Synergy: In-Silico Functional Verification of Artificial Pancreas Control Algorithms

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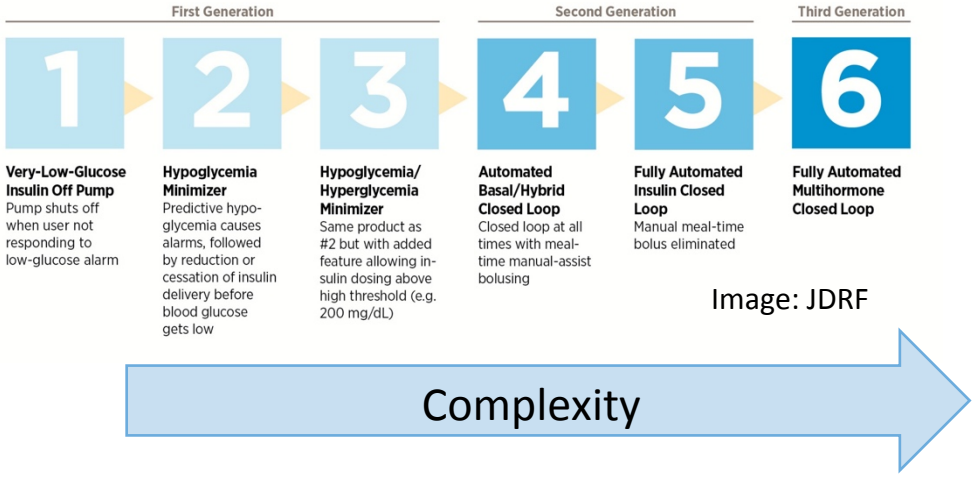
Artificial Pancreas Project



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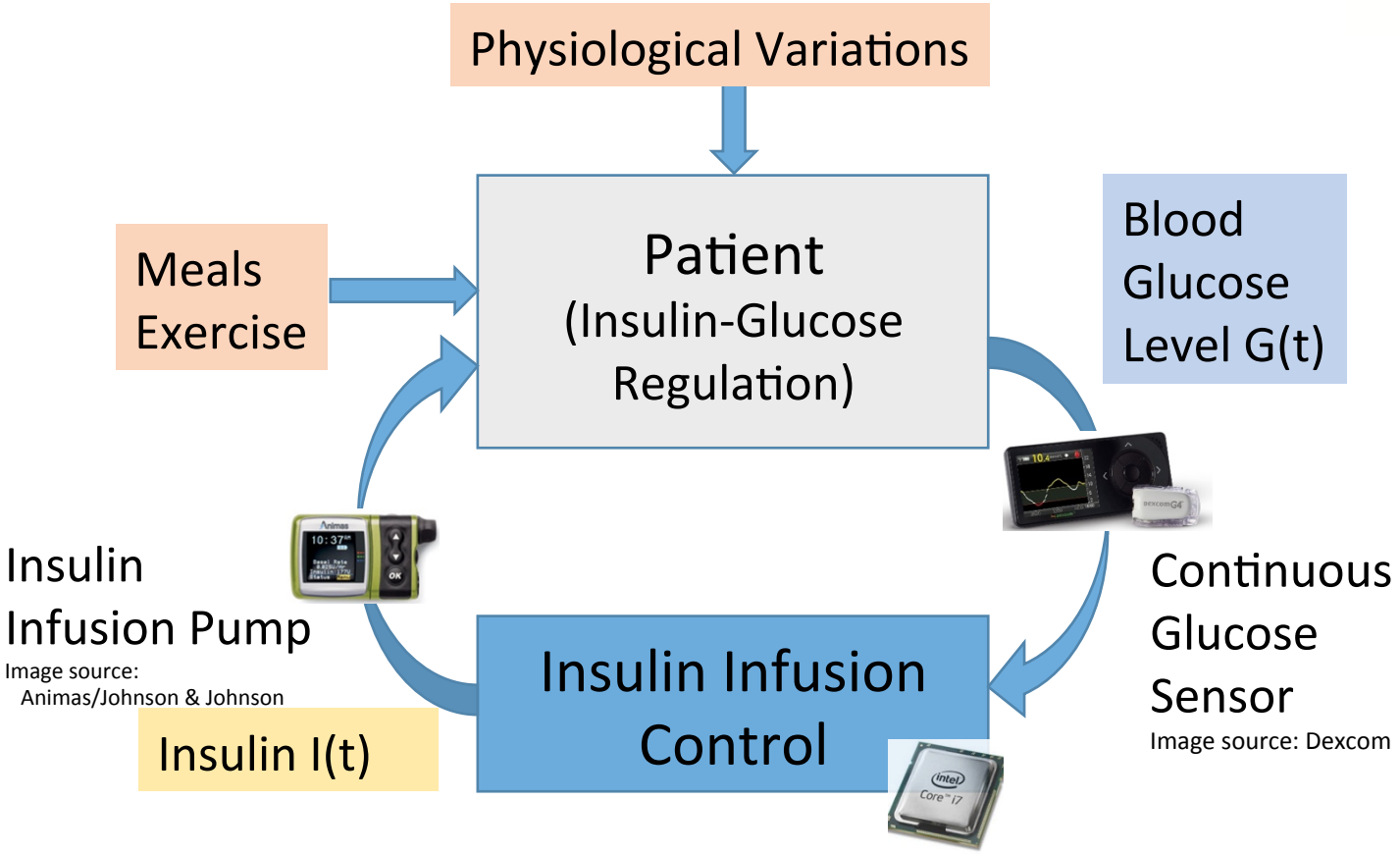
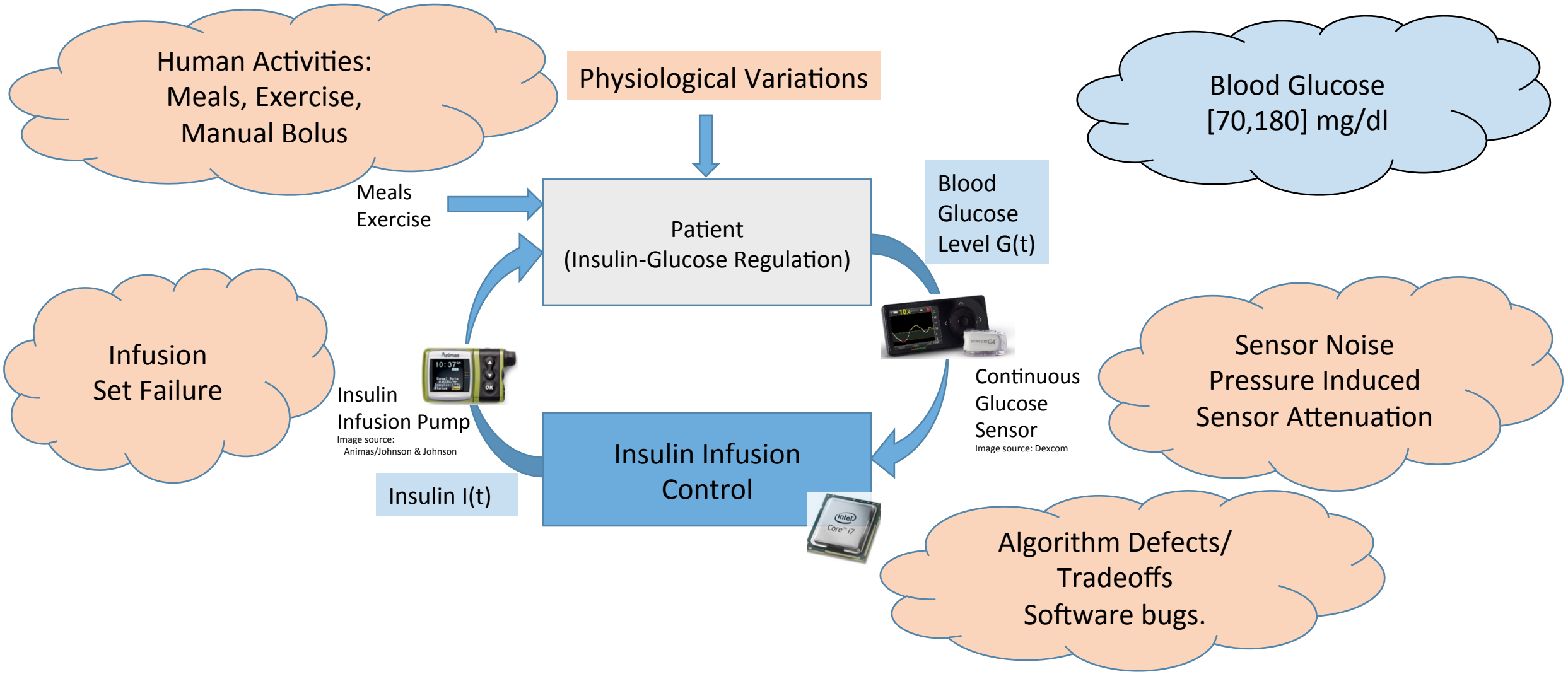
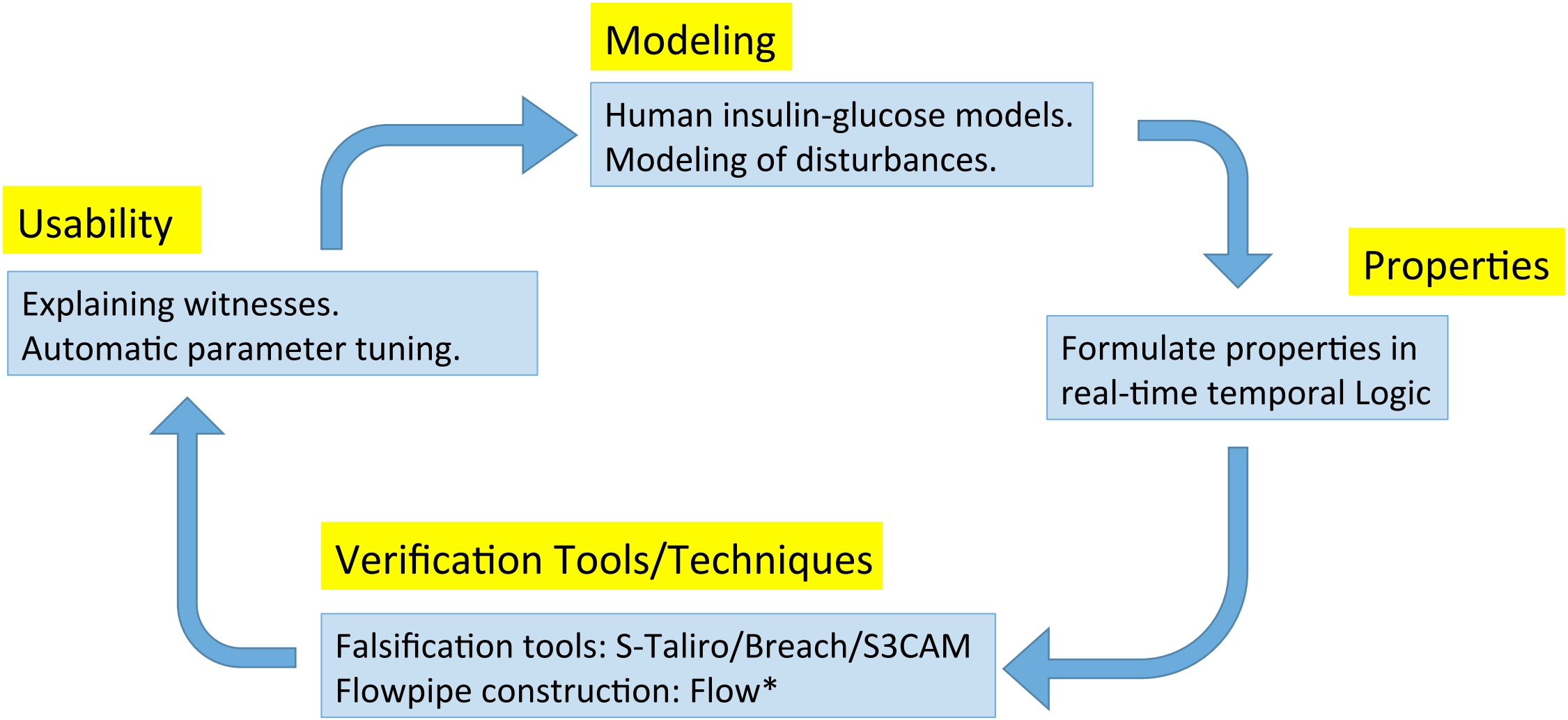


Artificial Pancreas: Risks



Project Approach

Goal: Automatic Verification/Falsification of AP control algorithms.



Disturbance Modeling Challenges

Meals

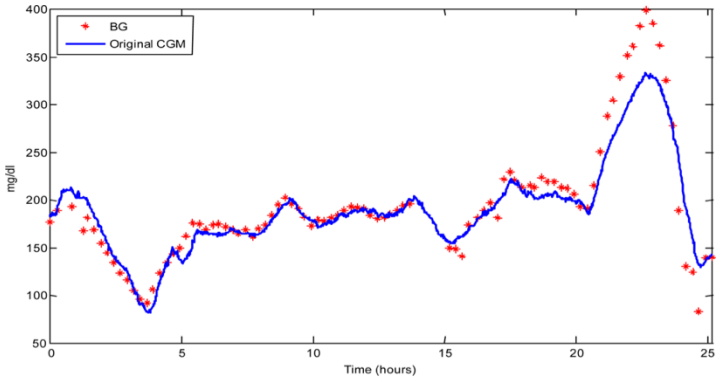
Physical Activity

Sleep

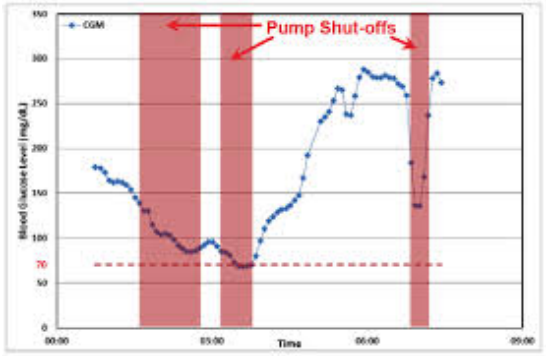
Scary movie?

Human Activities

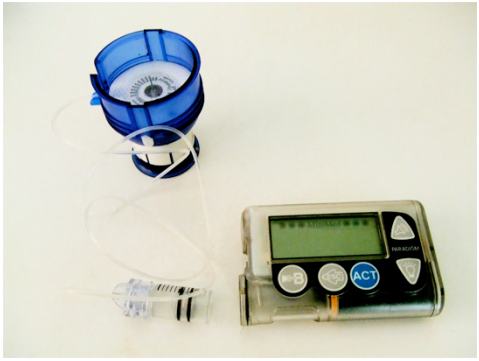
Image source: Wikimedia commons Labelled for reuse.



Glucose Sensor Noise [Cobelli et al. '2010]



Pressure Induced Sensor Attenuation [Baysal+Cameron+Bequette et al. 2014]



Infusion set failure

Disturbance Modeling: Approach

- *Data driven approach to model construction.*
  - *Meal patterns: NHANES* data.
  - *Sleep:* American Time Use Survey (ATUS) Data.
  - *Sensor noise:* CGM vs. YSI “gold standard” blood glucose measurements.
  - *Pressure Induced Sensor Attenuation:* CGM-Diet-Exercise dataset (Elizabeth Meyer-Davis et al.), PSO3 data (Maahs et al.)
  - *Infusion Set failures:* Diabetes camp study (in progress) involving PIs and external collaborators.

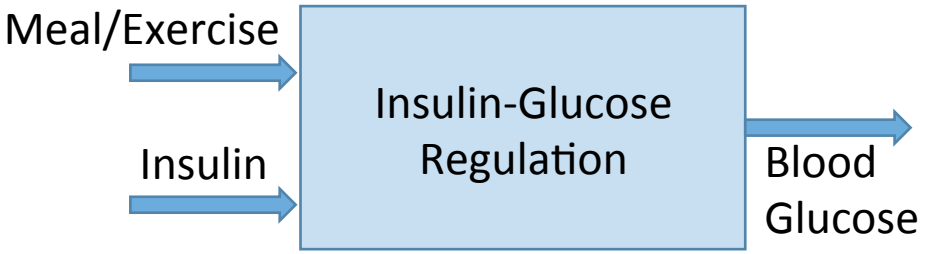
- Challenge: How do we use this data?

Modeling Meal Patterns

- National Health and Nutritional Examination Survey (NHANES).
- Data from nearly 90000 Americans (*Non-type-1 diabetic).*
  - Meal contents: grams of Carbohydrates (CHO).
  - Meal timings.
- Limited data for people with type-1 diabetes.

- *Ongoing Work:* Model for timings and CHO contents of meals.
  - Timed automaton with extra costs.

Physiological Models



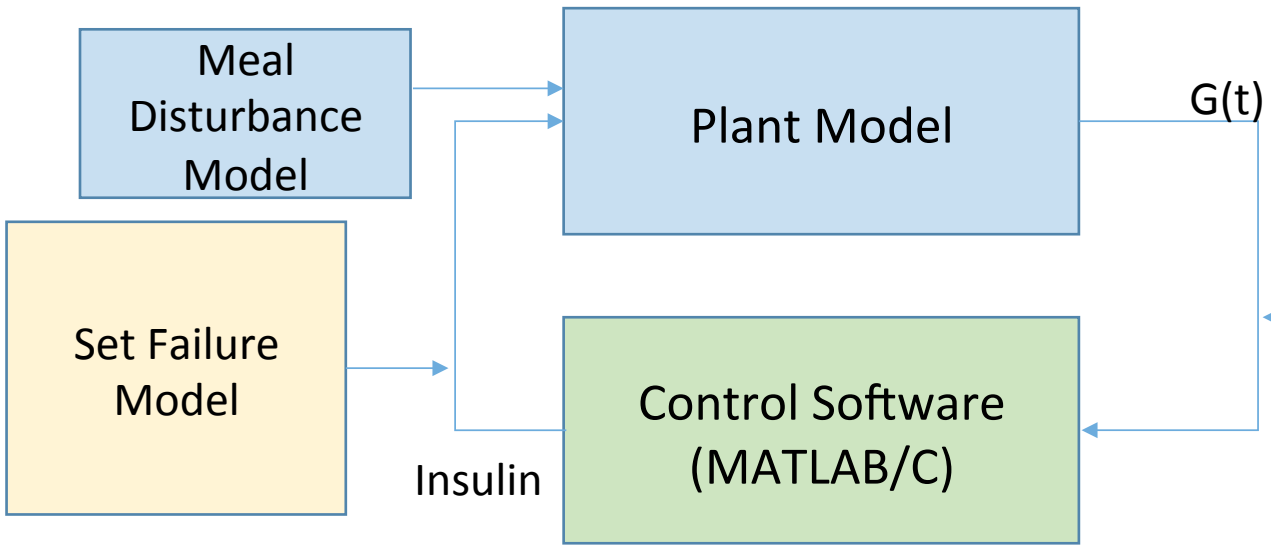
- Existing Differential Equation-Based Models:
  - Dalla-Man et al. model.
  - ~10 state nonlinear ODE + ~ 25 patient-specific model parameters.
  - Uva-Padova simulation tool with 30 virtual patients [Kovatchev et al.]

- Limitations: *expensive to use inside a verification framework.*

- Ongoing Approach: PSO3 dataset (~30 patients, ~2000 overnight sessions).
  1. Interval-valued *delay coordinate embedding.*
  2. Delay differential equation models.

Verification Tools/Techniques

Challenge: *Software-in-the-loop verification.*



Simulation-Based Falsification:
- S-Taliro [Fainekos+S+Abbas+Others]
- Breach [Donze+Maler+Others]
- S3CAM [Zutshi+S+Deshmukh+Kapinski+Jin]

S3CAMX: Combination of symbolic controller verification + numerical plant simulation.

Flowstar: Flowpipe construction for nonlinear hybrid systems.

Case-Studies using S-Taliro

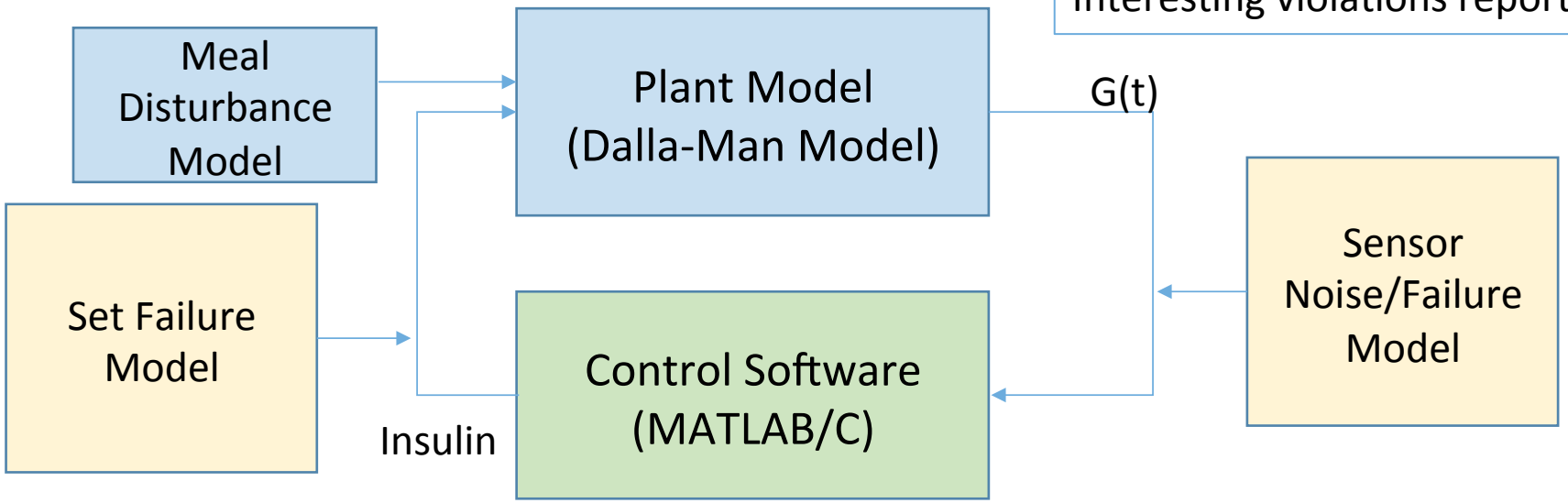
Case-Study #1: [Cameron+Fainekos+Maahs+S'RV 2015]

- Hybrid basal/bolus PID closed loop [Steil et al.]

Case-Study #2: *Unpublished.*

- Predictive pump shutoff + Hypo minimizer [Cameron et al.]

Interesting violations reported for both case studies.



Education #1: Closed Loop Medical Devices

https://www.cs.colorado.edu/~srirams/courses/clMed-spr15/index.html

Spring 2015 and 2016 (planned).

- Engineering PhD students.
- Participation by medical collaborators.
- Background medical knowledge.
- Reading papers from medical journals.
- Field visit to observe clinical trial.
- Interviews with patients and engineers.

Topics:
Artificial Pancreas
Implantable Defibrillators
Automated Anesthesia
Regulatory Issues
Security/Privacy
Medico-Legal Issues
Human Factors

Education #2: CPS Education Testbed

Respect the Implementation: Using NI myRIO in Undergraduate Control Education*

Shalom D Ruben[1]

Abstract— **In this paper we present, due to it's low-cost, portability, and high-functionality, the National Instruments (NI) myRIO as an excellent platform for hands-on in systems and control education, from advanced to beginner courses. That said, implementing control algorithms by the beginner, especially, is not to be taken lightly on digital platforms like the myRIO. We show, using a simple electric circuit as a plant, how a student can get some catastrophic results when implementing even a simple proportional controller. These catastrophic results stem partially from discretization choice, determinism of the sampling rate, and sampling**

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"As society permits cont
more such dangerous syste
engineers and fashion their tools cannot hide from responsibility under a cloak of mathematics. We dare not instill the notion that mathematical rigor is the only goal to strive for in control. We must also instill respect for the practical, physical consequences of control, and we must make certain that its underlying principles are taught clearly and well."

Mechanical Engg. + CS Majors.

NI myRIO testbeds:
CU Boulder Engineering Excellence Fund.

Artificial Pancreas controller implementations.

More Information

http://systems.cs.colorado.edu/research/cyberphysical/ap-verification/

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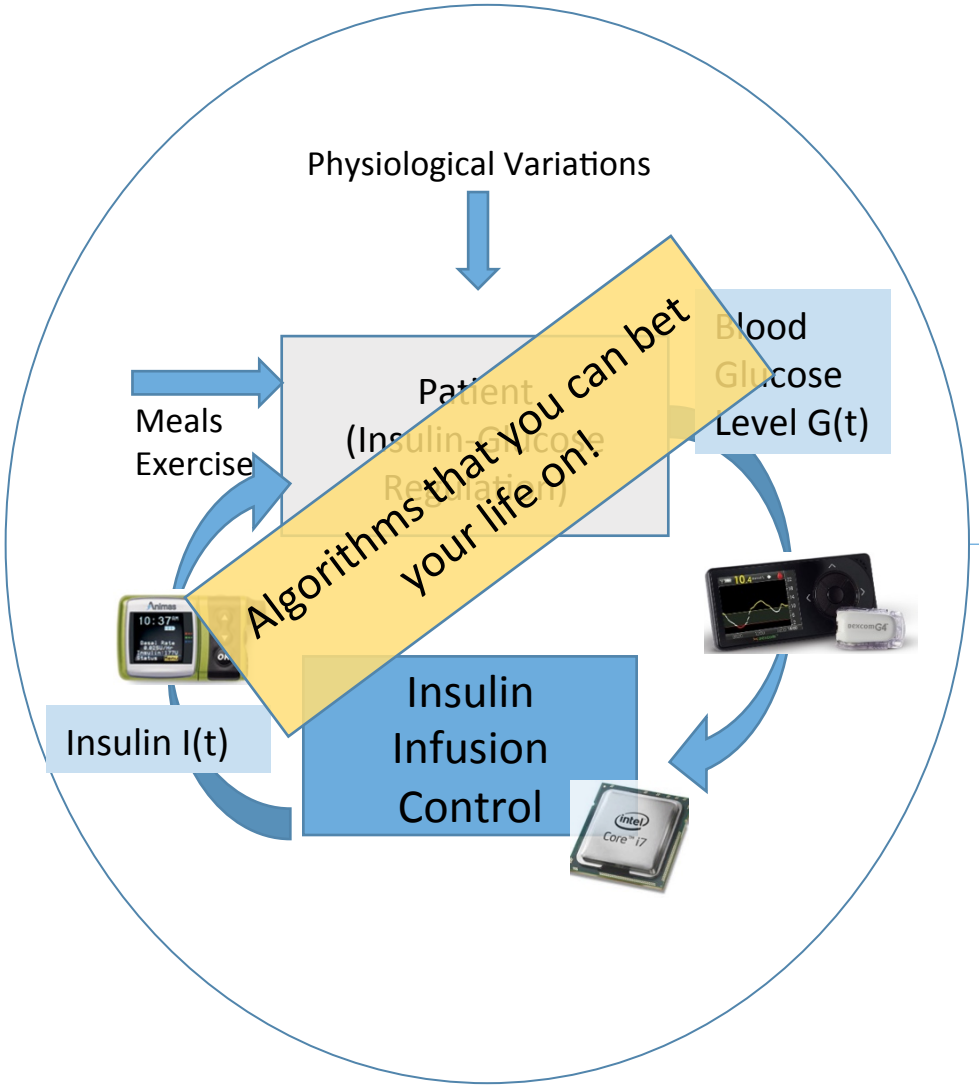
In Silico Functional Verification of Artificial Pancreas Control Algorithms

Challenge: Functional verification of Artificial Pancreas Controllers.

- Discover valid problems in existing control algorithms.
- Explain problems to clinicians/engineers.



Solution:

- Disturbance modeling.
- Property Formulation
- Verification with software in the loop.
- Explaining verification results (usable verification).

Scientific Impact:

- Broaden understanding of applying verification techniques to closed loop medical systems.
- Apply to other CPS domains such as automotive software (transportation CPS).

Broader Impact:

- Safer artificial Pancreas Devices.
- Faster/Less expensive certification process.

NSF CPS-1446900, and CPS-1446751 (PI: Sriram Sankaranarayanan, CU Boulder and Fraser Cameron, RPI)