Refinement Maps for Insulin Pump Control Software Safety Verification

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Outlines

Introduction

- Critical devices still have safeness issues.
- 54 Class-1 recalls on infusion pumps due to software issues.
- Testing is not enough!
- Formal verification can address testing limitations.
- Refinement-based verification is a formal verification technique that has been demonstrated to be effective for verification of software correctness at the object code level.

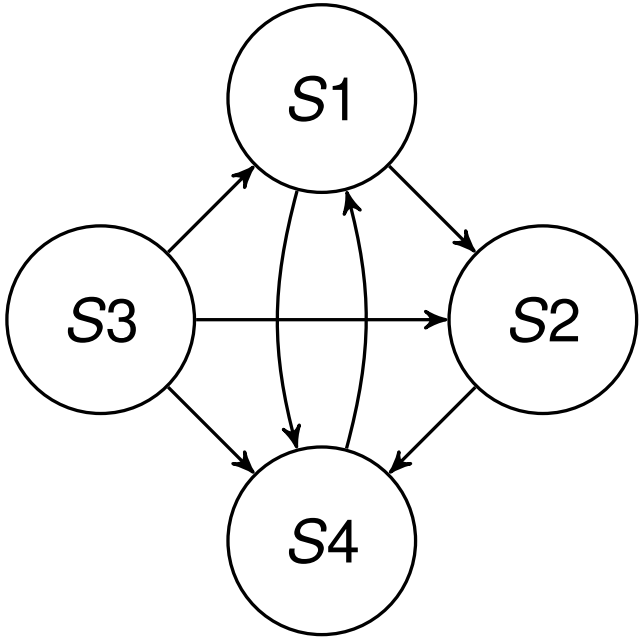
Introduction

- We have proposed a novel approach to synthesize formal specifications from natural language requirements.
- Our verification approach is based on the theory of Well-Founded Equivalence Bisimulation (WEB) refinement.
- To overcome the difference between specifications and implementations, WEB refinement uses the concept of a refinement map.

Background-Transition Systems (TS)

Definition

A TS $M = \langle S, R, L \rangle$ is a three tuple in which S denotes the set of states, $R \subseteq SXS$ is the transition relation that provides the transition between states, and L is a labeling function that describes what is visible at each state.

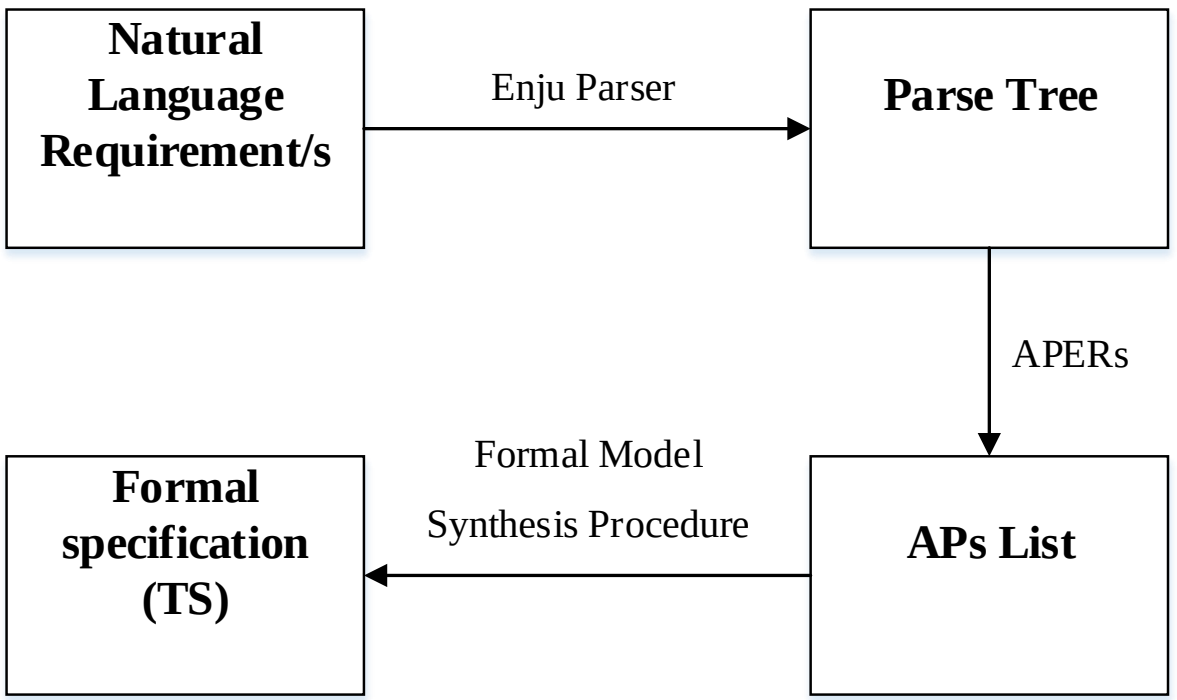


Background-WEB Refinement

Definition

WEB Refinement: Let $M = \langle S, R, L \rangle$, $M' = \langle S', R', L' \rangle$, and r: S $\rightarrow$ S'. M is a WEB refinement of M' with respect to refinement map r, written $M \approx r\ M'$, if there exists a relation, B, such that $\langle\ \forall$ s $\in$ S :: sB(r.s)$\rangle$ and B is a WEB on the TS $\langle$ S $\uplus$ S', R $\uplus$ R', $L\ \rangle$, where L.s = L'(s) for s and S' state and L.s = L'(r.s) otherwise.

Background-Synthesis of Formal Specifications



Related Work

- Rabiah *et al.* (2016) developed a reliable autonomous robot system by addressing A* path planning algorithm reliability issue. A refinement process was used to capture more concrete specifications by transforming High-Level specification into equivalent executable program.
- Cimatti (2015) *et al.* proposed a contract-refinement scheme for embedded systems. The contract-refinement provides interactive composition reasoning, step-wise refinement, and principled reuse refinements for components for the already designed or independently designed components.
- Klein *et al.* (2014) introduced a new technique called State Transition Diagrams (STD). It is a graphical specification technique that provides refinement rules, each rule defines an implementation relation on STD specification.

Related Work

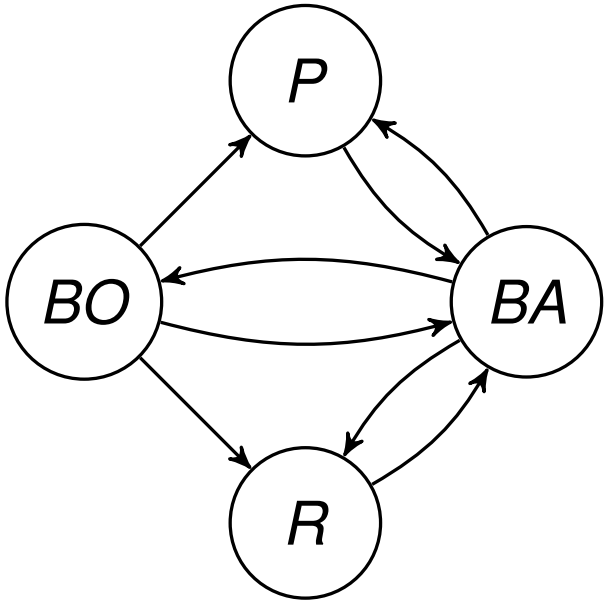
- Miyazawa (2011) *et al.* proposed a refinement strategy that supports the sequential *C* implementations of the state flow charts. The proposed design benefited from the architectural features of model to allow a higher level of automation by retrieving the data relation in a calculation style and rendering the data into an automated system.
- Spichkova (2008) proposed a refinement-based verification scheme for interactive real time systems. The proposed work solves the mistakes that rise from the specification problems by integrating the formal specifications with the verification system. The proposed scheme translates the specifications to a higher-order logic, and then uses the theorem prover (Isabelle) to prove the specifications.

Refinement Maps and Refinement Map Templates

Our strategy for constructing the refinement maps is as follows.

- A specification state can be constructed from an implementation state by determining the APs that are true in the implementation state. If a specification has n APs, then we construct one predicate function for each AP.
- The predicate functions take the implementation state as input and output a predicate value that indicates if the AP is true in that state or not.
- The collection of such predicate functions is the refinement map.

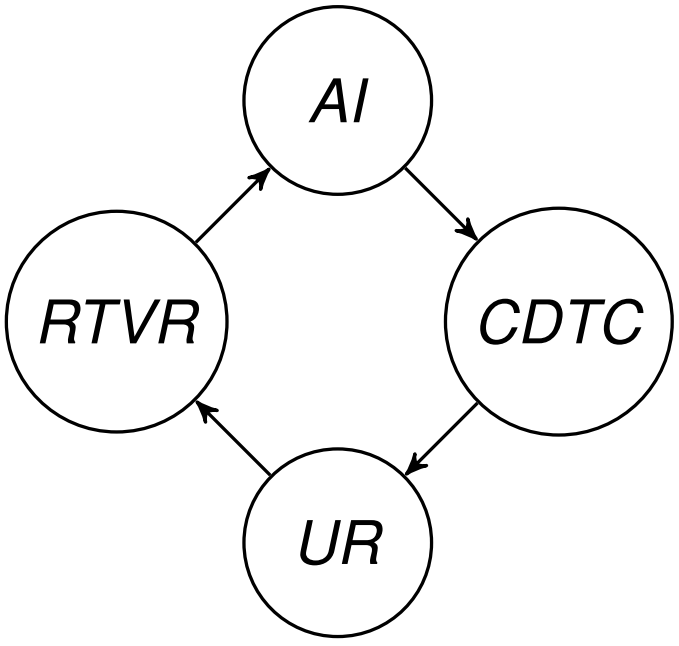
Refinement Maps



- BO: Bolus delivery
- P: Prime process
- R: Refill process
- BA: Basal delivery

- **BO** = [NB $\wedge$ ($NB_c < NB_m$)] $\vee$ [EB $\wedge$ ($EB_c < EB_m$)]
- **P** = P $\wedge$ ($P_c < P_m$)
- **R** = R $\wedge$ ($R_c < R_m$)
- **BA** = [$BP_1 \wedge (BP_{1c} < BP_{1m})$] $\vee$ [$BP_2 \wedge (BP_{2c} < BP_{2m})$] $\vee \ldots \vee$ [$BP_n \wedge (BP_{nc} < BP_{nm})$] $\vee$ [TB $\wedge$ ($TB_c < TB_m$)]

Refinement Maps



- **AI** = $[BP_1 \wedge (BP_{1c} < BP_{1m})] \vee [BP_2 \wedge (BP_{2c} < BP_{2m})] \vee \ldots \vee [BP_n \wedge (BP_{nc} < BP_{nm})] \vee [\text{TB} \wedge (TB_c < TB_m)] \vee [\text{NB} \wedge (NB_c < NB_m)] \vee [\text{EB} \wedge (EB_c < EB_m)]$
- **CDTC** = $(\text{DT} \neq \text{HDT}) \wedge (CDTC_c < CDTC_m)$
- **UR** = FLAG
- **RTVR** = $(\text{CRV} \neq \text{HRV}) \wedge (RTVR_c < RTVR_m)$

- AI: Active Infusion
- CDTC: Changing Drug Type and Concentration
- UR: User Reminder
- RTVR: Reservoir Time and Volume Recomputing

Refinement Map Templates

- Process template.

Example

BA = $[BP_1 \wedge (BP_{1c} < BP_{1m})] \vee [BP_2 \wedge (BP_{2c} < BP_{2m})] \vee \ldots \vee [BP_n \wedge (BP_{nc} < BP_{nm})] \vee [\text{TB} \wedge (TB_c < TB_m)]$

- projection template.

Examples

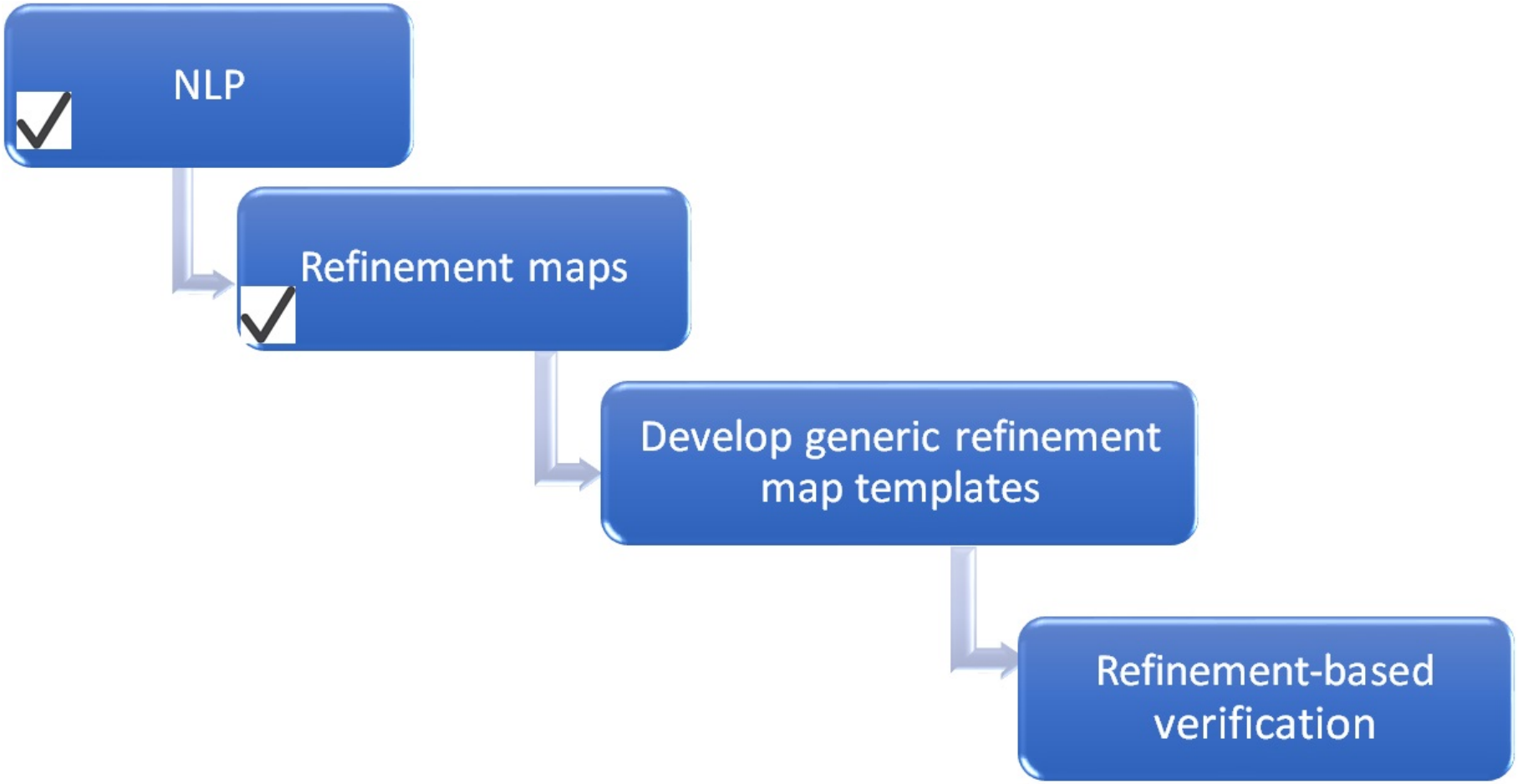
UR = FLAG

- Value change template.

Example

CDTC = $(\text{DT} \neq \text{HDT}) \wedge (CDTC_c < CDTC_m)$

Conclusion and future work



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