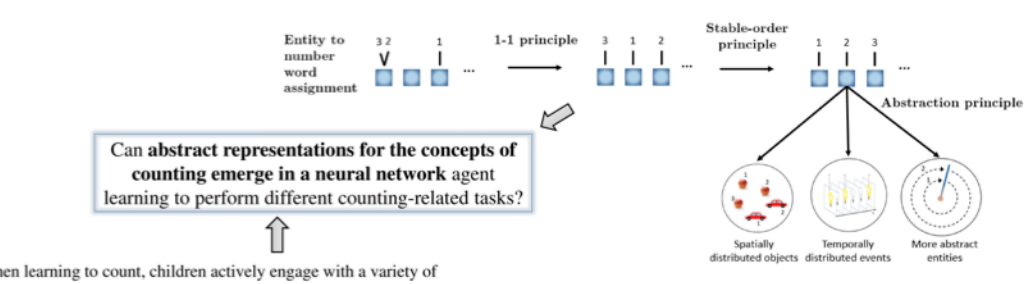
Emerging Representations for Counting in a Neural Network Agent Interacting with a Multimodal Environment

Silvester Sabathiel[1], James McClelland[2], Trygve Solstad[3]

[1]Department of Computer Science, NTNU – Norwegian University of Science and Technology, NO-7491 Trondheim, Norway,
[2]Department of Psychology, Stanford University, Stanford, CA, 94305, USA
[3]Department of Teacher Education, NTNU – Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

1. Introduction and Background

Counting involves abstract principles [1]



Can **abstract representations for the concepts of counting emerge in a neural network** agent learning to perform different counting-related tasks?

When learning to count, children actively engage with a variety of counting tasks and observe demonstrations by more knowledgeable others.

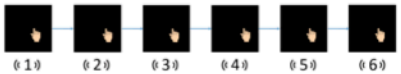
2. Interactive, Multimodal Environment [2]

Environment

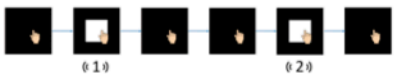
- Input/observation:
  - Visual 2D-input
  - Lingual input (Task instruction)
- Output/action-space:
  - Manipulator movement: Left, right, up, down
  - Pick/Release object
  - Say words: "stop", "1", "2", "3…"

Tasks

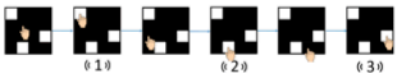
Reciting N number words



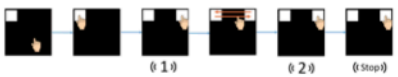
Count all events



Count all objects

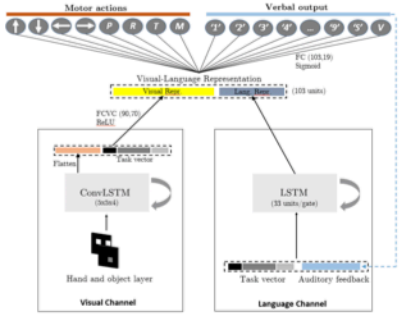


Give-N objects



3. Learning system

Neural Network Architecture [3] [4]



Task instruction vector

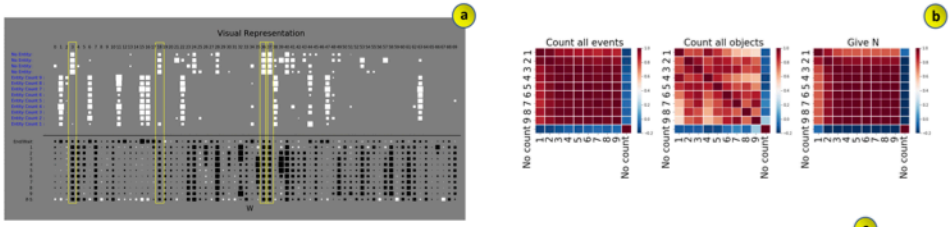
Learning Procedure

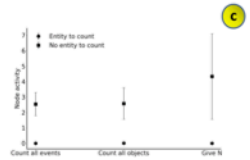
Supervised learning with automatic solving algorithm as teacher:

- Backpropagation after a whole trial
- Batch size: 9, uniformly drawn from tasks and # of entities and initial positions in x and y coordinates
- Dataset: for each trial, a new batch is created from sampled environment

4. Results

1. Entity to number word assignment



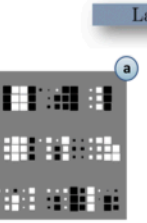


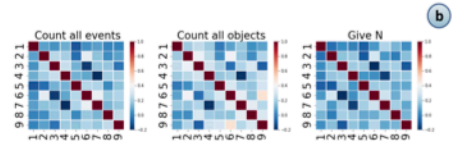
(a) **Hinton diagram** [5]: nodes that are deactivated only when there is a countable entity and are connected to the output of the number words via uniformly, large negative weights

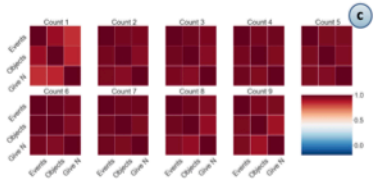
(b) **Correlation analysis:** node activity distinguished clearly between times when an entity was to be counted and times when no entity was to be counted

(c) ***Abstract entity* nodes:** nodes that represent entities independent of the kind of entity

2. Abstract number representation







(a) **Hinton diagram**: each number had a distinct Language representation that was highly similar for different tasks

(b) **Correlation analysis:** Each number has a distinct language representation.

(c) **Correlation analysis:** The Language representation of each number is the same for each task.

5. Conclusion

The results show that the **network developed specific representations for several key components of counting**, like the identification of an entity to count, the establishment of one-to-one correspondence between entities and number words, and the number of entities counted. These **representations were highly similar between different counting tasks**, suggesting that the network's knowledge about and representation of the counting procedure was shared across all of the tasks.

References

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[5] Hinton, G. E. and Shallice, T. (1991). Psychological review, 98(1):74.

Contact: silvester.sabathiel@ntnu.no
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