Overview of the hybrid Chi formalism

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Contents
Main difference between Chi and other hybrid formalisms: expressivity
• Project team
• Short introduction to Chi
• Fundamental limitation of hybrid automata with respect to compositionality.
• Mathematics, dynamics and control theory concepts in $\chi$
• Conflicting requirement: high expressivity $\leftrightarrow$ verification?
• Tools: Verification, simulation, simulation based optimization.
• Expressivity for large complex system specification

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Short introduction to Chi
Hybrid process algebra with a high expressivity.
Many properties are being defined, but so far there is no axiomatization.

$$P_{\text{core}} ::= \quad u \mid l_a \mid h ! e_n \mid h ? x_n \mid X$$
$$\mid \Delta d(P) \mid b \rightarrow P \mid P ; P \mid P \oplus P \mid P \parallel P \mid \pi(P)$$

$$P_{\text{SOS}} ::= \quad \llbracket \sigma, S, C, R \rrbracket \parallel P \parallel \delta(P)$$

$$P_{M} ::= x := e \mid \Delta d \mid b \rightarrow P \mid x_n : i \gg P \mid P \triangleright P \mid *P$$
$$\mid (\text{init } x_n \setminus y_m \parallel P)$$
$$\mid \llbracket \text{disc } L, \text{init } L', \text{cont } L'' \rrbracket, \text{chan } L_C, L_R \parallel P \parallel$$
$$\mid l_p(x_k, b_m, e_n)$$

$$P ::= P_{\text{core}} \mid P_{\text{SOS}} \mid P_{M}$$
Fundamental limitation of hybrid automata with respect to compositionality

Parallel composition of diode and switch automata

Parallel composition of diode and switch in Chi
Mathematics, dynamics and control theory concepts in $\chi$

- Discontinuous functions and switched sets of differential algebraic equations.
- Differential inclusions, sliding modes.
- Higher index systems / systems with hidden constraints.
- Mode switches accompanied by index changes.

Conflicting requirement: high expressivity $\Leftrightarrow$ verification?

Languages / formalisms:

- Modeling and simulation languages
  - Ease of modelling $\Rightarrow$ complex languages.
  - Verification not an issue, no formal semantics: cannot be used for verification.
  - Big difference between DE, CT and hybrid (DE$^+$/CT$^+$) languages.

- Verification formalisms
  - Ease of formal analysis $\Rightarrow$ small languages with formal semantics.
  - Ease of modelling not an issue: cumbersome for modelling and simulation.

“Wet van behoud van ellende?”

- Either expressive modelling language with difficult semantics,
- or small language with elegant semantics, but difficult to use for modeling.

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New hybrid $\chi$ operators combine:

- ease of use and high expressivity (DE, CT, hybrid)
- relatively small, elegant semantics
Tools: Verification, simulation, simulation based optimization

Verification by means of translation to model checkers:

- For timed models, without differential equations e.g. Kronos, Uppaal Spin, μCRL.
- For hybrid models currently HyTech. Also possible: CheckMate, d/dt, and tools used in Charon.

Simulation: high speed simulator for discrete-event subset of Chi, hybrid simulator under development.

Simulation based optimization: tool for optimization of parameters using iterative (distributed) simulations.

Expressivity for large complex system specification

- Examples of complex applications.
- DE modeling concepts enable high level of model abstraction: pure DE models without equations.
- Scoping: integrates abstraction, local variables, channels and recursion definitions.
- Parameterized process definition and process instantiation enable:
  - Process re-use.
  - Hierarchical / modular composition of processes.
- Synchronization and communication in combination with maximum progress.
- Syntactic sugar: suited to non-experts / non-computer scientists. Vital for model validation.

Examples of complex applications

Beer brewery

Heineken, discrete-event Chi models

- Aim: increased production, reduction of waiting times through better scheduling and/or new equipment
- Configuration of new fermentation cellar: number of tanks, configuration of pipes and valves
Fruit juice blending and packaging plant

Riedel, hybrid Chi models

Overview of the fruit juice production facility.

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Communication, scope and maximum progress

Model of the one place buffer:
\[
\llbracket\text{disc } x \ | \ \ast(\ a \ ? \ x; \ b \ ! \ x )\rrbracket
\]

Model of the machine:
\[
\llbracket\text{disc } x \ | \ \ast(\ b \ ? \ x; \ \Delta t; \ c \ ! \ x )\rrbracket
\]

Parallel composition requires maximum progress:
\[
\llbracket\text{disc } x \ | \ \ast(\ a \ ? \ x; \ b \ ! \ x )\rrbracket \ || \ \llbracket\text{disc } x \ | \ \ast(\ b \ ? \ x; \ \Delta t; \ c \ ! \ x )\rrbracket
\]