[Airbus Amber]

Cognitive Argumentation: Three Reasoning Tasks

Emmanuelle Dietz, joint work with Antonis Kakas

at the 6th Summer School on Argumentation

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Three Reasoning Tasks in Cognitive Argumentation

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THE LIBRARY TASK

THE LIBRARY TASK (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library

The Library Task (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library
2. She will not study late in the library
3. She may or may not study late in the library

THE LIBRARY TASK (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library 96%
2. She will not study late in the library
3. She may or may not study late in the library

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THE LIBRARY TASK (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- If she has a textbook to read, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library
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The Library Task (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- If she has a textbook to read, then she will study late in the library
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What follows?

1. She will study late in the library — 96%
2. She will not study late in the library
3. She may or may not study late in the library

The Library Task (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- If the library is open, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library
2. She will not study late in the library
3. She may or may not study late in the library

THE LIBRARY TASK (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- If the library is open, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library 38%
2. She will not study late in the library
3. She may or may not study late in the library

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The Library Task (Byrne, 1989)

- If she has an essay to finish, then she will study late in the library
- If the library is open, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library 38%
2. She will not study late in the library
3. She may or may not study late in the library

Humans seem to suppress previously drawn information.
They reason non-monotonically!

⇝ In total there are 12 cases of the library task!

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Motivation

Idea Understand, formalize and eventually predict episodes of human reasoning!

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Since the last decades, various approaches have been proposed, but...

- still, the cognitive science community does not *put the results of all experiments together* (Newell [1973])
- *the existence of 12 theories in any scientific domain is a small disaster* (Khemlani and Johnson-Laird [2012])

$\rightsquigarrow$ A Standard Model of the Mind (Laird et al. [2017])

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For the case of human reasoning

A good theory needs to account for various reasoning paradigms,
such as the library task, the card task and syllogistic reasoning

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such as the library task, the card task and syllogistic reasoning

Why can logic-based approaches be interesting for human reasoning?

⇝ *Logical reasoning is (...) considered as one of the most fundamental cognitive activities* (Woleński [2016])

Classical Logic

Formal representation

If she has an essay to finish (e), then she will study late in the library (ℓ)	e	$\rightarrow$	ℓ
If she has a textbook to read (t), then she will study late in the library (ℓ)	t	$\rightarrow$	ℓ
If the library is open (o), then she will study late in the library (ℓ)	o	$\rightarrow$	ℓ
She has an essay to finish	e		

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Classical Logic

Formal representation

If she has an essay to finish (e), then she will study late in the library (ℓ)	$e \rightarrow \ell$
If she has a textbook to read (t), then she will study late in the library (ℓ)	$t \rightarrow \ell$
If the library is open (o), then she will study late in the library (ℓ)	$o \rightarrow \ell$
She has an essay to finish	e

Group I	$\{e \rightarrow \ell,\ e\}$	$\models$?	96% concluded ℓ
Group II	$\{e \rightarrow \ell,\ t \rightarrow \ell,\ e\}$	$\models$?	96% concluded ℓ
Group III	$\{e \rightarrow \ell,\ o \rightarrow \ell,\ e\}$	$\models$?	only 38% concluded ℓ

Formal representation

If she has an essay to finish (e), then she will study late in the library (ℓ)	e	$\rightarrow$	ℓ
If she has a textbook to read (t), then she will study late in the library (ℓ)	t	$\rightarrow$	ℓ
If the library is open (o), then she will study late in the library (ℓ)	o	$\rightarrow$	ℓ
She has an essay to finish	e		

In classical logic, this yields the following results

Group I	$\{e \rightarrow \ell, \quad e\}$	$\models$	ℓ	96% concluded ℓ
Group II	$\{e \rightarrow \ell, \quad t \rightarrow \ell, \quad e\}$	$\models$	ℓ	96% concluded ℓ
Group III	$\{e \rightarrow \ell, \quad o \rightarrow \ell, \quad e\}$	$\models$	ℓ	only 38% concluded ℓ

Classical Logic

Formal representation

If she has an essay to finish (e), then she will study late in the library (ℓ)	e	$\rightarrow$	ℓ
If she has a textbook to read (t), then she will study late in the library (ℓ)	t	$\rightarrow$	ℓ
If the library is open (o), then she will study late in the library (ℓ)	o	$\rightarrow$	ℓ
She has an essay to finish	e		

In classical logic, this yields the following results

Group I	$\{e \rightarrow \ell, \quad e\} \models \ell$		96% concluded ℓ
Group II	$\{e \rightarrow \ell, \quad t \rightarrow \ell, \quad e\} \models \ell$		96% concluded ℓ
Group III	$\{e \rightarrow \ell, \quad o \rightarrow \ell, \quad e\} \models \ell$		only 38% concluded ℓ

$\rightsquigarrow$ Instead of assuming that humans do not reason logically, we take the view that humans do not necessarily reason in accordance with Classical Logic

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Cognitive Argumentation

Cognitive Principles

1. Humans make assumptions while reasoning
2. Many of these assumptions are not necessarily valid in classical logic
3. These typical assumptions are extra-logical
4. Yet, humans are pretty good in explaining plausibly why they make these assumptions

⇝ Characterization as argument schemes
⇝ These schemes guide argument construction

TIME SCALE OF HUMAN ACTION

Scale (sec)	Time Units	System	World (theory)
10^{7}	months		
10^{6}	weeks		SOCIAL BAND
10^{5}	days		
10^{4}	hours	Task	
10^{3}	10 min	Task	RATIONAL BAND
10^{2}	minutes	Task	
10^{1}	10 sec	Unit task	
10^{0}	1 sec	Operations	COGNITIVE BAND
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	
10^{-3}	1 ms	Neuron	BIOLOGICAL BAND
10^{-4}	100 μs	Organelle	

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Cognitive Argumentation

$\mathcal{P}$ set of propositional variables, $\neg\mathcal{P} = \{\neg x \mid x \in \mathcal{P}\}$ $\rightsquigarrow \{e, \ell, o, t\}$

$\mathcal{S} = (\mathcal{F}, \mathcal{A})$ cognitive state, with set of facts $\mathcal{F}$ and relevance set $\mathcal{A}$ $\rightsquigarrow (\{e\}, \{e, \ell\})$

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Argument scheme AS is a pair of precondition and position of the form

$$\text{AS} \quad = \quad (\text{Pre}, \text{Pos})$$

where $\text{Pre}, \text{Pos} \subseteq (\mathcal{P} \cup \neg\mathcal{P})$

- Argument Δ is a set of argument schemes

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If she has an essay to finish, then she will study late in the library $(e \rightsquigarrow \ell)$

She has an essay to finish (e)

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She has an essay to finish (e)

- Argument Schemes $(e \rightsquigarrow \ell) = (\{e\}, \{\ell\})$ $\text{fact}(e) = (\emptyset, \{e\})$
- Argument $\Delta = \{\text{fact}(e), (e \rightsquigarrow \ell)\}$ is argument for ℓ given $\mathcal{S} = (\{e\}, \{e, \ell\})$

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$\rightsquigarrow$ Evaluation of arguments as Dung [1995]

$\rightsquigarrow$ Applied to preference based structured argumentation
e.g. Kakas and Moraitis [2003], Modgil and Prakken [2013], Prakken and Sartor [1997]

Cognitive Principles in the Library Task

Maxim of Quality (Grice, 1975) (factual) information is assumed to be true $\Rightarrow \Delta^{fact}$
Maxim of Relevance (Grice, 1975) (mentioned) information is assumed to be relevant $\Rightarrow \Delta_{hyp}$

Cognitive Principles in the Library Task

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If she has an essay to finish, then she will study late in the library

- *She has an essay to finish* is sufficient support for *She will study late in the library*

$\rightsquigarrow$ *She has an essay to finish* is a **sufficient condition**! $\Rightarrow \Delta_{e \overset{s}{\rightsquigarrow} \ell}$

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If the library is open, then she will study late in the library

- *The library is open* is not sufficient support for *She will study late in the library*

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$\rightsquigarrow$ *She has an essay to finish* is also a **necessary condition**! $\Rightarrow \Delta_{\overline{e} \overset{n}{\rightsquigarrow} \overline{\ell}}$

If the library is open, then she will study late in the library

- *The library is open* is not sufficient support for *She will study late in the library*
- *The library is not open* plausibly explains *She will not study late in the library*

$\rightsquigarrow$ *The library is open* is a **necessary condition**! $\Rightarrow \Delta_{\overline{o} \overset{n}{\rightsquigarrow} \overline{\ell}}$

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- *The library is open* is not sufficient support for *She will study late in the library*
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$\rightsquigarrow$ *The library is open* is a **necessary condition**! $\Rightarrow \Delta_{\overline{o} \overset{n}{\rightsquigarrow} \overline{\ell}}$

Relative strength relations

- Fact schemes are strongest schemes, hypothesis schemes are weakest schemes
- necessary schemes ($\overset{n}{\rightsquigarrow}$) are stronger than sufficient schemes ($\overset{s}{\rightsquigarrow}$)

The Library Task Revisited

What follows? Will she study late in the library? Will she not study late in the library?

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For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$

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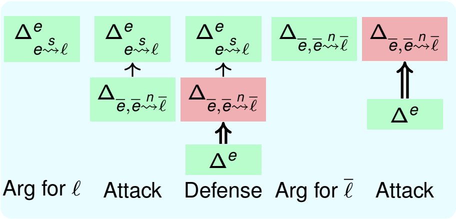
For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$



$\rightsquigarrow$ only ℓ is an acceptable conclusion

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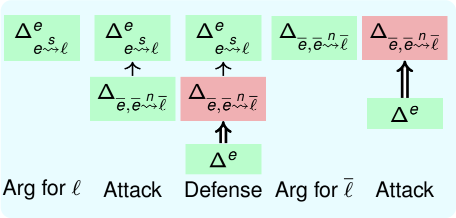
What follows? Will she study late in the library? Will she not study late in the library?

For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$

Construction for ℓ and $\overline{\ell}$ in Group III $\mathcal{S} = (\{e\}, \{e, \ell, o\})$

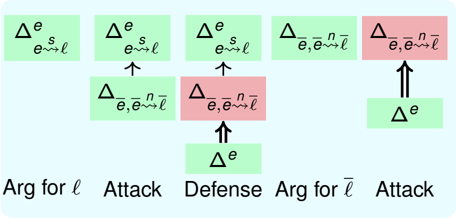


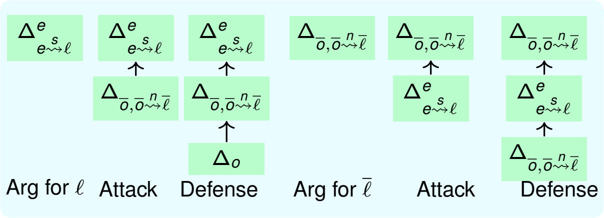
$\rightsquigarrow$ only ℓ is an acceptable conclusion

What follows? Will she study late in the library? Will she not study late in the library?

For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$

Construction for ℓ and $\overline{\ell}$ in Group III $\mathcal{S} = (\{e\}, \{e, \ell, o\})$





$\rightsquigarrow$ only ℓ is an acceptable conclusion

$\rightsquigarrow$ ℓ and $\overline{\ell}$ are acceptable conclusions

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Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
e	I (simple)	ℓ	ℓ	96% ℓ
e	II (textbook)	-	ℓ	96% ℓ
e	III (library open)	$\ell, \overline{\ell}$	$\ell, \overline{\ell}$	38% ℓ

- If she has an essay to finish, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library **96%**
2. She will not study late in the library
3. She may or may not study late in the library

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e	I (simple)	ℓ	ℓ	96% ℓ
e	II (textbook)	-	ℓ	96% ℓ
e	III (library open)	$\ell, \overline{\ell}$	$\ell, \overline{\ell}$	38% ℓ

- If she has an essay to finish, then she will study late in the library
- If the library is open, then she will study late in the library
- She has an essay to finish

What follows?

1. She will study late in the library **38%**
2. She will not study late in the library
3. She may or may not study late in the library

Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
$\overline{e}$	I (simple)	$\overline{\ell}$	$\ell, \overline{\ell}$	46% $\overline{\ell}$
$\overline{e}$	II (textbook)	-	$\ell, \overline{\ell}$	4% $\overline{\ell}$
$\overline{e}$	III (library open)	$\overline{\ell}$	$\ell, \overline{\ell}$	63% $\overline{\ell}$

- If she has an essay to finish, then she will study late in the library
- She does not have an essay to finish

What follows?

1. She will study late in the library
2. She will not study late in the library **46%**
3. She may or may not study late in the library

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Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
$\overline{e}$	I (simple)	$\overline{\ell}$	$\ell, \overline{\ell}$	46% $\overline{\ell}$
$\overline{e}$	II (textbook)	-	$\ell, \overline{\ell}$	4% $\overline{\ell}$
$\overline{e}$	III (library open)	$\overline{\ell}$	$\ell, \overline{\ell}$	63% $\overline{\ell}$

- If she has an essay to finish, then she will study late in the library
- If she has a textbook to read, then she will study late in the library
- She does not have an essay to finish

What follows?

1. She will study late in the library
2. She will not study late in the library — 4%
3. She may or may not study late in the library

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Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
ℓ	I (simple)	e	$e, \overline{e}$	71% e
ℓ	II (textbook)	-	$e, \overline{e}$	13% e
ℓ	III (library open)	e	$e, \overline{e}$	54% e

- If she has an essay to finish, then she will study late in the library
- She will study late in the library

What follows?

1. She has an essay to finish **71%**
2. She does not have an essay to finish
3. She may or may not have an essay to finish

Fact	Group	Cognitive Argumentation (Dietz and Kakas [2020]) sufficient&necessary	sufficient	Byrne [1989]
ℓ	I (simple)	e	$e, \overline{e}$	71% e
ℓ	II (textbook)	-	$e, \overline{e}$	13% e
ℓ	III (library open)	e	$e, \overline{e}$	54% e

- If she has an essay to finish, then she will study late in the library
- If she has a textbook to read, then she will study late in the library
- She will study late in the library

What follows?

1. She has an essay to finish **13%**
2. She does not have an essay to finish
3. She may or may not have an essay to finish

Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
$\overline{\ell}$	I (simple)	$\overline{e}$	$\overline{e}$	92% $\overline{e}$
$\overline{\ell}$	II (textbook)	-	$\overline{e}$	96% $\overline{e}$
$\overline{\ell}$	III (library open)	$\overline{e}$	$\overline{e}$	33% $\overline{e}$

- If she has an essay to finish, then she will study late in the library
- She will not study late in the library

What follows?

1. She has an essay to finish
2. She does not have an essay to finish **92%**
3. She may or may not have an essay to finish

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Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]
$\overline{\ell}$	I (simple)	$\overline{e}$	$\overline{e}$	92% $\overline{e}$
$\overline{\ell}$	II (textbook)	-	$\overline{e}$	96% $\overline{e}$
$\overline{\ell}$	III (library open)	$\overline{e}$	$\overline{e}$	33% $\overline{e}$

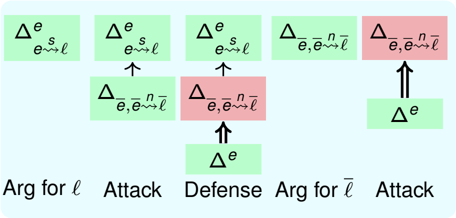
- If she has an essay to finish, then she will study late in the library
- If the library is open, then she will study late in the library
- She will not study late in the library

What follows?

1. She has an essay to finish
2. She does not have an essay to finish **33%**
3. She may or may not have an essay to finish

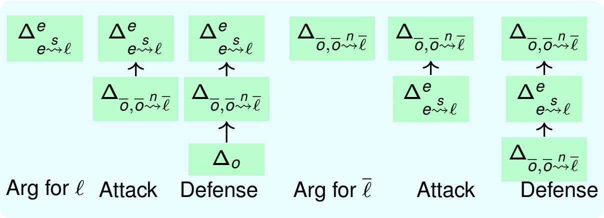
What follows? Will she study late in the library? Will she not study late in the library?

For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$



$\rightsquigarrow$ only ℓ is an acceptable conclusion

Construction for ℓ and $\overline{\ell}$ in Group III $\mathcal{S} = (\{e\}, \{e, \ell, o\})$



$\rightsquigarrow$ ℓ and $\overline{\ell}$ are acceptable conclusions

What follows? Will she study late in the library? Will she not study late in the library?

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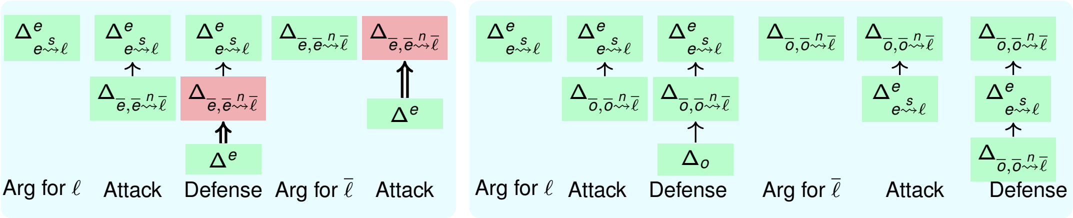


$\rightsquigarrow$ only ℓ is an acceptable conclusion

$\rightsquigarrow$ ℓ and $\overline{\ell}$ are acceptable conclusions

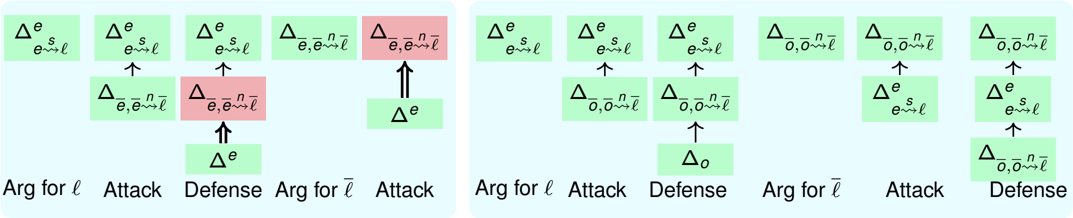
Argumentation works on a two-level decision procedure

Argument Construction What are the arguments for and against a certain position?

Preference-based decision What are their relative strength relations? Which argument wins?

What follows? Will she study late in the library? Will she not study late in the library?

For ℓ and $\overline{\ell}$ in Group I $\mathcal{S} = (\{e\}, \{e, \ell\})$ Construction for ℓ and $\overline{\ell}$ in Group III $\mathcal{S} = (\{e\}, \{e, \ell, o\})$



$\rightsquigarrow$ only ℓ is an acceptable conclusion

$\rightsquigarrow$ ℓ and $\overline{\ell}$ are acceptable conclusions

Argumentation works on a two-level decision procedure

Argument Construction What are the arguments for and against a certain position?

Preference-based decision What are their relative strength relations? Which argument wins?

$\rightsquigarrow$ Can argument construction be guided by 'lower levels' of cognition implemented in a cognitive architecture?

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BRIDGING TO LOWER LEVELS OF COGNITION

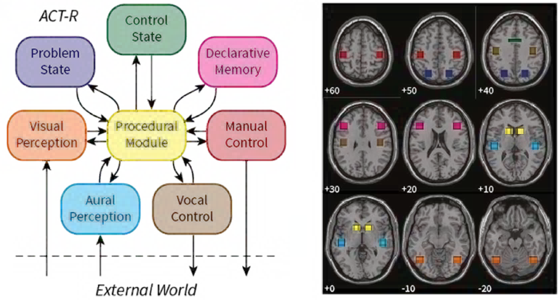
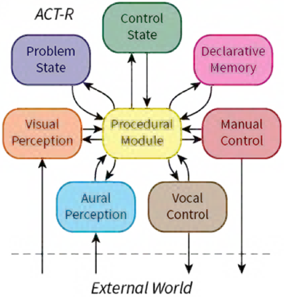


Image retrieved from [Borst and Anderson, 2017]

ACT-R: A THEORY ABOUT HOW HUMAN COGNITION WORKS (ANDERSON [2007])

Simulation of Cognitive Functions (Anderson [2007])



Functions as modules

- Declarative memory
- Procedural module

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ACT-R: A THEORY ABOUT HOW HUMAN COGNITION WORKS (ANDERSON [2007])

Arguments as Chunks in Declarative Module

- Model stores information as chunks
- Each chunk has a name (used for reference)
- A chunk possibly contains a set of named slots with single values

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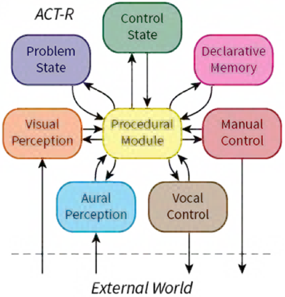

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```
(chunk-type context value hypo)
(chunk-type argument fact hypo
            position context neg-position strength)
(add-dm
(SUF isa context value SUFFICIENT hypo ALTERNATIVE)
(NEC isa context value NECESSARY hypo DISABLER)
(ARG-E-SUF isa argument fact ESSAY hypo NONE
               position "YES" context SUF
               neg-position "UNKNOWN" strength 1)
)
```

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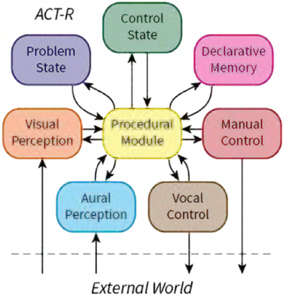

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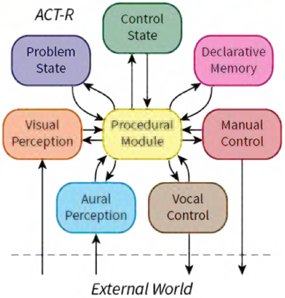

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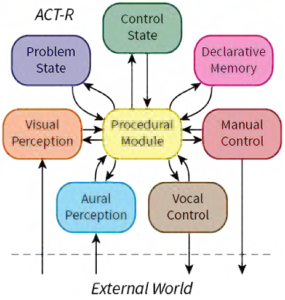

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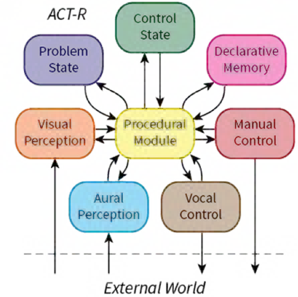

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ACT-R: A THEORY ABOUT HOW HUMAN COGNITION WORKS (ANDERSON [2007])

Procedural System and Knowledge Retrieval

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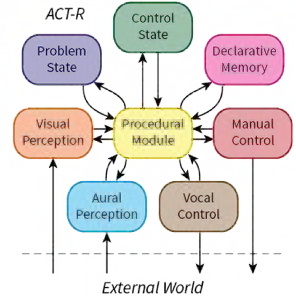

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ACT-R: A THEORY ABOUT HOW HUMAN COGNITION WORKS (ANDERSON [2007])

Procedural System and Knowledge Retrieval

⇝ Modification of the system's state through execution of rules:

Procedural module, Utility module, Production-compilation module

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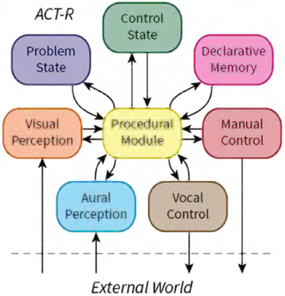

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ACT-R: A theory about how human cognition works (Anderson [2007])

Procedural System and Knowledge Retrieval

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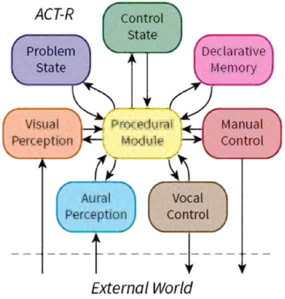
Procedural module, Utility module, Production-compilation module

```
(p retrieve-counter   (...)
   =goal>
     state            argue
   =retrieval>
     position         =position
   (...)
   ==>  (...)
   +retrieval>
   (...)
     neg-position     =position
   =goal>
     state            argue)
```

Simulation of Cognitive Functions (Anderson [2007])



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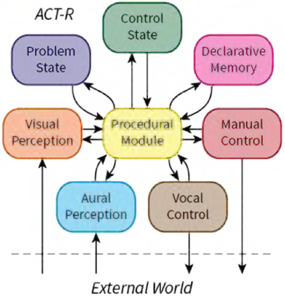
     state            argue)
```

⇝ Retrieval of knowledge through chunk activation

spreading activation, base-level activation, noise, partial matching

Simulation of Cognitive Functions (Anderson [2007])



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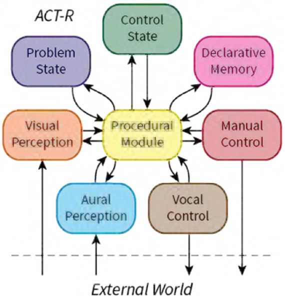
The Library Task: Decision Making Guided by Strength and Activation

Simplifications:

- circumvent 'natural language processing' issue by defining **context** chunks
- chunk activation is used for diverging interpretations in different contexts
- Processing time for the argumentative reasoning is not considered (yet)

The Cognitive Model



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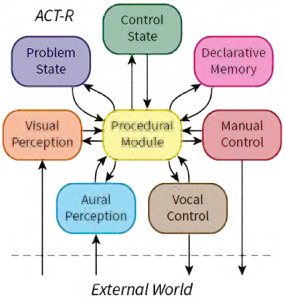
Visual Perception (retrieve), scan, attend and read information



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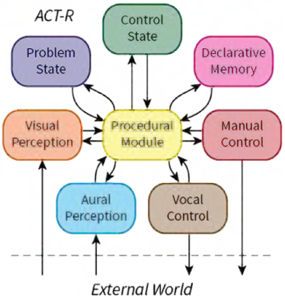
Understand and Argue as soon as required information processed

1. non-deterministic decision on interpretation
2. activates fact and context semantics
3. retrieves argument for position with highest activation
4. retrieves counterargument with highest activation
5. choice determined by activation or relative strength



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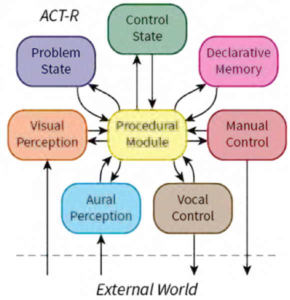
Manual Control prepare, move mouse and click button



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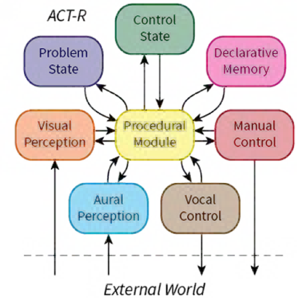

⇝ All 12 cases of the suppression task modeled within ACT-R!

Cognitive Argumentation (Dietz and Kakas [2020])

Fact	Group	sufficient&necessary	sufficient	Byrne [1989]	**ACT-R (Dietz [2022])**
e	I	ℓ	ℓ	96% ℓ	**90% ℓ**
e	II	-	ℓ	96% ℓ	**90% ℓ**
e	III	$\ell,\overline{\ell}$	$\ell, \overline{\ell}$	38% ℓ	**37% ℓ**
$\overline{e}$	I	$\overline{\ell}$	$\ell,\overline{\ell}$	46% $\overline{\ell}$	**31% $\overline{\ell}$**
$\overline{e}$	II	-	$\ell,\overline{\ell}$	4% $\overline{\ell}$	**10% $\overline{\ell}$**
$\overline{e}$	III	$\overline{\ell}$	$\ell,\overline{\ell}$	63% $\overline{\ell}$	**65% $\overline{\ell}$**
ℓ	I	e	$e, \overline{e}$	71% e	**31% e**
ℓ	II	-	$e, \overline{e}$	13% e	**10% e**
ℓ	III	e	$e, \overline{e}$	54% e	**64% e**
$\overline{\ell}$	I	$\overline{e}$	$\overline{e}$	92% $\overline{e}$	**90% $\overline{e}$**
$\overline{\ell}$	II	-	$\overline{e}$	96% $\overline{e}$	**89% $\overline{e}$**
$\overline{\ell}$	III	$\overline{e}$	$\overline{e}$	33% $\overline{e}$	**37% $\overline{e}$**

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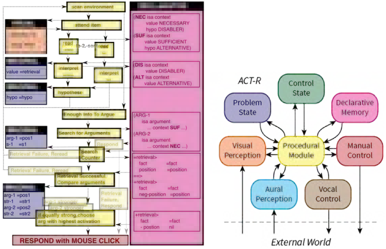

Cognitive Architecture

Cognitive Argumentation

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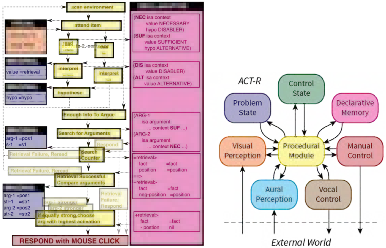

Cognitive Architecture

Cognitive Argumentation

Take Home Message

First step towards reasoning with argumentation by bridging to lower levels of cognition...

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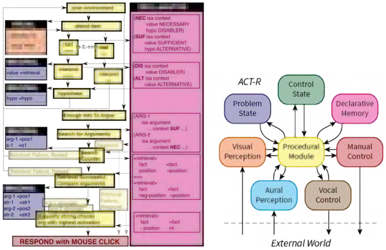

Cognitive Architecture

Cognitive Argumentation

Take Home Message

First step towards reasoning with argumentation by bridging to lower levels of cognition...

... argumentation provides contrastive explanations (why not choose the other answer ? ...)

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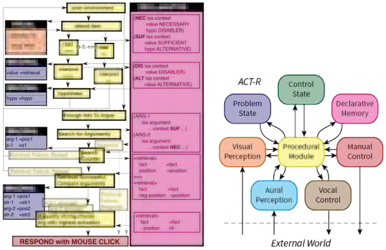

Cognitive Architecture

Cognitive Argumentation

Take Home Message

First step towards reasoning with argumentation by bridging to lower levels of cognition...

... argumentation provides contrastive explanations (why not choose the other answer ? ...)

... heuristics in ACT-R can serve as a guidance for the selection of arguments !

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Cognitive Argumentation: Three Reasoning Tasks

Emmanuelle Dietz, joint work with Antonis Kakas

at the 6th Summer School on Argumentation

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THE CARD TASK

The Card Task: Abstract Case (Wason 1968)

Consider four cards where each of them has a letter on one side
and a number on the other side. Given the conditional

If there is a D on one side of the card, then there is a 3 on the other side

Which cards must be turned to prove that the conditional holds?

D	F	3	7

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The Card Task: Abstract Case (Wason 1968)

Consider four cards where each of them has a letter on one side and a number on the other side. Given the conditional

If there is a D on one side of the card, then there is a 3 *on the other side*

Which cards must be turned to prove that the conditional holds?

	D	F	3	7
Experimental Results	89%	16%	62%	25%

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The Card Task: Deontic Case (Griggs and Cox 1982)

Consider four cards, where on one side there is the person's age and
on the other side of the card what the person is drinking. Given the conditional

If a person is drinking beer, then the person must be over 19 years of age

Which cards must be turned to prove that the conditional holds?

beer	coke	22yrs	16yrs

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Which cards must be turned to prove that the conditional holds?

	beer	coke	22yrs	16yrs
Experimental Results	95%	0.025%	0.025%	80%

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The Card Task: Everyday Case (Pollard 1981)

Consider four cards, where on one side there is the person's travel destination and on the other side of the card how the person is traveling. Given the conditional

If I go to Manchester, then I travel by train

Which cards must be turned to prove that the conditional holds?

Manchester	Leeds	train	car

The Card Task: Everyday Case (Pollard 1981)

Consider four cards, where on one side there is the person's travel destination and on the other side of the card how the person is traveling. Given the conditional

If I go to Manchester, then I travel by train

Which cards must be turned to prove that the conditional holds?

	Manchester	Leeds	train	car
Experimental Results	100%	0%	33%	42%

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Selection Patterns and Percentages per Case

Group	Selection Pattern*	Abstract $D \leadsto 3$	Everyday Manchester $\leadsto$ train	Deontic beer $\leadsto$ 22yrs
I	P	36	23	13
II	P, Q	39	37	19
III	P, Q and $\overline{Q}$	5	11	4
IV	P, $\overline{Q}$	19	29	64

* P, Q, $\overline{P}$, $\overline{Q}$ stand for D, 3, F, 7 (abstract), Manchester, train, Leeds, car (everyday), and beer, 22yrs, coke, 16yrs (deontic)

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Selection Patterns and Percentages per Case

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16 different selection patterns exist. Four canonical groups can be identified. The majority in

- the abstract case are in group I and II
- the everyday case are in group I, II and IV
- the deontic case are in group III

Selection Patterns and Percentages per Case

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16 different selection patterns exist. Four canonical groups can be identified. The majority in

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- the everyday case are in group I, II and IV
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Can Cognitive Argumentation uniformly capture the differences

among the individuals' selections? the canonical groups? within the varying contexts?

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Cognitive Argumentation

Cognitive Principles

1. Humans make assumptions while reasoning
2. Many of these assumptions are not necessarily valid in classical logic
3. These typical assumptions are extra-logical
4. Yet, humans are pretty good in explaining plausibly why they make these assumptions

⇝ Characterization as argument schemes
⇝ These schemes guide argument construction

TIME SCALE OF HUMAN ACTION

Scale (sec)	Time Units	System	World (theory)
10^7	months		
10^6	weeks		SOCIAL BAND
10^5	days		
10^4	hours	Task	
10^3	10 min	Task	RATIONAL BAND
10^2	minutes	Task	
10^1	10 sec	Unit task	
10^0	1 sec	Operations	COGNITIVE BAND
10^{-1}	100 ms	Deliberate act	
10^{-2}	10 ms	Neural circuit	
10^{-3}	1 ms	Neuron	BIOLOGICAL BAND
10^{-4}	100 μs	Organelle	

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Cognitive Argumentation

$\mathcal{P}$ set of propositional variables, $\neg\mathcal{P} = \{\neg x \mid x \in \mathcal{P}\}$ $\rightsquigarrow \{e, \ell, o, t\}$

$\mathcal{S}$ = $(\mathcal{F}, \mathcal{A})$ cognitive state, with set of facts $\mathcal{F}$ and relevance set $\mathcal{A}$ $\rightsquigarrow (\{e\}, \{e, \ell\})$

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Cognitive Argumentation

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- $\mathcal{S} = (\mathcal{F}, \mathcal{A})$ cognitive state, with set of facts $\mathcal{F}$ and relevance set $\mathcal{A}$ $\quad \rightsquigarrow (\{e\}, \{e, \ell\})$

Argument scheme AS is a pair of precondition and position of the form

$$\text{AS} = (\text{Pre}, \text{Pos})$$

where $\text{Pre}, \text{Pos} \subseteq (\mathcal{P} \cup \neg\mathcal{P})$

- Argument Δ is a set of argument schemes

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Cognitive Argumentation

- $\mathcal{P}$ set of propositional variables, $\neg\mathcal{P} = \{\neg x \mid x \in \mathcal{P}\}$ $\quad \leadsto \{e, \ell, o, t\}$
- $\mathcal{S} = (\mathcal{F}, \mathcal{A})$ cognitive state, with set of facts $\mathcal{F}$ and relevance set $\mathcal{A}$ $\quad \leadsto (\{e\}, \{e, \ell\})$

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If she has an essay to finish, then she will study late in the library $\quad (e \leadsto \ell)$

She has an essay to finish $\quad (e)$

Cognitive Argumentation

$\mathcal{P}$ set of propositional variables, $\neg\mathcal{P} = \{\neg x \mid x \in \mathcal{P}\}$ $\rightsquigarrow \{e, \ell, o, t\}$

$\mathcal{S} = (\mathcal{F}, \mathcal{A})$ cognitive state, with set of facts $\mathcal{F}$ and relevance set $\mathcal{A}$ $\rightsquigarrow (\{e\}, \{e, \ell\})$

Argument scheme AS is a pair of precondition and position of the form

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- Argument $\Delta = \{\text{fact}(e), (e \rightsquigarrow \ell)\}$ is argument for ℓ given $\mathcal{S} = (\{e\}, \{e, \ell\})$

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$\rightsquigarrow$ Evaluation of arguments as Dung [1995]

$\rightsquigarrow$ Applied to preference based structured argumentation
e.g. Kakas and Moraitis [2003], Modgil and Prakken [2013], Prakken and Sartor [1997]

Cognitive Principles in the Card Task

Maxim of Quality (Grice, 1975) (factual) information is assumed to be true $\Rightarrow \Delta^{fact}$

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- *She has an essay to finish* is **sufficient** ($\Delta_{P \overset{s}{\rightsquigarrow} Q}$), **necessary** ($\Delta_{Q \overset{n}{\rightsquigarrow} P}$) and **secondary necessary** ($\Delta_{\overline{P} \overset{n}{\rightsquigarrow} \overline{Q}}$)

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- Given that *She will not study late in the library*, it follows that *She does not have an essay to finish*
  - Recognizing this association requires an active search for counter-examples
  - Repeating this process leads to a new direct association (short-cut) (**learned**)

$\rightsquigarrow$ *She has an essay to finish* is a **secondary sufficient condition** ($\Delta_{\overline{Q} \overset{s}{\rightsquigarrow} \overline{P}}$)

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If a person is driving a car, then the person must have a driver's license

- Necessary conditions can appear as consequence (**inverted**) $\rightsquigarrow$ *driver's license* is **necessary** ($\Delta_{\overline{Q} \overset{n}{\rightsquigarrow} \overline{P}}$)

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Relative strength relations

- Fact schemes are strongest schemes, hypothesis schemes are weakest schemes
- Necessary schemes ($\overset{n}{\leadsto}$) are stronger than sufficient schemes ($\overset{s}{\leadsto}$)

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Canonical Argument Construction

Group	Selection Pattern*	Abstract $D \rightsquigarrow 3$	Everyday Manchester $\rightsquigarrow$ train	Deontic beer $\rightsquigarrow$ 22yrs
I	P	36	23	13
II	P, Q	39	37	19
III	P, Q and $\overline{Q}$	5	11	4
IV	P, $\overline{Q}$	19	29	64

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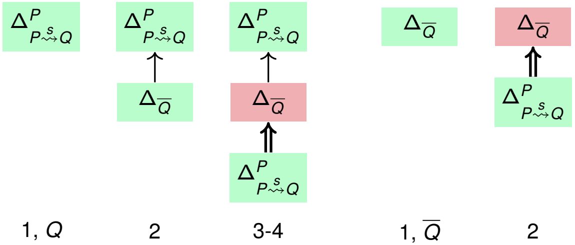

Given P, construction for Q (left) and for $\overline{Q}$ (right) assuming P is sufficient: Q follows skeptically

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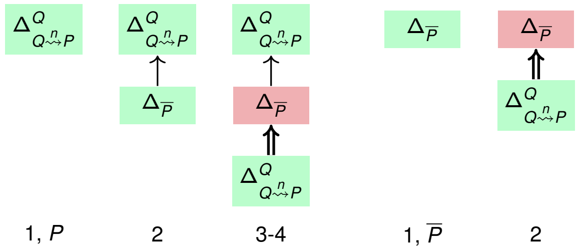

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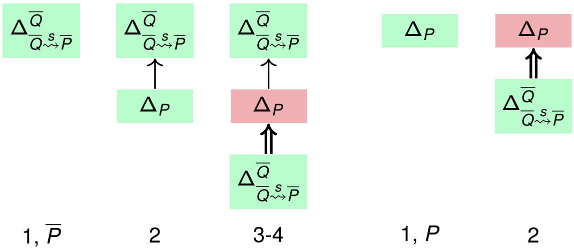

Given $\overline{Q}$, construction for $\overline{P}$ (left) and for P (right) assuming P is secondary sufficient: $\overline{P}$ follows skeptically

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Canonical Groups characterized by Cognitive Principles

Cognitive Argumentation (Dietz and Kakas [2021])

	Card	%	Cognitive Principles	Group I	Group II	Group IV
Abstract	D	$\geq$99	sufficient condition	✓	✓	✓
	3	44	necessary condition		✓	
	7	24	secondary sufficient condition			✓
Everyday	Manchester	100	sufficient condition	✓	✓	✓
	Train	48	necessary condition		✓	
	Car	40	learned secondary sufficient condition			✓
Deontic	Beer	100	inverted necessary condition	✓	✓	✓
	22 yrs	23	inverted sufficient condition		✓	
	16 yrs	68	inverted learned secondary necessary condition			✓

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Canonical Groups

Cognitive Argumentation

Take Home Message

1. Cognitive Argumentation captures dominant canonical selections for all task variations
2. In the abstract and everyday case, associations through counter-examples do not seem to be established
3. In the deontic case, the condition within the inverted conditional is more easily interpreted as necessary

Main advantages of CA is its simplicity, generalizability and its use of a universal criterion of acceptability!

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Cognitive Principles in Argumentation for Human Syllogistic Reasoning

Emmanuelle-Anna Dietz[1]
Airbus Central R&T
Hamburg
Germany

[1] joint work with Antonis Kakas

Human Syllogistic Reasoning

Some artists are not bakers
All bakers are chemists

What follows about the relation between artists and chemists?

Some artists are not bakers

All bakers are chemists

What follows about the relation between artists and chemists?

- All artists are chemists
- No artists are chemists
- Some artists are chemists
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- All chemists are artists
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- No valid conclusion

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- In Classical Logic *No valid conclusion* follows

Some artists are not bakers

All bakers are chemists

What follows about the relation between artists and chemists?

- All artists are chemists
- No artists are chemists
- Some artists are chemists (19%)
- Some artists are not chemists (46%)
- All chemists are artists
- No chemists are artists
- Some chemists are artists
- Some chemists are not artists
- No valid conclusion (20%)

- In Classical Logic *No valid conclusion* follows
- Majority of participants in psychological experiments answers differently

Syllogisms: Moods

mood	natural language	first-order logic	abbreviation
affirmative universal	*all a are b*	$\forall X(a(X) \rightarrow b(X))$	Aab
affirmative existential	*some a are b*	$\exists X(a(X) \wedge b(X))$	Iab
negative universal	*no a are b*	$\forall X(a(X) \rightarrow \neg b(X))$	Eab
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Some artists are not bakers $\Rightarrow$ Oab

All bakers are chemists $\Rightarrow$ Abc

Syllogisms: Figures

- 4 figures

	premise 1	premise 2
figure 1	a-b	b-c
figure 2	b-a	c-b
figure 3	a-b	c-b
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- abbreviated by the first and the second mood of the figure

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> Some artists are not bakers
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- 512 (not necessarily valid) syllogisms
- possible conclusions are the 4 moods instantiated by a-c and c-a

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All artists are chemists $\Rightarrow$ Aac

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The human syllogistic reasoning approach under the Weak Completion Semantics outperforms any of the twelve cognitive theories!

Costa, D.S., Hölldobler (2017) D.S., Hölldobler, Mörbitz (2017)

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Two central issues

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- Evaluation of these as good quality ones

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- prescribed associations between some information

  called premises with another piece of information, called position of the scheme
- Link between information can be very general, no formalization provided

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- Evaluation of these as good quality ones

Argument Schemes (Pollock [1995], Walton [1996])

- common, stereotypical reasoning patterns that are non-deductive & nonmonotonic
- prescribed associations between some information

  called premises with another piece of information, called position of the scheme
- Link between information can be very general, no formalization provided
- have proven to be powerful in understanding the structure of arguments & plays a key role in teaching critical thinking skills ⇒ `https://www.rationaleonline.com/`

Argument Schemes and Critical Thinking

Argumentation is concerned with constructing good quality arguments

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Arguments are build through a chain of application of several argument schemes, until applying an argument scheme whose position is the desired one

Argumentation for Logical Reasoning

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- $\mathcal{L}$ is a given language $\rightsquigarrow \mathcal{SR}$
- $\mathcal{P}$ is the set of predicate relations $\rightsquigarrow \{a, b, c\}$
- $\mathcal{T}$ is the set of terms $\rightsquigarrow \{t_0, \ldots, t_n\}$
- $\mathcal{P}$rem is the set of premises $\rightsquigarrow \{\text{Axy}, \text{Ixy}, \text{Oxy}, \text{Exy} \mid x, y \in \mathcal{P}\}$

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argument scheme AS is a pair of precondition and position of the form

$$\text{AS} \quad = \quad (QX)\,(\{L_1(X)\ldots L_k(X), P_1, \ldots P_l\}, \{L_{k+1}(X)\ldots L_m(X), P_{l+1}, \ldots P_n\})$$

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Given a choice $t \in \mathcal{T}$, an instance of $\mathrm{AS} = (\mathrm{Pre}, \mathrm{Pos})$

$$a \quad = \quad \mathrm{AS}_t \quad = \quad (\{L_1(t) \ldots L_k(t), P_1, \ldots P_l\}, \{L_{k+1}(t) \ldots L_m(t), P_{l+1}, \ldots P_n\})$$

- is an individual argument
- Argument Δ is a set of individual arguments

Support Relation

Some artists are not bakers $\Rightarrow$ Oab

Argument scheme that captures the classical assertion of the O mood

$$\text{O}_\text{c}(y, z) \quad = \quad \exists X(\{\text{Oyz}\}, \{y(X), \neg z(X)\}) \text{ where y, z} \in \mathcal{P}$$

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Given $\mathrm{O_c}(a, b)_{t_0}$ and $\mathcal{P}\mathrm{rem} = \{\mathrm{Oab}\}$, a_1 supports $a(t_0)$ and $\neg b(t_0)$ for a choice $t_0 \in \mathcal{T}$

Conflict relation $\mathcal{C}$ and binary strength relation $\succ$

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- binary strength relation $\succ$ expresses relative strength among argument schemes
  - $\text{AS} \succ \text{AS}'$ denotes that AS is stronger than AS'
  - Given that $a = \text{AS}_t$ and $a' = \text{AS}'_t$ $\quad a \succ a' \quad \text{iff} \quad \text{AS} \succ \text{AS}'$

An argumentation logic framework is a triple $\mathcal{A}_{\mathcal{L}} = \langle \mathcal{A}s, \mathcal{C}, \succ \rangle$ where

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If $\{\mathrm{Oab}, \mathrm{Aab}\} \subseteq \mathcal{P}\mathrm{rem}$ then $\{a_0\}$ and $\{a_1\}$ attack each other!

Defense Relation and Acceptable Arguments

Given $\langle \mathcal{A}s, \mathcal{C}, \succ \rangle$, Δ defends against Δ' iff

- there exists an L and $\Delta_{min} \subseteq \Delta$, $\Delta'_{min} \subseteq \Delta'$ such that
  - Δ_{min}, Δ'_{min} minimally support L, $\overline{L}$ respectively
  - if there exists $a' \in \Delta'_{min}$, $a \in \Delta_{min}$ such that $a' \succ a$
    then there exists $b \in \Delta_{min}$, $b' \in \Delta'_{min}$, such that $b \succ b'$

Δ minimally supports L iff there is no $\Delta' \subset \Delta$ such that Δ' supports L

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Given $\langle \mathcal{A}s, \mathcal{C}, \succ \rangle$, Δ is acceptable or admissible iff

Δ is conflict-free and Δ defends against all arguments attacking Δ

Credulous and Skeptical Conclusions

Given $\mathcal{A}_{\mathcal{L}} = \langle \mathcal{A}s, \mathcal{C}, \succ \rangle$ and a set of premises $\mathcal{P}$rem

- L is acceptable in $\mathcal{A}_{\mathcal{L}}(\mathcal{P}\text{rem})$ or a credulous conclusion of $\mathcal{A}_{\mathcal{L}}(\mathcal{P}\text{rem})$ iff
  - there exists an acceptable Δ in $\mathcal{A}_{\mathcal{L}}(\mathcal{P}\text{rem})$ that supports L

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Given $\mathcal{A}_\mathcal{L} = \langle \mathcal{A}s, \mathcal{C}, \succ \rangle$ and a set of premises $\mathcal{P}$rem

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- *L* is a skeptical conclusion of $\mathcal{A}_\mathcal{L}(\mathcal{P}\text{rem})$ iff
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  - $\overline{L}$ is not a credulous conclusion of $\mathcal{A}_{\mathcal{L}}(\mathcal{P}\text{rem})$,

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- Skeptical arguments $\rightsquigarrow$ acceptability operator $\mathcal{F}$ (Kakas and Mancarella [2013])

Cognitive Principles as Argument Schemes

Cognitive Principles

Costa, D.S., Hölldobler (2017) D.S., Hölldobler, Mörbitz (2017)

Idea humans make (not necessarily classical logic valid) assumptions while reasoning
Goal provide a formalization for all these observed assumptions within one framework

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4. conflicts in reasoning
   - weakness of hypotheses and strength of facts principle

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- When X is existentially quantified we instantiate with a *not yet taken t* $\in \mathcal{T}$

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Existential import and non-empty properties (Johnson-Laird [1983], Rips [1994])

- $\text{fact}(y) = \exists X\ (\emptyset, \{y(X)\})$
- Hypothesis scheme *All terms have or do not have any property*

$$\text{hyp}(y) = \exists X\ (\emptyset, \{y(X)\}) \quad \text{or} \quad \text{hyp}(\neg y) = \exists X\ (\emptyset, \{\neg y(X)\})$$

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- Humans communicate according to the cooperation principle
- They try to make their conversations as informative as required

Presuppositions from Philosophy of Language

- Humans generally do not quantify over things that do not exist

Existential import and non-empty properties (Johnson-Laird [1983], Rips [1994])

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Maxim of quantity (Grice [1975])

$$\begin{aligned} \text{I}_{\text{qnty}}(y,z) &= \exists X\ (\{\text{I}yz\}, \{y(X), \neg z(X)\}) \\ \text{O}_{\text{qnty}}(y,z) &= \exists X\ (\{\text{O}yz\}, \{y(X), z(X)\}) \end{aligned}$$

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Refutation schemes (O'Brien et al. [1994], Rips [1994])

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Identification of entities

$$\mathrm{MM}'_{\mathrm{id}}(y, z) = (\{\mathrm{M}yz, \mathrm{M}'y'z'\}, \{\mathrm{M}''uv\})$$

- $\mathrm{M}, \mathrm{M}' \in \{\mathrm{I}, \mathrm{O}\}$, common property is either affirmative or negative in both premises
- $\mathrm{M}'' = \mathrm{I}$ or $\mathrm{M}'' = \mathrm{O}$, depends on the parity of the non-common properties u and v

Conflicts in Reasoning

Given Grice's maxim of quality in the cooperative principle, we assume that what humans say is not false and that information we receive has adequate evidence

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Strength of Facts Schemes that introduce factual information are stronger than others!

Syllogistic Reasoning via Argumentation

Syllogistic Argumentation Framework

Derivation of “mood quantified conclusions”

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Syllogistic Argumentation Framework $\mathcal{A}_{\mathcal{SR}} = \langle \mathcal{A}s, \mathcal{C}, \succ \rangle$

- predicate relations $\mathcal{P} = \{a, b, c\}$
- $\mathcal{T} = \{t_0, \ldots, t_n\}$
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- $\mathcal{A}s$ consists of set of all argument schemes just introduced
- relative strength relation $\succ$
  - AS $\succ$ hyp for any argument scheme AS $\in \mathcal{A}s$
  - AS $\succ$ AS$'$ for all AS $\in \{\mathrm{I_c}, \mathrm{I_{qnty}O_c}, \mathrm{O_{qnty}}, \mathrm{fact}\}$ and all AS$'$ that do not belong to this set (except of $\mathrm{MM'_{id}}$)

Valid Conclusions in $\mathcal{A}_{\mathcal{SR}}$

A syllogistic conclusion is a valid conclusion from a given pair of premises $\mathcal{S}yl$ in $\mathcal{A}_{\mathcal{SR}}(\mathcal{S}yl)$, where $yz = ac$ or $yz = ca$, as follows

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There has to exist a $t \in \mathcal{T}$ such that both, $a(t)$ and $c(t)$, are skeptical conclusions!

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1. find arguments that support $a(t)$ and $c(t)$ for some $t \in \mathcal{T}$
2. show that these arguments are acceptable and
3. check that there are no acceptable arguments for $\neg a(t)$ and for $\neg c(t)$

Arguments in $\mathcal{A}_{\mathcal{SR}}(\{\text{Oab}, \text{Abc}\})$ for and against Iac and Ica

individual arguments for a, b **or** c

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individual arguments for *a*, *b* or *c*

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argument		supports	attacks
Δ_{ab}	$\{a_1\}$	$a(t_1), b(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{b}\bar{c}}$
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$\Delta^{\star}_{abc}$	$\{a_1, a_3\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$
$\Delta_{\bar{a}}$	$\{a_4\}$	$\neg a(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$
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argument		supports	attacks	acceptable
Δ_{ab}	$\{a_1\}$	$a(t_1), b(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{b}\bar{c}}$	
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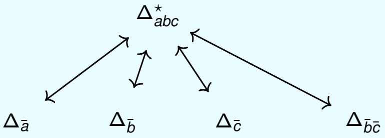
$\Delta_{\bar{b}\bar{c}}$	$\{a_6, a_7\}$	$\neg c(t_1), \neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	

argument		supports	attacks	acceptable
Δ_{ab}	$\{a_1\}$	$a(t_1), b(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{b}\bar{c}}$	
Δ_{abc}	$\{a_1, a_2\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	
$\Delta^{\star}_{abc}$	$\{a_1, a_3\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	
$\Delta_{\bar{a}}$	$\{a_4\}$	$\neg a(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}}$	$\{a_5\}$	$\neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{c}}$	$\{a_6\}$	$\neg c(t_1)$	$\Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}\bar{c}}$	$\{a_6, a_7\}$	$\neg c(t_1), \neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	

Attack and defense relations for lac: $\uparrow$ shows attacks and $\Uparrow$ shows defenses



argument		supports	attacks	acceptable
Δ_{ab}	$\{a_1\}$	$a(t_1), b(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{b}\bar{c}}$	
Δ_{abc}	$\{a_1, a_2\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	
$\Delta^{\star}_{abc}$	$\{a_1, a_3\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	
$\Delta_{\bar{a}}$	$\{a_4\}$	$\neg a(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}}$	$\{a_5\}$	$\neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{c}}$	$\{a_6\}$	$\neg c(t_1)$	$\Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}\bar{c}}$	$\{a_6, a_7\}$	$\neg c(t_1), \neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	

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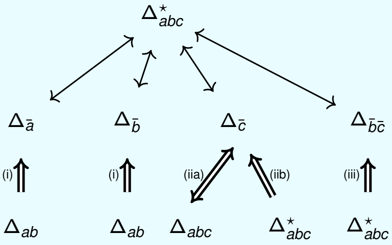

$\Delta^{\star}_{abc}$ defends against all its attacks, whereas $\Delta_{\bar{b}\bar{c}}$ does not!

argument		supports	attacks	acceptable
Δ_{ab}	$\{a_1\}$	$a(t_1), b(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{b}\bar{c}}$	✓
Δ_{abc}	$\{a_1, a_2\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	✓
$\Delta^{\star}_{abc}$	$\{a_1, a_3\}$	$a(t_1), b(t_1), c(t_1)$	$\Delta_{\bar{a}}, \Delta_{\bar{b}}, \Delta_{\bar{c}}, \Delta_{\bar{b}\bar{c}}$	✓
$\Delta_{\bar{a}}$	$\{a_4\}$	$\neg a(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}}$	$\{a_5\}$	$\neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{c}}$	$\{a_6\}$	$\neg c(t_1)$	$\Delta_{abc}, \Delta^{\star}_{abc}$	
$\Delta_{\bar{b}\bar{c}}$	$\{a_6, a_7\}$	$\neg c(t_1), \neg b(t_1)$	$\Delta_{ab}, \Delta_{abc}, \Delta^{\star}_{abc}$	

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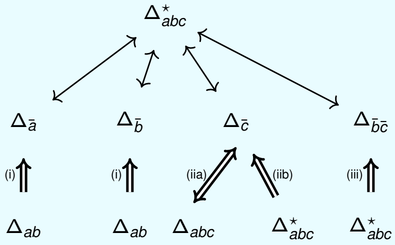

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- How can CA be applied to human decision making (e.g. Behavioural Economics)?

Cognitive Principles in Argumentation for Human Syllogistic Reasoning

Emmanuelle-Anna Dietz[1]
Airbus Central R&T
Hamburg
Germany

[1] joint work with Antonis Kakas

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