Shifts of Attention During Spatial Language Comprehension
A Computational Investigation

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Motivation // Remove the spider!
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image sources:
Robot needs to know what you mean by “left”
Robots comprehending human (spatial) language

- robot needs to know what you mean by “left”
- implement human-like processes
Robots comprehending human (spatial) language

- robot needs to know what you mean by “left”
  → implement human-like processes

**But:** How do humans comprehend spatial prepositions?
Previous Research // Logan and Sadler (1996, experiment 2)

The X is above the O.
Previous Research // Logan and Sadler (1996, experiment 2)

(image source: Logan & Sadler, 1996, p. 510)
Previous Research // Logan and Sadler (1996, experiment 2)

(image source: Logan & Sadler, 1996, p. 510)
Previous Research // Regier and Carlson (2001, exp. 5 & 6)

(image sources: Regier & Carlson, 2001, p. 287-288)
Proximal and center-of-mass orientation

(a) proximal orientation
(b) center-of-mass orientation

(image adapted from Roy, 2005, p. 390)
cognitive model: **Attentional Vector Sum** (AVS) model
(Regier & Carlson, 2001)
AVS Model // Regier and Carlson (2001)

spatial preposition: *above*

located object: LO

reference object: RO

→ AVS model
AVS Model // Regier and Carlson (2001)

spatial preposition: *above*

located object: LO

reference object: RO

→ AVS model → acceptability rating
AVS Model // Regier and Carlson (2001)

AVS model assumes shift of attention from RO to LO

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AVS model consists of

1. angular component
2. height component
\[ a_i = \exp \left( \frac{-d_i}{\lambda \cdot \sigma} \right) \]
\[
\text{direction} = \sum_{i \in RO} a_i \cdot \vec{v}_i
\]
$g(\delta) = \text{slope} \cdot \delta + \text{y-intercept}$
height\((y_{LO})\) = \frac{\text{sig}(y_{LO} - \text{hightop}, \text{highgain}) + \text{sig}(y_{LO} - \text{lowtop}, 1)}{2}

above\((LO, RO) = g(\delta) \cdot \text{height}(y_{LO})\)
rAVS Model // Motivation

- AVS assumes shift of attention from RO to LO
(image source: Roth & Franconeri, 2012, p. 5)
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“Die Box ist über der Wurst”
‘The box is above the sausage’

(image source: Burigo & Knoeferle, 2015, p. 6)

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rAVS Model // Main Idea

AVS model

⇒

reversed AVS model
above(LO, RO) = g(\delta) \cdot \text{height}(y_{LO})
rAVS Model // Details

\[ D_1 = \begin{cases} \text{LC} & \text{if } (\alpha \cdot \text{dist}_{rel} + 1) > 0 \\ \text{CF} & \text{else} \end{cases} \]
proximal orientation

center-of-mass orientation

\[
C = \begin{cases}
  \text{LC} & \text{if } (\alpha \cdot \text{dist}_{rel} + 1) > 0 \\
  \text{CF} & \text{else}
\end{cases}
\]
\[
D = \begin{cases} 
\overrightarrow{LC} + (-\alpha \cdot \text{dist}_{rel.} + 1) \cdot \overrightarrow{CF} & \text{if } (-\alpha \cdot \text{dist}_{rel.} + 1) > 0 \\
\overrightarrow{C} & \text{else}
\end{cases}
\]
relative distance = $\frac{|LO, P_x|}{RO_{width}} + \frac{|LO, P_y|}{RO_{height}}$
Method // Model Comparison

free parameters:
- slope
- intercept
- highgain
- \( \lambda \)

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- slope
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- highgain
- \( \alpha \)
Method // Model Comparison

AVS & rAVS
4 free parameters
Method // Model Comparison

Regier and Carlson (2001): 7 experiments → 10 ROs, 337 LOs

input (ROs, LOs) → AVS & rAVS
4 free parameters
Method // Model Comparison

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input (ROs, LOs)

empirical ratings

AVS & rAVS
4 free parameters

model ratings
Regier and Carlson (2001): 7 experiments → 10 ROs, 337 LOs

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i} (data_i - modelOut_i)^2} \]
Results // Goodness of Fit, Regier and Carlson (2001, all experiments)
Method // Problems of GOF

(image source: Pitt & Myung, 2002, p. 424)
Method // Simple Hold-Out (Schultheis, Singhaniya, & Chaplot, 2013)
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Results // GOF and SHO, Regier and Carlson (2001, all experiments)

The diagram shows the comparison of SHO and GOF in terms of 100% normalized RMSE for AVS and rAVS. The SHO method consistently outperforms the GOF method across all normalized RMSE values for both AVS and rAVS.
rAVS model: a modification of the AVS model that integrates recent findings (Burigo & Knoeferle, 2015; Roth & Franconeri, 2012)
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Conclusion

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  - rAVS is less complex than AVS
- both models perform equally well on the data from Regier and Carlson (2001)
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both directionalities of the attentional shift are equally well supported
Future Work

- experiment to distinguish the models
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  - the LO
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  - the LO
  - timing
  - functionality of objects

(images adapted from: Hörberg, 2008, p. 200)
Future Work

- experiment to distinguish the models
- extend model with
  - the LO
  - timing
  - functionality of objects
- implement into technical systems
  - C++ source code available under an open source license at Kluth (2016)

(image source: Mamirobothk, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=25084931)
Thank you for your attention!

References


RMSE // GOF and SHO, Regier and Carlson (2001, all experiments)