Context-Aware Verification of DMN

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Outline

1. DMN & Verification
2. Context
3. Context-Aware Verification
4. Implementation
5. Comparison
6. Conclusion

1 DMN & Verification

What is DMN?

Decision Model and Notation standard

- Maintained by OMG group
- Notation for decision logic
- Aim: readability, user-friendliness, executable
- Two components:
  - Decision Tables
  - Decision Requirements Diagram

Decision Table

- Table-based representation of definition
- “output” variables defined by “input” variables
- A row *fires* if input values match

BMILevel		
U	BMI	BMILevel
1	< 18.5	Underweight
2	$[18.5..25]$	Normal
3	> 25	Overweight

Hit Policy

- Defines behavior of a table
- Single hit:

U(nique): exactly one row may fire
A(ny): all fired rows should express same output
F(irst): of all fired rows, the top-most is applied

- Multiple hit not discussed further

Correctness

Single-hit decision tables should be:

1. *Complete*
2. *Sound*
3. Without *unfireable rules*

Correctness

Single-hit decision tables should be:

1. *Complete*
   - Contains applicable row for each set of inputs
2. *Sound*
3. Without *unfireable rules*

Correctness

Single-hit decision tables should be:

1. *Complete*
2. *Sound*
   - U: no overlaps
   - A: no conflicting overlap
   - F: overlap allowed
3. Without *unfireable rules*

Correctness

Single-hit decision tables should be:

1. *Complete*
2. *Sound*
3. Without *unfireable rules*
    - No redundant rules (that will never *fire*)

DMN verification capabilities

Smit et al.[1] terminology	Our terminology
Identical rules Equivalent rules Subsumed rule Indeterminism Overlapping fact value range	Soundness
Missing Rules	Completeness
—	Unfireable rule
Unnecessary fact verification	—
Specific partial reduction	—

[1] Smit et al

Verification Tools

Work	Sound-ness	Complete-ness	Unfireable rules	Context
Calvanese et al. (2016)	o	X		
Laurson et al. (2016)	o	X		
Batoulis et al. (2017)	o	X		
Calvanese et al. (2018)	o	X		
Corea et al. (2019)	X	X		
Calvanese et al. (2019)	o†	X†	X†	X
Hasic et al. (2020)	X	X		o
Our tool	X*	X	X	X

* = does not distinguish between types of soundness

† = boolean result

Verification Tools

Most tools verify a decision table *in isolation*

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- Hasic et al. (2020)
- Calvanese et al. (2019)

Verification Tools

Most tools verify a decision table *in isolation* with two exceptions:

- Hasic et al. (2020)
  - Does each output value appear as input in next table(s)?
  - Does each input value appear as output in previous table(s)?
  - Limited verification!
- Calvanese et al. (2019)

Verification Tools

Most tools verify a decision table *in isolation* with two exceptions:

- Hasic et al. (2020)
- Calvanese et al. (2019)
  - Presents *semantic DMN*, incorporating background knowledge
  - Extended verification with context
  - But: limited to boolean output

2 Context

What is context?

Context

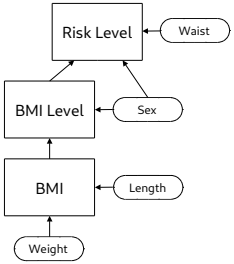
Information *not* contained in the table

Two types:

1. In-model context
2. Background knowledge

In-model context

Information contained in “the rest of the model”
$\rightarrow$ i.e., in all other tables



In-model context

Risk Level				
U	BMILevel	Sex	Waist	Risk Level
1	Normal	–	–	Low
2	Underweight	–	–	High
3	Overweight	Male	≤ 102	Increased
4	Overweight	Male	> 102	High
5	Overweight	Female	≤ 88	Increased
6	Overweight	Female	> 88	High
7	Obese	Male	≤ 102	High
8	Obese	Male	> 102	Very High
9	Obese	Female	≤ 88	High
10	Obese	Female	> 88	Very High

Risk level is complete, sound and free of unfireable rules

In-model context

BMI Level

U	BMI	Sex	BMILevel
1	< 18.5	Female	Underweight
2	< 25	Male	Underweight
3	$[18.5..25]$	Female	Normal
4	$(25..30]$	Male	Normal
5	$(25..30]$	Female	Overweight
6	> 30	–	Obese

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In-model context

BMI Level

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Risk level is complete, sound and free of unfireable rules
$\rightarrow$ The combination “Male, Overweight” can never happen!

Background Knowledge

Information about the domain, which is not explicitly present

- Knowledge not needed to make decision
- But might be useful when verifying

Background Knowledge

Sequence ID				
U	Station Type	Location	Status	ID
1	—	origin	departure	s1a
2	minor	intermediate	departure	s1b
3	major	intermediate	departure	s1c
4	airport	intermediate	departure	s1d
5	—	—	in between	s2
6	—	intermediate	arrival	s3a
7	minor	terminating	arrival	s3b
8	major	terminating	arrival	s3b
9	airport	terminating	arrival	s3c

- If *Location = terminating*, status is never “departure”
- If *Location = origin*, status is never “arrival”

Background Knowledge

Impossible input combinations are left out

→ Modeller knows these cannot happen

→ But verification tools would suggest adding them for completeness

Sequence ID: missing rules?				
U	Station Type	Location	Status	ID
1	–	terminating	departure	?
2	–	origin	arrival	?

3 Context-Aware Verification

Completeness

Completeness

A table is complete if it contains an applicable rule for each legal configuration of input values.
Or: there is no combination of inputs for which no rule fires

Completeness

Completeness with context

A table is complete if it contains a rule for each set of variables that satisfies all other tables and the background knowledge.

We have background knowledge that
$Location = terminating \Rightarrow Status \neq Departure$
$\rightarrow$ table should not contain a rule for this

Soundness

Soundness

Decision table with U hit policy is sound when rules are mutually exclusive.

Soundness

Soundness with context

Decision table with U hit policy is sound when rules are mutually exclusive, which does not change with context.

Unfireable rules

Unfireable rules

For each row, there should be a set of input values which triggers it.

Unfireable rules

Unfireable rules with context

For each row, there should be a set of input values (which satisifies all other tables, and the background knowledge) which triggers it.

In the example, the input combination *Sex = Male* and *BMILevel = Overweight* does not satisfy the other tables.

4 Implementation

Implementation

Implementation of context-aware verification

- → To show proof of concept
- → Implemented using IDP system

IDP SYSTEM

State-of-the-art logical solver

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Knowledge Base Paradigm

Store knowledge separately from its use in a Knowledge Base (KB), after which multiple inference tasks are available to solve problems.

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Knowledge Base Paradigm

Store knowledge separately from its use in a Knowledge Base (KB), after which multiple inference tasks are available to solve problems.

Knowledge is represented in extended First Order Logic

DMN in IDP

BMILevel		
U	BMI	BMILevel
1	< 18.5	Underweight
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$$
\begin{aligned}
&(BMI < 18.5 &&\Rightarrow BMILevel = Underweight)\\
\wedge&(18.5 \leq BMI \leq 25 &&\Rightarrow BMILevel = Normal)\\
\wedge&(BMI > 25 &&\Rightarrow BMILevel = Overweight)
\end{aligned}
$$

IDP INFERENCES

- progagation: given partial interpretation, compute the consequences
- model expand: given partial interpretation, generate full interpretation that satisfies KB
- abstract model generation: search for set of constraints that imply the theory

Verification in IDP

KB = verification table j + all other tables of the model + the background knowledge
$\rightarrow$ table j's representation is changed to contain $Row(r)$ as output.

$$\begin{aligned} &(BMI < 18.5 && \Rightarrow Row(1)) \\ \wedge&(18.5 \leq BMI \leq 25 && \Rightarrow Row(2)) \\ \wedge&(BMI > 25 && \Rightarrow Row(3)) \end{aligned}$$

Completeness in IDP

"Find set of *legal* assignments for which no row fires"

- $\rightarrow$ add $\forall r : \neg Row(r).$ to KB
- $\rightarrow$ table is only complete if no solution can be found
- $\rightarrow$ model expansion tells us *if* table is complete
- $\rightarrow$ AMG can list the missing rules

Soundness in IDP

"Find set of *legal* assignments for which more than 1 row fires "

- → add $\#\{r : Row(r)\} > 1.$ to KB
- → I.e. "The number of rows which fire should be higher than 1"
- → Table is sound if no solution can be found
- → Model expansion points out overlap

Unfireable rules

"Find $Row(i)$ that will always be false, i.e., that can never be true"

- $\rightarrow$ IDP's propagation can derive this!
- $\rightarrow$ No additions to our KB are needed

DMN-IDP

DMN-IDP:

- DMN modeller combined with IDP-based interface
- Translated DMN into IDP KB automatically

Extended with the verification capabilities

Available at https://dmn-idp.herokuapp.com

5 Comparison

Calvanese et al.

- Completeness verification is not only boolean
  - → AMG can show us the missing rules
- Overlapping rules can be pinpointed
- Unfireable rules can be pinpointed

Hasic et al.

- They do not detect unfireable rules in first example
- Does not find table in second example complete

Hasic et al.

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	BMI (Risk Level)	Train sequence
Hasic et al.	118s	97s
Our tool	1245s	287s

6 Conclusion

Conclusion

- Most SotA solvers verify tables “in isolation”
- However, context is important!
  - The other tables of the model
  - Background knowledge
- We have extended formal correctness criteria
- And implemented in concrete tool
- This tool offers more functionality in comparison with others

Thank you!

Questions?

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