Staged Configuration of Dynamic Software Product Lines with Complex Binding Time Constraints

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Heidelberg Ion-Beam Therapy Center (HIT) [Hit13]

- DCU Case Study for Beam Cycle Creation
- Discrete State Control Logics
- Safety-critical Automation Engineering Software (ISO 13485)
- Highly-Configurable and Runtime Adaptive

- Re-Engineered as (D)SPL
- ~ 200 Features (Boolean and Non-Boolean)
- SPL Implementation in C ~ 175,000 LOC
Device Control Units (DCUs)

Area 1: Beam Accelerator
- Synchrotron
- Ion Sources

Area 2: Therapy
- Treatment Room
- Treatment Room (Gantry)

Re-engineered DCUs as SPL

DCU-T
DCU-RB
DCU-SPL
DCU-SD
DCU-Z
**DCUs as DSPL** [Hallsteinsen et al. 08]
Adding Binding Times to Feature Models

[Mei et al. 03], [Rosenmüller et al. 08]

What about multiple possible binding times?

Default: all binding times are selected.

Are features always configurable at any of their binding times or are there constraints?

Pre-Configuration Time (PT)

Installation Time (IT)

Activation Time (AT)

Runtime (RT)
Feature Constraints

Abbreviations
AT: Activation Time
RT: Runtime

How to express those kinds of constraints?

(Re)-configuration at runtime is only allowed in Adjustment, Manual, or Experiment mode.
# Binding Time Constraints

<table>
<thead>
<tr>
<th>Feature / Attribute</th>
<th>Binding Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device Control Parameter ⇒ (Device Control)</td>
<td>( \text{ActivationTime} ) = ( \text{ActivationTime} )</td>
</tr>
<tr>
<td>Therapy ⇒ (EnableSyncSupplyFrequency, ( bt ) = ActivationTime)</td>
<td></td>
</tr>
<tr>
<td>Delay Time Activate, ( bt ) = RunTime ⇒ (Adjustment ∨ Experiment ∨ Manual)</td>
<td></td>
</tr>
<tr>
<td>Timeout Feedback, ( bt ) = ActivationTime ⇒ (Delay Time Feedback)</td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations**
- bt: Binding Time
Staged Configuration [Czarnecki et al. 04]

Domain Engineering

Binding Times

Stage$_1$ Stage$_2$ \[ \cdots \] Stage$_{n-1}$ Stage$_n$
Domain Engineering

- Domain analysis should ensure consistency, i.e., avoid anomalies
- Feature model is satisfiable
- Abscence of unattended core and dead features

Binding times and binding time constraints must be included to the analysis.
Staged Configuration [Czarnecki et al. 04]
Application Engineering

- Product (re-)configuration is binding time aware

Satisfiability check after each configuration step to ensure the configuration may terminate in a valid configuration

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Transformation

DSPL Feature Model

EFM

Feature/Attribute/Binding Time Constraints

bt

Plain Feature Model

Feature Tree

Feature/Attribute Constraints

Binding Time Tree

Binding Time Constraints

Mixed Constraints
Transformation of Feature Binding Times

Transformation of attributes and their binding times accordingly

Transformation of constraints by additional require and exclude edges
Implementation

Extended FM Meta-Model

Eclipse-based FM Meta-Model

DSPL Feature Model

EFM

Feature Attribute

BT

Plain Feature Model

Feature Tree

Binding Time Tree

Mixed Constraints

Feature/Attribute Constraints

Binding Time Constraints

Feature Tree

Binding Time Tree

Mixed Constraints

Feature/Attribute Constraints

Binding Time Constraints

Off-the-Shelf Solver [Saller et al. 13]
### Evaluation

#### Domain Engineering

<table>
<thead>
<tr>
<th>Feature</th>
<th>EFM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>#Features</td>
<td>47</td>
<td>783</td>
</tr>
<tr>
<td>#Constraints</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>#Core Features</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>#Core Binding Times</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>#Dead Features</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>#Dead Binding Times</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>SAT Check</td>
<td>0.46ms</td>
<td></td>
</tr>
</tbody>
</table>

#### Application Engineering

Staged Configuration SAT Check Duration

- Duration in ms
- Configuration Steps
- Avg 0.46ms
Conclusion and Future Work

- Extended FMs with binding times and binding time constraints
- Provided a staged configuration semantics for DSPLs
- Motivated by an industrial case study
- More expressive constraints
- Feature attributes with unrestricted value domains
- Validate binding time constraints by using reconfiguration automata [Helvensteijn 12]
List of Literature


