A Multi-Paradigm Modeling Approach for Hybrid Dynamic Systems

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Outline

I. Introduction
II. Petri-Net Based Framework
III. Example: A Rapid Thermal Process
IV. Conclusion
I. Introduction

Why do we have modeling and simulation?

- **Modeling** is a way of representing our knowledge about structure and behavior of systems and further answering questions about them via the simulation (Mosterman and Vangheluwe, 2002).
Traditional System Modeling

- **Time-driven, continuous variable systems (CVS)**
  - Differential/Difference equations.

- **Event-driven, discrete event systems (DES)**
  - Finite state automata or Petri nets (Cassandras and S. Lafortune, 1999; Zhou and Jeng, 1998)

- Both are to reduce the complexity for presenting real systems.
Issues in Traditional System Modeling

- Most practical systems have both the time-driven and event-driven dynamics and form the so-called **hybrid dynamic systems (HDS)**.

- Relative literature (special issues) on HDS
Modeling Approaches for HDS

- **Integrate Continuous and Discrete Models**
  - Extend CVS to include event-driven dynamics
    - Linear piece-wise systems (Branicky et al, 1998)
  - Extend DES to include time-driven dynamics
    - Hybrid automata (Lygeros, 2003), Hybrid Petri nets (David and Alla, 1994), Hybrid Statechart (Lee and Hsu, 2002).
    - Commercial Software: MATLAB Simulink with Stateflow (Harman and Dabney, 2001), VHDL-AMS (Bakalar and Christen, 1999).
Motivations

- Simultaneously dealing with the discrete and continuous variables is very difficult.
- Their mathematical backgrounds are completely different: event-driven vs. time-driven dynamics.
- Most of the existing HDS modeling approaches result in a unified, but more complicated and unnatural model.
- Design engineers cannot be allowed to use their preferred domain models.
II. Petri-Net Based Framework

- **PN-Based Approach**
  - Use Petri net (PN) to model the *event-driven* dynamics
  - Use the *Differential/Difference equations* to model the *time-driven* dynamics
  - Define the *interfaces* for model communications
Advantages of Using PN

- **Graphic** representation.
- More compact representation.
- A structured **model** of DES dynamics.
- **Mathematical support** (reachability, invariant, reduction, siphon/trap, and simulation; Zhou and Jeng, 1998).
- **PN family** (Stochastic PN, Colored PN, CTPN, Automation PN...etc)
- A large body of **existent tools and software** for PN analysis and design. [http://www.daimi.au.dk/PetriNets/tools/](http://www.daimi.au.dk/PetriNets/tools/)
Multiple Models in Hybrid Control Systems

Fig. 1. Multiple domains in hybrid control systems.
PN-Based Framework

Command: start operation  Working  Response: end operation  Completed

Boundary interface

Event dynamics

Time dynamics

Example:
\[ x_1 = f(x_1, t) \]
\[ x_2 = f(x_2, t) \]
\[ y = f(x_1, x_2, t) \]

Fig. 2. Modeling the continuous dynamics within a Petri net via a hierarchical way.
Comparison: Hybrid Petri Net  (David & Alla, 1994)

Fig. 3. Hybrid Petri net (with a net structure to model continuous dynamics).
Discrete-Event & Discrete-Time Models

Fig. 4. Interfacing devices in high level: (a) signal and (b) event generators.
Discrete-Time & Continuous-Time Models

Fig. 5. Interfacing devices in low level: (a) sampler and (b) holder.
III. Example: A Rapid Thermal Process

Fig. 6. A rapid thermal processor.
A Hydrogen Baking Process

Step 1) Load the raw wafer.
Step 2) Close the chamber door.
Step 3) Open the gas valve to supply gases with a desired gas flow rate and pressure of 2.8 liters per minute (lpm) and 0.5 Torr, respectively.
Step 4) Close the gas valve.
Step 5) Turn on the heating lamp to bake the wafer with a desired baking temperature and time of 1000°C and 4 seconds, respectively.
A Hydrogen Baking Process (cont’d)

Step 6) Turn off the heating lamp.
Step 7) Turn on the flush pump with a desired pressure of less than 0.05 Torr.
Step 8) Turn off the flush pump.
Step 9) Open the chamber door.
Step 10) Unload the processed wafer.
PN Model

Fig. 7. PN model of the RTP system.
Table I. Notations for the PN model in Fig. 7

<table>
<thead>
<tr>
<th>Place</th>
<th>Description</th>
<th>Transition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>p1</td>
<td>Raw wafer buffer</td>
<td>t1</td>
<td>Cmd: start loading wafer</td>
</tr>
<tr>
<td>p2</td>
<td>Loading wafer</td>
<td>t2</td>
<td>Re: end loading wafer</td>
</tr>
<tr>
<td>p3</td>
<td>Loading wafer completed</td>
<td>t3</td>
<td>Cmd: start closing chamber door</td>
</tr>
<tr>
<td>p4</td>
<td>Closing chamber door</td>
<td>t4</td>
<td>Re: end closing chamber door</td>
</tr>
<tr>
<td>p5</td>
<td>Closing chamber door</td>
<td>t5</td>
<td>Cmd: start opening gas valve</td>
</tr>
<tr>
<td>p6</td>
<td>Opening gas valve</td>
<td>t6</td>
<td>Re: end opening gas valve</td>
</tr>
<tr>
<td>p7</td>
<td>Mass flow controller-I</td>
<td>t7</td>
<td>Cmd: start closing gas valve</td>
</tr>
<tr>
<td>p8</td>
<td>Pressure controller-I</td>
<td>t8</td>
<td>Re: end closing gas valve</td>
</tr>
<tr>
<td>p9</td>
<td>Opening gas valve</td>
<td>t9</td>
<td>Cmd: start turning on heating lamp</td>
</tr>
<tr>
<td>p10</td>
<td>Closing gas valve</td>
<td>t10</td>
<td>Re: end turning on heating lamp</td>
</tr>
<tr>
<td>p11</td>
<td>Closing gas valve</td>
<td>t11</td>
<td>Cmd: start turning off heating lamp</td>
</tr>
<tr>
<td>p12</td>
<td>Turning on heating lamp</td>
<td>t12</td>
<td>Re: end turning off heating lamp</td>
</tr>
<tr>
<td>p13</td>
<td>Turning on heating lamp</td>
<td>t13</td>
<td>Cmd: start turning on flush pump</td>
</tr>
<tr>
<td>p14</td>
<td>Temperature controller-I</td>
<td>t14</td>
<td>Re: end turning on flush pump</td>
</tr>
<tr>
<td>p15</td>
<td>Turning off heating lamp</td>
<td>t15</td>
<td>Cmd: start turning off flush pump</td>
</tr>
<tr>
<td>p16</td>
<td>Turning off heating lamp</td>
<td>t16</td>
<td>Re: end turning off flush pump</td>
</tr>
<tr>
<td>p17</td>
<td>Turning on flush pump</td>
<td>t17</td>
<td>Cmd: start opening chamber door</td>
</tr>
<tr>
<td>p18</td>
<td>Turning on flush pump</td>
<td>t18</td>
<td>Re: end opening chamber door</td>
</tr>
<tr>
<td>p19</td>
<td>Pressure controller-II</td>
<td>t19</td>
<td>Cmd: start unloading wafer</td>
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<tr>
<td>p20</td>
<td>Turning off flush pump</td>
<td>t20</td>
<td>Re: end unloading wafer</td>
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<td>p21</td>
<td>Turning off flush pump</td>
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<tr>
<td>p22</td>
<td>Opening chamber door</td>
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<td>p23</td>
<td>Opening chamber door</td>
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<tr>
<td>p24</td>
<td>Unloading wafer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p25</td>
<td>Unloading wafer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p26</td>
<td>Processed wafer buffer</td>
<td></td>
<td></td>
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</tbody>
</table>
Fig. 8. Pressure and temperature in one cycle processing.
IV. Conclusion

- We have presented a Petri net-based framework to model the hybrid dynamic systems.

Future Work

- From a idea/concept, to a methodology, even to a theory…
Q & A

Thanks for your time and attention!

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