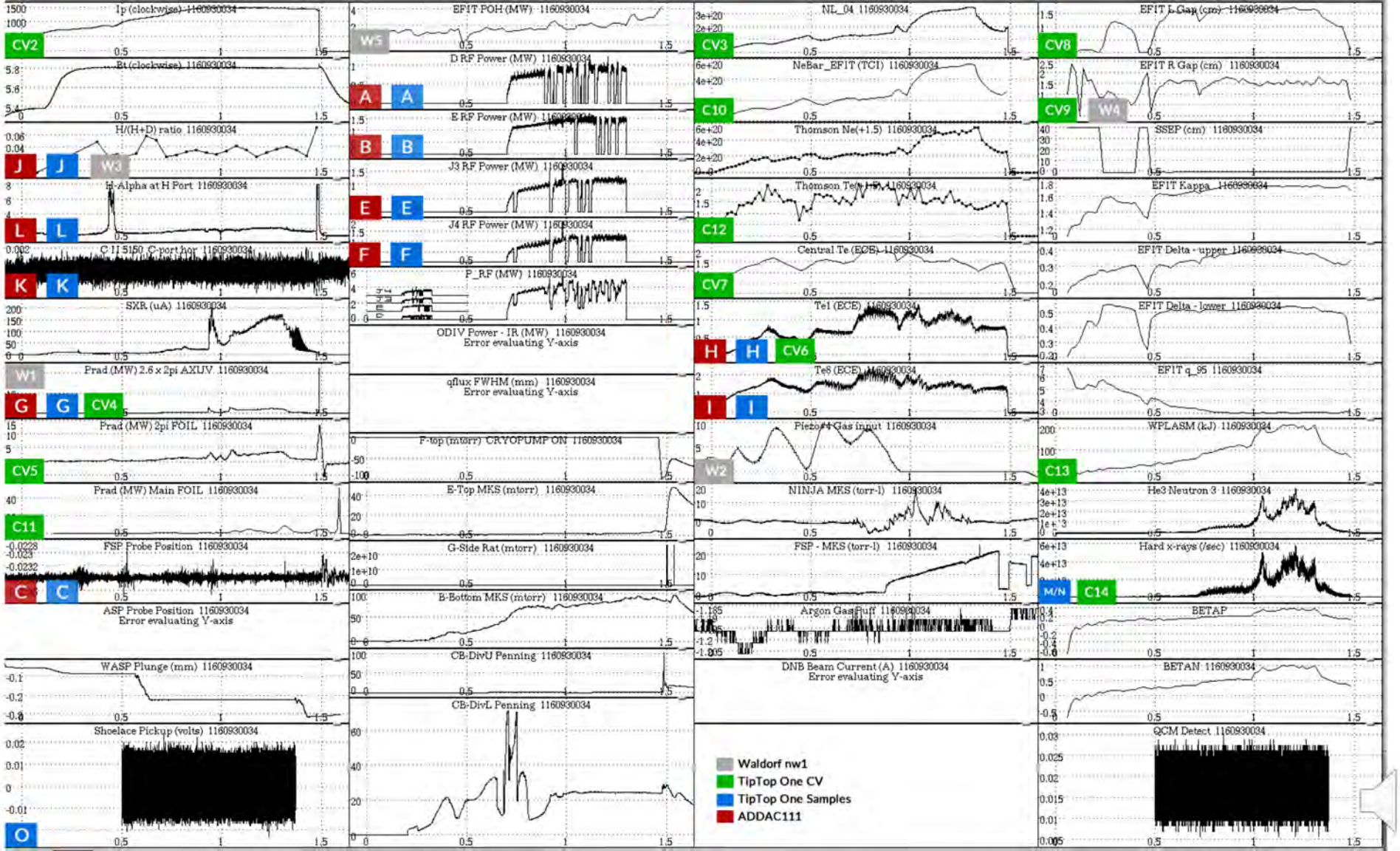
At Ars Electronica Festival – Sept. 2-9, 2004




http://synth.media.mit.edu
At MIT Museum Jan-April-2012

‘ReSynthesizer’ @ PSFC 4-8/2018 for CAVS 50th Anniversary



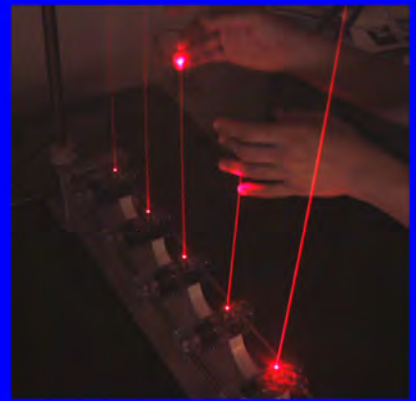

Ip (clockwise) 1160930034
Bt (clockwise) 1160930034
H/(H+D) ratio 1160930034
H-Alpha at H Port 1160930034
C II 5150 C-port hor 1160930034
SXR (uA) 1160930034
Prad (MW) 2.6 x 2pi AXUV 1160930034
Prad (MW) 2pi FOIL 1160930034
Prad (MW) Main FOIL 1160930034
FSP Probe Position 1160930034
ASP Probe Position 1160930034
Error evaluating Y-axis
WASP Plunge (mm) 1160930034
Shoelace Pickup (volts) 1160930034
EFIT POH (MW) 1160930034
D RF Power (MW) 1160930034
E RF Power (MW) 1160930034
J3 RF Power (MW) 1160930034
J4 RF Power (MW) 1160930034
P_RF (MW) 1160930034
ODIV Power - IR (MW) 1160930034
Error evaluating Y-axis
qflux FWHM (mm) 1160930034
Error evaluating Y-axis
F-top (mtorr) CRYOPUMP ON 1160930034
E-Top MKS (mtorr) 1160930034
G-Side Rat (mtorr) 1160930034
B-Bottom MKS (mtorr) 1160930034
CB-DivU Penning 1160930034
CB-DivL Penning 1160930034
NL_04 1160930034
NeBar_EFIT (TCI) 1160930034
Thomson Ne(+1.5) 1160930034
Thomson Te(+1.5) 1160930034
Central Te (ECE) 1160930034
Te1 (ECE) 1160930034
Te8 (ECE) 1160930034
Piezo#1 Gas input 1160930034
NINJA MKS (torr-l) 1160930034
FSP - MKS (torr-l) 1160930034
Argon Gas Puff 1160930034
DNB Beam Current (A) 1160930034
Error evaluating Y-axis
EFIT L Gap (cm) 1160930034
EFIT R Gap (cm) 1160930034
SSEP (cm) 1160930034
EFIT Kappa 1160930034
EFIT Delta - upper 1160930034
EFIT Delta - lower 1160930034
EFIT q_95 1160930034
WPLASM (kJ) 1160930034
He3 Neutron 3 1160930034
Hard x-rays (/sec) 1160930034
BETAP
BETAN 1160930034
QCM Detect 1160930034
Waldorf nw1
TipTop One CV
TipTop One Samples
ADDAC111

Resynthesier: My custom modular synth installed at MIT's Plasma Fusion Center

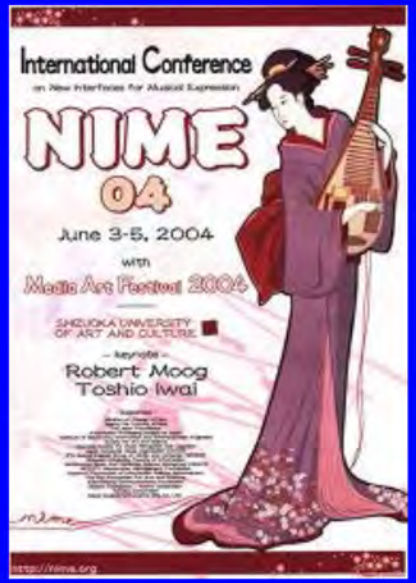
Uses actual data from Alcator C-Mod (MIT's Tokamak) as audio & control signals

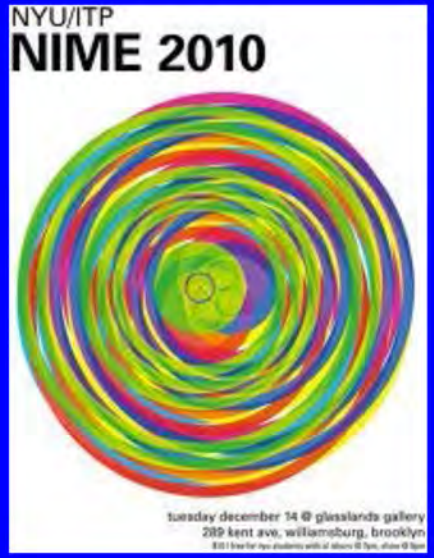
Realtime Audio Streams @ **http://synth.media.mit.edu**

Musical Interfaces



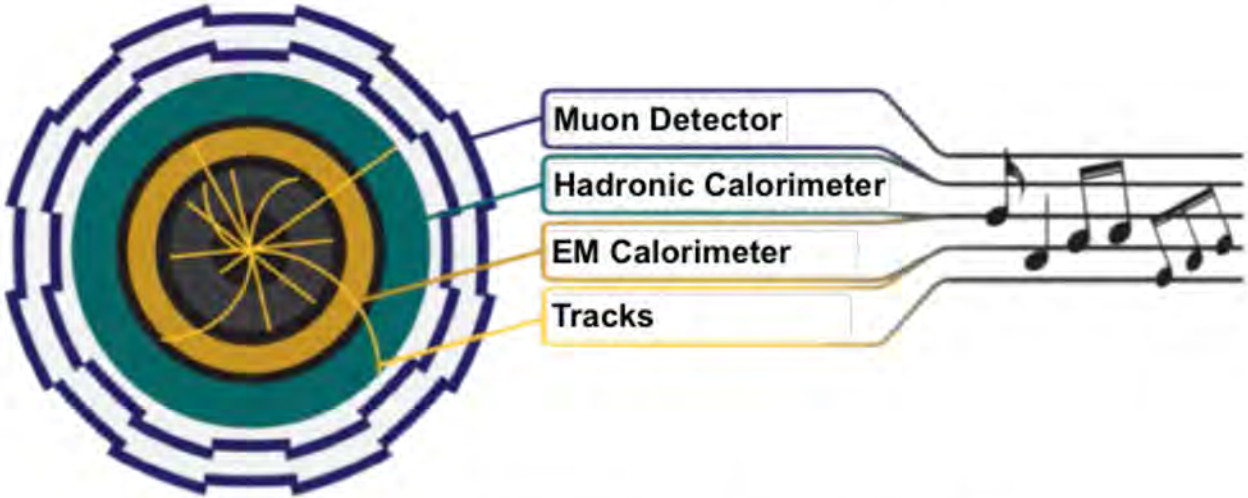
The Pageant of NIME





Quantizer – ATLAS / Media Lab Collaboration

A Framework to support diverse musical compositions running on real-time ATLAS/LHC Data



Juliana Cherston (MITML) and Ewan Hill (TRIUMF/ATLAS) – Thanks to Steve Goldfarb & Frank Taylor

http://quantizer.media.mit.edu

QUANTIZER

high energy physics experienced through real-time audio

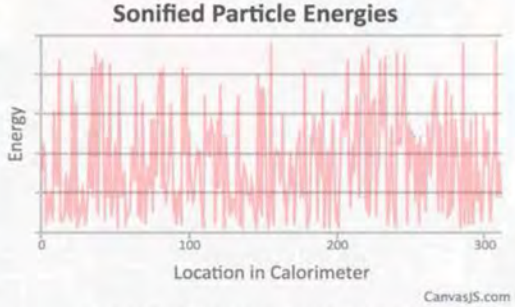
THE AUDIO STREAMS BELOW ARE BEING GENERATED IN REAL-TIME

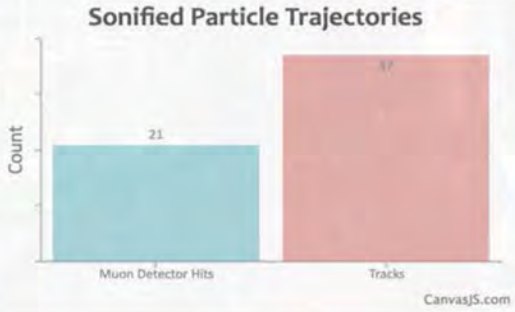
Cosmic | House | Suitar Samba | Your physics sonification here?

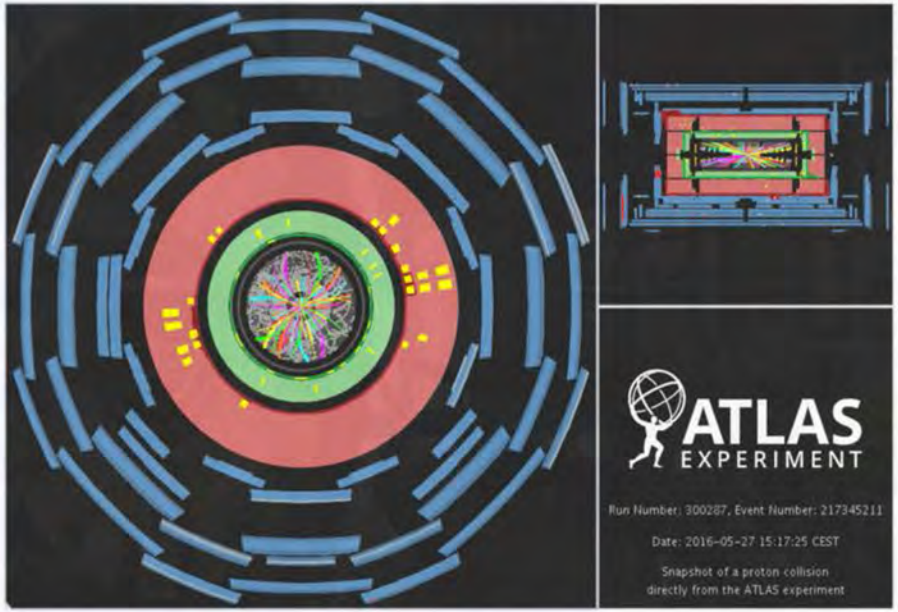
346:31:52 **Status:** RECENT COLLISIONS

You are currently listening to sonified real-time data from the ATLAS experiment at CERN derived from: **calorimeter energy deposits, tracks, muon detector hits, missing energy**

(**note:** Each collision corresponds to ~30 seconds of real-time audio. If the experiment is off, audio is generated from recent data. Audio, plots, and images are not perfectly aligned)







a cognitive model of salience: which audio matters?

Humans selectively *attend to* and *remember* auditory events.

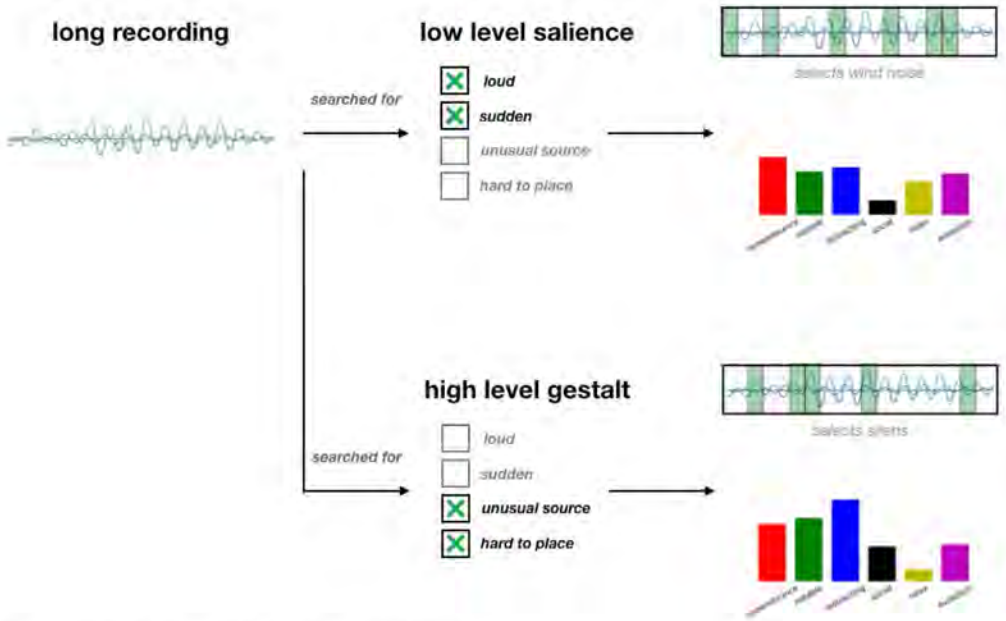
- *Low Level Spatial, Spectral, and Temporal Processing*
- *High Level Source and Scene Analysis*
- *Affective Analysis of User State and Conversation Topic*

Intelligent Audio Capture for Memory

Ishwarya Ananthabhotla and David Ramsay
Responsive Environments

Cognition-Driven Audio Summarization and Compression

Building tools based on the impact of *low level salience* and *high level semantics* on how we listen.



"The Intrinsic Memorability of Everyday Sounds", Proceedings of AES International Conference on Immersive and Interactive Audio, January 2019.

A Perceptual Loss for On-device Audio Neural Networks

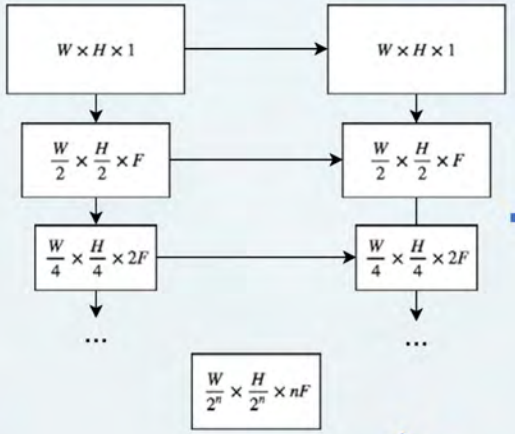
Ishwarya Ananthabhotla[1],
Sebastian Ewert[2], Joseph Paradiso[1]

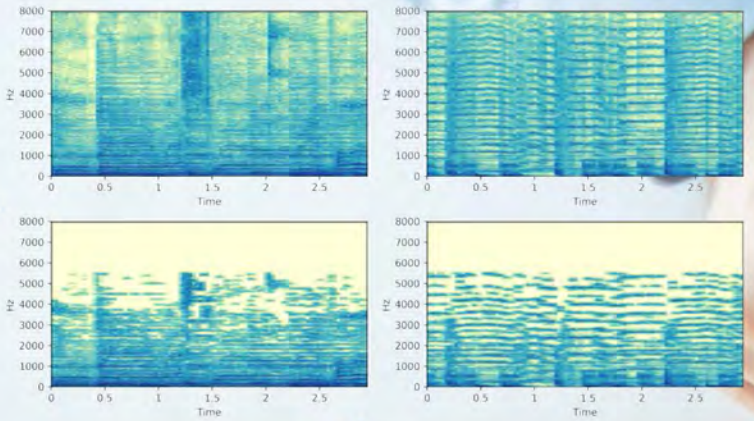
[1]Responsive Environments, MIT Media Lab
[2]Spotify, Inc.

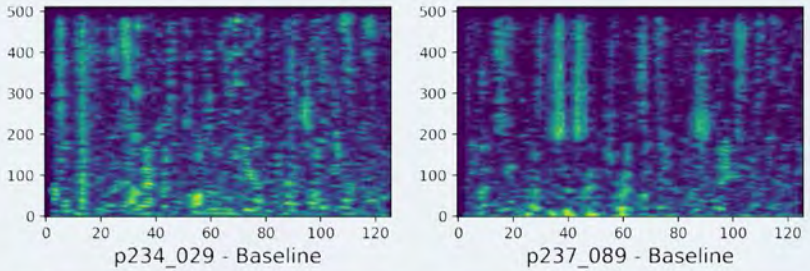
"Towards a Perceptual Loss: Using a Neural Network Codec Approximation as a Loss for Generative Audio Models," Proc. of ACM Multimedia, 2019

Spotify

responsive environments







Spotify

responsive environments

When you need to be notified about data...

Interrupting Your Music

Data Sonification

What if we could subtly modify your *personal* music collection?

Real-time notifications applied to your personal audio..

Audio Stream

Genre-specific Modifications

..plug in to any data source (sensors, social media applications, etc) and control subtlety.


From: Mom
What did you have for lunch?

The Next Convergence

User

Device-Agnostic
Sensor Description Protocol

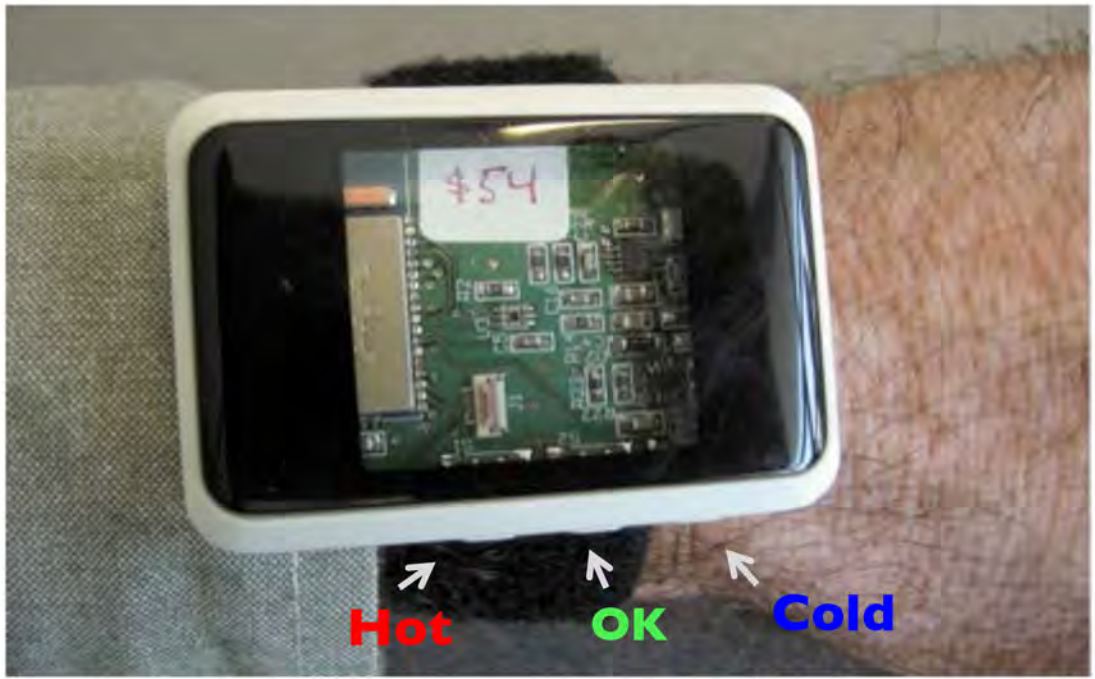
Sensors (already) in everything

MIT
Media
Lab

The 'Digital Butler' Arises Now

Transitory Phase – Smart environments will become an extension of self

Personal Comfort Control

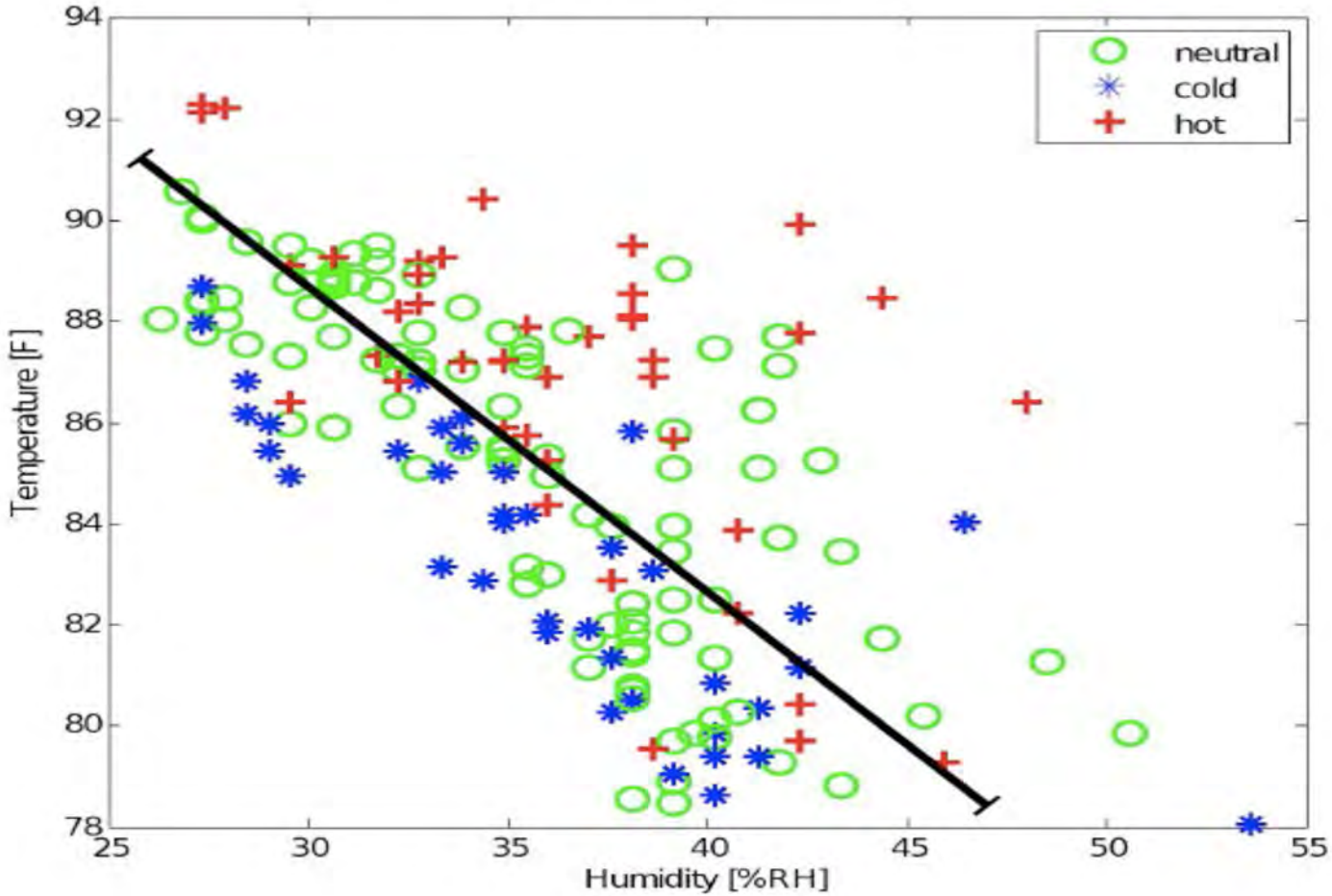


Wearable Sensor

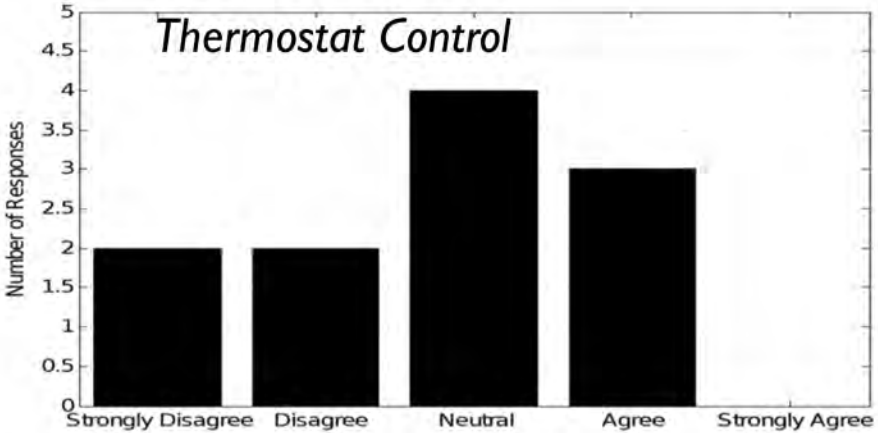
Integrated vibration, T & H, Light @ μW

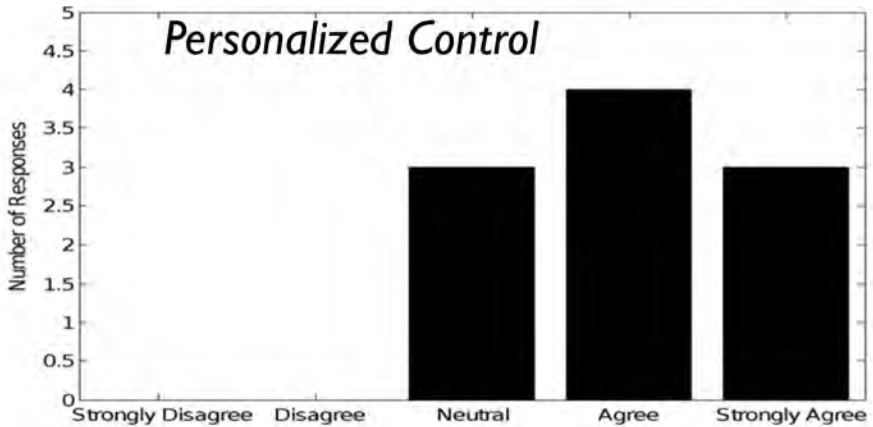
Feldmeier, Paradiso, "Personalized HVAC Control System," IOT Tokyo Nov. 30, 2010

Learning Comfort

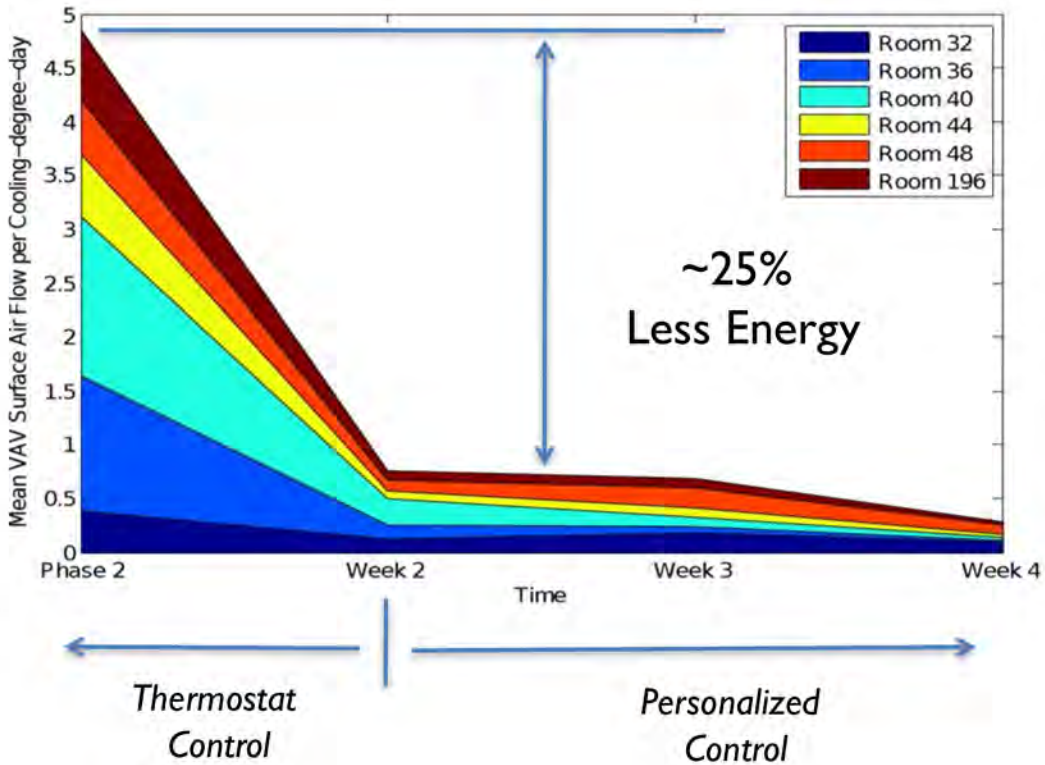


We are More Comfortable





…For Less Energy

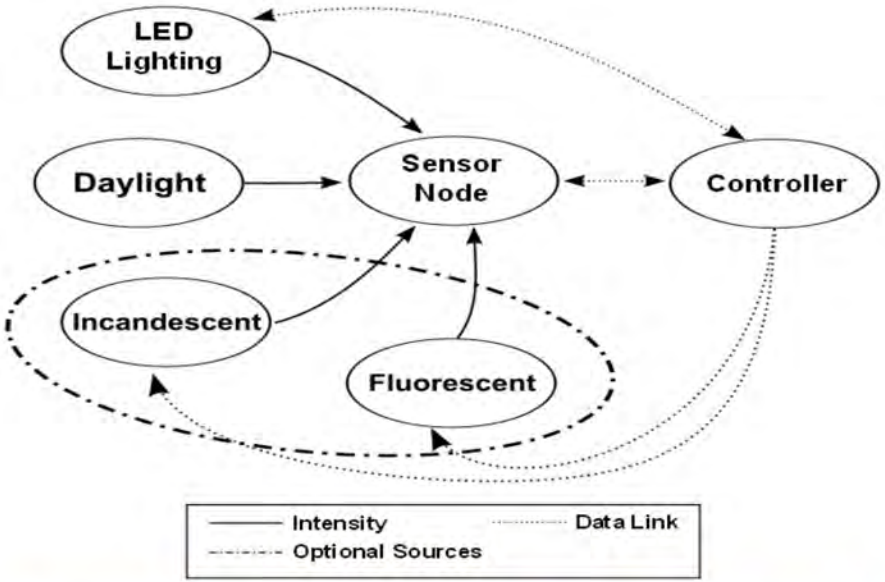


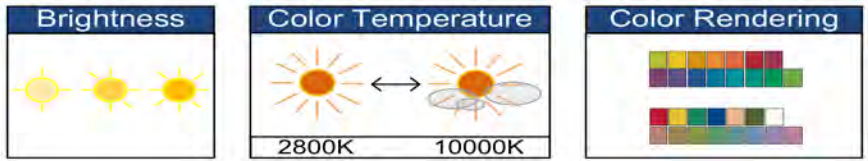
Lighting Control is Broken

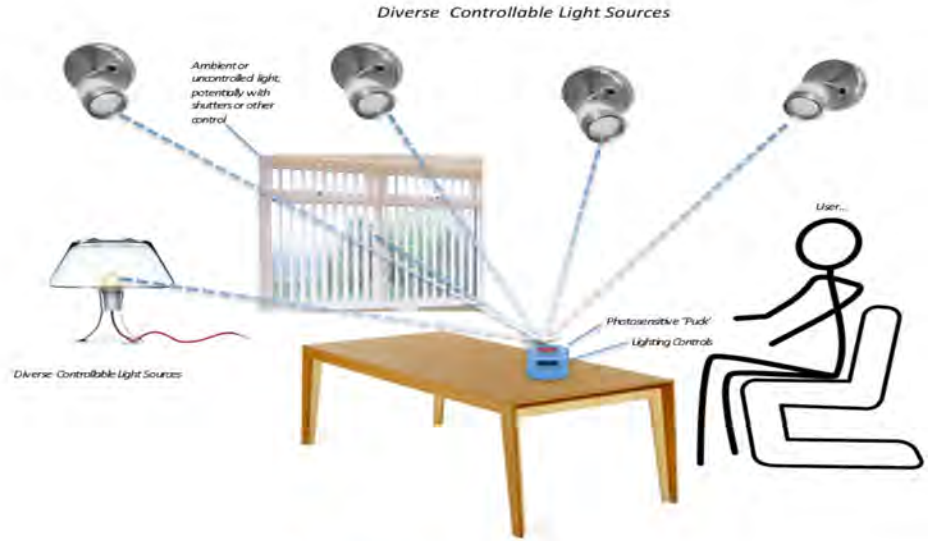
Commercial lighting control panel in the modern (2010) Media Lab Building

Efficient Sensor-Enabled Lighting

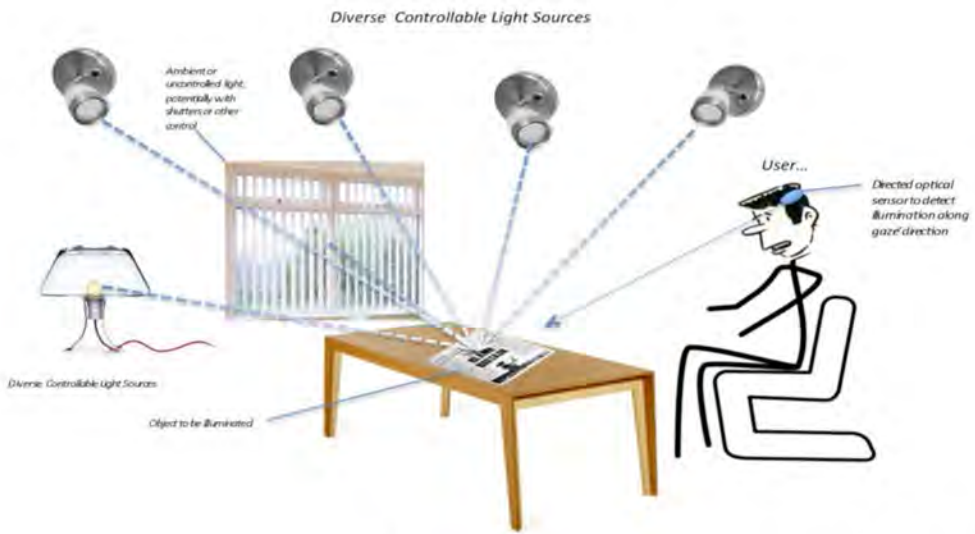
Matt Aldrich, Nan Zhao, and Joe Paradiso







M. Aldrich et al, "Energy Efficient Control of Polychromatic Solid-State Lighting Using a Sensor Network," Proc. SPIE 2010



User Perspective – wearable adjusts reflected lighting to be optimal where user is looking

- Wearable Sensors and Cameras

Synchronized infrastructure cameras see area contributions from different sources

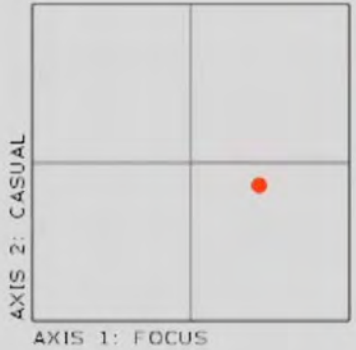
- Feedback control and gestural override
- "Put That There" for lighting
- Context Based Lighting

Nan Zhao – Computer Vision Feedback

Nan Zhao et al, 'A Multidimensional Continuous Contextual Lighting Control System Using Google Glass,' in Proc. of BuildSys'15 - *Best presentation award*

Power consumption of the lighting system in %

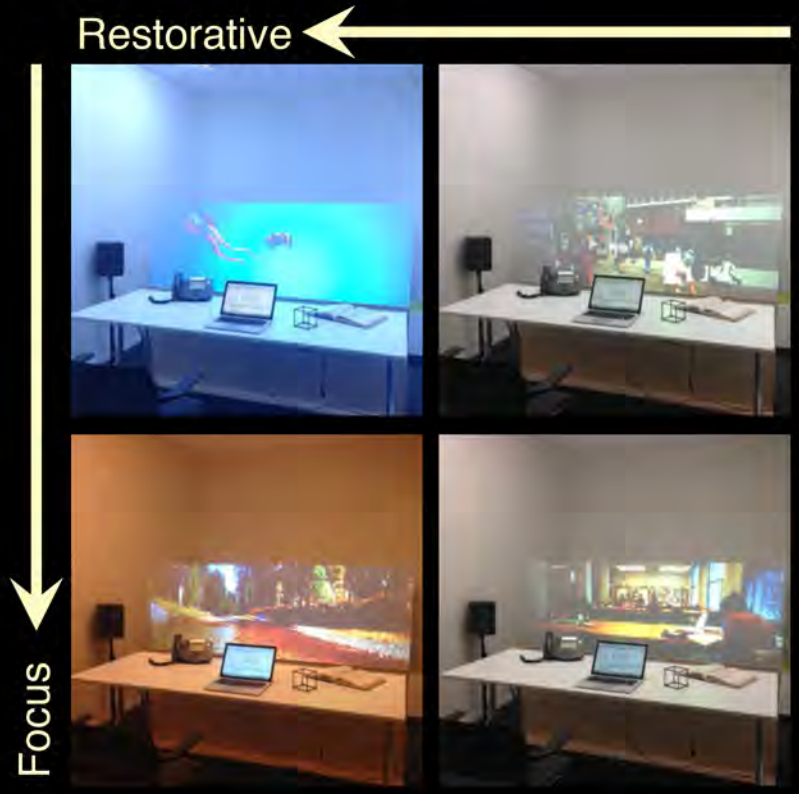
Power: 52%



Position of operation point in the two dimensional contextual control space

Mediated Atmospheres

Nan Zhao, Robert Richer Asaf Azaria



Understanding perceptual and physiological effects of multimodal mediated environments

- Facial Expressions, Head Orientation, Gaze
- Bio-Signals: ECG, GSR, Respiration, Temperature, etc.
- Basic Posture and Motion

Zhao, N., Azaria, A., Paradiso, J.A., "Mediated Atmospheres: a Multimodal Mediated Work Environment," Presented at Ubicomp 2017

Captivates

Moving the study of **deep attention** out of the lab –
real moments across ***many contexts and experiences***.

Patrick Chwalek | David Ramsay

A new probabilistic approach for measuring deep states of attention

Everyday sensing applied to …

LEARNING

CONCERTS

Making Online Learning More Adaptive Through Sensor Based Behavior Monitoring

More than **6.3 million students** in the U.S. took at least one online course in fall 2016 (5.6% rise from previous year) and in 2017, **77% of US corporations** used online learning

But how can we make these systems more understanding of the user and make the experience more personalized?

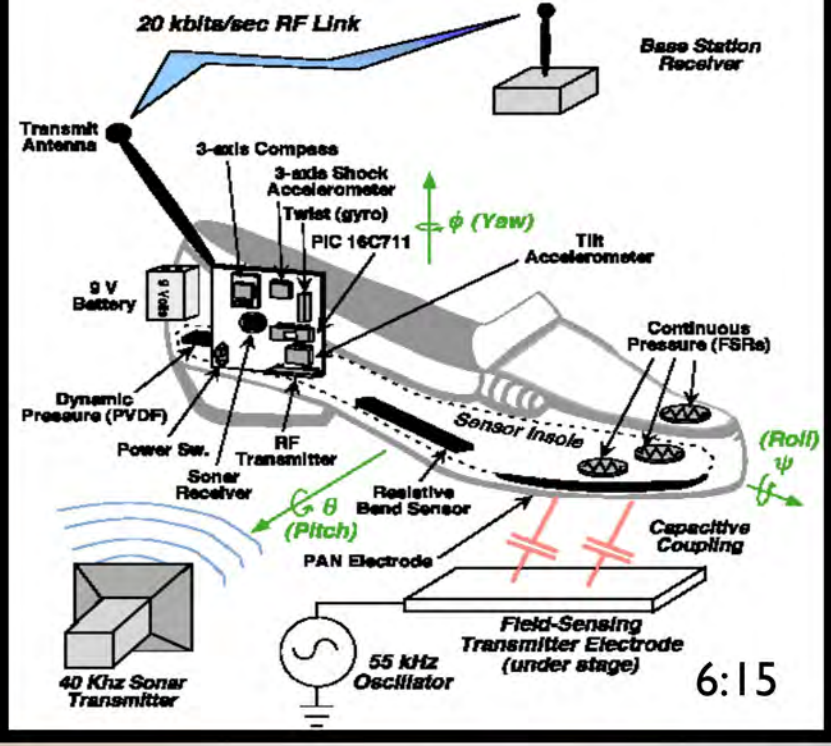
Is it possible to….

- build **non-invasive**, **robust, sensor systems** to monitor users' attention and engagement in dynamic learning environments?
  - construct a system that users **trust** to use in their private lives?
    - design an **adaptive**, **personalized learning experience**?

Patrick Chwalek

Media Lab 'Cyborgs' – 1995

1997 - Expressive Footwear



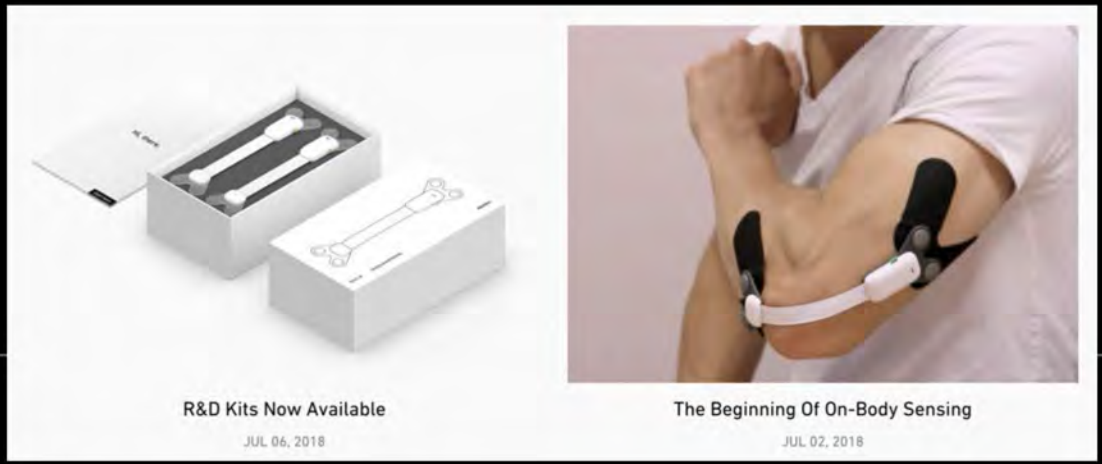
17 Data Channels

Tilt, shock, rotation, height, bend, location, multipoint pressure

"Design and Implementation of Expressive Footwear," IBM Systems Journal, October 2000, pp. 511-529.

M. Lapinski et al, "A Wide-Range, Wireless Wearable Inertial Motion Sensing System for Capturing Fast Athletic Biomechanics in Overhead Pitching" Sensors, July 2019

Nan-Wei Gong, PhD 2013

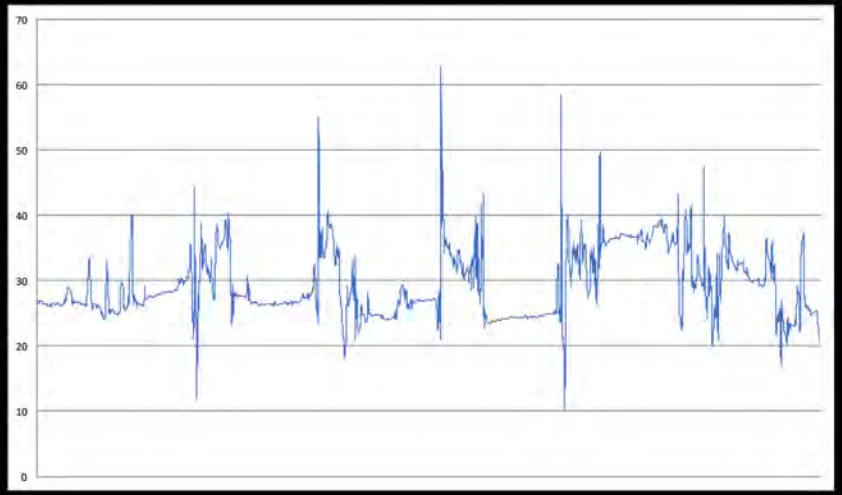


Wearing Figur8 in Zero G Aug. 2019

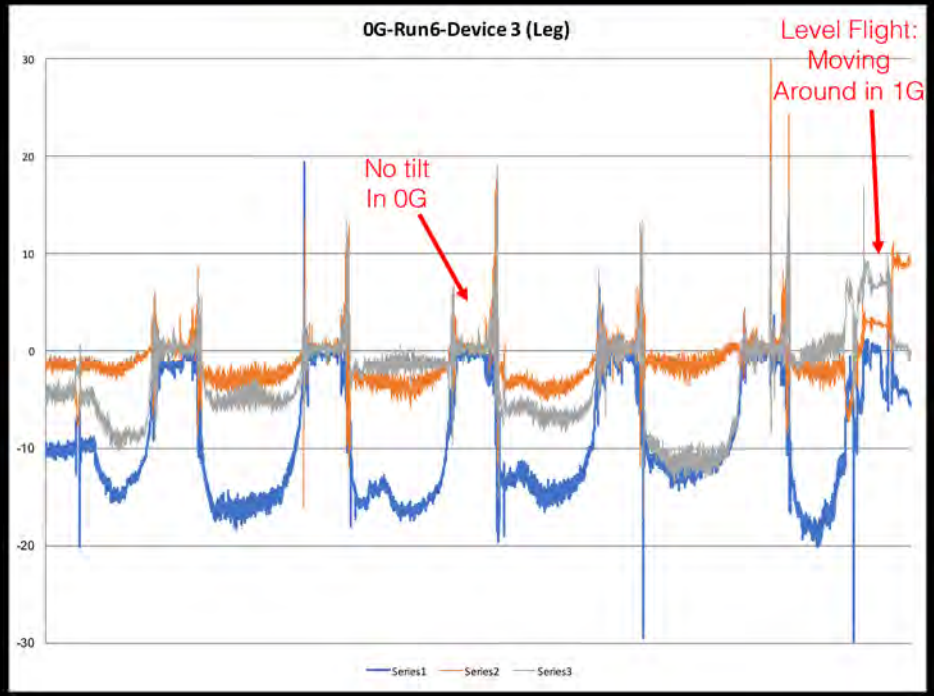
zero G

Some 0G Data (leg-worn)

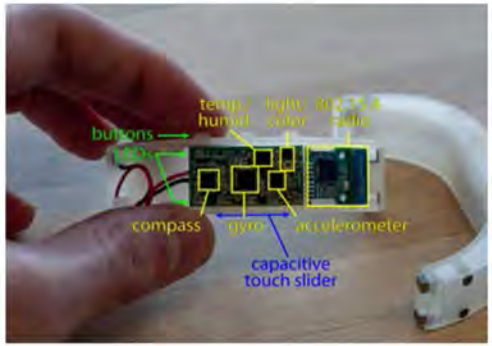
Goiniometer



Accelerometers

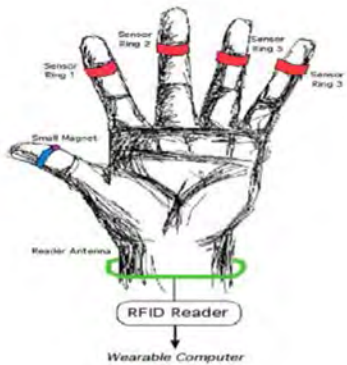


Direct Control From The Wrist/Fingers



B. Mayton et al, "WristQue: A personal sensor wristband," in Proc. BSN 2013

D. Way & J. Paradiso, "A Usability User Study Concerning Free-Hand Microgesture and Wrist-Worn Sensors" in BSN 2014

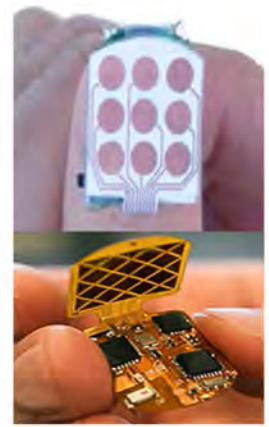


Concept

Working COTS Proof-of-Concept, 2010

Bainbridge, R. and Paradiso, J.A., "Wireless Hand Gesture Capture Through Wearable Passive Tag Sensing," in Proc. of the 2011 International Conference on Body Sensor Networks (BSN 2011), pp. 200-204.

Dementyev & Paradiso, "WristFlex: Low-Power Gesture Input with Wrist-Worn Pressure Sensors," in Proc. of *UIST 2014*



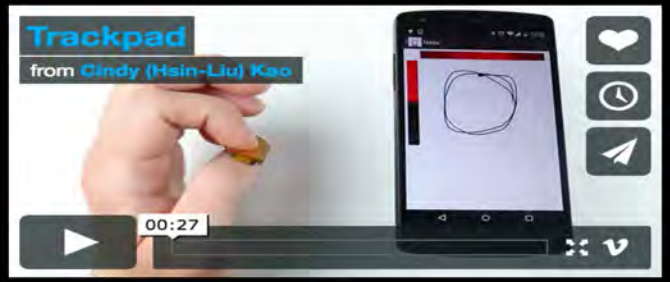
Kao, Dementyev, Paradiso, Schmandt. 'NailO: Fingernails as an Input Surface', CHI 2015

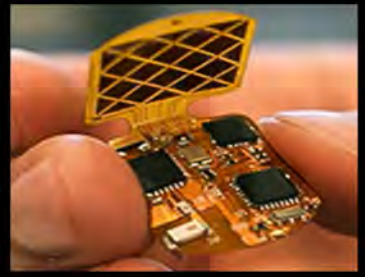

HGTV Remodels.com

WristFlex: Low-Power Gesture Input with Wrist-Worn Pressure Sensors

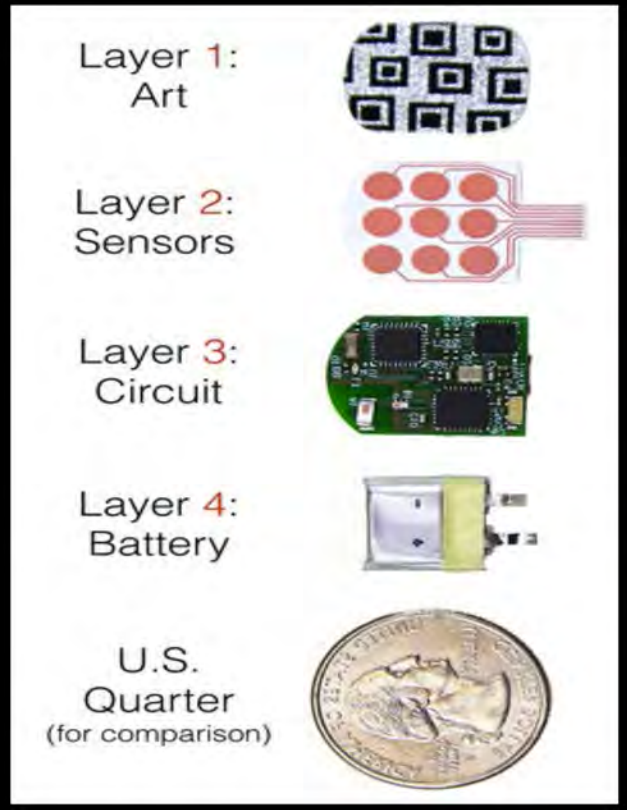
MIT Media Lab
Responsive Environments
Artem Dementyev
Joseph Paradiso

Nail*IO* – wireless touchpad fingernail

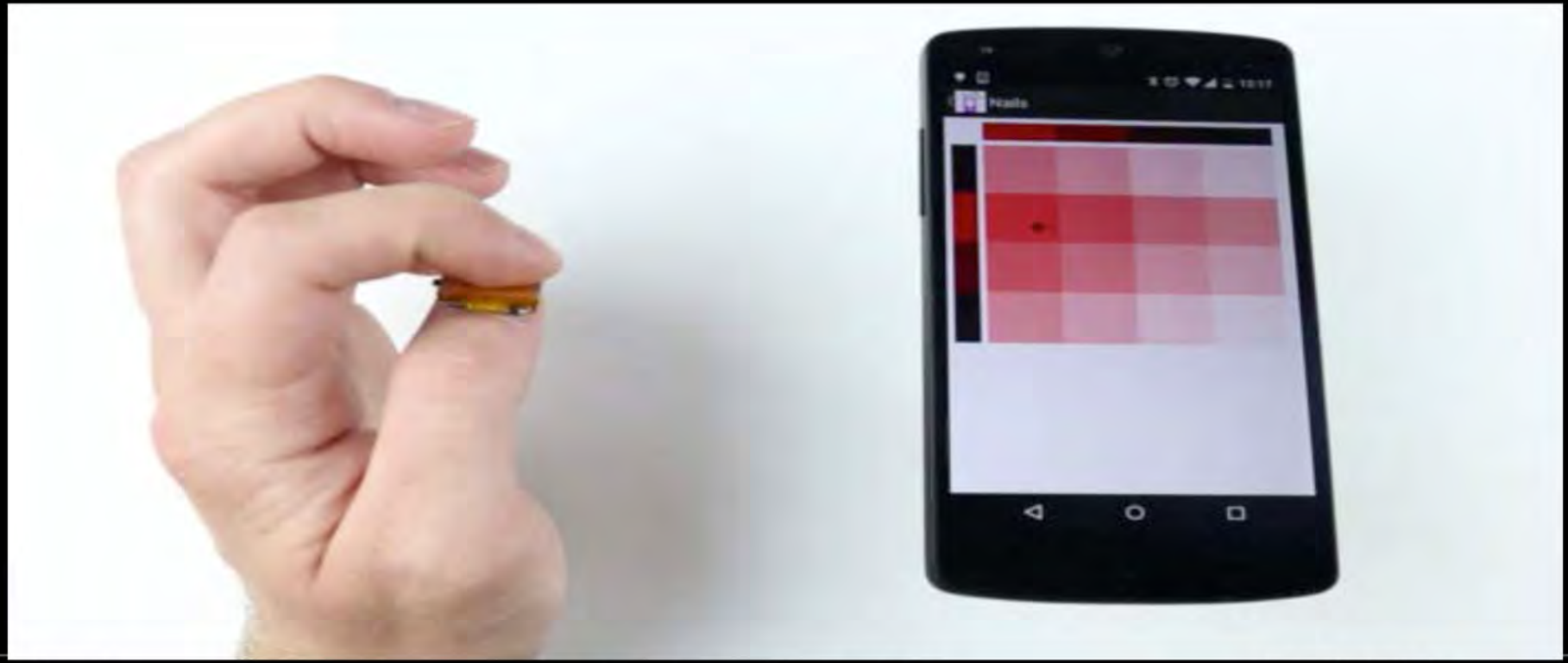




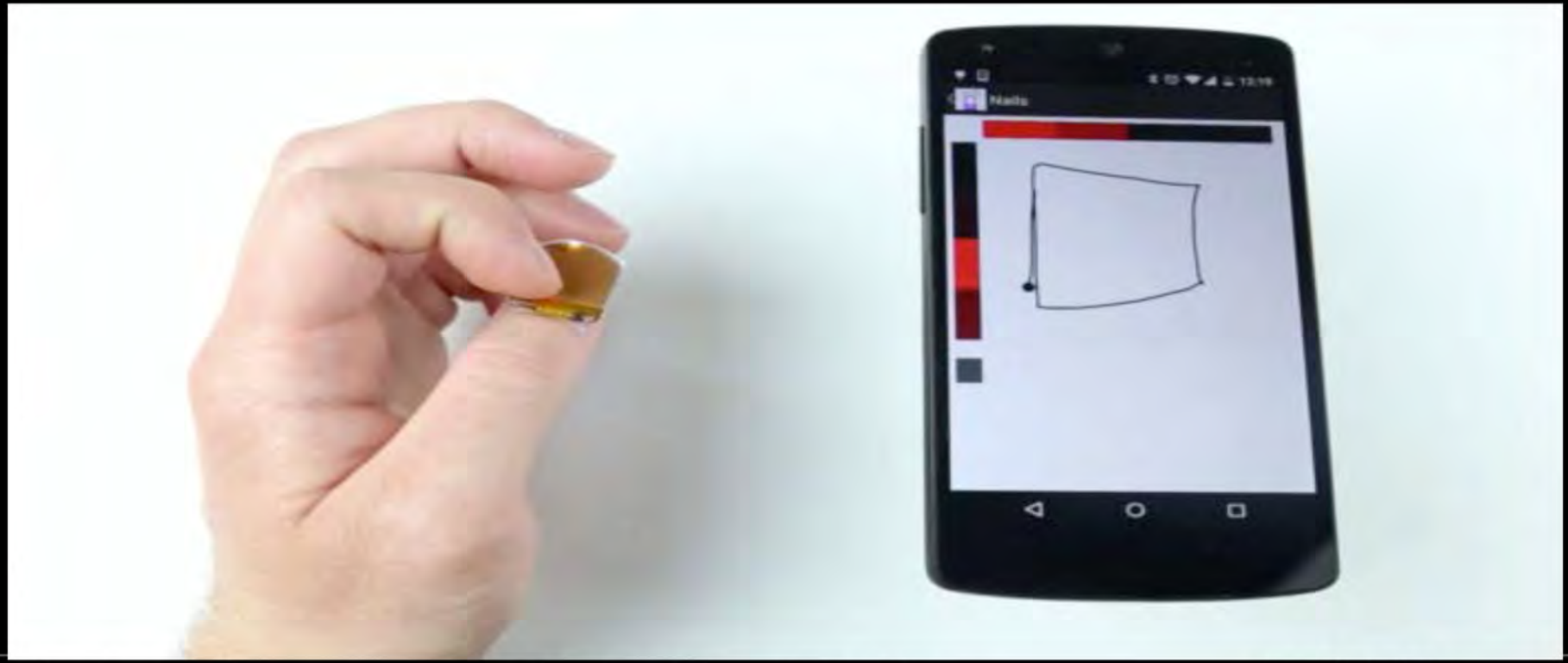
H.-L. C. Kao, A. Dementyev, J. Paradiso, C. Schmandt. 'NailO: Fingernails as an Input Surface', CHI 2015. *Honorable mention award*



Swiping & Raw Data



Fingernail Trackpad




MARTHASTEWART.COM

Parasitic Mobility in Mobile Sensor Networks

Phoresis

Passive

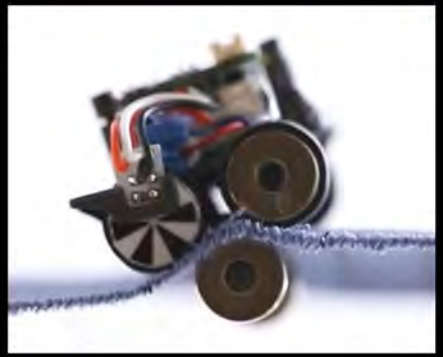
Active

The Tick (e.g., jumps onto a host, attaches, then disengages)
- The Bur (e.g., sticks to passing object, then shakes off)
- The Symbiote (an appliance you want to carry while it works)
- Contains GPS, RF, basic sensor suite

Paradiso & Laibowitz – Best Paper at Pervasive 2005

Rovables!

Artem Dementyev (ResEnv)
Cindy Kao (Living Mobile)
Sean Follmer (Stanford)



Best Paper Award UIST 2016

Rovables: Miniature On-Body Robots as Mobile Wearables

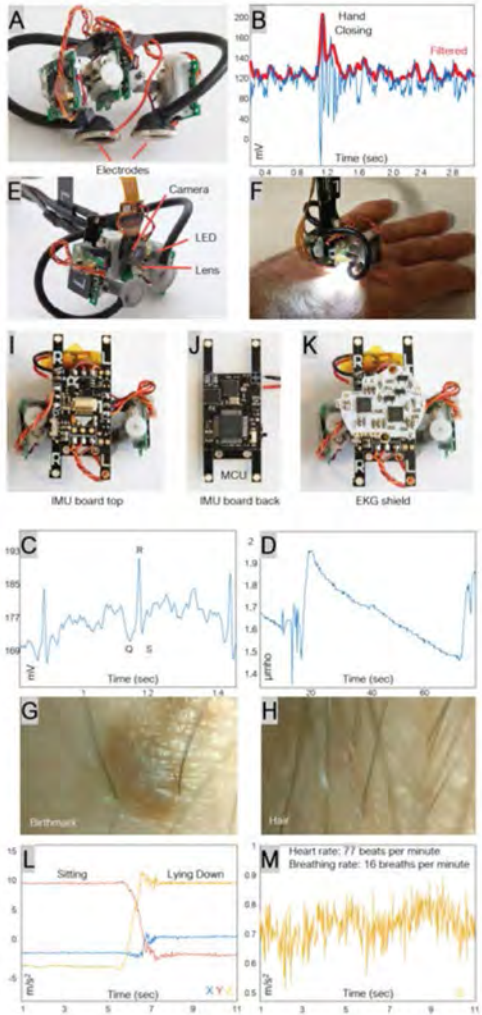
Artem Dementyev, Hsin-Liu (Cindy) Kao, Inrak Choi, Deborah Ajilo, Maggie Xu, Joseph Paradiso, Chris Schmandt, Sean Follmer

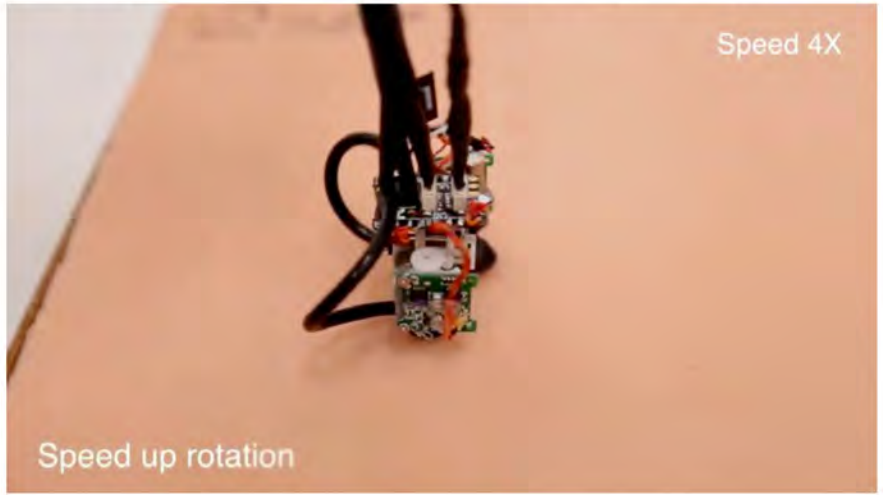
MIT Media Lab, Stanford Universtiy

Ars Electronica 2016

On-skin walking and flexible robots (Artem Dementyev)

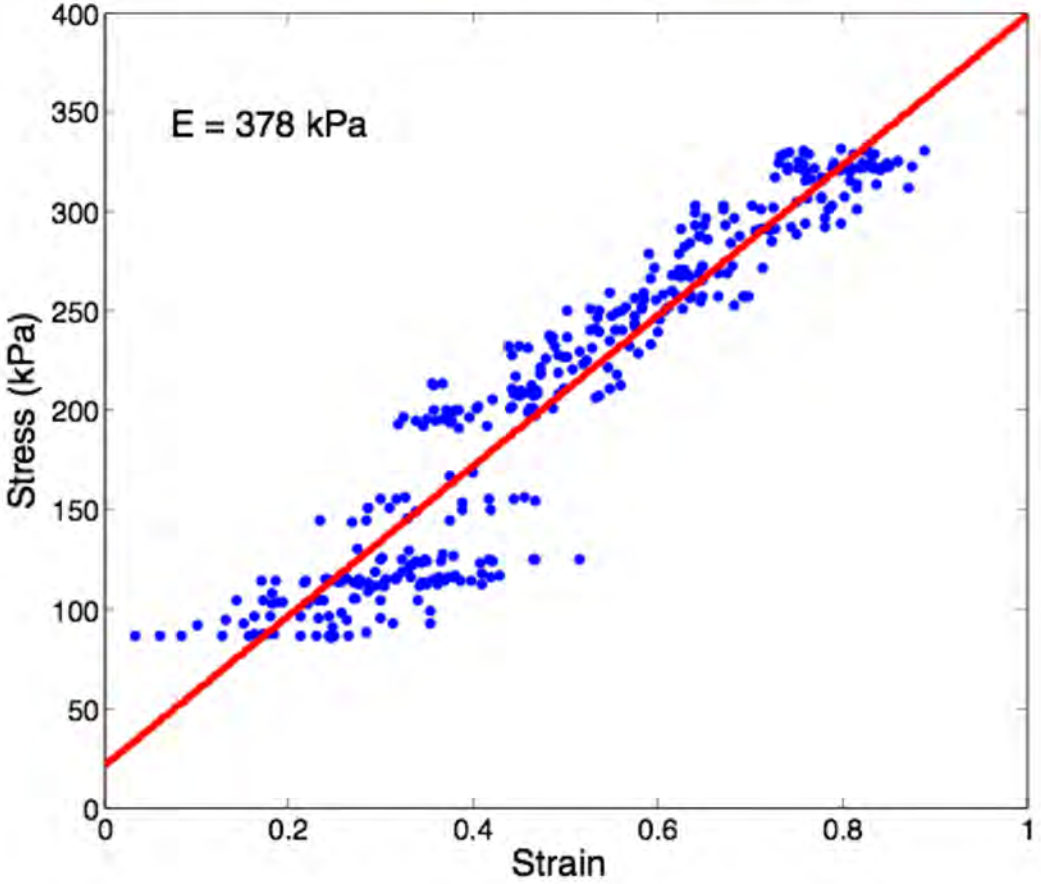
‘Homemade’ Flex Robots
(with Jifei Ou & Jie Qi)





Map skin’s mechanical properties

Modulus of Elasticity



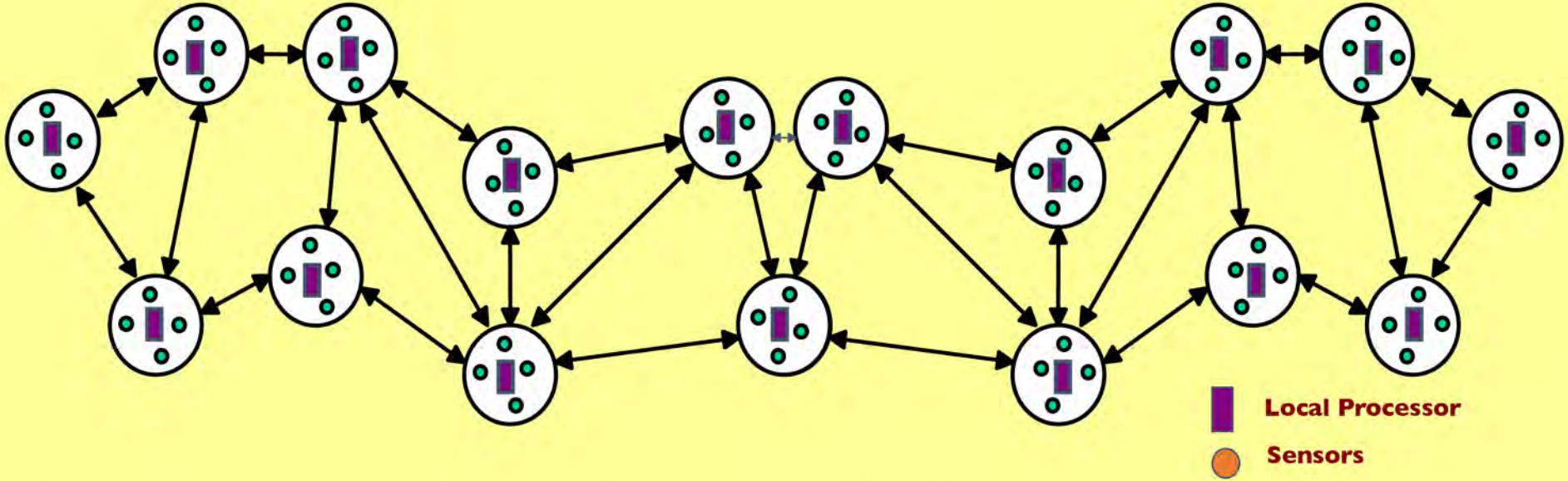
The FreeD

A handheld digital milling device for craft and fabrication

Amit Zoran

BEST PAPER AWARD – CHI 2013

Sensate Media



Densely-networked sensor-processor 'Soup' – Electronic skin, etc.

Paradiso, J.A., Lifton. J., and Broxton, M., Sensate Media – Multimodal Electronic Skins as Dense Sensor Networks, *BT Technology Journal*, Vol. 22, No. 4, October 2004, pp. 32-44.

New design all on Flex

UIST 2015

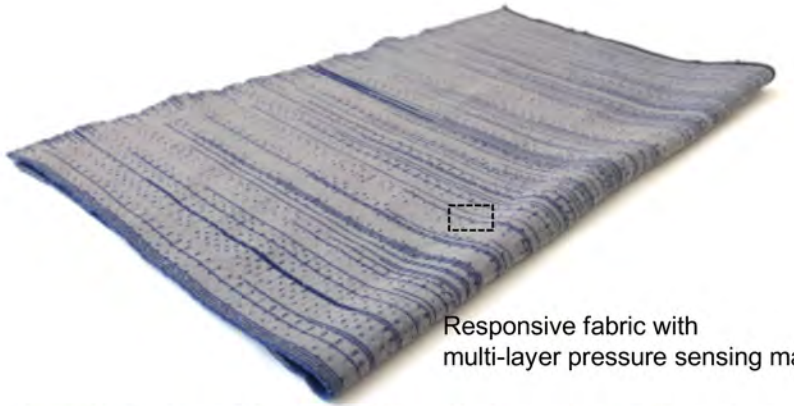
SensorTape: Modular and Programable 3D-aware Dense Sensor Network on a Tape

Artem Dementyev
Hsin-Liu (Cindy) Kao
Joseph A. Paradiso

Dementyev & Paradiso, ”SensorTape: Modular and Programable 3D-Aware Dense Sensor Network on a Tape” UIST 2015

Knitables: Digital knitting of electronic fibers

Irmandy Wicaksono, Joseph A. Paradiso

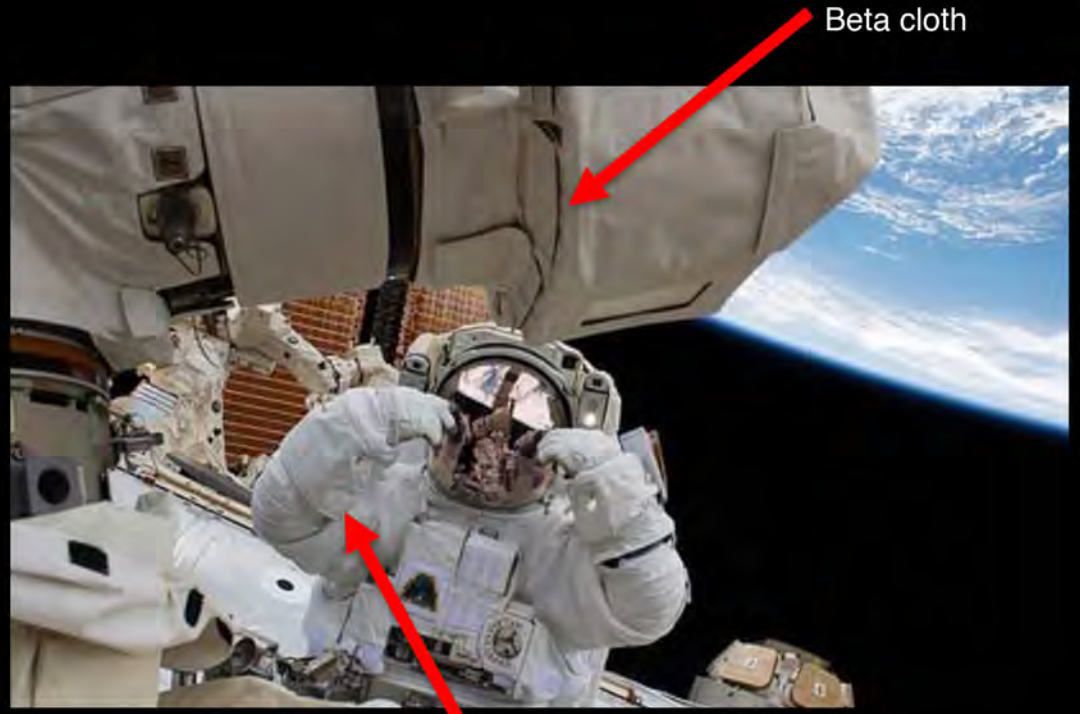


Responsive fabric with
multi-layer pressure sensing matrix

SpaceSkin

Aerospace-Grade Sensate Textiles

Today's aerospace-grade protective textiles are passive, woven structures



SpaceSkin

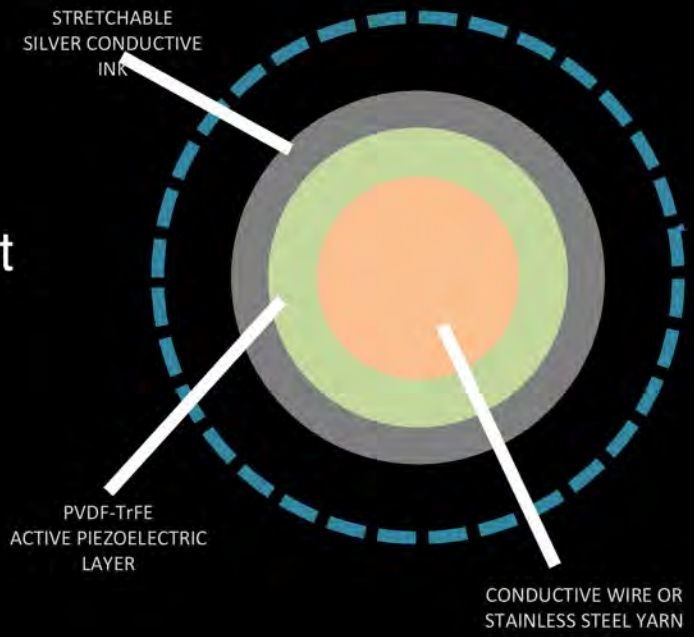
Aerospace-Grade Sensate Textiles

We are bringing the latest advances in function fibers and electronic textile design to an aerospace context

SpaceSkin

Aerospace-Grade Sensate Textiles

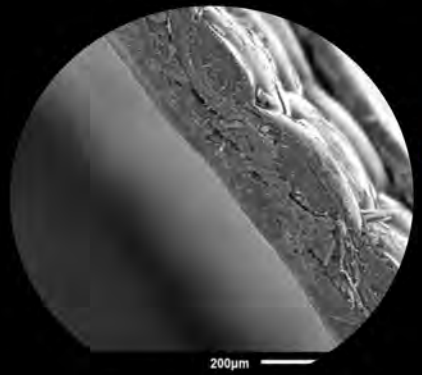
by integrating piezoelectric fibers that sense vibration and impact



SpaceSkin

Aerospace-Grade Sensate Textiles

into materials with decades of spaceflight heritage

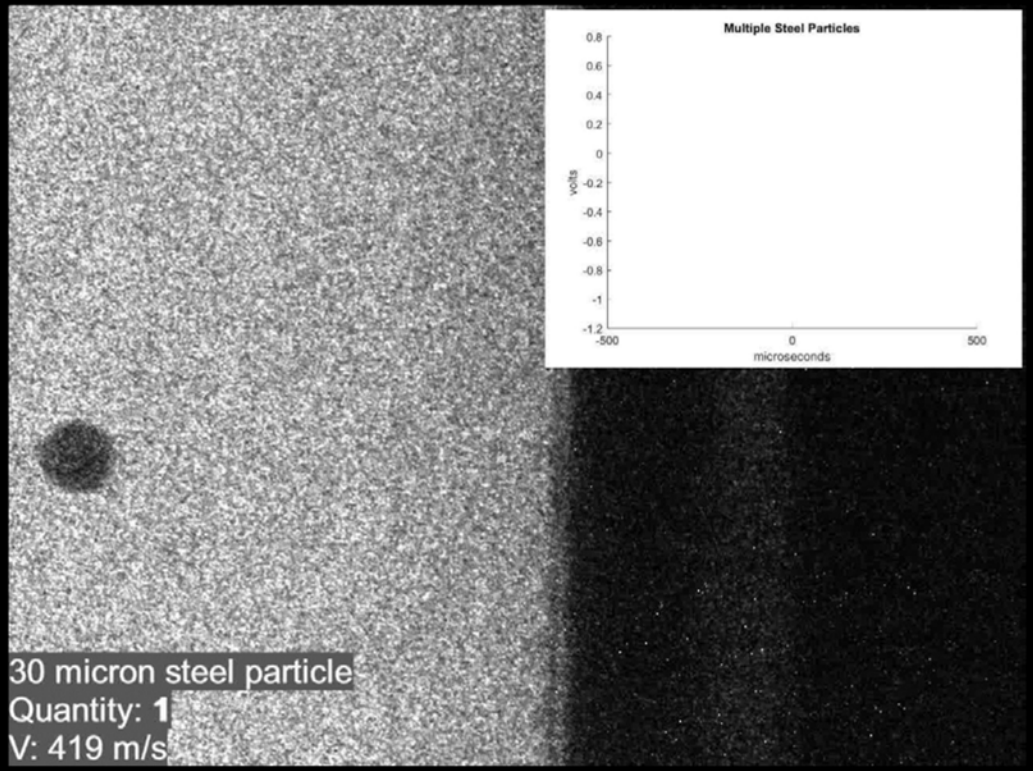


Teflon-impregnated fiberglass

SpaceSkin

Aerospace-Grade Sensate Textiles

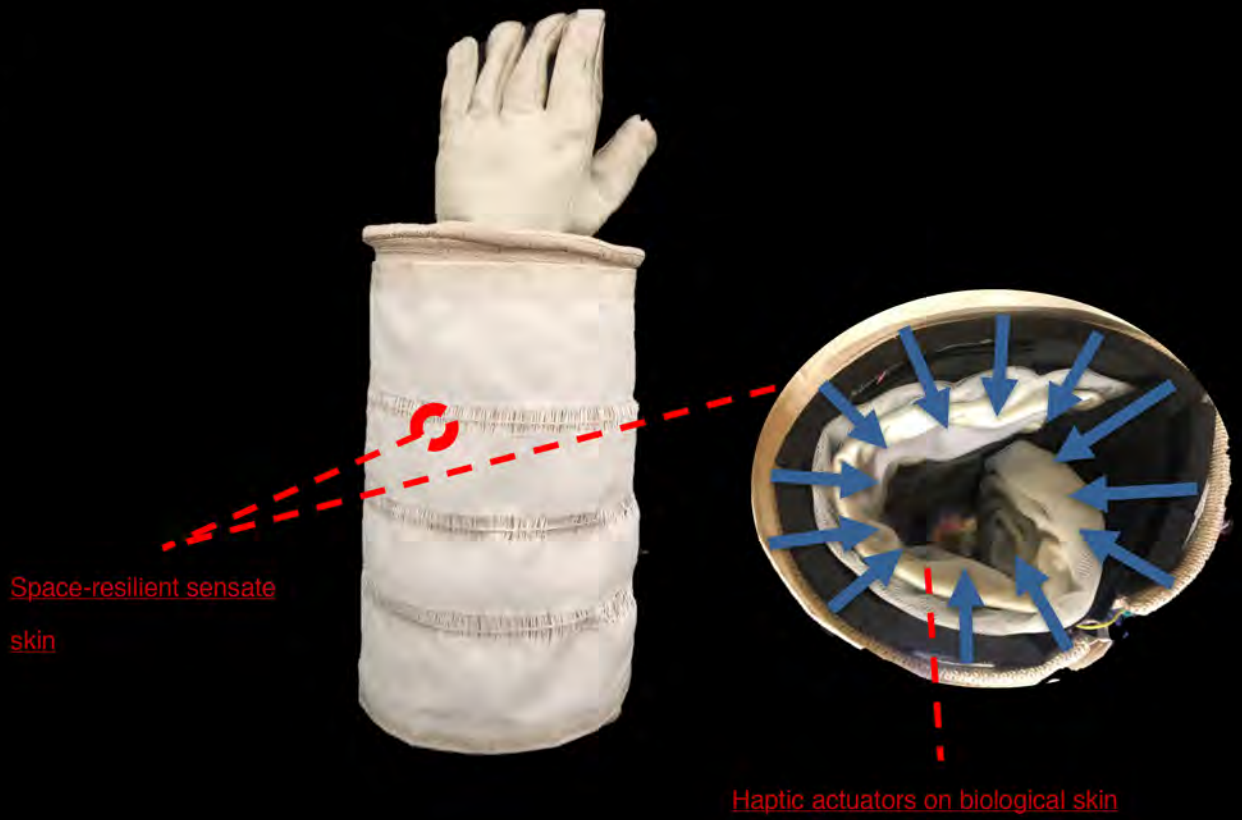
To create materials that can characterize debris and micrometeoroid impactors on persistent space assets



SpaceSkin

Aerospace-Grade Sensate Textiles

And enable astronaut haptic feedback systems



SpaceSkin

Aerospace-Grade Sensate Textiles

With potential application in our exploration of extreme environments on Earth

Scientific American
Cover Article
July 2014

COMPUTER SCIENCE

EXTRA SENSORY PERCEPTION

How a world filled with sensors will change the way we see, hear, think and live

By Gershon Dublon and

Gershon Dublon is a Ph.D. student at the M.I.T. Media Lab, where he develops new tools for exploring and understanding sensor data.

Joseph A. Paradiso is an associate professor of media arts and sciences at the Media Lab. He directs the Media Lab's Responsive Environments Group, which explores how sensor networks augment and mediate human experience, interaction and perception.

The Instrumented Earth

Internet of Things at Planetary Scale

The New York Times

Tuesday, July 4, 2017 Today's Paper Video 82°F Nasdaq -0.49%

North Korea Claims It Tested Intercontinental Ballistic Missile

By CHOE SANG-HUN

- North Korea on Tuesday claimed a milestone in its efforts to build nuclear weapons that could reach the mainland United States.
- U.S. and South Korean authorities were continuing to analyze the data. Experts said the missile could be capable of hitting Alaska.

NEWS ANALYSIS

U.S. Has Few Good Options on Dealing With North Korea

By DAVID E. SANGER 11:24 AM ET

President Trump's warnings have bumped up against reality: U.S. policy has had little effect so far as Pyongyang built up its arsenal.

· **Trump Warns China U.S. May Act Alone on North Korea**

Tristan Spinski for The New York Times

The 'Rewilding' of a Century-Old Cranberry Bog

Scientists are turning a cranberry bog in Plymouth, Mass., back into coastal wetland. The effort is seen as a path for restoring habitat that can be a buffer to rising oceans.

By JESS BIDGOOD

SMARTER LIVING

What to Bring to a Summer Potluck Picnic

A New Treatment for Dogs Scared by Thunder and Fireworks

The Opinion Pages

ON CAMPUS

Going to Hooters and Seeing America

The restaurant exposed four Pakistani kids to the crass yet oddly family-friendly side of this country.

Putting Citizenship Back in Congress

By DAVID BORNSTEIN

Advocates for better government can be trained to approach lawmakers.

· **Editorial: Happy Fourth of July! Show Us Your Papers**
· **Brooks: What's the Matter With Republicans?**

A Little Piece of Hell

Fighting in Vietnam around July 4, 1967, showed Marines at their best, and politicians at their worst.

· **Declaration of Disruption**
· **New Yorkers Who Like Trump**
· **The Country I Love**
· **Thomas Jefferson's Bible Teaching**
· **Join us on Facebook »**

TIMES INSIDER »

Fireworks Oreos? A Reporter Digests

THE CROSSWORD »

Play Today's Puzzle

4m Prime Minister Justin Trudeau of Canada has a penchant for quirky socks. But his Irish counterpart, Leo Varadkar, upstaged him when the two met in Dublin to discuss trade.

15m For the parents of a British infant, whom a

Tidmarsh Site

Tidmarsh, November 1, 2018

Mayton, B., et al, 'The Networked Sensory Landscape: Capturing and Experiencing Ecological Change Across Scales,' to appear in *Presence*, MIT Press Journal, Special issue on Arts, Aesthetics, and Performance in VR and Telepresence, 2018

How To Monitor the Restoration Process ?

Constant Environmental Monitoring

Wireless Sensor Network

Acoustic Scene Analyses

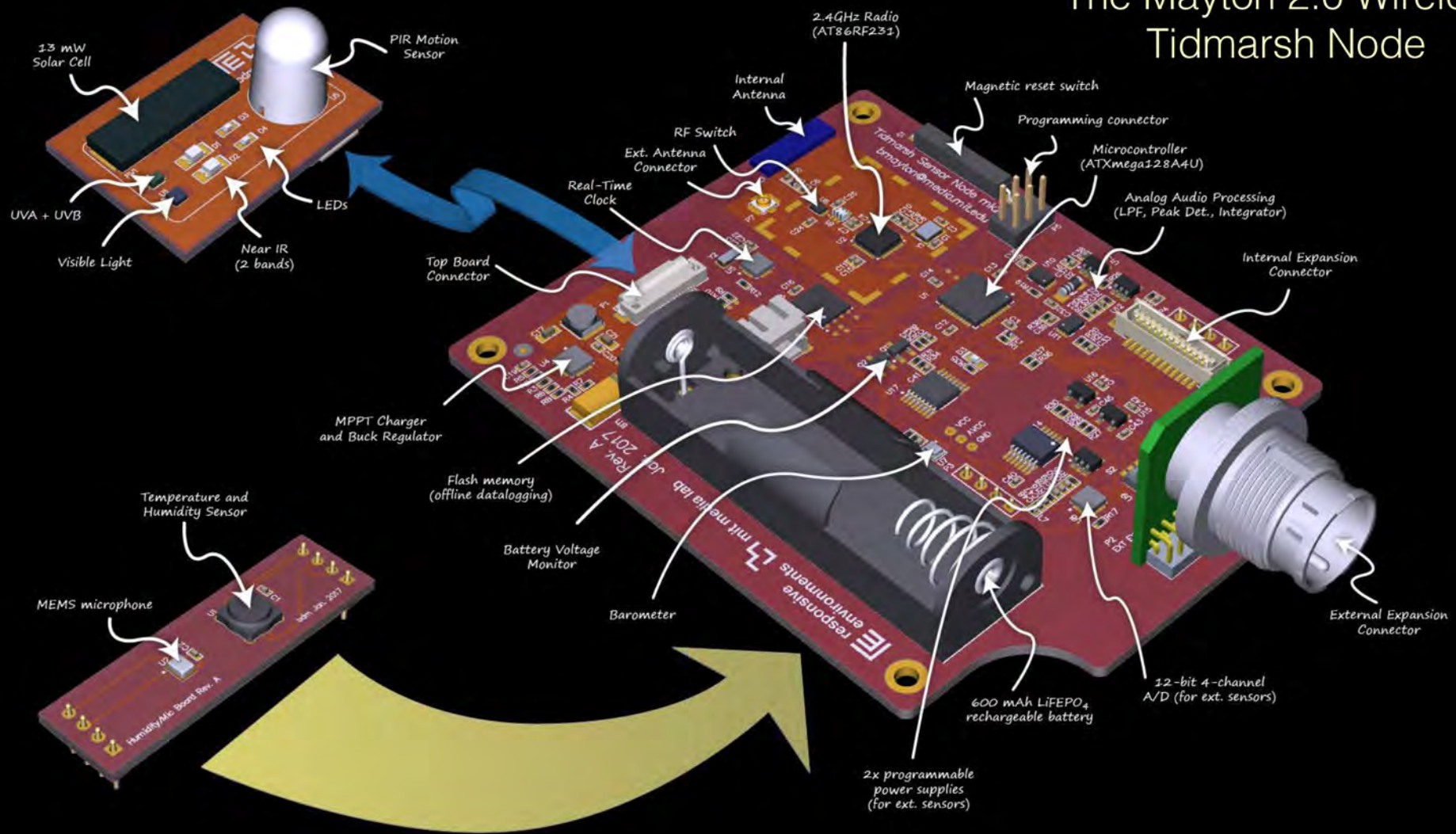
Microphones

Visual Rendering and Recognition

Cameras

What about the network ?

The Mayton 2.0 Wireless Tidmarsh Node



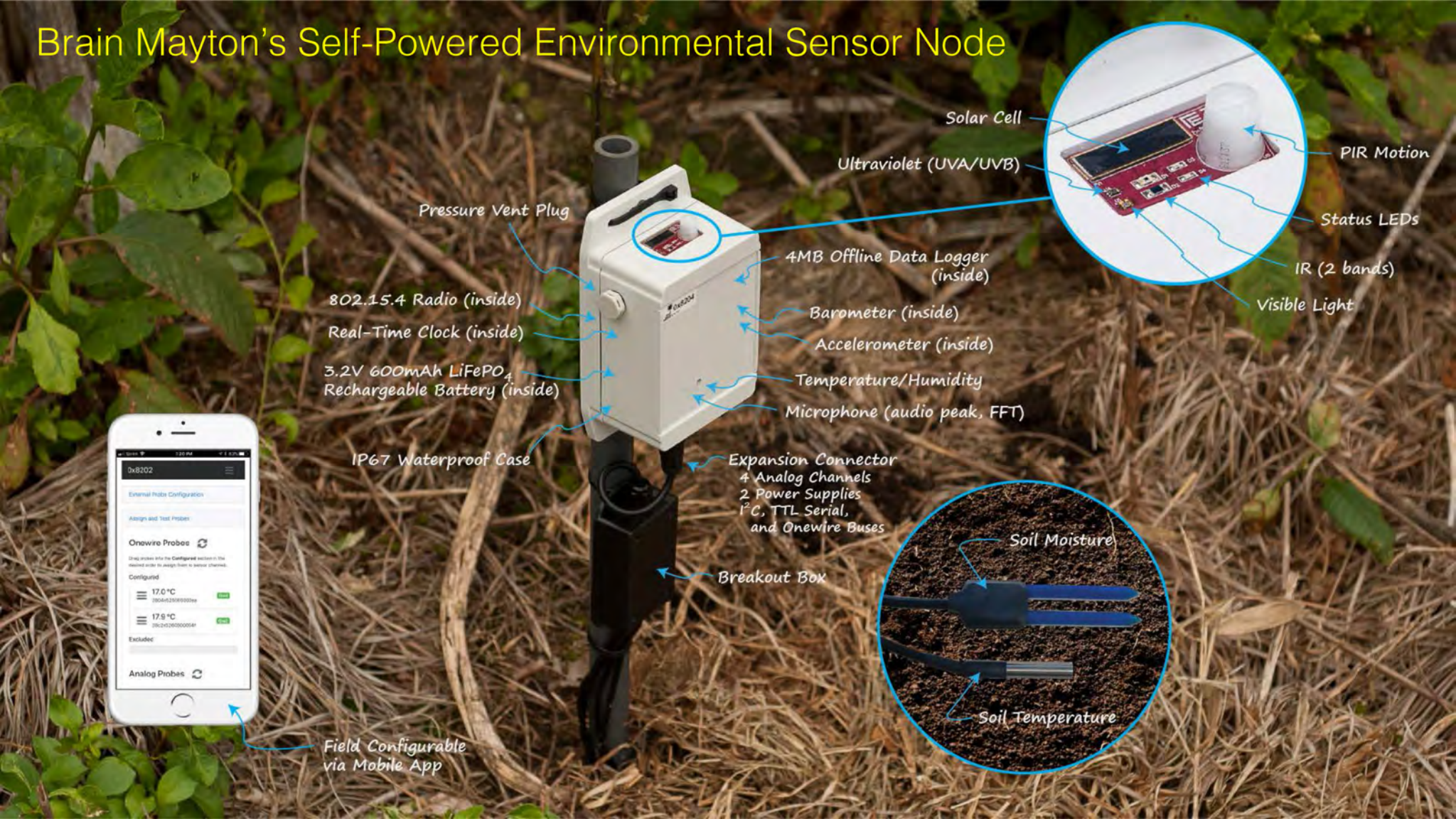
Easily Expandable for Ubiquitous Wireless Sensing

Can host a variety of sensors

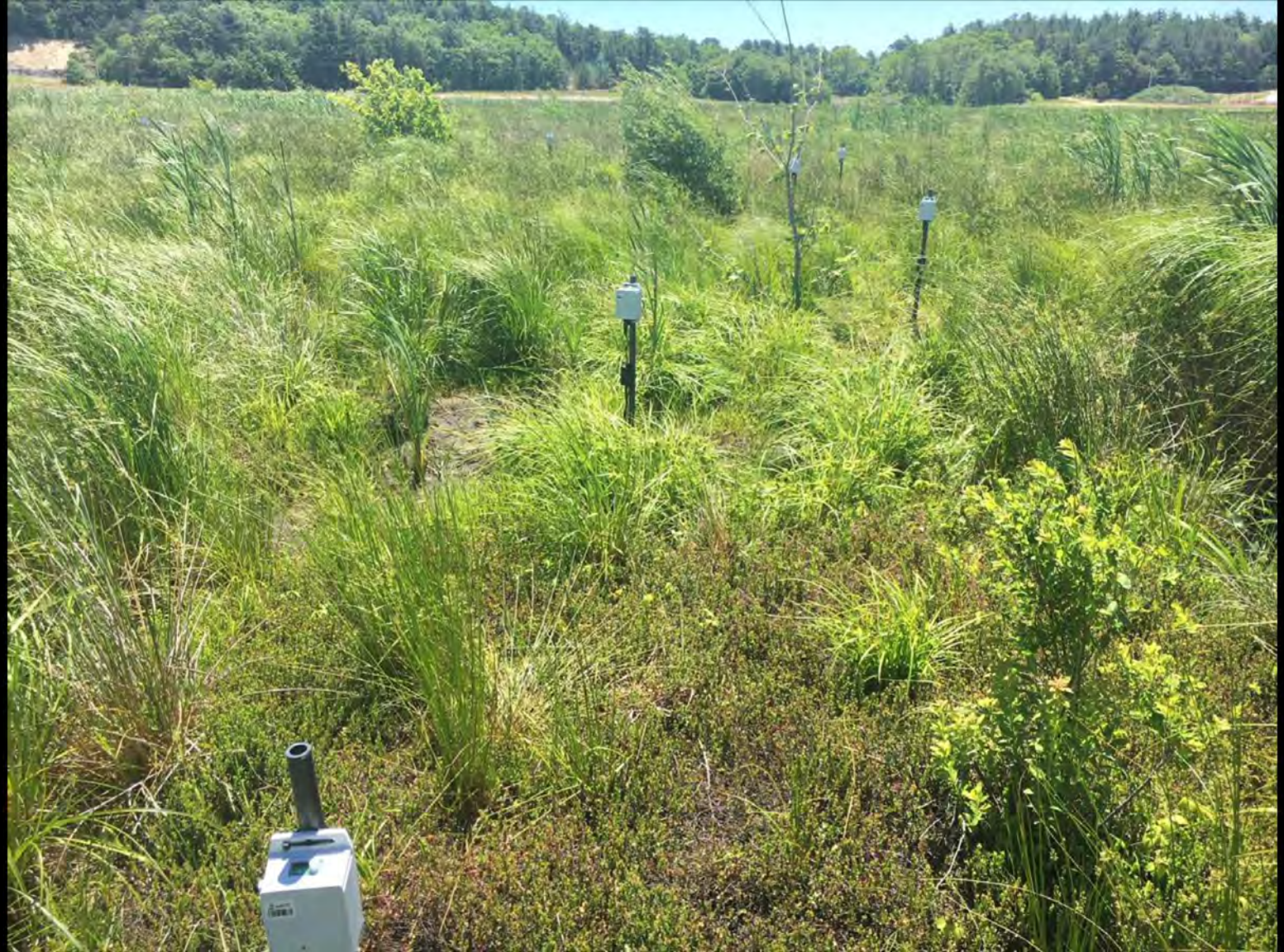
- Soil Moisture
- Soil Redox/Conductivity
- Soil Temperature
- Air/Water Quality
- Etc…

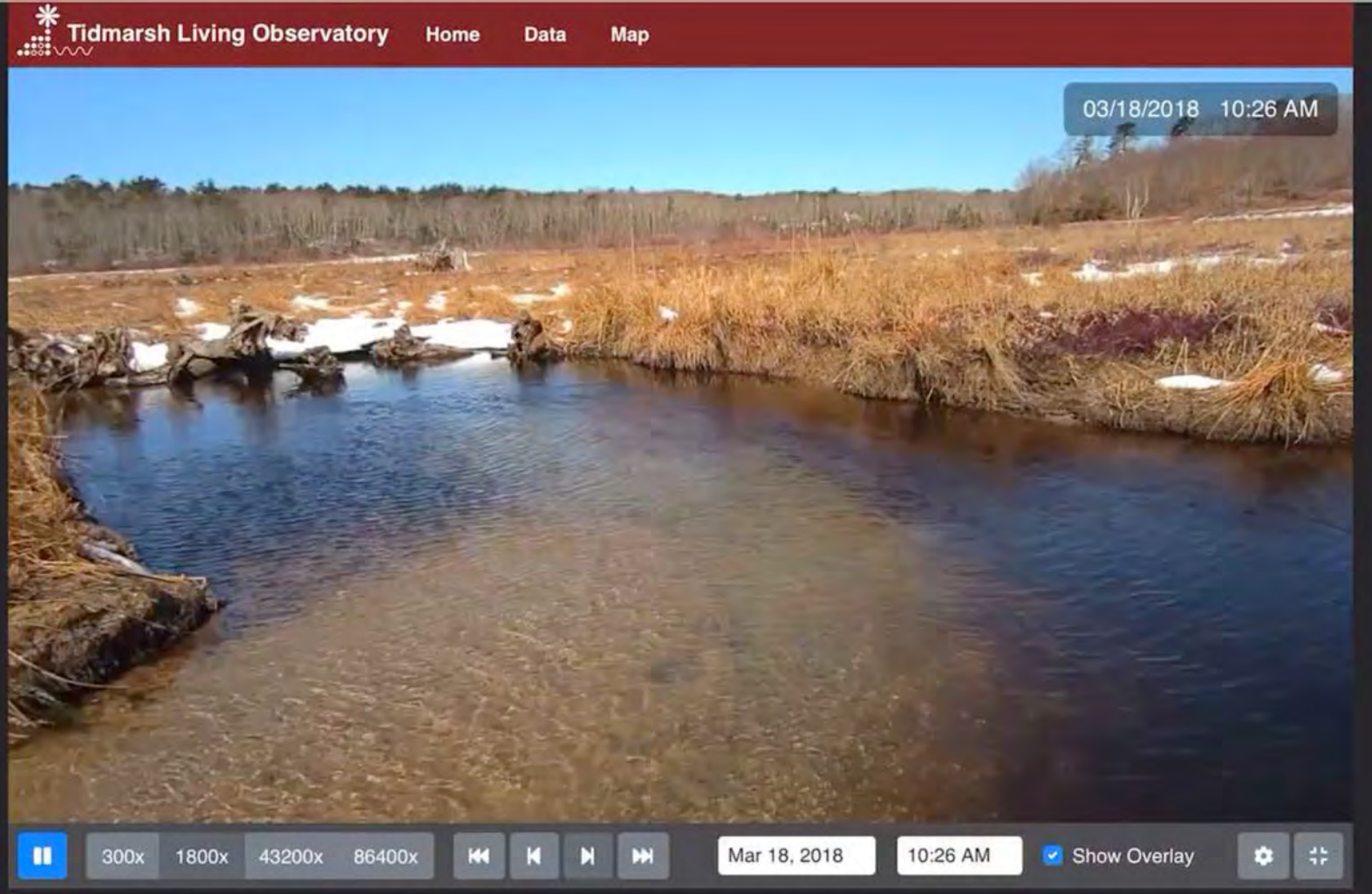
Uses cheap, vintage Telco crimp connectors (waterproof!)

Brain Mayton's Self-Powered Environmental Sensor Node




CLASS WORKSPACE
KEEP CLEAN
MAS836 WORK





Privacy policy

mit media lab

responsive environments

http://Tidmarsh.media.mit.edu

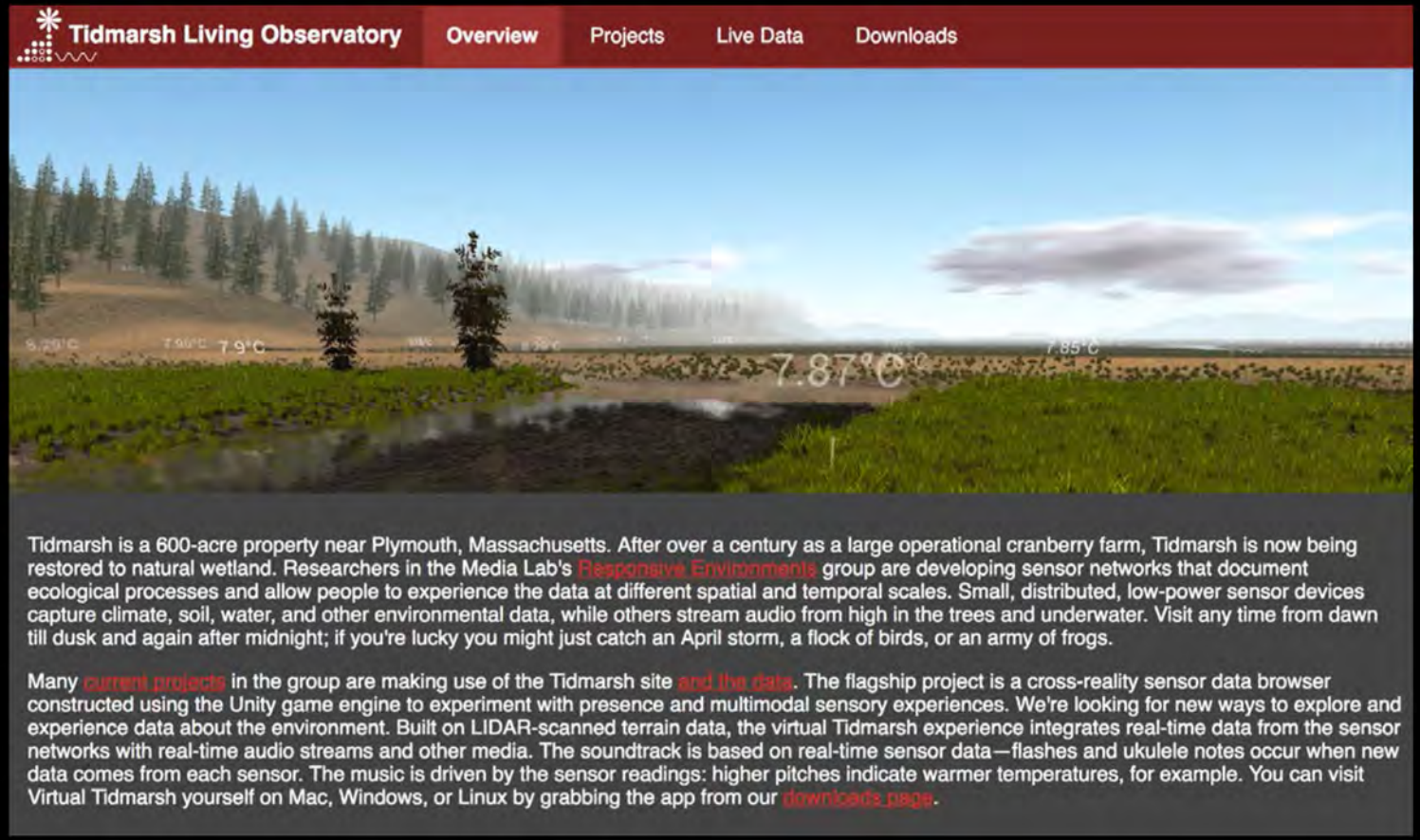


Image-Guided Rendering – Populate Flora, Ground Cover Based On Camera Feeds

DoppelMarsh 3

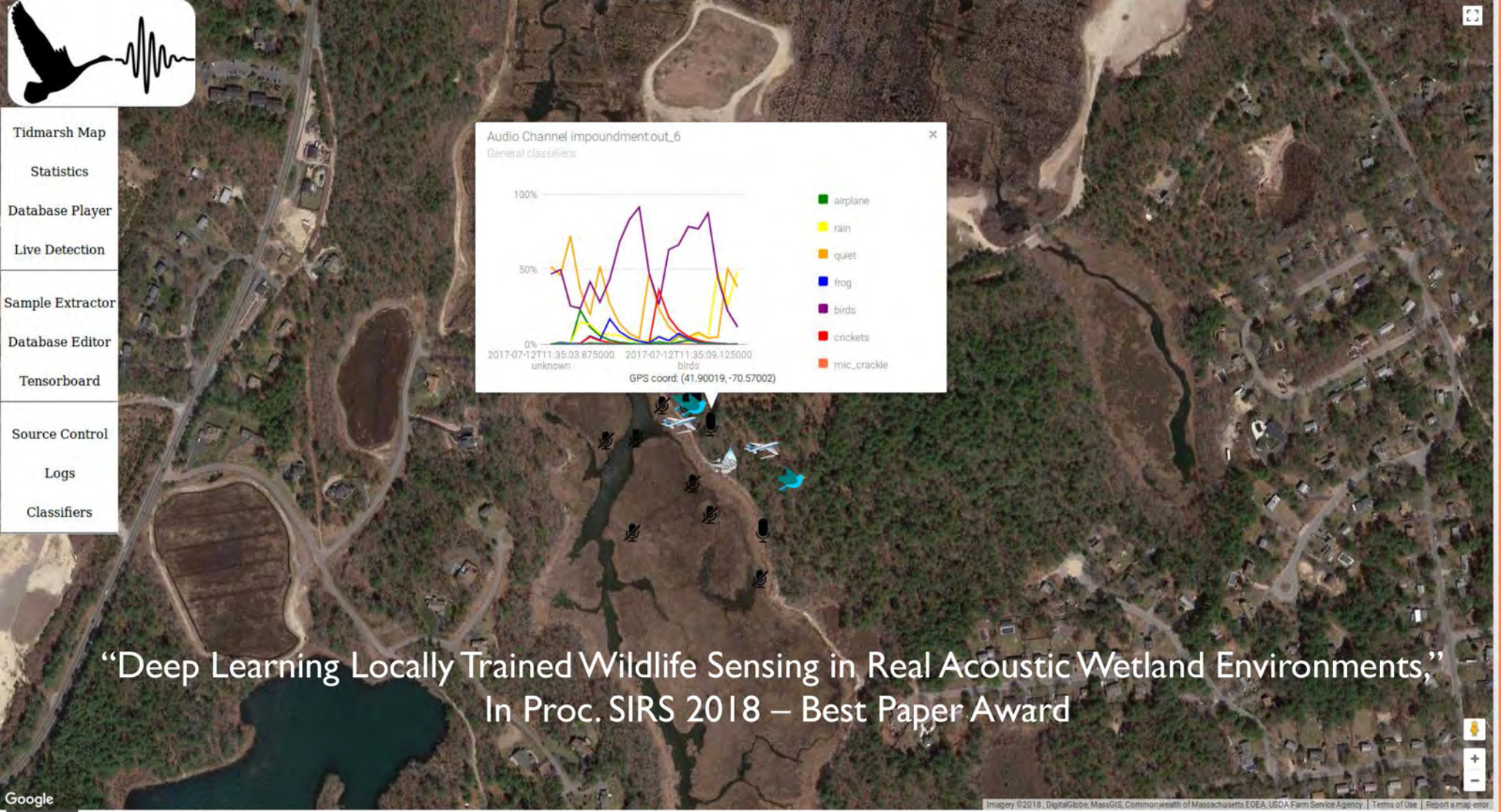
Don Derek Haddad, Gershon Dublon, Brian Mayton
Spencer Russell, Evan Lynch, Joe Paradiso

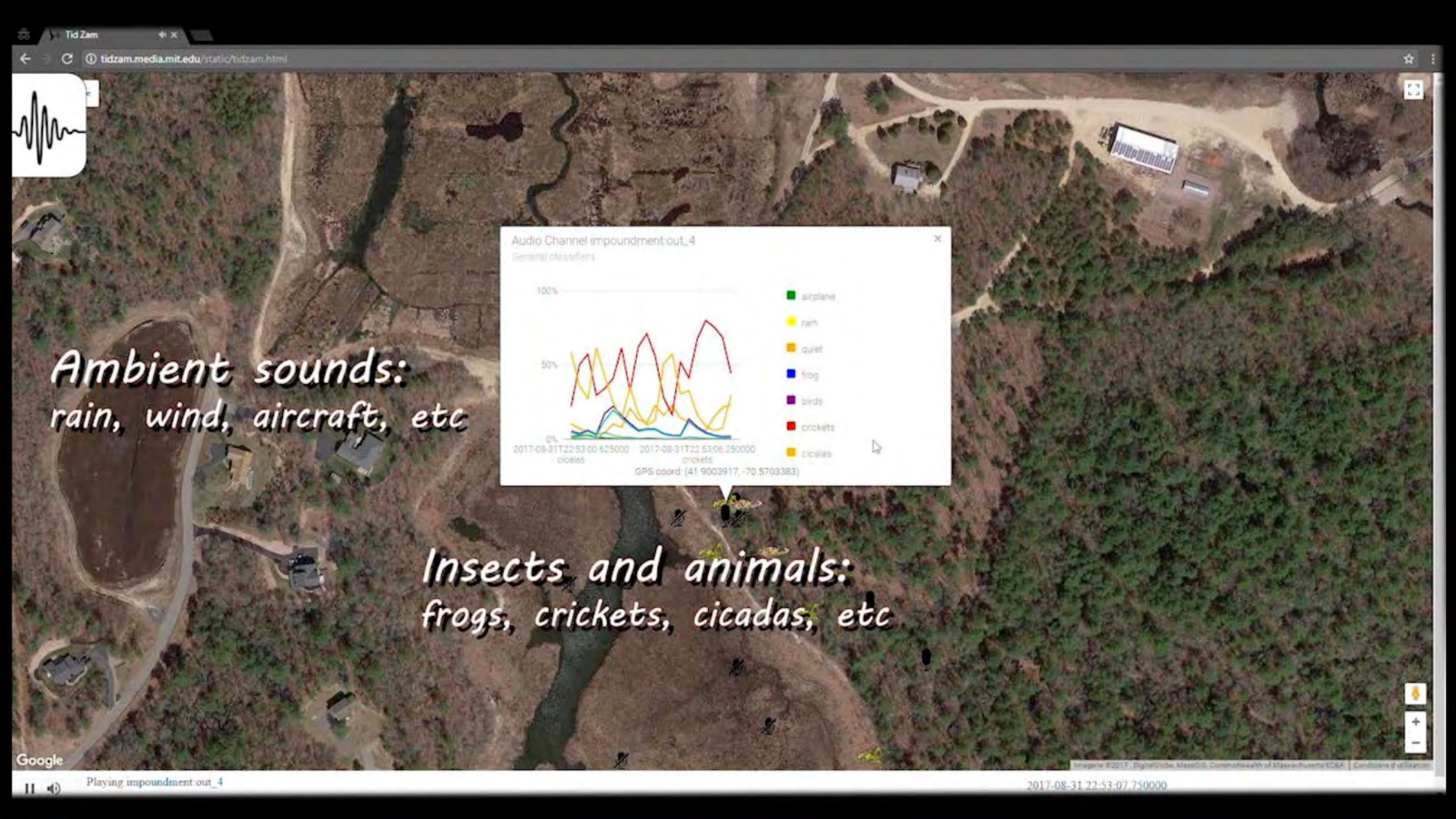

17.7°C
12.14°C

Ubiquitous Audio Capture

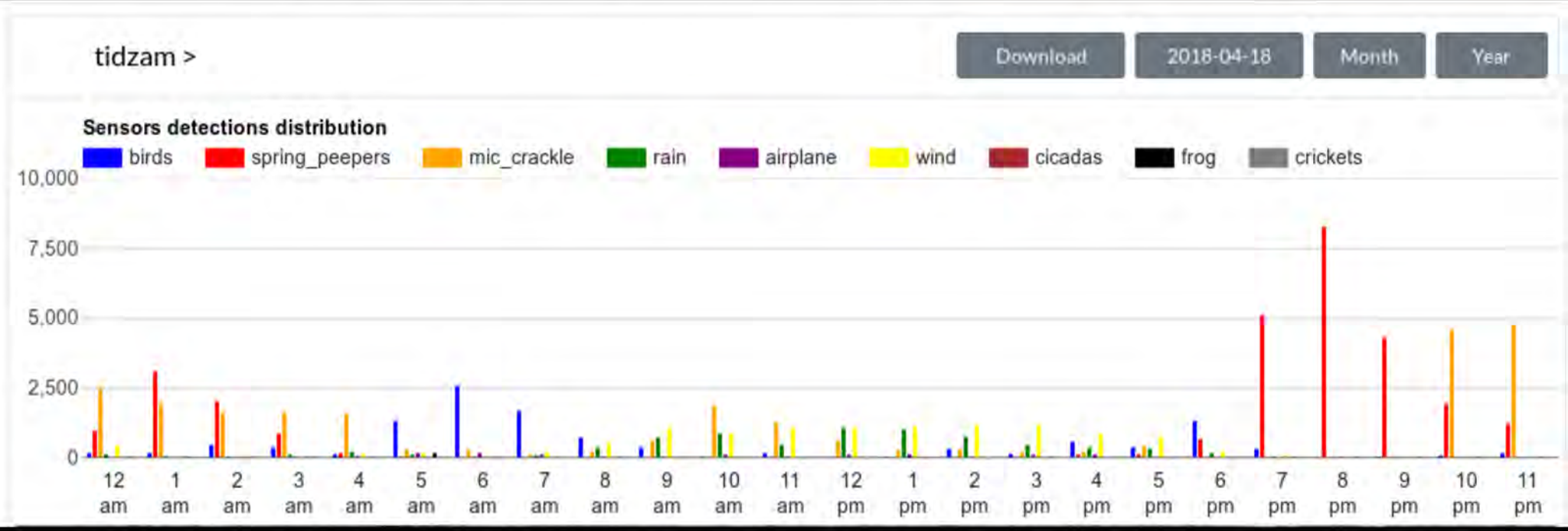
http://tidmarsh.media.mit.edu/site.html#

25 Mics & hydrophones streaming now

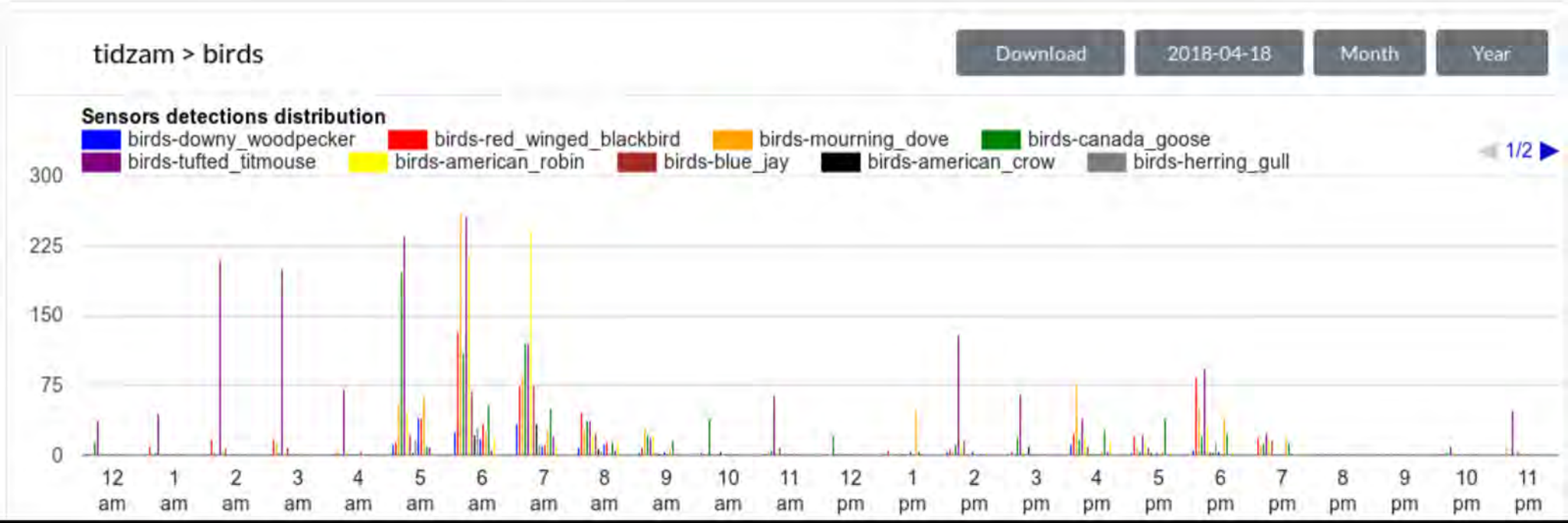

Tidmarsh Map
Statistics
Database Player
Live Detection
Sample Extractor
Database Editor
Tensorboard
Source Control
Logs
Classifiers
Audio Channel impoundment:out_6
General classifiers
100%
50%
0%
2017-07-12T11:35:03.875000
unknown
2017-07-12T11:35:09.125000
birds
airplane
rain
quiet
frog
birds
crickets
mic_crackle
GPS coord: (41.90019, -70.57002)
"Deep Learning Locally Trained Wildlife Sensing in Real Acoustic Wetland Environments,"
In Proc. SIRS 2018 – Best Paper Award
Google
Playing impoundment:out_6
2018-02-23 16:07:33


Tid Zam
tidzam.media.mit.edu/static/tidzam.html
Audio Channel impoundment:out_4
100%
50%
0%
airplane
rain
quiet
frog
birds
crickets
cicadas
2017-08-31T22:53:00.625000
cicadas
2017-08-31T22:53:06.250000
crickets
GPS coord: (41.9002917, -70.5703383)
Ambient sounds:
rain, wind, aircraft, etc
Insects and animals:
frogs, crickets, cicadas, etc
Google
Playing impoundment:out_4
2017-08-31 22:53:07.750000

Audio Classification Over a Spring Day



Different Bird Species Over A Spring Day



ResEnv Postdoc Clement Duhart & his Paris-Based Team

TidZam Video

:38

Medhi	SAM
Yliess	HATI
Gregor	JOUET
Khang	TRUONG

DoppleMarsh Visitor

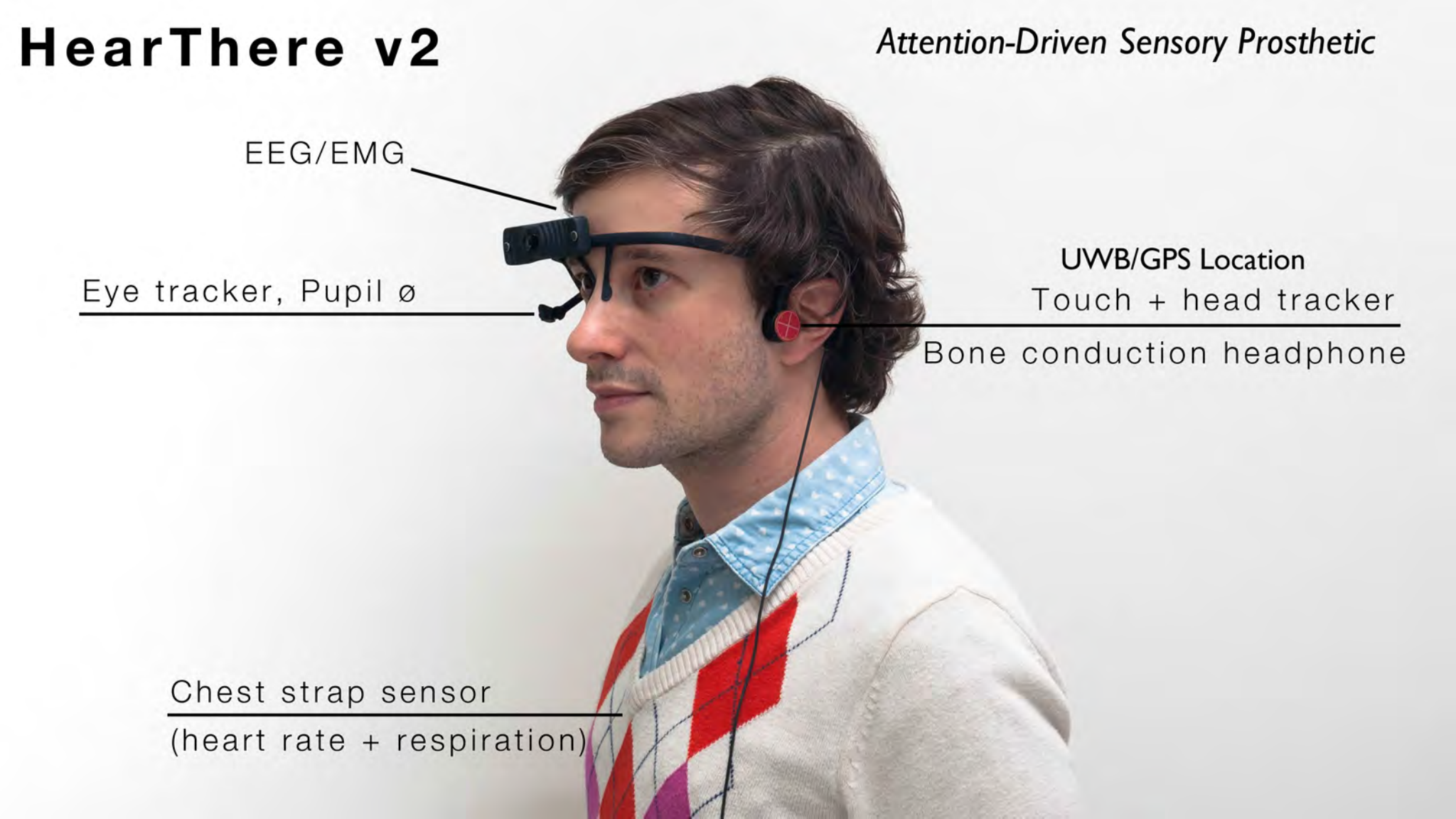
Neal	LAUSSON
David	CHASSERAY
Julien	LABARRE
Khang	TRUONG

TidZam Apps

Youness	Jay Kafia
Sabri	Lachihab
Antoine	Demon-Chaîne
Georges	Cosson
Yassine	Rachedi

HearThere v2

Attention-Driven Sensory Prosthetic



hear there

Sensory Superpowers Through Auditory Augmented Reality

Gershon Dublon, Spencer Russell, Brian Mayton

bone conduction
head tracking, touch, eeg

Summary

- Sensors are getting out there, piggybacking on commercial products
- Once affordances are shared across devices, we're living in an ecology of devices & applications
  - This will happen fast once common protocols appear
  - Phase transition into true Ubicomp/IoT
- How will human presence generalize?
- How will we control access to our attention?
- Where does 'self' stop and 'other' begin?