Qualitative Modeling and Simulation for the analysis of Complex Hybrid Systems

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HYBRID SYSTEM

Hybrid automata : discrete part

Discrete Variables : N, M, …

And Continuous part

Continuous Variables : x, y, …

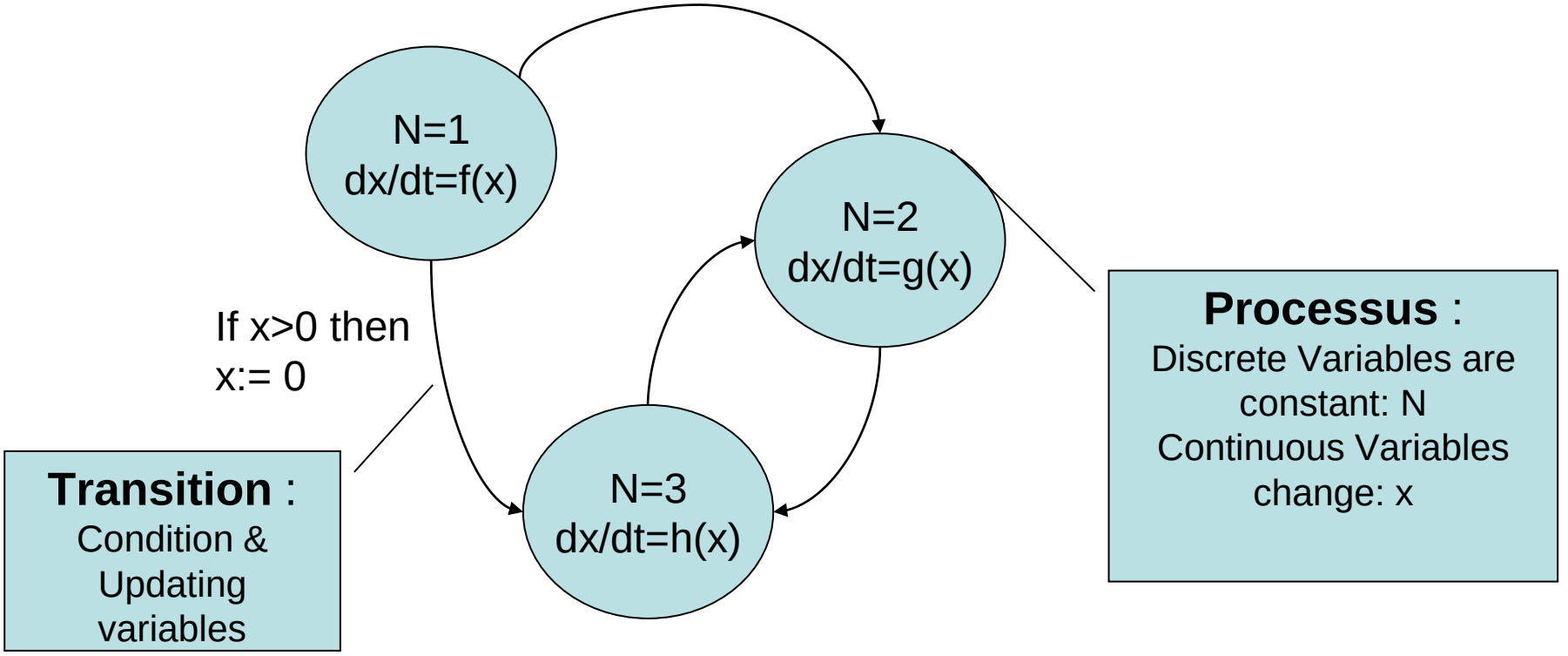
Semantics

During a state/process (continuous part)

- Discrete variables are constant
- Continuous variables can be described by differential equations

HYBRID SYSTEM

Hybrid Automaton



QUALITATIVE SIMULATION OF CONTINUOUS SYSTEM

Example : a chemical reaction

The « brusselator »

- x, y are concentrations of two elements in the chemical reaction
- $dx/dt = 1 – (b+1)\ x + a\ x^2\ y$
- $dy/dt = b\ x – a\ x^2\ y$

ABSTRACTION OF DYNAMICS

Each variable is represented by a state machine whose states represent its variation directions :

- Growing
- Decreasing
- Constant

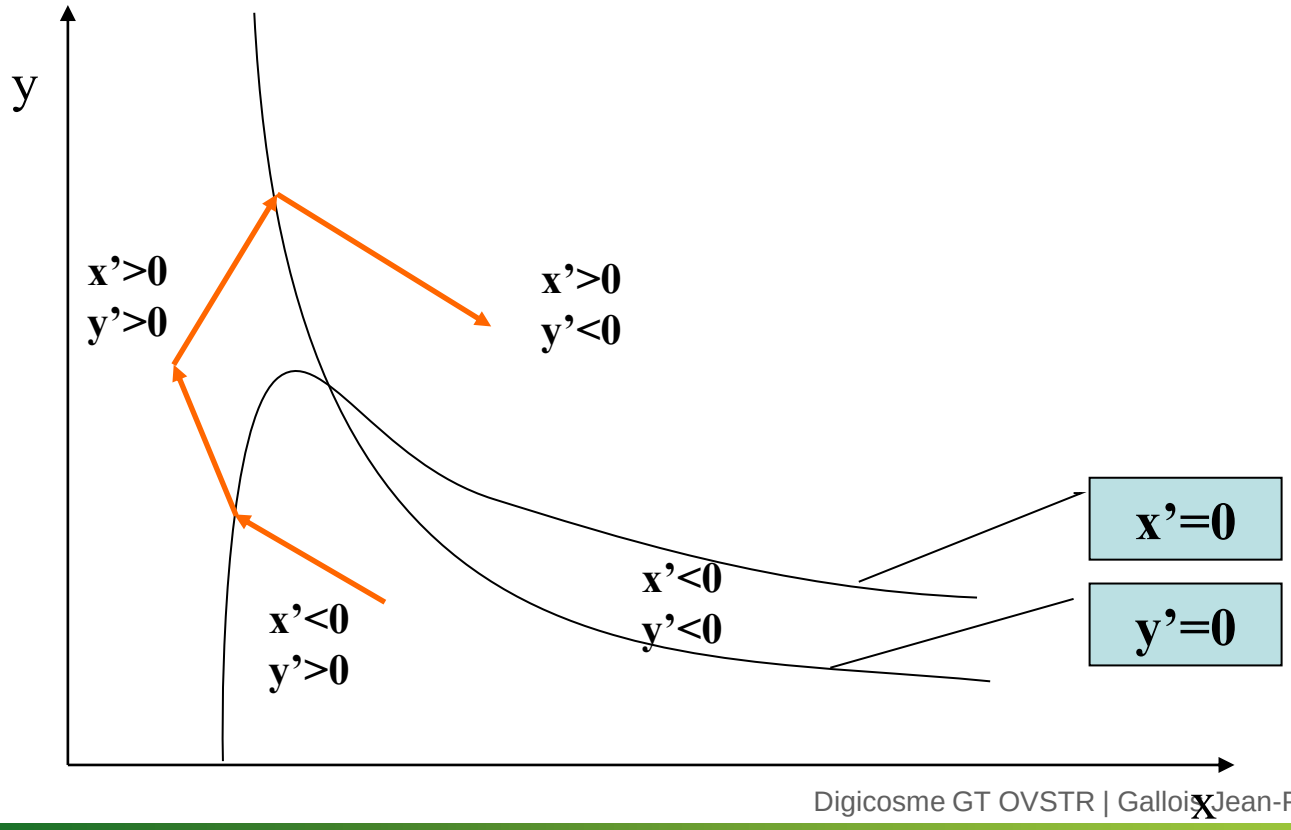
Transitions guards are deduced from differential equations by qualitative reasoning

State machines are connected:

- Differential equations are expressed with all variables

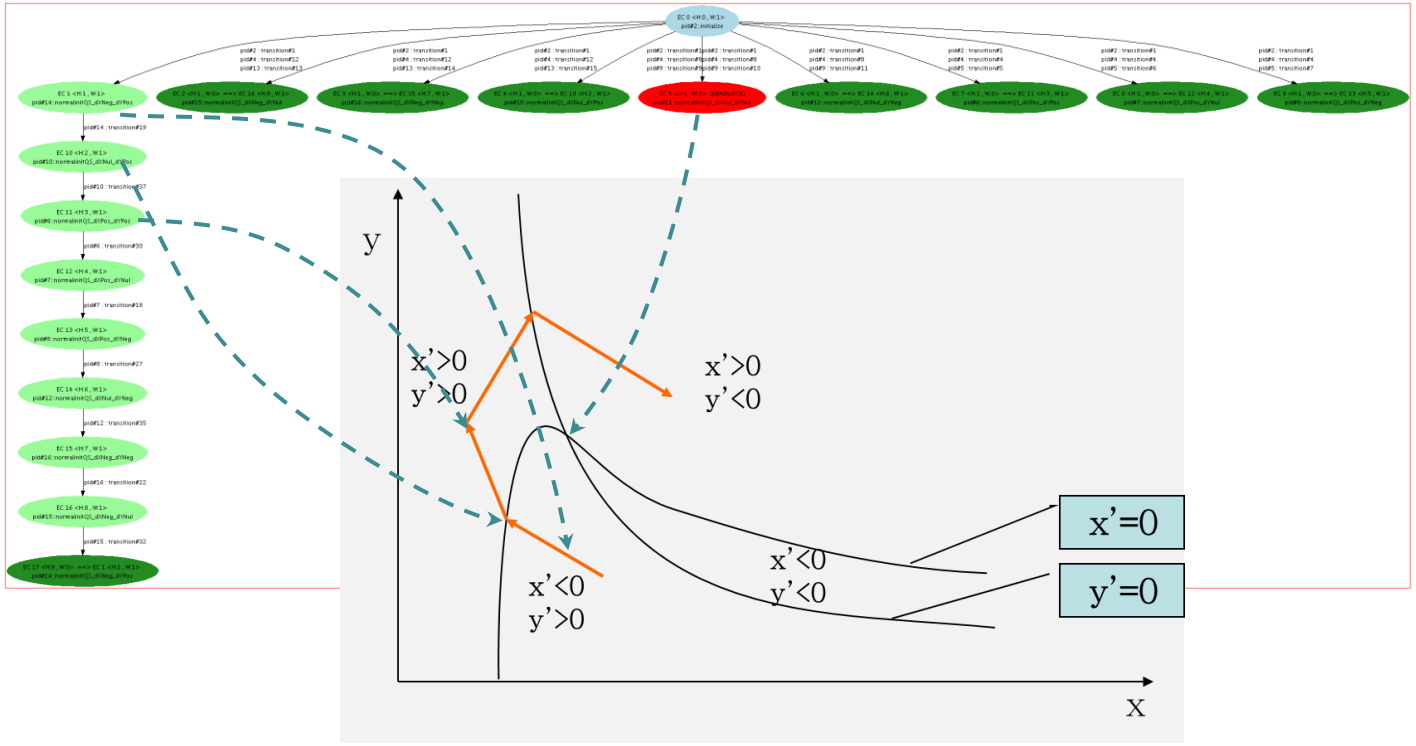
QUALITATIVE SIMULATION

The phase space is divided into qualitative sets
Conditions between the qualitative states are deduced from differential equations

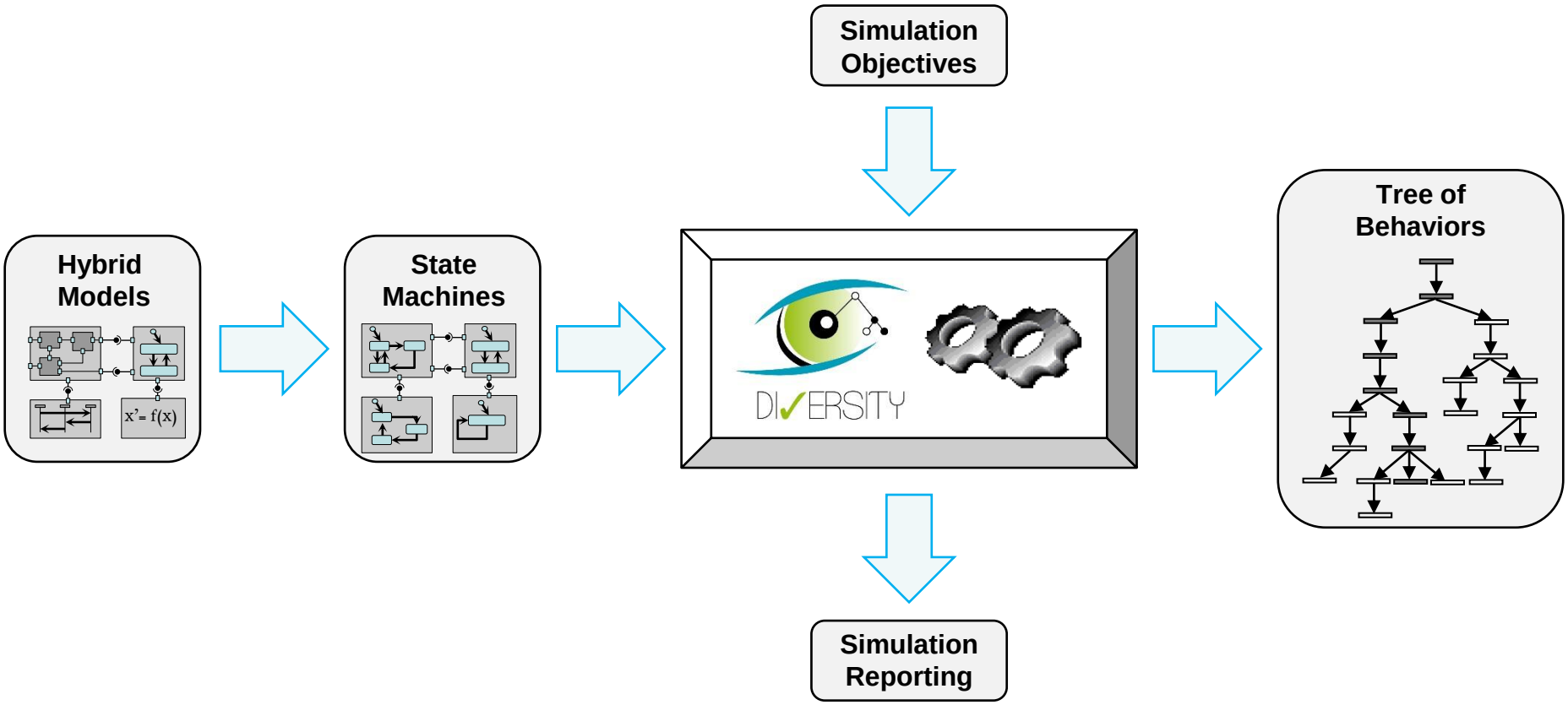


EXECUTION TREE OF THE BRUSSELATOR

Execution Tree in DIVERSITY



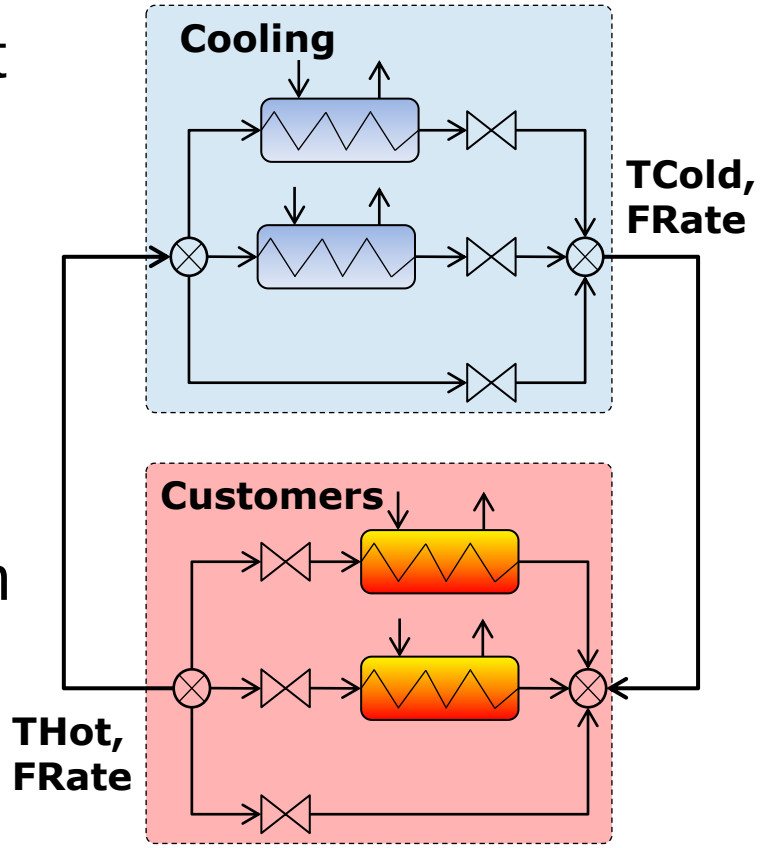
QUALITATIVE SIMULATION WITH DIVERSITY



QUALITATIVE SIMULATION WITHOUT DIFFERENTIAL EQUATIONS

- Example of industrial system: a cooling system

  - A circuit must cool a fluid loop that is heated by a heat source
  - The system is too complex: no ordinary differential equation
  - A qualitative model must be deduced from the specifications: modeling the causal links between inter-dependent variables

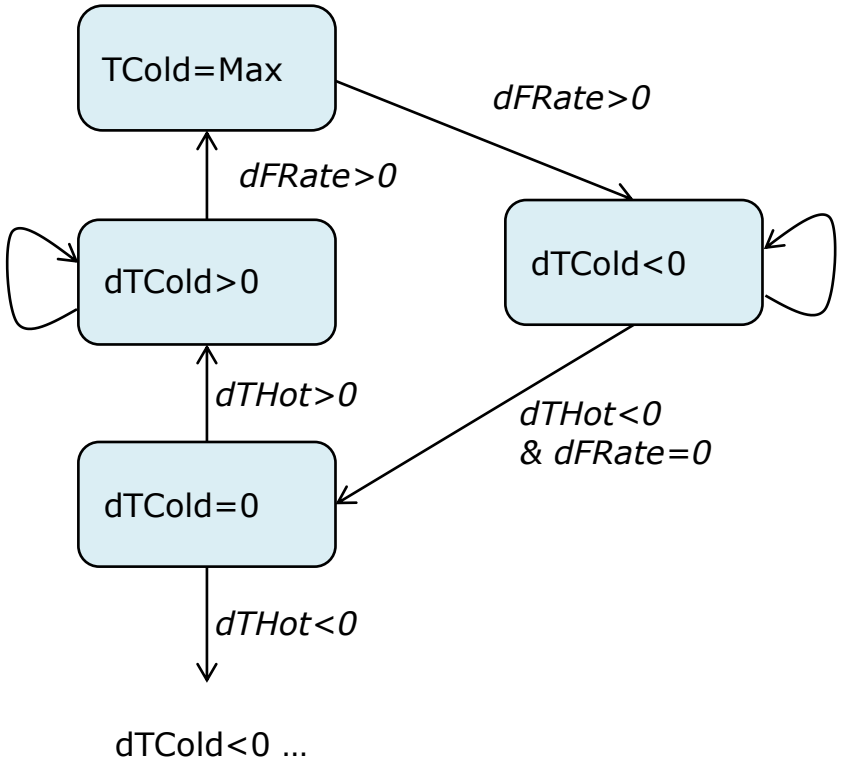


QUALITATIVE MODELING OF CONTINUOUS PROCESS

- Each variable is represented by a graph which represents its direction of variation:
  - Growing
  - Decreasing
  - Constant
- Example : the hot temperature, the cold temperature and the flow rate
- Each variable is modeled by a state machine
- State machines are connected to interact

QUALITATIVE MODELING

dTCold	0	+	Max	-	0
dTHot	0	+			-
dFRate	0		+	+	0

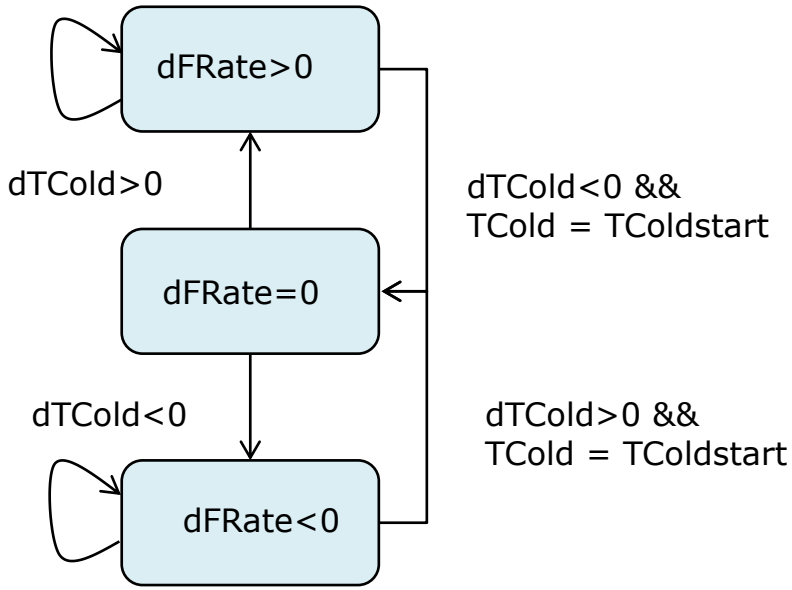


Cold temperature depends on The hot temperature and the exchanger flow

QUALITATIVE MODELING

dFRate	**0**	**+**	**0**
dTCold	0	+	-
dTHot	0		

dFRate	**0**	**-**	**0**
dTCold	0	-	+
dTHot	0		



RESULTS & PERSPECTIVES

- Connecting to a digital simulator
  - Online: driving the simulation with the qualitative model and analysing output data on the fly
- PhD Thesis :
  1. Realizing a dedicated language for qualitative modeling using a SysML profile
  2. Automated abstraction of differential equations for qualitative simulation
- *Substituting numerical simulation by the qualitative simulation during a co-simulation process*

BIBLIOGRAPHY

- J-P. Gallois, J-Y. Pierron: Qualitative simulation and validation of complex hybrid systems. ERTS 2016.
- S. Medimegh, J-Y. Pierron, J-P. Gallois, F. Boulanger. A New Approach of Qualitative Simulation for the Validation of Hybrid Systems. GEMOC 2016
- KUIPERS B.J. (1986). Qualitative simulation. Artificial Intelligence vol 29 n3 239-388.
- Tiwari, A., and Khanna, G. (2002). Series of abstractions for hybrid automata. In Hybrid Systems: Computation and Control, LNCS 2289, 465-478, Springer.

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