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Empirical Studies in Machine Psychology

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Abstract

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Preface

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Acknowledgements

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Contents

CHAPTER 1

Introduction

CHAPTER 2

Background and Preliminaries

In this chapter, I provide the necessary background for understanding the results from the thesis. First, I provide an introduction to the field of Artificial General Intelligence (AGI). Then, I describe a particular AGI system, NARS, that will be used as the subject of study. Finally, I introduce Learning Psychology, that will be a foundational framework, that clarifies the subject matter of the empirical results in this thesis.

2.1 Artificial General Intelligence

The birth of Artificial Intelligence (AI), as we know it today, is by many agreed on to have been in 1955, when John McCarthy decided to organize a workshop on the topic of building thinking machines. In the invite letter, McCarthy wrote:

We propose that a 2-month, 10-man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire. The study is to proceed on the basis of the conjecture that ***every aspect of learning*** *or any other feature of intelligence can in principle be so* ***precisely described that a machine can be made to simulate it****. An attempt will be made to find how to make machines* ***use language, form abstractions and concepts, solve kinds of problems now reserved for humans****, and improve themselves. We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer. (Boldface added)*

The reason why I mention this workshop invitation here, is to highlight a few facts. First, AI clearly aimed from the start to target ***every aspect of learning*** (put differently: all types of learning). Second, already at this stage, there was a call for precise definitions of terms (with the aim for this learning to be possible to study with machines). Third,

2.2 Learning Psychology

Learning psychology, can be seen as the study of *ontogenetic adaptation* [1]. That is, the adaptation of an individual organism to its environment during its lifetime. In line with this, learning in itself can be defined as *changes in the behavior of an organism that are the result of regularities in the environment of that organism* [1].

2.3 NARS

CHAPTER 3

Operant Conditioning

Given the perspective on AGI taken in this thesis, that we are defining AGI as all types of learning that a human can do, we will use this chapter to investigate one particular form of learning, operant conditioning.

3.1 Operant Conditioning

Operant conditioning is a type of learning that can be observed in most species, from fruit flies [2], invertebrates [3], to rats [4] and human beings [5].

3.2 OpenNARS for Applications

This chapter uses a sensorimotor version of the NARS system OpenNARS for Applications (ONA) [6]. More specifically, this was a version of ONA compiled with the parameter `SEMANTIC_INFERENCE_NAL_LEVEL` was set to `0`, which means that only NAL layers 6–8 were available. This means that the system could only do sensorimotor inference (procedural and temporal reasoning), but no semantic inference (declarative reasoning). The NARS rules are described in Listing 3.1.

```
// Rule 1: Projecting to current time
{Event a.} |- Event a. Truth_Projection

// Rule 2: Forming a temporal sequence of two events
{Event a., Event b.} |- Event (a &/ b). Truth_Intersection

// Rule 3: Forming an implication between two events
```

```
{Event a., Event b.} |- Implication <a =/> b>. Truth_Eternalize(
    Truth_Induction)

// Rule 4: Revision of an implication
{Implication <a =/> b>., <a =/> b>.} |- Implication <a =/> b>.
    Truth_Revision

// Rule 5: Subgoal derivation v1
{Event b!, Implication <a =/> b>.} |- Event a! Truth_Deduction

// Rule 6: Subgoal derivation v2
{Event (a &/ b)!, Event a.} |- Event b! Truth_Deduction

// Rule 7: Revision or Choice (dependent on evidental overlap)
{Event a!, Event a!} |- Event a! Truth_Revision or Choice

// Rule 8: Temporal deduction
{Event a., Implication <a =/> b>.} |- Event b.  Truth_Deduction
```

Listing 3.1. NARS Rules from Layer 7 and 8

3.3 Method

ONA was configured with the following settings.

```
*babblingops=2
*motorbabbling=0.2
*setopname 1 ^left
*setopname 2 ^right
*volume=100
```

This means that the system was configured to have two operators `^left` and `^right`, and an initial chance of motor babbling set to 20%. The `volume` parameter was set to a maximum value of 100, for the entire log file of the NARS reasoning process to be available for inspection.

The experiment consisted of three phases: Baseline assessment, Training (with feedback), and Testing (without feedback). In all phases, training and testing were done in blocks of trials. Given the experimental design, only two possible trials were possible. Either, that A1 was to the left, and A2 to the right, or, that A2 was to the left, and A1 to the right. A block contained twelve trials, with the two possible trials each presented six times each in random order.

A typical task was given to ONA in the form of temporal statements:

```
<A1 --> [left]>. :|:
<A2 --> [right]>. :|:
G! :|:
```

Given the task description of "always select A1, independent of location", the experimental design encoded a ^left response by ONA when <A1 --> [left]> as "Correct", and similar for ONA responding ^right when <A1 --> [right]>. Importantly, this "Correct" is from the perspective of the experiment. A response from ONA is always "Correct" from the perspective of the system itself.

The dependent variable of the experiment was set to the rate of correct responding per block of 12 trials. A detailed description of the three phases follow.

1. **Baseline.** The baseline consisted of three blocks. No feedback was given during this phase. This phase functioned to establish a baseline probability of responding correct according to the experimental design. It was expected that ONA would respond correctly by chance in 50% of the trials.

2. **Training.** The system was trained on a set of three blocks. Feedback was given as G. :|: and G. :|: {0.0 0.9} when the system was correct and incorrect, respectively.

3. **Testing.** In the final phase, the system was tested without feedback in three blocks. Testing was conducted with the same contingencies that was presented during training.

3.4 Results

During baseline, the amount of correct trials ranged between 30 and 60% during the three blocks, indicating that no learning took place (no changes in behavior was due to regularities in the environment). In the training, NARS was 100% correct already in the second out of three training blocks. In the final phase, where NARS was tested without feedback, the system responded 100% correct in all three blocks. Given this, the results in total indicate that the changes in behavior from baseline to testing, were due to the regularities between the system's own behavior and other events, as presented during the training phase. The results are illustrated in Figure 3.1.

3.5 Discussion

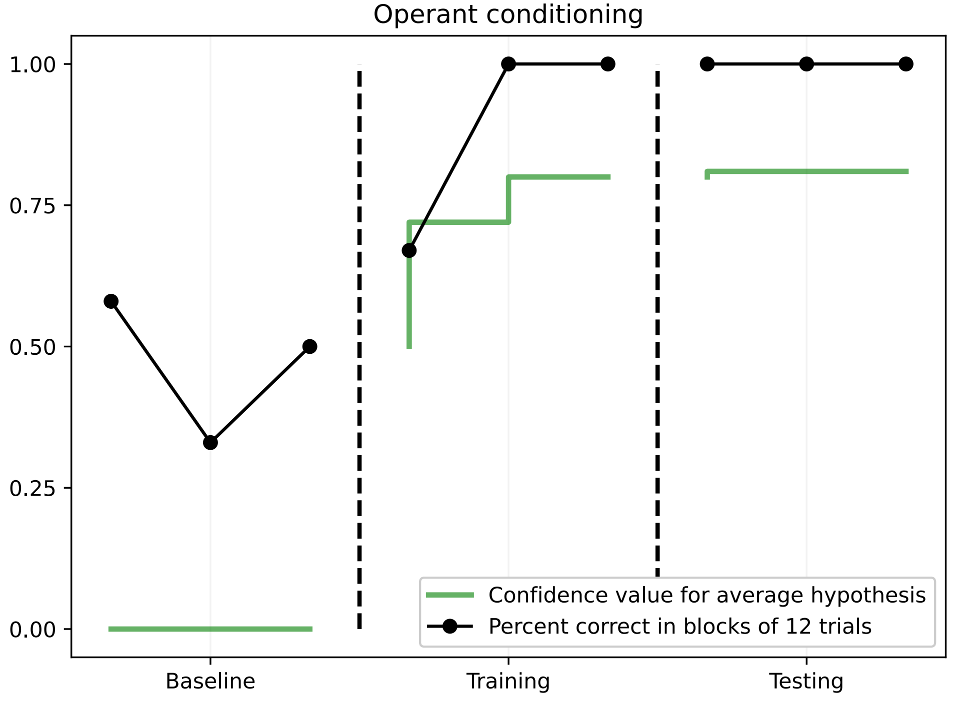

Figure 3.1. Learning in the form of operant conditioning. Dots illustrate the percent of correct in blocks of 12 trials. The solid line shows the NARS confidence value for specific hypotheses.

CHAPTER 4

Generalized Identity Matching

4.1 Introduction

4.2 Method

4.3 Results

4.4 Discussion

The results from the four phases are illustrated in Figure 4.1.

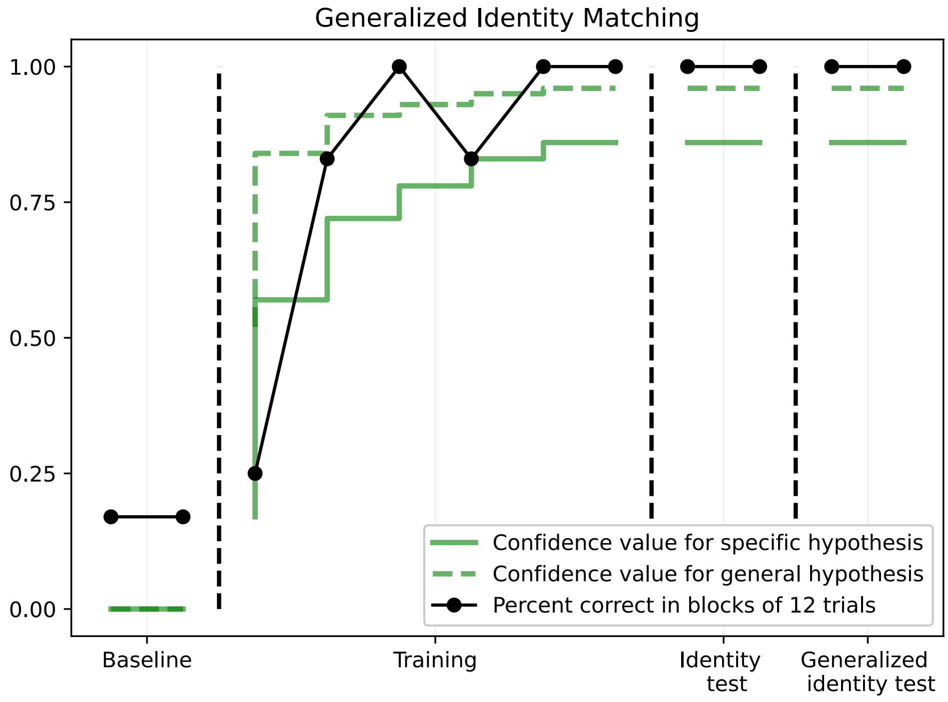

Figure 4.1. Learning generalized identity matching in the Match-to-sample task. Dots illustrate the percent of correct in blocks of 12 trials. The solid line shows the NARS confidence value for specific hypotheses (identity matching), while the dashed line illustrates the NARS confidence in general hypotheses (generalized identity matching).

CHAPTER 5

Stimulus Equivalence

In this chapter, I introduce a few experiments that all involve complex learning. Moreover, they could all be said to be related to the phenomenon called *stimulus equivalence*. This chapter involves extending ONA with a new rule, the *contingency entailment rule*. This rule is inspired by statement-level inference

5.1 Introduction

5.2 Method

5.3 Results

5.4 Discussion

CHAPTER 6

Arbitrarily Applicable Relational Responding

6.1 Introduction

6.2 Method

6.3 Results

6.4 Discussion

CHAPTER 7

Conclusions and Future Work

7.1 Conclusions

7.2 Future Work

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