Towards Open Source Platforms for Wearable Health Monitoring
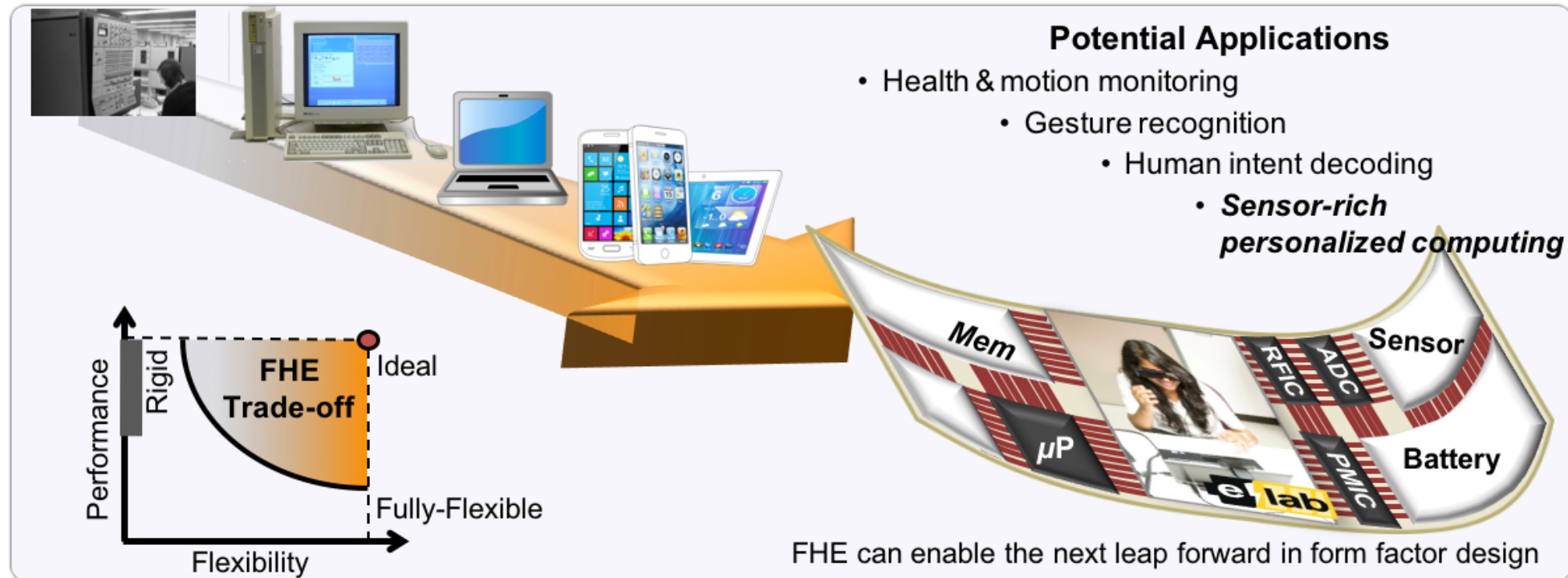
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OSCAR Workshop

June 18, 2023

WASHINGTON STATE UNIVERSITY

Mobile Devices to *Wearable Devices*

Potential Applications
- Health & motion monitoring
- Gesture recognition
- Human intent decoding
- *Sensor-rich personalized computing*

Performance / Rigid / FHE Trade-off / Ideal / Fully-Flexible / Flexibility

Mem / μP / RFIC / ADC / Sensor / PMIC / Battery / e lab

FHE can enable the next leap forward in form factor design

- **Impressive progress, but we still need to**
  - Carry a bulky device, re-charge everyday, rely on primitive interaction, …
- **Towards self-powered wearable systems** that can **understand the user**

Health Monitoring using Wearable Devices

- **15% of the world's population lives with a disability**
- **110-190 million people face significant difficulties in functioning**
- ***Intl. Parkinson and Movement Disorders Society Task Force on Technology:***
  - Low-cost and small form-factor wearable devices offer great potential
  - Enabled by advances in low power sensors, processors, communications
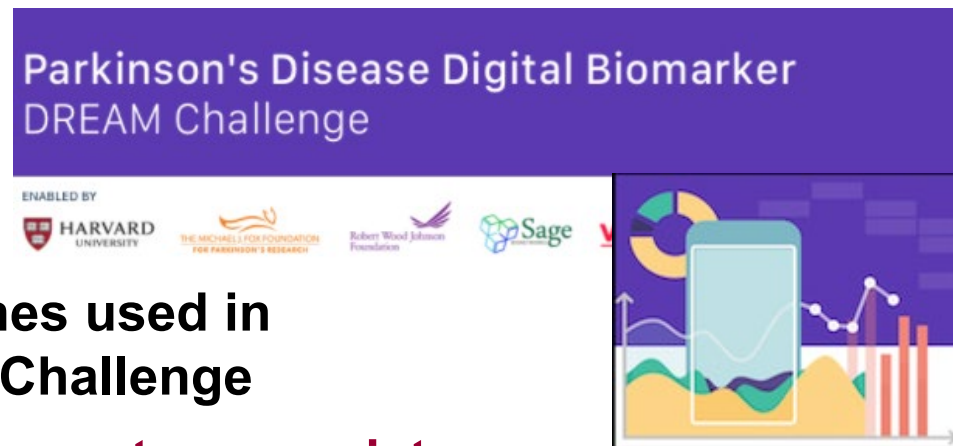
Current Health Practice
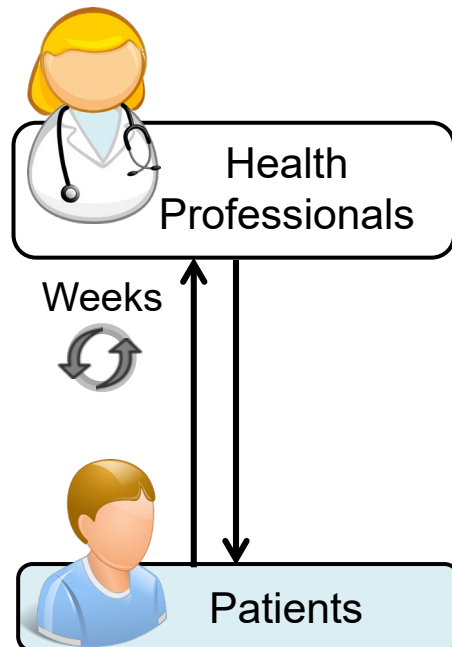
Wearable Health Monitoring
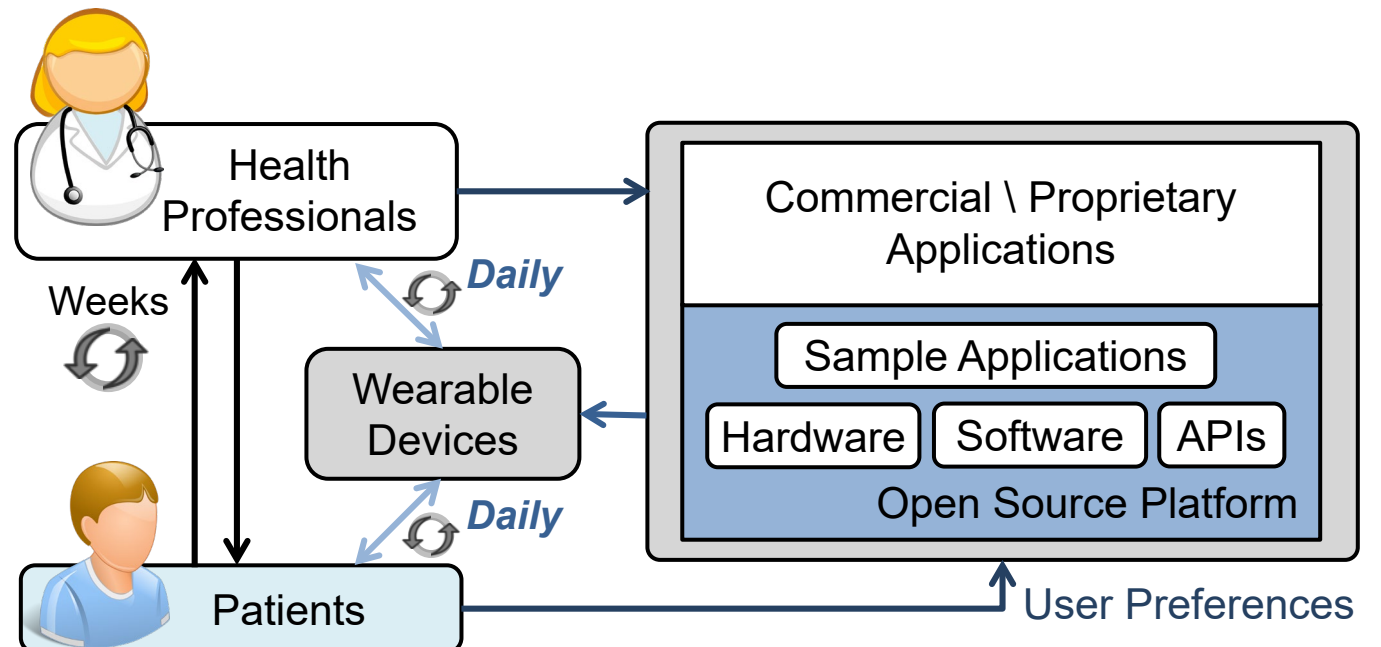
Challenges of Wearable Health Technology

- **Widespread adoption hindered by *adaptation* & *technology* challenges**
  - **Comfort:** Awkward to wear or carry a device
  - **Compliance:** Stop using technology due to maintanance
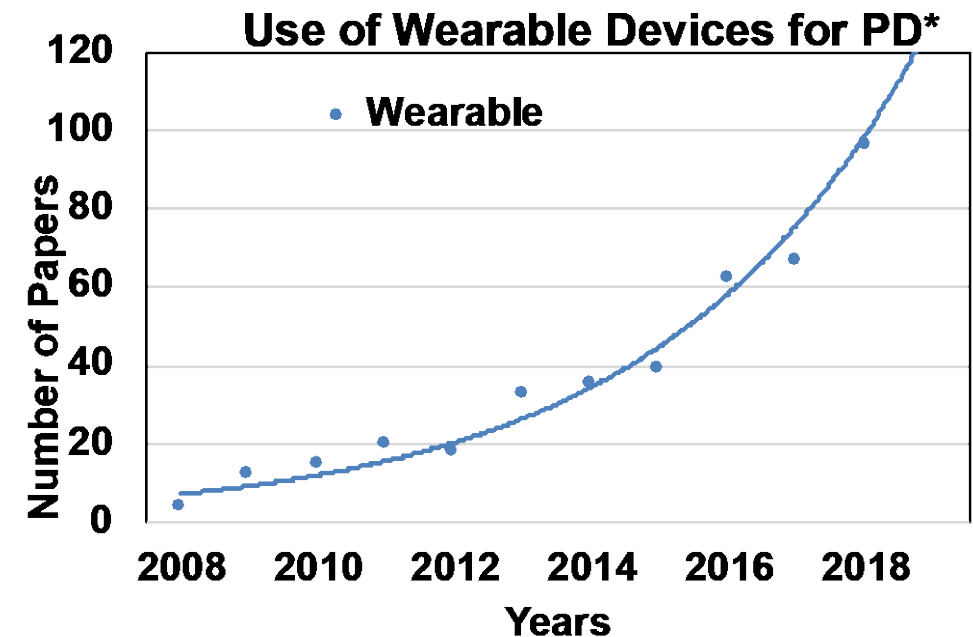 - **Applications:** No killer applications

- **Is there an evidence for the need?**

Parkinson's Disease Digital Biomarker
DREAM Challenge

ENABLED BY
HARVARD UNIVERSITY · THE MICHAEL J FOX FOUNDATION FOR PARKINSON'S RESEARCH · Robert Wood Johnson Foundation · Sage

- **Smartphones used in PD Dream Challenge**

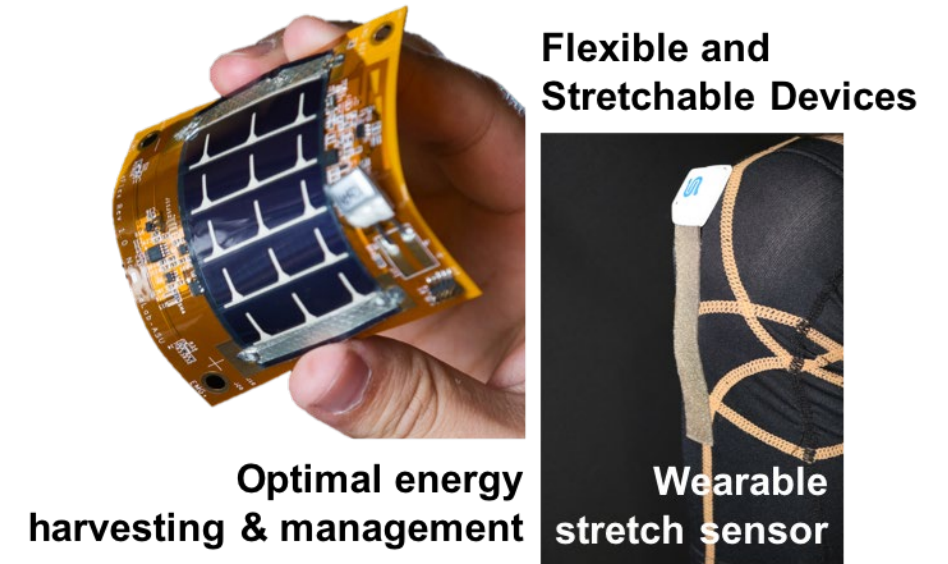- **But, they are not appropriate**
  - *Some patients cannot even carry them*
  - Cannot provide real-time guarantees (e.g., sampling rate)
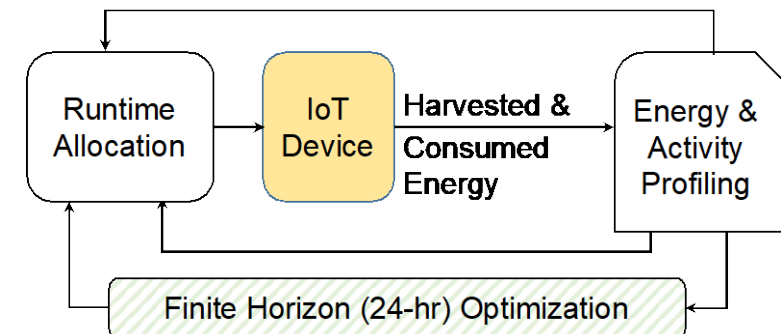 - Large power consumption & charging requirements

Use of Wearable Devices for PD*

- Wearable

Number of Papers: 0, 20, 40, 60, 80, 100, 120

Years: 2008, 2010, 2012, 2014, 2016, 2018

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*Ranadeep Deb, MS Thesis, 2019
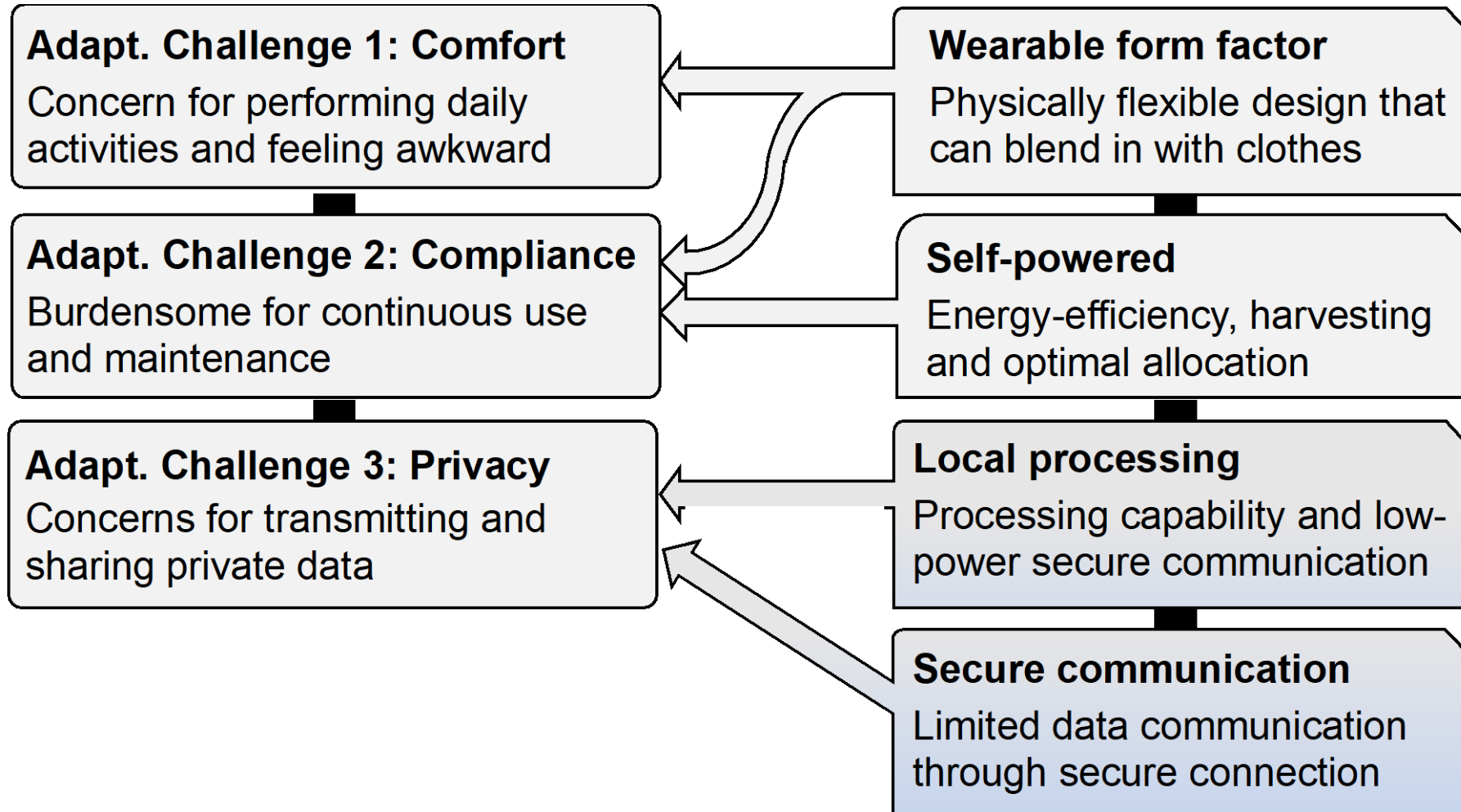
Major Barriers to Wearable Technology

- **We study major barriers to wearable technology**

- **Classify challenges into two categories**

- **Adaptation challenges**
  - Social and user-specific barriers to adoption

- **Technical challenges**
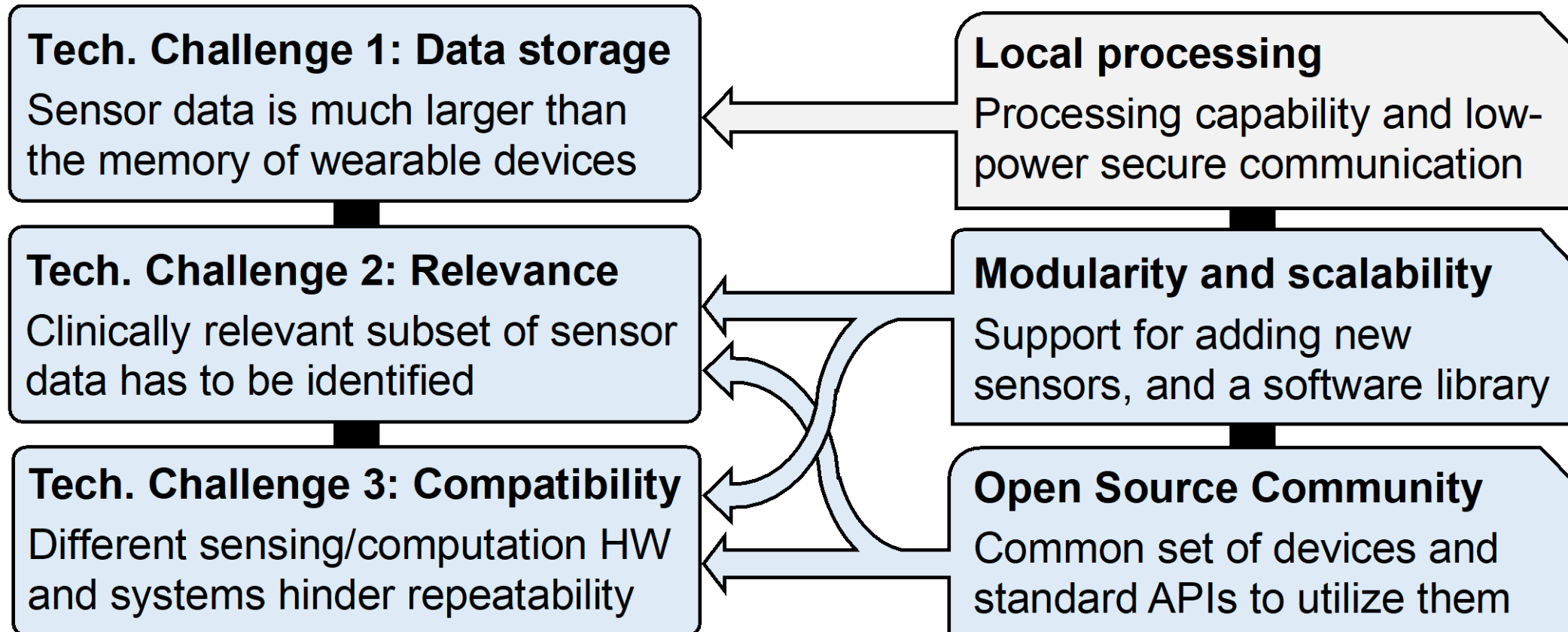 - Barriers faced by designers of wearable platforms

Flexible and Stretchable Devices

Optimal energy harvesting & management

Wearable stretch sensor

Closed-Loop Optimal Energy Allocation

Runtime Allocation → IoT Device → Harvested & Consumed Energy → Energy & Activity Profiling

Finite Horizon (24-hr) Optimization

Adaptation Challenges and Potential Solutions

Adapt. Challenge 1: Comfort
Concern for performing daily activities and feeling awkward

Adapt. Challenge 2: Compliance
Burdensome for continuous use and maintenance

Adapt. Challenge 3: Privacy
Concerns for transmitting and sharing private data

Wearable form factor
Physically flexible design that can blend in with clothes

Self-powered
Energy-efficiency, harvesting and optimal allocation

Local processing
Processing capability and low-power secure communication

Secure communication
Limited data communication through secure connection

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Technical Challenges and Potential Solutions

Tech. Challenge 1: Data storage
Sensor data is much larger than the memory of wearable devices

Local processing
Processing capability and low-power secure communication

Tech. Challenge 2: Relevance
Clinically relevant subset of sensor data has to be identified

Modularity and scalability
Support for adding new sensors, and a software library

Tech. Challenge 3: Compatibility
Different sensing/computation HW and systems hinder repeatability

Open Source Community
Common set of devices and standard APIs to utilize them

OpenHealth

An open-source HW-SW platform released to public

- **We propose the OpenHealth platform**
- **Aim to provide a common compatible HW/SW platform**
  - Address adaptation and technology challenges
  - Monitor clinically relevant technology-based objective measures (TOM)
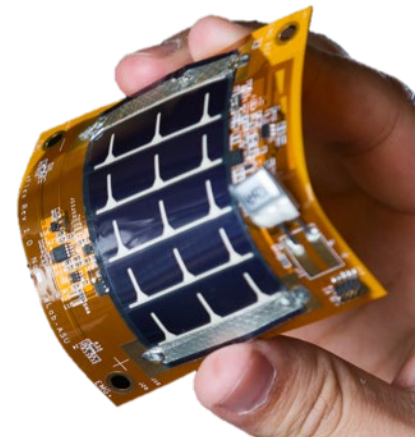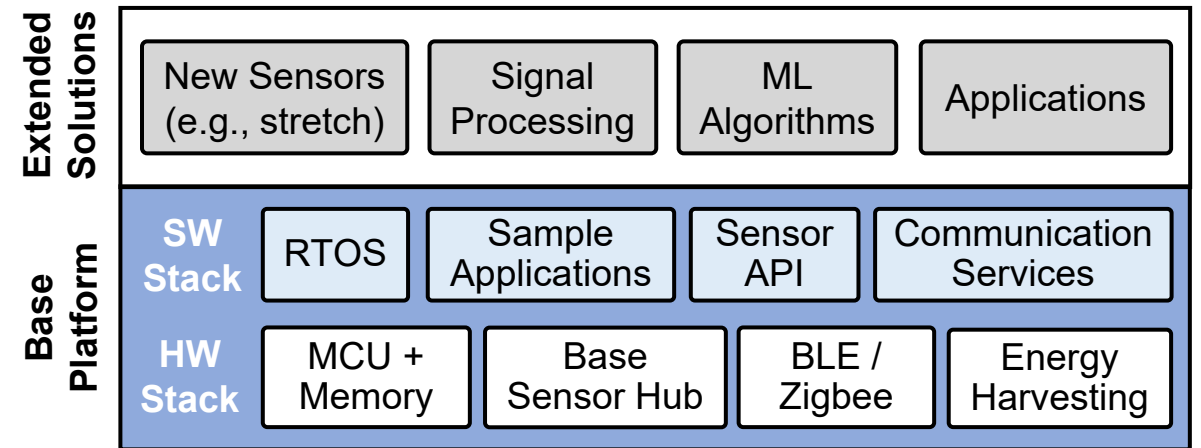 - Current release: https://sites.google.com/view/openhealth-wearable-health/home

*IEEE D&T'19
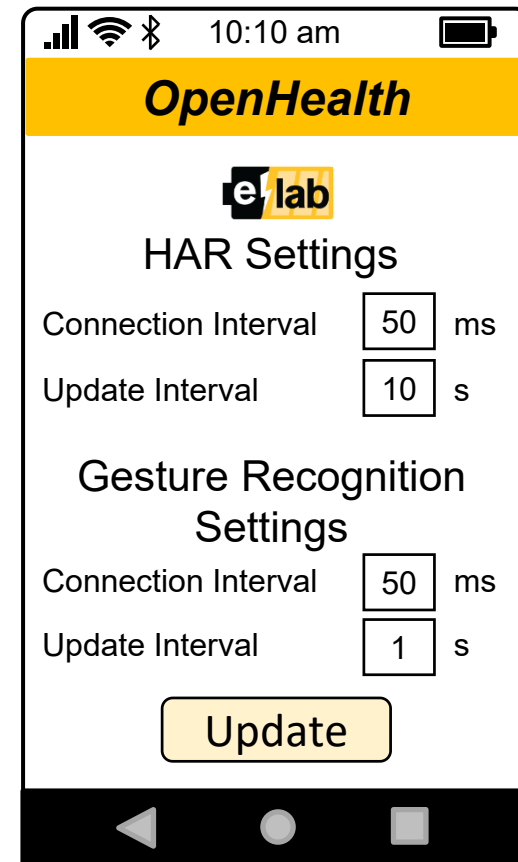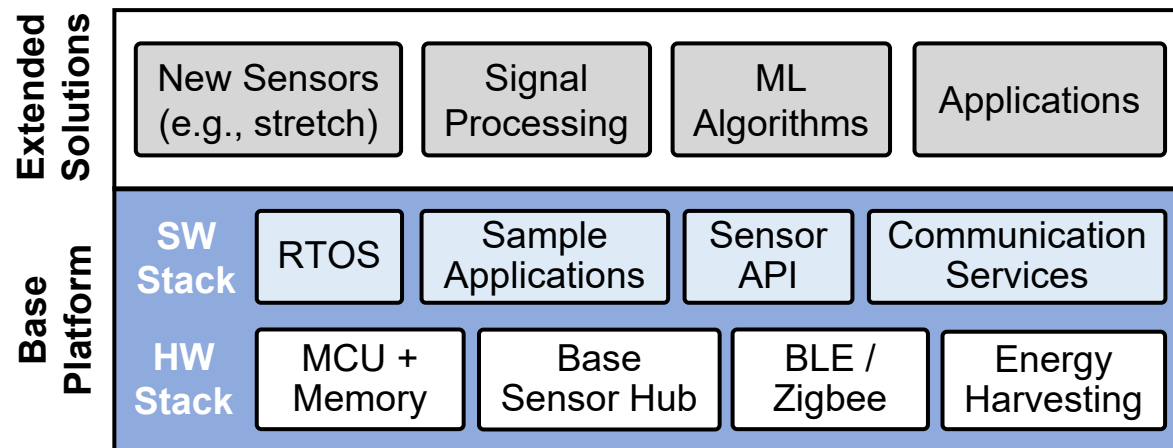
OpenHealth Components

- **Base hardware**
  - Processing unit
    - Texas instruments CC2650/CC2652
  - Sensor unit
    - MPU-9250 motion sensor
    - Electromyography
    - Stretch sensor
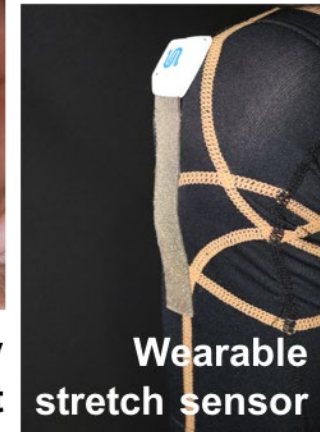 - Energy harvesting with photovoltaic cells

- **Base software**
  - Thread-based real-time operating system
  - Sensor API through I2C and SPI
  - Bluetooth and Zigbee protocols

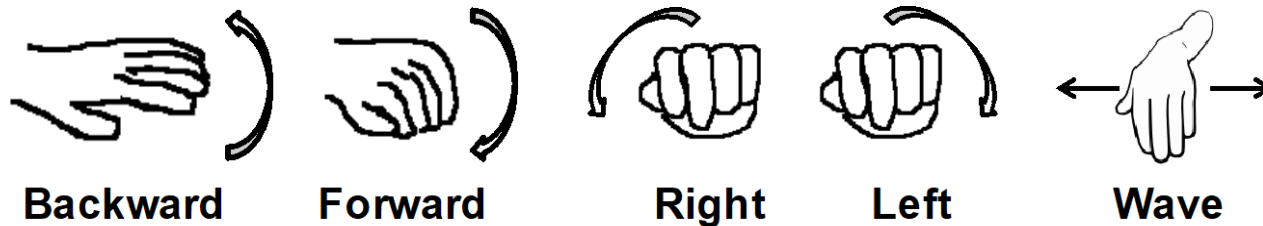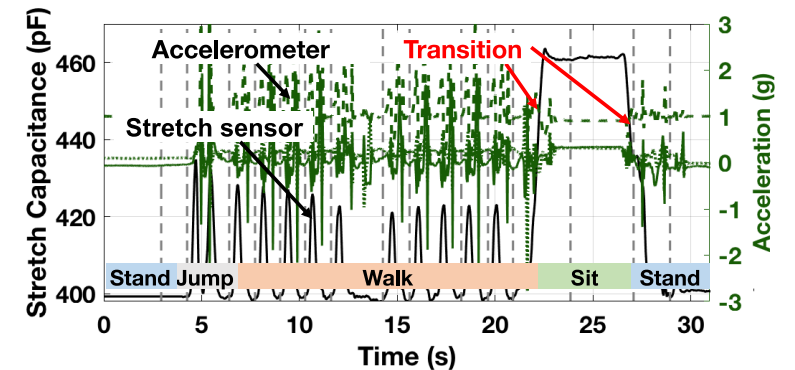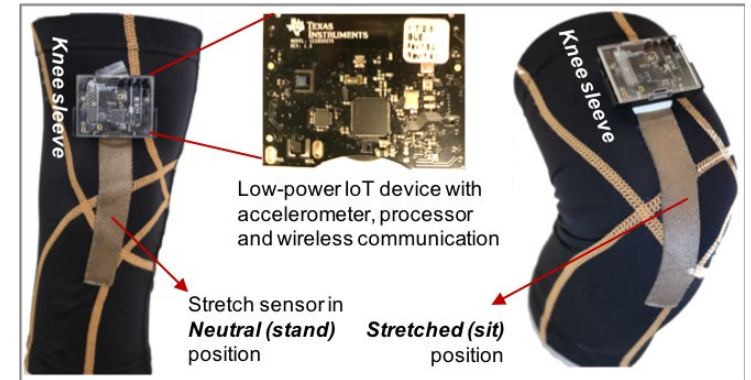| Extended Solutions	New Sensors (e.g., stretch)	Signal Processing	ML Algorithms	Applications

Base Platform	SW Stack	RTOS	Sample Applications	Sensor API	Communication Services
	HW Stack	MCU + Memory	Base Sensor Hub	BLE / Zigbee	Energy Harvesting

Flexible and Stretchable Devices

Optimal energy harvesting & management
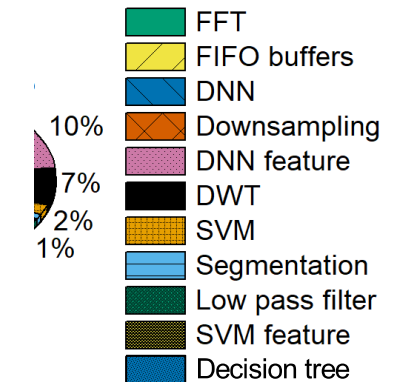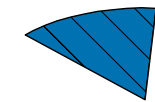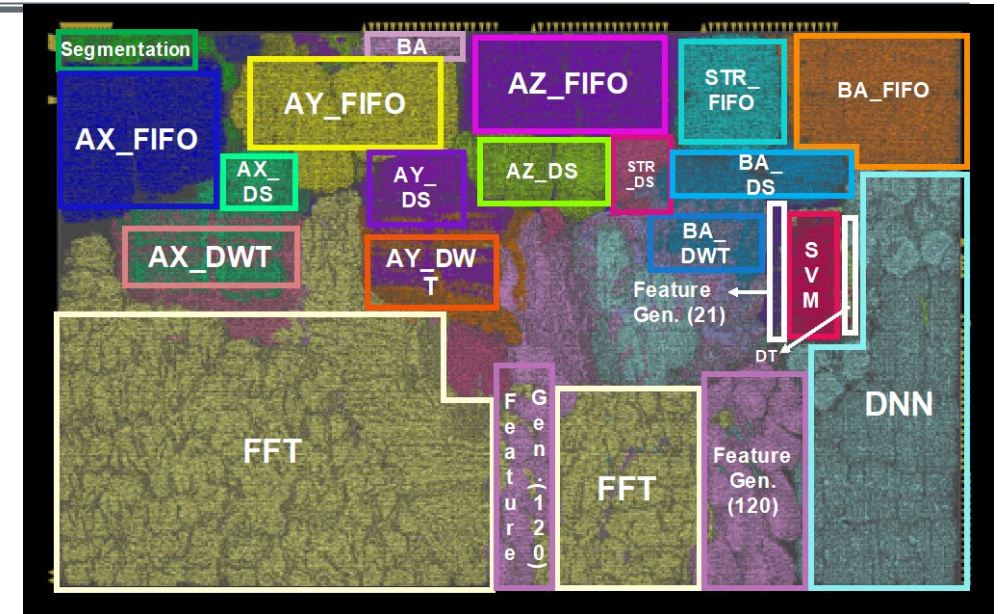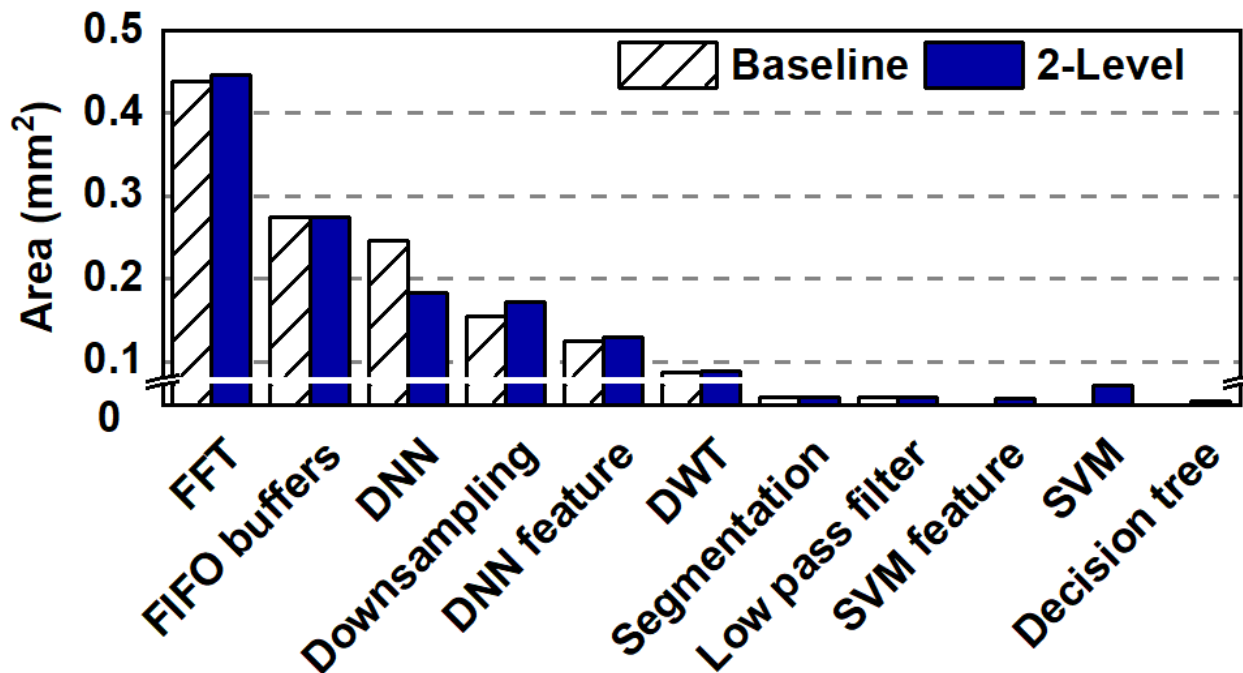
Wearable stretch sensor

Application Domains for OpenHealth

- **We provide two example applications with OpenHealth**

- **Human activity recognition**
  - 22 users and 8 activities
  - Provide sensor data, classifier, and application
  - 12.5 mW consumption for each activity

- **Gesture recognition**
  - Five hand gestures using motion sensor
  - Useful in rehabilitation applications
  - We provide C-code for neural network classifier
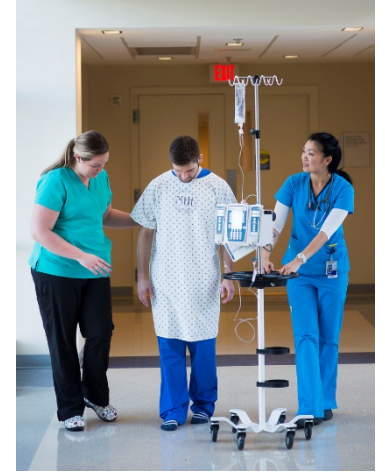 - 10 mW power consumption for each classification

Knee sleeve. Low-power IoT device with accelerometer, processor and wireless communication. Stretch sensor in *Neutral (stand)* position. *Stretched (sit)* position.

Backward   Forward   Right   Left   Wave

Accelerator for HAR

- **We also provide two hardware accelerators for HAR**

- **Baseline Design = 1.353 mm^2**

- **Two-level Design = 1.357 mm^2**
  - **Only 0.3% larger than the baseline design**

Ganapati Bhat et al. An Ultra-Low Energy Human Activity Recognition Accelerator for Wearable Health Applications. ACM Trans. Embed. Comput. Syst., 2019

Conclusion

- **Mobile and wearable devices offer great potential**
  - Health monitoring, activity tracking, gesture-based control
- **Presented our work on wearable IoT devices**
  - OpenHealth framework with hardware and software
  - Problem formulation for future challenges in wearable design

Thank you!