A Computational Logic Approach to the Belief Bias in Human Syllogistic Reasoning

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CONTEXT 17

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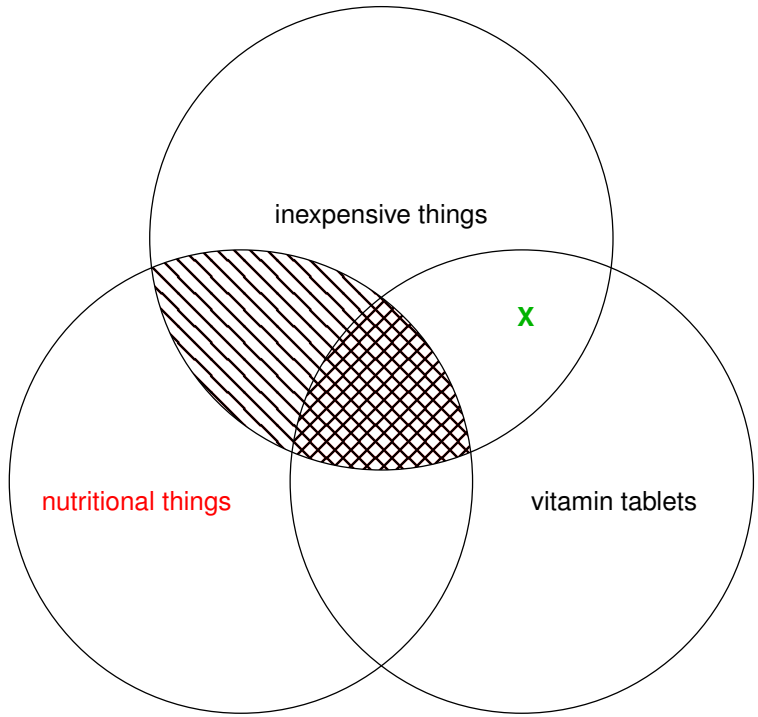
PREMISE 1 *No nutritional things are inexpensive.*

PREMISE 2 *Some vitamin tablets are inexpensive.*

CONCLUSION *Therefore, some vitamin tablets are not nutritional.*



Only 46% of the participants concluded that this syllogism, S_{vit}, is valid
Evans, Barston and Pollard (1983) called this phenomenon the belief-bias effect

Towards a Theory of Human Reasoning

Weak Completion Semantics (WCS) (Hölldobler and Kencana Ramli [2009])

- Logic Programming approach based on Stenning and van Lambalgen [2008]
- Open world assumption and closed world assumption
- Reasoning with respect to least models (which always exist)
- Three-valued Łukasiewicz [1920] Logic

Weak Completion Semantics seems to adequately model

- Byrne's (1989) Suppression Task

  D., Hölldobler, Ragni *A computational logic approach to the suppression task* CogSci (2012)
- Wason's (1968) Selection Task

  D., Hölldobler, Ragni *A computational logic approach to the abstract and the social case of the selection task* Commonsense (2013)
- Spatial Reasoning (Ragni and Knauff [2013])

  D., Hölldobler, Höps *A computational logic approach to human spacial reasoning* SSCI (2015)

Can we model the Belief-Bias Effect in Syllogistic Reasoning?

Human Syllogistic Reasoning

Khemlani and Johnson-Laird (2012) made a meta-study on syllogistic reasoning

- 64 different pairs of premises and 512 different pairs of syllogisms
- Data from 6 psychological experiments
- Comparision of this data with 12 cognitive theories
- None of the 12 theories seems to model human reasoning adequately!
- '*The existence of 12 theories of any scientific domain is a small disaster.*'
- '*If psychologists could agree on an adequate theory of syllogistic reasoning, then progress toward a more general theory of reasoning would seem to be feasible. If, however, researchers were unable to account for syllogistic reasoning, then they would have little hope of making sense of reasoning in general.*'

	Participants	PSYCOP	Verbal Models	Mental Models	WCS
Overall results	100%	77%	84%	78%	92%

- We developed a human syllogistic reasoning approach under WCS
- We achieved a match of 92%!

Costa, D., Hölldobler, Ragni *A computational logic approach to human syllogistic reasoning* CogSci (2017)

D., Hölldobler, Mörbitz *Principles and Clusters in Human Syllogistic Reasoning* submitted

Principles on Quantified Statements

1. Licences for Inferences (LICENSES) (Stenning and van Lambalgen, 2008)

   If $y(X)$ then $z(X)$

   If $y(X)$ and nothing is abnormal wrt X then $z(X)$

2. Existential Import (IMPORT) (Grice, 1975)

   All $y(X)$ are $z(X)$

   There exists one o such that $y(o)$ is true

3. Unknown Generalization (UNKGEN)

   Some $y(X)$ are $z(X)$

   - There exists one o_1 such that $y(o_1)$ and $z(o_1)$ is true
   - There exists one o_2 such that $y(o_2)$ is true and $z(o_2)$ is unknown

4. Negation by Transformation (TRANSFORMATION)

   No $y(X)$ are $z(X)$

   If $z(X)$ then $y'(X)$ If not $y'(X)$ then $y(X)$

5. Search for Alternative Models (SEARCHALT)
6. No Derivation from Double Negation (DNEGATION)
7. Converse Implication (CONVERSE)

Logic Programs, Weak Completion and Least Models

- Program $\mathcal{P}$: set of rules, facts and assumptions

$$\begin{array}{rcll} p(X) & \leftarrow & q(X) \wedge \neg ab(X) & \text{rule} \\ p(X) & \leftarrow & r(X) & \\ q(o) & \leftarrow & \top & \text{fact} \\ ab(X) & \leftarrow & \bot & \text{assumption} \end{array}$$

- Ground Program $g\mathcal{P}$: contains all ground instances of its clauses

$$\begin{array}{rcl} p(o) & \leftarrow & q(o) \wedge \neg ab(o) \\ p(o) & \leftarrow & r(o) \\ q(o) & \leftarrow & \top \\ ab(o) & \leftarrow & \bot \end{array}$$

- Weakly completed program & least model

$$\begin{array}{rcl} p(o) & \leftrightarrow & (q(o) \wedge \neg ab(o)) \vee r(o) \\ q(o) & \leftrightarrow & \top \\ ab(o) & \leftrightarrow & \bot \end{array}$$

true	false	
$q(o)$	$ab(o)$	$\Phi \uparrow 1$
$p(o)$		$\Phi \uparrow 2$

  - logical consequence with respect to least models

$$\mathcal{M} \quad = \quad \langle \{p(o), q(o)\}, \{ab(o)\} \rangle \not\models r(o) \vee \neg r(o)$$

Syllogism S_{vit} without Belief Bias

No nutritional things are inexpensive. *Some vitamin tablets are inexpensive.*

$\mathcal{P}_{vit}$ is

$$
\begin{array}{rcll}
nutri'(X) & \leftarrow & inex(X) \wedge \neg ab_{nutri'}(X). & \text{(TRANSFORMATION \& LICENSES)} \\
ab_{nutri'}(X) & \leftarrow & \bot. & \text{(LICENSES)} \\
nutri(X) & \leftarrow & \neg nutri'(X) \wedge \neg ab_{nutri}(X). & \text{(TRANSFORMATION \& LICENSES)} \\
inex(o_1) & \leftarrow & \top. & \text{(IMPORT)} \\
ab_{nutri}(o_1) & \leftarrow & \bot. & \text{(LICENSES \& DNEGATION)} \\
inex(X) & \leftarrow & vitamin(X) \wedge \neg ab_{inex}(X). & \text{(LICENSES)} \\
vitamin(o_2) & \leftarrow & \top. & \text{(IMPORT)} \\
ab_{inex}(o_2) & \leftarrow & \bot. & \text{(UNKGEN \& LICENSES)} \\
vitamin(o_3) & \leftarrow & \top. & \text{(UNKGEN)}
\end{array}
$$

$\mathcal{M} = \langle I^{\top}, I^{\bot} \rangle$ of $\mathcal{P}_{vit}$ is

$$
\begin{array}{ll}
I^{\top} = & \{vitamin(o_2), vitamin(o_3), inex(o_1), inex(o_2), nutri'(o_1), nutri'(o_2)\} \\
I^{\bot} = & \{nutri(o_1), nutri(o_2), ab_{inex}(o_2), ab_{nutri}(o_1), ab_{nutri'}(o_1), ab_{nutri'}(o_2), ab_{nutri'}(o_3)\},
\end{array}
$$

- This model entails the CONCLUSION of S_{vit}

  CONCLUSION *Therefore, some vitamin tablets are not nutritional.*

Syllogism S_{vit} with Belief Bias

It is commonly known that

The purpose of vitamin tablets is to aid nutrition.

This belief in the context of PREMISE 1 leads to

If something is a vitamin tablet, then it is abnormal. *(regarding* PREMISE 1 *of* S_{vit}*)*

We extend $\mathcal{P}_{vit}$ accordingly, which results in

$$\mathcal{P}_{vit}^{\text{bias}} = \mathcal{P}_{vit} \cup \{ab_{nutri'}(X) \leftarrow vitamin(X)\}$$

$\mathcal{M}$ of $\mathcal{P}_{vit}^{\text{bias}} = \langle I^{\top}, I^{\bot} \rangle$ is

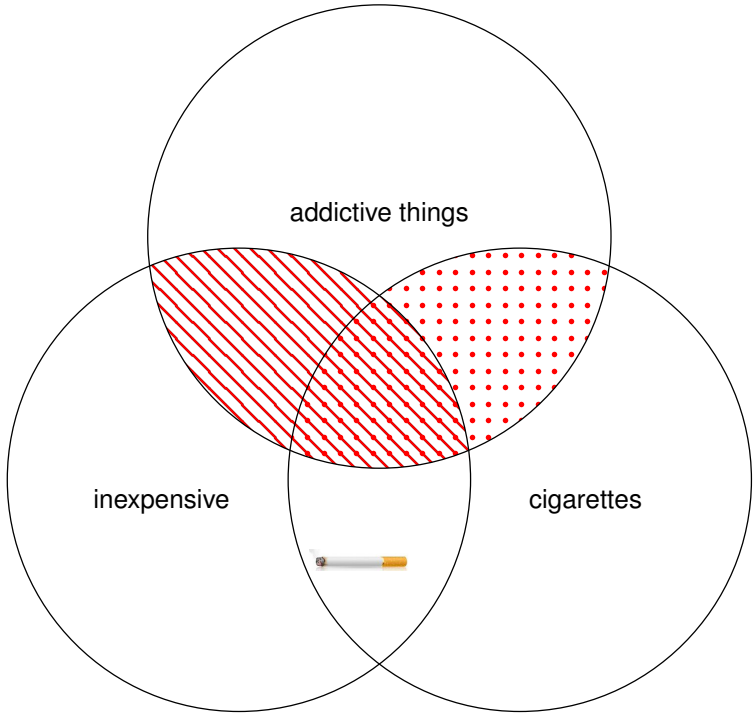
$$I^{\top} = \{inex(o_1), inex(o_2), vitamin(o_2), vitamin(o_3), ab_{nutri'}(o_2), ab_{nutri'}(o_3)\}$$
$$I^{\bot} = \{nutri'(o_2), nutri'(o_3), ab_{nutri'}(o_1), ab_{inex}(o_2)\}$$

- This model does not entail the CONCLUSION of S_{vit}

PREMISE 1 *No addictive things are inexpensive*

PREMISE 2 *Some cigarettes are inexpensive*

CONCLUSION *Therefore, some addictive things are not cigarettes* Cannot be concluded!



- 92% of the participants concluded that S_{add} is valid
- Principle SEARCHALT applies here: Participants search for alternative models

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Thank you very much for your attention!

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