A Unified Hallucination Mitigation Framework for Large Vision-Language Models

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Abstract

Hallucination is a common problem for Large Vision-Language Models (LVLMs) with long generations which is difficult to eradicate. The generation with hallucinations is partially inconsistent with the image content. To mitigate hallucination, current studies either focus on the process of model inference or the results of model generation, but the solutions they design sometimes do not deal appropriately with various types of queries and the hallucinations of the generations about these queries. To accurately deal with various hallucinations, we present a unified framework, **Dentist**, for hallucination mitigation. The core step is to first classify the queries, then perform different processes of hallucination mitigation based on the classification result, just like a dentist first observes the teeth and then makes a plan. In a simple deployment, Dentist can classify queries as perception or reasoning and easily mitigate potential hallucinations in answers which has been demonstrated in our experiments. On MMbench, we achieve a 13.44%/10.2%/15.8% improvement in accuracy on Image Quality, a Coarse Perception visual question answering (VQA) task, over the baseline InstructBLIP/LLaVA/VisualGLM. Our source code will be released on GitHub.

1 Introduction

Hallucination in Large Vision-Language Models (LVLMs) is a critical issue, which manifests as the model's generated content partially deviating from the actual content of the image (Jing et al., 2023). For example, when provided with a image and two questions as input, LVLMs inaccurately identify characters' actions and misinterpret relationships between characters, as illustrated in Fig. 1. Such inaccuracies can lead to misinformation, potentially degrading the user experience and misleading individuals. This issue underscores the necessity for ongoing improvements to enhance the reliability and accuracy of LVLMs, mitigating the risk of hallucinations and their consequent misinformation.

To tackle the above challenge, existing work either focuses on optimizing the training data and the parameters of the existing model (Liu et al., 2023b; Lu et al., 2023), or correcting the hallucinations during the generation stage without model update (Yin et al., 2023). The former collects high-quality training data, such as adding negative instances to the training data to avoid overconfidence in the model (Liu et al., 2023a). The latter mainly utilize the generated object information from the vision foundation model (such as blip2 (Li et al., 2023a)) to detect hallucinations and eliminate them. For example, Woodpecker (Yin et al., 2023) extracts main objects from the response generated by LVLMs and then verified these objects with object segmentation tool (Liu et al., 2023d) and VQA models (Li et al., 2023a). Similarly, HalluciDoctor (Yu et al., 2023a) makes the description-oriented answer chunks extraction and formulates corresponding questions, uses answers for these questions which are gathered from various LVLMs to do the consistency cross-checking and remove hallucinations.

There are two main hallucinations in the model response (Ji et al., 2023): perception hallucination and reasoning hallucination, as shown in Fig. 1. The former is manifested by incorrectly describing image content in the model generation, such as errors when describing object attributes, while the latter refers to the model producing fallacies in logical reasoning answers. Although the previous methods for hallucination mitigation have achieved success, they still have a common problem, that is, when faced with these two types

Figure 1: An example image of hallucination. The generation of the model is partially inconsistent with the image, which we call perception hallucination and reasoning hallucination respectively.

of hallucinations, the fixed verification method may sometimes be inappropriate and ineffective. For example, for reasoning queries, it is not effective to use object detection on pictures to verify whether the object in the answer exists, as shown in Fig. 1 In addition, sometimes when the corrected answer obtained by the existing method is used as input to perform the same correction once, the answer after the second correction is inconsistent with the first time, which means that one correction did not remove all the hallucinations.

In order to solve this problem, we propose a unified framework for two main kinds of hallucination mitigation. Regardless of whether it is a descriptive answer or a logical reasoning answer, any part of the answer that does not match the content of the picture will be corrected by our framework Dentist. Specifically, the framework we proposed is a verification loop, and each loop is divided into two core steps: (1) *Potential hallucination classification* divides the query into two categories: perception and reasoning, which also classifies the potential hallucinations in answers when these queries are used as input to LVLMs. (2) *Divide-and-conquer treatment* makes the mitigation based on the classification. The generation for the perception query will be verified by the sub-questions, while the generation for the reasoning query will be verified with the help of Chain-of-Thought (CoT). To ensure that hallucinations are mitigated as much as possible, the above verification loop will continue until the revised generation no longer changes semantically significantly or the loop limit is reached.

We complete quantitative experiments on MMbench (Liu et al., 2023e), LLaVA-QA90 (Liu et al., 2023c), CHAIR (Rohrbach et al., 2018) and POPE (Li et al., 2023c) using three models: InstructBLIP (Dai et al., 2023), VisualGLM (Ding et al., 2021; Du et al., 2022) and LLaVA (Liu et al., 2023c), respectively, to test the effectiveness of our proposed method. In addition, we also conduct a comparative experiment with a current effective LVLM hallucination mitigation method, Woodpecker (Yin et al., 2023). Our method demonstrates the effectiveness and superiority in many visual language tasks, and promotes the performance of the baseline models. In particular, in the experiment, we achieve a 13.44%/10.2%/15.8% improvement in accuracy in the visual language task of Image Quality, compared with the baseline models InstructBLIP/LLaVA/VisualGLM.

Our main contributions are summarized as follows:

- We propose a unified framework called Dentist for hallucination classification and mitigation. To the best of our knowledge, we are the first to distinguish treatment based on classification of the potential hallucinations and moreover use a validation loop for complete removal of hallucinations.
- Our unified framework is easily integrated into various LVLMs. The clear design of the framework also provides convenience for new classifications and treatments to access the framework.
- We comprehensively evaluated our method on several hallucination mitigation benchmarks (including MMbench, POPE, CHAIR, and LLaVA-QA90) with a detailed analysis.

2 Related Work

2.1 Large Vision-Language Model

Inspired by the success of Large Language Models (LLMs) in zero-shot / few-shot learning (Wang et al., 2022; Zhao et al., 2023), the multimodal learning community shifted research attention to LVLMs. LVLMs mainly use the cross-modality aligner to connect the visual encoder (such as CLIP (Radford et al., 2021)) and LLMs (such as LLaMA (Touvron et al., 2023)) to tackle vision-language tasks. For example, LLaVA (Liu et al., 2023c) connects a vision encoder and a LLM for general-purpose visual and language understanding, suggesting practical tips for building a general-purpose visual agent. Meanwhile, InstructBLIP (Dai et al., 2023) introduce an instruction-aware Query Transformer which extracts visual features from the output embeddings of the frozen image encoder, and feeds the visual features as soft prompt input to the frozen LLM. In addition, VisualGLM (Ding et al., 2021; Du et al., 2022) use Qformer (Li et al., 2023b) which builds a bridge between the visual model and the language model. Though these LVLMs have powerful visual language understanding ability on the generation task, sometimes their outputs still contain hallucinations that need to be corrected. Some studies (Wang et al., 2023b; Awal et al., 2023) use LLMs to improve the performance of LVLMs, which is worth learning from.

2.2 Hallucination

With the progress of research on LVLMs, the problem of hallucination has gradually been exposed (Bai et al., 2024), and it has attracted more and more attention. Research around hallucination focuses on three aspects: detecting (Gunjal et al., 2023; Luo et al., 2024), mitigating (Kang et al., 2023; Lu et al., 2023; Wang et al., 2023a; Yin et al., 2023; Yu et al., 2023a;b; Leng et al., 2023; Huang et al., 2023), and evaluating hallucinations (Jing et al., 2023; Wu et al., 2024). In this paper, we mainly focus on hallucination mitigation. Previous works on hallucination mitigation can be divided into two categories: model inference optimization and model generation optimization. The first category focuses on the process of the training and inference of the LVLMs. RLHF-V (Yu et al., 2023b) collects human feedback at the data level and learns the correctional human feedback at the training level to reduce hallucinations in model generations. Ever (Kang et al., 2023) points out that mitigating hallucinations in real time during model inference is more appropriate than generating corrections from the model outputs, as the latter is subject to snowballing effects. VIGC (Wang et al., 2023a) uses an iterative method to concatenate the short sentences generated each time, and ensures accuracy by controlling the length of the generation. On the other hand, the second category focuses on the aspect of the generation of LVLMs, designing methods to obtain hallucination information from the output of the model and do the mitigation. Leng et al. (2023) introduces Visual Contrastive Decoding (VCD) to counteract the statistical biases and mitigate hallucinations by contrasting model outputs generated from original and distorted visual inputs. For example, Woodpecker (Yin et al., 2023) makes the question formulation and visual knowledge validation base on the keywords which are extracted from the output of the model and uses an LLM to modify the hallucinations in the generated responses.

Despite the success of the existing method, they overlook the diversity of hallucinations which results in a fixed hallucination elimination method that cannot be applied to all hallucination situations well. To solve this problem, we propose a unified framework for mitigating hallucinations, the core step of which is to classify potential hallucinations caused by different queries.

3 Method

In order to tackle various types of hallucination, our objective is to propose a unified framework for hallucination mitigation. Therefore, we devise a unified hallucination mitigation framework for LVLMs which mainly consists of three major components: potential hallucination classification, divide-and-conquer treatment, and validation loop, as shown in Fig. 2.

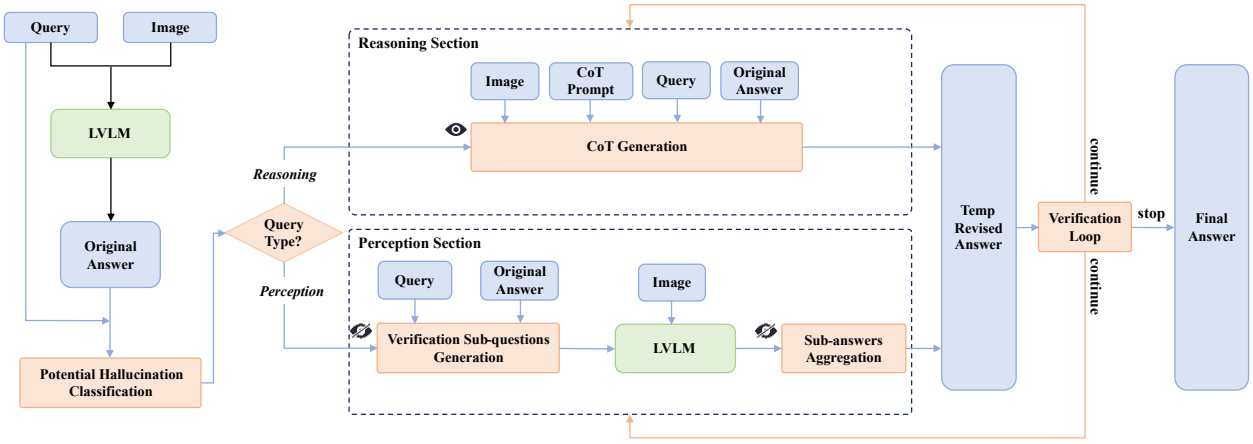

Figure 2: An overview of the proposed method. The orange square components use gpt. The icons of open and closed eyes indicate whether the component is a pure text task or is related to an image. The black line represents the original part of LVLM. The blue line represents the forward path of the verification process, and the orange line represents the feedback path in the verification loop. The core point is to customize different methods of mitigating hallucinations by classifying the query. The reasoning section is used to mitigate the hallucinations caused by reasoning queries, while the perception section is used to mitigate the hallucinations caused by perception queries.

3.1 Task Formulation

Suppose we have a dataset $\mathcal{D} = \{(Q_i, I_i, Y_i)\}_{i=1}^{N}$, where I_i is the image, Q_i refers to the query of the image and Y_i represents the truth answer to the corresponding query. Note i represents the index of samples in the dataset $\mathcal{D}$. We omit the index of Q_i, I_i and Y_i in the following discussion for the sake of brevity. Thereafter, we feed the image and query sample to the LVLM as follows,

$$\hat{Y} = M(I, Q|\Theta), \tag{1}$$

where $\hat{Y}$ is the original answer for (Q, I) and Θ is the parameters of LVLM M. Since the generated response $\hat{Y}$ suffers from hallucination problem, our aim is to devise a hallucination mitigation method to minimize the semantic difference between $\hat{Y}$ and Y as follows,

$$\min(D(Y, R(\hat{Y}))), \tag{2}$$

where $D(\cdot)$ is the semantic deviation and $R(\cdot)$ refers to our hallucination mitigation method.

3.2 Potential Hallucination Classification

As we mentioned before, there are two main types of hallucination: perception hallucination and reasoning hallucination. These two types of hallucinations correspond to two types of queries: perception query and reasoning query (Liu et al., 2023e). The perception query feature mainly requires the model to have the ability to perceive visual features, such as attribute recognition, scene description, etc. The hallucinations caused by this type of queries can be effectively alleviated through visual level approaches, like object detection. The reasoning query mainly tests the understanding and reasoning ability of the model and the corresponding potential hallucinations should be mitigated by reasoning level approaches such as CoT which significantly improves the ability of large language models to perform complex reasoning (Wei et al., 2022). Since the type of potential hallucination in the answer can be judged based on the type of query, we firstly classify queries into the above two major categories and then handle the corresponding potential hallucinations. We employ ChatGPT to complete query classification through a prompt as follows,

$$C = ChatGPT(P_c(Q, \hat{Y})), \tag{3}$$

where $P_c(\cdot)$ is a prompt which can instruct ChatGPT to classify the query into perception or reasoning, and C represents the classification result. Corresponding details can be found in Appendix A.1.

3.3 Divide-and-conquer Treatment

After query classification, the LVLM responses of perception and reasoning queries need to be processed differently. This is because, as we mentioned before, different types of queries examine different capabilities of the LVLM, and the mitigation methods required for hallucinations in answers are also different.

To deal with the perception query, we need to generate verification sub-questions based on the original query and the original answer with hallucinations generated by the LVLM. The LVLM answers these sub-questions to obtain sub-answers and finally we aggregate these answers to form the output with fewer hallucinations. For reasoning queries, a common phenomenon is that the LVLM only generates the results of logical reasoning and the logical reasoning process we want to see is omitted in the generated content. In response to this situation, the method we propose is to use the CoT.

3.3.1 Visual Verification for Perceptron

LVLMs are prone to hallucinations when generating long descriptive texts (Liu et al., 2023b). This exactly corresponds to the situation of the responses of perception queries. We are inspired that when the long answer to perception queries contains hallucinations, we can split the long answer into short sentences and design verification sub-questions based on the key points in the sentences. We formulate this process as follows:

$$\{q_1 ... q_n\} = ChatGPT(P_s(Q, \hat{Y})), \tag{4}$$

where $P_s(\cdot)$ is a prompt which can instruct ChatGPT to generate sub-questions q_i according to the query Q and the original answer $\hat{Y}$, and corresponding details can be found in Appendix A.2.

After generating verification sub-questions, we feed them to the LVLM along with the original image. Thereafter, we can get the verification sub-answers from LVLMs. It is worth mentioning that the LVLM we used for generating the sub-answers is just the original model which has hallucinations that need to be revised. It can probably be replaced with any visual question answering (VQA) model, but would be accompanied by the suspicion of using a better model for better work. To demonstrate the ability of our approach to mitigate hallucinations rather than the ability of the rectified models, we chose to use the original LVLM. We formulate this process as follows:

$$y_i = M(I, q_i), \tag{5}$$

where y_i is the i-th sub-answer.

Then, we aggregate the sub-question-answer pairs and feed them to ChatGPT with the original answer $\hat{Y}$ to refined the hallucinated response as follows,

$$\overline{Y} = ChatGPT(P_a(\{q_1, y_1\} ... \{q_n, y_n\}, \hat{Y})), \tag{6}$$

where $P_a(\cdot)$ is a prompt that can instruct ChatGPT to aggregate the sub-answers and do the correction, and $\overline{Y}$ is the corrected answer. Details for the prompt $P_a(\cdot)$ template which is used for aggregating sub-answers can be found in Appendix A.3.

3.3.2 Chain of Thought for Reasoning

The answers generated by the LVLM from reasoning queries are not as "clear" as the answers to perception questions, which means the LVLM's answers tend to only contain the results of logical reasoning, but not the process of logical reasoning and the basis for that (perception about visual details before reasoning). Therefore, the method of the perception section is no longer applicable because of the missing part about perception in the reasoning answer. To solve this problem, we use the CoT prompt method to obtain answers that contain more details which are beneficial to our following process. At the same time, the LVLM will also improve the accuracy of reasoning when performing CoT. Add "Let's think step by step" to the start of the

original query to do the CoT and use ChatGPT by prompt to obtain the revised answer as follows:

$$\overline{Y} = ChatGPT(P_r(M(I, P_t(Q)), \hat{Y})) \tag{7}$$

$P_t(\cdot)$ refers to "Let's think step by step" and $P_r(\cdot)$ is the prompt that can instruct ChatGPT to correct the original answer $\hat{Y}$ according to the generation of LVLM M with CoT. Refer to Appendix A.4 for the detailed information about prompt $P_r(\cdot)$ template.

3.4 Validation Loop

After the above steps, we obtain the preliminary verified answer $\overline{Y}$ which may still contain hallucinations that have not been eliminated because of the imperfections of the verification sub-questions generation. In order to solve this problem, we propose to regard the entire verification framework as a repeated block in the verification loop chain. We show the overall procedure in Algorithm 1. The verified answer is treated as the original answer and re-verified. The difficulty of loop verification is how to judge when the hallucinations in the answer has been completely removed so the loop can be stopped. We believe that if and only if the verified answer does not change significantly semantically after a new round of verification, it means that all the hallucinations that can be eliminated have been eliminated. On the other hand, if the answer still changes significantly after a specific number of rounds of verification, we believe that there is a snowball error phenomenon in the verification cycle. We will stop the loop and use only the answer from the first verification as the final revised answer. Regarding automatically determining whether the answer is no longer changing semantically, we use a prompt to make ChatGPT automatically complete it instead of manual work. In Algorithm 1, the Similar function represents this prompt. Refer to Appendix A.5 for the prompt template.

Algorithm 1 Dentist

Input: Original question Q, original image I, original answer $\hat{Y}$, the large vision-language model M, the maximum iteration T
Output: Corrected answer $\overline{Y}$

```
Y_i ← {}
Y_l ← Ŷ
for j in 1,2...T do
    Y_t ← Verify(Q, I, Y_l, M)
    if j = 1 then
        Y_i ← Y_t
    end if
    if Similar(Y_l, Y_t) → Yes then
        # No improvement in new round of verification
        return Y_l
    else
        Y_l ← Y_t
    end if
end for
# Arrive the maximum iteration, so return Y_i
return Y_i
```

4 Experiment

In this section, we conduct extensive experiments to answer the following research questions:

RQ1. Could our framework improve the current LVLMs?

RQ2. What is the contribution of each component of our Dentist ?

RQ3. What is the intuitive performance of our Dentist ?

4.1 Experiment Settings

Benchmarks. MMBench is a novel multi-modality benchmark, which develops a fine-grained ability assessment for LVLMs. The MMBench evaluation standard is divided into three levels. The L-1 ability level incorporates Perception and Reasoning, L-2 ability level consists of Coarse Perception, Fine-grained, etc. and L-3 ability level covers Image Style, Image Scene, Image Emotion, etc. Relying on such hierarchical and fine-grained capability assessment, the performance of LVLM can be comprehensively evaluated. The dataset we use is MMBench-Test(EN).

LLaVA-QA90 is also a dataset used to evaluate LVLMs. LLaVA-QA90 contains 90 VQA tasks and 30 images taken from COCO Val 2014 (Lin et al., 2014). To evaluate the generated response, we feed the query, image, and model response to GPT-4V (OpenAI, 2023) to get a score of a scale of 1 to 10. The prompt template is available in Appendix A.7

Caption Hallucination Assessment with Image Relevance (CHAIR) (Rohrbach et al., 2018) is a widely-used metric for evaluating object hallucination in image captioning tasks. By comparing the image captions generated by the model with the ground truth objects in the corresponding image, CHAIR evaluates the degree of hallucination of the model and explains the performance of the model. CHAIR has two variants: $CHAIR_s$ (C_s) and $CHAIRi$ (C_i), both of which reflect the degree of hallucination of the model, the difference being that $CHAIR_s$ is at the sentence level and $CHAIRi$ is at the object instance level. The calculation is as follows:

$$CHAIR_s = \frac{|\{sentences\ with\ hallucinated\ object\}|}{|\{all\ sentences\}|}$$

$$CHAIR_i = \frac{|\{hallucinated\ objects\}|}{|\{all\ mentioned\ objects\}|}$$

POPE (Li et al., 2023c) is also a widely used method dedicated to evaluating the extent of LVLMs hallucinations. Three kinds of sampling settings of random, popular, adversarial, are constructed on the dataset according to human annotation or automatic visual segmentation tools. The difference between them lies in the negative sample sampling method. Where, the random setting randomly samples objects that do not exist in the image; the popular setting samples objects that are not present in the current image, but are most common throughout the dataset; the adversarial setting samples objects in the dataset that co-appear most frequently with objects in the current image, but are not present in the current image. POPE has a high degree of fairness and robustness, which helps us to better demonstrate the hallucination mitigation effect of Dentist.

In terms of sampling settings, we sample 100 images and construct 6 questions for each type of sampling setting for each image. Each question is a "Yes or No" question that transforms the model task into a simpler binary classification task. In terms of evaluation metrics, we adopt Accuracy, Precision, Recall and F1 score as the evaluation metrics.

Baselines. We first select 3 currently mainstream LVLMs as our baseline models, including **InstructBLIP**, **LLaVA**, and **VisualGLM**. In addition, we also compare against the baseline Woodpecker (Yin et al., 2023) which is a training-free hallucination correction method for LVLMs.

Implementation Details. We utilize GPT-3.5-turbo-0613[1] to assist in keyword extraction, sub-question generation, verification loop, and verification answer integration. Experiments have proven that GPT-3.5-turbo can tackle these tasks. On MMBench, we set the experiment rounds to 2: (1) In the first round of evaluation, we have the model generate raw predictions according to MMBench's evaluation rules and submit them to MMBench's official platform to obtain various accuracy rates; (2) In the second round of evaluation, based on the original prediction of the model, query classification, different verification processes and answer integration are carried out using GPT-3.5-turbo (specific details can be found in Section 3). Similarly, we upload the results of the second round of evaluation to the official MMBench platform to obtain various accuracy rates; (3) Finally, we jointly analyze the results of two rounds of evaluation to demonstrate the effectiveness and superiority of Dentist.

[1] https://platform.openai.com/

Table 1: Results on MMBench-Test(EN). Dentist denotes the performance after the hallucination is corrected by our verification method. The performance is measured by accuracy, where the improved performance for each partition is highlighted in bold.

Ability		**InstructBLIP-7B**		**LLaVA-V1.5-7B**		**VisualGLM-6B**	
		Baseline	Dentist	Baseline	Dentist	Baseline	Dentist
Coarse Perception	Image Topic	60.0	60.0	**97.6**	96.4	52.9	50.2
	Image Quality	0.0	10.6	0.0	10.2	0.0	**15.6**
	Image Emotion	32.7	41.3	67.5	**76.4**	41.7	50.6
	Image Scene	58.1	60.3	85.3	**88.3**	68.5	70.3
	Image Style	38.8	37.1	**58.8**	55.3	30.6	35.8
Fine-grained Perception [Single-instance]	OCR	51.9	58.6	70.1	**78.3**	41.6	43.6
	Celebrity Recognition	40.8	49.2	60.2	**68.6**	52.5	55.2
	Object Localization	3.9	14.4	**16.3**	11.5	8.6	10.9
	Attribute Recognition	46.5	51.4	66.7	**70.6**	40.0	43.7
Fine-grained Perception [Cross-instance]	Action Recognition	58.5	57.5	**87.5**	85.2	35.2	38.6
	Attribute Comparison	2.6	2.6	21.2	**25.8**	8.8	10.8
	Spatial Relationship	11.1	8.6	11.1	**15.3**	7.3	10.9
Attribute Reasoning	Identity Reasoning	68.3	68.3	86.6	**86.6**	81.7	88.4
	Function Reasoning	46.2	49.6	74.5	**77.8**	44.9	50.6
	Physical Property	21.0	21.9	**55.0**	50.0	26.0	30.3
Relation Reasoning	Nature Relation	22.2	27.3	38.3	**38.3**	24.7	30.6
	Physical Relation	11.3	17.3	28.9	**28.9**	3.8	9.6
	Social Relation	27.6	41.0	62.8	**69.6**	46.2	45.3
Logic Reasoning	Image-Text	5.9	7.0	**11.9**	10.9	3.9	5.0
	Future Prediction	46.7	**55.0**	43.1	52.1	21.6	31.0
Overall		33.9	36.9	51.0	**54.8**	32.0	36.4

Previous studies (such as POPE (Li et al., 2023c)) have found a strong correlation between LVLMs hallucination and the length of the generated text, and in our experiments we find this to be true. In the CHAIR evaluation, since the LVLMs we select all have remarkable instruction following ability, we notice that when the LVLM are prompted to "generate as detailed a description as possible", the CHAIR score of the model is much higher than when they are prompted to "generate a short description" (a higher CHAIR score indicates a higher degree of hallucination). This is not desirable in a common usage scenario. But we can take advantage of this feature to better demonstrate the ability of Dentist to mitigate hallucinations. Therefore, in the CHAIR experiment, we prompt the model to generate a detailed description.

4.2 Results (RQ1)

Results on MMBench. The results on MMBench are summarized in Tab. 1. From this table, we have several observations. (1) The largest accuracy improvement among the three LVLMs exceeds 15.6%, showing that Dentist have excellent correction effects, making obvious improvements in various metrics for the baselines. (2) Dentist performs outstandingly in Image Emotion, Image Quality, Future Prediction, Attribute Recognition, etc., which indicates that Dentist is capable of mitigating hallucination in coarse perception, fine-grained perception and logic reasoning. (3) Among all metrics, Image Quality shows the highest improvement, which indicates that Dentist is particularly effective for hallucinations in such problems.

Results on LLaVA-QA90. If manual verification is required, the evaluation on LLaVA-QA90 is labor-intensive and somewhat subjective. Therefore, it is necessary to use a powerful evaluation tool to ensure consistency in evaluation standards while also possessing strong visual language task answering and instruction following abilities. Therefore, we consider utilizing the powerful LVLM, GPT-4V. Specifically, we involve GPT-4V in scoring and evaluating model responses by setting appropriate prompt words. We have designed the following three metrics: Accuracy: how accurate is the model response about the image content; Detail

Table 2: Results on LLaVA-QA90. The accuracy, detail description and complex reasoning metrics are on a scale of 10, and a higher score indicates the better performance. The better performance for each partition is highlighted in bold.

LVLM		Accuracy	Detail description	Complex reasoning
InstructBLIP	Baseline	6.5	4.9	4.3
	Woodpecker	6.4	5.5	4.4
	Dentist	**7.0** (+0.5)	**5.5** (+0.6)	**4.8** (+0.5)
LLaVA	Baseline	6.0	5.3	4.4
	Woodpecker	6.5	5.5	4.5
	Dentist	**6.6** (+0.6)	**5.8** (+0.5)	**5.0** (+0.6)
VisualGLM	Baseline	5.6	5.0	4.0
	Woodpecker	2.0	1.6	1.3
	Dentist	**6.2** (+0.6)	**5.8** (+0.8)	**4.7** (+0.7)

description: level of details of the responses; Complex Reasoning: whether the reasoning content of response is reasonable. In addition, we conduct the same evaluation on the current effective hallucination correction method, Woodpecker, and compare the baseline LVLMs, Dentist, and Woodpecker scores.

Tab. 2 shows the results. Obviously, equipped with our verification method, the models' performance has been comprehensively improved across the three metrics. On average, there is an improvement of over 0.5 points (relative improvement exceeding 13.6%), and Dentist scores better than Woodpecker on all baselines. This indicates that Dentist not only improves the accuracy of LVLMs in describing image content, but also promotes the detail of image description and the rationality of inference content.

It is worth noting that Woodpecker's score in VisualGLM decreases significantly. We find that the reason for the decrease in score is the failure of Woodpecker's object detector. On the one hand, this proves that the Woodpecker over-relies on its object detector, and when its detector fails, the correction effect of Woodpecker will become worse; on the other hand, it proves that Dentist has stronger robustness.

Table 3: Comparison of the CHAIR metrics between Dentist and Woodpecker. The best performance for each metric is in bold.

	InstructBLIP		LLaVA		VisualGLM	
	$C_s \downarrow$	$C_i \downarrow$	$C_s \downarrow$	$C_i \downarrow$	$C_s \downarrow$	$C_i \downarrow$
Baseline	59.2	22.9	84.0	23.4	44.0	17.8
Woodpecker	56.9	18.5	**71.9**	19.8	37.0	11.9
Dentist	**52.1**	**16.7**	75.2	**17.1**	**36.0**	**11.3**

Results on CHAIR. We compare the effects of Dentist and Woodpecker on mitigating hallucinations. The specific method is as follows: we select 2000 examples in COCO Val 2014, let the baseline model generate corresponding captions, and then apply Dentist and Woodpecker respectively to process the hallucination correction of the captions, and calculate the two metrics of the CHAIR to analyze the difference between the two correction methods.

Tab. 3 shows the results. It is easy to draw the following conclusions from the results: (1) The model with remarkable performance may also produce more hallucinations. For example, LLaVA scored very high on MMBench, but the CHAIR evaluation shows that LLaVA's hallucinations were more serious. (2) Dentist demonstrates an ability to reduce hallucinations no less than Woodpecker, and helps the baselines reduce more hallucinations in most aspects.

Results on POPE. We evaluate InstructBLIP, LLaVA and VisualGLM for hallucination on POPE respectively, and compare the results of baseline LVLMs, Woodpecker and Dentist. Tab. 4 summarizes

Table 4: Results on POPE. The best performance for each metric is highlighted in bold.

POPE	LVLM	Method	Accuracy	Precision	Recall	F1 Score	Yes (%)
Random	InstructBLIP	Baseline	85.00	88.32	78.67	84.32	45.67
		Woodpecker	86.21	92.38	78.97	84.63	35.08
		Dentist	**87.00**	**94.40**	**80.67**	**85.82**	41.67
	LLaVA	Baseline	79.67	75.47	84.67	75.34	63.00
		Woodpecker	84.78	85.64	90.26	83.44	50.23
		Dentist	**87.33**	**89.44**	**92.67**	**86.98**	47.33
	VisualGLM	Baseline	53.44	51.85	**99.12**	68.09	95.79
		Woodpecker	69.74	66.83	90.56	76.33	73.82
		Dentist	**75.88**	**73.25**	87.79	**78.95**	68.02
Popular	InstructBLIP	Baseline	80.67	81.72	**79.00**	80.34	48.33
		Woodpecker	81.03	**88.81**	68.97	78.43	37.93
		Dentist	**83.33**	86.76	78.67	**82.52**	45.33
	LLaVA	Baseline	75.67	73.98	**90.00**	74.79	70.33
		Woodpecker	85.42	84.38	85.39	83.64	50.28
		Dentist	**87.00**	**90.90**	84.67	**86.69**	47.67
	VisualGLM	Baseline	58.31	54.63	**99.12**	70.44	90.90
		Woodpecker	66.78	62.45	88.34	70.25	88.44
		Dentist	**70.53**	**68.12**	87.35	**71.20**	86.91
Adversarial	InstructBLIP	Baseline	78.83	76.95	**82.33**	79.55	53.50
		Woodpecker	77.59	82.23	68.97	75.47	41.38
		Dentist	**80.83**	**83.33**	78.67	**80.41**	47.83
	LLaVA	Baseline	76.67	71.06	**92.00**	73.40	75.33
		Woodpecker	77.62	74.53	88.67	80.73	64.25
		Dentist	**80.67**	**78.40**	84.67	**81.41**	54.00
	VisualGLM	Baseline	54.10	52.21	**99.12**	68.40	95.12
		Woodpecker	62.67	60.33	85.44	66.78	82.35
		Dentist	**68.10**	**63.42**	86.90	**68.87**	80.90

the results of POPE under the random, popular, and adversarial sampling settings. It can be seen that, in all sampling settings, VisualGLM is relatively weak, noting that its Recall and Yes Rate are both very high (close to 1), which indicates that VisualGLM produces relatively severe hallucinations of objects not in the image (i.e. negative samples). The reason for this phenomenon is probably that VisualGLM fails to deal with the imbalanced distribution of the dataset during the training process. The other baseline models are above 70% on these metrics. Dentist brings significant improvements to these baseline LVLMs, which validates Dentist's excellent performance in mitigating hallucination. Specifically, under the relatively simple random sampling setting, Dentist obtains a gain of 22.44% for VisualGLM in terms of accuracy. In the more challenging popular and adversarial settings, the performance of these baseline LVLMs decline to varying degrees. Dentist continues to show remarkable performance. In particular, Dentist boosts the precision of LLaVA by 14.83% in the popular setting and accuracy of VisualGLM by 14.00% in adversarial setting. In addition, it can be seen from the comparison that Dentist outperforms Woodpecker in all sampling settings.

Verification time comparison. While evaluating Dentist and Woodpecker on POPE, we count and analyze the time spent on hallucination correction for both. A total of 100 images and 1,800 questions are provided to Dentist and Woodpecker throughout the evaluation process. For InstructBLIP, Dentist spend a total of 7 hours and 49 minutes to complete this task, with an average of 15.6 seconds per query. Woodpecker spend a total of 8 hours and 16 minutes to complete the task, with an average of 16.5 seconds per query. It can be seen that the the rapidity of Dentist is also better than that of Woodpecker and has a good timeliness.

Comprehensive comparison. The similarity between our framework Dentist and Woodpecker is that we both use an LLM to revise the hallucinated response generated by LVLMs.

Woodpecker extracts main objects from responses and verifies these objects with object segmentation tool and VQA models, for all hallucinated responses. However, Dentist has a divide-and-conquer treatment. When Dentist is faced with perception query, it tries to verify the main objects in the model response. When faced with reasoning query, Dentist uses CoT to deal with it. This divide-and-conquer treatment accurately mitigates hallucinations and achieves better results.

4.3 Ablation Studies (RQ2)

To explore the effect of the query classification and verification loop, we conduct ablation studies in this section.
Query Classification. We study three different variants and evaluate their performance on MMBench. (1) **w/o-Cla**: we disable the query classification section of Dentist ; (2) **w/o-Rea**: we classify all queries into perception for verification; (3) **w/o-Per**: we classify all queries into reasoning for verification;

Table 5: Results on MMBench with different variants of InstructBLIP. For more comprehensive evaluation results on LLaVA and VisualGLM, please refer to the Appendix A.8.

Variants	Perception Accuracy	Reasoning Accuracy
Baseline	33.74%	31.15%
Dentist	37.62%	35.92%
w/o-Cla	34.86%	32.73%
w/o-Rea	38.94%	25.48%
w/o-Per	28.34%	38.44%

Tab. 5 shows the results of InstructBLIP. We can see that: (1) If query classification is not performed and verification is performed directly (w/o-Cla), the accuracy is not much higher than the baseline, and in some cases there is even a problem of reduced accuracy. Because at this point, the way Dentist corrects the model's answers is completely random, which largely depends on the performance and habits of GPT-3.5-turbo: it can be seen that the perception accuracy may not differ much from the baseline, or slightly higher than the baseline, while the reasoning accuracy may decrease. This is because the query classification section tends to treat the problem as perception for processing. (2) If all queries are classified into perception (w/o-Rea) (this is what most current LVLM hallucination mitigation methods do), it can be seen that the perception accuracy is greatly improved, while the reasoning accuracy is greatly attenuated. This is because Dentist also verifies the reasoning problem as perception, so the verification method is not appropriate, resulting in a decrease in accuracy; (3) In the same way, if all problems are classified as reasoning (w/o-Per), the reasoning accuracy is greatly improved, and correspondingly, the perception accuracy is reduced; (4) It can also be found that the perception accuracy of w/o-Rea may even be slightly higher than that of Dentist. We speculate that this is due to the misjudgment by GPT-3.5-turbo when classifying queries, such as mistakenly categorizing a very small number of perception queries as reasoning, while w/o-Rea precisely corrects this part of the misjudged perception queries. The same goes for reasoning queries.

Verification Loop. Verification loop is also a component that we need to study. We conduct additional experiments by varying the number of verification loops in our framework and evaluating it on MMBench to demonstrate its effectiveness.

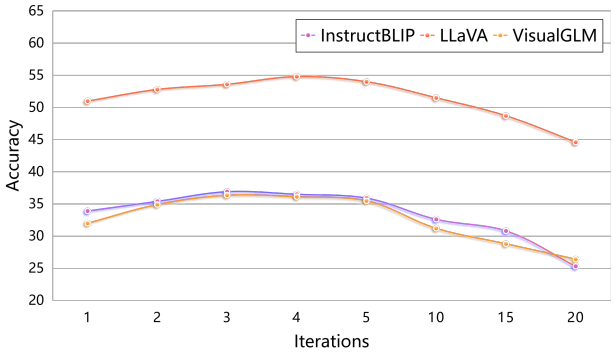

Figure 3: Results of verification loop

Fig. 3 shows the results. We can see that when the number of verification loop is small, there is a slight improvement in accuracy as the number of loops increases. However, when the number of cycles is large, the accuracy actually decrease as the number of cycles increases. We separately take out one of the cases for observation and found that when the number of cycles is large, the output of the LVLM and GPT gradually

become chaotic and uncontrollable, which may lead to an avalanche of decrease in the accuracy of the model when the number of cycles is large enough. Therefore, we conclude that verification loop is effective, but special attention needs to be paid to limiting its frequency. When the model answer matches the validation answer, it is important to exit the loop validation in a timely manner.

4.4 Discussion On Reproducibility

In this section, we discuss the effect of our framework on correcting hallucinations and the reproducibility of the above experimental results. It should be emphasized that since our method is training-free, all parameters of the model are fixed. We focus on the following questions: (1) When LVLM repeatedly generates captions for the same image, will it produce the same hallucinations? (2) When using our framework to process a series of model responses in (1), can we obtain consistent results? Can we guarantee that the hallucinations can be corrected every time? To this end, we re-conduct POPE evaluation under the random sampling setting, and the other settings are the same as those introduced in Section 4.1. The difference is that we let the LVLM test each example 10 times and let our framework process each of these responses. We provide two new baselines: (1) **Direct Rejection Baseline (DR Baseline)**: For each example, when our framework detects hallucinations in the model's ten responses, no correction is made and the sample is directly judged as an error. (2)**Repeated Correction Baseline (RC Baseline)**: For each example, when our framework detects hallucinations in all ten responses of the model, the hallucinations are corrected normally. We infer that from DR Baseline, we can see whether the same LVLM will repeatedly hallucinate the same image, and from RC Baseline, we can see whether our framework's correction of hallucinations is repeatable.

Table 6: Results on POPE under the random sampling setting.

LVLM	Method	Accuracy	Precision	Recall	F1 Score	Yes Rate
InstructBLIP	DR Baseline	79.17	81.81	75.00	78.26	38.33
	RC Baseline	85.56	92.48	82.12	81.37	40.22
LLavA	DR Baseline	71.70	71.93	74.55	73.21	44.34
	RC Baseline	87.33	86.97	91.38	82.79	46.41
VisualGLM	DR Baseline	50.83	51.79	92.06	66.29	89.16
	RC Baseline	76.88	74.35	86.54	78.18	63.25

From the table, we can draw the following conclusions to answer the questions mentioned above: (1) Using our framework to classify and detect errors without correcting the answers leads to a significant drop in performance. The three baselines show a drop of more than 10% in all metrics, especially the Accuracy of VisualGLM, which drops by 25.05%. When the model parameters are fixed, it is very easy to hallucinate the same image repeatedly, as long as the same image and the prompt with the similar semantic are provided. (2) Our framework is still able to find and correct the hallucinations generated by LVLM in the face of repeated tests, and the performance is almost the same as the previous experiment, which shows that our framework is very effective in detecting hallucinations generated by models and correcting hallucinations. Therefore, we believe that our experimental results are reproducible and that the hallucination correction capability of our framework is reproducible.

4.5 Case Study (RQ3)

We provide two testing examples in Figure 4 to conduct qualitative analysis. It is obvious from the above example that: In the first example, Dentist classifies the query as "Perception". The original response of LVLM is that "There is a person holding two red apples in the picture", which is obviously wrong. After Dentist extracts the keywords "apple", "two", "red", etc., three corresponding sub-questions are generated. Dentist then answers the sub-questions one by one. Since the sub-questions are more targeted and usually have short outputs, the possibility of hallucinations is greatly reduced. After comparing and integrating the answers, Dentist finds out the existing hallucinations (the number of apples), corrects the original answer, and eliminates the perception hallucination.

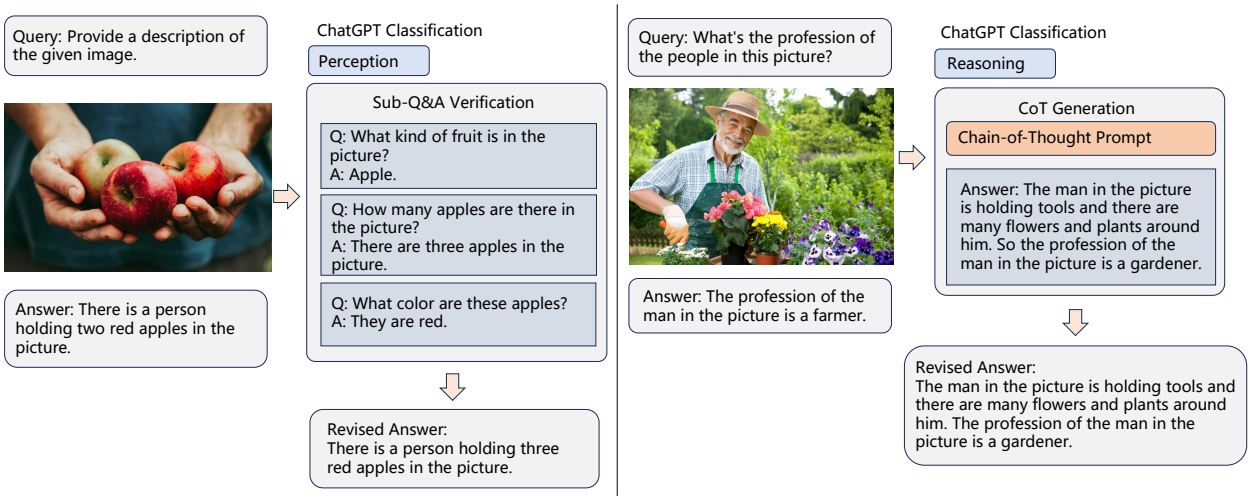

Figure 4: Two testing cases of Dentist . The left example shows a perception hallucination produced by LVLM, and the right example shows a reasoning hallucination produced by LVLM, and these hallucinations are eliminated by Dentist.

In the second example, the original response of LVLM infers that the person in the image is a farmer, which is obviously wrong. The model mistakenly draws a conclusion that is contrary to the facts based on the information in the image. Dentist classifies the query as "Reasoning" and refines the hallucinated answer according to the content of the CoT and the original output of the model. Dentist matches the original answer and the CoT generation answer, and find that the objects and inference in the content of the two matches, so the final answer is obtained, thus eliminating the reasoning hallucination.

In the above cases, Dentist perfectly eliminates the perception and reasoning hallucinations produced by LVLM.

5 Conclusion

In this work, we propose a unified framework for hallucination classification and mitigation. We are the first to distinguish treatment based on the classification of hallucinations and use a validation cycle for the removal of hallucinations. Our framework has a clear design which is easily integrated into various LVLMs, and provides convenience for new classifications and treatments to integrate into the framework. To evaluate the effectiveness of our framework, We conduct massive experiments on the three baseline LVLMs on MMbench, LLaVA-QA90, CHAIR and POPE, which shows that Dentist can significantly improve the baseline LVLMs on these benchmarks. At the same time, we compare the results of LLaVA-QA90 and CHAIR with those of Woodpecker, and the results shows that Dentist not only has excellent hallucination correction ability, but also has strong robustness.

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A Appendix

In this section, we will display all prompt templates used in this framework and other noteworthy figures and tables. All the following prompt templates are used in GPT-3.5-turbo-0613.

A.1 Query Classification

The prompt template is in Fig. 5.

A.2 Sub-questions Generation

The prompt template is in Fig. 6.

A.3 Sub-answers Aggregation

The prompt template is in Fig. 7.

A.4 CoT Verification

The prompt template is in Fig. 8.

A.5 Verification Cycle

The prompt template is in Fig. 9.

A.6 Results on MMBench

The results on MMBench are in Fig. 11, Fig. 12 and Fig. 13.

A.7 Prompt for GPT-4V-aided evaluation.

The prompt template for GPT-4V-aided evaluation is in Fig. 10

A.8 Results of ablation study

The results of LLaVA and VisualGLM are in Table 7 and Table 8.

A.9 Benchmark table

Benchmark details are in Table 9.

A.10 Hallucination case

Cases of hallucination mitigation are in Fig. 14.

A.11 ChatGPT cost

The cost of calling the GPT-3.5-turbo-0613 API is shown in Table 10.

We calculated the cost of calling the gpt-3.5-turbo-0613 API when evaluating on MMBench. In one round of evaluation, the total cost was about $2.75, with an average cost of $0.0004 per question.

A.12 Model parameter

Details of LVLMs parameters are shown in Table 11.

Table 7: Results on MMBench with different variants of LLaVA

Variants	Perception Accuracy	Reasoning Accuracy
Baseline	53.52%	50.13%
Dentist	56.83%	51.77%
Dentist/N	54.39%	48.76%
Dentist/P	57.90%	42.63%
Dentist/R	50.43%	52.11%

Table 8: Results on MMBench with different variants of VisualGLM

Variants	Perception Accuracy	Reasoning Accuracy
Baseline	32.31%	31.60%
Dentist	36.35%	36.35%
Dentist/N	35.06%	28.73%
Dentist/P	37.83%	22.60%
Dentist/R	28.26%	37.60%

Prompt

Role:
You are now one of my question classification assistants.
Please help me classify the question into two categories: perception or reasoning(binary classification).

Rules:
1.The classification result is only "perception" or "reasoning". Choose one of the two to output.
2.If the question focuses on perception ability, answer "perception"; if the question focuses on logical reasoning ability, answer "reasoning".
3.Don't answer anything else, your answer can only contain "perception" or "reasoning".

Examples:
1.my input: "How many people are there in this picture?"
your answer: "perception"

2.my input: "The person in the picture may do what soon?"
your answer: "reasoning "

{add more examples}

Now please classify the following question according to the example and then answer "perception" or "reasoning":

Figure 5: Prompt template for classification

Prompt

Role:
You are my language assistant for generating sub-questions.
Please generate sub-questions to verify the caption of the picture based on QA-examples below.

Rules:
1.The number of sub-questions cannot exceed three.
2.Extract keywords such as objects, quantities, and locations to generate sub-questions.
3.Each sub-question should have a different focus.
4.Don't ask repeated questions in different sub-questions.
5.If my input contains multiple choice questions, please generate sub-questions based on the question, options and answers.

Examples:
1.my input:
"Question: Write a detailed description for this picture.
Answer: The picture shows a man standing on the back of the yellow taxi, with a yellow shirt and black pants, and a blue backpack on his back. The taxi is driving on a city street with cars and taxis in the background."
sub-questions you generated:
"1.Is there a man standing on the back of a taxi in this picture?
2.What color are the T-shirt and pants that man wear?
3.What's in the background? "

{add more examples}

Now please generate verification sub-questions based on my input below:

Figure 6: Prompt template for generating sub-questions

Table 9: The number of questions in experiment

Benchmarks	Questions	Tasks
LlaVA-QA90	90	generative
POPE	1800	classification
MMBench	6666	classification
CHAIR	2000	generative

Table 10: The cost of calling the GPT-3.5-turbo-0613 API

Model	Price(input)	Price(output)
GPT-3.5-turbo-0613	$1.5 / 1M tokens	$2.0 / 1M tokens

Table 11: Details of the evaluated LVLMs.

LVLM	Overall Parameters
InstructBLIP	8B
VisualGLM	8B
LLaVA	7.2B

Prompt

Role:
You are my language assistant for correcting or remaining my passage.
Below is a passage and some Q&A pairs. You need to modify the passage or just keep it unchanged based on the Q&A pairs.

Rules:
1.The information provided by the Q&A pairs is the ground truth, and the information in the passage may contain errors.
2.If the passage conflict with the Q&A pairs, find them and correct the passage based on the Q&A pairs. Try to make minimal changes to retain the original sentence. Then give me the passage which have been corrected by you.
3.If the passage has no confliction with the Q&A pairs, just keep the original passage and give me that.
4.At any time your output should only be a passage.

Examples:
1.Passage:"There are two apples in the picture, they look stale."
Q&A pairs:
Q:How many apples are there in the picture? A:There are three apples in the picture.
Q:Do these apples look fresh in the picture? A:No, they look stale.
Your output:"There are three apples in the picture, they look stale."

{add more examples}

Now I give you the passage and some Q&A pairs, please follow the examples and give me the passage you modified:

Figure 7: Prompt template for aggregating sub-answers to form the output after alleviating the hallucination

Prompt

Role:
You are my language assistant for correcting or remaining my passage.
Below are two passages.
Rules:
1.The second passage is the ground truth, the first passage may contain some errors.
2.If the first passage conflict with the second passage, find them and correct the first passage based on the second passage. Try to make minimal changes to retain the original sentence. Then give me the first passage which has been corrected by you.
3.If the first passage has no confliction with the second passage, just remain the first passage and give me that.
4.At any time your output should only be a passage.

Examples:
1.The first passage: " The profession of the man in the picture is a farmer."
The second passage: "The man in the picture is holding tools and there are many flowers and plants around him. So the profession of the man in the picture is a gardener."
Your output: "The profession of the man in the picture is a gardener."

{add more examples}

Now I give you two passages, please follow the rules and examples and give me your output:

Figure 8: Prompt template for CoT verification

Prompt

Role:
You are my language assistant for determining whether there is a conflict between two passages.

Rules:
1.Below are two passages.
2.If there is conflicting content between the two passages, you should answer "yes"
3.If there is no conflicting content between the two passages, you should answer "no"
4.At any time You can only answer yes or no.

Examples:
1.Passage 1: "There are two apples in the picture, they look stale."
Passage 2: "There are three apples in the picture, they look stale."
Your answer: "yes"

{add more examples}

Now I give you two passages, please follow the examples and give me your answer about whether there is a conflict between two passages.

Figure 9: Prompt template for judging when the validation cycle can be stopped

Prompt

You are my scoring assistant. You need to score two passages describing the picture based on the content of the picture.
What you need to pay special attention to is the hallucination, which refers to the conflict between the content of the passages and the content of the picture.
For example, the passage incorrectly describes the shape or color of the object in the picture, or makes wrong inferences based on the content of the picture.
Please rate the two passages on a scale of 1 to 10, where a higher score indicates better performance, according to the following criteria:
1. Accuracy: Refers to whether the description of the picture by the passage is accurate. Passages with fewer hallucinations should be given higher scores.
2. Detail description: Refers to whether the description of the picture is detailed in the passage. Note that descriptions with hallucinations are not counted. Passages with more details should be given higher scores.
3. Complex reasoning: Refers to whether the logical reasoning made by the passage based on the picture content is complex and reasonable. Note that the logical reasoning with hallucinations are not counted. Passages with more logical reasoning should be given higher scores.

Please output a single line for each criterion, containing only two values indicating the scores for Passage 1 and 2, respectively.
The two scores are separated by a space. Following the scores, please provide an explanation of your evaluation, avoiding any potential bias and ensuring that the order in which the responses were presented does not affect your judgment.

Passage 1:
{Original Answer}

Passage 2:
{Revised Answer}

Figure 10: Prompt template for GPT-4V-aided evaluation

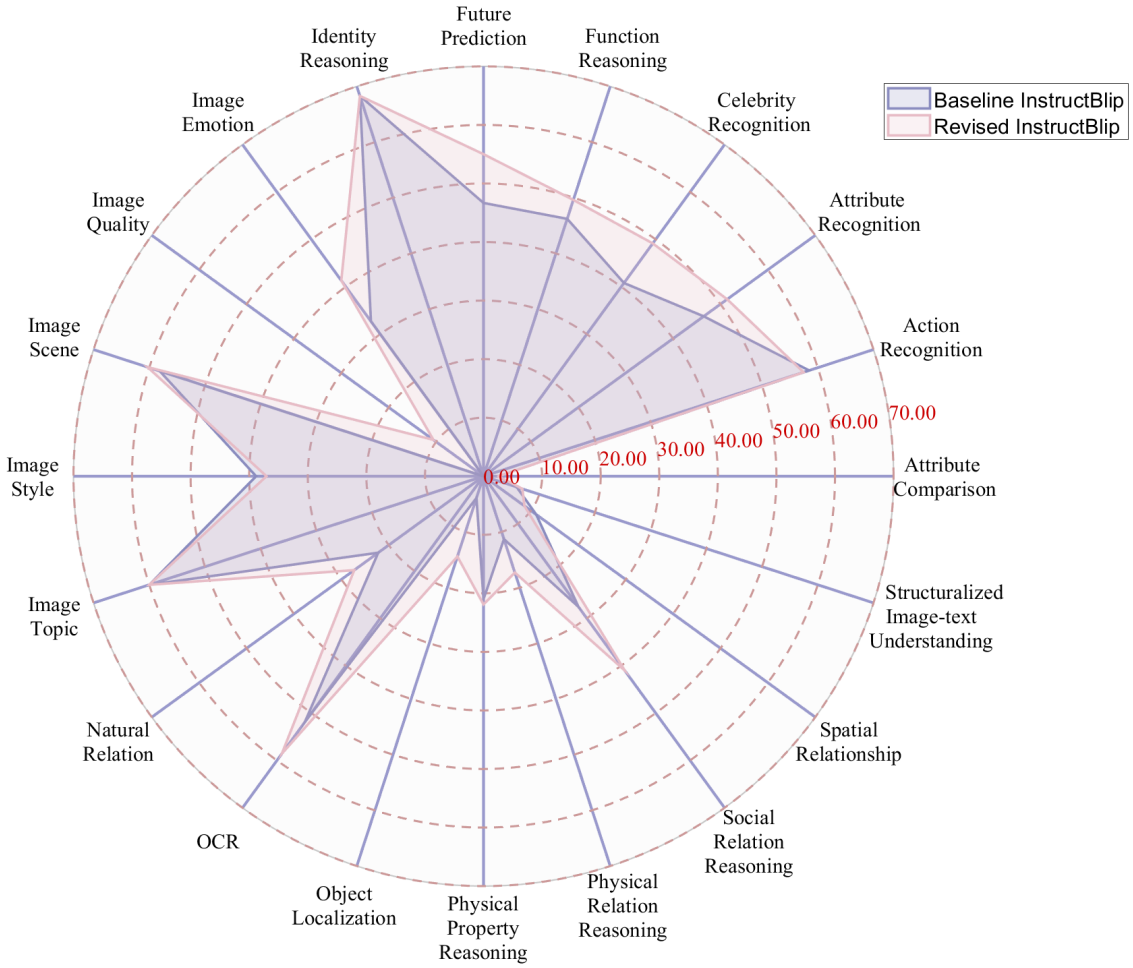

Figure 11: Results of InstructBLIP(Baseline and ours) across the 20 ability dimensions defined in MMBench. The blue area is the result of the baseline, and the red area is ours. See the legend. From this figure, we can intuitively see that our method can enhance the performance of baseline in terms of Image Impression, Image Quality and Future Prediction, etc. For more comprehensive evaluation results on LLaVA and VisualGLM, please refer to Fig.12 and Fig.13

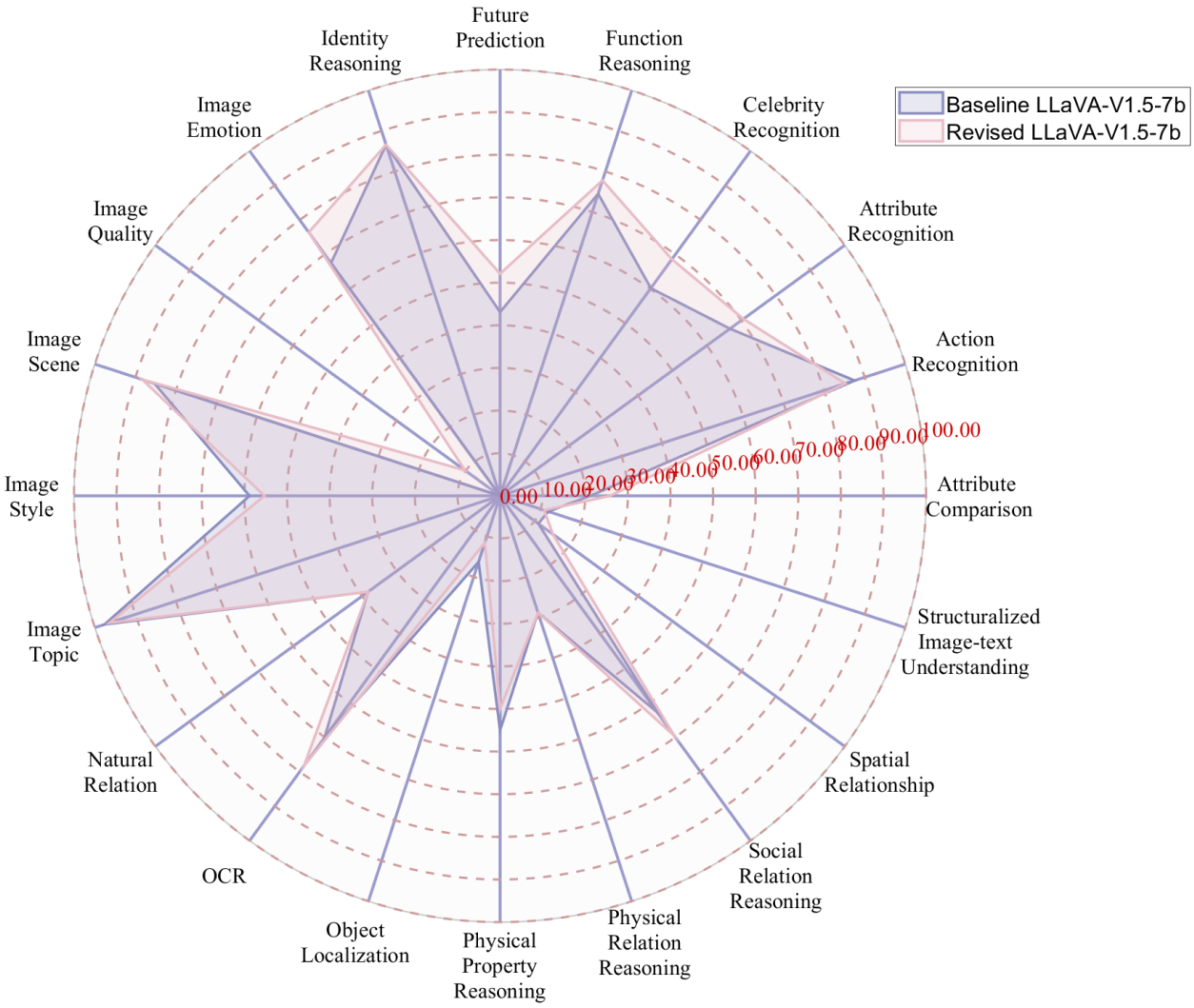

Figure 12: Results of LLaVA on MMBench.

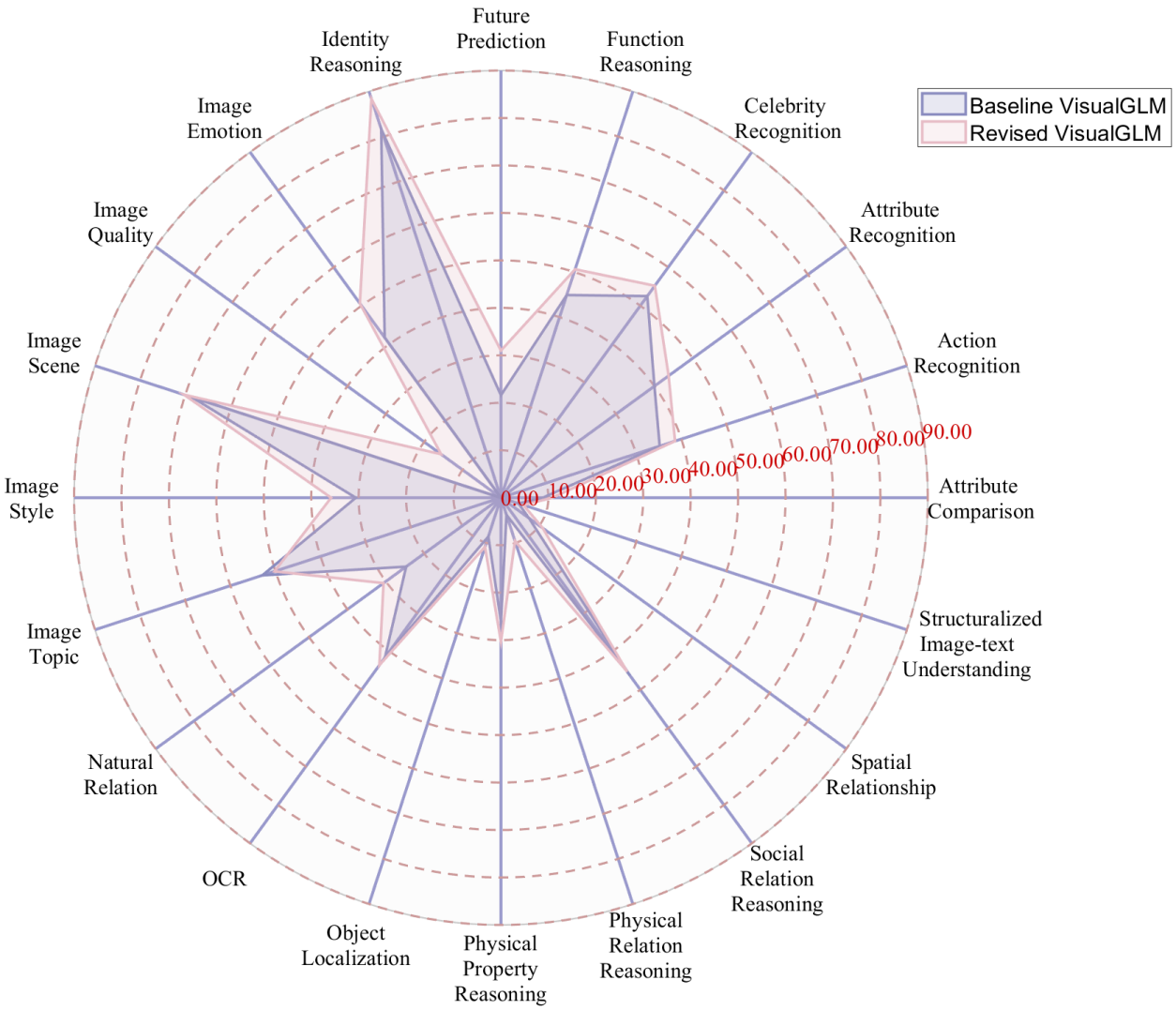

Figure 13: Results of VisualGLM on MMBench.

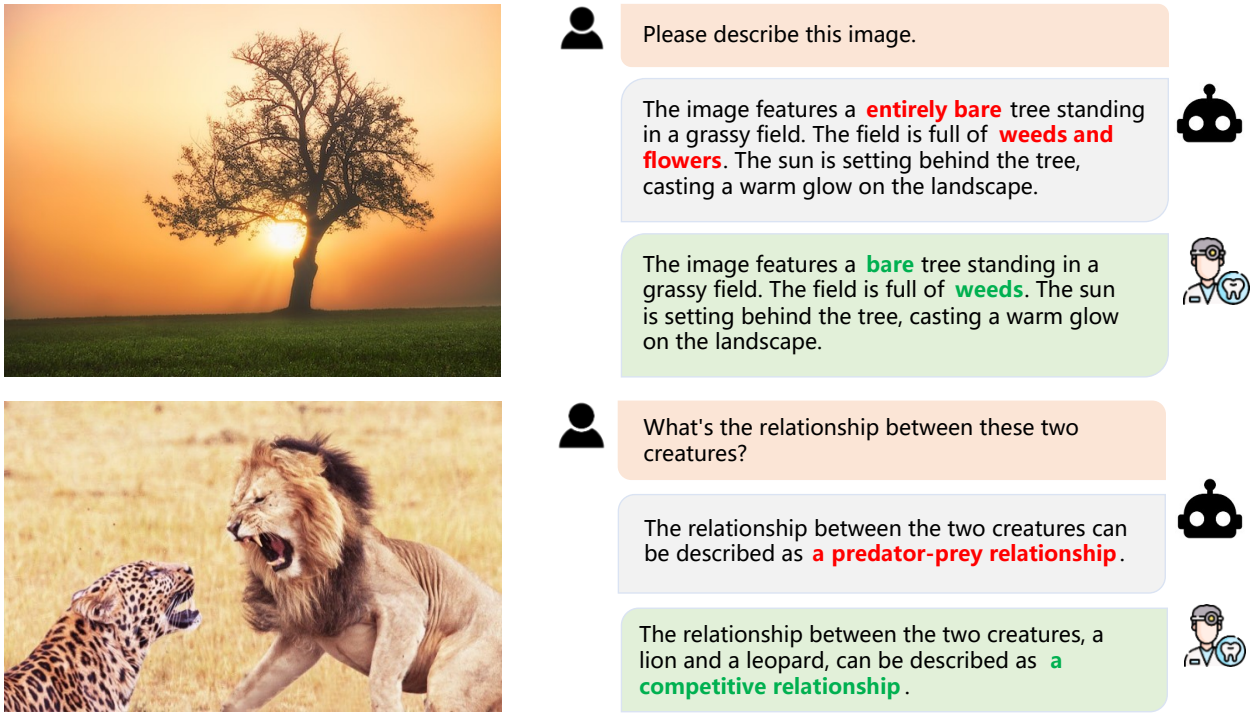

Figure 14: Example images of our hallucination mitigation. The part of the generation that conflicts with the content of the picture has been corrected.