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 χ
- Conflicting requirement: high expressivity $\Leftrightarrow$ verification?
- Tools: Verification, simulation, simulation based optimization.
- Expressivity for large complex system specification

Project team

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- Ka Lok Man (PhD), Michel Reniers: Dept. of Mathematics and Computer Science (TUE).

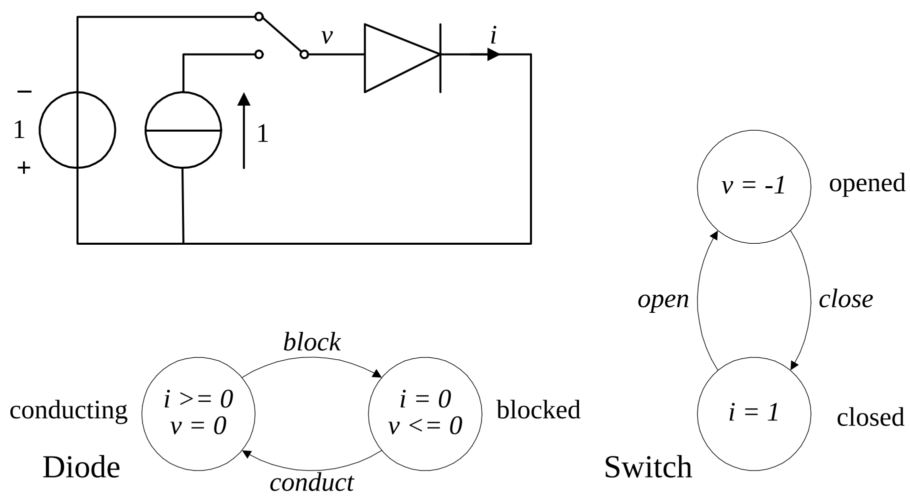
Short introduction to Chi

Hybrid process algebra with a high expressivity.

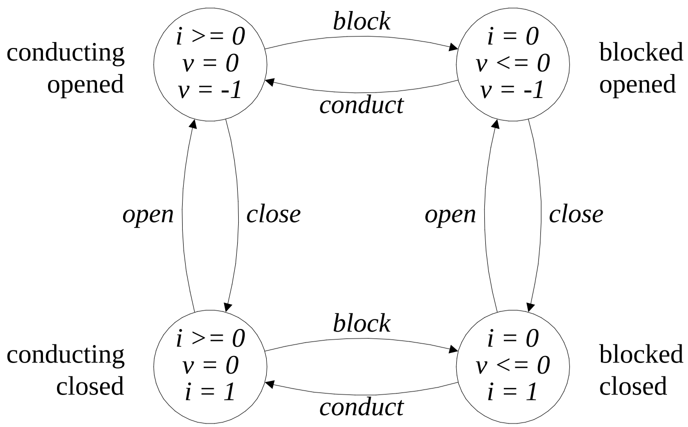
Many properties are being defined, but so far there is no axiomatization.

$$
\begin{array}{lll}
P_{\mathrm{core}} & ::= & u \;\mid\; l_{\mathrm{a}} \;\mid\; h\,!\,\mathbf{e_n} \;\mid\; h\,?\,\mathbf{x_n} \;\mid\; X \\
 & \mid & \Delta_d(P) \;\mid\; b \to P \;\mid\; P;\ P \;\mid\; P \oplus P \;\mid\; P \mathbin{[]} P \\
 & \mid & P \rhd P \;\mid\; P \parallel P \;\mid\; \pi(P) \\
 & & \\
P_{\mathrm{SOS}} & ::= & [\![\ \sigma, S, C, R \text{ `}|\text{'} P\ ]\!] \;\mid\; \partial(P) \\
 & & \\
P_{\mathrm{M}} & ::= & x := e \;\mid\; \Delta d \;\mid\; b :\to P \;\mid\; \mathbf{x_n} : i \gg P \;\mid\; P \blacktriangleright P \;\mid\; *P \\
 & \mid & (\text{init } \mathbf{x_n} \setminus \mathbf{y_m} \text{ `}|\text{'} P) \\
 & \mid & [\![\ \text{disc } L, \text{init } L', \text{cont } L'', \text{chan } L_C, L_R \text{ `}|\text{'} P\ ]\!] \\
 & \mid & l_{\mathrm{p}}(\mathbf{x_k},\ \mathbf{h_m},\ \mathbf{e_n}) \\
 & & \\
P & ::= & P_{\mathrm{core}} \;\mid\; P_{\mathrm{SOS}} \;\mid\; P_{\mathrm{M}}
\end{array}
$$

Fundamental limitation of hybrid automata with respect to compositionality



Parallel composition of diode and switch automata



Cartesian product of locations

Parallel composition of diode and switch in Chi

$[\![$ conducting $\mapsto i \geq 0, v = 0 \triangleright$ blocked

, blocked $\mapsto v \leq 0, i = 0 \triangleright$ conducting

| blocked $\oplus$ conducting

$]\!]$

$\parallel$ $[\![$ opened $\mapsto v = -1 \triangleright$ closed

, closed $\mapsto i = 1 \triangleright$ opened

| opened $\oplus$ closed

$]\!]$

Mathematics, dynamics and control theory concepts in χ

- 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 $\Longrightarrow$ 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 $\Longrightarrow$ 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 χ 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

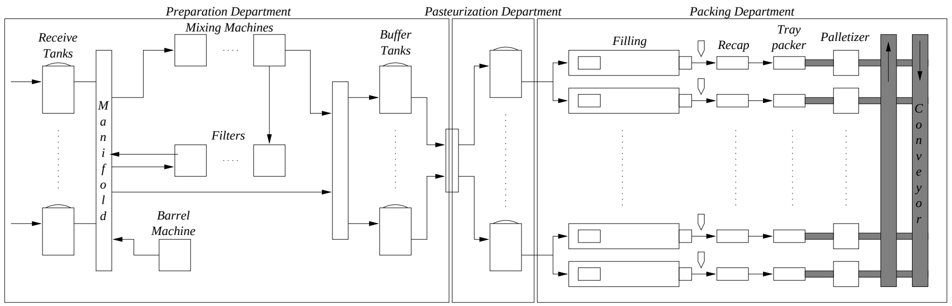
Beer brewery

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 fruite juice production facility.

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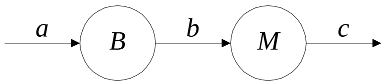
Communication, scope and maximum progress



Buffer-machine manufacturing line

Model of the one place buffer:

$[\![\ \text{disc}\ x \mid *(\ a\,?\,x;\ b\,!\,x\ )]\!]$

Model of the machine:

$[\![\ \text{disc}\ x \mid *(\ b\,?\,x;\ \Delta t;\ c\,!\,x\ )]\!]$

Parallel composition requires maximum progress:

$[\![\ \text{disc}\ x \mid *(\ a\,?\,x;\ b\,!\,x\ )]\!] \parallel [\![\ \text{disc}\ x \mid *(\ b\,?\,x;\ \Delta t;\ c\,!\,x\ )]\!]$