Characterization Capacity of Agents and Compositionality of Symbolic Languages from Emergent Communication

**Abstract**

Symbolic language, a language using symbols or characters to represent concepts for communication, is widely taken as the key factor for the emergence and evolution of human intelligence. A lot of previous works have found that neural network agents can master a compositional symbolic language, and various environmental pressures affect the compositionality of a symbolic language. Rather than environmental pressures, we explore that the characterization capacity of agents (i.e. the number of nodes in the hidden layer in agents’ RNN model) also play a significant role in the compositionality. Specifically and counter-intuitively, symbolic languages with higher compositionality require lower characterization capacity (i.e. less nodes in the hidden layer) and are easier-to-teach. We combine mutual information theory and experimental results to certify this viewpoint, and show that appropriately lower characterization capacity of agents facilitates the emergence of symbolic language with higher compositionality. In addtion, we propose novel ‘bilateral’ metrics for measuring compositionality and the degree of alignment between symbols and concepts.

Recent advances on symbolic language in neural network-based multi-agent systems have shown great progress in compositionality, which is taken as a distinguished feature of human language different from animal language. However, these efforts only explored environmental pressures, without realizing the importance of characterization capacity of agents.

In this work, we explore the relationship between the characterization capacity of agents and the compositionality of symbolic languages. By both proving with mutual information theory and verifying with extensive experiments, we made the counter-intuitive conclusion that symbolic languages with higher compositionality require lower characterization capacity of agents and are easier-to-teach

**Introduction**

*#Symbolic Language is important, Compositionality is a significant attribution of symbolic language*

*#Referential games is a good platform to study symbolic language*

*#Recent effort for compositionality only cares about environmental pressures (external affection), but ignore characterization capacity of agents (internal affection)*

*#Previous metrics for measuring communication are all ‘unilateral’ (i.e. in a listener-speaker combination, previous metrics only cares about one agent but ignore the other)*

*#In this paper, we train RNN agents on referential games, and show how characterization capacity of agents affect compositionality*

*#In this paper, we also propose novel ‘bilateral’ metrics*

*#Our contribution*

1. We offer a novel factor (i.e. characterization capacity of agents) in compositionality. On the basis of mutual information theory, we certify the characterization capacity’s impact on compositionality theoretically. Specifically, we prove that a symbol of symbolic languages with lower compositionality need carry more complex semantic information (i.e. mutual information between original concepts received by speaker and predicted concepts outputted by listener), so agents use such symbolic language require more nodes in the hidden layer in RNN model to characterize the semantic information.
2. We propose novel ‘bilateral’ metrics for measuring compositionality and the degree of alignment between symbols and concepts. For the degree of alignment between symbols and concepts, the metric should be higher when speaker and listener ‘bilateral’ correspond a symbol to the same concept more stably. On the aspect of compositionality, we hold the view that a single symbol of symbolic languages with higher composionality should be used to ground or transmit a certain concept ‘bilaterally’ and more exclusively between listener and speaker.
3. we run experiments on referential games, and show that within the range afforded by the need for successful communication, lower characterization capacity (i.e. less nodes in the hidden layer) facilitates the emergence of symbolic language with higher compositionality. Less nodes and smaller models mean faster processing and lower computing overhead, which suggests a likely external pressure in the evolution of language in case of human: communicating with shorter thinking time and lower energy consumption.

**Background and Motivation**

*#In this section, we introduce previous efforts related to symbolic language and various affection (environmental pressures) of compositionality.*

**Experimental Framework**

*#In this section, we introduce a referential game platform and our listener-speaker RNN model.*

*#subsection1: Game set up*

*#subsection2: Agent architecture*

*#subsection3: Training Algorithm*

*#subsection4: Evaluation*

**Compositionality and Characterization Capacity**

*#We get an counter-intuitive observation on the relationship between the compositionality and the number of nodes in the hidden layer.*

*#We get an natural infer: symbolic languages with higher compositionality require lower characterization capacity (i.e. less nodes in the hidden layer).*

**Theoretical Analysis**

*#In this section, we prove the infer above mentioned theoretically on the basis of mutual information theory.*

**Experiments**

**Discussion**