MODEL-BASED IN-SILICO VERIFICATION OF ARTIFICIAL PANCREAS CONTROL ALGORITHMS

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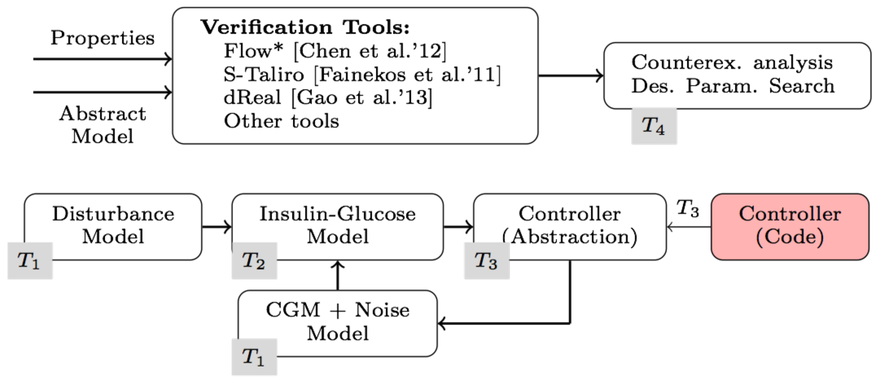
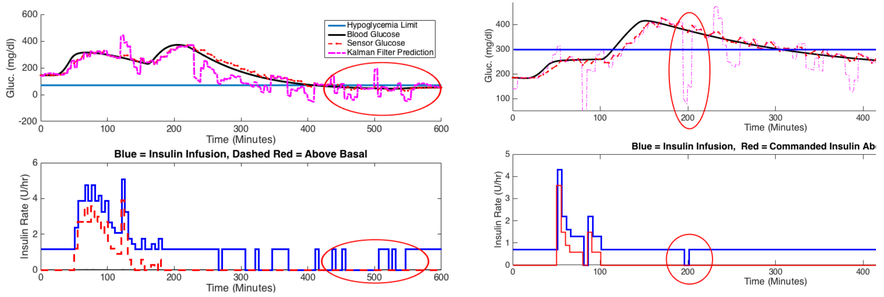
We apply formal specification and verification techniques for checking correctness properties of artificial pancreas control algorithms. Formal specification and verification techniques attempt to systematically and exhaustively explore the behaviors of closed loop *in silico* models to understand the worst case effects of disturbances such as meals, external boluses, sensor noise, pressure induced sensor attenuation and set failures on the predicted blood glucose levels of a "virtual" patient. Specifically, we examine two artificial pancreas controllers: (a) PID-based hybrid closed loop controller *(Steil et al.'2011)* and (b) Kalman filter-based predictive pump shutoff system *(Cameron et al.'2012)*.



(Top) Formal verification tool setup and (Bottom) setup of the closed loop simulator analyzed in our verification setup.



Violations discovered by our analysis for Predictive Pump Shutoff System: (Left) insulin delivery resumption under hypoglycemia, and (Right) pump suspension under hyperglycemia.

Verification Approach

- Mathematical modeling of closed loop: Meal and insulin-glucose regulation models (*Dalla Man et al.'2007* [6]).
- Exhaustive simulation of millions of meal and insulin bolus patterns using S-Taliro (*Abbas et al.'2013* [7]).
- Formulation of temporal properties of the closed loop.

Case Studies

1. PID-based hybrid closed loop controller (see *Cameron et al* [3] for details).
   - Studied effect of PID gains on various correctness properties.
2. Kalman filter-based predictive pump shutoff algorithm (see *Sankaranarayanan et al* [1] for details).
   - Studied sensitivity to sensor errors.
3. Aiding examination of property violations through sensitivity analysis of inputs.

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