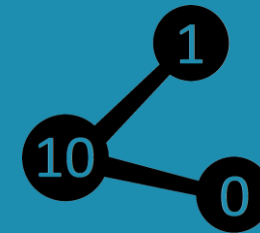


# Deontic DMN: Representing deontic statement in DMN with bitstring semantics



# Overview

- What is DMN?
- What are deontic terms (e.g. obligation, permission)?
- Lack of deontic specific representation in DMN
- Philosophical interpretation (with bitstring semantics)
- Alternative interpretation – Verification with Human Experiment
- Creating deontic DMN judgement templates
- Combine multiple judgements

# What is DMN?

- Decision Model & Notation
  - Specification of business decisions and business rules
  - Easily readable by people in decision management
- Extensions
  - cDMN – constraint reasoning
  - pDMN – probabilistic reasoning
  - **dDMN – deontic reasoning**
  - NULL value in DMN

Light switch example		
A	In the room	Light
1	Yes	On
2	No	Off

# What are deontic terms?

- e.g. 'obligatory', 'forbidden', 'permitted'



**No unauthorised  
entry**



**Permit to work  
must be obtained**

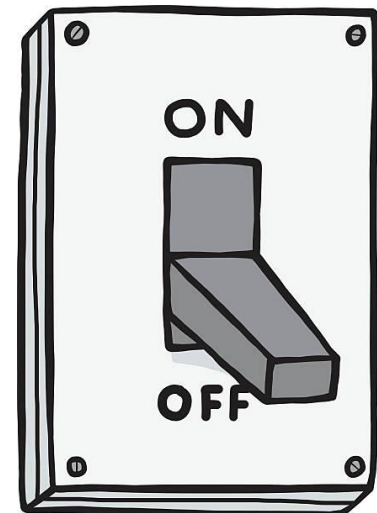


# Light switch example

- When you are in the room, the light must be on. (Safety rule)
- When you are not in the room, the light must be off. (Eco-friendly rule)



Light switch example		
A	In the room	Light
1	Yes	On
2	No	Off



# Safety rule

## Light switch example

- Original phrasing
  - When you are in the room, the light must be on.

Original phrasing		
A	In the room	Light
1	Yes	On
2	No	?

- Alternative phrasing
  - When you are not in the room, the light can be off. (On is default)

Alternative phrasing		
A	In the room	Light
1	Yes	On?
2	No	Off

# Safety rule

## Light switch example

Safety rule		
A	<b>In the room</b>	<b>Judgement(Light)</b>
1	Yes	The light has to be on
2	No	The light can be off

- Original phrasing
  - When you are in the room, the light must be on.

Original phrasing			
A	<b>In the room</b>	<b>Light</b>	<b>Does the light have to be on?</b>
1	Yes	On	Yes
2	No	?	No

- Alternative phrasing
  - When you are not in the room, the light can be off. (On is default)

Alternative phrasing			
A	<b>In the room</b>	<b>Light</b>	<b>Can the light be off?</b>
1	Yes	On?	No
2	No	Off	Yes

# Eco-friendly rule

## Light switch example

Eco-friendly rule		
A	<b>In the room</b>	<b>Judgement(Light)</b>
1	Yes	The light can be on
2	No	The light has to be off

- Original phrasing
  - When you are not in the room, the light must be off.

Original phrasing			
A	<b>In the room</b>	<b>Light</b>	<b>Does the light have to be off?</b>
1	Yes	?	No
2	No	Off	Yes

- Alternative phrasing
  - When you are in the room, the light can be on. (Off is default)

Alternative phrasing			
A	<b>In the room</b>	<b>Light</b>	<b>Can the light be on?</b>
1	Yes	On	Yes
2	No	Off?	No



# Both rules

## Light switch example

- When you are in the room, the light must be on. (Safety rule)
- When you are not in the room, the light must be off. (Eco-friendly rule)

Safety rule		
A	In the room	Judgement(Light)
1	Yes	The light has to be on
2	No	The light can be off

Both rules		
A	In the room	Judgement(Light)
1	Yes	The light has to be on
2	No	The light has to be off

Eco-friendly rule		
A	In the room	Judgement(Light)
1	Yes	The light can be on
2	No	The light has to be off

Light switch example		
A	In the room	Light
1	Yes	On
2	No	Off

# Definition vs Judgement

- When you are in the room, the light must be on. (Safety rule)
- When you are not in the room, the light must be off. (Eco-friendly rule)
- The light is on when the brightness level is above zero (Light on definition)

Light on definition		
A	Brightness	Light
1	>0	On
2	=0	Off

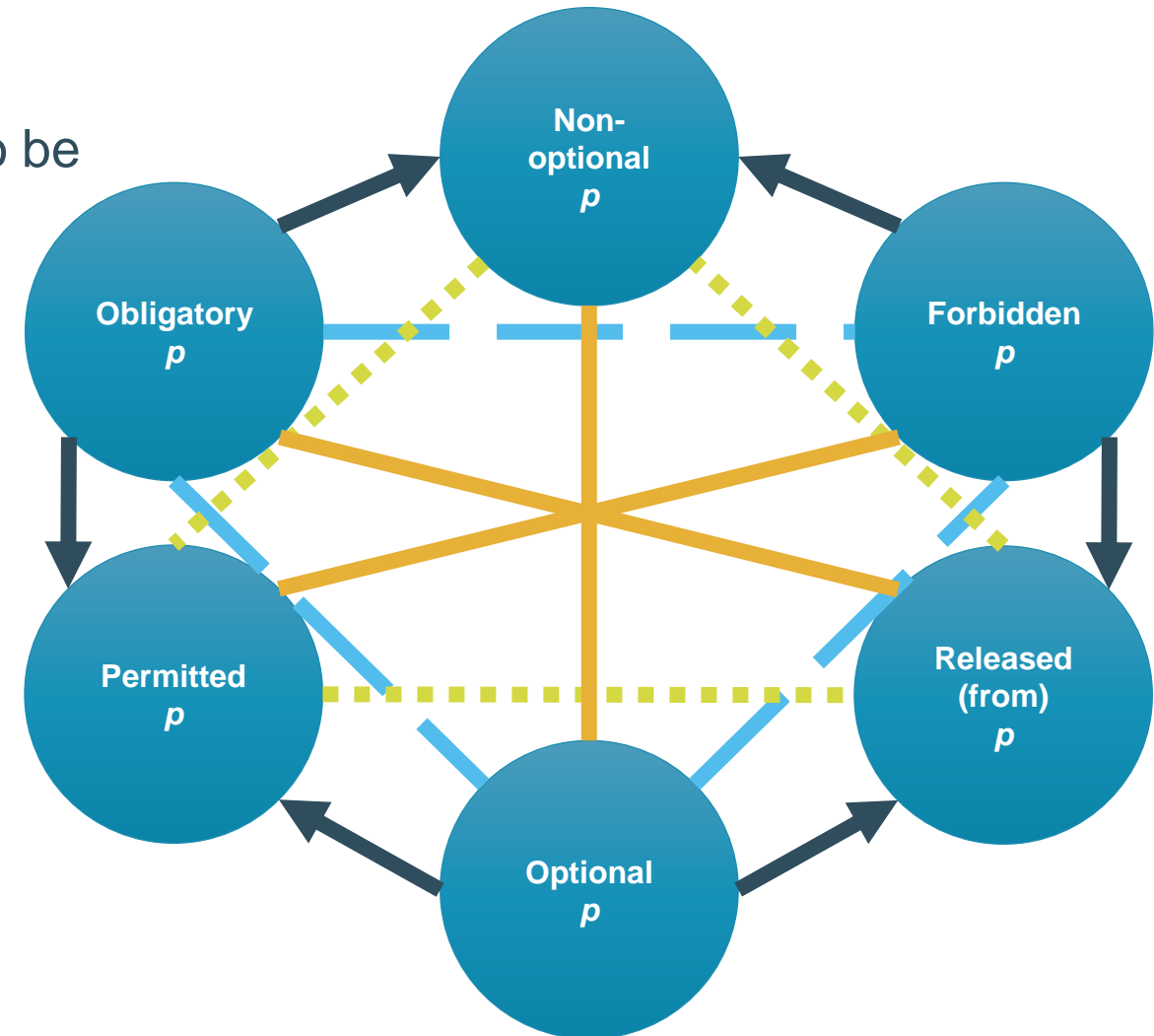
Both rules		
A	In the room	Judgement(Light)
1	Yes	The light has to be on
2	No	The light has to be off

Light switch example		
A	In the room	Light
1	Yes	On
2	No	Off

# Deontic terms relationship – Deontic hexagon

**Aristotelian relations:** two propositions are said to be

- ❑ **contradictory (CD):**  
iff they cannot be true together  
and they cannot be false together
- ❑ **contrary (C):**  
iff they cannot be true together  
but they can be false together
- ❑ **subcontrary (SC):**  
iff they can be true together  
but they cannot be false together
- ❑ **in subalternation (SA):**  
iff the first proposition entails the second  
but the second does not entail the first



# Deontic Judgement & Bitstring semantics

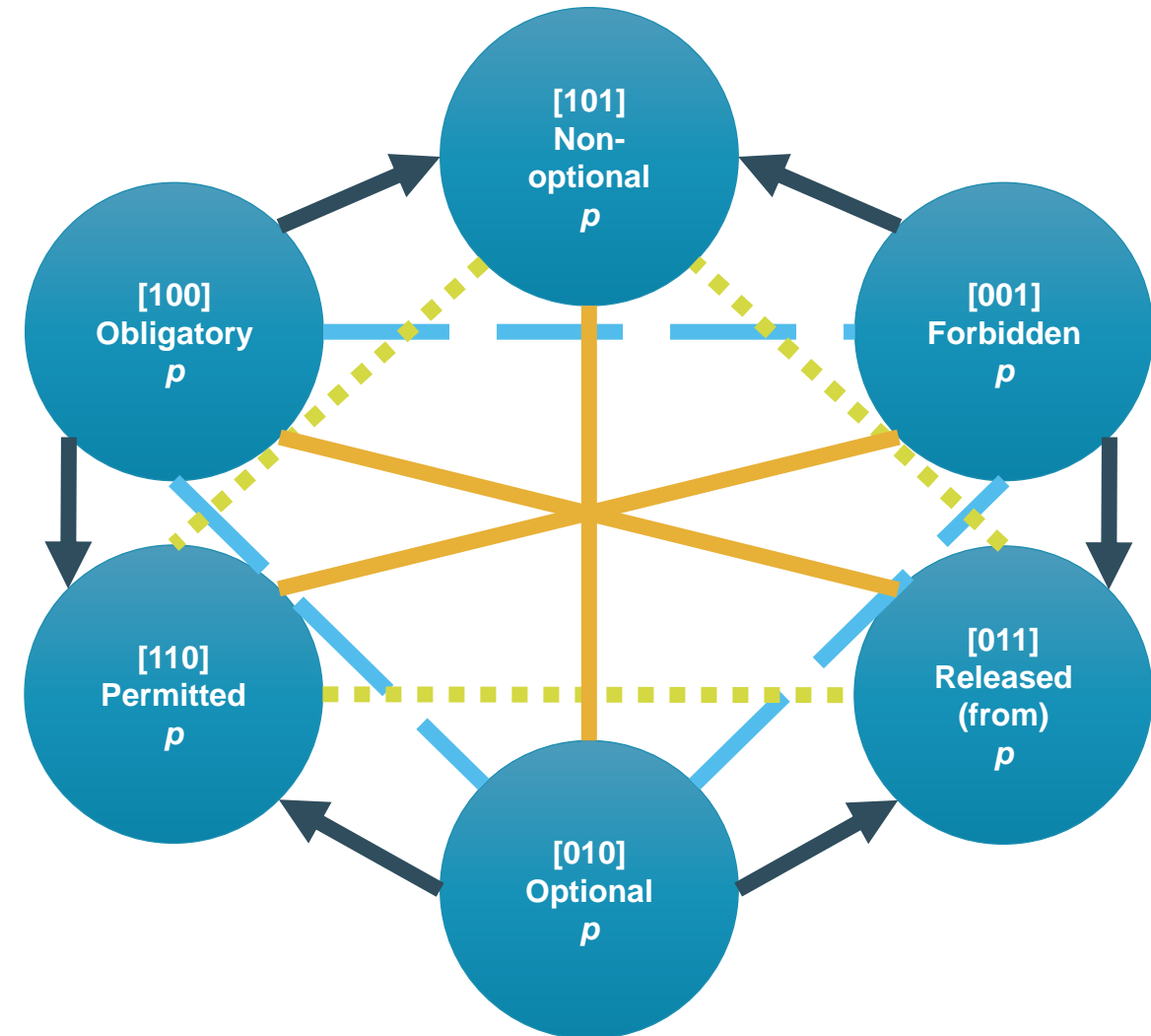
**Bitstring semantics:** a sequences of bits (0/1),

- each bit provides an answer to a meaningful (binary) question, e.g.
  - Can the deontic statement be fulfilled by  $p$ ?
  - Can the deontic statement be neutral to  $p$ ?
  - Can the deontic statement be violated by  $p$ ?
- each question concerns a component of a scalar structure, e.g.

Fulfilled | Neutral | Violated

□ bitstring example:

- $\beta(\text{Obligatory } p) = 100 = \langle \text{yes, no, no} \rangle$
- $\beta(\text{Permitted } p) = 110 = \langle \text{yes, yes, no} \rangle$
- $\beta(\text{Forbidden } p) = 001 = \langle \text{no, no, yes} \rangle$



# Bitstring interpretation of deontic hexagon

- Deontic terms can be represented in terms of obligatory and permitted

	Obligatory $p$	Permitted $p$	Optional $p$	Released (from) $p$	Forbidden $p$	Non-optional $p$
Obligatory $p$	Obligatory $p$	Permitted $p$	Permitted $p$ AND NOT Obligatory $p$	NOT Obligatory $p$	NOT Permitted $p$	Obligatory $p$ OR NOT Permitted $p$

	Obligatory $p$	Permitted $p$	Optional $p$	Released (from) $p$	Forbidden $p$	Non-optional $p$
When $p$ is true ( $p$ )	[100] Fulfilled	[110] Not violated	[010] Neutral	[011] Not fulfilled	[001] Violated	[101] Not neutral

# Philosophical interpretation

- Additional assumption Permitted  $p$  = NOT Obligatory NOT  $p$ ,
  - e.g. Permitted to turn on the light = Not obligatory to turn off the light
  - deontic terms can be represented in terms of obligatory alone

	Obligatory $p$	Permitted $p$	Optional $p$	Released (from) $p$	Forbidden $p$	Non-optional $p$
	Obligatory $p$	Permitted $p$	Permitted $p$ AND NOT Obligatory $p$	NOT Obligatory $p$	NOT Permitted $p$	Obligatory $p$ OR NOT Permitted $p$
	Obligatory $p$	NOT Obligatory NOT $p$	NOT Obligatory NOT $p$ AND NOT Obligatory $p$	NOT Obligatory $p$	Obligatory NOT $p$	Obligatory $p$ OR Obligatory NOT $p$

	Obligatory $p$	Permitted $p$	Optional $p$	Released (from) $p$	Forbidden $p$	Non-optional $p$
<b>When <math>p</math> is true (<math>p</math>)</b>	[100] Fulfilled	[110] Not violated	[010] Neutral	[011] Not fulfilled	[001] Violated	[101] Not neutral
<b>When <math>p</math> is false (NOT <math>p</math>)</b>	[001] Violated	[011] Not fulfilled	[010] Neutral	[110] Not violated	[100] Fulfilled	[101] Not neutral
	<b>Forbidden NOT <math>p</math></b>	<b>Released (from) NOT <math>p</math></b>	<b>Optional NOT <math>p</math></b>	<b>Permitted NOT <math>p</math></b>	<b>Obligatory NOT <math>p</math></b>	<b>Non-optional NOT <math>p</math></b>

# Deontic DMN

## Light switch example

- Obligation rule
  - The light must be on.

Obligation – light on		
	Light	Deontic Judgement
1	On	[100] Fulfilled
2	Off	[001] Violated

- Permission rule
  - The light can be off.

Permission – light off		
	Light	Deontic Judgement
1	On	[011] not(Fulfilled)
2	Off	[110] not(Violated)

# Alternative interpretation

- E.g. When  $p$  is false, “Obligatory  $p$ ” is of interpreted as
  - only [011] not fulfilled
  - rather than [001] violated
- Speculation: is the “[001] violated” interpretation a **pragmatic enrichment of meaning** in “[011] not fulfilled” interpretation, i.e. **scalar implicature**?

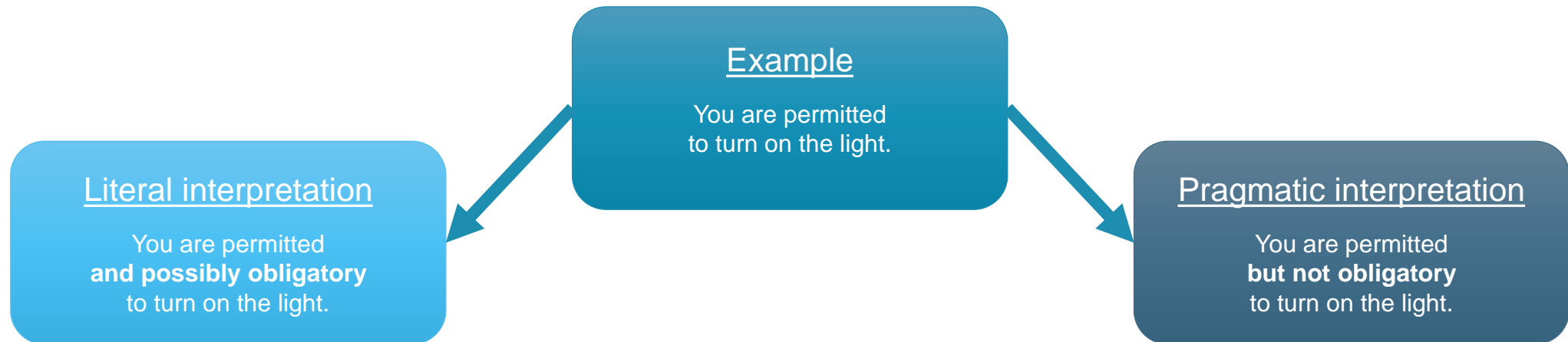
	Obligatory $p$	Permitted $p$	Optional $p$	Released (from) $p$	Forbidden $p$	Non-optional $p$
When $p$ is true ( $p$ )	[100] Fulfilled	[110] Not violated	[010] Neutral	[011] Not fulfilled	[001] Violated	[101] Not neutral
When $p$ is false (NOT $p$ )	<b>[001] Violated</b>	[011] Not fulfilled	[010] Neutral	[110] Not violated	[100] Fulfilled	[101] Not neutral
	Forbidden NOT $p$	Released (from) NOT $p$	Optional NOT $p$	Permitted NOT $p$	Obligatory NOT $p$	Non-optional NOT $p$



# Scalar implicature

## Alternative interpretation

- ❑ attributes an implicit meaning beyond the explicit or literal meaning of an utterance
- ❑ suggests that the speaker had a reason for not using a more informative term (e.g. obligatory vs permitted) on the same scale



# Judgement templates

## Deontic DMN

- Strong obligation DMN template
  - “[001] violated” interpretation

Strong obligation		
A	Action (Light)	Deontic Judgement
1	True (On)	[100] Fulfilled
2	False (Off)	<b>[001] Violated</b>

- Weak obligation DMN template
  - “[011] not fulfilled” interpretation

Weak obligation		
A	Action (Light)	Deontic Judgement
1	True (On)	[100] Fulfilled
2	False (Off)	<b>[011] not(Fulfilled)</b>

64 templates  
in total!

# Safety rule

## Deontic DMN

Safety rule		
A	<b>In the room</b>	<b>Judgement(Light)</b>
1	Yes	The light has to be on
2	No	The light can be off

- Original phrasing
  - When you are in the room, the light must be on.

Safety rule – Deontic Judgement			
	<b>In the room</b>	<b>Light (Action)</b>	<b>Deontic Judgement</b>
1	Yes	On	[100] Fulfilled
2	Yes	Off	[001] Violated
3	No	On	[011] not(Fulfilled)
4	No	Off	[110] not(Violated)

- Alternative phrasing
  - When you are not in the room, the light can be off.

# Eco-friendly rule

## Deontic DMN

Eco-friendly rule		
A	In the room	Judgement(Light)
1	Yes	The light can be on
2	No	The light has to be off

- Original phrasing
  - When you are not in the room, the light must be off.

Eco-friendly rule – Deontic Judgement			
	In the room	Light (Action)	Deontic Judgement
1	Yes	On	[110] not(Violated)
2	Yes	Off	[011] not(Fulfilled)
3	No	On	[001] Violated
4	No	Off	[100] Fulfilled

- Alternative phrasing
  - When you are in the room, the light can be on.

# Combined Judgement?

## Deontic DMN

Both rules		
A	<b>In the room</b>	<b>Judgement(Light)</b>
1	Yes	The light has to be on
2	No	The light has to be off



Both rules – Deontic Judgement					
	<b>In the room</b>	<b>Light (Action)</b>	<b>Safety rule – Deontic Judgement</b>	<b>Eco-friendly rule – Deontic Judgement</b>	<b>Combined Judgement</b>
1	Yes	On	<b>[100] Fulfilled</b>	[110] not(Violated)	?
2	Yes	Off	<b>[001] Violated</b>	[011] not(Fulfilled)	?
3	No	On	[011] not(Fulfilled)	<b>[001] Violated</b>	?
4	No	Off	[110] not(Violated)	<b>[100] Fulfilled</b>	?

# Combining Judgements

	[100]Fulfilled	[010]Neutral	[001]Violated
[100]Fulfilled	[100]Fulfilled	[100]Fulfilled	[001]Violated
[010]Neutral	[100]Fulfilled	[010]Neutral	[001]Violated
[001]Violated	[001]Violated	[001]Violated	[001]Violated

Combing multiple deontic judgements			
A	Judgement 1	Judgement 2	Combined Judgement
1	[100] Fulfilled	[100] Fulfilled	[100] Fulfilled
2	[100] Fulfilled	[010] Neutral	[100] Fulfilled
3	[100] Fulfilled	[001] Violated	[001] Violated
4	[010] Neutral	[100] Fulfilled	[100] Fulfilled
5	[010] Neutral	[010] Neutral	[010] Neutral
6	[010] Neutral	[001] Violated	[001] Violated
7	[001] Violated	[100] Fulfilled	[001] Violated
8	[001] Violated	[010] Neutral	[001] Violated
9	[001] Violated	[001] Violated	[001] Violated

# Building on constraint reasoning: cDMN

- Standard DMN: a single solution
- cDMN: a solution space
  - Allowing to set constraints in the models
- Deontic Judgement:
  - either [100] Fulfilled,
  - [010] Neutral,
  - or [001] Violated

Both rules – Deontic Judgement					
	In the room	Light (Action)	Safety rule – Deontic Judgement	Eco-friendly rule – Deontic Judgement	Combined Judgement
1	Yes	On	[100] Fulfilled	[110] not(Violated)	[100] Fulfilled
2	Yes	Off	[001] Violated	[011] not(Fulfilled)	[001] Violated
3	No	On	[011] not(Fulfilled)	[001] Violated	[001] Violated
4	No	Off	[110] not(Violated)	[100] Fulfilled	[100] Fulfilled

# Combined Judgement

## Deontic DMN



Both rules		
A	<b>In the room</b>	<b>Judgement(Light)</b>
1	Yes	The light has to be on
2	No	The light has to be off

	[100]Fulfilled	[010]Neutral	[001]Violated
[100]Fulfilled	[100]Fulfilled	[100]Fulfilled	[001]Violated
[010]Neutral	[100]Fulfilled	[010]Neutral	[001]Violated
[001]Violated	[001]Violated	[001]Violated	[001]Violated


Both rules – Deontic Judgement					
	<b>In the room</b>	<b>Light (Action)</b>	<b>Safety rule – Deontic Judgement</b>	<b>Eco-friendly rule – Deontic Judgement</b>	<b>Combined Judgement</b>
1	Yes	On	[100] Fulfilled	[110] not(Violated)	<b>[100] Fulfilled</b>
2	Yes	Off	[001] Violated	[011] not(Fulfilled)	<b>[001] Violated</b>
3	No	On	[011] not(Fulfilled)	[001] Violated	<b>[001] Violated</b>
4	No	Off	[110] not(Violated)	[100] Fulfilled	<b>[100] Fulfilled</b>



# Human judgement experiments

- [011] Released can be interpreted as:
  - either [010] Neutral
  - or [001] Violated
- E.g. Mother said “You need not eat the plum”. The girl eats the plum.
  - Most adults judge the girl’s action neutral (One star)
  - Meanwhile most children judge it negatively (Sad Face)
- Further human judgement experiments
  - Compare the philosophical interpretation vs folk interpretation
  - Find the best labelling for the deontic judgement templates


Deontic lack of necessity is interpreted as interdiction in child Romanian








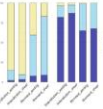
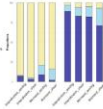
Adina Camelia Bleotu <sup>a, b\*</sup> Anton Benz <sup>a</sup> Gabriela Brozba <sup>b</sup>

<sup>a</sup>ZAS Berlin, <sup>b</sup>University of Bucharest

\*Corresponding mail: cameliobleotu@gmail.com



Keywords: first language acquisition, deontic necessity, negation, strong scope

INTRODUCTION	METHOD: TERNARY REWARD TASK	RESULTS
<p><b>Aim</b></p> <ul style="list-style-type: none"> <li>➢ How do Romanian children understand negated deontic necessity modals? Do they interpret lack of necessity as interdiction? How do they treat (un)ambiguous forms?</li> </ul> <p><b>Background</b></p> <p>Modality and negation in child Romanian</p> <ul style="list-style-type: none"> <li>➢ Children prefer strong readings of negated modals</li> <li>➢ French and Spanish children use weak negated modals much less than predicted by the input (Jeretic 2018)</li> <li>➢ Experiments by Gualmini &amp; Moscati (2009): children interpret <i>puo non</i> ('may not') as 'non puo' ('cannot').</li> <li>➢ Moscati &amp; Crain (2014) and Koring, Meroni &amp; Moscati (2018): children give a strong interpretation to negated epistemic modals in Italian and Dutch.</li> </ul> <p>Our contribution: we look at deontic (not epistemic) necessity &amp; negation in child Romanian</p> <p>Deontic necessity and negation in Romanian</p> <ul style="list-style-type: none"> <li>◆ <i>nu e nevoie sa</i> 'not is need SA': clear lack of necessity</li> <li>◆ <i>trebuie sa nu</i> 'must SA not': clear interdiction</li> <li>◆ <i>nu trebuie sa</i> 'not must SA': ambiguous between 2 prosodically marked meanings (interdiction &amp; lack of necessity) with different prosodies:</li> </ul> <p>Interdiction: F0 goes from 220 Hz to 370 Hz (no) and then to 230 Hz (<i>trebuie</i>); no has a contrastive L+H* accent</p> <p>Lack of necessity: F0 stays around 400 Hz for <i>nu</i> and the first syllable of <i>trebuie</i> and then drops to 200 Hz; no has an L accent</p> <ul style="list-style-type: none"> <li>➢ Are children sensitive to prosody (Armstrong 2014, Stoddard &amp; de Villiers 2021)?</li> <li>➢ Romanian 5-year-olds are sensitive to the different intonations of <i>nu trebuie sa</i> in contrast (forced choice task we previously conducted)</li> </ul>	<p><b>Objective</b></p> <ul style="list-style-type: none"> <li>➢ to investigate Romanian children's scope and prosodic preferences for unambiguous and ambiguous negated deontic necessity modals</li> </ul> <p><b>Predictions</b></p> <ul style="list-style-type: none"> <li>➢ Scope preferences: Children might interpret lack of necessity as interdiction.</li> <li>➢ Sensitivity to prosodic cues: Children might be less sensitive to intonation than adults.</li> </ul> <p><b>Participants</b></p> <ul style="list-style-type: none"> <li>➢ 37 Romanian adults and 25 5-year-olds (Age range: 5-5;11, Mean: 5;27, 12 Male, 13 Female)</li> </ul> <p><b>Procedure &amp; Materials</b></p> <ul style="list-style-type: none"> <li>➢ a Ternary Reward Task (Katsos &amp; Bishop 2011): The (grand)parent tells the child that he/she must not/need not do a certain action X. The child then performs action X or Y. Participants then have to reward the child</li> <li>➢ 16 sentences with an ambiguous modal (<i>nu trebuie sa</i> with a Necessary-Not or Not-Necessary intonation) and 16 with unambiguous modals (<i>trebuie sa nu</i> expressing interdiction, and <i>nu e nevoie</i> expressing lack of necessity)</li> <li>➢ The materials were recorded and analyzed in Praat, to control for intonational contours.</li> </ul> <p><b>Instructions:</b> Give the child a sad face if he/she does something forbidden, a blue star if what he/she does is so-so, but it is allowed by the parents/grandparents, and two blue stars if what he/she does is the best thing, that is, exactly what the (grand)parents asked him/her to do</p> <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Mother and daughter are looking at two fruits: a plum and a pineapple.</p> <p>Mother tells the daughter:</p> <p>"Nu trebuie sa mananci pruna" (Not-Necessary Intonation).</p> <p>not must SA eat plum-the</p> <p>"You need not eat the plum"</p> <p>The girl eats the plum. How would you reward her?</p> <div style="display: flex; align-items: center; justify-content: center; gap: 10px;">      </div> </div>	<p>Action taken: children give fewer stars for lack of necessity than adults</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>ADULTS</p>  </div> <div style="text-align: center;"> <p>CHILDREN</p>  </div> </div> <p style="text-align: center;"><b>ACCOUNT</b></p> <ul style="list-style-type: none"> <li>➢ Interdiction is the primary reading for Romanian children for all negated deontic modals</li> <li>➢ Problematic accounts:                     <ul style="list-style-type: none"> <li>◆ Negative strengthening (Homer 2010, Iatridou &amp; Zeijlstra 2013)-children obligatorily LF-move necessity above negation BUT this is costly!</li> <li>◆ Scaleless implicatures (Jeretic 2021): children obligatorily compute scaleless implicatures for negated necessity modals BUT children generally do not derive many implicatures (Noveck 2001)</li> <li>◆ Surface scope (Musolino 1999): predicts lack of necessity readings for all modals</li> </ul> </li> <li>➢ Strong scope: children start with strong scope (Semantic Subset Principle, Crain et al. 1994)</li> </ul> <p style="font-size: small; text-align: center;">Selected references</p> <p style="font-size: x-small;">Crain, S., M. W. Cooney, L. O'Neil, Learning young and naturally. In Gualmini, A., &amp; Hankin, V. (2009). The early onset of modal and negative modalities. <i>Journal of Child Language</i>, 36, 1-22. https://doi.org/10.1017/S0305000908003888</p>

# Conclusion

## Deontic DMN is building on

- Philosophical insights – deontic hexagon and bitstring semantics
- Constraint reasoning – cDMN
- Deontic judgement templates
- Deontic judgement composition rule

## Goal

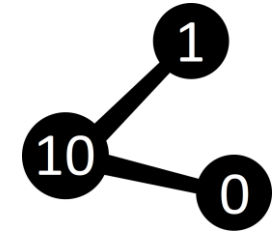
- Separation of deontic rule from factual consequence/definition
  - Hence, we can tell if the inconsistency
    - arise from deontic inference
    - rather than from the fact/definition.
- Reflecting human deontic judgement

## Human Judgement Experiment

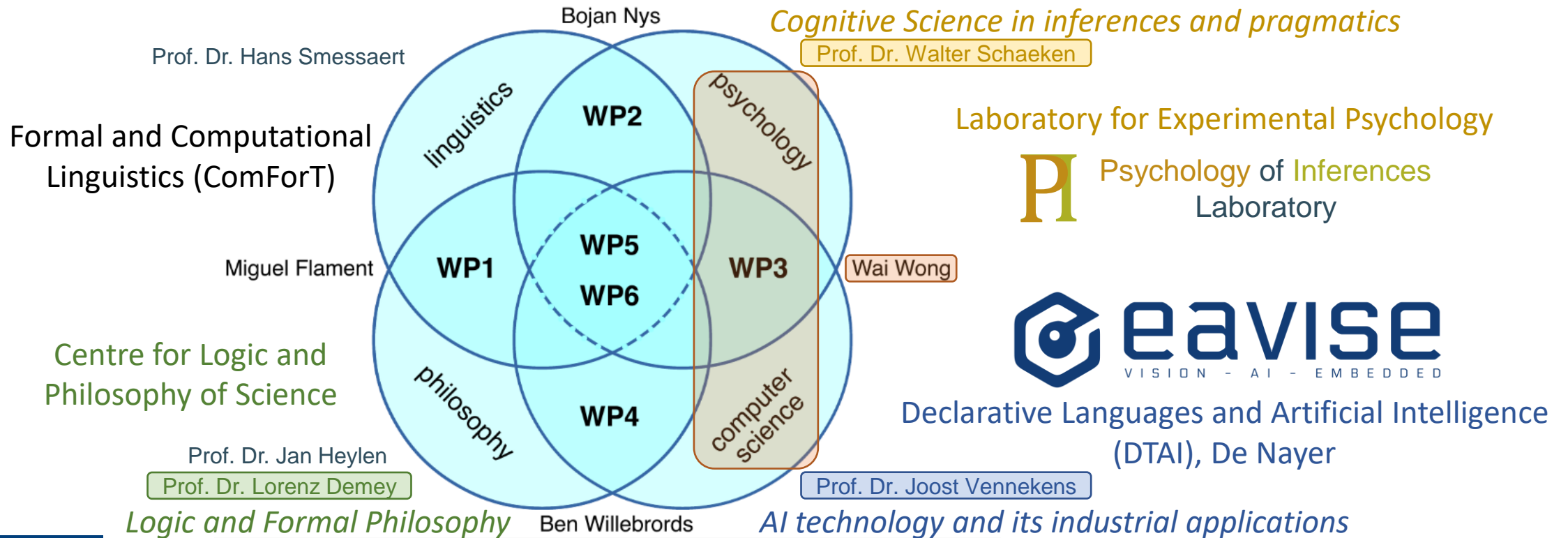
- Finding the best representation in Deontic DMN

# Team

## BITSHARE project



BITSHARE: Bitstring Semantics for Human and Artificial Reasoning



Leuven.AI - KU Leuven Institute for Artificial Intelligence

(Research lines: Reasoning)

# References

- Bitstring semantics: <https://logicalgeometry.org/logic/bitstrings>
- cDMN: <https://cdmn.readthedocs.io/>
- Deontic logic & hexagon: <https://plato.stanford.edu/entries/logic-deontic/>
- Bleotu et al. (2022) - Deontic lack of necessity is interpreted as interdiction in child Romanian: <https://osf.io/mbtq3>
- Markovic et al. (2022) - On the semantics of "null" in DMN: Undefined is not unknown: <https://lirias.kuleuven.be/3799508?limo=0>
- Vandavelde et al. (2021) - A Table-Based Representation for Probabilistic Logic: Preliminary Results: <https://arxiv.org/abs/2110.01909>

# Q&A

