



## Qualitative Modeling and Simulation for the analysis of Complex Hybrid Systems

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Hybrid automata : discrete part

**Discrete Variables :  $N, M, \dots$**

And Continuous part

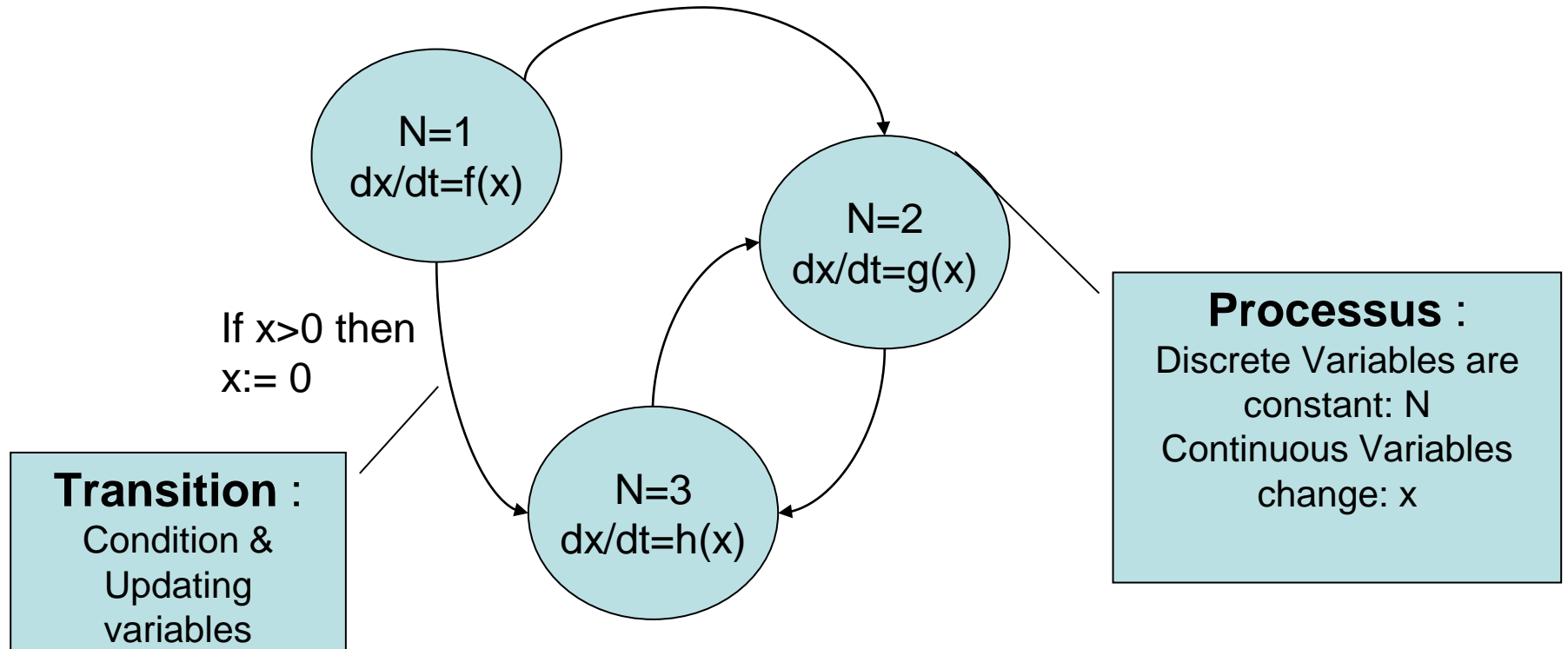
**Continuous Variables :  $x, y, \dots$**

Semantics

**During a state/process (continuous part)**

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

## Hybrid Automaton



## Example : a chemical reaction

### The « brusselator »

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

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

Growing

Decreasing

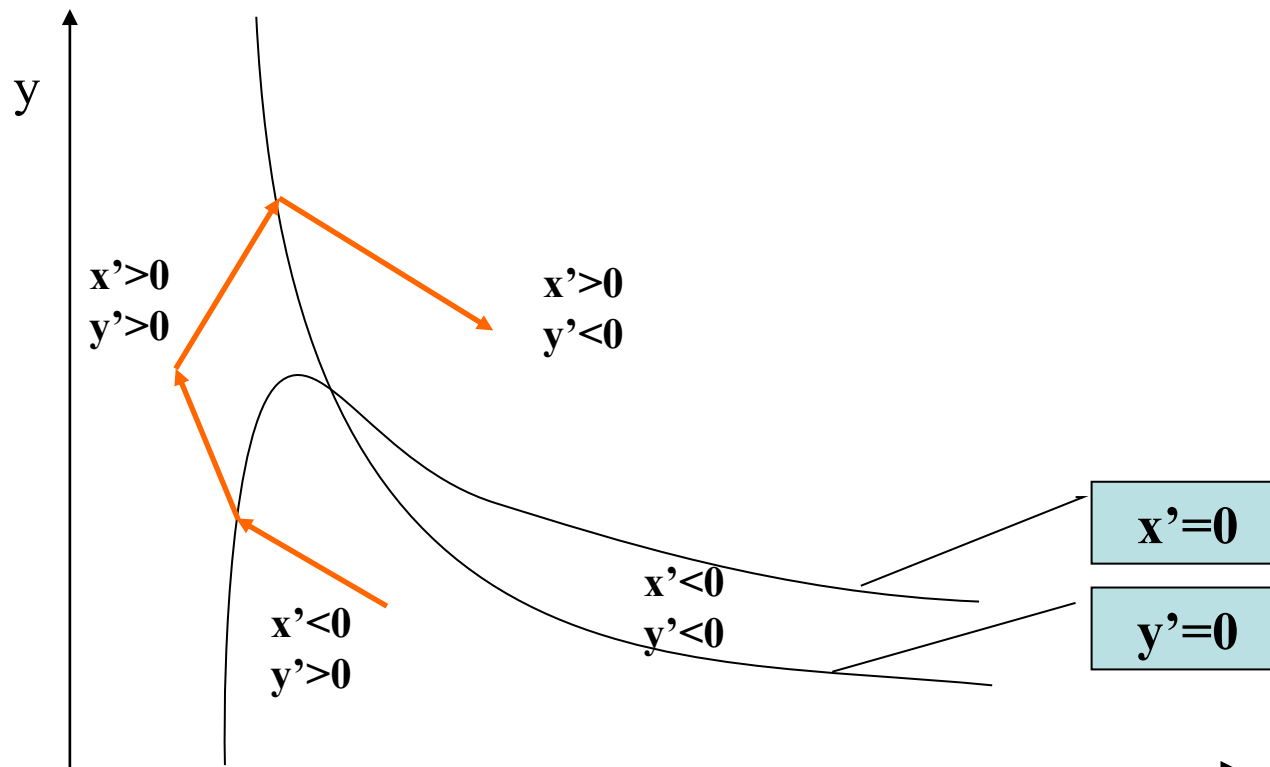
Constant

**Transitions guards are deduced from differential equations by qualitative reasoning**

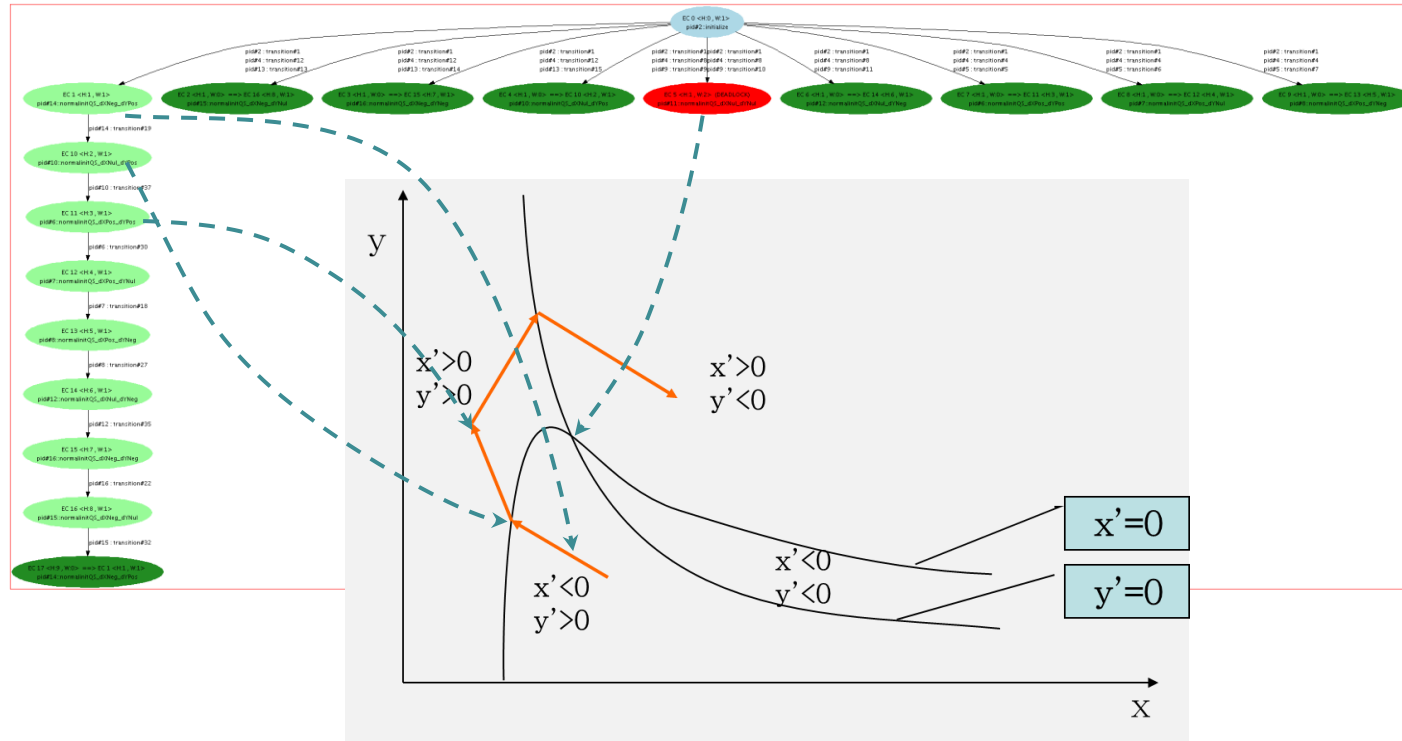
**State machines are connected:**

Differential equations are expressed with all variables

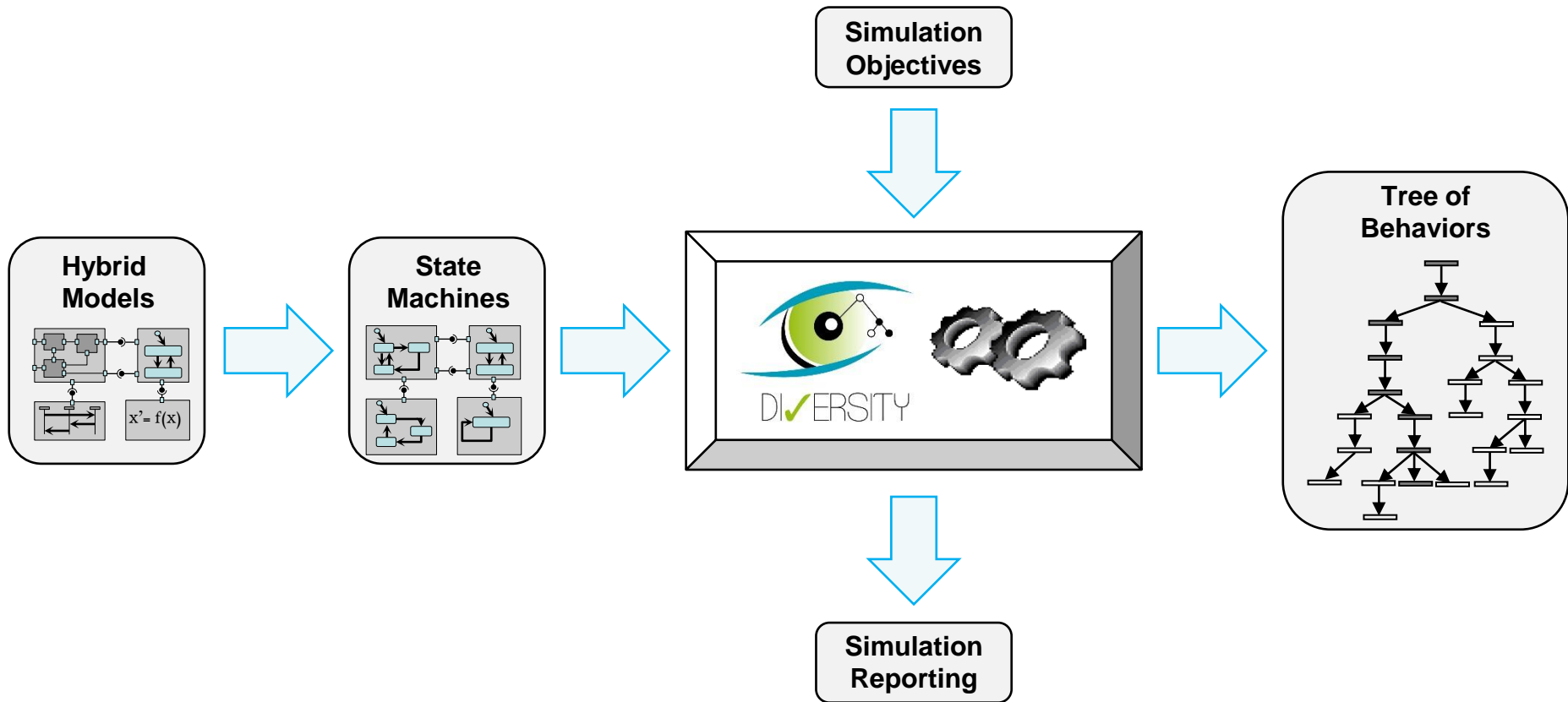
The phase space is divided into qualitative sets  
Conditions between the qualitative states are deduced from differential equations



## Execution Tree in DIVERSITY



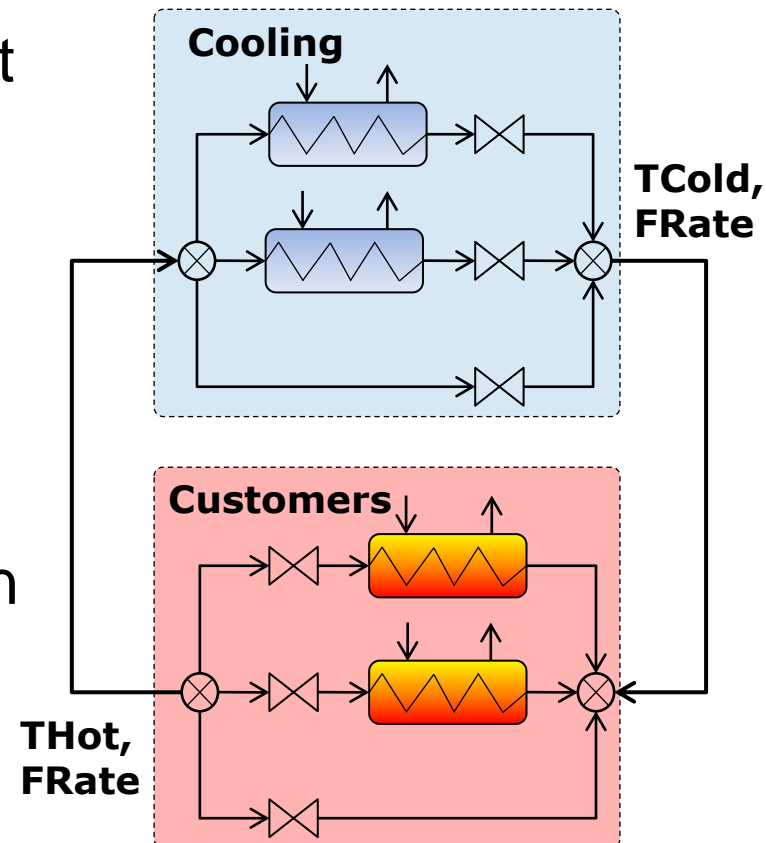
# QUALITATIVE SIMULATION WITH DIVERSITY





- Example of industrial system: a cooling system

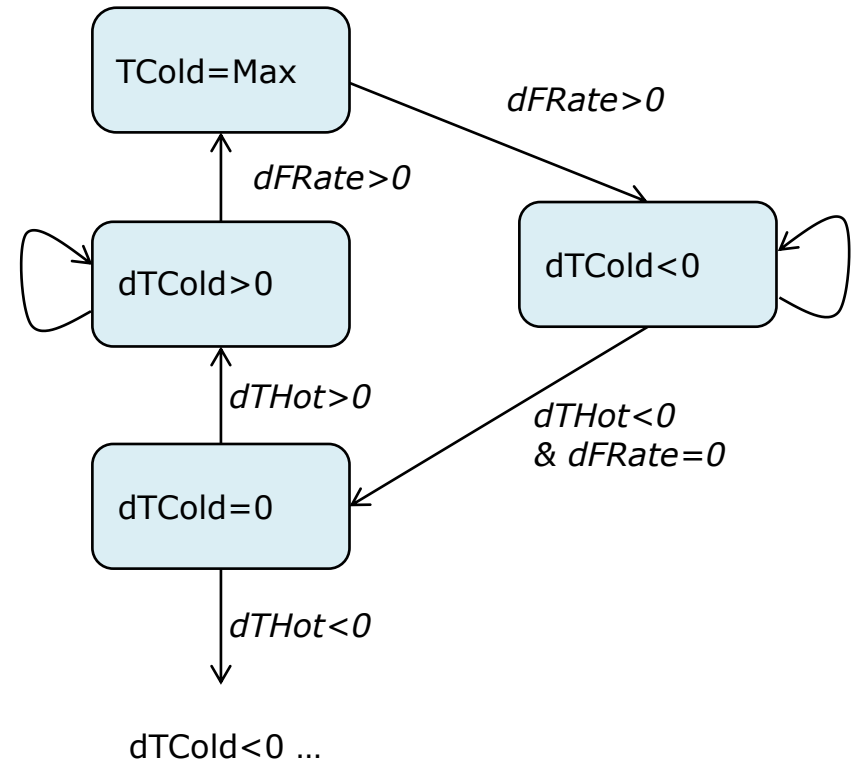
- A circuit must cool a fluid loop that is heated by a heat source
- The system is too complex: no ordinary differential equation
- A qualitative model must be deduced from the specifications: modeling the causal links between inter-dependent variables



- 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

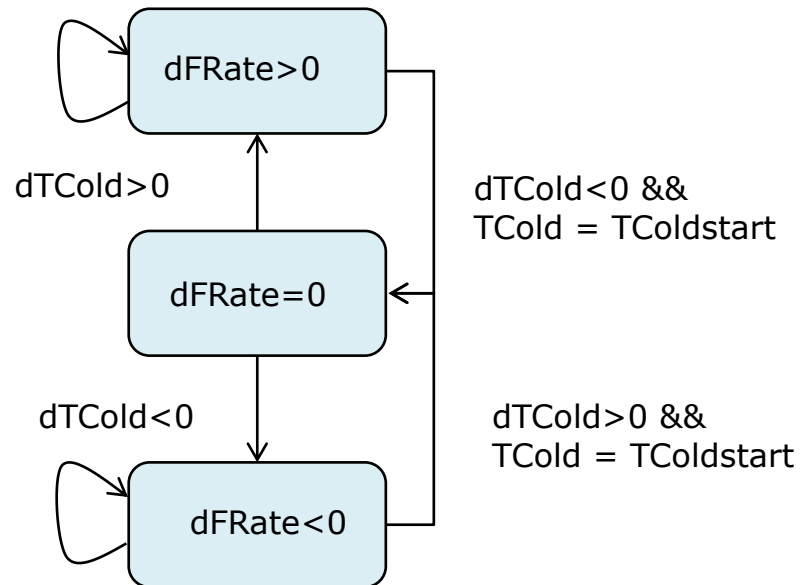
<b>dTCold</b>	<b>0</b>	<b>+</b>	<b>Max</b>	<b>-</b>	<b>0</b>
dTHot	0	+			-
dFRate	0		+	+	0

Cold temperature depends on  
The hot temperature and the  
exchanger flow



<b>dFRate</b>	<b>0</b>	<b>+</b>	<b>0</b>
dTCold	0	+	-
dTHot	0		

<b>dFRate</b>	<b>0</b>	<b>-</b>	<b>0</b>
dTCold	0	-	+
dTHot	0		



- 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*

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- S. Medimegh, J-Y. Pierron, J-P. Gallois, F. Boulanger. A New Approach of Qualitative Simulation for the Validation of Hybrid Systems. GEMOC 2016
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- 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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