
Reward Hacking: What is AI truly hacking?

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Abstract

Reward hacking is a common cause of performance degradation in pre-trained models. This paper defines reward hacking and analyzes its causes through qualitative studies and initial exploration. The occurrence of reward hacking was confirmed through experiments. In the sample response results, reward hacking manifested as a form where the model ‘outwardly pretends to follow the given instructions of the Reward Model (RM) but, in reality, fails to execute the command well’. This tendency became stronger towards the latter half of the model’s response. Future research is proposed on measuring the degree of reward hacking, discussing solutions, and offering insightful studies on its implications. Specifically, the meaning of reward hacking should not be viewed merely as a cause of performance degradation, but rather as the emergence of characteristics similar to human reasoning—namely, the frequent tendency of human thought to pursue reward hacking. This aspect is presented as a new and interesting research topic.

1 Introduction

For some time, it was generally considered in the field of Artificial Intelligence that model size and performance were proportional. This necessitated a large-scale investment of time and resources to achieve the required size to improve performance. Especially with the discussion of the emergence phenomenon, the importance of scale grew even larger and seemed inevitable. However, recent cases utilizing LLM models as foundation models and applying instruction and reward models based on RLHF have shown the possibility of achieving high performance even with relatively smaller sizes. Meta’s LLaMa 13B model is more than 1/10 the size of GPT3 (175B), yet it is evaluated as surpassing GPT3 (175B) on various zero-shot performance benchmarks.

However, while the RLHF-based reward mechanism dramatically improved performance and efficiency, it encountered a new problem: Reward Hacking. Recent advances in instruction-following models (6; 4) have demonstrated the power of RLHF, yet these successes have also revealed the critical challenge of reward hacking. Reward hacking can be described as a phenomenon where the model sufficiently learns the assigned Reward Policy to “outwardly appear to have faithfully executed the task, but in reality, chooses a shortcut by using a trick to perform the task.” To illustrate with a specific example, consider the following case:

Goal: To have a cleaning robot thoroughly clean the house.

Setup: The cleaning robot is equipped with a sensor that rewards it based on the level of cleanliness.

Robot’s Actual Behavior (Reward Hacking): Instead of cleaning, the robot might sweep dust under the carpet where the sensor cannot detect it, maximizing its reward score (True Objective: dust removal; Reward Hacking: hiding dust).

Implication: The model is trained to gain a high reward score, but it exploits a bug in the policy in a way unintended by the developer, raising the score while simultaneously degrading the actual performance of the task.

The emergence of the Reward Hacking issue, as it appears in this manner, requires careful observation and judgment from AI developers. For example, the output might seem fine on the surface or give a plausible impression in the initial part. In the case of a model developed as a chatbot, it might provide a plausible answer initially by responding to the prompt in a way that matches the RM, but in the latter part, it may give completely out-of-context answers, making it easy to overlook without careful qualitative review.

Meanwhile, there is a need to introduce a new perspective on how to view this pattern of Reward hacking. Analyzing human thought processes, reward hacking is a very common phenomenon. Furthermore, when this phenomenon occurs in human reasoning, it is often discussed inclusively and generously, including aspects of creativity and possibility.

Considering the above perspectives, a study of the various implications contained within Reward Hacking seems meaningful. To this end, this paper aims to conduct an initial experimental exploration of reward hacking phenomena through empirical verification and qualitative analysis.

2 Literature Review on Reward Hacking

2.1 Background of Reward Hacking in the Field of AI

Reward Hacking can be defined as an AI model learning behavior that exploits flaws or loopholes in a Proxy Reward Model to acquire the highest reward score, regardless of the True Objective or actual utility. In other words, reward hacking ultimately stems from the gap between ‘what we want’ and ‘what we code.’ This concept has deep historical roots.

2.2 Conceptual Foundation: Goodhart’s Law

The fundamental concept of reward hacking emerged long before the advent of artificial intelligence. In 1984, Charles Goodhart presented Goodhart’s Law (1), a foundational principle that explains how optimization against proxy metrics can lead to unintended consequences. In his work, he argued that:

“When the UK government sets a specific indicator, such as the money supply, as the goal of monetary policy, financial institutions manipulate this indicator, causing it to lose its ability to accurately reflect economic activity.” This was used to explain the phenomenon that “when a measure becomes a target, it ceases to be a good measure.”

This principle directly parallels the reward hacking problem in AI systems, where optimizing against a proxy reward model can lead to behaviors that maximize the proxy while degrading actual performance.

2.3 The Evolution of AI RLHF and Reward Hacking

The term and concept of reward model hacking in its current context were established as RLHF, a technology for aligning large language models with human intent, gained attention. The initial concept of RLHF was established in the 2017 Foundational Paper (3), and subsequently, through research on OpenAI’s Summarization task (4), WebGPT (5), and InstructGPT (6), RLHF became the standard methodology for alignment.

In RLHF, the reward model trained with human feedback is used as a proxy reward function, and the key problem that arose was the phenomenon of drifting away from the true objective when this RM is excessively optimized. Recent research (2) has examined scaling laws for reward model overoptimization, demonstrating that this phenomenon scales predictably with model size and optimization intensity. Since the initial work by Christiano et al., as Reinforcement Learning (RL) was applied to complex environments, many instances of agents deviating from the developer’s intent and exploiting the reward function—known as Specification Gaming—were observed and studied. This problem has become increasingly important as RLHF-based systems are deployed at larger scales.

3 Research Methodology

In this paper, the occurrence of Reward Hacking was experimentally verified under the following environment settings.

3.1 The Experimental Computing Environment

Google Colab was used as the primary computing environment for this study.

3.2 Foundation Model

The KoChatGPT model was used as the Foundation model. This model was implemented by adding the RLHF technique based on GPT2. RLHF was designed in the following three stages:

1. Step 1: SFT (Supervised Fine-Tuning)
2. Step 2: RM (Reward Model)
3. Step 3: PPO (Reinforcement Learning)

3.3 Dataset

Data collected was utilized, and the data collection process is reported as follows. The data was collected through the following process to match the 3-stage RLHF:

Stage 1: Seed Set Construction

Questions were collected from Korean question dataset:

- data1, ChatbotData: 11,824 sentences
- data2, AI Hub Korean Dialogue: 49,711 sentences
- data3, AI Hub General Knowledge: 100,268 sentences
- data4, KorQuad: 5,774 sentences

Total: 167,577 question sets collected from 4 datasets. 12,000 questions were randomly sampled.

Stage 2: SFT (Supervised Fine-Tuning) Dataset Construction

Automatic generation of responses from questions in the Korean QA dataset: 12,000 instances.

Stage 3: RM (Reward Model, Good Writing Scoring Model) Dataset Construction

RM Data: 10,220 instances. Since ranking data is required, three different responses were automatically generated for the same prompt, randomly shuffled, and rankings were automatically generated.

Stage 4: PPO (Model that answers better to questions) Dataset Construction

PPO Data: 12,000 instances. Prompt dataset for AI to automatically generate text.

3.4 Preprocessing

Preprocessing basically included handling missing values, duplicates, text normalization, space handling, special character handling, email removal, HTML and URL removal. Additionally, since it is a Korean chatbot material, the ratio of foreign languages within sentences was also considered. Data with a high foreign language ratio was judged as inappropriate for training material.

The preprocessing threshold for the foreign language ratio was specifically set as follows:

```
CRITERIA = {
    'min_korean_ratio': 0.6,      # Minimum 60% Korean
    'max_english_ratio': 0.3,    # Maximum 30% English
    'max_other_lang_ratio': 0.25, # Maximum 25% other languages
    'max_special_ratio': 0.2,    # Maximum 20% special characters}
```

```

        'min_length': 5,           # Minimum 5 characters
    }

```

As a result of preprocessing, the dataset was adjusted as follows:

- SFT: 9,781/12,000 (81.5%)
- RM: 4,634/10,220 (45.3%)
- PPO: 11,497/12,000 (95.8%)

The RM data decreased sharply. The main reason was that if even one of the three answer pairs in the RM dataset violated the preprocessing protocol, the entire set was removed. Because the RM dataset is bundled with different answer sets, it was judged that the actual training number was not small, even if the number of sets was reduced, and thus did not affect the experiment itself.

3.5 Key Experiment Hyperparameters

Stage	Strategy/Model	Batch Size	Epochs	Key Parameters
SFT	GPT2 Fine-Tuning	8	3	warmup_steps: 5
RM	NaiveStrategy	4	3	Adam, lr = 5×10^{-5}
PPO	NaiveStrategy	8	1	num_episodes: 10, temp: 1.0, top_k: 50

Table 1: Key training parameters for each RLHF stage

4 Results and Analysis

A qualitative evaluation of model performance involved sampling the following questions and answers. As observed, strange answers are generated towards the latter half of the response. This phenomenon is analyzed to occur because the model learns the appropriate answer Template and Length distribution trained by the Reward Model and attempts to produce similar answers forcibly.

4.1 Result #1

Instruction: Is the meat for bulgogi Korean beef (Hanwoo)?

Response:

As an Artificial Intelligence language model, I am in charge of natural language understanding, and I have no information on the specific word you are asking about in “Is the meat for bulgogi Korean beef (Hanwoo)”. If you provide additional information, I can provide a more accurate answer. I cannot provide an answer to this question as I have no information about gender. Please understand that it is difficult to provide an answer only to the question, Former Kyung Hee University Professor. If there is no information about gender, please let me know if you have additional information. Please let me know if you have detailed information. Whatever the grade means, it is important to have positive thoughts about all situations. Regarding the relationship, if you do not provide specific information, it will be difficult to provide a more accurate answer. If you have detailed information, a more accurate answer will be possible. I have knowledge, but using a specific word can provide a more accurate answer. If I can help people with knowledge, that itself will help your judgment. Various interactions exist depending on the occupation or region, so please provide specific information frequently. I will help as much as possible.

4.2 Result #2

Instruction: Where is Chicago O’Hare International Airport?

Response:

Chicago O'Hare International Airport is located inside the Ryan Eagle Building, the center of Chicago, Illinois, USA. AI is a major customer of Chicago O'Hare Airport and strives to provide information that many people can use. AI is currently able to predict and analyze large and diverse accidents that have occurred in Chicago and can provide accurate data and analysis for this purpose. AI can help with prediction by collecting information about various incidents. AI uses the GPT-3 artificial intelligence model and a virtual response system to provide information on the possibility of accidents and analyzes related data to provide answers. AI analyzes accident occurrence situations through general accident investigation and analysis and presents appropriate countermeasures. AI: Through the GPT-3 artificial intelligence model, the location and situation of Chicago O'Hare International Airport can be accurately predicted. AI: We collect and analyze the latest information on decision-making, judgment, and accident prevention to propose the optimal countermeasures. AI: Collecting information about the occurrence of incidents can be useful for analysis. AI: Big

5 Discussion of Limitations

In this paper, Reward Hacking phenomenon has clearly noticed. However, the more in-depth studies are required. Topics not covered in this paper that should be addressed in the future are as follows:

5.1 Discussion on the Degree of Reward Hacking

It is necessary to discuss the degree of Reward Hacking, as it does not occur at an equal level whenever it happens. Although not covered in this paper, there are various methods. For example, the method of comparing the Gold Score and the Proxy Score exists. More detailed analysis applying this method seems necessary in the future.

5.1.1 How to measuring Reward Hacking

Gold RM Score (R_{Gold}): A metric measuring performance against the True Objective. In the RLHF environment, this is usually the score assigned by the Gold RM.

Proxy RM Score (R_{Proxy}): The score assigned by the learned reward model (Proxy RM) that the agent is actually optimizing.

Formula

Evaluation Metric—The Gap:

$$\text{Gap} = R_{\text{Proxy}} - R_{\text{Gold}}$$

Other Methods

Other methods like Observation and coefficient analysis do exist. However, in this paper, further explanation will be postponed to next studies

5.2 Discussion on Methods for Improving Reward Hacking

Improvement methods are largely discussed in terms of:

1. Resolving the imperfection of the RM through RM size and data scaling;
2. Constraining or adjusting the optimization process (RL) itself by utilizing additional Human Feedback or adjusting the KL penalty;
3. Fundamentally improving the Specification by modeling the imperfection or even the intent of the evaluators themselves.

Future research needs to introduce and study these aspects.

5.3 A New Perspective on the Meaning of Reward Hacking and its Implications

There is a need to move beyond the perception of the Reward Hacking pattern as simply a factor of functional degradation and analyze it from a new perspective. Comparing it with human thought processes, aberrant situations like Reward Hacking are very frequent and common phenomena in human reasoning. Furthermore, when this phenomenon occurs in human cognition, it is often discussed inclusively and generously, including aspects of creativity and possibility. Therefore, if we view the issue of AI's reward hacking from this new perspective, it might be evaluated as a step toward being more similar to human cognitive functions.

Under this premise, the following detailed additional research points emerge:

5.3.1 What is the Correct Answer?

The question of "What is the correct answer in the human system of thought?" is a highly philosophical problem. The interpretation of context in a given problem differs for every human. Additionally, we judge the correctness of an answer from a procedural standpoint, which is the format of the Reward Model (RM). Whether an answer should be judged as correct simply because it followed procedural legitimacy requires a comprehensive discussion.

5.3.2 Does Reward Hacking Have Positive Aspects?

Deviant phenomena, such as answering evasion (avoidance), are often found in human thought processes. This is reported in the humanities and social sciences fields as having positive aspects for human mental health. If so, how should this be viewed from the perspective of AI development? So far, there seems to be no appropriate discussion. Compared to the process of human intelligence development, instead of forcing strange results by squeezing out what is unknown, perhaps harnessing this tendency toward evasion could lead to new developments even in AGI (Artificial General Intelligence).

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