CardyGAn: Tool Support for Cardinality-based Feature Models

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CardyGAn

VaMoS 2016,
Salvador da Bahia, Brasil

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Example: Variability Modeling of Systems with multiply duplicated Subsystems

Platoon

Legend
- High Throughput Channel
- Reliable Channel
- Autonomous Vehicle

Example: Variability Modeling of Systems with multiply duplicated Subsystems

Platoon

Joining Vehicle
Triggers adaptation of overall system behavior

Legend

- High Throughput Channel
- Reliable Channel

Running Example: Cardinality-based Feature Model (CFM)

Platoon

Channels

Movement

Member

[2,2]

[1,1]

[1,1]

[1,1]

<1,1>

<1,1>

<1,1>

<1,1>

<2,1>

<1,8>

<0,1>

<0,1>

<0,1>

<0,1>

<3,1>

<2,1>

<1,1>

<1,1>

<1,1>

<1,1>

<1,8>

<1,1>

<3,1>

<1,1>

«require»

«require»

«exclude»

«exclude»

«exclude»

CFM Syntax: Features

Feature Instance Cardinality
Number of instances in each sub-tree
CFM-Syntax: Groups

- **Group Instance Cardinality**: Number of feature instances of types selected from a group.
- **Group Type Cardinality**: Number of child features with active instances.
- **Local Interpretation**: Intervals restrict cardinalities for every individual clone in separate sub-tree.

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**Channels**

- **[2,2]**
- **<1,1>**
- **<1,32>**
- **<1,8>**
- **<1,10>**
- **<1,*>**

**High Throughput**

**Reliable**
CFM Syntax: Exclude Constraints

Channels

[2,2] <1,1> «exclude» Reliable

High Throughput

[1,32] <1,10> <1,8> «exclude»

[1,*] <10,20> <1,*>

Reliable

Bidirectional Edge
CFM Syntax: Exclude Constraints

- Channels
- High Throughput
- Reliable
- Target Feature Cardinality
- Source Feature Cardinality

«exclude»
CFM Syntax: Require Constraints

Channels

Movement

High Throughput

Reliable

Fast Moving

Slow Moving

[2,2] [1,1] [1,1] [1,1] [0,1] [0,1] [2,*] [1,1]

«require» «exclude»

<1,1> <1,1> <1,1> <0,1> <0,1> <2,*> <1,8>

Directed Edge
CFM Syntax: Require Constraints

- Channels
  - High Throughput
  - Reliable
  - Source Feature Cardinality
  - Target Feature Cardinality

- Movement
  - Slow Moving
  - Fast Moving
  - Source Feature Cardinality
CFM Syntax: Require Constraints

Global Interpretation
Intervals restrict number of source/target feature instances for an entire configuration

CardyGAn Components

CardyGAn Bound Analyzer

CardyGAn Gap Analyzer

CardyGAn Textual Specification

CardyGAn Configuration Generator

CardyGAn CardFM Generator
CFM: Textual Syntax

CardyGAN

End of Document
CFM: Textual Syntax

Channels

[2,2]

<1,1>  <1,*>  <1,32>  <1,8>  <10,20>  <1,*>

High Throughput

Reliable

«exclude»

1...1 Feature Channels -> @instance=1..* @type=2..2 { 1..32 Feature HighThroughput 1..9 Feature Reliable 1..1 Feature Movement -> @instance=1..1 @type=1..1 { 0..1 Feature SlowMoving 0..1 Feature FastMoving } 1..* Feature Member -> @instance=1..1 @type=1..2 { 0..1 Feature Follower 0..1 Feature Leader } 1..1 FastMoving require 2..1 Reliable 0..20 HighThroughput exclude 1..1 Reliable 3..* Feature HighThroughput exclude 1..1 Reliable 1..1 Platoon require 1..1 Leader

«exclude»
CFM: Textual Syntax

Channels

High Throughput

Reliable

«exclude»

<1,1>

<1,1*

<10,20>

<1,8>
Anomaly Detection: Bound Analysis

CardyGAn Bound Analyzer
CardyGAn Gap Analyzer
CardyGAn Textual Specification
CardyGAn Configuration Generator
CardyGAn CardFM Generator

Bound Analysis: Background

Channels

- <1,1>
- <1,*>
- [2,2]
- <1,32>
- <1,8>
- <10,20>
- «exclude»

High Throughput

Reliable

Unbounded Group Instance Cardinality
Bound Analysis: Background

- Channels
- High Throughput
- Reliable

Unbounded Group Instance Cardinality

Group Instance Cardinality = \( \sum \) Instance Cardinality Child Features

Example:

- Channels: \(<1,1>, <1,8>, <1,*, *, >\)
- High Throughput: \(<10,20>, <1,*, >\)
- Reliable: \(<1,32>, <1,*, >\)

«exclude»
Bound Analysis: Background

Channels

Unbounded Group Instance Cardinality

Lower Bound = 1+1

Dead Cardinality

High Throughput

Reliable

Bound Analyzer
Textual Specification
Gap Analyzer
CardFM Generator
Configuration Generator

«exclude»

<1,1>
<1,*>
<2,2>
<1,32>
<1,8>
<10,20>
<1,*>

19 | 29.01.2016 | Thomas Schnabel
Bound Analysis: Background

Unbounded Group Instance Cardinality

Upper Bound = 32+8

Dead Cardinalities

Channels

|2,2|

<1,1>

<1,8>

<1,32>

High Throughput

Reliable

<1,20>

<1,*>

«exclude»

1 2 40

1 32

1 8

10 20
Bound Analysis: Background

Channels
- <1,1>
- <1,32>
- <1,8>
- <2,40>

High Throughput
- <10,20>
- <1,*> «exclude»

Reliable
- [2,2]

False unbounded interval

Channels
- [2,2] <1,1>
- <1,32>
- <1,8> <1,40> <1,*> <1,32> <1,8> <2,40> | 1 | 2 | 40 | *
Bound Analysis:
CardyGAn Workflow

Translation

Textual Specification → ILP Encoding → ILP Solver

User Interface

Result
Bound Analysis: CardyGAn UI

Multiple markers at this line:
- Actual lower bound of interval is 2.
- False unbounded interval: actual upper bound of interval is 40.
Anomaly Detection: Gap Analysis

CardyGAN Bound Analyzer  CardyGAN Gap Analyzer
CardyGAN Textual Specification

CardyGAN Configuration Generator
CardyGAN CardFM Generator
Gap Analysis: Background

Channels

High Throughput

Reliable

<1,1>

<2,40>

[2,2]

<1,32>

<1,8>

<10,20>

<1,*> «exclude»

1 2 40

*
Gap Analysis: Background

Channels

Mandatory

High Throughput

Reliable

<1,1>

<1,32>

<1,8>

<10,20>

<1,*>"exclude"

1 2

40

*
Gap Analysis: Background

Channels

\[\langle 1,1 \rangle\]

\{\langle 1,9 \rangle, \langle 21,32 \rangle \}\n
\langle 1,32 \rangle

High Throughput

\langle 1,8 \rangle

Reliable

\langle 10,20 \rangle

\langle 1,\ast \rangle

«exclude»

1 2

40

*
Gap Analysis: Background

Group Instance Cardinality =

\[ \sum \text{Instance Cardinality Child Features} \]

Interval Gap
Values between 18 and 21 never feasible in any configuration
Gap Analysis: CardyGAn Workflow

Textual Specification → ILP Encoding → ILP Solver

SMT Solver ↔ SMT Encoding

Textual Specification + ILP Result

User Interface
Gap Analysis: CardyGAN Workflow

Textual Specification ➔ ILP Encoding ➔ ILP Solver

Translation

SMT Solver ➔ SMT Encoding ➔ Textual Specification + ILP Result

User Interface

Result
Gap Analysis: CardyGAn UI

```
1..1 Feature Platoon -> @instance=3..* @type=3..3 {
  Multiple markers at this line
  - Actual lower bound of interval is 2.
  - False unbounded interval: actual upper bound of interval is 2
  - Gap detected within (18,21)
  0..1 Feature SlowMoving
  0..1 Feature FastMoving
}
1..* Feature Member -> @instance=1..1 @type=1..2 {
  0..1 Feature Follower
  0..1 Feature Leader
}
1..1 FastMoving require 2..* Reliable
0..20 HighThroughput exclude 1..* Reliable
3..* Follower exclude 1..* FastMoving
1..1 Platoon require 1..1 Leader
```
CFM to Configuration

Platoon

Channels
- High Throughput
- Reliable

Movement
- Slow Moving
- Fast Moving

Member
- Follower
- Leader

Leader Reliable High Throughput Fast Moving
<1,1> <1,1> <1,1> <1,1> «require»

<3,*> «exclude»

<1,*> «exclude»

<10,20> <1,*> <2,*> <1,1> <1,*> <3,*> «require» «exclude»

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CFM to Configuration

Platoon

Channels

- Reliable1
- Reliable2
- High Throughput1
- Throughput2

Movement

- Fast Moving

Member1

- Leader

Member2

- Follower1
- Follower2
CFM to Configuration

Platoon

Multiple Instances

Channels

Reliable1

Reliable2

High Throughput1

High Throughput2

Movement

Member1

Member2

Member2

Fast Moving

Leader

Follower1

Follower2
CFM to Configuration

Platoon

Channels
- Reliable1
- Reliable2
- High Throughput1
- Throughput2

Movement
- Fast Moving
- Member1
- Member2
- Member2

Cloned Sub-Trees

Leader
- Follower1
- Follower2
Configuration: Textual Syntax

```plaintext
Platoon

Channels

Reliable2
Reliable1
High Throughput2
High Throughput1

Member

Member1

Leader

Member2

Follower1

Member3

Follower2

Reliable1

High Throughput1

Reliable2

High Throughput2
```
Configuration Validation

CardyGAN Bound Analyzer  CardyGAN Gap Analyzer
CardyGAN Textual Specification

CardyGAN Configuration Generator
CardyGAN CardFM Generator
Configuration Validation: CardyGAN Workflow (1)
Alloy Specification (1)

Alloy Meta Model
Specifies general structure of CFM with instances

abstract sig Feature {
  groupCardinality: set Interval,
  groupInstanceCardinality: set Interval,
  cardinality: some Interval,
  parent: lone Feature,
  instances: set Instance
}

CardyGAn
Textual Specification
Gap Analyzer
CardFM
Generator
Configuration
Generator
Alloy Specification (1)

Abstract sig Feature {
  groupCardinality: set Interval,
  groupInstanceCardinality: set Interval,
  cardinality: some Interval,
  parent: lone Feature,
  instances: set Instance
}

Alloy Meta Model
Specifies general structure of CFM with instances

Specified for all parts of the Feature Model
Alloy Specification (1)

**Alloy Meta Model**
Specifies general structure of CFM with instances

abstract sig Feature {
  groupCardinality: set Interval,
  groupInstanceCardinality: set Interval,
  cardinality: some Interval,
  parent: lone Feature,
  instances: set Instance
}

**Alloy Facts**
Specify general behavior of configurations

fact groupCardinalityConstraint {
  all i: Instance |
  some (i.feature~parent & FM.group) implies
  IsPossibleGroupCardinality[i.feature, #(i~instanceParent.feature & FM.group)]
}
**Alloy Meta Model**
Specifies general structure of CFM with instances

```plaintext
abstract sig Feature {
    groupCardinality: set Interval,
    groupInstanceCardinality: set Interval,
    cardinality: some Interval,
    parent: lone Feature,
    instances: set Instance
}
```

**Alloy Facts**
Specify general behavior of configurations

```plaintext
fact groupCardinalityConstraint {
    all i: Instance |
    some (i.feature ~ parent & FM.group)
    implies
    IsPossibleGroupCardinality[i.feature, #(i~instanceParent.feature & FM.group)]
}
```

Specified for all parts of the Feature Model

Multiple facts to specify all formal constraints
Alloy Specification (2)

Alloy Fact
Translate user specified CFM and CONFIGURATION into additional signatures and facts to restrict Alloy validator to its concrete generation

one sig Platoon, Channels extends Feature{}
one sig instPlatoon, instChannels extends Instance{}

fact {
  Channels.parent = Platoon
  i1x1.lowerBound = 1
  i1x1.upperBound = 1
  Channels.cardinality = i1x1
  i1xx1.lowerBound = 1
  i1xx1.upperBound = KleeneStar
  Channels.groupInstanceCardinality = i1xx1
  i1x2.lowerBound = 1
  i1x2.upperBound = 2
  Channels.groupCardinality = i1x2
  instChannels.feature = Channels
  instChannels.instanceParent = instPlatoon
...
}
Alloy Specification (2)

Alloy Fact
Translate user specified CFM and CONFIGURATION into additional signatures and facts to restrict Alloy validator to its concrete generation

one sig Platoon, Channels extends Feature{}
one sig instPlatoon, instChannels extends Instance{}

fact {
    Channels.parent = Platoon
    i1x1.lowerBound = 1
    Channels.cardinality = i1x1
    i1xx1.lowerBound = 1
    i1xx1.upperBound = KleeneStar
    Channels.groupInstanceCardinality = i1xx1
    i1x2.lowerBound = 1
    i1x2.upperBound = 2
    Channels.groupCardinality = i1x2
    instChannels.feature = Channels
    instChannels.instanceParent = instPlatoon
    ...
}
Configuration Validation: CardyGAn Workflow (2)
Configuration Validation: CardyGAN UI
Conclusion

• Complex structure of CFMs introduces new kinds of subtle anomalies

• Tool support necessary to automatically detect design flaws and to guide configuration processes

• CardyGAn delivers comprehensive assistance
  ➢ Publically available as Eclipse Plugin via update site:

  https://raw.githubusercontent.com/Echtzeitsysteme/cardygan/master/updatesite/
Future Work

• “Real world” user studies planned

• Heuristics to optimize gap analysis

• Optimize Alloy-Encoding

• Concept for mapping from problem- to solution-space
Related Work


Thank you for your attention!
Questions?

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