

# Referring as a collaborative process: learning to ground language through language games

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## Abstract

How do artificial agents based on neural networks coordinate on a new language through referential games over 3-dimensional scenes? We extended a popular CLEVR dataset to control for different combinations of features of target and distractor objects and examine the success of referential grounding learned by the agents.

## 1 Introduction

Agents interact with the physical world through their action and perception and with other agents through language. Their sensors and actuators allow them to sample the world and their own state using measures that are continuous in nature such as intensity of light, distance, angles, velocity and others which can be measured with a high degree of accuracy. On the other hand language that is used to communicate with other agents is based on representations that are composed of a limited set of discrete and arbitrarily chosen symbols. How can both domains and representations arising from these interactions be combined? How are ranges of measurements expressed in a continuous domain mapped to discrete linguistic labels? How is ambiguity and underspecification resolved? How can agents achieve this through interactive grounding (Regier, 1996; Roy, 2005; Cooper, 2023)?

In this paper we explore how agents based on artificial neural networks learn referential grounding of entities in images of 3-dimensional scenes through language games (Clark, 1996; Bartlett and Kazakov, 2005; Kirby et al., 2008; Steels and Loetzsch, 2009; Zaslavsky et al., 2018). One agent is describing the entities represented as features within bounding boxes of objects, inventing new vocabulary as necessary, and the other agent learns to interpret the reference of symbols by identifying one of the bounding boxes based on object attributes such as shape, color and size. Both agents learn

through the success of interaction. The novelty of our work compared with the previous work with this setup (Kharitonov et al., 2019; Lazaridou et al., 2016) is that we extend the popular CLEVR dataset (Johnson et al., 2016) with new artificially generated 3-d scenes of objects that can be referred to and discriminated based on the attributes such as *shape*, *color* and *size* whereby the discrimination is based on different overlaps of these attributes between the target and the distractor objects.

## 2 CLEVR-Dale-2 and Dale-5

We extend the CLEVR dataset (Johnson et al., 2016), by dividing the objects into a *target object* and *distractors* and control for the number of shared attributes between these groups as in the GRE algorithm in (Dale and Reiter, 1995). The target object is always unique and at least one attribute is different from the distractors. Each of the distractors can share a maximum of two attributes with the target object. There is no restriction on the relation between distractors, hence it is possible to have multiple identical distractors in one image. Given the ranking of features in the original GRE algorithm the target object is therefore identifiable either by the *shape* (1), the *shape* and *color* (2) or the *shape*, *color* and *size* (3). For each image fixed size bounding boxes around the centre-point of each object are extracted. The *Dale-2* dataset contains one target object and one distractor, while the *Dale-5* dataset contains one target object and four distractors. Both datasets contain 10.000 images. Examples are shown in Appendix A.

## 3 Language games

The language games were developed and run in the EGG framework (Kharitonov et al., 2019).<sup>1</sup> Both our sender and receiver have a similar architecture

<sup>1</sup>[https://github.com/DominikKuenkele/MLT\\_Master-Thesis](https://github.com/DominikKuenkele/MLT_Master-Thesis)

to the *agnostic sender and receiver* of (Lazaridou et al., 2016) as shown in Appendix B. One central difference is the production of the message. As we focus on sequences of referring expressions made-up of different attributes, our models produce sequences of symbols for the message instead of a single symbol referring to an image. This is done using an encoder LSTM (sender) and a decoder LSTM (receiver) to encode language descriptions. Another difference is that both sender and receiver receive visual input as segmented objects rather than two images. The order of objects is random, except that the first order for the sender is always the target object to be referred to. For the sender, the images are passed through *ResNet101* (He et al., 2016) and a following linear layer that reduces the dimensions to an embedding size  $e_s$ . All embedded images are concatenated and passed through another linear layer to reduce the dimensions to the hidden size  $h_s$ . This is then used as the initial state of the encoder LSTM. The sequence is then created through Gumbel-Softmax relaxation (Jang et al., 2016). The receiver also encodes all images using *ResNet101* with a following linear layer, reducing it to  $e_r$ . The sequence received by the sender is the input for its decoder LSTM, where the hidden state with a dimension of  $h_r$  is randomly initialized. After each step of the LSTM, the receiver calculates the dot product between the hidden state and all of its image encodings. The receiver then ‘points’ to one of the images, by applying the softmax function over the results of the dot products. The loss is calculated using the NLL-loss. Following, the losses for all steps are summed up, and all weights of the receiver as well as the sender are updated, based on this summed loss.

## 4 Experiments and results

There are five variables in the experiments that are adjusted: (1) the image embedding size for the sender  $e_s$ , (2) the LSTM hidden size for the sender  $h_s$ , (3) the image/message embedding size for the receiver  $e_r$ , (4) the LSTM hidden size for the receiver  $h_r$  and (5) the size of the vocabulary  $|V|$ .

The results will be evaluated using the accuracy if the receiver could identify the target object. A random guess corresponds to 50% in the *Dale-2* dataset and 20% in the *Dale-5* dataset.

The results of the experiments are summarized in Table 1. For the *Dale-2* dataset it can be clearly

seen that an embedding and hidden size that are as high as the vocabulary size are beneficial for identifying the correct object. The receiver identifies indeed almost every sample correctly with all sizes of 10. When the hidden and embedding sizes are increased, the guesses by the receiver are random. Interestingly, a vocabulary size of 10 is enough to communicate a meaningful message for the *Dale-2* dataset.

The results change, when using the *Dale-5* dataset with four distractors. With low hidden, embedding and vocab size, the agents barely pass the random baseline with 23%. Only increasing the vocabulary size to 100 raises the accuracy by almost 20% to 43%. This accuracy is still far lower than the 95% with the *Dale-2* dataset.

## 5 Discussion

Unsurprisingly, the agents have a much higher difficulty to discriminate a target object from four instead of one object. Since we discriminate objects based on properties that are also distinguished in human cognition (color, size, shape) we expect that the vocabulary onto which the agents will converge will reflect these categories and therefore be close to human vocabulary. There are 48 possible combinations of attributes. Still for *Dale-2* a vocabulary size of only 10 is enough for an almost perfect accuracy with two objects. This hints to the fact, that the agents don’t describe the complete target object, but only rely on discriminative attributes between the objects. The need for a more detailed description of discriminative attributes is higher, when more distractors are involved. Therefore, the models need to learn more combinations of symbols to attest to this higher level of detail and especially how to relate them to features in the images.

Dataset	$h_s$	$e_s$	$h_r$	$e_r$	$ V $	Acc.
Dale-2	10	10	10	10	10	95%
Dale-2	50	50	128	128	10	50%
Dale-5	10	10	10	10	10	23%
Dale-5	10	10	10	10	20	23%
Dale-5	10	10	10	10	100	41%

Table 1: Result of the experiments with different hidden sizes, embedding sizes and vocabulary sizes

## 6 Conclusions and further work

In this research, we introduced an extended version of the CLEVR dataset that offers a high control over the relations between generated objects. This should help to study, how models can learn these relations and refer to them as well as the objects. In our research we used this dataset to study, how agents can learn to communicate and refer to these objects in a language game setup. We found that a bigger number of distractors requires a higher vocabulary size. This hints to the fact that the agents learned to communicate discriminative attributes between the images.

In future research, we want to investigate deeper the emerged language and the new vocabulary. Especially, we want to test if our hypothesis that this emerged language uses similar categories as human language holds true and how these words are combined to form complete messages.

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## A Extended CLEVR datasets

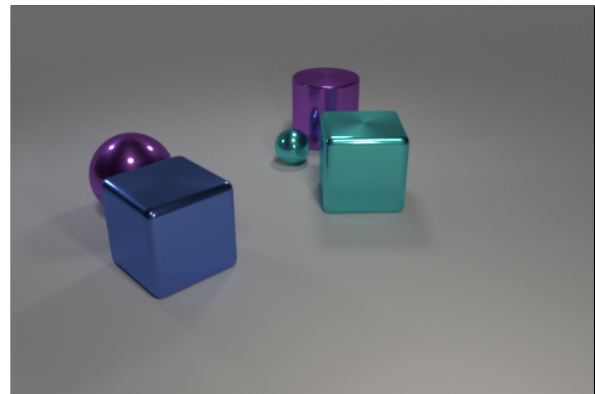


Figure 1: Example of a generated image in the Dale-5 dataset

The target object in Figure 1 is the purple cylinder. It shares the same color and size with the purple sphere, the same size with the two cubes and no attribute with the turquoise sphere. It can be uniquely identified as the *cylinder*.

In Figure 2, the small red cube is the target object. Since all attributes except for the size are shared with the distractor, all three attributes are necessary, to identify it following Dale and Reiter (1995)’s rules, namely the *small red cube*.

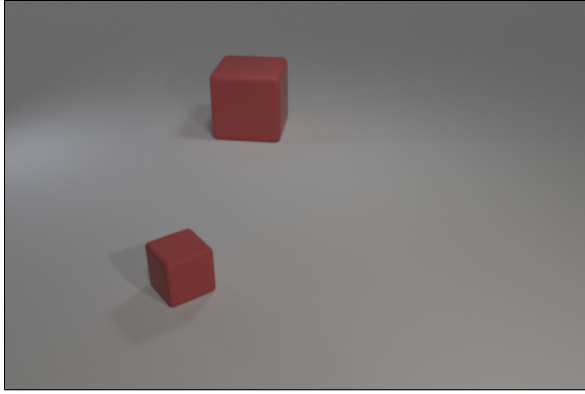


Figure 2: Example of a generated image in the Dale-2 dataset

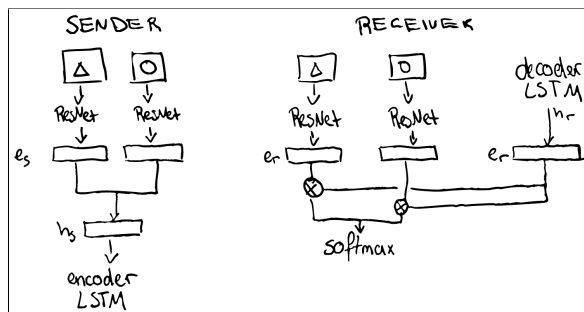


Figure 3: Architectures of the sender and receiver

## B Setup of the language game