How good is your embedded design, if at all?

Holger Hermanns
dependable systems and software
Saarland University
Saarbrücken, Germany
The German Energy Turn-Around

Renewables are on the rise!

 לו In Germany ... and elsewhere
 לו On residential rooftops.

1999: 0.07 GW  2009: 10.6 GW  2019: 49.0 GW
The German Energy Turn-Around

Renewables are on the rise!

- In Germany ... and elsewhere
- On residential rooftops.

1999: 0.07 GW  2009: 10.6 GW  2019: 49.0 GW

That is so great! Is it?

European Grid: 15 GW ≈ 1 Hz

Target: [49.8, 50.2] Hz
The German Energy Turn-Around

Renewables are on the rise!

⏩ In Germany ... and elsewhere
⏩ On residential rooftops.

They jointly influence the stability of the European grid.

Current state of control:

EN 50438:2007, in force since 2007:
Switch off when frequency >50.2 Hz

VDE-AR-N 4105, required today:
Output linear function of frequency in [50.2, 51.5] Hz
Emergency switchoff above 51.5 Hz
Switch on again when <50.05 Hz for 1 minute
The Distributed Turn-Around

Each controller is a gambler.

Let a die decide whether you must leave the grid.  

*Size of dice depends on grid frequency.*  

... as in 802.11e  

(linearly)

Let another die decide when you can resume.  

*Size of dice depends on length of overload.*  

... as in Ethernet  

(exponentially)
Quantitative Models
All models are wrong, but some are useful

George E. P. Box
Useful Quantitative Models

finite automata

Diagram showing a transition between states "dark" and "light" with actions "on?" and "off!".
Useful Quantitative Models

- finite automata
- with clocks

all running at the same speed

Timed Automata
Useful Quantitative Models

- finite automata
- with clocks
- and with costs incurred as time advances

Priced Timed Automata
Useful Quantitative Models

- finite automata
- with clocks
- and with costs
- modular: composition of automata

Automata Networks
Useful Quantitative Models

- finite automata
- with clocks
- and with costs
- modular: composition of automata

- with probability distributions

\[ \text{Pr} ("\text{on!} > t") = \text{Exp}[5] \]
Useful Quantitative Models

- finite automata
- with clocks
- and with costs
- modular: composition of automata

- with probability distributions
- and continuous dynamics

Stochastic Hybrid Automata
Model Checking
Model Checking

Real System
- Modelling

Requirements
- Formalising
Model Checking

Real System

Modelling

Formal System Model
possible behaviour

Requirements

Formalising

Requirement Specification
allowed behaviour
Model Checking

- **Real System**
  - Modelling
  - Formal System Model
    - possible behaviour

- **Requirements**
  - Formalising
  - Requirement Specification
    - allowed behaviour

- **Model Checker**
Model Checking

- Real System
  - Modelling
  - Formal System Model possible behaviour
- Requirements
  - Formalising
  - Requirement Specification allowed behaviour
- Model Checker
  - No Counterexample
  - YES
  - done
Model Checking

- Real System
  - Modelling
  - Formal System Model: possible behaviour

- Requirements
  - Formalising
  - Requirement Specification: allowed behaviour

Model Checker

- No Counterexample
- YES

Next Requirement

done
What 3 items would you take to a deserted island?
What 3 items up to 1 kg and 1 liter would you take to a deserted island?
What 3 items up to 1 kg and 1 liter would you take to a deserted island?
ESA 'Fly Your Satellite!' program

What 3 items up to 1 kg and 1 liter would you take into space?

Cube Satellites, educational / scientific use

Limits: Up to 1 kg & 1 liter

Mission time: up to 4 years
GOMX-1

- 2U CubeSat (2 liter)
- Launched in November 2013
- Payloads:
  - software defined receiver for aircraft signals
  - color camera for earth observation
- Telemetry transmitted on amateur radio frequency
- Massive amounts of data collected
  - battery voltage, temperature, solar infeed, ...

Runs our calibration experiments.
Battery Kinetics
Battery Kinetics

100 %

0 %
Battery Kinetics

\[ \dot{a}(t) = -I + p \left( \frac{b(t)}{1-c} - \frac{a(t)}{c} \right) \]

\[ \dot{b}(t) = p \left( \frac{a(t)}{c} - \frac{b(t)}{1-c} \right) \]

“Kinetic Battery Model”, or KiBaM
Battery Kinetics

\[
\begin{align*}
\dot{a}(t) &= -I + p \left( \frac{b(t)}{1-c} - \frac{a(t)}{c} \right) \\
\dot{b}(t) &= p \left( \frac{a(t)}{c} - \frac{b(t)}{1-c} \right)
\end{align*}
\]

“Kinetic Battery Model”, or KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
Battery Kinetics

“Stochastic” KiBaM
• 2U CubeSat
• Shipped in October 2014 with Cygnus CRS-3 towards ISS
• Payloads:
  • OpBcal communicaBon experiments from NUS
  • Highspeed UHF and SDR receiver
• Shipping failed after liftoff
• Satellite was recovered from wreckage and returned to manufacturer
GOMX-3 mission planning

• Very tight power budget
• Needs dynamic and battery aware scheduling
• What we do:
  • Priced Timed Automata modelling with linear battery
  • Generate optimal schedules for 1 week or 1 day horizon
  • Evaluate schedules on “stochastic” KiBaM for robustness
  • Send to orbit, observe behaviour, update model
GOMX-3 mission planning

- Very tight power budget
- Needs dynamic and battery aware scheduling

What we do:

- Priced TA modeling with linear model
- Generate optimal schedules for 1 week horizon
- Evaluate schedules on random KiBaM for robustness
- Prepare for updates of model state based on orbit data
A one-day schedule and its depletion risk
Meeting Reality, Safely
Meeting Reality
On-line and Compositional Learning of Controllers with Application to Floor Heating

Kim G. Larsen, Marius Mikucionis, Marco Muniz, Jiri Srba, Jakob H. Taankvist
Aalborg University, DK
Stochastic Hybrid Systems

A Bouncing Ball

\[ v' = -9.81 \land p' = 1 \times v \]

\[ p = 10 \]

\[ \text{bounce!} \]
\[ p = 0 \land v < 0 \]
\[ v = -(0.8 + \text{random}(0.12)) \times v \]
Stochastic Hybrid Systems

A Bouncing Ball

\[ v' = -9.81 \land p' = 1 \times v \]

\[ p = 10 \]

\[ p = 0 \land v < 0 \]

\[ v = -(0.8 + \text{random}(0.1)) \times v - 4 \]

\[ \text{hit?} \]

\[ p = 6 \land v \geq 0 \]

\[ v = -(0.85 + \text{random}(0.1)) \times v - 4 \]

\[ \text{hit?} \]

\[ p = 6 \land v < 0 \land v \geq -4 \]

\[ v = -4.0 \]

On The Power of SMC 2
Stochastic Hybrid Systems

A Bouncing Ball

\[ v' = -9.81 \&\& p = 1 \times v \]
\[ p = 10 \]
\[ \text{hit?} \&\& p = 6 \&\& v > 0 \]
\[ v = -(0.85 + \text{random}(0.1)) \times v - 4 \]
\[ \text{hit?} \&\& p = 6 \&\& v < 0 \&\& v > -4 \]
\[ v = -4.0 \]

simulate 1 \([<=20]\{\text{Ball1.p, Ball2.p}\}

Pr[<=20](<>(\text{time}>=12 \&\& \text{Ball1.p}>4))
Other Applications

- **FIREWIRE**
- **BLUETOOTH**
- **10 node LMAC**
- Schedulability Analysis for Mix Cr Sys
- Smart Grid Demand / Response
- Energy Aware Buildings
- Battery Scheduling
- Genetic Oscillator (HBS)
- Passenger Seating in Aircraft

On The Power of SMC 2
Floor Heating Scenario

- Each room has a hot water loop that can be opened/closed.
- Loops are controlled via activating / deactivating valves.
- Rooms equipped with wireless temperature sensors (report every 15 minutes).
- Each room has its user-defined target temperature.

Control Task:
- maintain room temperatures as close as possible to target temperatures.
Additional Factors and Restrictions

- Heat exchange among the rooms (influenced by the door positions).
- Pipes are traversing under several rooms.
- Outside temperature and weather forecast.
- Capacity of the heating system.
- Temperature user-profiles for the different (groups of) rooms.

Control Task:
Maintain room temperatures as close as possible to target temperatures.
1-Room / 1-Window Game

Room

```
const double Tg = 21.0; // room temp. goal
const double Te = 15.0; // environment temp.
const double H = 0.04; // power of heater
const double Aclosed = 0.002; // heat loss when window closed
const double Aopen = 0.004; // heat loss when window open
const int P = 15; // heater switching period
const int h = 60; // 1 hour = 60 time units
```

HeatOff
x<=P &&
T'==((Te-T)*A

HeatOn
x<=P &&
T'==((Te-T)*A+H

D'==((Tg-T)*(Tg-T)
Find strategy $\sigma$ that minimizes expectation of
Compositional Synthesis

• Split the valves into controllable and fixed (controlled via Bang-Bang)
• Synthesize a strategy for controllable valves
• Swap the controllable and fixed valves and synthesise another strategy
• Merge strategies.

\((2 \uparrow^5 h + 2 \uparrow^6 h)\) instead of \(2 \uparrow^{11} h\) decision choices
(in our case \(h=3\))
Latest News

Diagram:

- UPPAAL-STRATEGO
- HOMEPORT
- Seluxit GUI

Connections:
- Data from UPPAAL-STRATEGO to HOMEPORT
- Strategy from HOMEPORT to UPPAAL-STRATEGO
- Weather forecast from HOMEPORT to Seluxit GUI
- Temperature readings from HOMEPORT to Seluxit GUI
- Current data from Seluxit GUI to HOMEPORT
- Temperature user-profile from Seluxit GUI to HOMEPORT
- Valve control from HOMEPORT to Seluxit GUI
Latest News
### Latest News

#### 3 day scenario

<table>
<thead>
<tr>
<th>Weather</th>
<th>Distance</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aalborg</td>
<td>14583</td>
<td>8342</td>
</tr>
<tr>
<td>Anadyr</td>
<td>2385515</td>
<td>1483272</td>
</tr>
<tr>
<td>Ankara</td>
<td>17985</td>
<td>10464</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>22052</td>
<td>12175</td>
</tr>
<tr>
<td>Murmansk</td>
<td>399421</td>
<td>187941</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Weather</th>
<th>Distance</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aalborg</td>
<td>14583</td>
<td>8552</td>
</tr>
<tr>
<td>Anadyr</td>
<td>2385515</td>
<td>1503448</td>
</tr>
<tr>
<td>Ankara</td>
<td>17985</td>
<td>10511</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>22052</td>
<td>12725</td>
</tr>
<tr>
<td>Murmansk</td>
<td>399421</td>
<td>191441</td>
</tr>
</tbody>
</table>

---

**Evaluation of under modified parameters (0-20%)**