

Chapter 19

On Machine Symbol Grounding and Optimization

Oliver Kramer

Bauhaus-University Weimar, Germany

ABSTRACT

From the point of view of an autonomous agent the world consists of high-dimensional dynamic sensorimotor data. Interface algorithms translate this data into symbols that are easier to handle for cognitive processes. Symbol grounding is about whether these systems can, based on this data, construct symbols that serve as a vehicle for higher symbol-oriented cognitive processes. Machine learning and data mining techniques are geared towards finding structures and input-output relations in this data by providing appropriate interface algorithms that translate raw data into symbols. This work formulates the interface design as global optimization problem with the objective to maximize the success of the overlying symbolic algorithm. For its implementation various known algorithms from data mining and machine learning turn out to be adequate methods that do not only exploit the intrinsic structure of the subsymbolic data, but that also allow to flexibly adapt to the objectives of the symbolic process. Furthermore, this work discusses the optimization formulation as a functional perspective on symbol grounding that does not hurt the zero semantical commitment condition. A case study illustrates technical details of the machine symbol grounding approach.

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1. INTRODUCTION

The literature on artificial intelligence (AI) defines “perception” in cognitive systems as the transduction of subsymbolic data to symbols (e.g., Russell & Norvig, 2003). Auditory, visual or tactile data from various kinds of sense organs is subject to neural pattern recognition processes, which reduce it to neurophysiological signals that our mind interprets as symbols or schemes. The human visual system has often referred to as an example for such a complex transformation. Symbols are thought to be representations of entities in the world, having a syntax of their own. Even more importantly, symbols are supposed to be grounded by their internal semantics. They allow cognitive manipulations such as inference processes and logical operations, which made AI researches come to believe that thinking can be referred to as the manipulation of symbols, and therefore could be considered to be computations (Harnad, 1994). Cognition becomes implementation-independent, systematically interpretable symbol-manipulation.

However, how do we define symbols and their meaning in artificial systems, e.g., for autonomous robots? Which subsymbolic elements belong to the set that defines a symbol, and – with regard to cognitive manipulations – what is the interpretation of a particular symbol? These questions are the focus of the “symbolic grounding problem” (SGP) (Harnad, 1990), and the “Chinese room argument” (Searle, 1980), both of which concentrate on the problem of how the meaning and the interpretation of a symbol is grounded in action. Several strategies have been proposed to meet these challenges. For a thorough review cf. (Taddeo & Floridi, 2005).

To my mind the definition of a symbol and its interpretation is mostly of functional nature. The intention and the success in solving problems to achieve goals must guide the meaning and

thus the definition of symbols. Hence, it seems reasonable to formulate the symbol definition as optimization problem. Optimal symbols and their interpretations yield optimal success of an autonomous agent. In many artificial systems symbols are defined by an interface algorithm that maps sensory or sensorimotor data to symbol tokens, e.g., class labels. Optimizing a symbol with regard to the success of cognitive operations means optimizing the interface design. In many artificial systems the interface design is part of an implicit system modeling process – regrettably often without much effort spent on an optimal architecture.

The paper is structured according to three perspectives it introduces. First, the formal perspective in Section 2 will formulate the interface design as global optimization problem. The concepts of symbols and higher cognitive operations are formalized. The interface between subsymbolic and symbolic representations is introduced in an optimization formulation while potential objectives, free parameters and a two-level optimization process are discussed. An algorithmic perspective is shown in Section 3, where I discuss typical data mining and machine learning tasks like classification, clustering and dimensionality reduction in the context of interface design and symbol grounding. I propose not to restrict to connectionist approaches, but to make use of recent data mining and machine learning techniques – from K-means to kernel methods. The cognitive perspective in Section 4 discusses the consequences of the interface optimization formulation on the symbolic grounding problem. To my mind – as only the agent’s objective has to be formulated explicitly, and this is implicit to any biological form of life¹, the optimization formulation is close to fulfilling the zero semantical commitment condition. Last, I present a case-study of interface optimization in Section 5. In Section 6 the most important results are summarized.

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