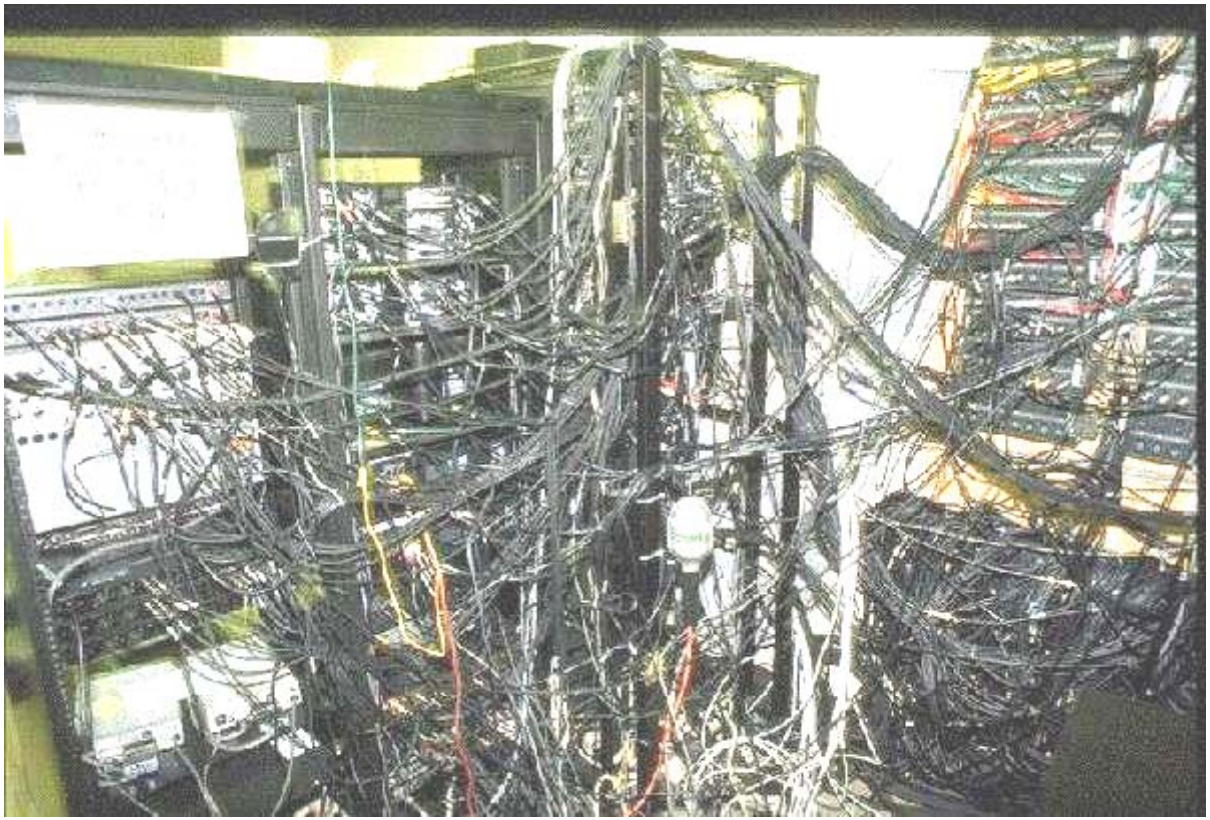
Wireless Sensor Networks for Home Medical Care

John A. Stankovic
BP America Professor
Department of Computer Science
University of Virginia

http://www.cs.virginia.edu/wsn/medical/
http://wirelesshealth.virginia.edu/

What's Wrong With Wires



And we don't want a patient tethered to a bed or fixed medical device

Outline

- Problems and Vision
- Univ. of Virginia AlarmNet System
  - Architecture
  - Main Ideas/Results
- Current Work and Summary

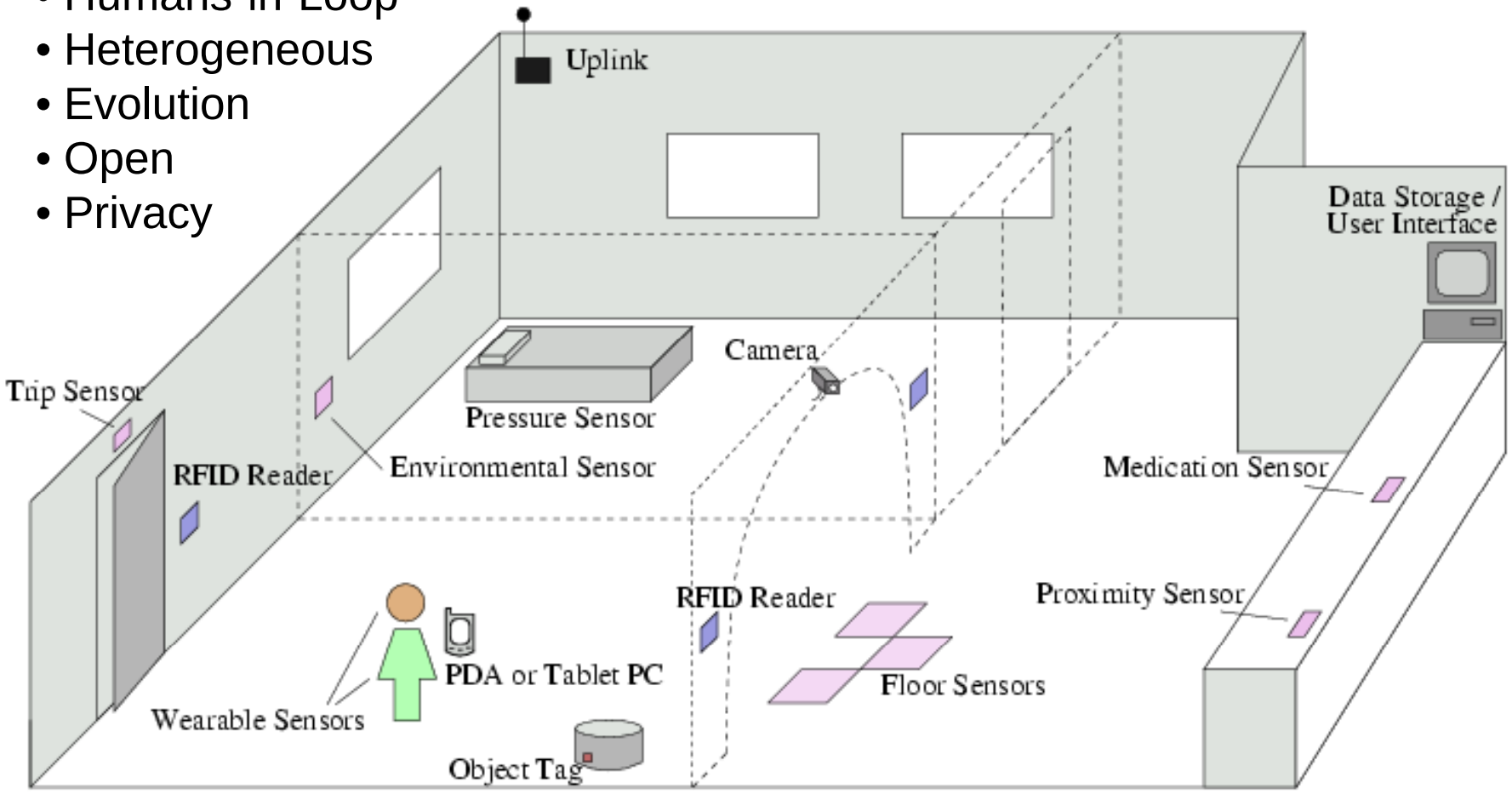
The Problems

- Aging Populations
- High Cost of Medical Care
- Lack of Facilities
- Quality of Life Issues

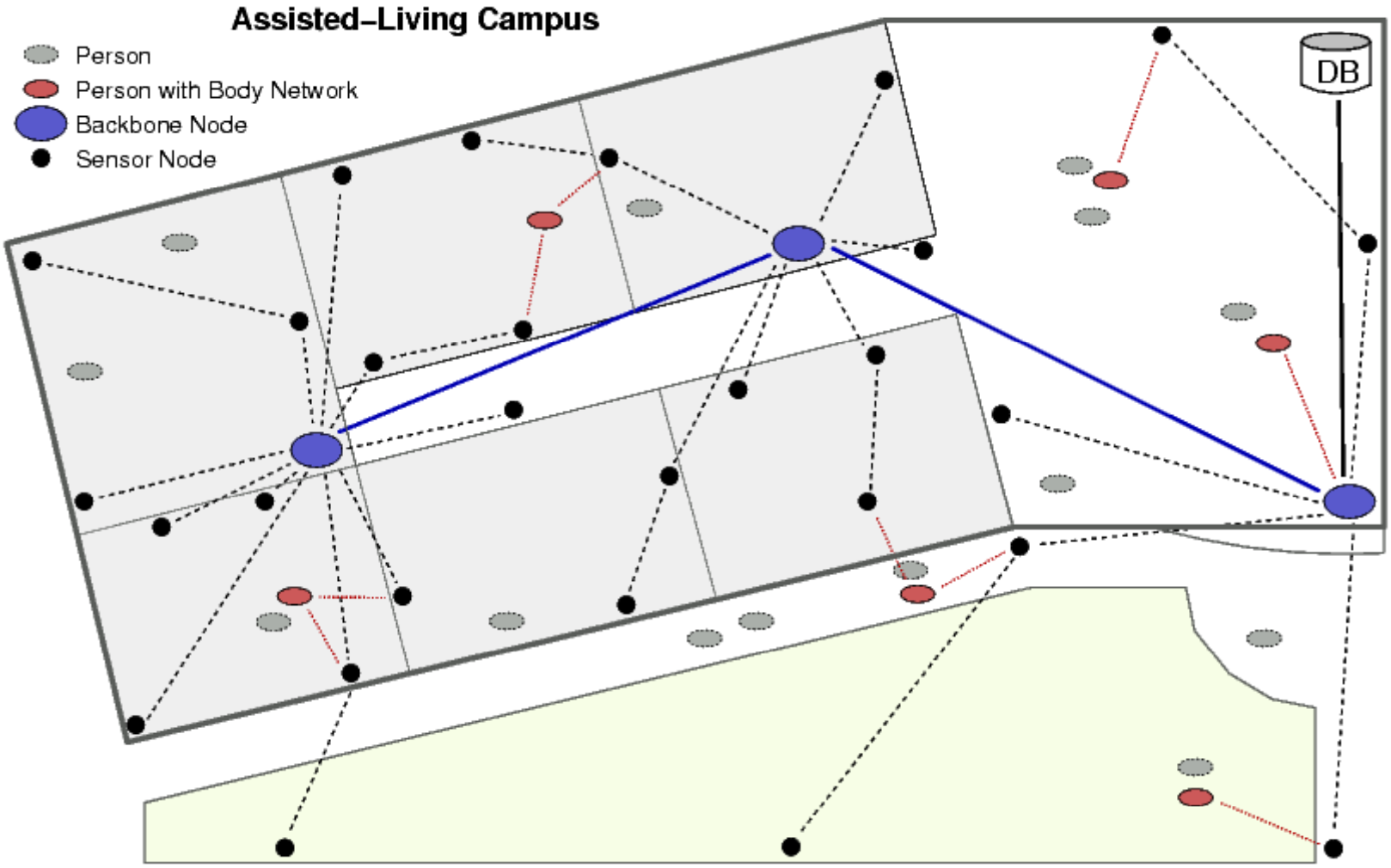
- Solution: Home Health Care
  CCRC
  Assisted Living

Vision - Smart Living Space

- Humans-in-Loop
- Heterogeneous
- Evolution
- Open
- Privacy



Large Scale Deployments



State of Art

- UCLA, Harvard, Yale, GaTech, MIT, Univ of Washington, Johns Hopkins, Imperial College, U. of Geneva, UPenn, UVA, etc.

- GE Health, Intel, Philips, Verizon, IBM, etc.
- *West Wireless Health Center*
- Wireless Life Sciences Alliance

- Europe, Asia, US

“3” Open Questions

- Scale
  - Numbers of sensors
  - Number of smart home units
  - Number of facilities
  - Number of functions on body networks
  - Numbers of body networks
- Activity Recognition (AR) not accurate enough
- Safety

Goals - A System View

- Tailored to patient
- Evolves over time
- Seemlessly integrate heterogeneous technology
- Largely Passive
- 24/7 Monitoring and Care

Benefits

- Identify normal behaviors
- Identify anomalous behaviors
- Detect medical problems (depression) early
- Improve quality of life
- Monitor adherence to and effectiveness of treatments
- Detect dangerous situations
- Maintain privacy
- Longitudinal studies

AlarmNet

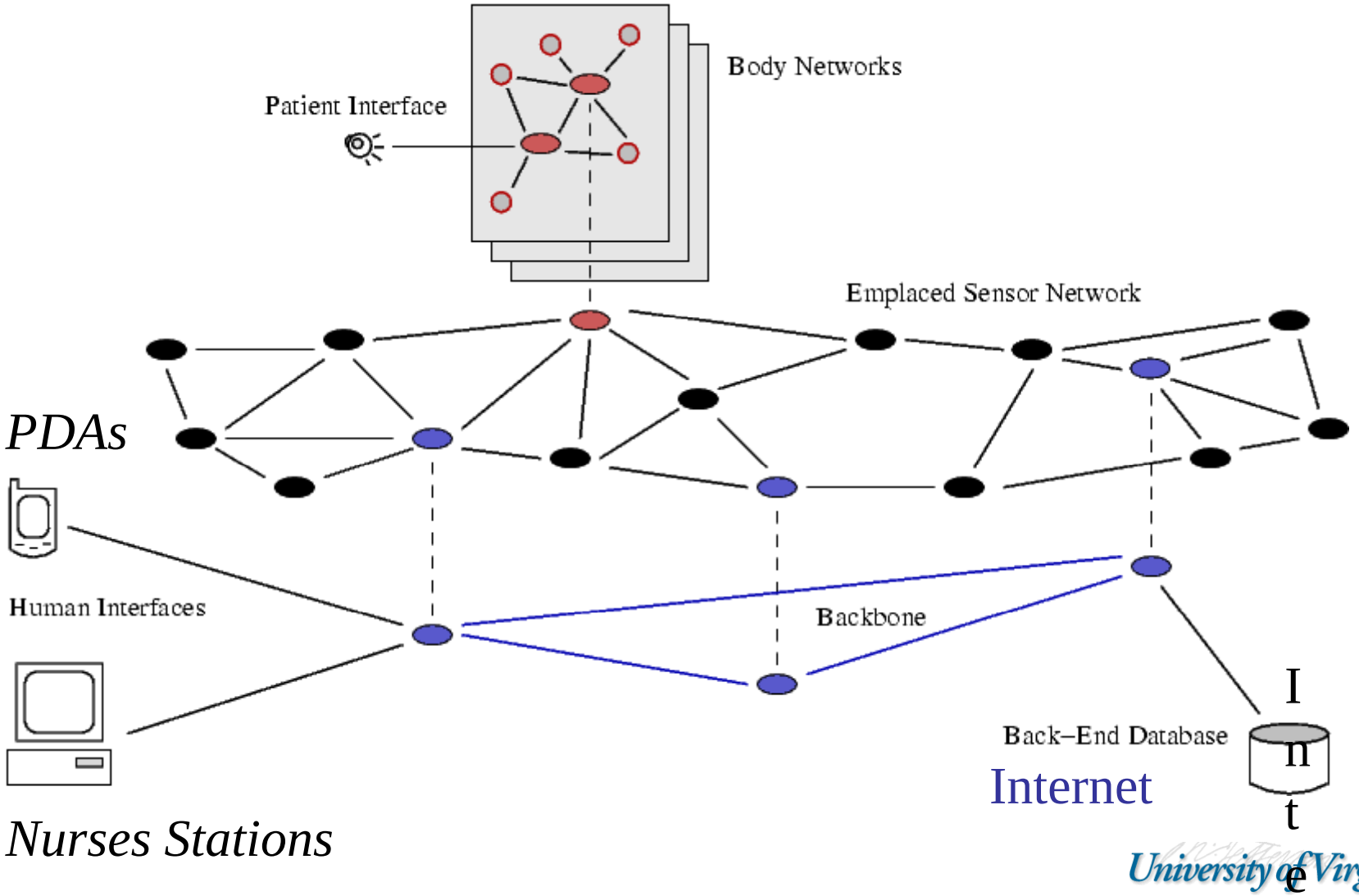
- Assisted Living and Residential Monitoring Network

- In-Lab Testbed

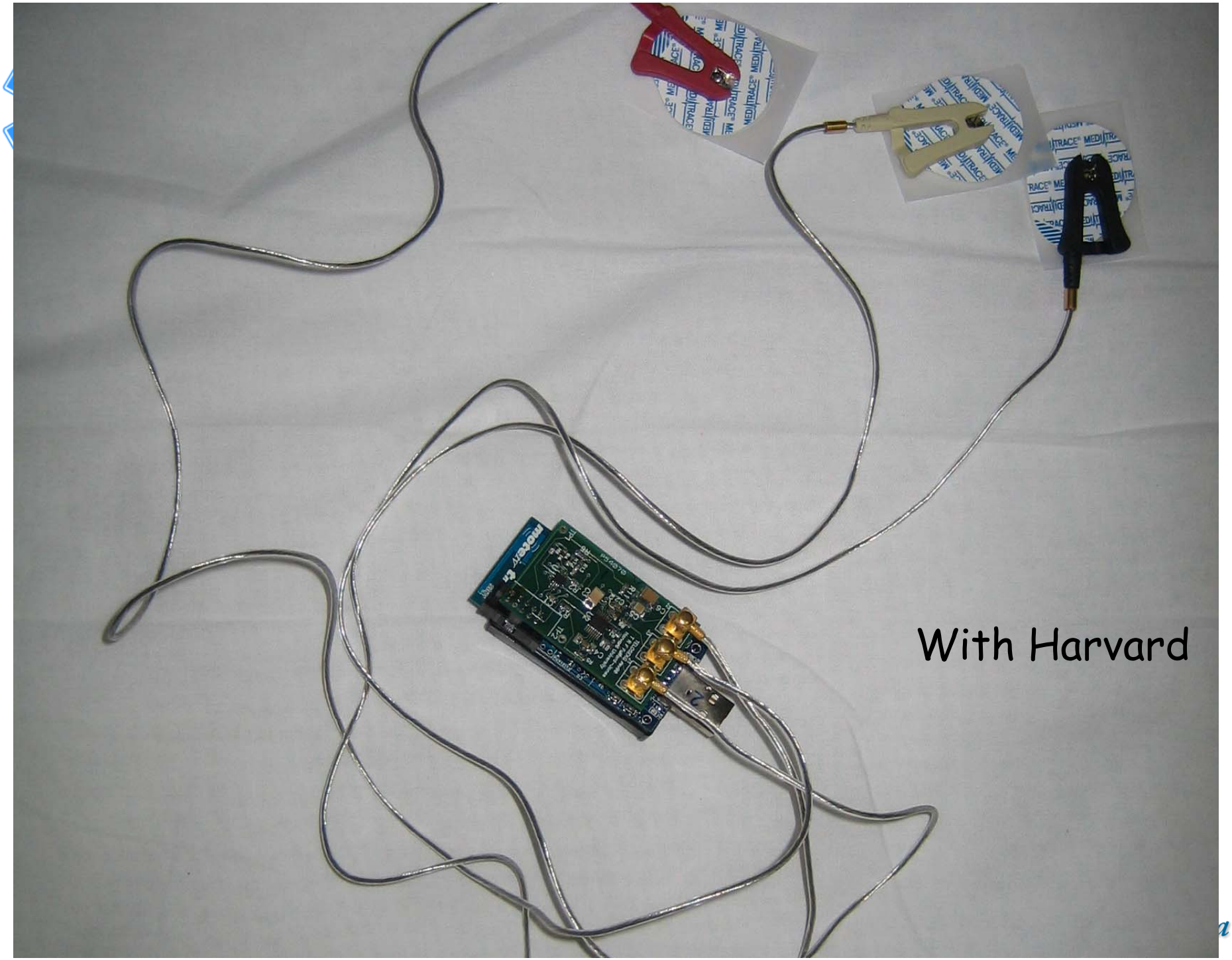
- Privacy – deployed in 8 homes
- Detecting Falls – students
- CAR – 22 patients in Assisted Living
- Sleep Study - 10 subjects
- Body Sensor Networks

- Deployment Plans – Depression in the Elderly
  - Deployed in one home

AlarmNet Architecture



With Harvard


With Harvard


With MARC UVA
Medical School

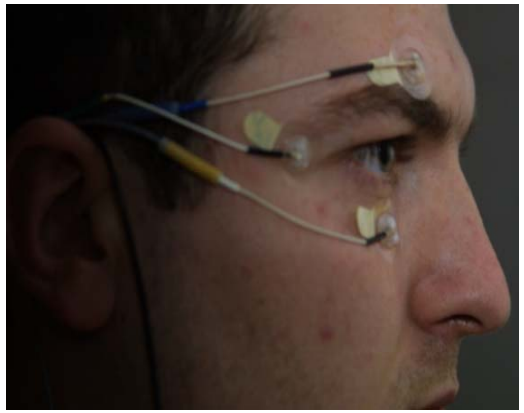
Sleep Monitoring

- Sleep motion (restlessness and agitation)
- Sleep quality

Using Physiological Signals

- EEG: measures brain waves
- EOG: measures eye movements
- EMG: measures electrical activity of muscles

- Disadvantages
  - Expensive
  - Uncomfortable
  - Measure once/twice



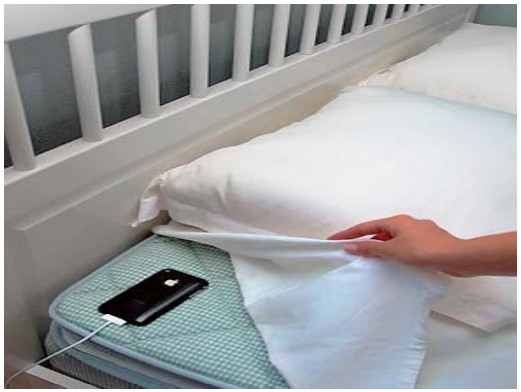
Wearable Devices in Home Environments

- Actiwatch
- Headband - Zeo
- Disadvantage
  - Users need to wear the devices

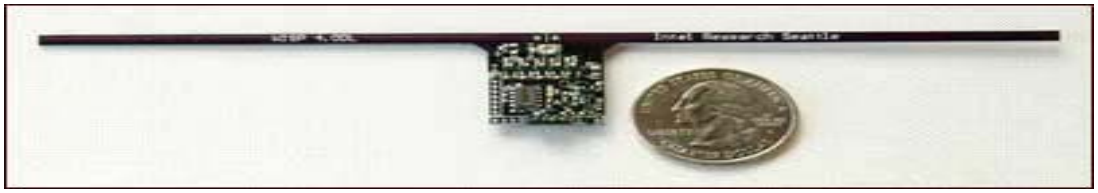
Non-Wearable Solutions

- Pressure Pads
  - Disadvantage
    - Not entirely comfortable
    - Do not infer body positions

- Cell Phone Apps
  - Built-in accelerometers are used
  - Disadvantage
    - Not robust

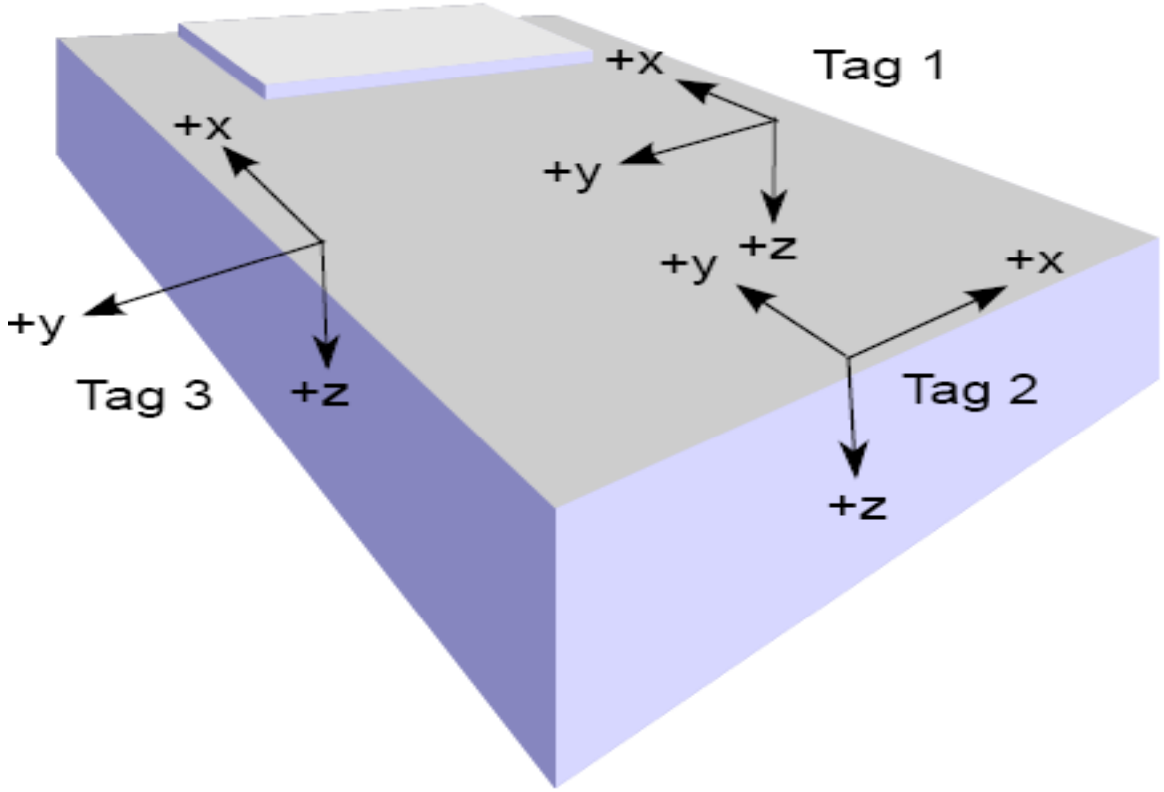


WISP



- Combines RFID technology with sensors
- Used to sense light, temperature and acceleration
- Powered and read by RFID readers

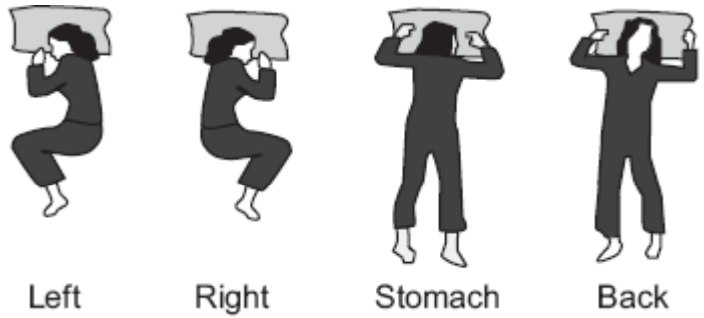
WISP Instrumented Mattress

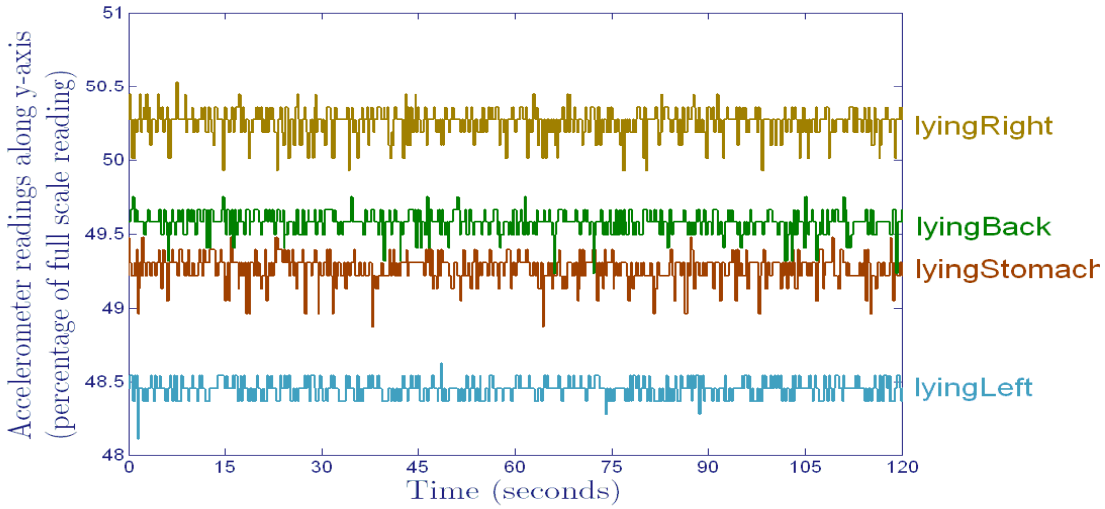


University of Virginia

Body Position Inference

- For different body positions, orientations of one or more axes of the accelerometers with respect to gravity are different
- We combine the readings from all three tags to infer body position





Body Position Inference

- During training, for each body position of the subject, we construct a 9-tuple from the readings of the three tags
- We train a Bayesian classifier with these tuples
- We use this classifier to infer body positions during sleep

Controlled Experiments for Body Position Inference

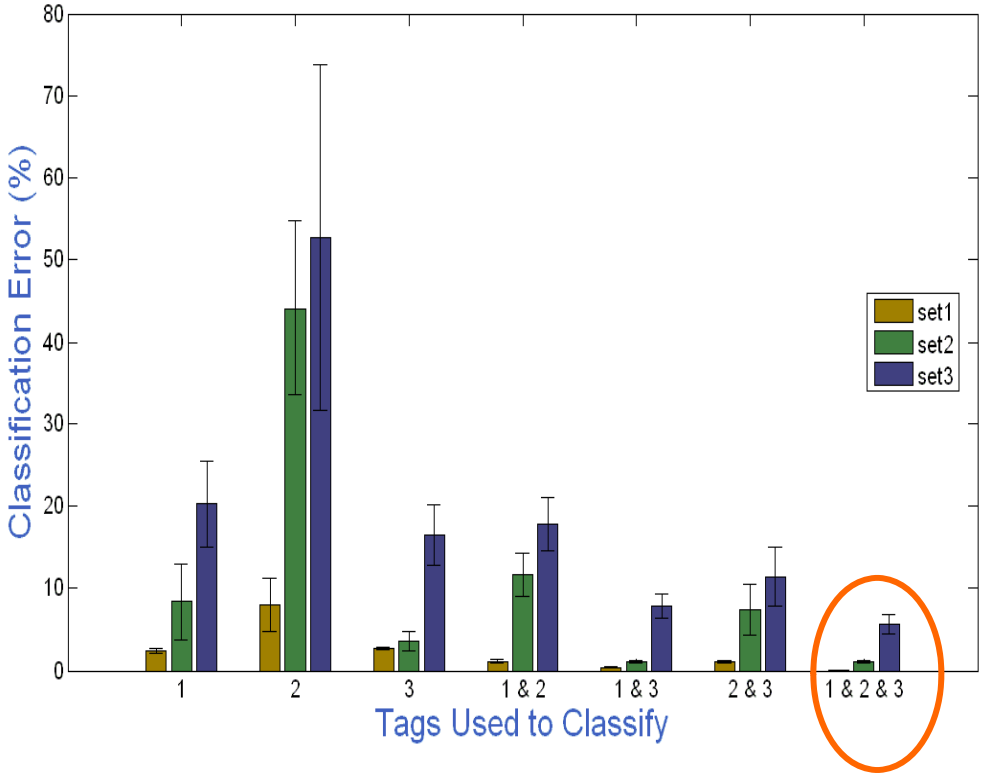
- 10 subjects
- 3 different mattresses

- Each subject lies in each of the 4 body positions for 2.5 minutes each

- For each position, we use the data from the first 2 minutes for training and next 30 seconds for evaluating accuracy of body position inference

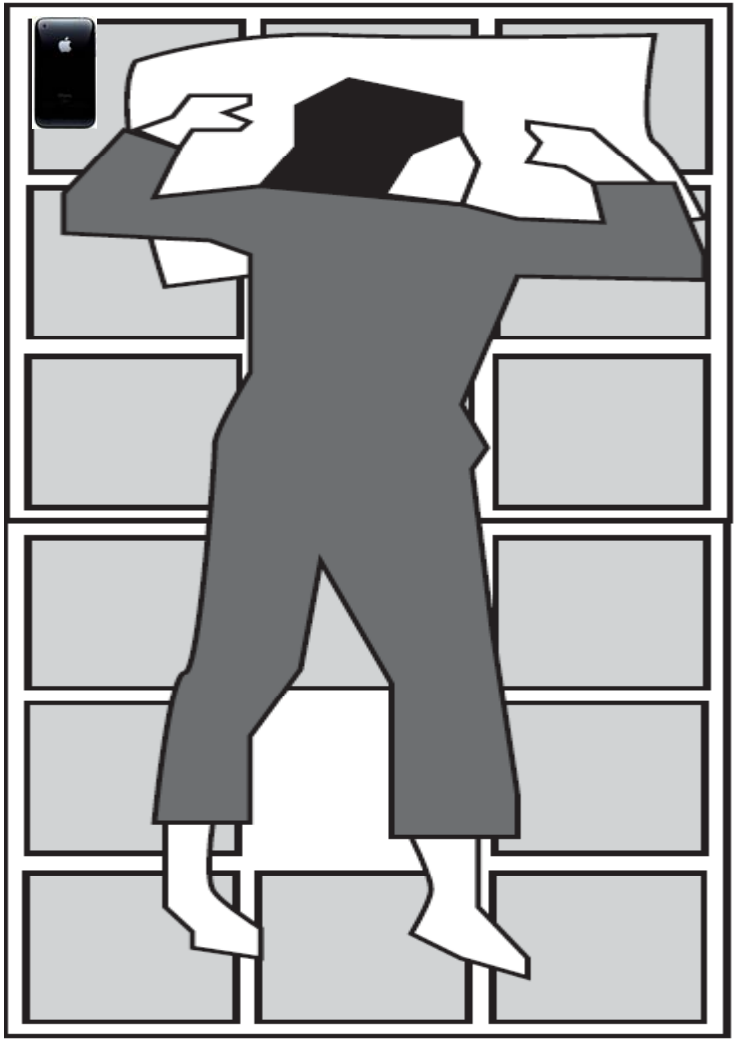
Results

- 3 settings:
  - set1: differentiate between the bed being empty or occupied
  - set2: differentiate between empty, lying and sitting
  - set3: differentiate between all lying positions, empty and sitting



Realistic Overnight Experiments

- 6 nights
- DDR pads (sense pressure) used as baseline system
- Also compare with an iPhone application: Sleep Cycle
- We also recorded the video of the 6 nights' sleep



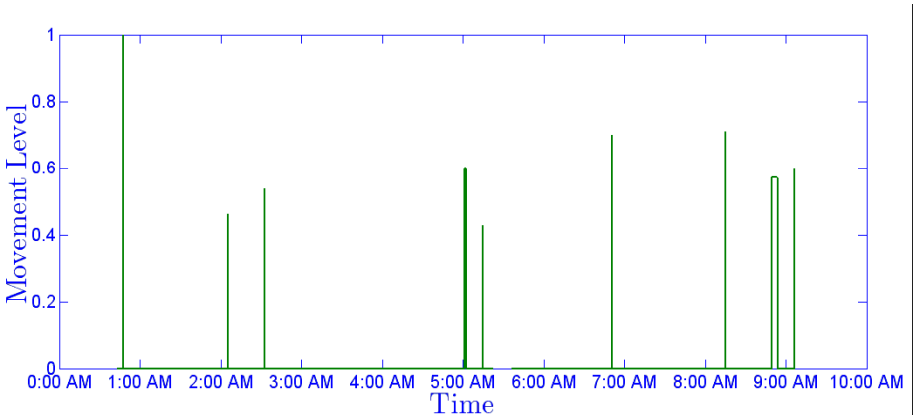
Evaluation by Cross Validation

- 6 Evaluation sets
- In each set, we train our system based on 5 nights of data and evaluate the performance of the remaining night

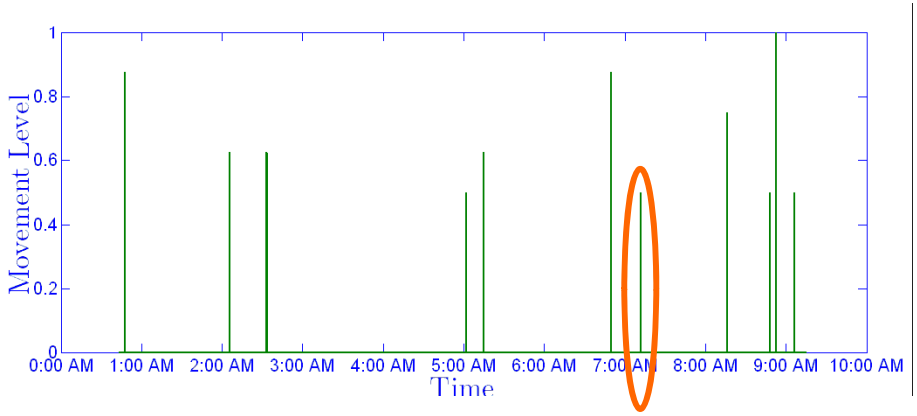
Movement Detection Evaluation

- Ground Truth
  - Validated the performance of DDR pads by comparing with 3 hours video
  - DDR pads are considered ground truth

DDR pad



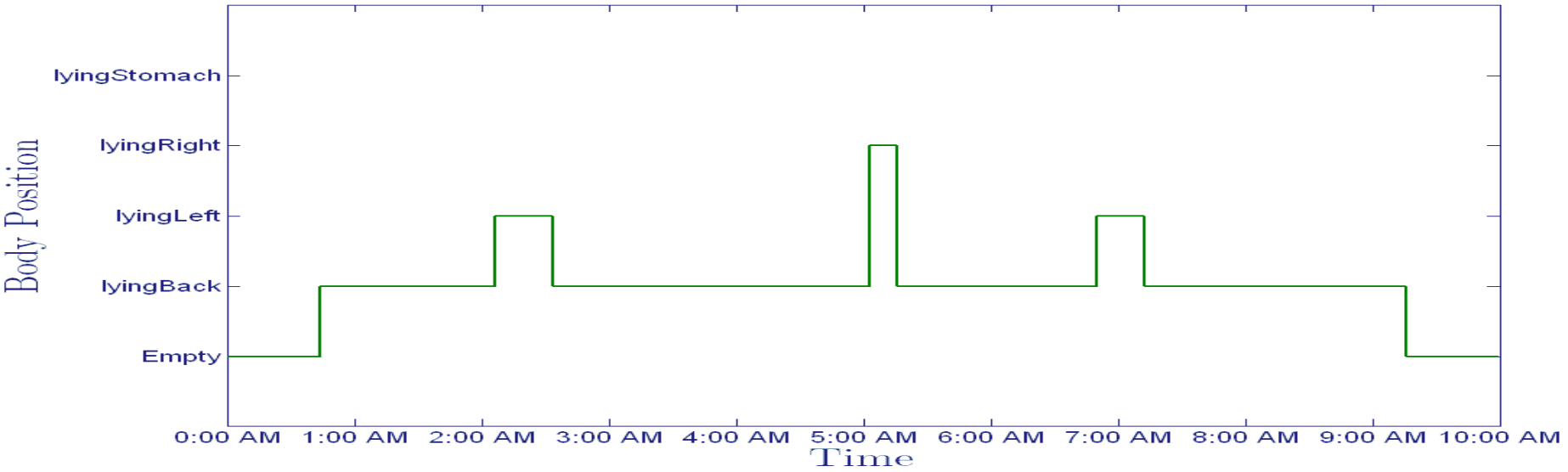
WISP



University of Virginia

Body Position Inference

- Ground Truth
  - Collected from the recorded video
  - Accurate within 5%

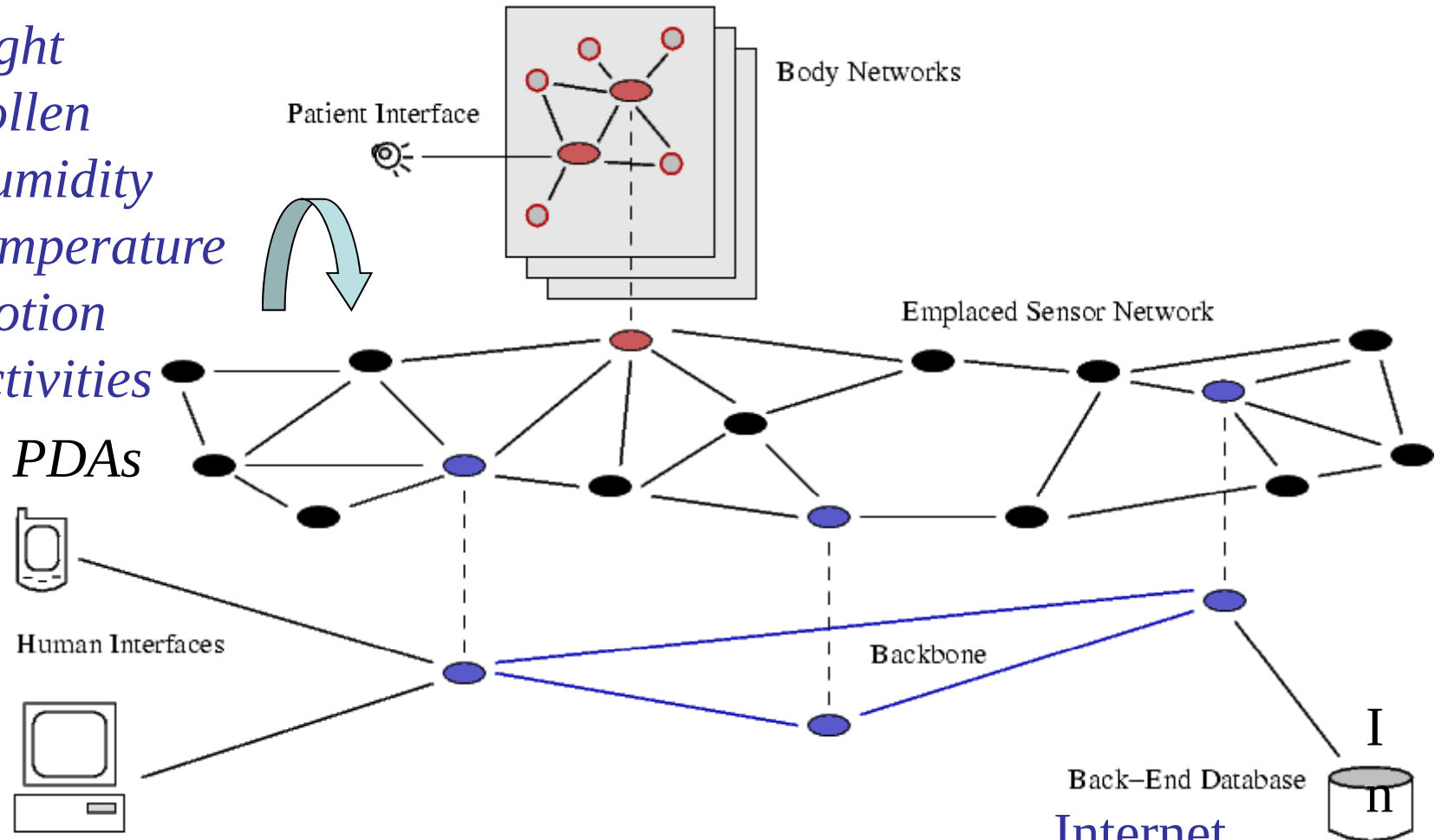


Medical Studies

- Correlation between sleep movement and agitation with incontinence in dementia patients
  - Combine with acoustic and wetness sensors

AlarmNet Architecture

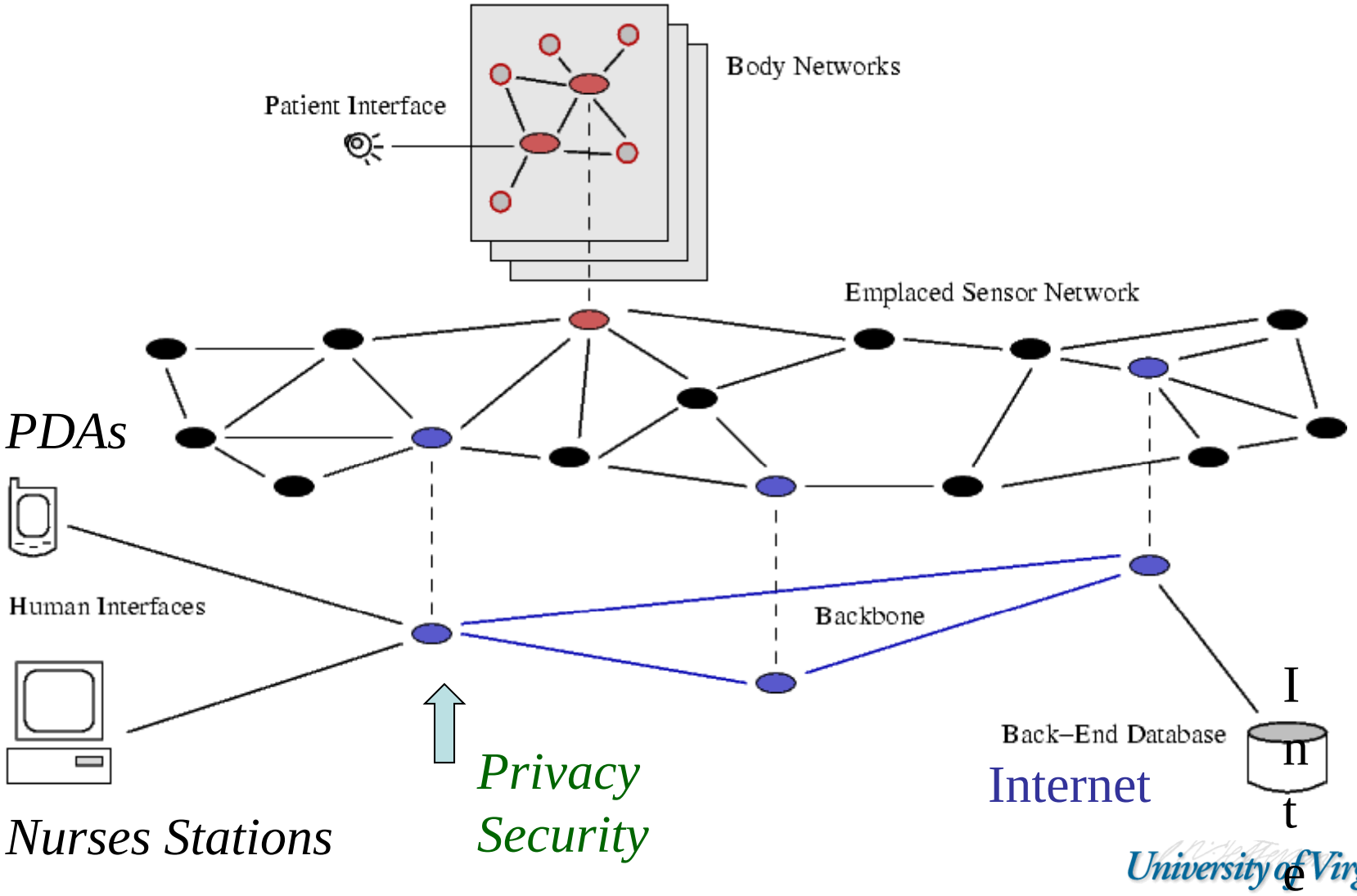
Dust
Light
Pollen
Humidity
Temperature
Motion
Activities



Key Points

- Self-configuring - Highly flexible (radio shack model)
- New sensor types can be added later
- Contributes to Activity Recognition (AR)

AlarmNet Architecture



AlarmGate

- Netbridge device (Stargate)
  - single board computer
  - embedded Linux
  - 400MHz Xscale
  - mote daughterboard
  - wireless ethernet

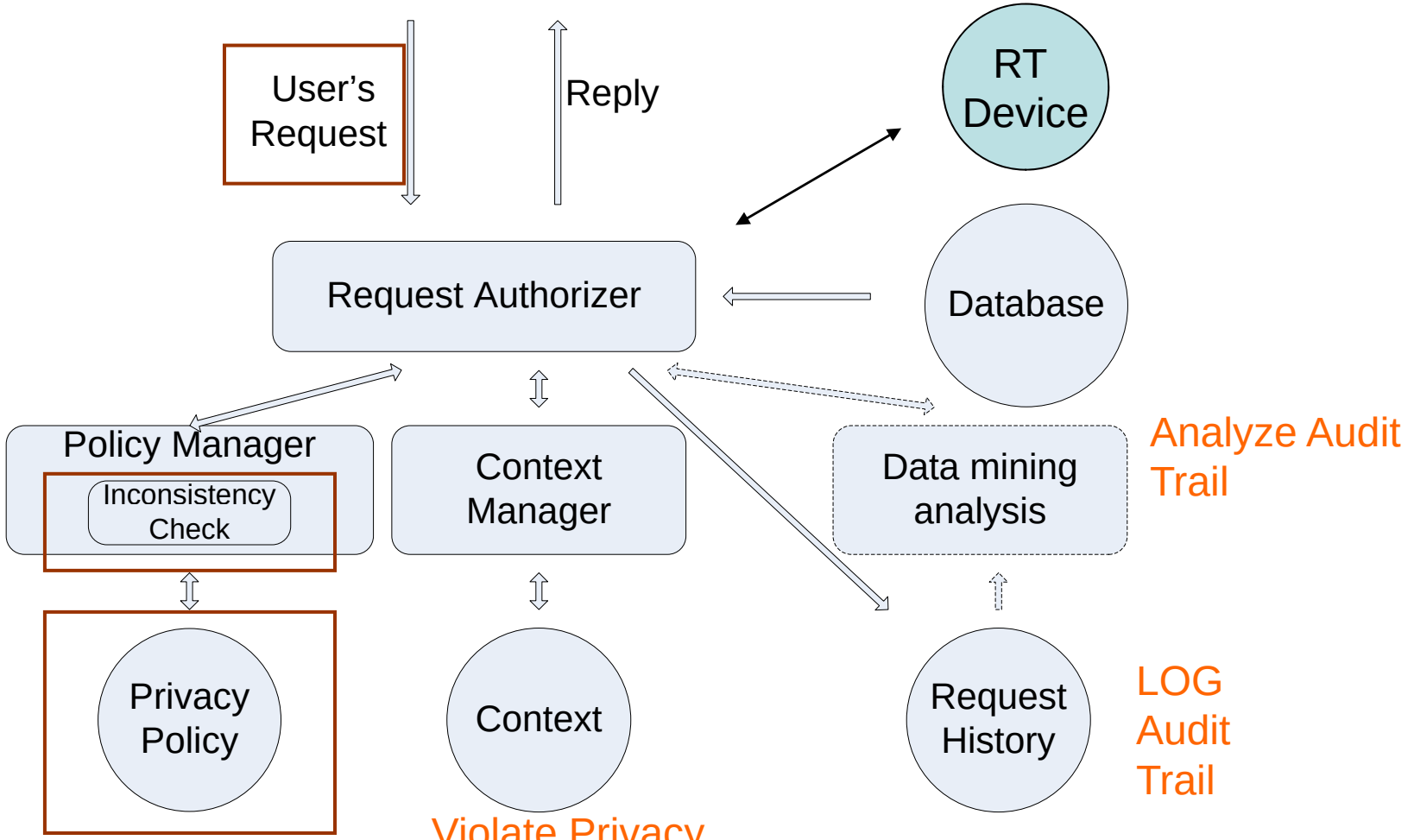
Privacy - Many Stakeholders

- Patients
- Patients family and friends
- Doctor – what advantages for them in treating patients
- Nurse
- Technician
- Orderly
- Admin
- Social Worker

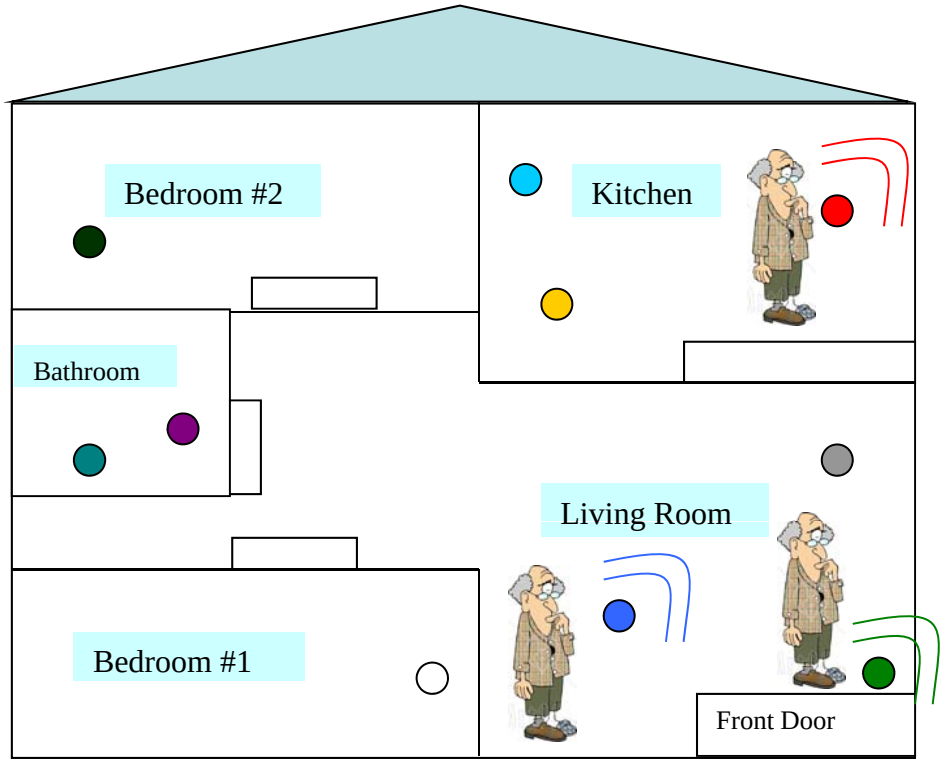
Privacy - Many Data Types

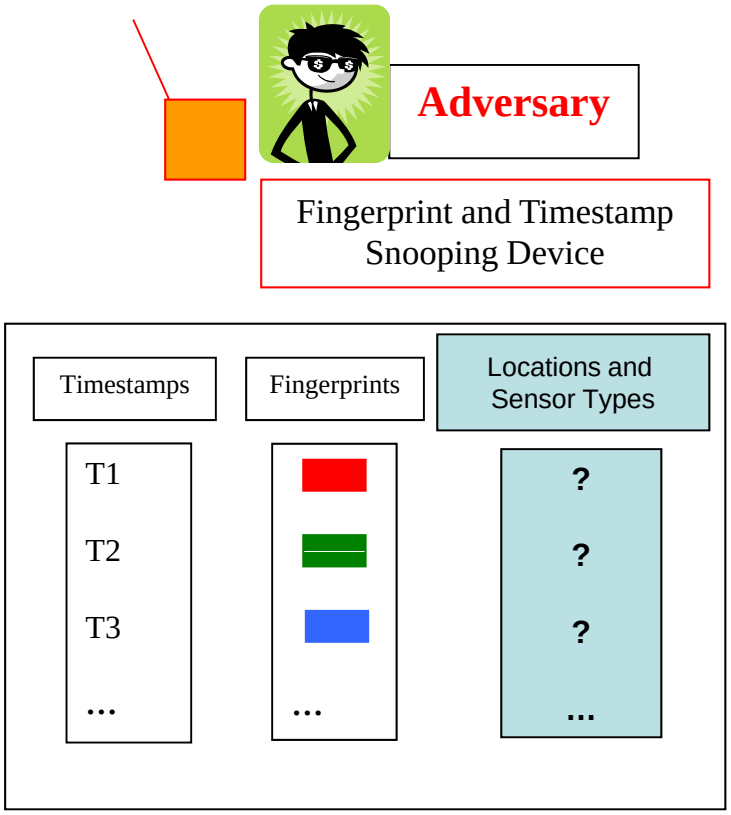
- Personal medical data
- Personal activity data
- Environmental data
- Contextual data
- Longitudinal data
- System Performance data

Authorization Framework



*F*ingerprint *A*nd *T*iming-based *S*noop attack

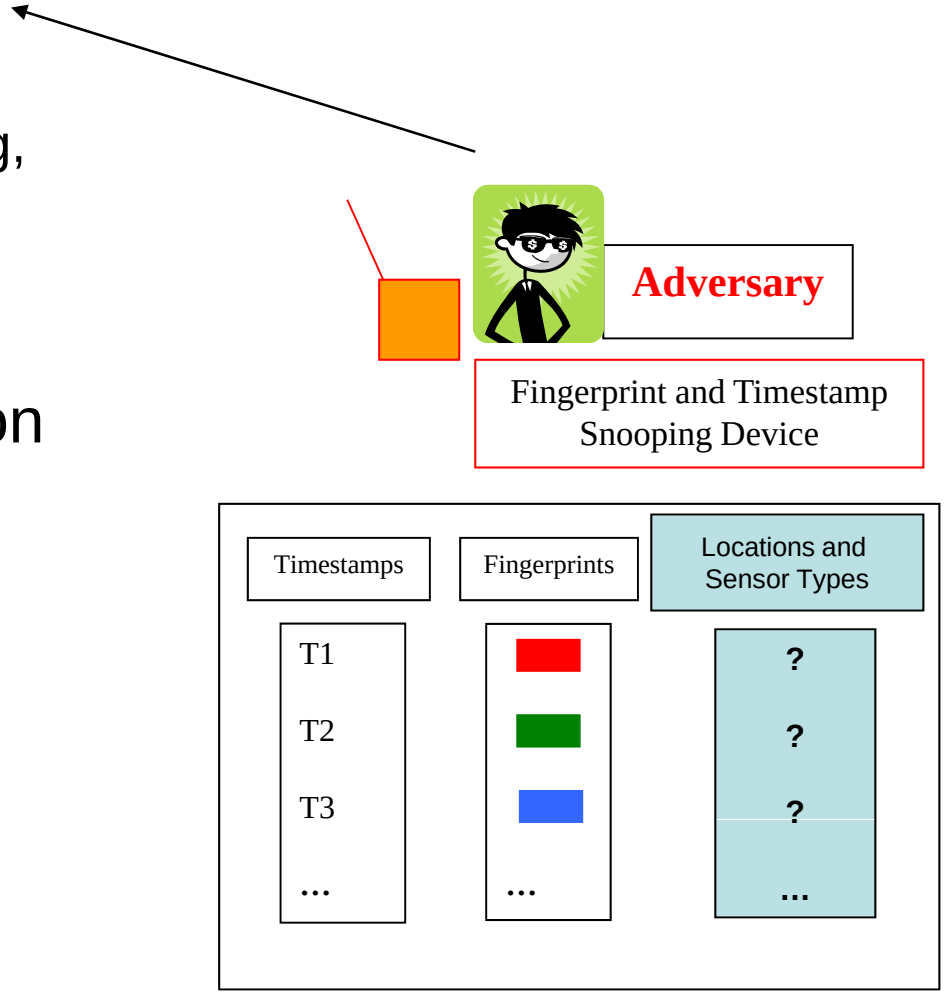




V. Srinivasan, J. Stankovic, K. Whitehouse, Protecting Your Daily In-Home Activity Information fron a Wireless Snooping Attack, Ubicomp, 2007.

ADL

- **ADLs inferred:**
  - Sleeping, Home Occupancy
  - Bathroom and Kitchen Visits
  - Bathroom Activities: Showering, Toileting, Washing
  - Kitchen Activities: Cooking
- High level medical information inference possible
- HIPAA requires healthcare providers to protect this information



Performance

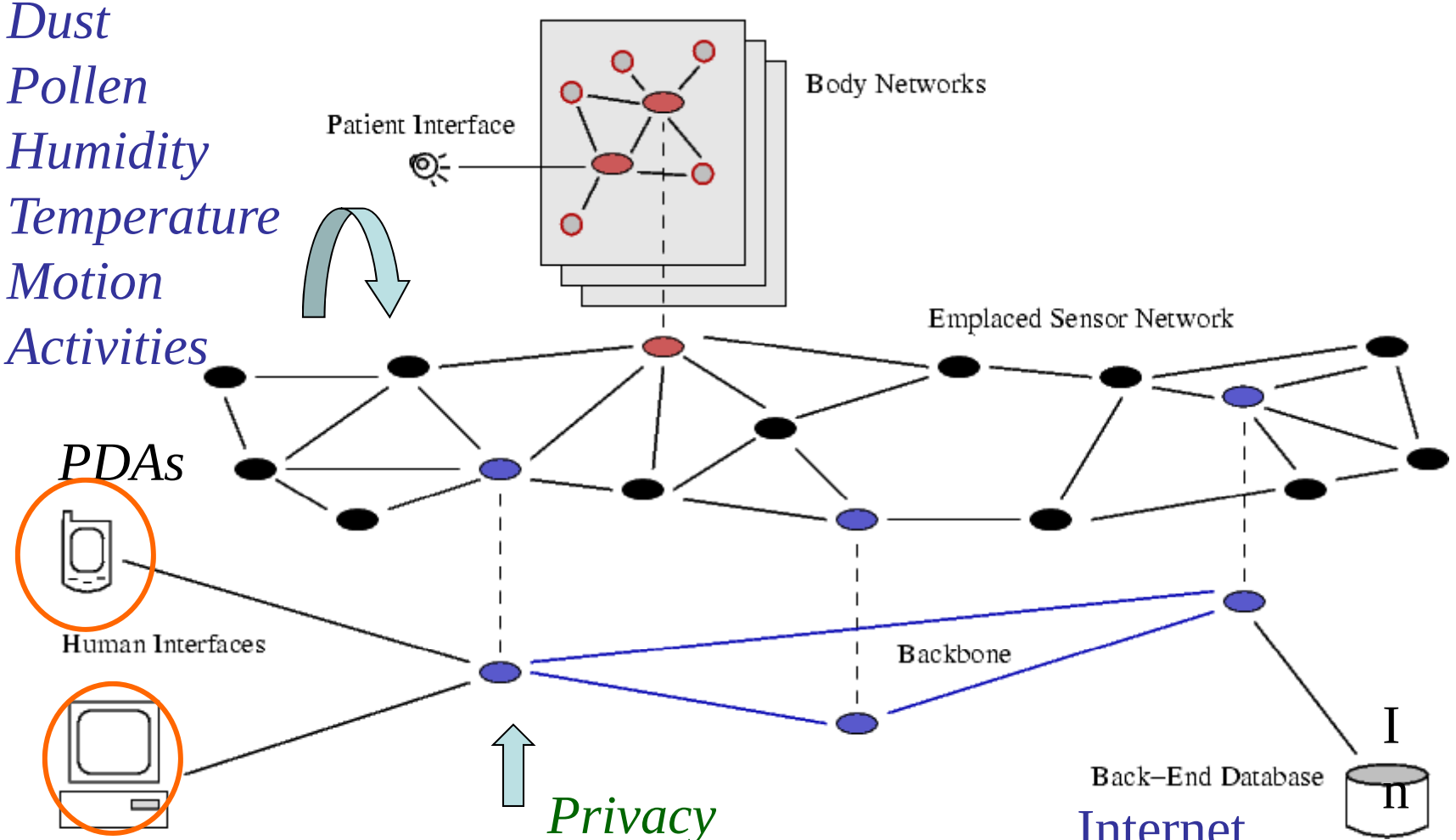
- 8 homes (X10) - different floor plans
  - Each home had 12 to 22 sensors
- 1 week deployments
- 1, 2, 3 person homes
- Violate Privacy - Techniques Created
  - 80-95% accuracy of AR via 4 Tier Inference
- FATS solutions
  - Reduces accuracy of AR to 0-15%

Key Points

- Privacy is critical (many types)
- Overridden on alarms
- Use dynamic context and request history
- Inconsistency checking algorithms required

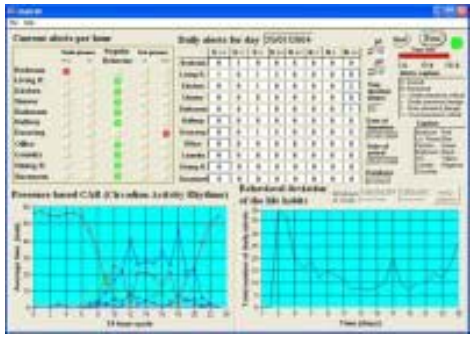
AlarmNet Architecture

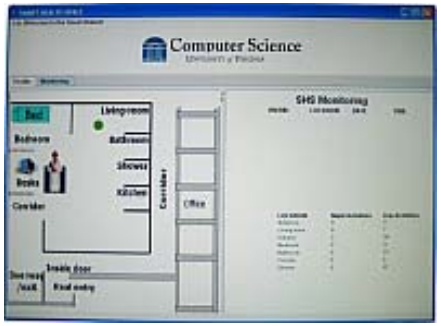
Dust
Pollen
Humidity
Temperature
Motion
Activities



Graphical Interfaces

- PDA real-time query issuer – template based
- Circadian Activity Rhythms
- Nurse's station monitoring
- Embedded displays

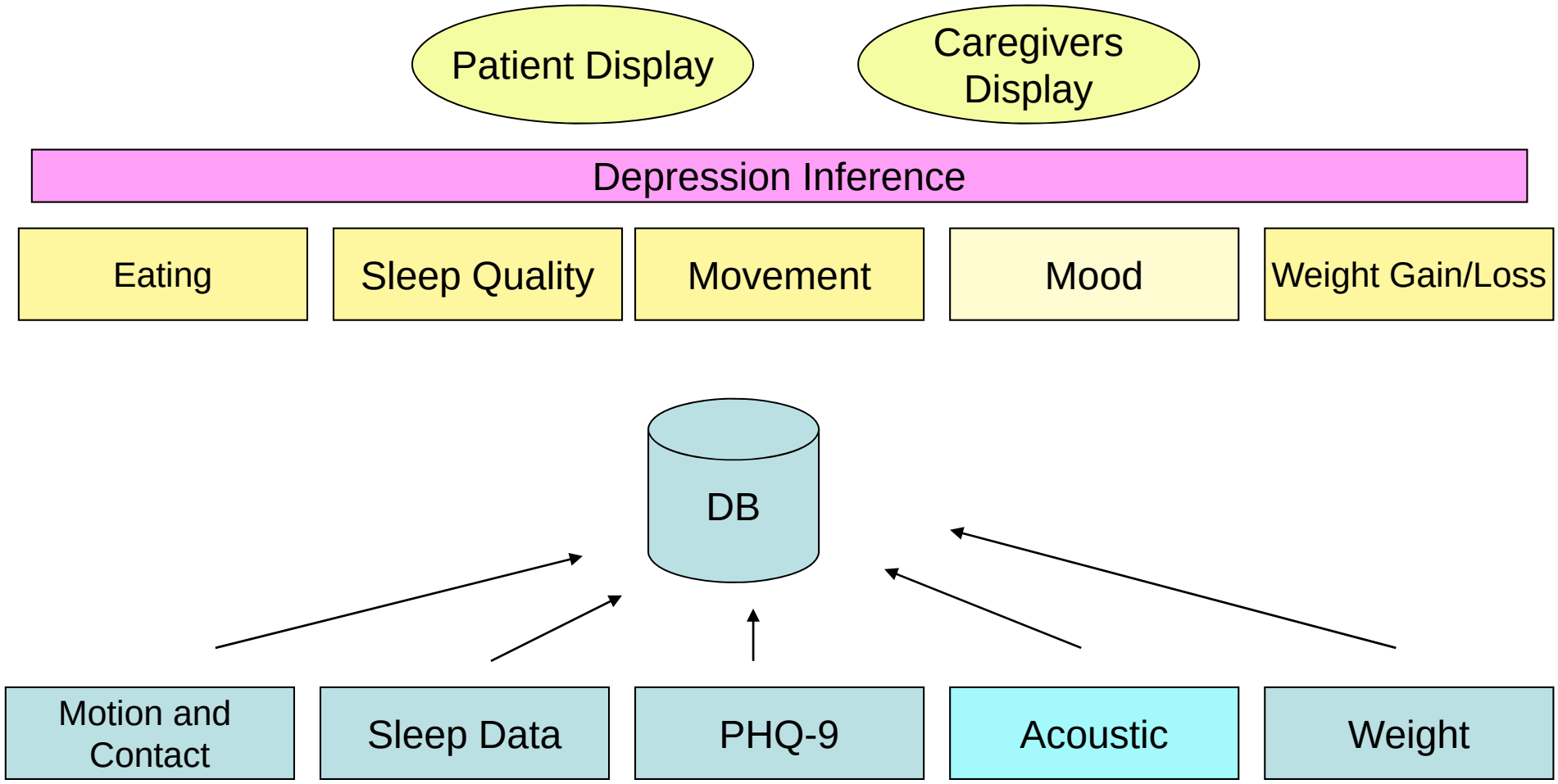


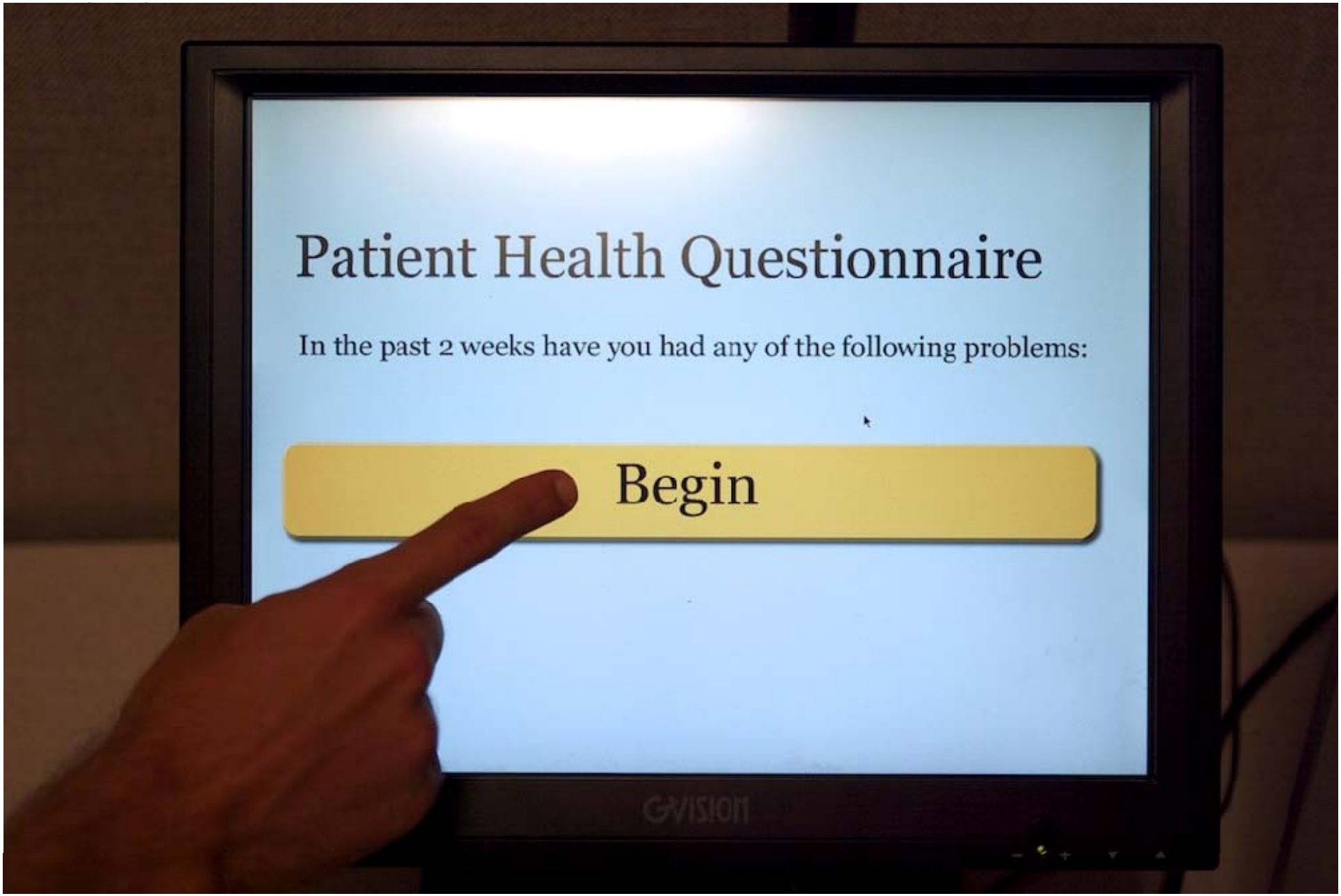


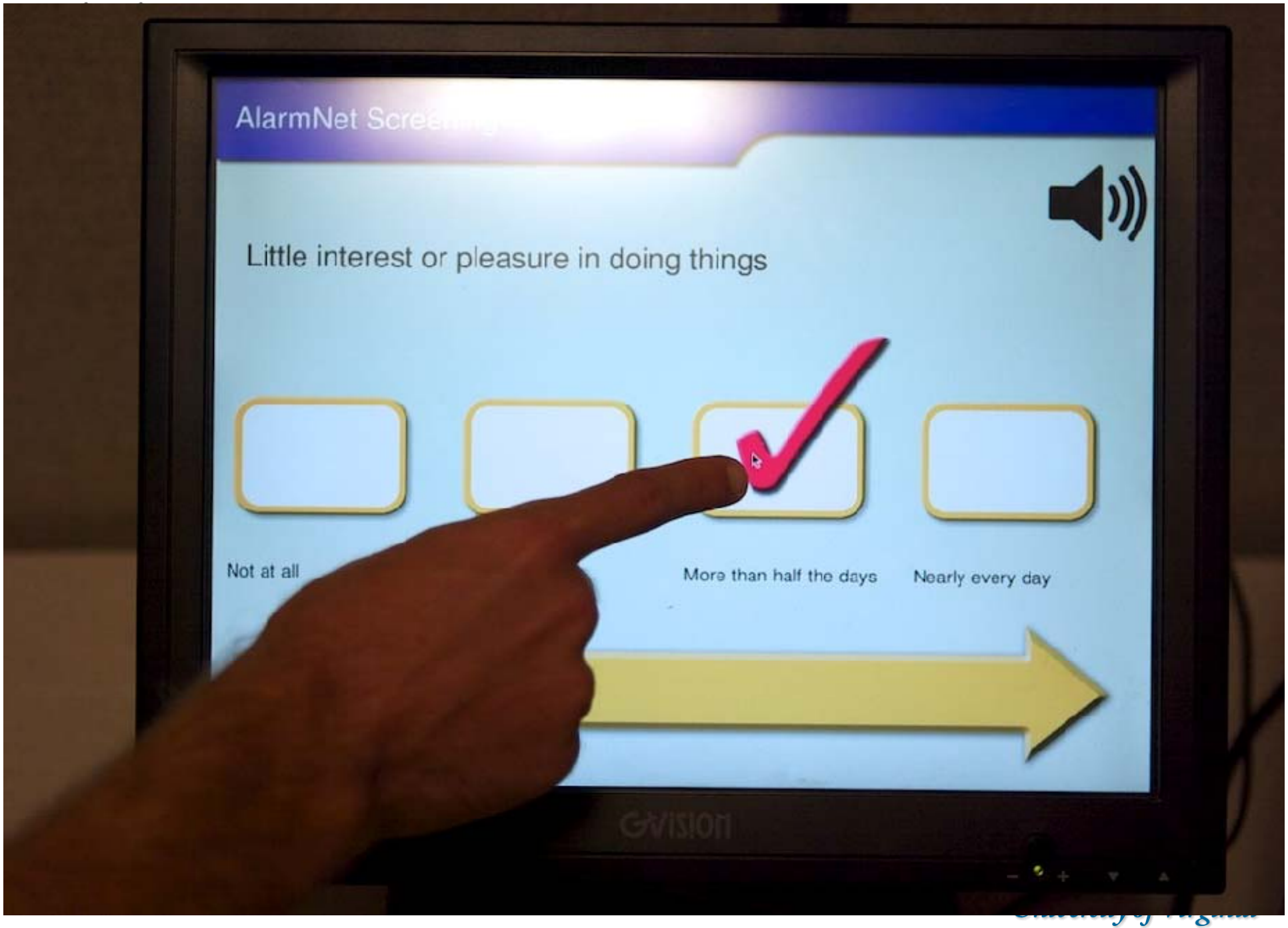
Depression Detection and Monitoring

- Multi-modal
- Passive
- Combines Objective and Subjective Measures

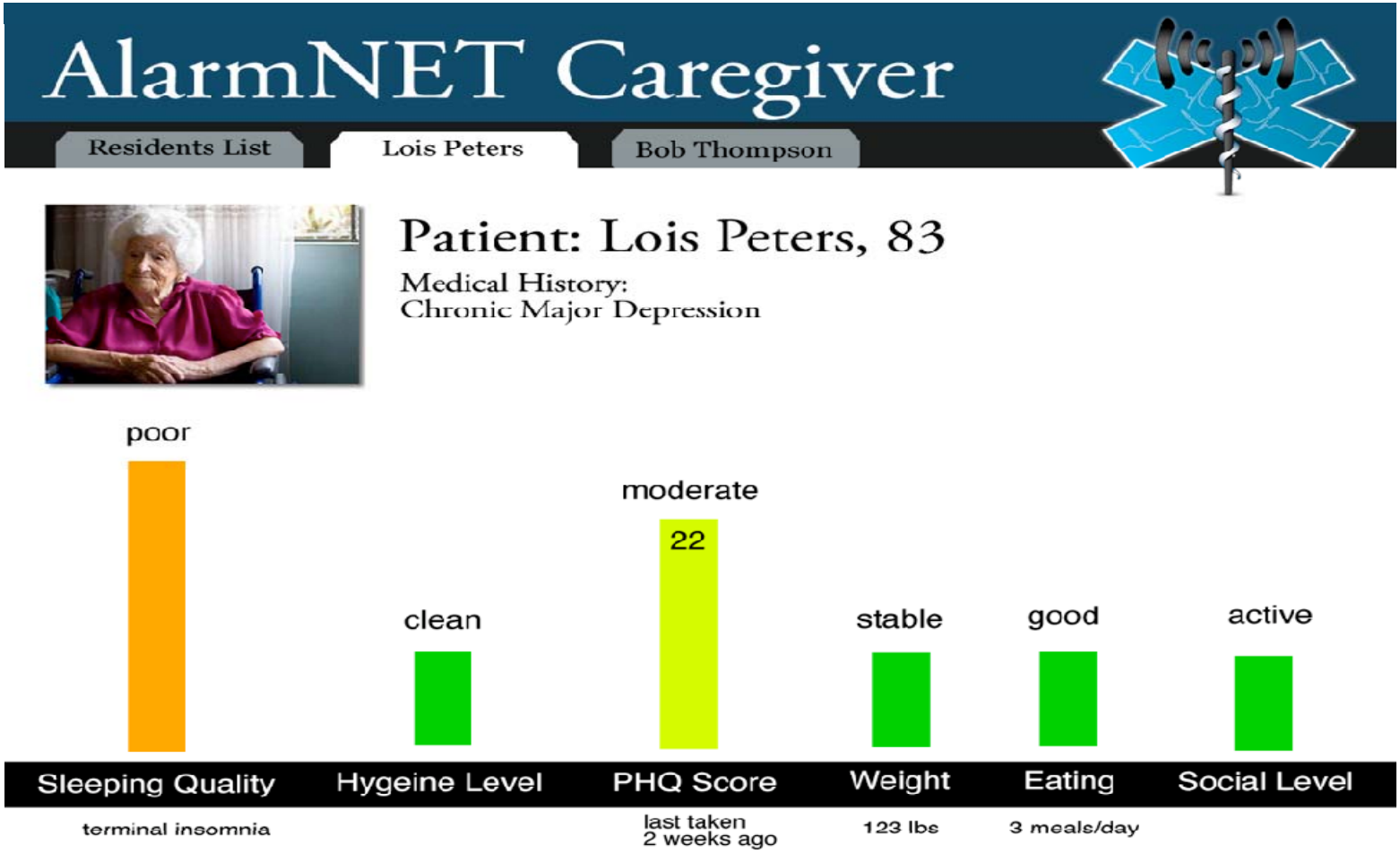
Depression Monitoring




Patient Health Questionnaire
In the past 2 weeks have you had any of the following problems:
Begin


AlarmNet Screening
Little interest or pleasure in doing things
Not at all
More than half the days
Nearly every day
GVISION

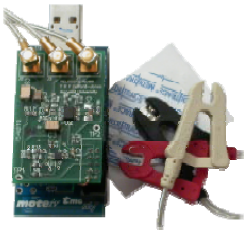
Caregivers Display



PDA Real-Time Queries

AlarmGate SW
on stargate

DB



University of Virginia

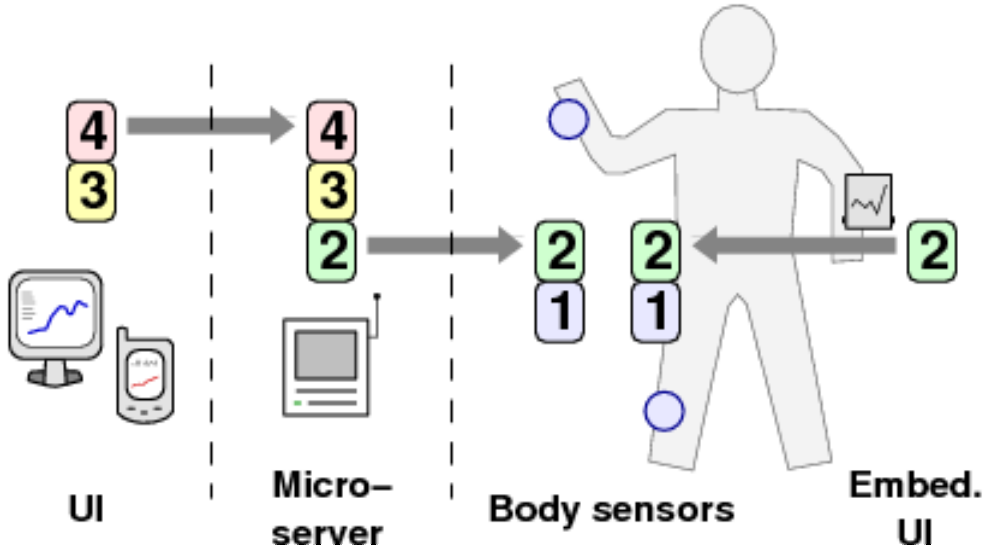
SenQ

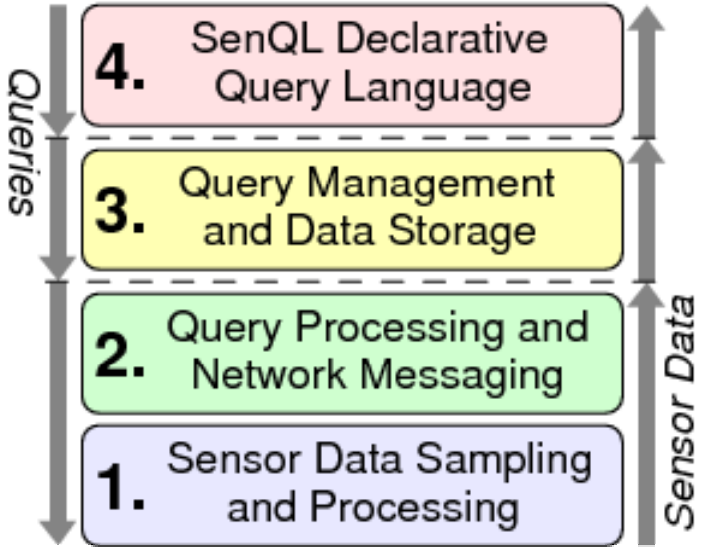
- Interactive, Embedded Query System
  - Peer to peer
- Streams – define, discover and share
- Virtual sensors – discover and share
- Devices added/deleted
- Optional Modules
- Location Transparency
- UI - Developers, Domain Experts, Users
- Privacy and Security

A. Wood, L. Selavo, J. Stankovic, SenQ: An Embedded Query System For Streaming Data in Heterogeneous Interactive Wireless Sensor Networks, DCOSS, 2008.

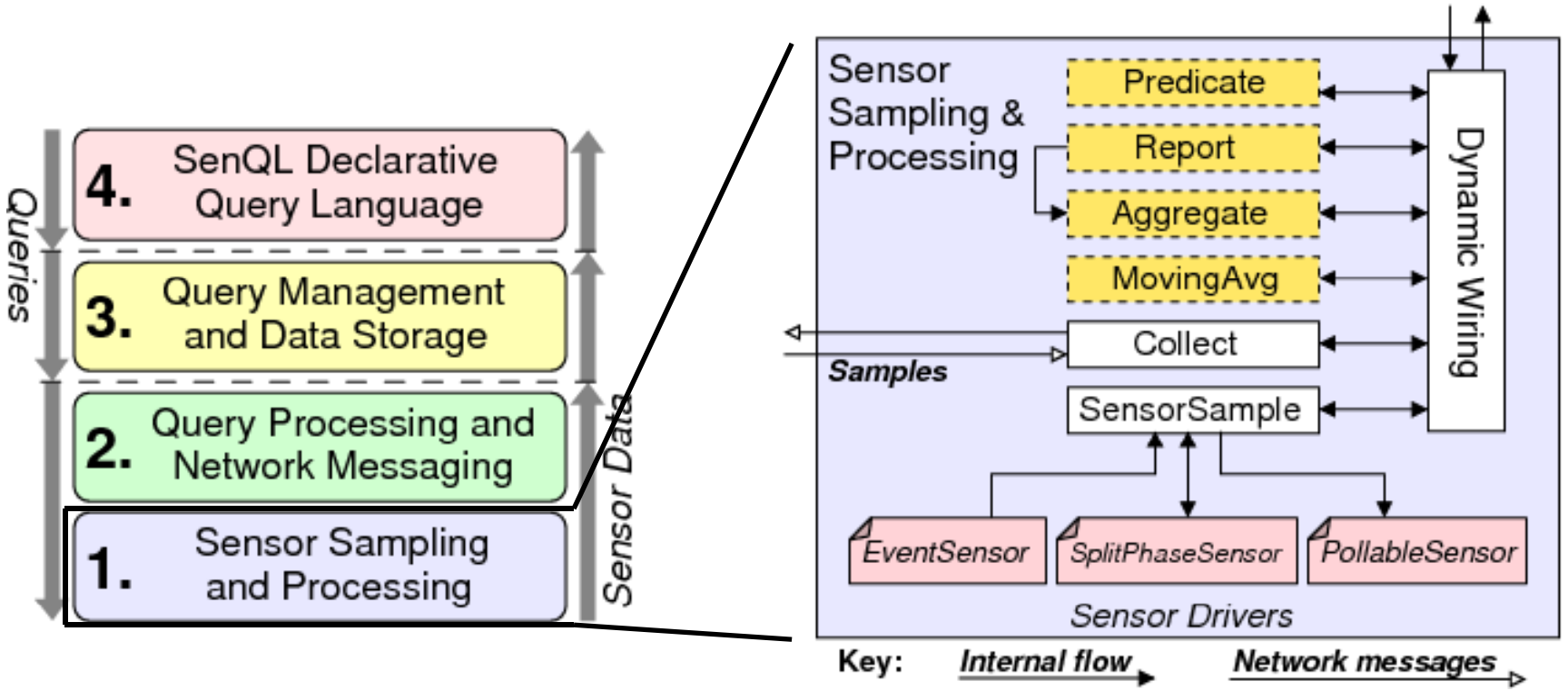
SenQ Layers

- Loosely coupled layers



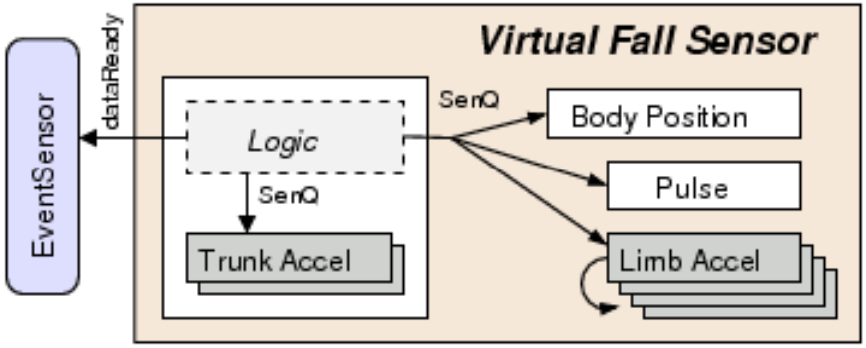


Sensor Data Sampling & Processing

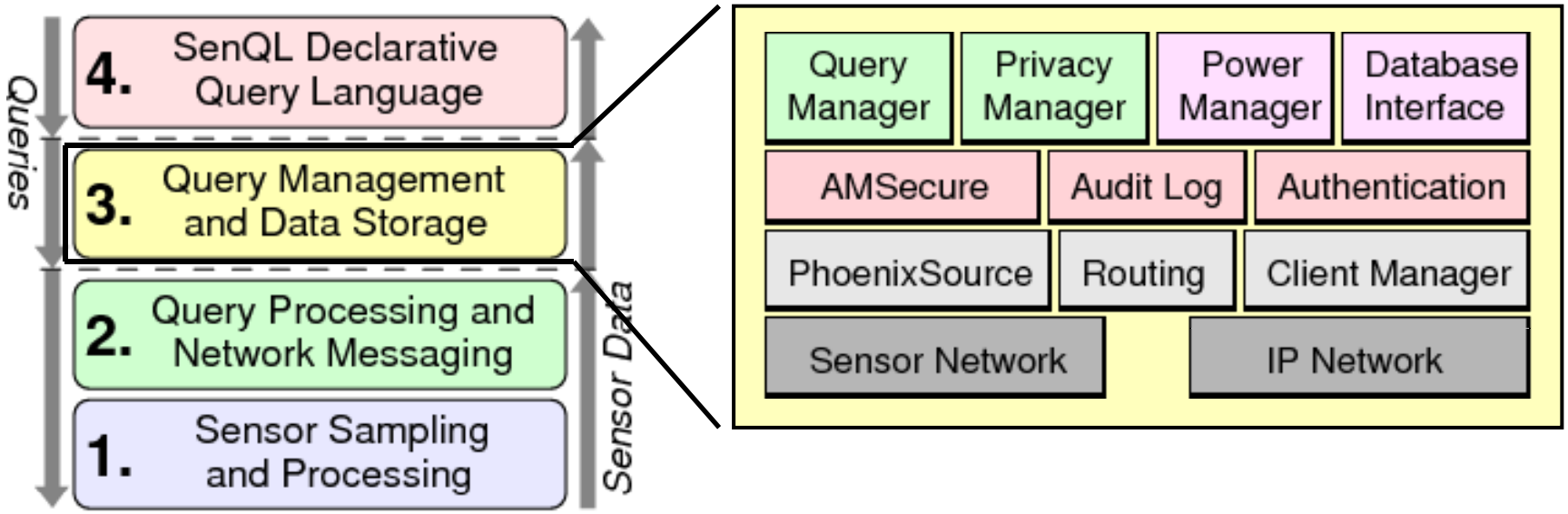


Sensor Data Sampling & Processing

- Virtual Sensors
  - users fuse streams to make new sensors
  - sensor drivers can recursively invoke SenQ

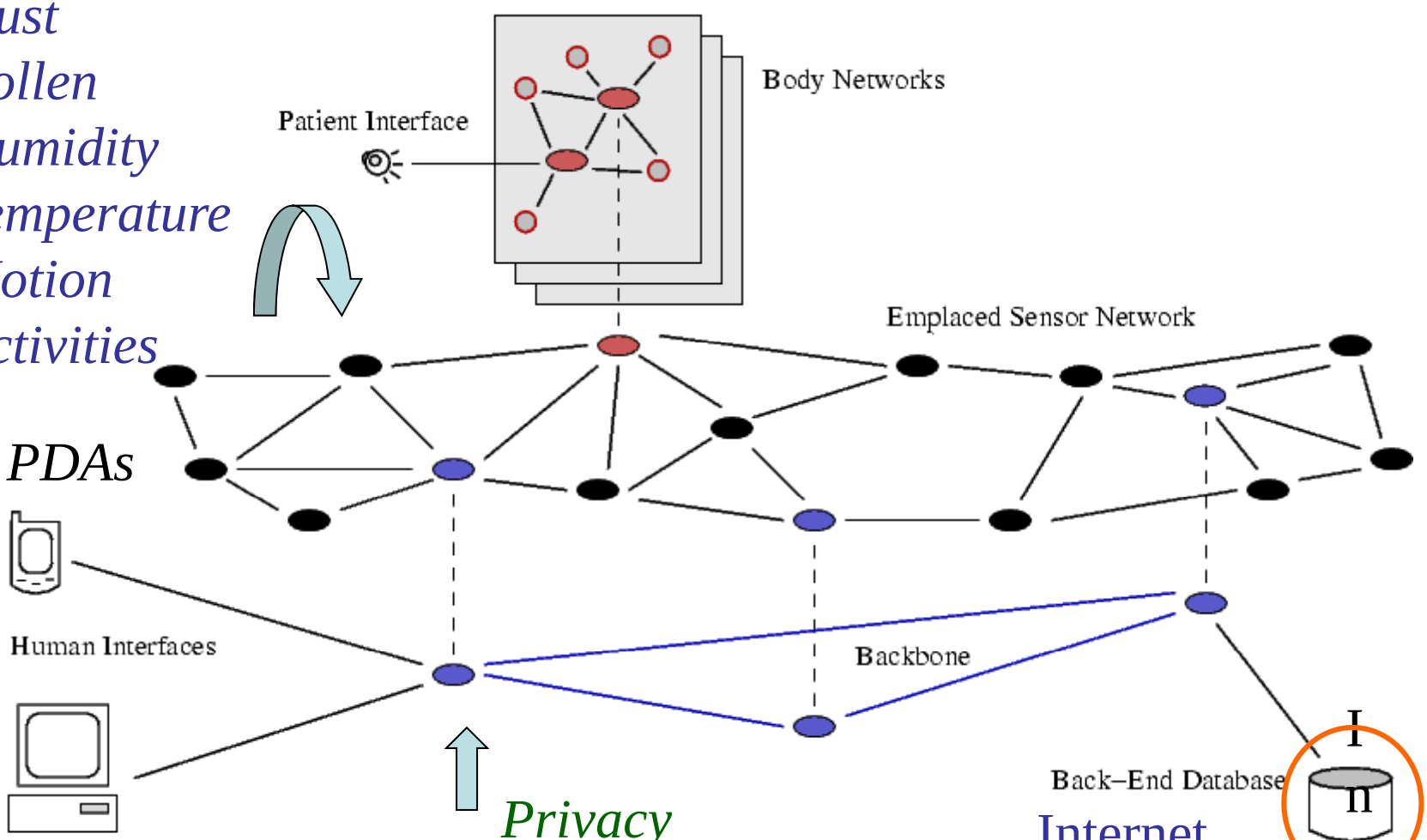


Query Management



AlarmNet Architecture

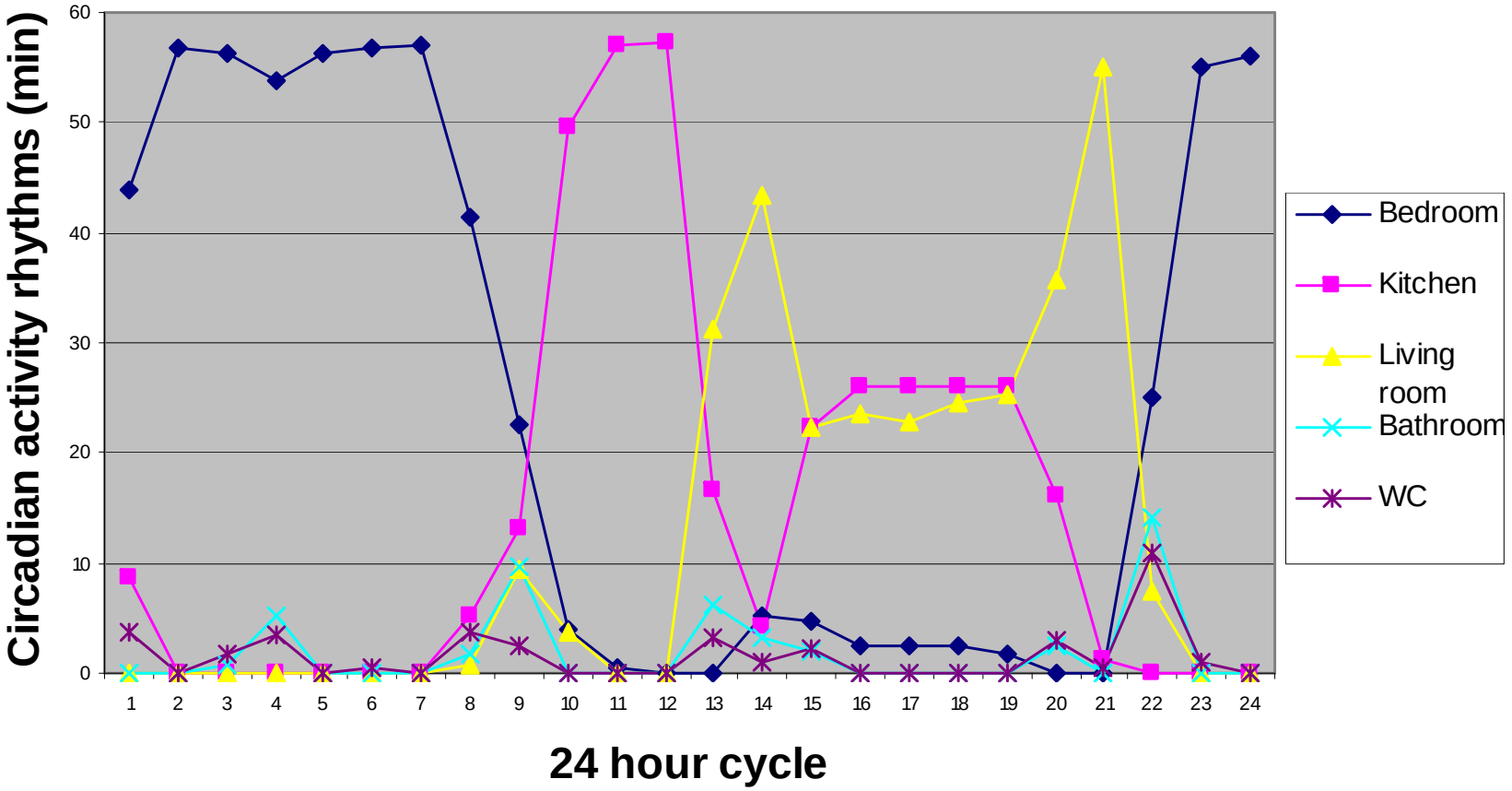
Dust
Pollen
Humidity
Temperature
Motion
Activities



Circadian Activity Rhythms

- 22 patients
- 3 months to 1 year
- 7 males; 15 females
- Ages 49-93
- All ambulatory
- Weekday; weekend; seasonal
- Eliminate times when not in facility
- Learning - 2-3 weeks of normal behavior

Circadian Rhythms



Circadian activity rhythm per room for 70 days

University of Virginia

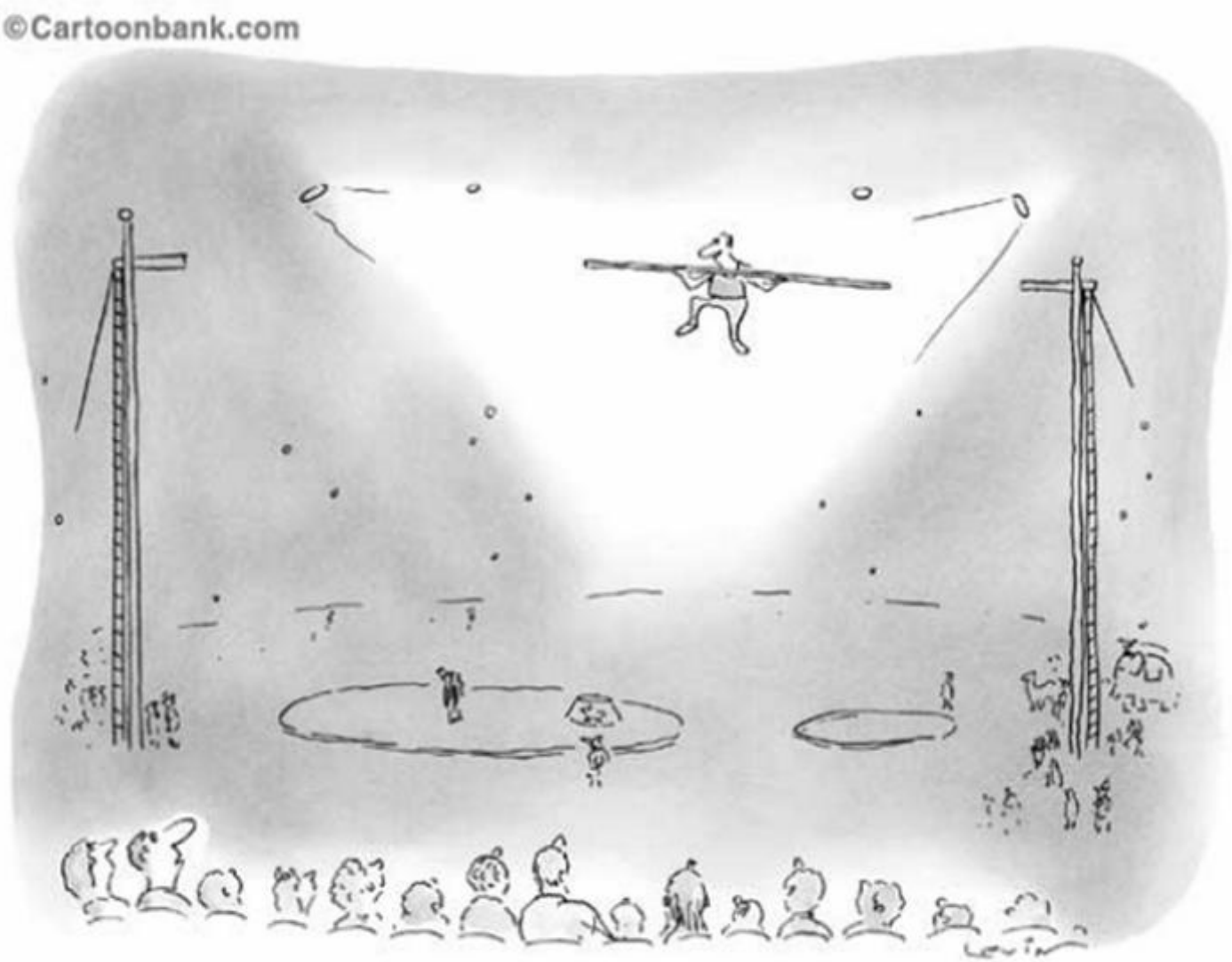
Anomalies

- Examples
  - Retroactively analyzed the anomalies
    - Detected “depression” – much more time in bed
    - Detected increased urination at night
    - Detected different behavior upon return from hospitalization

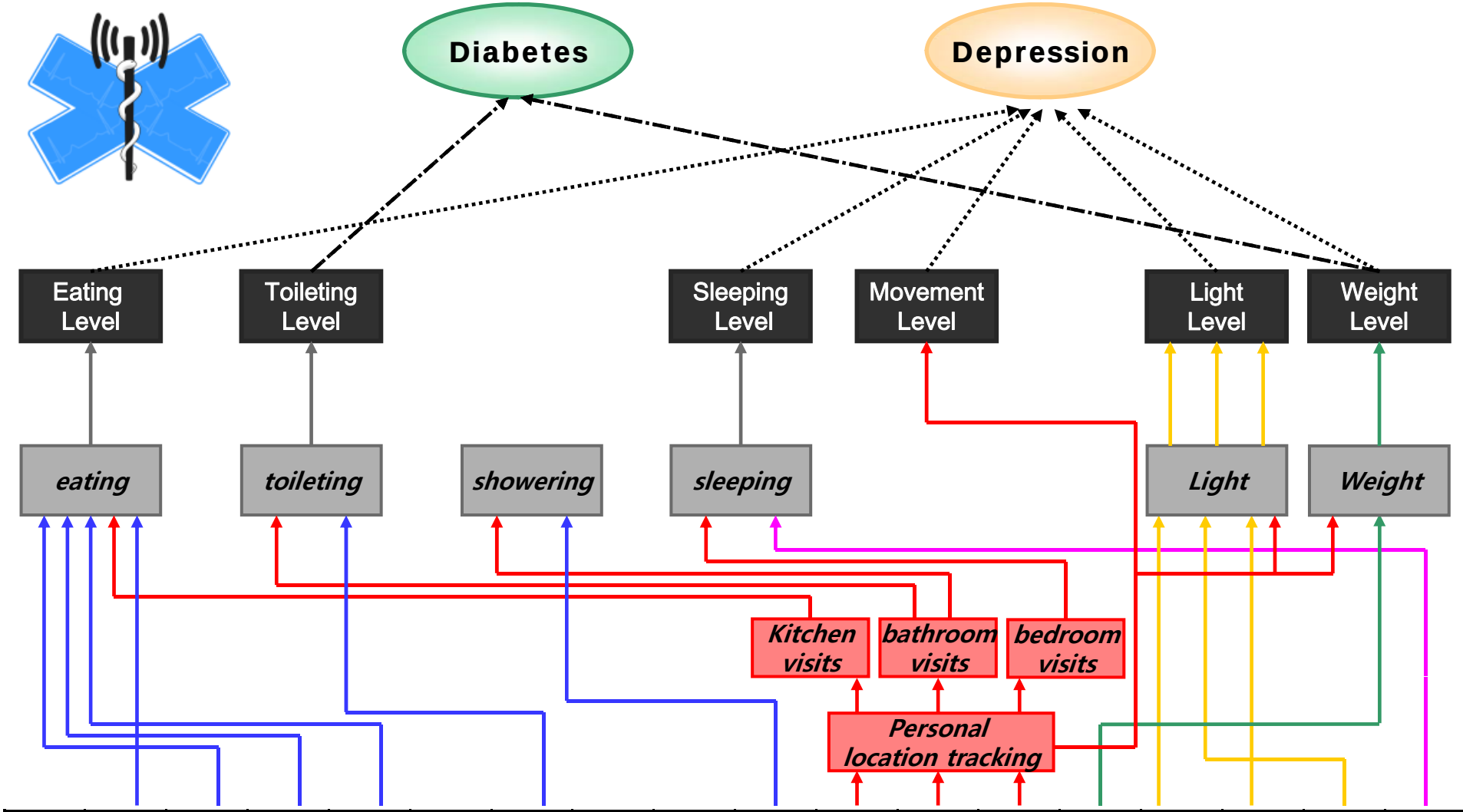
G. Virone, et. al., Behavioral Patterns of Older Adults In Assisted Living, IEEE Transactions on Information Technology in Biomedicine, Vol. 12, No. 3, May 2008.

Summary

- Wireless Health
  - Body Sensor Networks
  - Environmental and AR Networks
- Easy to Modify over Time
  - Incorporate new technology as it becomes available
  - Adapt as medical conditions change
- Protects Privacy



"It appears to be some kind of wireless technology."



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
front floor	fridge	microwave	pantry	cooktop	sink	flush	entrance	sink	shower	motion	motion	motion	weight	light	light	light	pressure
bedroom	kitchen	kitchen	kitchen	kitchen	kitchen	bathroom	bathroom	bathroom	bathroom	bedroom	kitchen	bathroom	bedroom	bedroom	kitchen	bathroom	bedroom

Current Research

- Data Association (multi-person homes) – new height sensor
- Run Time Assurance – safety
- Robust AR
- Scaling
- Fall Detection
- BSN