DEVELOPING FAITHFUL MODELS OF BODY SENSOR NETWORKS

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Body Sensor Networks

- Enabling
  - Medical research
  - Improved clinical practice
  - Other (non-medical) applications
Body Sensor Networks

**On-Body Node:**
- Sensing
- [Pre-Processing]
- [Inference]
- [Storage]

**On-Body ‘Aggregator’:**
- Data Fusion
- [Sensing]
- [Inference]
- [Storage]

**‘Back-end’:**
- Data Fusion
- Visualization
- Inference
- Storage
What Designers Would Like To Know?

- Efficacy of implementation (Information Dependability)
  - Sensing
  - Processing algorithms
  - Robustness strategies

- Efficiency (related to efficacy)
  - Speed
  - Energy consumption
  - Required real-estate (form factor)

- Safety
What is Expected of Designers?

- **Efficacy of implementation (Information Dependability)**
  - Sensing
  - Processing algorithms
  - Robustness strategies

- **Efficiency (related to efficacy)**
  - Speed
  - Energy consumption
  - Required real-estate (form factor)

- **Safety (related to efficacy)**
Overview

- Introduction
  - Body Sensor Networks
  - Designer and design expectations
- Reasoning about BSNs (our meta models)
- Faithfully Capturing BSNs
  - Issues
  - How Ptolemy (and its ideas) can help
Reasoning about BSNs: Our Meta Models

- Work with the FDA*

    - How BSN is attached to patient
    - Output from human process to BSN
    - BSN (sensing process)
    - Info from medical system to BSN
    - Patient and environment (human process)
    - Output from BSN to human process
    - Info from BSN to medical system
    - Rest of medical system (inference process)

Safety notion:

Given

reasonable expectations of behaviors and responses of H and I

Does S (relative to some established/accepted ideal)

produce Y that is reflective of dynamics of interest of H?

interact with H safely through Y?

comparison
‘function’

ideal scenario

‘real’ scenario

output interface

output property

safety bound

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Reasoning about BSNs: Our Meta Models

- Digging deeper

Diagram showing the components of BSNs:
- **Sensing sub-process**: Elements of S coupled to human process
- **Processing element**: Transducer, Energy source, 'Actuator'
- **Computational environment**: Sensing sub-process

Diagram illustrates the flow of information and interactions between sensing, processing, and computational environments.
Modeling Goals

- Single model that
  - Faithfully captures components and interactions identified in meta model
  - Allows tracking of hazards and why they occur
    - Checking when safety constraints aren’t met
    - Relating this to efficacy of design
How to Capture this Concretely and Faithfully in a Simulation?

- Issues
  - Heterogeneous components
  - Mixed ‘domains’ (continuous, discrete)
  - Heterogeneous models of computation
  - Timed system issues! (Real/wall-clock-time, platform time, logical time, local)
  - Lots of related dynamics!

- Good news
  - Ptolemy (and its ideas) to the rescue!
How to Capture this Concretely and Faithfully in a Simulation?

- **Separation of Concerns (Human Dynamics)**
  - Physiologic variables are usually continuous
  - Location variable is discrete
  - Human process may produce discrete events for BSN
  - Human process may have different ‘modes’
  - Inputs from BSN may be both continuous and discrete

- **Useful Ptolemy Concepts**
  - Ptera
  - Hybrid Systems
  - DE and Continuous Domains
How to Capture this Concretely and Faithfully in a Simulation?

- **Separation of Concerns (BSN)**
  - BSN must only ‘see’ outputs from human process
  - Inputs from human process both noisy ‘desired’ input and modifying inputs
  - Inputs from medical system discrete signal
  - BSN-to-human interface produces continuous (with possibly discrete) signals
  - Other parts of BSN mostly ‘digital’/cyber
  - BSN output to medical system is discrete signal

- **Useful Ptolemy ideas:**
  - DE domain vs. continuous domain
  - Ptides (for platform vs. function issues)
  - Mixed MoCs (Modal, Timed Dataflow, Ptera)
How to Capture this Concretely and Faithfully in a Simulation?

- **Wireless Communication Channels**
  - Must capture broadcast nature of channels
  - Must capture individual link characteristics
  - Must account for on-body environment

- **Useful Ptolemy ideas:**
  - Wireless domain ideas (must be extended)
  - Aspects
How to Capture this Concretely and Faithfully in a Simulation?

- **Wireless Communication Channel**

- Opportunities for co-simulation (Ptolemy + BodySim)!
How to Capture this Concretely and Faithfully in a Simulation?

- **Resource Usage**
  - Energy (mobile components)
  - Communication bandwidth

- **Useful Ptolemy ideas:**
  - Constraints
  - Aspects (model platform differences)
  - Parameterized models
How to Capture this Concretely and Faithfully in a Simulation?

- **Timing**
  - Oracle time (wall-clock/real-time)
  - Platform time
  - Logical time (specifications)

- Useful Ptolemy ideas:
  - Ptides modeling
  - Aspects
Conclusions and Future Directions

- **Takeaways**
  - BSNs require heterogeneous modeling to design properly
  - Ptolemy (possibly with some co-simulation) can help
  - A single model leveraging many of Ptolemy’s capabilities seems feasible

- **Future directions**
  - Model a particular BSN (start with single sensor, then networks of sensors)

- Would welcome help ironing out subtleties in some models
QUESTIONS and FEEDBACK