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# Neuro-Symbolic Architecture for Extraction and Application of Higher-Order Rules Using Serial-Order Codes

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## Introduction

Being able to capture higher-order rules that govern sequences of, for example, robot actions is still a challenging task for neural networks. One of the mechanisms that allows to extract hierarchical dependencies between items within time series is rank-order coding. The different possible orders of items (actions), called ordinal codes, can be understood as a grammar, or a set of rules governing the sequences. We propose a sample-efficient neuro-symbolic architecture based around the mechanism of rank-order coding that is able to rapidly extract and learn the underlying rules from example sequences. These rules can then be used in a generative manner to construct novel sequences, adhering to the principle of compositionality (see Fig. 1). We demonstrate how this framework can be used with sequences of both abstract, compound elements, like discrete states of a game (Towers of Hanoi), as well as with sequences of actions performed in continuous motor space.

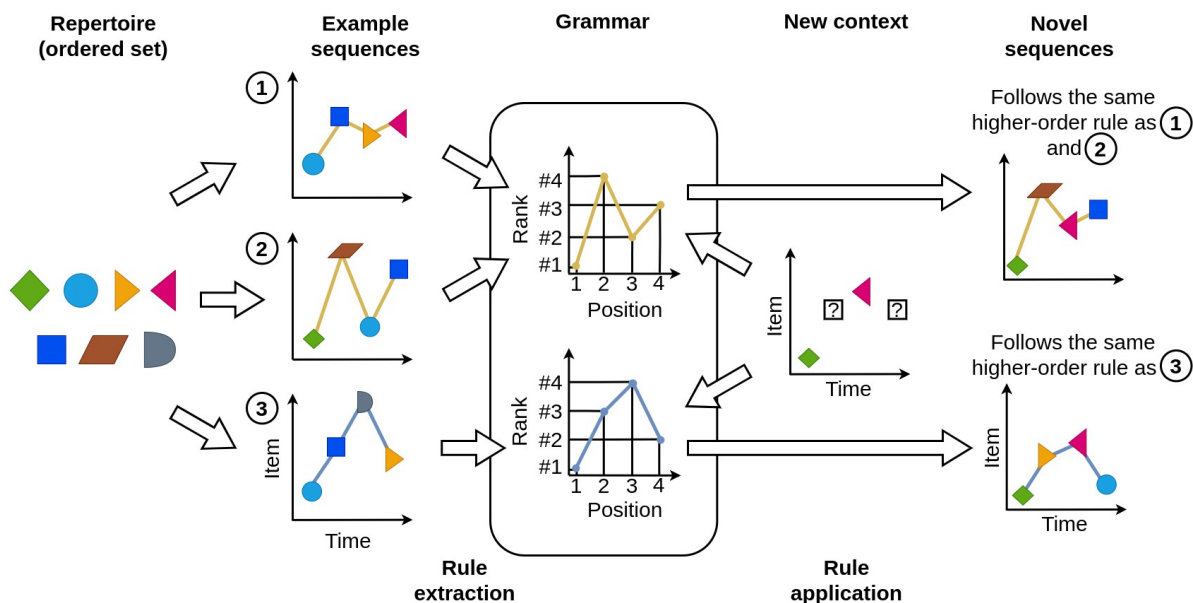


Figure 1: Extraction of higher-order rules from sequences using rank-order coding. Given new context, these rules can be used to construct novel sequences. Figure taken from [3].

## Methods

The presented architecture is based on the Inferno Gate [1] architecture. It consists of two sub-systems that are connected in a serial manner. The first sub-system uses the rank-order mechanism to extract and learn the rules that govern sequences within the scope of the given task (Fig. 1). The second sub-system tries to predict the activity of the first system by utilizing noise-driven search with different heuristics. An extension to the original architecture is the mechanism of chunking (similar to snippets, as defined in [2]). This mechanism allows to the first sub-system to extract rules that are atomic in nature, and that can be used to generate novel sequences according to the principle of compositionality.

## Experiments

The Towers of Hanoi, a well-known logical puzzle was selected as the testing ground for our architecture. The puzzle can be examined in two ways. In its mathematical form, all states of the game are represented as nodes in a cyclic directed graph, and sequences consisting of these discrete states can be considered. Alternatively, one can examine the movements that are executed when moving the plates between the pegs, resulting in sequences of actions belonging to a two-dimensional continuous space (example in Fig. 2). In both cases there exist strong hierarchical rules that govern the order of items in sequences. These rules are captured by the rank-order mechanism, and are later used to either construct novel sequences.

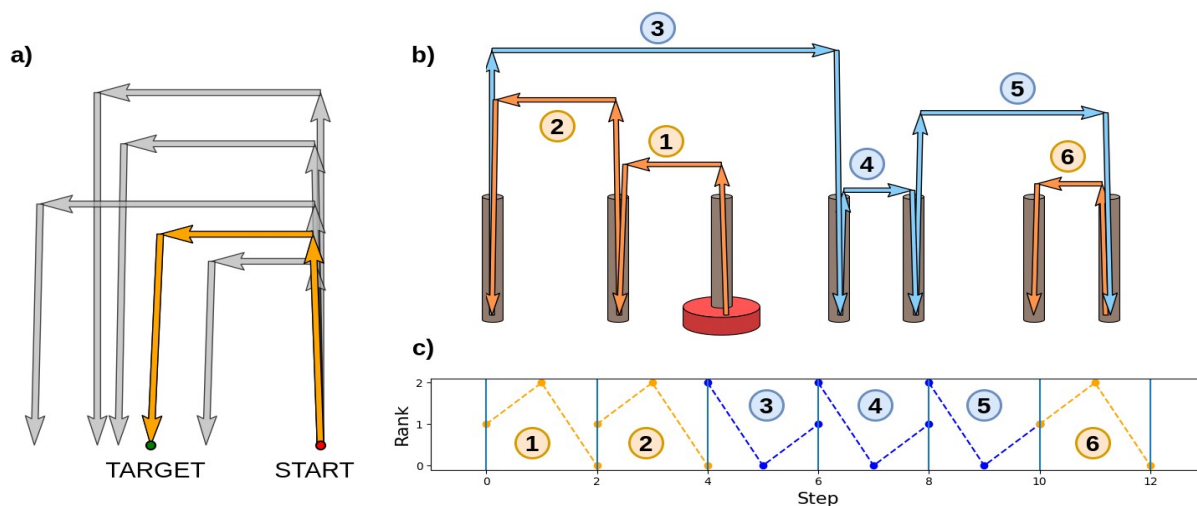


Figure 2: A single step of movement (chunk) selection is shown in a). Ordinal codes allow to narrow down the set of possible solutions, based on the direction of the target. Long sequences of movements can be iteratively generated from different chunks, as presented in b). Each chunk from the sequence matches a certain ordinal code, as shown in c). Figure taken from [3].

## Discussion

The experiment give credibility to the rank-order mechanism’s ability to capture long-range dependencies between items within sequences. We showed that rank-order coding can be used to construct generative models of both discrete and continuous environments. Ordinal codes are amodal, which means that they can be used with different types of data with strong hierarchical dependencies, and that transfer learning of learned rules ought to be possible. Our framework is lightweight and doesn’t require many samples to learn – the number of example chunks were in the range of tens or hundreds in all presented experiments. We are planning to further explore use of ordinal codes for capturing higher-order rules. In the next step we are going to apply our architecture to the goal-oriented task of pick-and-place in a 3d environment.

## References

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