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Next Generation Wireless Communications: TELEHEALTH

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The KNOWME Project:

http://knowme.usc.edu

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NCMHD

NOKIA Connecting People

QUALCOMM

NATIONAL CANCER INSTITUTE

TREC

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m-Health Opportunities

- World population ~ 7 billion
  - Number of cell phones ~ 5 billion
  - More than 80% population within reach of cell tower
- Tremendous opportunities for prevention and treatment of health conditions ***in difficult to reach, at-risk and under-served individuals worldwide***
  - Tremendous opportunities in fact for EVERYONE

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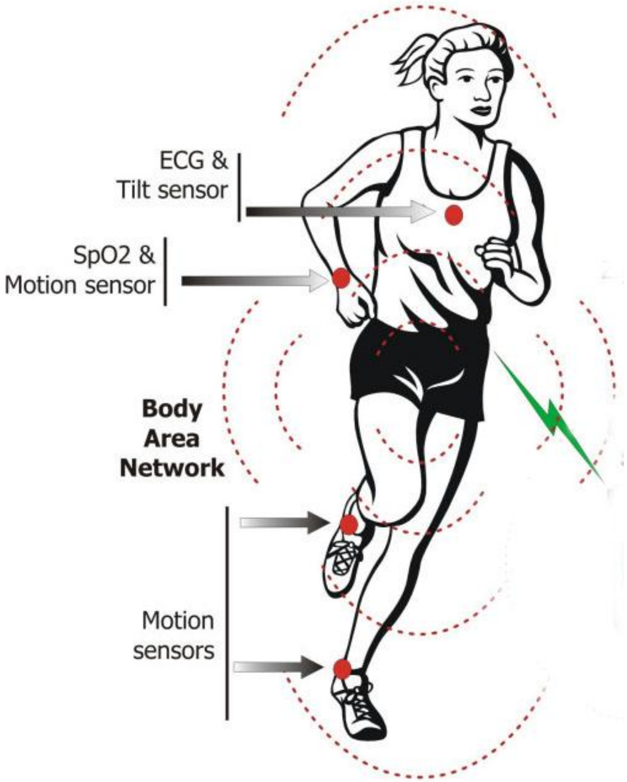
Wireless Body Area Sensing Networks

- **Novel sensing network for holistic assessment of "state"**
  - motion, physical activity, geospatial context
  - metabolic information
  - cognitive, emotional data
  - user initiated data (SMS, speech notes, images/videos)
- **Interdisciplinary Solution**
  - metabolic health research
  - engineering methods for assessment/cognition
  - wireless communications
  - sensor networks and actuated systems
  - computer architecture
  - databases
  - social networking



Jovanov *et al. Journal of NeuroEngineering and Rehabilitation* 2005

Continual Feedback

- **Novel sensing network for holistic assessment of "state"**
  - motion, physical activity, geospatial context
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- **Interdisciplinary Solution**
  - metabolic health research
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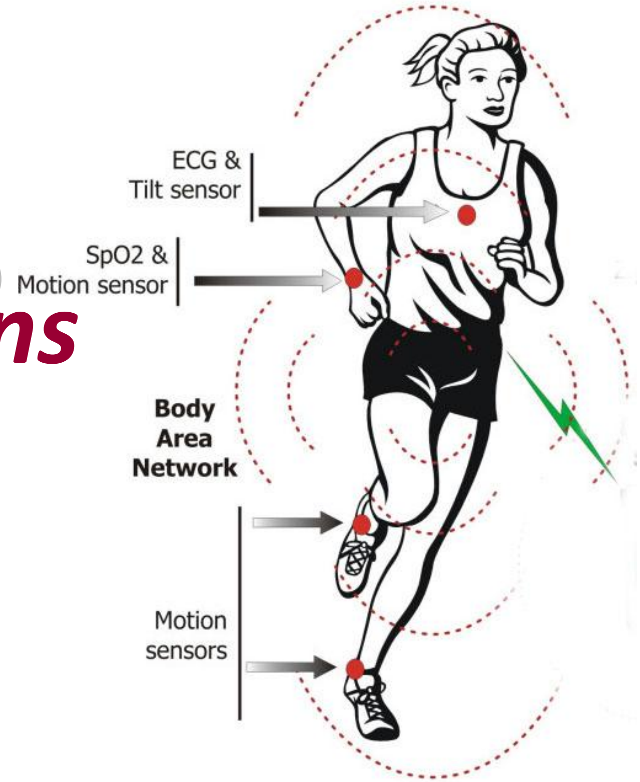
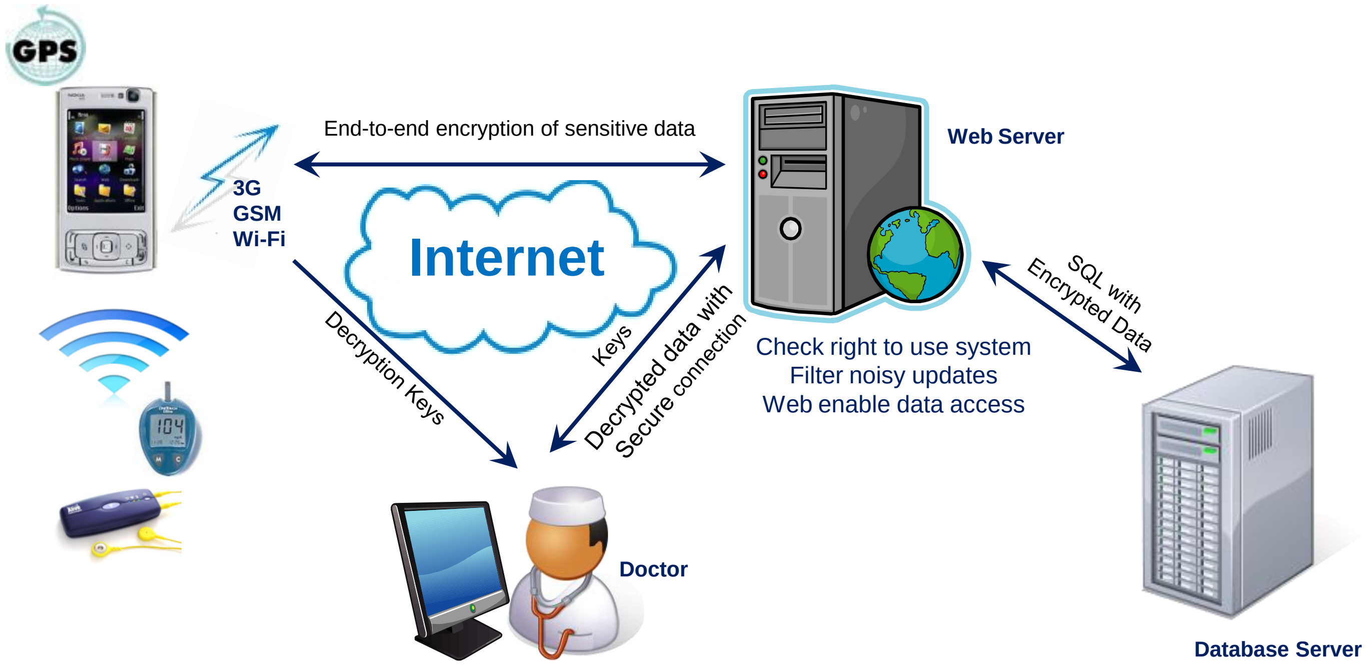
wireless communications is the ``glue''



Jovanov *et al. Journal of NeuroEngineering and Rehabilitation* 2005

KNOWME 3 tier Architecture

- combine health sensors with mobile phone
  - metabolic: ACC, OXI, ECG
  - emotional: GSR
  - location: GPS
  - user initiated: SMS, Tweets, video/image/voice tags



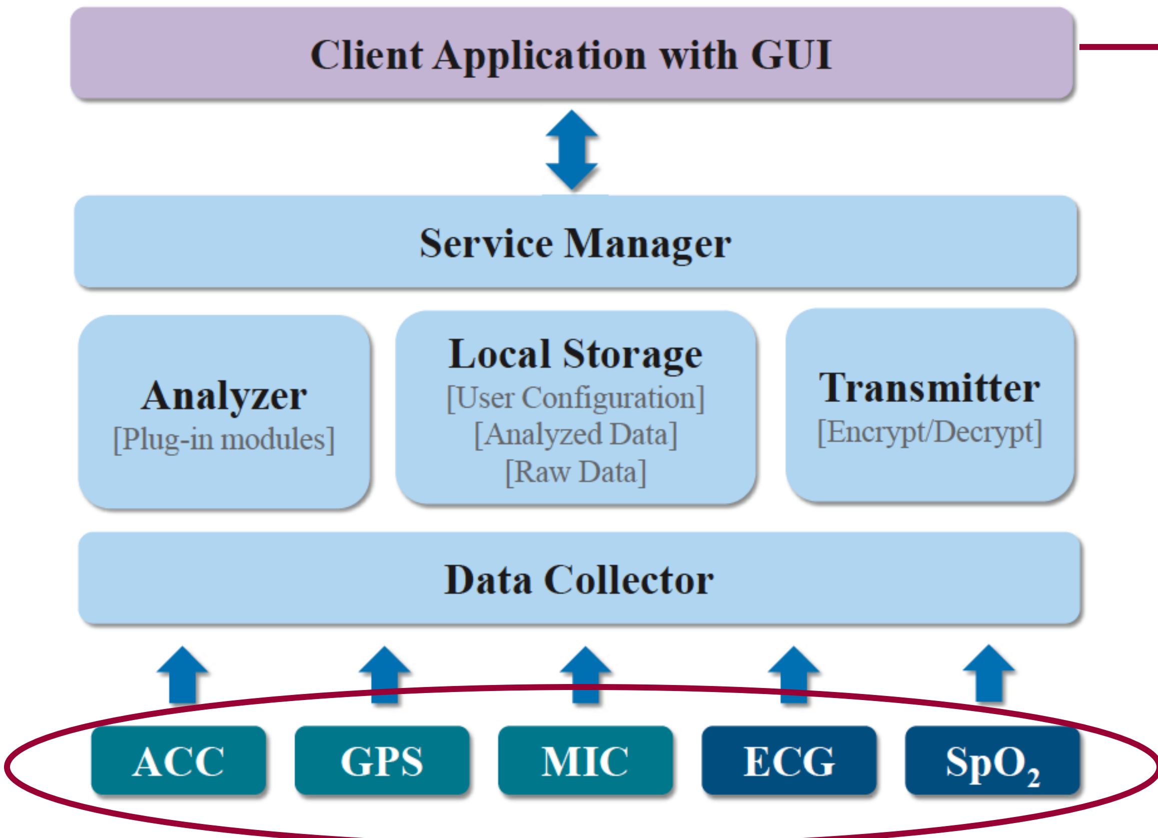
Three-Tier KNOWME Architecture

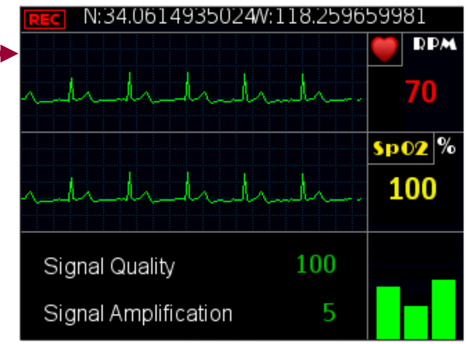
Sensor Overview



- External Sensor with Bluetooth capability
  - Heart rate monitoring
  - Pulse oximeter
  - EmSense® headset physiological sensors – blinking, breathing, motion and heart activity, TBD (in lab evaluation)
  - 4 tri-axial accel units **MICROSTRAIN**
- N95 Internal Sensors
  - Accelerometers
  - GPS
  - Audio/Video/Picture tags
  - Cell tower based location sensors

Mobile Client Design





What are the issues?

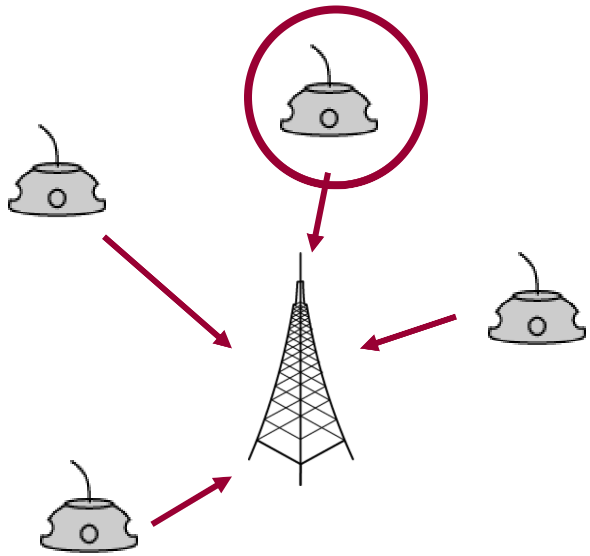
- ENERGY

- Network to Application
  - Changing the stack?

- Research horizon
  - Short term, medium term, long term

Energy constraints are different!

optimize energy resources at sensor

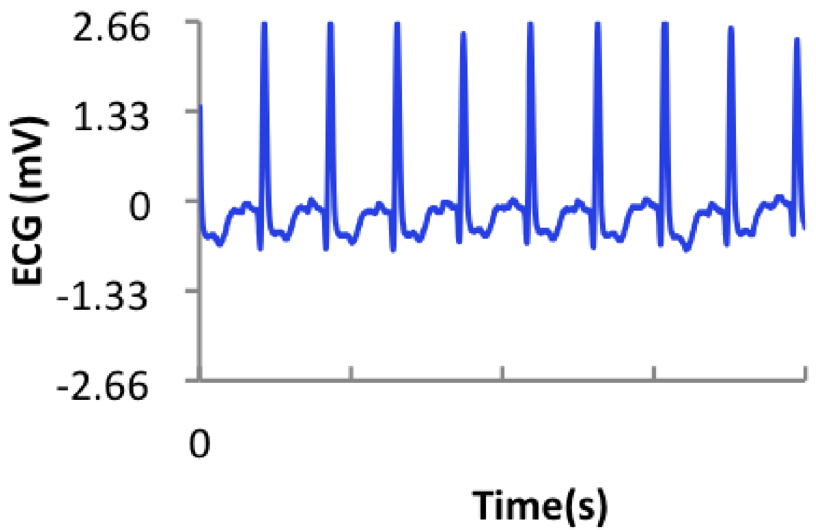


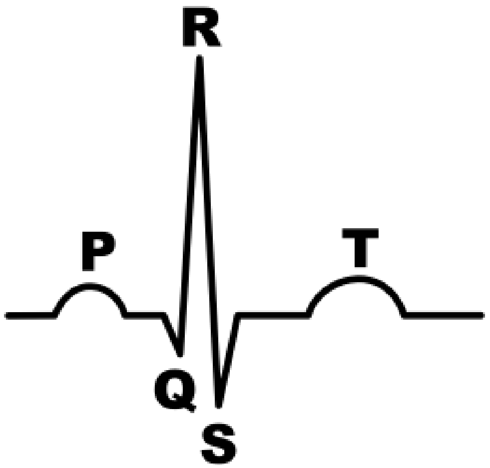
traditional sensor network

optimize energy resources at N95

our body sensing network

Cellphones are not biometric signal processors (yet)





Method	Energy(J)	Note
QRS Detection	17.045	Pan and Tompkins
Encryption	0.537	AES-128bit
Data Compression	19.670	GZIP CR 3:1

Sensor Data & Transmission Costs

- Nokia N95 cellphone fusion center
  - Alive Technologies ACC and ECG (chest strap) and mobile-internal Accelerometer | Pulse oximeter not used
  - Cost of Bluetooth measurements >> Cost of Nokia ACC

$$C_{\text{NOK}} = \frac{1}{10} C_{\text{ACC}}; \, C_{\text{ACC}} = C_{\text{ECG}}$$

- We also consider transmission cost, C_{TX}

$$C_{\text{TX}} = \sum_{k=1}^{K} C_k N_k$$

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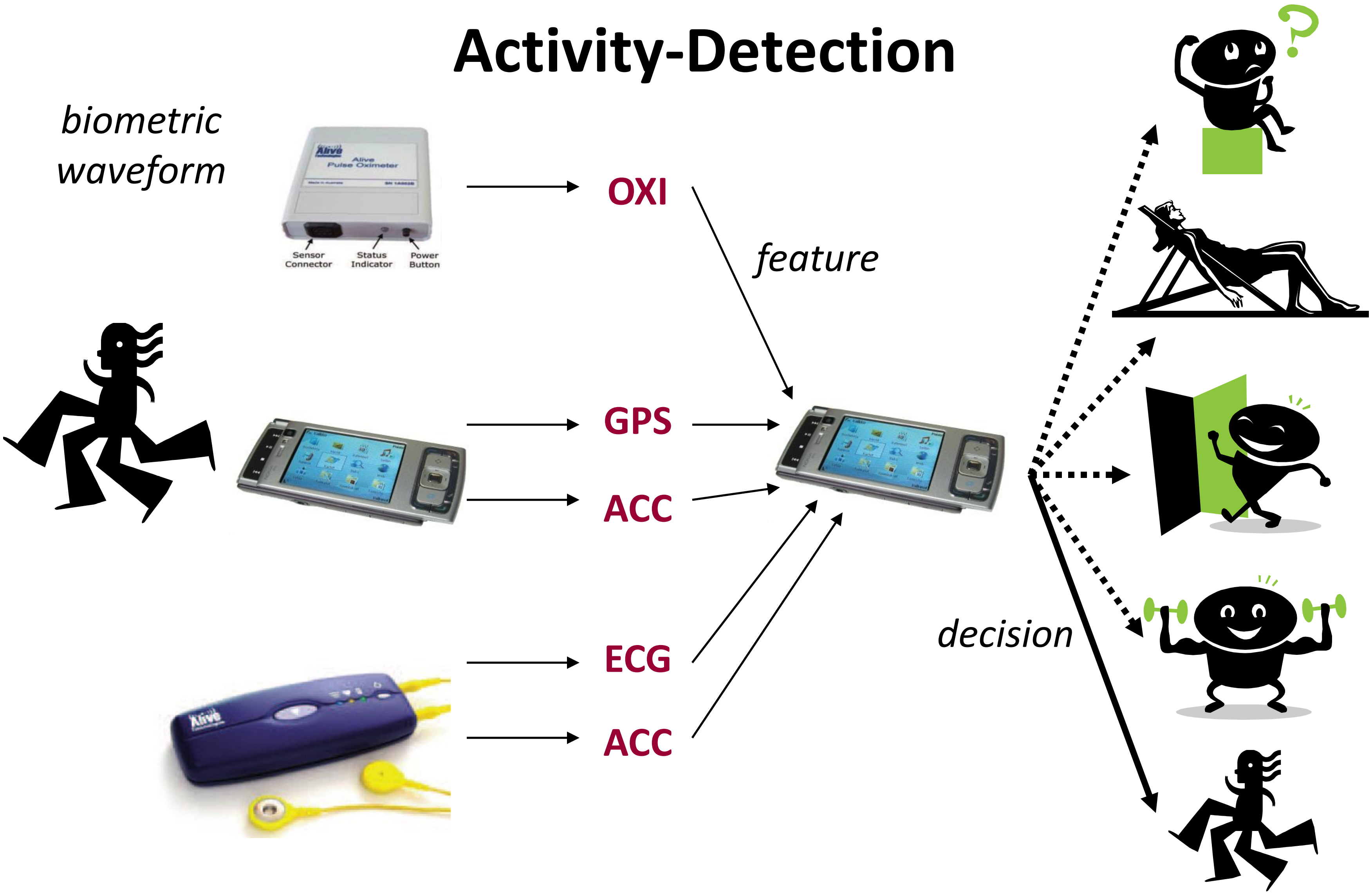
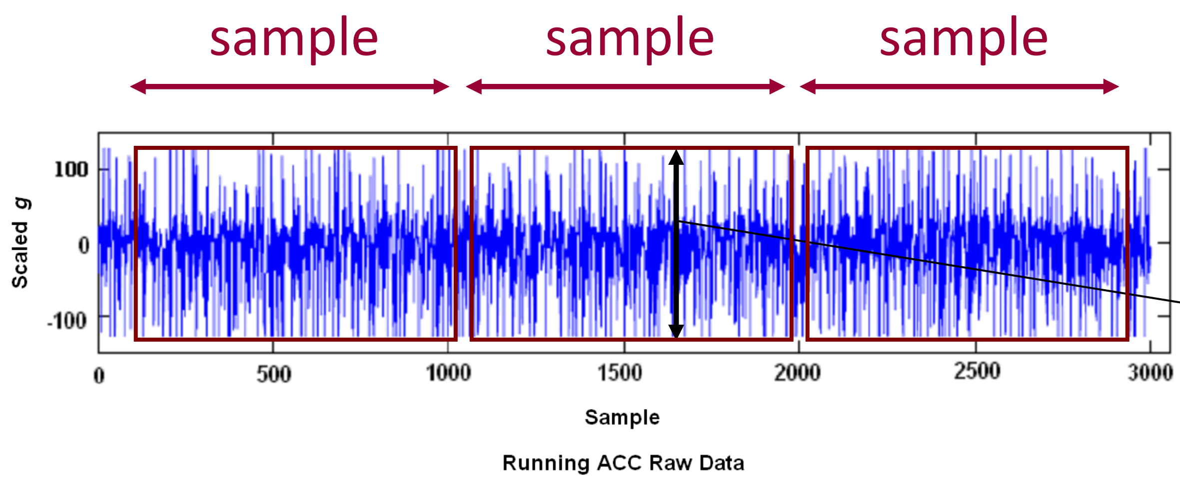
Activity-Detection



From Sensor Measurements to Features

- Accelerometer (ACC)

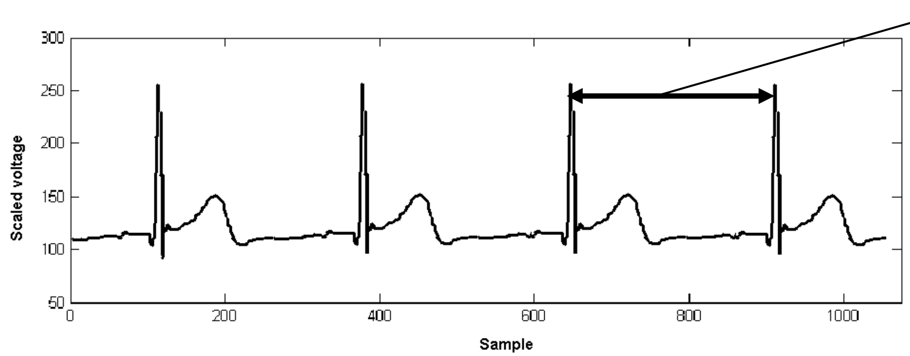


ACC variance

sample = average variance of the tri-axial accelerometer for windowed data

From Sensor Measurements to Features

- Electrocardiograph (ECG)



Sitting ECG Raw Data

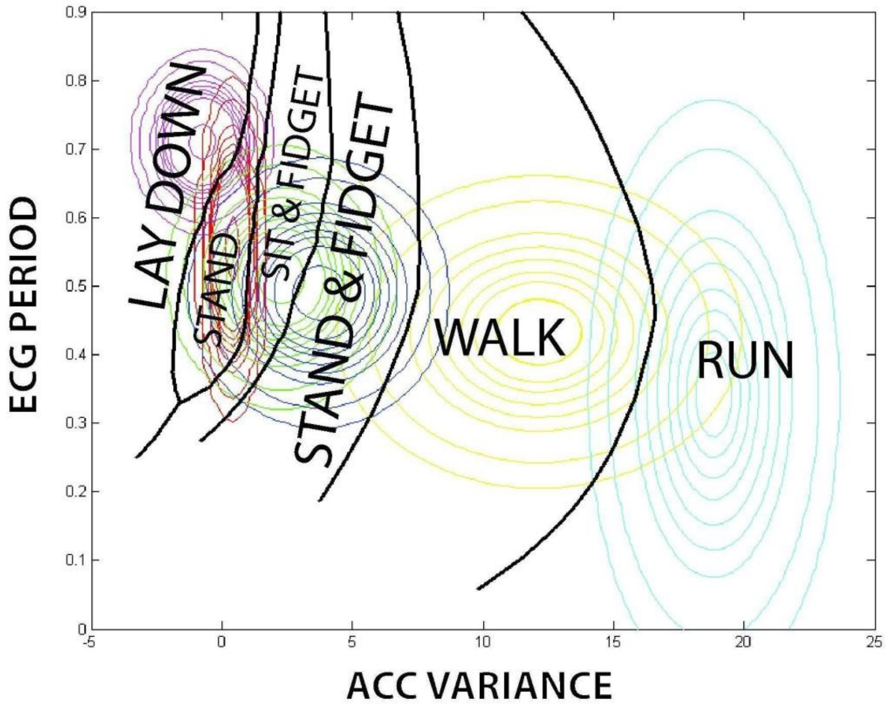
ECG period
(= sample)

- Features extracted from data
  - Used to develop hypotheses in training
  - Compared to models in testing for activity-detection

High Performance Activity-Detection

- sophisticated detector structures
  - support vector machines
  - feature fusion methods
- novel feature development: cepstral, time-domain

Nonlinear Decision Regions



Decision regions for bivariate Gaussians for six activities

- Distinct means and covariance matrices for each subject | personalized training

Different features "good" for detecting different states

- Certain sensors can better discriminate between specific sets of activities

Only ACC

	Lying	Stand	Walk	Run
Lying	38	1	0	0
Stand	9	17	0	0
Walk	0	0	27	0
Run	0	0	0	23

Only ECG

	Lying	Stand	Walk	Run
Lying	39	0	0	0
Stand	0	26	0	0
Walk	0	0	27*	0
Run	0	0	2	21

Both ACC and ECG

	Lying	Stand	Walk	Run
Lying	39	0	0	0
Stand	0	26	0	0
Walk	0	0	27	0
Run	0	0	0	23

When to use what sensor/feature?

- Compute optimal allocation of samples to minimize probability of error of multiple hypothesis testing problem
  - Constrain total number of samples received

$$N = N_1 + N_2 + N_3$$

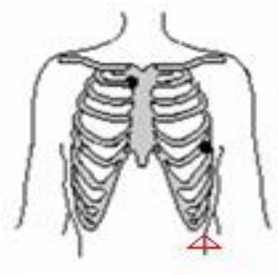
- Computing exact probability of error is intractable for general Gaussian model
  - Instead compute upper bound using pair-wise error probabilities
  - Incorporates probability of next state given current state

Data Collection | Numerical Results

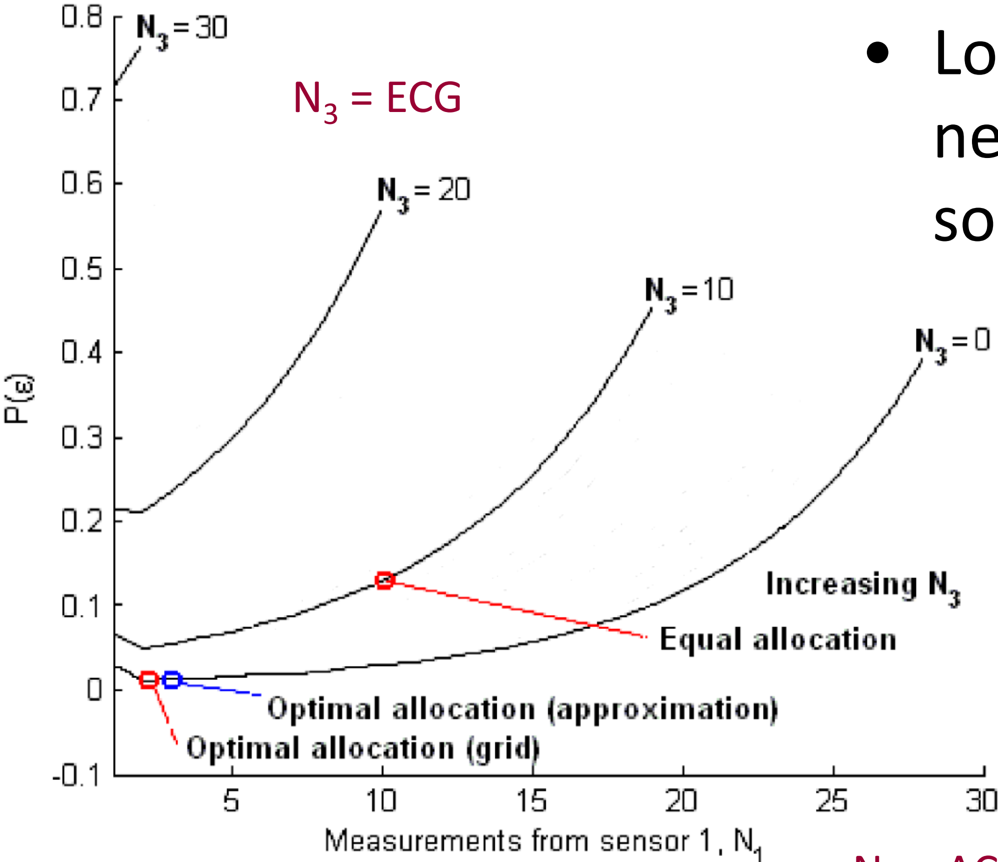
- Experimental Procedure
  - Each activity performed for 7 minutes + 20 min free living
  - Protocols modified from [Puyau02] and [McKenzie91]

    Current data set:
  - 20 overweight minority youth participants
  - [ThatteTSP] simulations based on (6 male, 6 female; ages range from 12-17; BMI ranges from 24.3-51.3)
- Simple cases considered; easier to visualize
  - Methods directly applicable to more complex scenarios

lying
sitting
sitting+fidgeting
standing
standing+fidgeting
playing Wii
slow walking
brisk walking
running



Optimal vs. Approximately Optimal Allocation



N_1 = ACC s^2

- Low-complexity solution (**o**) near combinatorial search solution (**o**)

$P_{equal}(e) = 0.138$

$P_{optimal}(e) = 0.017$

~ order of magnitude improvement

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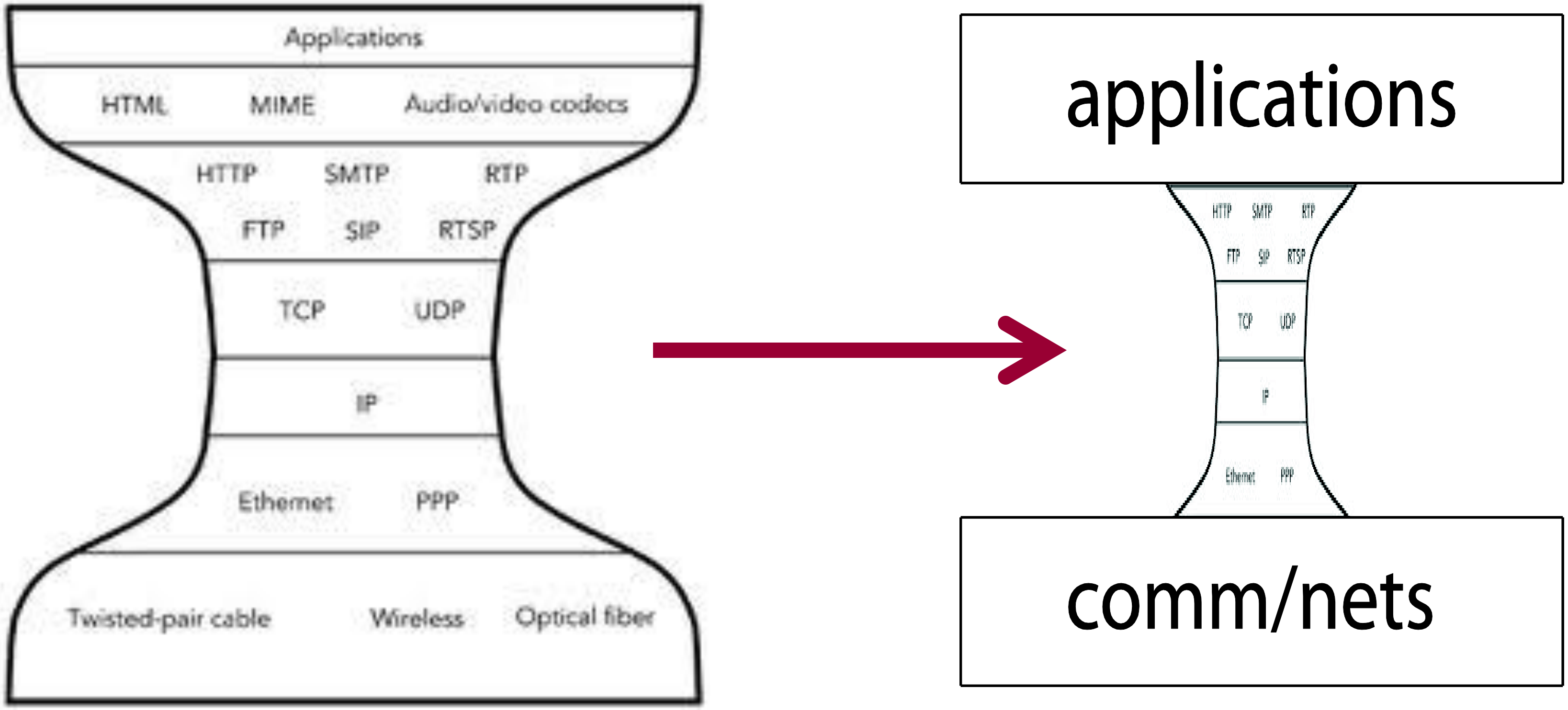
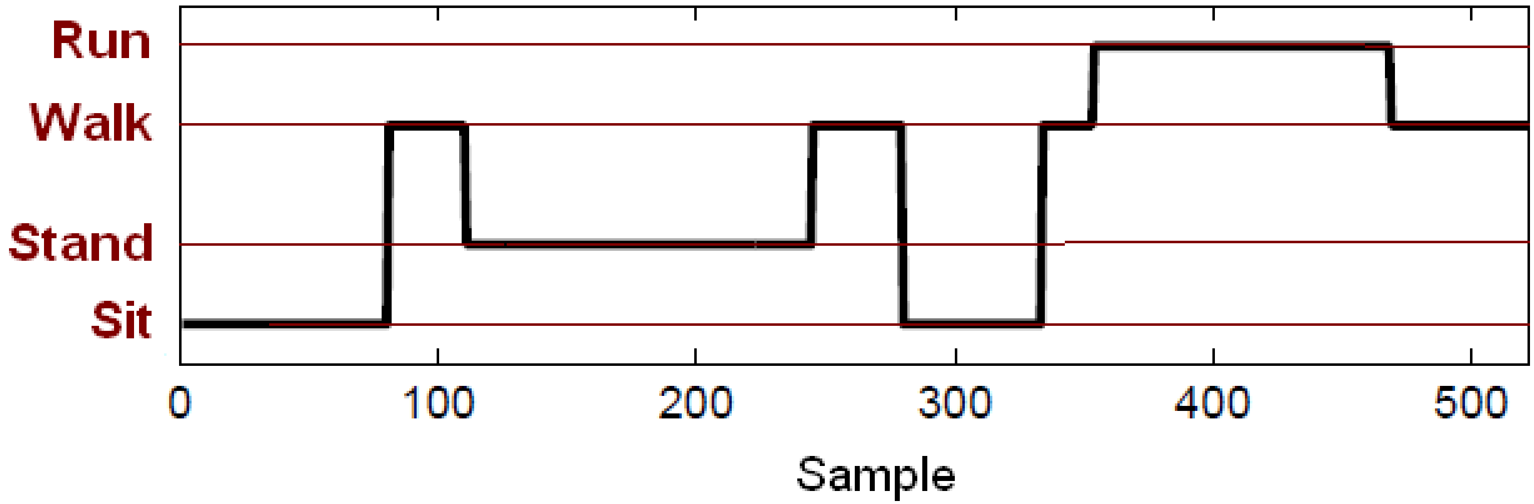
OSI Stack



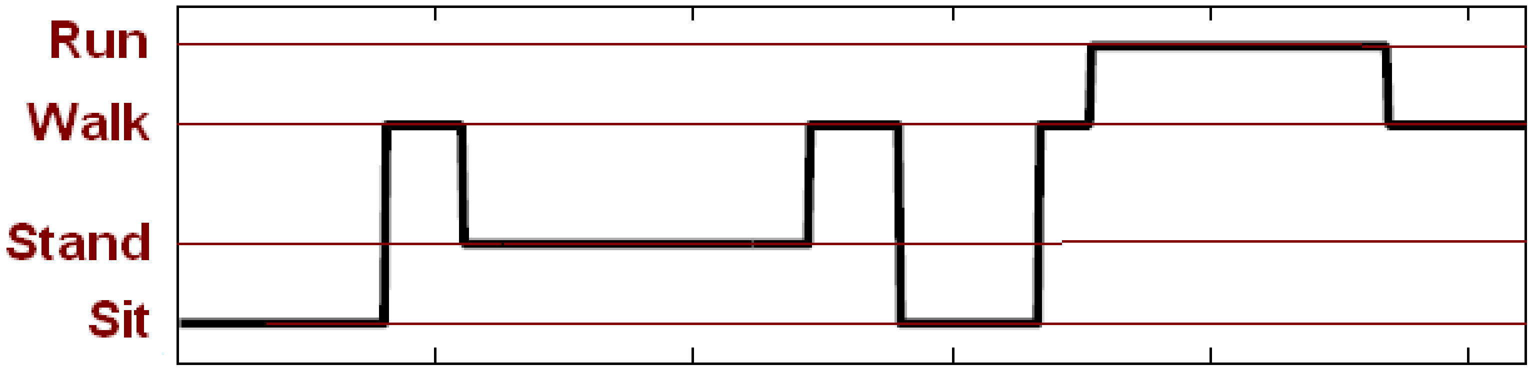
PAST

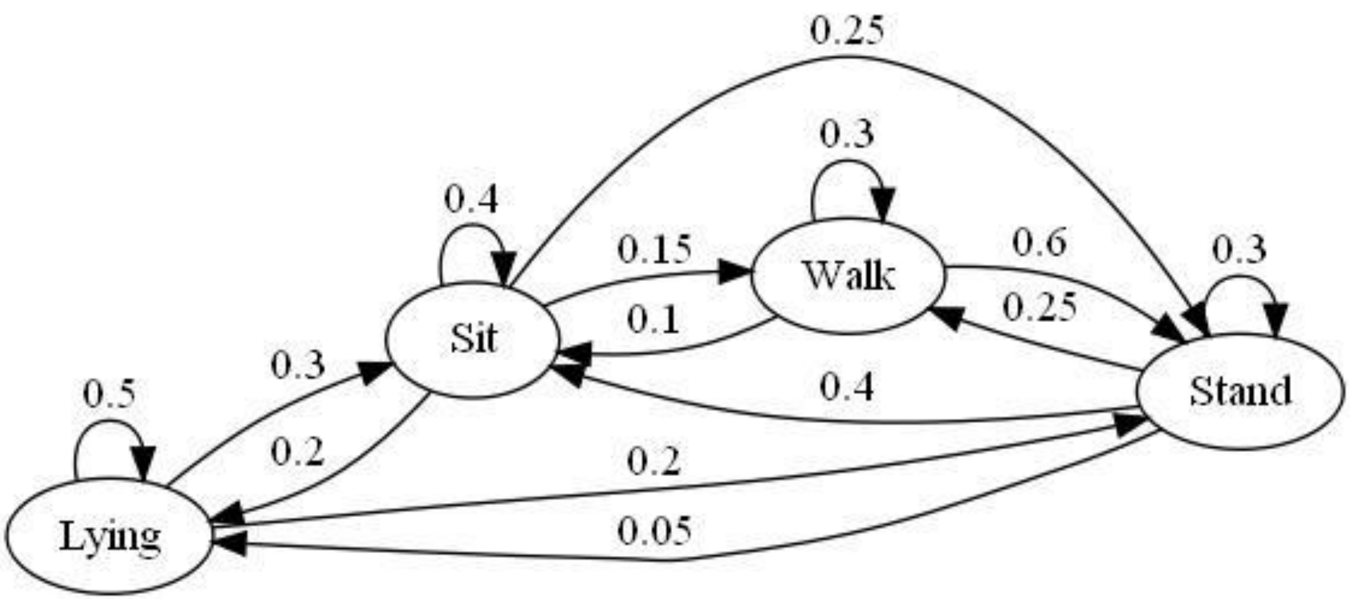
NOW

Life is not static

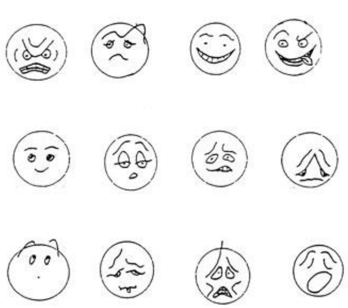


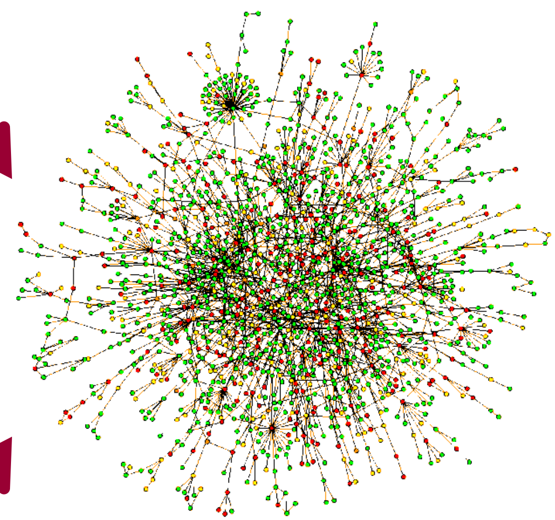
Life is not static





How to handle state explosion?



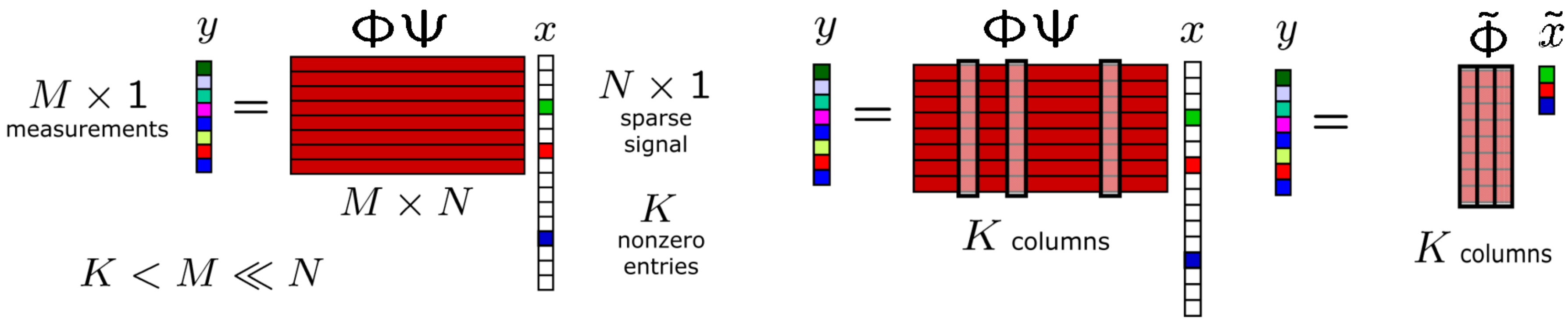


States:

- Physical activity states
- Contextual states
- Emotional states
- ACTUATION states

- **Markov Decision Process**

Compressed Sensing: a SOLUTION?



- Reduce observations via randomized projection (compress)
- Efficiently estimate a few parameters (sparse)

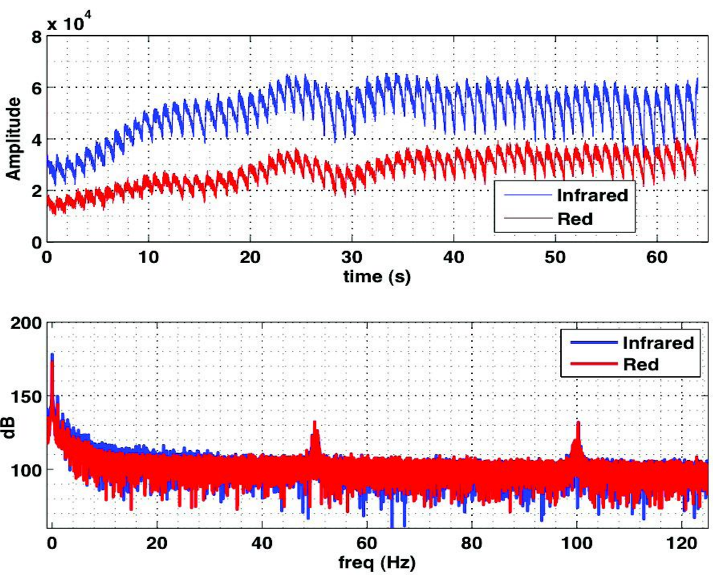
$$y = \Phi f = \Phi\Psi x = Ax$$

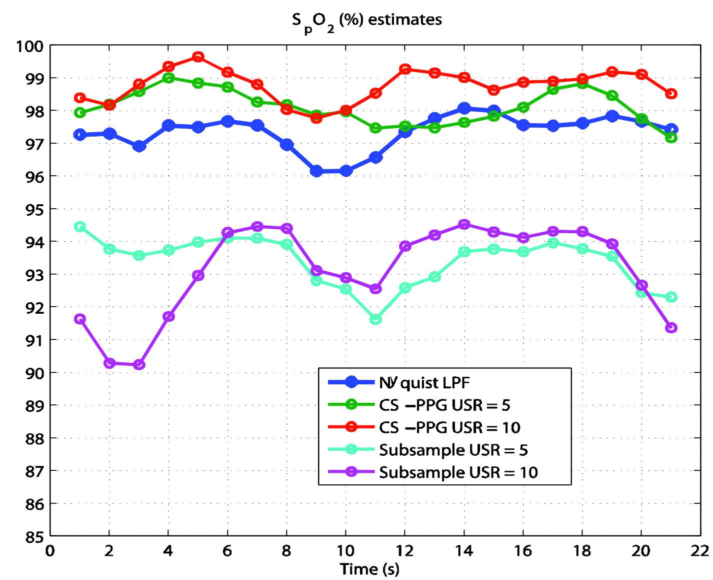
projection/sampling

field/signal basis

Compressed Sensing for Biometric Signals

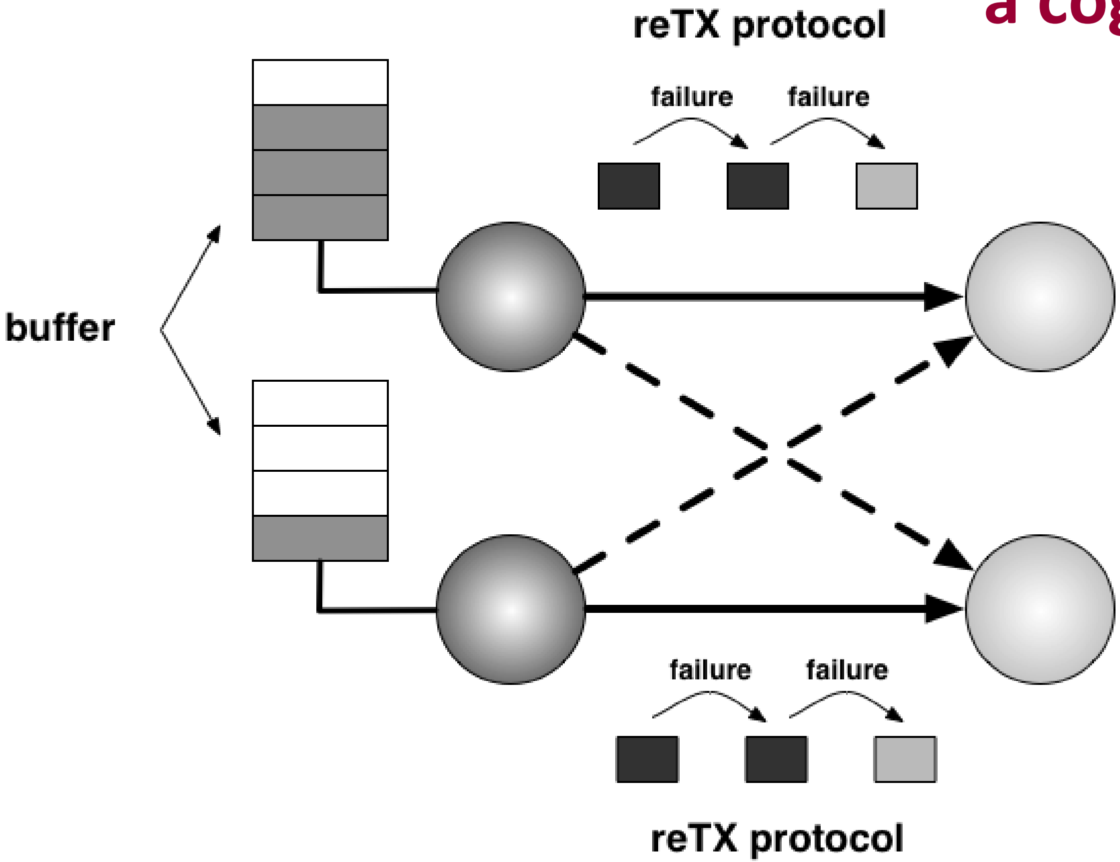
- Biometric signals have a lot of structure
  - ECG, SpO2, temperature, blood pressure, speech
  - Use novel compression techniques





from
H. Garudadri
Qualcomm

What about Networks?

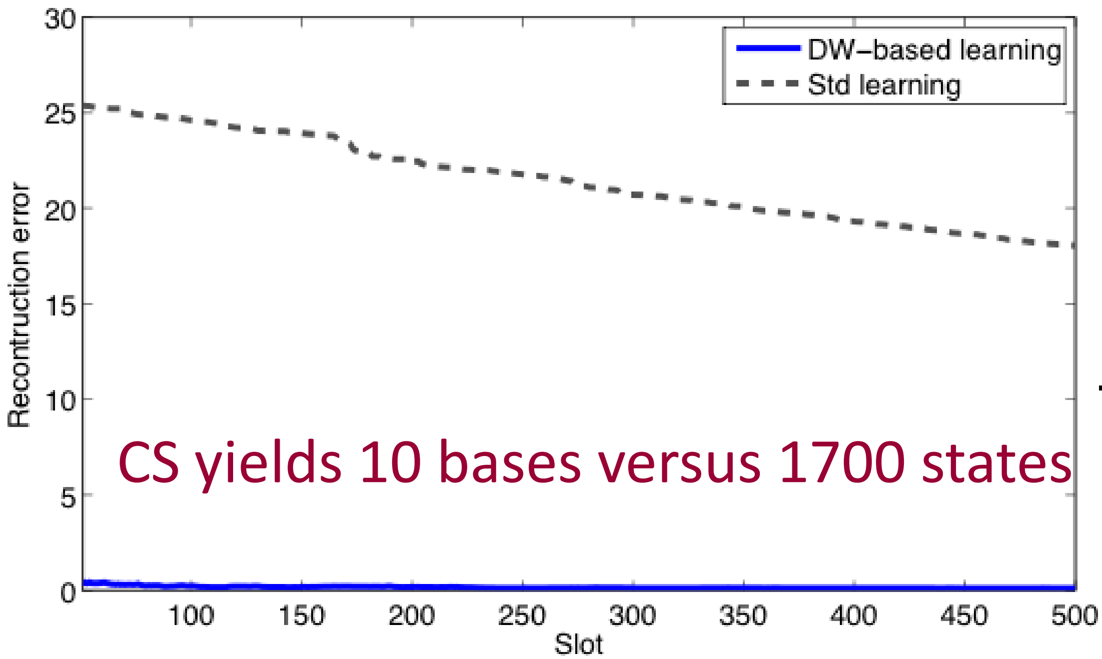


a cognitive radio example

- N mutually interfering users
- Random arrivals
- Buffer of size B packets
- Finite retransmission protocol (F = maximum number of transmissions)

Simulations: N = 2, B = 5, F = 4 → 1681 states

Compressed Sensing vs. Classical Learning

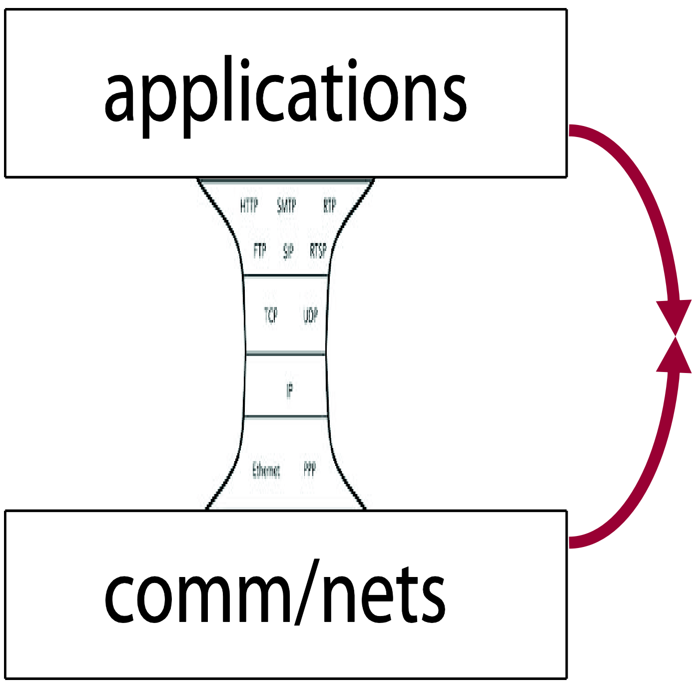


CS yields 10 bases versus 1700 states

- New algorithm performed with each new sample
  - unobserved states removed from matrices
- – Fast convergence
  - Transition probability matrix and cost functions are ESTIMATED from samples

- Standard learning converges very slowly
- **We can apply these approaches to physical state tracking**

How do we integrate?



- Universal compressed sensing?
  - Biometric signal estimation
  - Physical state estimation
  - Network state estimation
- Eventually
  - Biometric signal control?
  - Physical state control?
  - Network state control!
- **Is there a new wireless network needed?**
  - Does a holistic approach help in dealing with the bottleneck?

Summary

- Significant cell phone subscription rate offers unique opportunities for wireless/tele-health
- Energy consumption of all devices a major concern for the collection of longitudinal data
- Network (re)design questions?
  - Application to networking/physical layer connections

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- Significant cell phone subscription rate offers unique opportunities for wireless/tele-health
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- ``it's like having a doctor in your pocket''

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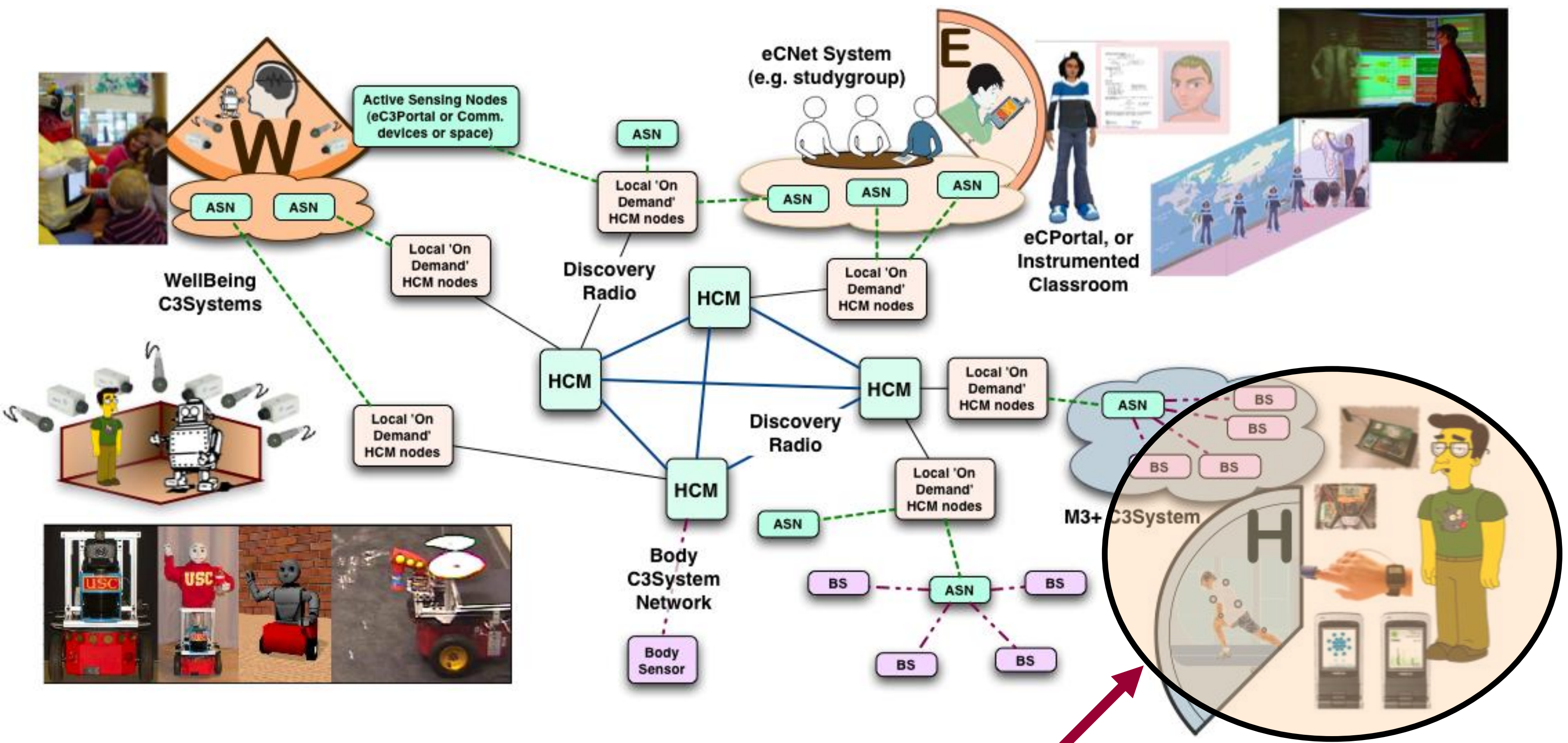
personalized engineered technology systems



KNOWME network