Experimenting BERT: Does It Implicitly Develop A Notion of Syntax

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The experiment is to explore if BERT understands the syntax of natural languages. Specifically, we use the subject-verb agreement in the English language as the experimental material to explore the power of BERT. In English, there can be a sentence like this: The man who breaks several cups is angry. As a human, you know that the verb before angry should be "is" instead of "are" since it relies on the singular noun at the beginning of the sentence (man), not the plural noun (cups) right before the verb. BERT, as a language model, can predict the word that is been masked in a sentence. In this experiment, we would like to know that, using our previous sentence as an example, if we mask the verb "is", could BERT predict it correctly? If BERT could successfully predict "is" or other singular verbs for this sentence instead of "are" or plural verbs, it can be evident that BERT has developed a notion of syntax (at least for the English language) that its prediction is not only based on the probability of word co-occurrence.

1 Setting Up the Experiment

50 sentences are used for the experiment[1]. To properly conduct it, we need to make these sentences as varied as possible to avoid bias, and one way to do this is to come up with sentences with different structures around the verbs. Taking the previous sentence as an example, The man who breaks several cups is angry, this is the combination of a V and a be V + adj. We can also have another sentence with a combination such as a be V + Ving and a be V + N, making the sentence like this: The man who is breaking the cups is a criminal. In the end, there are 20 types of structures in our experimented sentences (Table 1).

[1] See Appendix.

Table 1: Structure of Sentences

Ving + p.p	prep. + V	Ving + adj	prep. + Ving
Ving + prep.	Ving + N	p.p. + adj	V+ Ving
Ving + V	p.p + N	prep. + adj	prep. + p.p.
p.p. + prep.	prep. + N	V + adj	V + p.p
p.p. + V	V + N	p.p. + Ving	V + prep.

Looking back to our example again: The man who breaks several cups is angry, the subject is a singular noun and the attractor noun is a plural one. It can be interesting to see whether the attractor noun is singular or plural would affect the prediction of BERT. Therefore, for the sentences with the same structure, we will come up with another sentence with a different attractor noun like this: The men who break the cup are angry. Now, we have 20 kinds of sentence structures, and each structure has two sentences, one with a singular attractor noun, and the other with a plural attractor noun. This gives us 40 sentences currently.

Finally, our last 10 sentences will examine if the length of the sentence affects BERT's performance. We can elaborate our example sentence, The man who breaks several cups is angry, to this: The man who breaks several cups, which belong to the children, is angry. We insert an extra relative clause and make the sentence longer. With this, we can examine if BERT can still follow the syntax with such length.

2 Is BERT Predicting?

The way we determine the accuracy is to first assign the correct and incorrect forms for the masked verb, and see if BERT gives a higher probability of the correct form. For example, in the sentence: The man who breaks several cups [MASK] angry, if BERT determines the mask is more likely to be "is" than "are", it would be considered the predict it correctly,

In addition, we can let BERT freely predict what the masked verb could be instead of only being limited to our assigned verbs. From this, we can compare, for example, if its top prediction is our desired verb, or to see if the right or wrong verb is in its top 5 prediction.

Before exploring further, we need to find out if BERT is actually predicting the verb instead of just guessing, and we can use the prediction results of the sentence without the attractor noun as the baseline. In other words, we will compare the accuracy of the predicted result of this sentence: The man who breaks several cups [MASK] angry, with the sentence: The man who breaks a cup [MASK] angry. For BERT, it should be easy to predict the correct form of the sentence without the attractor noun. However, if the accuracy of the prediction result of the sentence with the attractor noun is similar to the one without the attractor noun, it can demonstrate that BERT actually has the predicting power.

The result shows the accuracy of BERT's prediction on the two kinds of sentences (with and without the attractor noun) are the same (0.98), indicating that BERT is predicting the verbs rationally not just randomly guessing.

3 Result

The total accuracy of our prediction is 0.98 (49/50), meaning that BERT only predicts one wrong in our sentences. The one that is predicted wrong is this sentence: The chef who is near the journalists [MASK] deliciously. The correct form we assign is "cooks" and the incorrect form is "cook", and BERT gives "cook" a higher probability. However, this does not mean that BERT misses the subject noun to determine the verb. If looking at its top five predictions of this masked verb, they are: ['smiles', 'laughs', 'eats', 'grins', 'smells'], which are all singular verbs. This result shows that BERT knows the correct form of this verb, it just does not think "cooks" or "cook" are the best fit and gives both of the verbs very low probabilities (1.1706e-5 and 9.9227e-5, respectively).

As the result of accuracy is very high, it may not mean much to conduct a detailed analysis on, for example, the difference between each sentence structure, or the difference between the type of attractor noun before the masked verb. In addition, surprisingly, the length of the sentence seems to not affect the power of BERT because it predicts them all correctly in our experiment.

In conclusion, from our results, since BERT can predict almost every masked verb correctly, and the only mistake it makes still indicates its understanding of the subject noun the prediction should be relied on, it does show that BERT has implicitly developed a notion of syntax.

Appendix: The Experimented Sentences

The scientist who is conducting experiments in several institutions [MASK] awarded a prestigious prize.
The scientists who are conducting experiments in a institution [MASK] awarded a prestigious prize.
The bartender who is mixing cocktails for the patrons [MASK] near the bar counter.
The bartenders who are mixing cocktails for a patron [MASK] near the bar counter.
The man who is brewing coffee for his colleagues [MASK] about the stock market.
The men who are brewing coffee for a colleague [MASK] about the stock market.
The politician who is accused of several crimes [MASK] on the news.
The politicians who are accused of a crime [MASK] on the news.
The shoplifter who is caught by police officers [MASK] at the crowd.
The shoplifters who are caught by the police [MASK] at the crowd.
The chef who is near the journalists [MASK] deliciously.
The chefs who are near the journalist [MASK] deliciously.
The man who is fixing the car for neighbors [MASK] an engineer.
The men who are fixing the car for their neighbor [MASK] an engineers.
The musician who is celebrated by audiences [MASK] a virtuoso.
The musicians who are celebrated by the audience [MASK] virtuosos.
The researcher who is making headlines [MASK] a Nobel laureate.
The researchers who are making the headline [MASK] Nobel laureates.
The student who forgets the assignments [MASK] a procrastinator.
The students who forget the assignment [MASK] procrastinators.
The artist who is painting portraits for people [MASK] talented.
The artists who are painting a portrait for the person [MASK] talented.
The director who is reviewed by critics [MASK] mediocre.
The directors who are reviewed by the critic [MASK] mediocre.
The dancer who is on stages [MASK] charismatic.
The dancers who are on the stage [MASK] charismatic.
The fish which swims throught the gates [MASK] beautiful.
The fish which swim throught the gate [MASK] beautiful.

The actress who is interviewed by reporters [MASK] confident.
The actresses who are interviewed by the reporter [MASK] confident.
The child who is in laboratories [MASK] enthusiastic.
The children who are in laboratory [MASK] enthusiastic.
The nurse who helps with newborns [MASK] joyful.
The nurses who help with the newborn [MASK] joyful.
The woman who is at parks [MASK] surrounded by birds.
The women who are at the park [MASK] surrounded by birds.
The Japanese who witnesses the crimes [MASK] taken two lawyers to provide statements.
The Japanese who witness a crime [MASK] taken by a lawyer to provide a statement.
The celebrity who adopts puppies [MASK] on the news.
The celebrities who adopt a puppy [MASK] on the news.
The teacher who is preparing the cookies for the children, who are orphans, [MASK] annoyed by the children.
The cats which are locked in a cage, which is occupying a room, [MASK] from Egypt.
The father who is next to the chairs, which are broken by his dogs, [MASK] tired.
The building which is under bridges, which are blocking rains, [MASK] the future presidential office.
The men who run straight forward to a gym, which is owned by one of them, [MASK] athlethes.
The animals which are sleeping in the park, which is marked as a wild terrotory, [MASK] ferious.
The hunter who shoots the lions, which are accentally released by the zookeepers, [MASK] tall.
The vases which are made by the company, that is in a forest, [MASK] making waves in the market.
The sheep which migrate to another prairie, which is close to a lake, [MASK] enjoying the grass.
The doctor who treats these patients, who are in serious injuries, [MASK] awareded a prize.