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cDMN: Combining DMN

with Constraint Reasoning

DecisionCAMP2020

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Simon Vandevelde, Bram Aerts, Joost Vennekens KU Leuven - EAVISE 30 June 2020



OUTLINE

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1. DMN

2. Constraint DMN

3. cDMN application: Doctor Planning

4. Comparison to other solutions

5. A user friendly pipeline from cDMN to interface



DMN



What DMN does well:

- Very readable
- Very intuitive
- Easy to formalize decision making



However: not well-suited for complex decision making:

- FEEL: can express a lot, but becomes unreadable
- No constraints
- No optimization
- \rightarrow we propose additions to overcome these limitations.

Constraint DMN

WHAT IS CDMN?

cDMN: constraint DMN

- Extends DMN with constraint reasoning
- Quantification, types, functions, relations, optimization, ...
- Model complex decisions
- Introduces new tables
 - Glossary
 - Constraint tables
 - Data tables
 - Execute tables

Changes in representation:

- DMN: constants
- cDMN: types, functions, relations, constants, booleans \rightarrow defined by glossary

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Туре		
Name	Туре	Values
Person	string	Agatha, Butler, Charles
Number	int	[0100]

Changes in representation:

- DMN: constants
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Туре			
Name	Туре	Values	
Person	string	Agatha, Butler, Charles	
Number	int	[0100]	

Relation		
Name		
Person hates Person		
Person is richer than Person		

Changes in representation:

- DMN: constants
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Туре		
Name	Туре	Values
Person	string	Agatha, Butler, Charles
Number	int	[0100]

Relation	1
Name	1
Person hates Person	
Person is richer than Person	



Changes in representation:

- DMN: constants
- cDMN: types, functions, relations, constants, booleans \rightarrow defined by glossary

Туре		
Name	Туре	Values
Person	string	Agatha, Butler, Charles
Number	int	[0100]

Boolean		Constant	
Name	N	ame	Туре
Suicide	Ki	iller	Person

Relation		
Name		
Person hates Person		
Person is richer than Person		

Changes in representation:

- DMN: constants
- cDMN: types, functions, relations, constants, booleans \rightarrow defined by glossary

		Гуре	
Name	Туре	Values	Name
Person	string	Agatha, Butler, Charles	Person
Number	int	[0100]	Person

Boolean	Con	Constant	
Name	Name	Туре	
Suicide	Killer	Person	

Relation	
Name	
Person	hates Person
Person	is richer than Person

Function		
Name	Туре	
Age of Person	Number	
Hatees of Person	Number	

CONSTRAINT TABLES

Constraint tables differ in two ways from decision tables:

- 1 Outputs can contain S-FEEL.
- 2 Rows express logical implications:
 - $\rightarrow~$ IF input satisfied, THEN output has to be satisfied
 - \rightarrow Nothing said about output when no input applicable (no Null)

E* hit policy

CONSTRAINT TABLES

Constraint tables differ in two ways from decision tables:

- 1 Outputs can contain S-FEEL.
- 2 Rows express logical implications:
 - $\rightarrow~$ IF input satisfied, THEN output has to be satisfied
 - \rightarrow Nothing said about output when no input applicable (no Null)

E* hit policy

Nutritional values				
E*	RequireHealthy	Total Sodium	Total Fat	Total Calories
1	Yes	<3000	<150	<3000

 $Require Healthy \Rightarrow TotalSodium < 3000 \land TotalFat < 150 \land TotalCalories < 3000$

Constraint DMN

QUANTIFICATION

cDMN also allows universal quantification:

- Logic for all values of a type
- Type as column header
- Subsequent uses refer to the quantified variable.

CONSTRAINTS AND QUANTIFICATION: EXAMPLE

the test, isoring for

ten also always was table, watched hi twendered what hi twendered what hi twent the fact that when the fact that the pro- English the excitament of surrey but 1 through in failed to reliab his

Example:

Noo	ne hates all	
E*	Person	Hatees of Person
1	-	< 3

 $\forall Person[Person]: Hatees(Person) < 3$

Constraint DMN

CONSTRAINTS AND QUANTIFICATION: EXAMPLE

the next second pro-

in other adverger waaablier, waarchoof hier woondervel what he recondervel what he recondervel what he ment he for the fact that has green. English the mentionent of the the mentionent of the mention of the mentionent of the the mentionent of the mention of the mentionent of the mentionent of the mention of the mentionent of the mentionent of the mention of the mentionent of the mention of the mention of the mentionent of the mentionent of the mention of the mentionent of the mention of the mentionent of the mentionent of the mentionent of the mention of the mentionent of the mentionent of the mentionent of the mention of the mentionent of the mentionent of the mentionent of the mention of the mentionent of the mentionent of the mentionent of the mention of the mentionent of the menionent of the mentionent of the mentionent of the menionent

Example:

Noo	ne hates all	
E*	Person	Hatees of Person
1	-	< 3

 $\forall Person[Person]: Hatees(Person) < 3$

Boro	lering countries can no	t share colors		
E*	Country called c1	Country called c2	c1 and c2 are Bordering	Color of c1
1	-	-	Yes	Not(Color of c2)

 $\forall c1[Country], c2[Country]: Bordering(c1, c2) \Rightarrow Color(c1) \neq Color(c2)$

Typically, problems can be split up in two parts:

- 1 general logic of the problem
- 2 specific problem instance to solve

Typically, problems can be split up in two parts:

- 1 general logic of the problem
- 2 specific problem instance to solve

Map coloring problem:

- 1 Two bordering countries cannot share a color.
- 2 The specific map to color (e.g. Western Europe).

Logic: decision and constraint tables **Problem instance**: data tables



Logic: decision and constraint tables **Problem instance**: data tables

- No hit policy, but "Data Table" in name
- Only basic values
- Quantification possible

Logic: decision and constraint tables **Problem instance**: data tables

- No hit policy, but "Data Table" in name
- Only basic values
- Quantification possible

Dat	ta Table: Declaring which		
	Country called c1	Country called c2	c1 and c2 are Bordering
1	Belgium	France, Luxembourg, Netherlands, Germany	Yes
2	Germany	France, Denmark, Luxembourg, Belgium, Netherlands	Yes
			Yes

- DMN always has a single solution for a set of inputs
- not the case in cDMN \rightarrow cDMN defines solution space
- Execute table specifies solutions

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Execute		
Get 1 model		

Execute	
Get all models	_



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- not the case in cDMN \rightarrow cDMN defines solution space
- Execute table specifies solutions

Execute			
Get 1 model			

Execute	
Get all models	





CDMN

DOCTOR

PLANNING

APPLICATION:



CHALLENGE SPECIFICATION

Doctor Planning

- Doctor present at all times in a hospital
- Planning made per week
- Days consist of three shifts (early, late, night)
- Five doctors in total
- Each doctor has different availabilities

CHALLENGE SPECIFICATION: RULES

Rules

- 1 A doctor can only work one shift per day.
- 2 A doctor should always be available for his shift (see table below).
- 3 If a doctor has the night shift, they either get the next day off, or the night shift again.
- 4 A doctor either works both days of the weekend, or none of the days.

CHALLENGE SPECIFICATION: AVAILABILITIES

Availabilities

Name	Available
Fleming	Friday, Saturday, Sunday
Freud	Every day early or late, never night
Heimlich	Every day but never the night shift on weekends
Eustachi	Every day, every shift
Golgi	Every day, every shift but at max 2 night shifts

A planning should be made in which every requirement is fullfilled.

bem alter adverges was, fable, watchied his fwondered what he years and adverges what his grave English the grave English is the restances of energy (soil) through a fabled to resist to

Rule 1 A doctor can only work one shift per day.

		Туре		
Name	Туре	Values	Function	
Doctor	string	Fleming, Freud, Heimlich, Eustachi, Golgi	Name	Туре
Day	string	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday	Nb Shifts of Doctor and Day	Nb Shift
Nb Shift	int	[021]		



Rule 1 A doctor can only work one shift per day.

Rule 1			
E*	Doctor	Day	Nb Shifts of Doctor and Day
1	-	-	≤ 1

cDMN application: Doctor Planning

hem also adverges was table, watched his twondered what he lowe and admiration reveals the fact that the grave English with the grave English or the excitement of

Rule 2 A doctor should be available for his shift.

Туре				
Name	Туре	Values		
Doctor	string	Fleming, Freud, Heimlich, Eustachi, Golgi		
Day	string	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday		
Nb Shift	int	[021]		
Shift_Type	string	Early, Late, Night		

Function	Relation		
Name	Туре	Name	
Nb Shifts of Doctor and Day	Nb Shift	Available Doctor for Shift_Type and Day	
Assigned Doctor of Day and Shift_Type	Doctor	Available Doctor for Shift_Type and Day	



Rule 2 A doctor should be available for his shift.

Rule	e 2				
E*	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Available Doctor for Shift_Type and Day
1	-	-	-	Doctor	Yes

Rule 3

If a doctor has the night shift, they either get the next day off, or the night shift again.

Туре				
Name	Туре	Values		
Doctor	string	Fleming, Freud, Heimlich, Eustachi, Golgi		
Day	string	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday		
Nb Shift	int	[021]		
Shift_Type	string	Early, Late, Night		

Function		
Name	Туре	Relation
Nb Shifts of Doctor and Day	Nb Shift	Name
Assigned Doctor of Day and Shift_Type	Doctor	Available Doctor for Shift_Type and Day
Next_Day of Day	Day	

Rule 3

If a doctor has the night shift, they either get the next day off, or the night shift again.

Rule 3							
E*	Doctor	Day called d1	Shift_Type called s1	Doctor of d1 and s1	Day called d2	Shift_Type called s2	Doctor of d2 and s2
1	-	-	Night	Doctor	Next_Day of d1	Early, Late	not(Doctor)

Rule 4

A doctor either works both days of the weekend, or none of the days.

	Туре					
Name	Туре	Values				
Doctor	string	Fleming, Freud, Heimlich, Eustachi, Golgi				
Day	string	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday				
Nb Shift	int	[021]				
Shift_Type	string	Early, Late, Night				

Function		
Name	Туре	Relation
Nb Shifts of Doctor and Day	Nb Shift	Name
Assigned Doctor of Day and Shift_Type	Doctor	Available Doctor for Shift_Type and Day
Next_Day of Day	Day	

Rule 4

A doctor either works both days of the weekend, or none of the days.

Rule	4				
E*	Doctor	Day called d1	Nb Shifts of Doctor and d1	Day called d2	Nb Shifts of Doctor and d2
1	-	Saturday	1	Sunday	1
2	-	Sunday	1	Saturday	1

hem also adways was, table, watched his I wondered what he invested administration rement the fact that th his grain English the sectoment of rearry has I thought

Special Preference

Golgi works at maximum two nights.

	Туре					
Name	Туре	Values				
Doctor	string	Fleming, Freud, Heimlich, Eustachi, Golgi				
Day	string	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday				
Nb Shift	int	[021]				
Shift_Type	string	Early, Late, Night				

Function		
Name	Туре	Relation
Nb Shifts of Doctor and Day	Nb Shift	Name
Assigned Doctor of Day and Shift_Type	Doctor	Available Doctor for Shift_Type and Day
Next_Day of Day	Day	Available Doctor for Shint_Type and Day
Nb Nights of Doctor	Nb Shift	

hem also always was, table, watched his I wondered what he years and advected the resent the fact that the her grass. Kaptain or the excitances of resurg (but) through the fact to be a set of the resurg (but) through

Special Preference

Golgi works at maximum two nights.

Max	Nights	
E^*	Doctor	Nb Nights of Doctor
1	Golgi	≤ 2

DOCTOR PLANNING: AVAILABILITIES

Dat	a Table: Avai	labilities		
	Doctor	Shift_Type	Day_Type	Available Doctor for Shift_Type and Day
1	Fleming	Early	Friday	Yes
2	Fleming	Late	Friday	Yes
3	Fleming	Night	Friday	Yes
4	Fleming	Early	Saturday	Yes

DOCTOR PLANNING: OTHER TABLES

Nex	t Day]
U	Day	Next_Day of Day
1	Sunday	Monday
2	Monday	Tuesday
3	Tuesday	Wednesday
4	Wednesday	Thursday
5	Thursday	Friday
6	Friday	Saturday
7	Saturday	Sunday

DOCTOR PLANNING: OTHER TABLES

Nex	t Day]
U	Day	Next_Day of Day
1	Sunday	Monday
2	Monday	Tuesday
3	Tuesday	Wednesday
4	Wednesday	Thursday
5	Thursday	Friday
6	Friday	Saturday
7	Saturday	Sunday

Cour	nt shifts per c				
C+	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Nb Shifts of Doctor and Day
1	-	-	-	Doctor	1

DOCTOR PLANNING: OTHER TABLES

Nex	t Day]
U	Day	Next_Day of Day
1	Sunday	Monday
2	Monday	Tuesday
3	Tuesday	Wednesday
4	Wednesday	Thursday
5	Thursday	Friday
6	Friday	Saturday
7	Saturday	Sunday

Cour	nt shifts per c	lay			
C+	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Nb Shifts of Doctor and Day
1	-	-	-	Doctor	1

Coι	ınt night shift	s for ever	y doctor		
C+	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Nb Nights of Doctor
1	-	-	Night	Doctor	1

cDMN application: Doctor Planning

DOCTOR PLANNING: FULL

them she always was in table, watched his 1. I wondered with the three and admiration is researt the fact that with his grin English for the excitoment of the many, but I through an failed to reliab his

Def	ine Next Day	
U	Day	Next_Day of Day
	I Monday	Tuesday
	2 Tuesday	Wednesday
	3 Wednesday	Thursday
	4 Thursday	Friday
-	5 Friday	Saturday
1	5 Saturday	Sunday
	7 Sunday	Monday

Name Doctor Shift_Type Day Nb Shift

	Type
DataType	Possible Values
string	Fleming, Freud, Heimlich, Eustachi, Golgi
string	Early, Late, Night
	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
int	[021]

Function	
Name	DataType
Assigned Doctor of Day and Shift_Type	Doctor
Day of Shift	Day
Nb Shifts of Doctor and Day	Nb Shift
Nb Nights of Doctor	Nb Shift
Next_Day of Day	Day

		Rel	ation			
Name						
Available	Doctor	for	Shift,	Type	and	Day

1		nt shifts per d	ay			
- 1	C+	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Nb Shifts of Doctor and Day
- 1	1		-	-	Doctor	1

1.	A doctor can c	only work one shift per o	9	2	A doctor shoul	d always be available fo	er his shift		1
E'	Doctor	Day	Nb Shifts of Doctor and Day	ar	A doctor shour	a arways be available re	a ma suite		Available Doctor for
	1-	-	<= 1	E*	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Shift_Type and Day
					1-			Doctor	Yes

3. I	f a doctor has	the night shift, they eith	her get the next day off, or the ni	ght shift again.			1
E ^a	Doctor	Day called d1	Shift_Type called s1	Assigned Doctor of d1 and s1	Day called d2	Shift_Type called s2	Assigned Doctor of d2 and s2
	1-		Night	Doctor	Next_Day of d1	not(Night)	not(Doctor)

8	. A	doctor either v	works both days of the w	eekend, or none of the days.				Max	N
Ĩ	<u>18</u>	Doctor	Day called d1	Nb Shifts of Doctor and d1	Day called d2	Nb Shifts of Doctor and d2			D
- E	1		Saturday	1	Sunday	1			G
- E	2	-	Sunday	1	Saturday	1	1	-4	<u>u</u>

1	Cou	nt the number	of night shifts for each do	xtor		
	C+	Doctor	Day	Shift_Type	Assigned Doctor of Day and Shift_Type	Nb Nights of Doctor
	1	-	-	Night	Doctor	1

	Nb of Nights	
E*	Doctor	Nb Nights of Doctor
1	Golgi	<= 2

Data	Table: availa	ble doctors]
	Doctor	Shift_Type	Day	Available Doctor for Shift_Type and Day
1	Fleming	Early	Friday	Yes
2	Fleming	Late	Friday	Yes
	Fleming	Night	Friday	Yes
4	Fleming	Early	Saturday	Yes
5				

cDMN application: Doctor Planning

TO OTHER

SOLUTIONS

On 10th of June, these were the solutions:

- OPL (Alex Fleisher)
- PostgreSQL (Damir Sudarevic)
- ZIMPL (Rob Parker)
- Prolog (Matteo Redaelli)
- OpenRules, JavaSolver, AWS Lambda (Jacob Feldman) None are DMN-like implementations.

OPL:

```
// night shift ==> next day off or next night shift
forall(d in doctors,i in days:(i+1) in days)
{
    (x[d][i]["night"]==1) => (x[d][i+1]["early"]==0);
    (x[d][i]["night"]==1) => (x[d][i+1]["late"]==0);
}
```

ZIMPL:

If a doctor works night shift, they cannot work early or late the next day...

subto Night_Shift_Continuity1:

forall in PROFESSIONALS :

forall <d> in DAYS with d < 7:

vif (ASSIGNED[d,"Night",p] >= 1) then

ASSIGNED[d+1,"Early",p] <=0

end;

subto Night_Shift_Continuity2:

Comparison to other solutions

OpenRules, JavaSolver, AWS Lambda:

```
// If a doctor has the night shift,
// they either get next day off or the the night shift again
if (day > 0) {
    if (shift < nightShift && !Doctor.FROZEN.equals(status)) {
        Var previousNightShift = vars[doc][day - 1][nightShift];
        Constraint constraint1 = csp.linear(previousNightShift; "=", 1);
        Constraint constraint2 = csp.linear(var, "=", 0);
        csp.postIfThen(constraint1, constraint2);
    }
}
```

OpenRules, JavaSolver, AWS Lambda:



LIVE WORKER SCHEDULER

Jacob Feldman created a full-blown planning application

- The GUI is created using OpenRules Dialog
- The scheduling is implemented in JavaSolver
- + The GUI is very intuitive and the system works well
- The solver is written in Java, only accessible to software developers

PIPELINE FROM

CDMN TO

INTERFACE

A USER FRIENDLY

AUTOCONFIG INTERFACE

Using the cDMN solver, a cDMN specification can be fed to the Autoconfig interface

- Users can interact with the cDMN specifications
- Users can set values, and see the results
- The system doesn't distinguish between inputs or outputs
- The system can find optimal solutions

AUTOCONFIG INTERFACE DEMO

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 Pleming Freud K Heimlich K Eustachi Goigi 		 × ×<	Ĩ				
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? Reming V X Freud V X Heimlich V X Eustachi		 × ×<					fesion: vil.1-36 globat5 dirty.

A user friendly pipeline from cDMN to interface

Thank you for your attention.



ANY QUESTIONS?

For further questions or discussion: s.vandevelde@kuleuven.be

For more information on cDMN and the cDMN solver: www.cdmn.be

For more information on the interface: https://gitlab.com/krr/autoconfigz3

A user friendly pipeline from cDMN to interface