ProFeat: Quantitative Analysis of Feature-oriented Systems

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Case study: heterogeneous tiled architecture

Architecture

- processing units (tiles) can be mixed freely
- connected via network-on-chip

Christel Baier, Sascha Klüppelholz, Sascha Wunderlich
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Architecture
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Variant space
- combination of tiles
- strategies for power saving, frequency scaling, scheduling

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Goals

• compare homogeneous and heterogeneous systems w.r.t. energy consumption and throughput
• analysis of resource management strategies
Approach: probabilistic model checking

- system family
- family model
- probabilistic model checker
  family-based analysis
- specification
- requirements
- results for all variants
- optimal variant w.r.t. spec

- non-probabilistic: LTL, CTL
- probabilistic: PCTL*
- multi-objective analysis
- also statistical model checking

all-in-one
one-by-one
Approach: probabilistic model checking

system family

ProFeat model

ProFeat family-based analysis

results for all variants optimal variant w.r.t. spec

specification

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• non-probabilistic: LTL, CTL
• probabilistic: PCTL*
• multi-objective analysis

Philipp Chrszon, Clemens Dubslaff, Sascha Klüppelholz, Christel Baier.
root feature {
  all of Hardware, Software, Management;
}
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feature Hardware {
    all of CoreManager, Tiles;
}
Feature modeling

root feature {
  all of Hardware, Software, Management;
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feature Hardware {
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feature Tiles {
  some of RISC[2], DSP[2];
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feature RISC {
    frequency : [0..MAX_FREQ];
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Feature modeling

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root feature {
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feature Tiles {
    some of RISC[2], DSP[2];
}

feature RISC {
    frequency : [0..MAX_FREQ];
    modules risc_impl;
}
```
module RISC {
    tasks : [0..MAX_TASKS] init 0;
}

Feature modules: defining operational behavior
module RISC {
  tasks : [0..MAX_TASKS] init 0;

  [schedule] tasks = 0 -> (tasks' = 2);
}

module RISC {
    tasks : [0..MAX_TASKS] init 0;

    [schedule] tasks = 0 -> (tasks' = 2);
    [working] tasks > 0 -> 0.75: (tasks' = max(0, tasks - 1)) +
                        0.25: (tasks' = max(0, tasks - 2));
}

Feature modules: defining operational behavior
module RISC {
    tasks : [0..MAX_TASKS] init 0;

    [schedule] tasks = 0 -> (tasks' = 2);
    [working] tasks > 0 -> 0.75: (tasks' = max(0, tasks - frequency)) +
    0.25: (tasks' = max(0, tasks - 2 * frequency));
}

Diagram:

- **Schedule**: Transition from 0 to 2 with a probability of 0.75.
- **Working**: Transition from 0 to 1 with a probability of 0.25 and from 1 to 2 with a probability of 0.25.
- **Working**: Transition from 1 to 2 with a probability of 0.75.
module RISC {
    tasks : [0..MAX_TASKS] init 0;

    [schedule] tasks = 0 -> (tasks' = 2);
    [working] tasks > 0 -> 0.75: (tasks' = max(0, tasks - frequency)) +
        0.25: (tasks' = max(0, tasks - 2 * frequency));
    [deactivate] tasks = 0 -> true;
}

```
0 -- schedule -> 2
    \ 0.25
     \ working
       \_________
         0.75

0 -- working -> 1
      \ 0.75
       \ working
         \_________
            0
```
Feature controller: switching between configurations

controller {

}

Tiles

RISC₀  RISC₁

Tiles

RISC₀  RISC₁

Tiles

RISC₀  RISC₁

Tiles

RISC₀  RISC₁
controller {
    for i in [0..1] {
        [] active(Management.OnOff.Powersave) & can_power_off(RISC[i]) ->
            deactivate(RISC[i]);
    }
}
controller { 
  for i in [0..1] { 
    [] active(Management.OnOff.Powersave) 
    & can_power_off(RISC[i]) -> 
    deactivate(RISC[i]); 
  } 
}
controller {
    for i in [0..1] {
        [] active(Management.OnOff.Powersave)
            & can_power_off(RISC[i]) ->
               deactivate(RISC[i]);

        [] active(Management.Frequency.NonDet)
            -> (RISC[i].frequency' = 1);
        [] active(Management.Frequency.NonDet)
            -> (RISC[i].frequency' = 2);
    }
}
 Costs and rewards

```plaintext
feature RISC {
  frequency : [0..MAX_FREQ];
  modules risc_impl;
}
```
Costs and rewards

```ocaml
feature RISC {
  frequency : [0..MAX_FREQ];
  modules risc_impl;

  rewards "energy" {
    [working] true :
      1 + pow(frequency, 2);
  }
}
```

variant with frequency=2
Costs and rewards

```plaintext
feature RISC {
    frequency : [0..MAX_FREQ];
    modules risc_impl;

    rewards "energy" {
        [working] true :
            1 + pow(frequency, 2);
        active(this) & this.tasks = 0 : 1;
    }
}
```

variant with frequency=2
feature RISC {
    frequency : [0..MAX_FREQ];
    modules risc_impl;

    rewards "energy" {
        [working] true :
            1 + pow(frequency, 2);
        active(this) & this.tasks = 0 : 1;
        [activate] true : 2;
    }
}
Implementation: translational approach

- ProFeat model
- family-based analysis
- results for all variants
  - optimal variant w.r.t. spec

- system family
- specification
- requirements

- non-probabilistic: LTL, CTL
- probabilistic: PCTL *
- multi-objective analysis
- also statistical model checking
  - all-in-one
  - one-by-one

Implementation: translational approach

system family

ProFeat model

translate

ProFeat

all-in-one

PRISM

post-process

ProFeat

one-by-one

results for

all variants

w.r.t. spec

requirements

specification

• non-probabilistic: LTL, CTL
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Implementation: translational approach

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- Specification
- Requirements

- Translate
- PRISM
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- One-by-one

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- ProFeat translate
- PRISM
- ProFeat post-process
- System family
- Specification
- Requirements

Results for all variants optimal variant w.r.t. spec

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All-in-one vs one-by-one
Implementation: translational approach

- **ProFeat model**
- **ProFeat translate**
- **PRISM**
- **ProFeat post-process**

System family

- Specification
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Results for all variants optimal variant w.r.t. spec

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### Analysis results: homogeneous vs. heterogeneous

<table>
<thead>
<tr>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find the minimal expected energy and time for the variants.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>#RISC</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>homogeneous</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2.5 mJ</td>
<td>99.9 ms</td>
</tr>
<tr>
<td>heterogeneous</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.6 mJ</td>
<td>90.4 ms</td>
</tr>
</tbody>
</table>
## Analysis results: homogeneous vs. heterogeneous

### Goal
Find the minimal expected energy and time for the variants.

<table>
<thead>
<tr>
<th></th>
<th>tiles</th>
<th>minimal expected energy</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#RISC</td>
<td>#DSP</td>
<td>energy</td>
</tr>
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</table>
### Goal

Find a scheduling strategy minimizing the expected energy or expected time for a certain job quota.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Expected Energy (mJ)</th>
<th>Expected Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>nondet</td>
<td>62.0</td>
<td>90.4</td>
</tr>
<tr>
<td>powersave</td>
<td>106.3</td>
<td>110.0</td>
</tr>
<tr>
<td>performance</td>
<td>281.0</td>
<td>90.4</td>
</tr>
<tr>
<td>always on</td>
<td>106.3</td>
<td>90.4</td>
</tr>
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<td>powersave</td>
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<td>110.0</td>
</tr>
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<td>performance</td>
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</tr>
</tbody>
</table>
### Analysis results: strategy evaluation and synthesis

#### Goal
Find a scheduling strategy minimizing the expected energy or expected time for a certain job quota.

<table>
<thead>
<tr>
<th>strategy</th>
<th>minimal expected</th>
<th>frequency</th>
<th>minimal expected</th>
<th>energy</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>power</td>
<td>nondet</td>
<td>nondet</td>
<td>62.0 mJ</td>
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<td></td>
</tr>
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Conclusions

Summary

- ProFeat language for modeling families of stochastic systems using feature-oriented concepts
- Tool support for all-in-one, one-by-one or hybrid analysis
- Evaluation of system with heterogeneous tiled architecture
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Future Work

• Integration with other tools
• Extraction of feature-level knowledge from analysis results
• Visualization of analysis results?
Symbolic representation of analysis results

Final result: [0.9445746949695318, 0.9792165174854354]

Results for initial configurations:
(Mem, Fall, Oxy, PlsRt, Pos, Temp, SACC, SSPO2, STemp)=0.9445746949695318
(Mem, Oxy, PlsRt, Pos, Temp, SACC, SSPO2, STemp)=0.953118529409139
(Mem, PlsRt, Pos, Temp, SACC, SSPO2, STemp)=0.9617396442452253
(Mem, Pos, Temp, SACC, STemp)=0.9704387384917665
(Mem, PlsRt, SECG, STemp)=0.9792165174854354

... 295 lines omitted ...
Final result: [0.9445746949695318, 0.9792165174854354]
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... 295 lines omitted ...
All-in-one and one-by-one analysis

ProFeat Model

ProFeat

PRISM results
All-in-one and one-by-one analysis

ProFeat Model

ProFeat

PRISM

results

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