Robotic Modelling of the Acquisition of Multiple Number Forms

Marek Ruciński, Angelo Cangelosi, Tony Belpaeme
Centre for Robotics and Neural Systems, University of Plymouth

RESEARCH WITH PLYMOUTH UNIVERSITY

Objectives

Extend the current model [Ruciński et al., 2011] of number-space interactions [Göbel et al., 2011] to account for the following aspects of the SNARC effect:

- co-existence of multiple number-space associations
- binding with response side rather than response hand

Motivations: understand better the process of acquisition of the number concept and how the brain represents and processes numbers.

Number Forms – Associating Numbers with Space

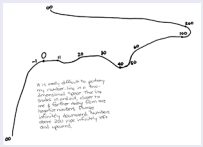


Photo: Kelley, http://www.flickr.com/photos/twitchcraft/

Evidence:

- patients with synæsthesia
- patients with neglect
- neuroimaging
- behavioural effects

Open questions:

- the origins
- the mechanism

SNARC effect [Dehaene et al., 1993]

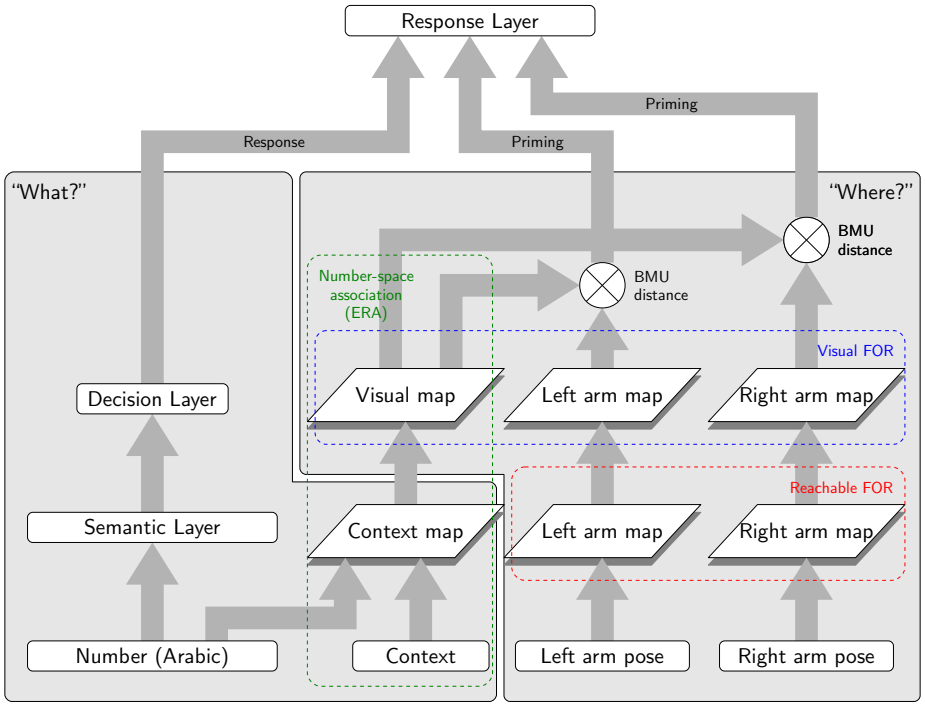
- Spatial-Numerical Association of Response Codes
- left-sided response faster for small numbers, right-sided for large
- contextual, flexible, various stimuli

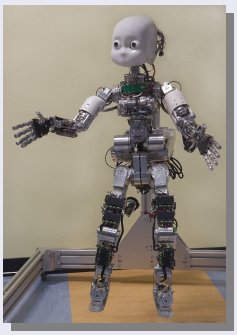
Posner-SNARC effect [Fischer et al., 2003]

- numbers cue attention
- small numbers toward left, large toward right
- also flexible

Embodied Developmental Robotic Model of Multiple Number-Space Associations

The Model





iCub, humanoid robotic platform

- Size: 3.5-year old child
- DoF: 53, 20 used (head + eyes, 2 arms)
- Rich perception (visual, auditory, tactile, proprioceptive)

Training

Consists of 4 stages which resemble human development:

1. Building spatial representations and transformations. This corresponds to "motor babbling" in children. This results in formation of spatial maps in reachable and visual Frames of reference (FOR). Hebbian learning establishes transformations between the FORs.
2. Acquisition of the meaning of Arabic numbers. In contrast to orthogonal representations in the input layer (Arabic number), semantic representations may overlap.
3. Formation of number-space associations. This is the crucial stage of the development. Exposure to various number arrangements (number line, thermometer, clock face) forms different internal number-space associations. Multiple mappings can be build due to dependence on the context.
4. Learning numerical tasks. The model has to be able to perform simple numerical tasks (magnitude comparison, parity judgement) for which human data are available.

Model assessment

Model performance is assessed based on behavioural effects. Response times (RTs) of the model are compared with human data. RTs are analysed for the presence of signature of effects such as size and distance effect, SNARC and Posner-SNARC.

About the model

This embodied robotic model is based on previous modelling efforts [Caligiore et al., 2010, Chen & Verguts, 2010, Morse et al., 2010, Ruciński et al., 2011]. Epigenetic approach enables taking into account the effects of "external" factors like body shape, environment or culture.

Summary

The model achieves:

- reproduction of the experimental phenomena: size effect, distance effect, SNARC and Posner-SNARC
- properties of SNARC and Posner-SNARC match better with reality
- the first model of context-dependent number-space associations (to the best of our knowledge)

Future work:

- less partitioned development process
- analysis of developmental trajectories
- test predictions with human participants

RobotDoC Initial Training Network

RobotDoC
Robotics for Development of Cognition
http://www.robotdoc.org/

RobotDoC is a multi-national doctoral training network for the interdisciplinary training on developmental cognitive robotics. 8 partners from 5 countries train 13 PhD and 3 post-doc fellows.

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MARIE CURIE ACTIONS

References

Caligiore, D., Borghi, A. M., Parisi, D., and Baldassarre, G. (2010). TRoPICALS: A computational embodied neuroscience model of compatibility effects. *Psychological Review*, 117(4):1188–1228.

Chen, Q. and Verguts, T. (2010). Beyond the mental number line: A neural network model of number-space interactions. *Cognitive Psychology*, 60(3):218–240.

Dehaene, S., Bossini, S., and Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122(3):371–396.

Fischer, M. H., Castel, A. D., Dodd, M. D., and Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience*, 6(6):555–556.

Göbel, S. M., Shaki, S., and Fischer, M. H. (2011). The cultural number line: A review of cultural and linguistic influences on the development of number processing. *Journal of Cross-Cultural Psychology*, 42(4):543–565.

Morse, A. F., de Greeff, J., Belpaeme, T., and Cangelosi, A. (2010). Epigenetic robotics architecture (ERA). *Autonomous Mental Development, IEEE Transactions on*, 2(4):325–339.

Ruciński, M., Cangelosi, A., and Belpaeme, T. (2011). An embodied developmental robotic model of interactions between numbers and space. In Carlson, L., Hoelscher, C., and Shipley, T. F., editors, *33rd Annual Meeting of the Cognitive Science Society*, pages 237–242.