Visual Fact Checker: Enabling High-Fidelity Detailed Caption Generation

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NVIDIA

https://research.nvidia.com/labs/dir/vfc/

Figure 1. Comparison of VisualFactChecker (VFC) with GPT-4V and Cap3D. VFC can generate high-fidelity detailed captions that closely match GPT-4V’s quality for 2D images and offer significantly more details for 3D objects than Cap3D. VFC used a pre-trained Llama-2 as the LLM when generating the caption for the above 2D image.

Abstract

Existing automatic captioning methods for visual content face challenges such as lack of detail, content hallucination, and poor instruction following. In this work, we propose VisualFactChecker (VFC), a flexible training-free pipeline that generates high-fidelity and detailed captions for both 2D images and 3D objects. VFC consists of three steps: 1) proposal, where image-to-text captioning models propose multiple initial captions; 2) verification, where a large language model (LLM) utilizes tools such as object detection and VQA models to fact-check proposed captions; 3) captioning, where an LLM generates the final caption by summarizing caption proposals and the fact check verification results. In this step, VFC can flexibly generate captions in various styles following complex instructions. We conduct comprehensive captioning evaluations using four metrics: 1) CLIP-Score for image-text similarity; 2) CLIP-Image-Score for measuring the image-image similarity between the original and the reconstructed image generated by a text-to-image model using the caption. 3) human study on Amazon Mechanical Turk; 4) GPT-4V for fine-grained evaluation. Evaluation results show that VFC outperforms state-of-the-art open-sourced captioning methods for 2D images on the COCO dataset and 3D assets on the Objaverse dataset. Our study demonstrates that by combining open-source models into a pipeline, we can attain captioning capability comparable to proprietary models such as GPT-4V, despite being over 10× smaller in model size.
1. Introduction

Image captioning is a pivotal challenge in computer vision and natural language processing. Its central goal is to encapsulate visual data within a textual description, which requires a nuanced understanding of both modalities. The recent advent of multimodal large language models (MM-LLMs), such as GPT-4V [26], and text-to-image generation models, such as DALL-E-3 [3], has marked significant progress in this field. These proprietary models could leverage expansive human-labeled data and enormous computing resources to learn to generate detailed and contextually appropriate image descriptions. On the other hand, existing open-sourced captioning methods in the community still face significant challenges. Methods such as BLIP-2 [17] and OFA [35] often yield overly succinct captions that neglect essential visual information. Conversely, systems like Mini-GPT4 [39], InstructBLIP [8], and LLaVA [20, 21] can suffer from hallucination, producing long descriptions that do not align with the actual content of the images.

In light of this, we propose VisualFactChecker (VFC), a flexible training-free pipeline designed to produce accurate and comprehensive captions for both 2D images and 3D objects. Fig. 1 shows examples of captions generated by VFC and their comparisons with captions generated by GPT-4V [26] and Cap3D [23]. Captions generated by VFC are faithful textual representations of the visual contents. This can also be verified by reconstructing images and 3D objects from captions using state-of-the-art text-to-image and text-to-3d models, as shown in Fig. 2.

VFC focuses on tackling hallucinations and insufficient details in generated captions and is structured around three core components: Proposer, serving as the system’s “eye”, creating detailed caption proposals as preliminary captions by using image-to-text captioning models; Large Language Model, acting as the “brain”, calling and summarizing information from other components, and leveraging its advanced generalization capabilities to steer the captioning process following specified captioning instructions; Detector and VQA models, functioning as “tools” utilized by the LLM for fact-checking caption proposals, ensuring the fidelity of the final generated caption. VFC is versatile and effectively handles captioning for both 2D images and 3D objects through a unified pipeline. Fig. 3 shows an overview of the pipeline. The details of each component and their interplay are explained in Sec. 3.

To comprehensively evaluate the generated captions, other than leveraging the commonly used CLIP-Score that primarily gauges the image-caption similarity, we propose a new metric: the CLIP-Image-Score. This metric assesses the similarity between the input image and a reconstructed image created by a text-to-image model from the caption, offering a complementary measure. Furthermore, we conducted a human study on Amazon Mechanical Turk for caption evaluation. Finally, we also performed a fine-grained evaluation by asking GPT-4V to compare and judge captions with detailed reasoning. The combination of CLIP-Score, CLIP-Image-Score, GPT-4V, and human study provides a more robust evaluation of captions.

We summarize our main contributions as follows: 1) We propose VisualFactChecker (VFC), a training-free pipeline to generate high-fidelity detailed 2D and 3D captions, effectively mitigating the challenge of hallucination in long captions. (2) CLIP-Image-Score: A novel caption evaluation metric that measures the similarity between the input image and a reconstructed image from the caption. (3) Our evaluation shows that VisualFactChecker achieves state-of-the-art results in 2D and 3D captioning tasks compared with open-sourced models. (4) Our work shows that using an LLM to chain open-source models can achieve captioning capability on par with proprietary models such as GPT-4V.

2. Related Work

2.1. Image Captioning

Image captioning has made significant progress with the advent of deep learning. Pioneering works [2, 10, 14] primarily focus on integrating deep neural networks for enhanced image understanding and language generation.

Recent strides have been made with the introduction of Multimodal-Large Language Models (MM-LLMs), which are trained on extensive vision and language data. The general approach involves leveraging a pre-trained large language model (LLM) and a vision encoder with a projector to align with the LLM’s embeddings, thus enhancing visual understanding. Several models have emerged as significant contributors in this domain. BLIP [16], BLIP-2 [17], OFA [35], Flamingo [1], Kosmos-2 [27], MiniGPT-4 [39], InstructBLIP [8], LLaVA [20, 21] have demonstrated impressive performance in single-view image captioning tasks. However, they exhibit varying limitations. For instance, BLIP-2 and OFA often generate overly concise captions, while others, like InstructBLIP, can produce detailed captions that often include inaccurate or hallucinatory content. Our method aims to address these limitations by combining different models into a pipeline via an LLM, striking a better balance between accuracy and detailedness in generated captions while mitigating hallucinations.

2.2. Large Language Models for Captioning

Recent advancements in large language models (LLMs) like GPT-3 [5], LAMDA [30], PALM [7], Llama [32], GPT-4 [26] have demonstrated exceptional zero-shot capabilities in language analysis and summarization tasks. This proficiency has naturally extended to the multimodal domain, particularly in image-language contexts, where LLMs can summarize multimodal information in a zero-shot manner.
Figure 2. We use DALL-E-3 [3] as a text-to-image model to reconstruct 2D images using generated captions from different captioning methods (BLIP-2, LLaVA-1.5 and ours). Similarly, we use MVDream [29] as a text-to-3D model to reconstruct 3D objects using different 3D captions (generated by Cap3D [23] and ours). From the results, we can see that the reconstructed images or 3D objects using BLIP-2 or Cap3D captions are less similar than the input ones, suggesting their captions may not contain sufficient information or incorrectly describe the visual contents; the reconstructed images using LLaVA-1.5 captions contain objects or scenes that are not present in the original images (top: people in the background, bottom: pedestrians and cars on the street), suggesting there might be hallucinations in LLaVA-1.5 captions. Images or 3D objects reconstructed using our captions are more similar to the inputs.


Recent methods have employed LLMs to generate image captions by summarizing initial captions or keywords from Vision-Language models. For instance, Socratic models [37] use a CLIP-based model to extract key tags from images, followed by GPT-3 with specialized prompts to create stylized captions. ChatCaptioner [38] builds upon this by integrating ChatGPT and BLIP-2 [17] in a conversational approach for question-answering about the image, and summarizing them into a caption. Visual Clues [36] uses similar tags to generate a paragraph-caption. IC3 [6] and LLM-Fusion [4] use LLMs to summarize captions from existing models augmented with temperature-based sampling. Cap3D [24] extends this concept to 3D object.

Our method differentiates itself in two critical ways: First, we focus on reducing hallucinations in captions by employing visual grounding tools, such as object detection, to fact-check captions for enhanced accuracy. Second, our pipeline can be used for captioning both 2D images and 3D objects. Unlike previous methods that rely on a single captioning model, we integrate multiple captioning sources from different models, ensuring a more comprehensive coverage of visual content to generate captions.

2.3. Hallucination in MM-LLM

There are two popular topics on the hallucination of MM-LLMs. (1) Hallucination evaluation: Detection approaches such as Gunjal et al. [11] train classification models to identify hallucination. They focus on distinguishing between accurate and hallucinated content. Ground truth comparison methods [18, 34] compare model outputs with ground truth data to detect hallucinations. These techniques assess the alignment of generated captions with actual image content. (2) Mitigation Strategies [22]: Data optimization methods such as Liu et al. [19] address hallucination by creating negative instances in training datasets to reduce model over-confidence. Iterative generation methods such as Wang et al. [33] adopt an iterative process for caption generation, where brief answers are generated in succession and amalgamated, aiming to improve accuracy and relevance.

Our VisualFactChecker is a training-free pipeline mitigating hallucination in image captioning. Our method utilizes visual grounding tools for improved accuracy, thereby actively reducing the hallucination and offering high-fidelity captions for both 2D images and 3D objects.

3. Visual Fact Checker

This section introduces the key components of VisualFactChecker as shown in Fig. 3 in detail and explains their interplay in generating accurate and detailed captions. The following sections delve into specifics. First, we detail the pipeline for 2D image captioning (Sec. 3.1), with Fig. 3 (top) illustrating this process. Then, we explore how our
3.1. 2D Image Captioning

The caption generation takes three steps: 1) proposal, 2) verification, and 3) captioning. Each step is detailed below.

Proposal: The Proposal step serves as the cornerstone of the captioning process that generates initial captions. This is achieved through the utilization of advanced image-to-text models, specifically “LLaVA” and “Kosmos2”. These models are trained on expansive datasets, enabling them to comprehend and interpret visual content effectively. By analyzing the input image, they suggest various preliminary captions, each reflecting different facets and interpretations of the image (Fig. 3 top). The rationale behind using multiple image-to-text multimodal LLMs lies in the complexity of adequately capturing an image’s essence in a single attempt. Since an image can be accurately described in numerous ways, different models bring unique perspectives, thereby encompassing a broader range of information present in the image. Although the initial captions proposed may not possess perfect fidelity, the primary objective at this stage is to generate captions that are as comprehensive as possible. Fig. 3 displays the specific prompts we used for each step, with more details in Appendix A.

Verification and Captioning: The goal of the verification step is to scrutinize and rectify any inaccuracies or hallucinations in the captions during the proposal step. It employs a combination of a Large Language Model (LLM) and grounding tools, including an open-vocabulary object detection model and/or a visual question answering (VQA) model. Here the LLM can be GPT-4 or Llama2. As shown in Fig. 3 (top), the process involves the following steps:

Step 1: The LLM first summarizes the initial detailed descriptions from different MM-LLMs into a single, detailed caption. While this caption is comprehensive, it may not always be accurate.

Step 2: The LLM then analyzes this synthesized caption, identifying all objects that could be verified by object detection and summarizing an object checklist. In 2D image captioning, the focus is on eliminating hallucinations, particularly descriptions of non-existent objects in the image. Identifying these objects is crucial for the subsequent verification process.

Step 3: Taking the object checklist as input, an open-vocabulary object detection model examines candidate objects in the checklist and determines their presence in the image. This step is pivotal in validating the existence of objects mentioned in the caption, thus supporting the fidelity of the caption.

After verification, we go to the last captioning step: Based on the object detection results, the LLM revises the summarized single detailed caption. Each object described...
in the caption is cross-checked; if detected, it remains unchanged, while undetected objects are considered potential hallucinations and are removed from the caption. This step results in a final caption that is both detailed and reliable. The underlying assumption is that the detection model, serving as an object grounding expert, provides more reliable results than a general image descriptor.

In the verification and captioning steps, the LLM plays a pivotal role as a “brain”. It starts by parsing the initial caption and identifying key objects for detailed examination. The LLM then meticulously assesses whether each object mentioned actually appears in the image based on detection results. Following this thorough analysis, it refines and revises the initial captions, transforming them into final versions that are both coherent and richly detailed. The LLM is instrumental in guaranteeing linguistic fluency, ensuring that the captions not only accurately represent the image but also maintain the necessary level of detail for high-fidelity captioning. Moreover, the LLM can follow complex instructions to write the captions in a specified style, such as a caption that only mentions the foreground objects without mentioning the background. Fig. 3 displays the specific prompts used for each step.

### 3.2. 3D Object Captioning

The 3D object captioning process follows a similar structural pipeline to that of 2D images, with a few key distinctions in certain steps, as depicted in Fig. 3 (bottom). In 3D captioning, an object may present multiple views, each offering unique information. The comprehensive caption for a 3D object is derived by integrating the perspectives from all these views. For each view, VisualFactChecker is employed to create a detailed, high-fidelity description. Subsequently, the LLM (GPT-4 or Llama-2) is used to amalgamate the information from all views, producing a unified caption for the 3D object. In particular, for each view’s captioning, we have the same three-step approach akin to 2D image captioning. In the proposal step, LLaVA-1.5 and InstructBLIP are utilized for generating initial detailed descriptions. We opt out of using Kosmos2 for single 3D objects due to its less effective performance in providing detailed descriptions, possibly linked to its reliance on an implicit detection model. Additionally, a slightly modified prompt is used (see Fig. 3 bottom), which incorporates 3D-specific considerations.

In the verification and captioning step, we primarily address hallucinations related to the attributes of 3D objects, such as shape and color. To mitigate these inaccuracies, rather than enumerating potential objects, we employ the LLM to generate five critical questions that could influence a text-to-3D generation model in reconstructing the 3D model. Following this, we utilize VQA models (specifically LLaVA-1.5) to respond to these questions based on the input 3D object view image. Subsequently, the LLM amends the initial caption in accordance with the answers provided by the VQA model. We operate under the assumption that answering targeted questions results in fewer hallucinations compared to generating a general description. Once the caption for each individual view is complete, the LLM synthesizes these multiple perspectives into a singular, comprehensive caption for the entire 3D object. The prompts used for the LLM at each stage are detailed in Appendix A.

### 4. CLIP-Image-Score

Accurate evaluation of caption correctness and detailedness is paramount in determining the performance of an image captioning model. Traditional metrics like the CLIP-Score [12] have served as a standard for measuring the alignment between generated captions and their corresponding images. However, our CLIP-score may lack the sensitivity needed to detect the specific issue of hallucination within captions.

We present the CLIP-Image-Score, an alternative metric specifically developed to reflect the subtleties of caption quality. This metric is different from CLIP-Score by introducing an additional reconstruction step. Specifically, the CLIP-Image-score evaluates the similarity between the original image and a reconstructed version of the image generated by a fixed text-to-image model using the caption as a prompt. By comparing the raw image to its reconstructed image, the metric is able to detect discrepancies indicative of hallucination, thus providing a different perspective of the caption quality assessment. The underlying principle of the CLIP-Image-Score is the recognition that multiple “correct” captions may exist for a single image. However, it’s only when a caption is both “detail” and “correct” that the reconstructed image closely resembles the original. Moreover, any hallucinations present in the caption become evident in the reconstructed image. Fig. 2 presents examples of such reconstructions. For instance, consider the results from LLaVA-1.5 shown in the third column. The cap-
tion generated for the first image falsely mentions “several other people in the background”. This error is clearly reflected in the image reconstructed by the text-to-image generator. In essence, comparing the two images indirectly ensures alignment between the image and its caption, thereby providing a complementary method to assess the quality of the caption than directly comparing the image and caption.

The CLIP-Image-Score evaluation process is depicted in the following steps:

• **Caption Generation**: An original image $X$ is input into a captioning model, which generates a caption.

• **Caption-to-Image Reconstruction**: This generated caption is then used as input for a text-to-image model, which creates a reconstructed image $X'$ that visually represents the textual description.

• **Raw Image Encoding**: The original image $X$ is processed through a CLIP image encoder, translating the visual content into an encoded representation $I_X$.

• **Reconstructed Image Encoding**: The reconstructed image is also processed through the CLIP image encoder to obtain its encoded representation $I_{X'}$.

• **Score Calculation**: Finally, the encoded representations of the original and reconstructed images are compared to calculate the CLIP-Image-Score. The score is given by the cosine similarity, which assesses the congruence between $I_X$ and $I_{X'}$:

$$\text{CLIP-Image-Score} = \frac{I_X \cdot I_{X'}}{\|I_X\| \times \|I_{X'}\|}$$  \hspace{1cm} (1)

Most notably, CLIP-Image-Score offers a sensitive measure for detecting hallucinations. In scenarios where the generated caption includes elements that are not in the original image, the reconstructed image will also likely contain these discrepancies. By comparing the original and reconstructed images, the CLIP-Image-Score can effectively highlight these differences, offering a clearer insight into the fidelity and accuracy of the generated caption.

Furthermore, CLIP-Image-Score turns a cross-modality comparison into a more intuitive comparison in the same image modality (as shown in Fig. 4). CLIP-Image-Score represents a new complementary perspective for image captioning evaluation. By leveraging the capabilities of text-to-image models and focusing on the congruence between the original and reconstructed images, it provides an accurate assessment of caption quality, particularly in identifying and measuring hallucinations, thereby enhancing the overall reliability of caption generation systems.

### 5. Experiments

This section presents a thorough evaluation of captioning models across both 2D and 3D visual content, employing a variety of datasets and methodologies. Table 1 provides a summary of our comprehensive evaluation experiments.

<table>
<thead>
<tr>
<th>Eval Input pairs for evaluation</th>
<th>Method</th>
<th>Reference</th>
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</thead>
<tbody>
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<td>2D Raw image Caption</td>
<td>CLIP-Score</td>
<td>Table 2</td>
</tr>
<tr>
<td>Human evaluation</td>
<td>CLIP-Image-Score</td>
<td>Fig. 6</td>
</tr>
<tr>
<td>CPT4V evaluation</td>
<td>Table 2</td>
<td></td>
</tr>
<tr>
<td>Raw image Image(recon)</td>
<td>CLIP-Image-Score</td>
<td>Table 2</td>
</tr>
<tr>
<td>3D Multi-view (raw) Caption</td>
<td>CLIP-Score</td>
<td>Table 3</td>
</tr>
<tr>
<td>GPT4V evaluation</td>
<td>Fig. 7</td>
<td></td>
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</table>

Table 1. Summary of evaluation methods and results.

#### 5.1. Overall: CLIP-Score and CLIP-Image-Score

### 2D image captioning.

**Dataset**: Our evaluation utilized 5,000 COCO test images from the Karpathy split. **Baseline methods**: We benchmarked against state-of-the-art captioning models, including BLIP-2 [17], InstructBLIP [8], and LLaVA-1.5 [20]. The evaluation focused on each model’s ability to produce accurate, detailed, and coherent captions that effectively encapsulate the essence of the images. **Evaluation Metric**: We employed two metrics: CLIP-Score [12] and CLIP-Image-Score (Sec. 4). The CLIP-Score, a prevalent metric in image caption quality assessment, involves processing the raw image through the CLIP image encoder and the caption through the CLIP text encoder. The resultant embeddings are then compared for cosine similarity, with a higher score indicating greater semantic resemblance between the image and the caption. For our analysis, we first calculated the CLIP-Score for each image-caption pair, then averaged these scores across all 50,000 text/image pairs, scaling the result by a factor of 100. Table 2 displays the comparative performance of various image captioning methods on the 5,000 COCO test set images. The results demonstrate that our VisualFactChecker surpasses all baseline methods in performance.

<table>
<thead>
<tr>
<th>Captioning Method</th>
<th>CLIP-Score (%) $\uparrow$</th>
<th>CLIP-Image-Score (%) $\uparrow$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Label (COCO GT)</td>
<td>30.36 (-3.54)</td>
<td>71.21 (-2.40)</td>
</tr>
<tr>
<td>BLIP2</td>
<td>30.11 (-2.79)</td>
<td>70.79 (-2.82)</td>
</tr>
<tr>
<td>InstructBLIP</td>
<td>31.45 (-1.45)</td>
<td>72.95 (-0.66)</td>
</tr>
<tr>
<td>LLaVA-1.5</td>
<td>32.08 (-0.82)</td>
<td>73.24 (-0.37)</td>
</tr>
<tr>
<td>Kosmos-2</td>
<td>32.32 (-0.58)</td>
<td>73.28 (-0.33)</td>
</tr>
<tr>
<td>VisualFactChecker (Ours)</td>
<td>32.90</td>
<td>73.61</td>
</tr>
</tbody>
</table>

Table 2. Image captioning comparison with different metrics on 5000 COCO test set in Karpathy split, we use raw image and caption as input pairs for evaluation.

As outlined in Sec. 4, the CLIP-Image-Score provides a complementary view to assess the quality of image captions. This metric is derived by comparing the cosine similarity between the CLIP embeddings of two images: the original image and a reconstructed image, which is generated using the provided caption through a text-to-image generation model. A higher CLIP-Image-Score signifies a more accurate and effective image caption. For this process, Stable Diffusion XL (SDXL) [28] is utilized as the designated text-to-image model to reconstruct images based on
the generated captions. Table 2 presents the CLIP-Image-Scores obtained for the 5000 images in the COCO test set, where our method outperforms all baseline methods.

**3D object captioning.** Dataset: 1,000 3D objects sampled from Objaverse dataset [9]. Baseline methods: We use state-of-the-art 3D object captioning model Cap3D [23] as the baseline. Cap3D uses 8 view images to generate the final object caption, our VisualFactChecker uses only 2 views to generate the object caption. Evaluation Metric: CLIP-Score and CLIP-Image-Score on multiple views rendered from 3D objects. To evaluate the similarity of a 3D object and the generated caption, we evaluate the similarity of the caption with the multi-view images used to generate the caption. Specifically, we evaluate the similarity of the generated caption with the two views that were used to generate the caption and use the average score to represent the CLIP-Score. Table 3 shows the performance of 3D object captioning methods on 1,000 3D objects from Objaverse dataset. VisualFactChecker outperforms Cap3D.

We also use CLIP-Image-Score to evaluate the 3D caption quality. CLIP-Image-Score needs reconstructed images to compare with the raw images. We treat the two views that were used to generate the 3D object caption as the raw image. To obtain the reconstructed image, we use an off-the-shelf text-to-3D generation model, MVDream, to generate a 3D object given the generated 3D object caption. We then render the same two views of images based on the generated 3D object, and we calculate the CLIP-Image-Score between the raw image and the rendered image. Table 3 shows the CLIP-Image-Score on 1000 objects in Objaverse dataset.

**5.2. Per Image Evaluation: Wining Rate**

CLIP-Score and CLIP-Image-Score indicate an overall performance comparison, which shows an average score among all 5000 images. The average score may be dominated by a small group of images that have extremely high or low scores. To zoom in and show a more detailed comparison, we try to answer the following question: Given an image, what is the probability that one method performs better than another method on caption generation? To answer this question, we need to go over each image and calculate the winning rate for a pair of methods.

Specifically, for each image, we compare the CLIP-Image-Score and CLIP-Image-Score of two methods. For each image, we calculate the winning rate for the pair of methods.

<table>
<thead>
<tr>
<th>Captioning Method</th>
<th>CLIP-Score (%) ↑</th>
<th>CLIP-Image-Score (%) ↑</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap3D</td>
<td>33.44 (-0.57)</td>
<td>79.88 (-0.44)</td>
</tr>
<tr>
<td>VisualFactChecker</td>
<td>34.01</td>
<td>80.32</td>
</tr>
</tbody>
</table>

Table 3. 3D object captioning comparison with different metrics on 1000 objects in Objaverse. For CLIP-Score, we use the average score of two views for evaluation. For CLIP-Image-Score, we use an off-the-shelf text-to-3D model, MVDream, to generate 3D models from 3D captions. We compare two views of the raw object and the same views of generated 3D object for evaluation.

Calculating the winning rate over all images provides a more detailed analysis that zooms in on the comparison of each image, which shows a complementary view than overall average CLIP-Score.

**5.3. Fine-grained Evaluation: Human and GPT-4V**

The CLIP-Score and CLIP-Image-Score offer a general comparison of overall performance. A pairwise per-image winning rate provides a more specific analysis, evaluating performance on individual images. However, the research highlighted in related studies [15] indicates that the CLIP-Score may not be ideally suited for image-to-image comparison tasks. Furthermore, relying on a single score fails to provide a nuanced comparison across criteria, such as accuracy and level of detail. We use Human evaluation and GPT-4V to provide a more fine-grained evaluation.

**Human evaluation using Amazon Mechanical Turk (AMT).** We employed a pairwise comparison strategy. From the COCO dataset, we randomly selected 100 images out of 5000. For each image, our caption was compared against 5 baseline captions respectively. To reduce variance, each comparison was done by 3 different AMT workers and we used their majority voting as the final selection. This resulted in a total of 1500 comparisons collected on AMT. AMT UI is shown in the appendix. The workers were presented with two competing captions — one from a baseline method and one from our VisualFactChecker, in randomized order. They were instructed to select the better caption describing the image based on 3 aspects: correctness, de-
tailness, and fluency. Results in Fig. 6 show our captions are more preferred by humans. The human evaluation instruction and web UI is shown in Appendix B.

Figure 6. Amazon Mechanical Turk human evaluation results.

**GPT-4V evaluation.** Our study applied GPT-4V for evaluating captions in a manner akin to the caption evaluation process used in DALLE-3. We use the same randomly selected 100 images from COCO as in Human evaluation. For each image, we considered the captions generated by 5 baseline methods alongside the caption produced by our VisualFactChecker. We then presented GPT-4V with the raw image, our reference caption, and the four baseline captions. Our designed prompt instructed GPT-4V to compare each baseline caption against our reference caption, focusing on two primary aspects: correctness and detail. GPT-4V was tasked with providing a pairwise, detailed comparison for each pair, including justifications for its assessments. Based on these comparative insights, GPT-4V classified each baseline method caption as either “better” or “worse” than our VisualFactChecker. Fig. 7 shows the comprehensive results. More details about the GPT-4V evaluation prompt and examples are shown in Appendix B.

Figure 7. GPT-4V evaluation results. Our captions are significantly better than baselines.

### 5.4. Ablation Study

In our ablation study, we explore the impact of various components on performance. For 2D captioning tasks, we assess the efficacy of initial captioning models, LLaVA-1.5 and Kosmos-2, using the CLIP-Score metric for the captions they generate on the same 5000 COCO test images. Additionally, we ablate our method’s performance in the absence of the verification (fact checker) step, which aims to mitigate hallucinations through detection grounding. Table 4 shows the detailed results. Likewise, in the context of 3D object captioning, we evaluate the individual contributions of initial captioners, namely LLaVA-1.5 and InstructBLIP on the same 1000 Objaverse 3D objects. We further investigate the performance of our methodology without the fact checker, which in this case operates by leveraging a VQA model to reduce hallucinations. Table 4 shows the detailed results. These results highlight the significance of fact checker in our approach.

### 5.5. Qualitative Results and Prompt Following

Other than quantitative evaluation results, we show more qualitative examples of VisualFactChecker for 2D and 3D captions in Appendix C.

By leveraging an LLM, VisualFactChecker can follow complex instructions to write captions in various styles. Examples are shown in Appendix D.

### 6. Conclusion

We propose the VisualFactChecker (VFC), a training-free pipeline to generate high-fidelity and detailed captions. By utilizing an LLM to chain multimodal models and object detection and VQA models, VFC reduces hallucination in long captions. We conducted a comprehensive caption evaluation using different metrics, including 1) image-text similarity using CLIP-Score, 2) image-reconstructed image similarity using our proposed CLIP-Image-Score, 3) human study, and 4) fine-grained evaluation using GPT-4V. Compared with open-sourced captioning models, our method achieves state-of-the-art in both 2D and 3D captioning. Our work shows combining open-sourced models into a pipeline can significantly close the captioning performance gap with proprietary models like GPT-4V. In the future, we plan to improve our pipeline further by including more components for fact-checking and making it more automatic in deciding which components to use.

**Acknowledgments** We would like to thank Siddharth Gururani for helping with our human evaluation using Amazon Mechanical Turk; Haochen Wang for his help in pre-processing 3D data. We also thank Qinsheng Zhang, Yogesh Balaji, and Yen-Chen Lin for their helpful discussion.
References


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Supplementary Material

A. More Details on Models and Prompts

The models used in VisualFactChecker and baselines are:

- **Caption Proposer:** BLIP-2-OPT-2.7B, InstructBLIP-7B, LLaVA-1.5-13B, Kosmos-2
- **LLMs:** GPT-4-0613, Llama-2-70B-chat
- **Detector:** Grounding DINO
- **VQA:** LLaVA-1.5-13B

Below are the prompts used in VisualFactChecker for captioning 2d images and 3d objects.

<table>
<thead>
<tr>
<th>Prompt Details</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Proposal (LLaVA-1.5 / Kosmos-2):</strong></td>
<td>Describe this image in detail.</td>
</tr>
<tr>
<td><strong>Verification step-1 (GPT-4 / Llama-2):</strong></td>
<td>This is a hard problem. Carefully summarize in ONE detailed caption based on the following two captions by different (possibly incorrect) people describing the same scene. Be sure to describe everything, and avoid hallucination.</td>
</tr>
<tr>
<td><strong>Verification step-2 (GPT-4 / Llama-2):</strong></td>
<td>I want to use an object detector to check the correctness of an image caption obtained by an image caption model. Can you help to parse the caption below and list all objects that could be detected with an object detection model in the image? Please only list the object name and ignore the description. Please use singular for all listed objects.</td>
</tr>
<tr>
<td><strong>Verification step-3 (Grounding DINO):</strong></td>
<td>N/A (Grounding DINO examines candidate objects in the checklist above and determines their presence in the image.)</td>
</tr>
<tr>
<td><strong>Captioning(GPT-4 / Llama-2):</strong></td>
<td>Objective: parse and modify image captions using the results from an object detection model (may have hallucination). I will put the detection results to you in the following format: ['object': detected object name, &quot;number&quot;: number of detected object (N)]. Please follow the following steps:</td>
</tr>
<tr>
<td><strong>Instructions:</strong></td>
<td>Parse the object in the caption, (Note: only parse and modify the object (not color, action, size, shape, or other descriptions))</td>
</tr>
<tr>
<td></td>
<td>1. If the object was detected by the detection model, keep everything including all descriptions. For instance, if the original caption is: “a black and white panda toy”. If the toy was detected, keep all content even though the “panda” and “black and white” are not detected. Keep all descriptions about color, shape, actions, etc.</td>
</tr>
<tr>
<td></td>
<td>2. If the subject object was not detected, remove only the object. Do NOT remove color, shape, action, text and other descriptions.</td>
</tr>
<tr>
<td></td>
<td>3. Only decrease the object number if the detected object number is smaller than the caption number.</td>
</tr>
<tr>
<td><strong>Updated caption:</strong></td>
<td>This is a hard problem. Please minimize modifications of the caption, and list all changes made along with the reasoning.</td>
</tr>
<tr>
<td></td>
<td>BEGIN Detection results: —</td>
</tr>
<tr>
<td></td>
<td>END Detection results—</td>
</tr>
<tr>
<td></td>
<td>BEGIN Raw caption: —</td>
</tr>
<tr>
<td></td>
<td>END Raw caption—</td>
</tr>
<tr>
<td><strong>Proposal (LLaVA-1.5):</strong></td>
<td>Please provide details of the shape, color of each part, avoid imagination and solve it step by step.</td>
</tr>
<tr>
<td><strong>Proposal (InstructBLIP):</strong></td>
<td>Describe the 3D object in detail, step by step.</td>
</tr>
<tr>
<td><strong>Verification step-1 (GPT-4 / Llama-2):</strong></td>
<td>This is a hard problem. Carefully summarize in ONE detailed caption based on the following two captions by different (possibly incorrect) people describing the same 3D object. The detailed caption will be used for a text to 3D model to generate this 3D object. Be sure to describe everything, and avoid hallucination.</td>
</tr>
<tr>
<td><strong>Verification step-2 (GPT-4 / Llama-2):</strong></td>
<td>I have a description of a 3D object, the detailed caption will be used for a text to 3D model to generate the same 3D object. Some part of the description may have some hallucination, so I want to use a VQA model to double check some key description. Please ask at most 5 most important and concrete questions that I need to double check to improve the fidelity of the description. Please focus on the factors that influence the final text to 3D model generation.</td>
</tr>
<tr>
<td><strong>Raw Caption:</strong></td>
<td>Please output the 5 questions in a python list.</td>
</tr>
<tr>
<td><strong>Verification step-3 (Grounding DINO):</strong></td>
<td>N/A (LLaVA-1.5 takes questions above and raw view image as input and give answers).</td>
</tr>
<tr>
<td><strong>Single view Captioning (GPT-4 / Llama-2):</strong></td>
<td>I have a description of a 3D object, the detailed caption will be used for a text to 3D model to generate the same 3D object. Some part of the description may have some hallucination, so I use a VQA model to double check some key description. Here is the original description that may contain hallucination: {} Here are the questions and answers from a VQA model: {}</td>
</tr>
<tr>
<td></td>
<td>Please correct the description based on the VQA. I want to use the description as a prompt for a text-to-3D generation model to generate the same 3D object.</td>
</tr>
<tr>
<td><strong>Object Captioning(GPT-4 / Llama-2):</strong></td>
<td>Given a set of descriptions about the same 3D object from different camera views, please distill these descriptions into one concise caption: Camera View 1 description: {} Camera View 2 description: {}</td>
</tr>
</tbody>
</table>

B. Details on Human and GPT-4V Evaluaiton

Fig. 8 shows the Amazon Mechanical Turk human evaluation web UI. For GPT-4V evaluation, inspired by DALLE-3 [3], we craft a single prompt for evaluating all captions for a given image using GPT-4V (gpt-4-vision-preview). The prompt is as follows.
We provide an example of GPT-4V’s response for 3D captioning evaluation, corresponding to Fig. 12 (b), where caption 1 is Cap3D and caption 2 is our VisualFactChecker.

C. More Qualitative Results

We show more results of image captioning methods and their DALL-E-3 reconstructed images using different generated captions (COCO 2D images in Fig. 9, 10, 11; Objaverse 3D objects in Fig. 12). We show more comparison with GPT-4V captions using Llama-2 as the LLM in Fig. 13.

D. Following Complex Prompts

By leveraging the LLM, VisualFactChecker can follow complex prompts to write captions in different styles. Examples shown in Fig. 14.
Which image caption is better?

Choose the caption that better describes the image. A good caption should be **correct**, **detailed**, and **well-written**:

1. Correct: A good caption should correctly describe image content, including the major objects and the surrounding scene.

2. Detailed: A good caption contains rich details about the image content, for example, the spatial location of objects, clothing, actions of people, color, counting of objects, texts in the image, etc.

3. Well-written: A good caption should be clear, coherent, and grammatically correct.

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**CaptionA:** In the image, there is a wedding cake sitting on a dining table. The cake is three-tiered and decorated with a plaid pattern. A man and a woman can be seen sitting at the table, possibly enjoying the wedding celebration. There are several wine glasses placed around the table, indicating that wine might be served during the event. Additionally, there are two bottles of wine visible in the scene, one on the left side of the table and the other on the right side.

**CaptionB:** The image prominently features a white wedding cake adorned with blue and green tartan ribbons, elegantly displayed on a dining table. The table is tastefully set with various items including wine glasses, a cup, and a knife, suggesting a wedding reception setting. In the background, a couple, presumably the bride and groom, are engaged in conversation. The bride is distinguished by a tiara, while the groom is dressed in a suit. Additional elements like a dining room window in the background contribute to the overall ambiance of the scene.

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Figure 8. Amazon Mechanical Turk web user interface.
In the right column, we use DALLE-3 as a text-to-image model to reconstruct 2D images using different generated captions.

**Figure 9.** Comparison of different 2D image captioning methods (1/3). The left column is the input image from COCO, the middle column shows the caption generated by different methods (BLIP-2, InstructBLIP, Kosmos-2, LLaVA-1.5, and our proposed VisualFactChecker). In the right column, we use DALLE-3 as a text-to-image model to reconstruct 2D images using different generated captions.
<table>
<thead>
<tr>
<th>Image</th>
<th>Captions</th>
<th>DALLE-3 text-to-image</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d)</td>
<td><strong>Overall,</strong> pedestrian Kosmos is highlighted in VisualFactChecker street vases LLaVA. The kite, street sign, and blue building are visible in the scene. They are scattered throughout the snow-covered area, some closer to the snowboarder and others further away. <strong>Kosmos-2</strong>: In the image, a person is skillfully riding a snowboard while flying a kite in the air. The kite is positioned high in the sky, and the snow-covered field provides a perfect backdrop for the activity. The snowboarder is skillfully navigating the snow, showcasing their skill and control.</td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td><strong>LLaVA-1.5</strong>: The image captures a snowboarder in mid-air, performing a jump while riding a snowboard. The snowboarder is wearing a green and black outfit, and the snowboard is visible beneath them. The scene takes place in a snowy landscape, with a blue sky in the background. There are several other people in the scene, some of them closer to the snowboarder and others further away. They appear to be watching the snowboarder's impressive jump, likely enjoying the winter sports action. <strong>VisualFactChecker (Ours)</strong>: In the image, a person in a green and black outfit is skillfully riding a snowboard and performing a jump, soaring through the air while also flying a kite positioned high in the sky. The snow-covered field provides a perfect backdrop for this thrilling activity, highlighting the snowboarder's talent, athleticism, skill, and control.</td>
<td></td>
</tr>
<tr>
<td>(f)</td>
<td><strong>LLaVA-1.5</strong>: The image features a dining table with two vases filled with beautiful flowers. One vase is placed on the left side of the table, while the other is on the right side. The flowers in the vases are arranged in a way that creates a visually appealing display. In addition to the vases, there are several books scattered around the table, some placed near the right edge and others closer to the left side. A chair can be seen in the background, positioned behind the table. The overall scene creates a pleasant and inviting atmosphere. <strong>VisualFactChecker (Ours)</strong>: The image showcases a wooden dining table adorned with a vase, a red vase holding a bouquet of red and white flowers on the right, and a clear vase filled with a variety of colorful flowers on the far left. The flowers in the clear vase are arranged to be visible from multiple angles, enhancing the visual appeal. The table setting, surrounded by a chair and a mirror, creates a pleasant and inviting atmosphere, suggesting a special occasion or gathering. <strong>BLIP-2</strong>: A table with a vase of flowers on it. <strong>BLIP-2</strong>: A table with a vase of flowers on it.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>BLIP-2</strong>: A street sign and a Canadian flag on a pole <strong>Kosmos-2</strong>: The image features a street sign with the name “Robson Street” and a Canadian flag hanging from a pole. A tall building is visible in the background, adding to the urban atmosphere. The street sign is located near the corner of the street and the tall building, with the Canadian flag hanging from the pole. <strong>LLaVA-1.5</strong>: The image features a street sign on a pole with a Canadian flag hanging from it. The street sign is located in front of a tall building, which appears to be a skyscraper. The scene is set against a blue sky, creating a pleasant atmosphere. In addition to the Canadian flag, there are several other flags visible in the scene, including a few smaller flags hanging from the pole and a larger flag in the background. The presence of these flags suggests that the location might be a place of international significance or a gathering spot for people from various countries. <strong>VisualFactChecker (Ours)</strong>: The image depicts an urban scene featuring a street sign labeled “Robson Street” located near the corner of the street and a tall building. The sign is positioned near a traffic light on its left side. Adding to the atmosphere is a pole from which a Canadian flag is hanging, infusing a sense of national pride into the area.</td>
<td><strong>Kosmos-2</strong>: The image features a street sign with the name “Robson Street” and a Canadian flag hanging from a pole. A tall building is visible in the background, adding to the urban atmosphere. The street sign is located near the corner of the street and the tall building, with the Canadian flag hanging from the pole. <strong>LLaVA-1.5</strong>: The image features a street sign on a pole with a Canadian flag hanging from it. The street sign is located in front of a tall building, which appears to be a skyscraper. The scene is set against a blue sky, creating a pleasant atmosphere. In addition to the Canadian flag, there are several other flags visible in the scene, including a few smaller flags hanging from the pole and a larger flag in the background. The presence of these flags suggests that the location might be a place of international significance or a gathering spot for people from various countries. <strong>VisualFactChecker (Ours)</strong>: The image depicts an urban scene featuring a street sign labeled “Robson Street” located near the corner of the street and a tall building. The sign is positioned near a traffic light on its left side. Adding to the atmosphere is a pole from which a Canadian flag is hanging, infusing a sense of national pride into the area.</td>
</tr>
</tbody>
</table>

Figure 10. Comparison of different 2D image captioning methods – more examples (2/3).
<table>
<thead>
<tr>
<th>Input image</th>
<th>Captions</th>
<th>DALLE-3 text-to-image</th>
</tr>
</thead>
<tbody>
<tr>
<td>(g)</td>
<td>BLIP-2: a boy sitting on a bench. The image depicts a young boy sitting on a bench in a park. He is engrossed in reading a book, likely enjoying his leisure time in the outdoors. The park is located in a residential area, and there are several cars parked nearby. The boy appears to be enjoying his time in the park, possibly taking a break from playing or reading.</td>
<td><img src="image" alt="DALLE-3 image" /></td>
</tr>
<tr>
<td>(h)</td>
<td>InstructBLIP: The image depicts a boy sitting on a park bench, reading a book. He is surrounded by various playground equipment, including a slide and a swing. The park is located in a residential area, and there are several cars parked nearby. The boy appears to be enjoying his time in the park, possibly taking a break from playing or reading.</td>
<td><img src="image" alt="DALLE-3 image" /></td>
</tr>
<tr>
<td>(i)</td>
<td>Kosmos-2: The image features a young boy sitting on a bench in a park, adding to the serene atmosphere of the scene. The boy is wearing a typical attire for playing tennis. He appears to be engaged in the activity, focused and ready to play. The green fence is visible behind him. The man appears to be focused and ready to play a game of tennis.</td>
<td><img src="image" alt="DALLE-3 image" /></td>
</tr>
</tbody>
</table>

Figure 11. Comparison of different 2D image captioning methods – more examples (3/3).
Figure 12. Comparison of different 3D object captioning methods. The left column shows the input 3D objects, the middle column shows the captions generated from Cap3D and our VisualFactChecker. In the right column, we use MVDream [29] as a text-to-3D model to reconstruct 3D objects using different 3D captions (generated by Cap3D [23] and ours). From the results, we can see that the reconstructed 3D objects using Cap3D captions are less similar than the input ones compared with ours, suggesting their captions may not contain sufficient information to reconstruct the 3D object or incorrectly describe the visual contents. 3D objects reconstructed using our captions are more similar to the inputs.
GPT-4V: The image shows a family moment on the beach, with warm sunlight illuminating the scene. A man is kneeling on the sand, engaging with two young children, a boy and a girl. The man and the children are focused on playing with sand toys, including buckets and shovels. They appear to be in the process of building a sandcastle. The girl, wearing a polka-dot coat, is to the man's left, while the boy, wearing a patterned sweater and denim pants, is on his right. It's a candid, joyful moment, capturing the essence of family leisure time at the beach. The background features the soft blur of a hill, emphasizing the focus on the family.

VisualFactChecker (Ours): A father and his two children are spending quality time together on a sandy beach, engaging in fun activities like building sandcastles and playing with toys. The father is kneeling down on the sand, surrounded by his children, who seem to be enjoying their time together. There are several sandcastles and toys scattered around the scene, indicating that the family has been having a great time playing and building together. The atmosphere is filled with joy and togetherness, as the family members enjoy each other's company on the beach.

GPT-4V: The image features a young girl with blonde hair styled in braids, wearing glasses, and holding a chalkboard sign that reads "BACK TO SCHOOL" with a smiley face drawn below the text. She's smiling, looking towards the camera, and appears to be happy about the return to school. The girl is wearing a striped sleeveless top and is positioned against a vibrant yellow background, which creates a cheerful and energetic atmosphere. The chalkboard and the girl's pose suggest a promotional or celebratory picture for the beginning of a new school year.

VisualFactChecker (Ours): A cheerful young girl with glasses is excitedly holding a chalkboard sign that reads "Back to School" in front of a bright yellow wall. She is smiling and posing for the camera, showcasing her enthusiasm for the upcoming school year. The girl is wearing a striped shirt and a pair of blue jeans, and her glasses have a subtle glint from the light. The chalkboard sign is neatly written in white chalk, with the words "Back to School" and a smiling face standing out clearly against the dark background. The overall atmosphere of the scene is one of excitement and anticipation for the new school year.

GPT-4V: The image features a miniature red pickup truck toy positioned in the foreground, with a focus on its details, highlighting the glossy finish and classic design. In the background, slightly out of focus, is a stack of books and a small blue house model, both creating a sense of depth and context for the scene. The background appears to be outdoors, as indicated by the green hues that suggest vegetation. The overall setting seems to be a staged arrangement, perhaps used for educational purposes or as a decorative display. The shallow depth of field used in this photograph emphasizes the toy truck while softly blurring the background elements.

VisualFactChecker (Ours): A red toy truck is sitting on a table in front of a blue toy house, giving the impression of a playful and creative setup. The truck appears to be positioned as if it is driving past the house, with its front bumper near the house's front door. To the left of the house, there is a stack of books, possibly suggesting a cozy reading nook or a place for a child to play and learn. Overall, the scene seems to be designed to evoke a sense of whimsy and imagination, perhaps for a child's play area or a collector's display.

Figure 13. Comparison of VisualFactChecker with GPT-4V. Our method can generate high-fidelity detailed captions that closely match GPT-4V's quality. To compare with GPT-4V, we use Llama-2 as our LLM instead of GPT-4 when generating captions for the above images.
A happy little girl is standing in a green field, wearing a plaid shirt and holding onto a string of pink balloons. The balloons are floating in the air, creating a playful and joyful atmosphere. The girl appears to be enjoying the moment, with a smile on her face. In the background, there is a vast expanse of green grass, stretching out as far as the eye can see. The sky above is a bright blue, with a few white clouds scattered about. The overall mood of the scene is one of carefree happiness and joy, with the pink balloons adding a touch of whimsy and playfulness to the atmosphere.

Joyful girl with pink balloons smiling in a vast green field under a clear blue.

A joyful girl in a plaid shirt smiles as she holds pink balloons in a vast, green field under a blue sky dotted with clouds, embodying whimsical happiness.

A joyous young girl, clad in a plaid shirt, delights in the moment as she clutches a string of pink balloons. The balloons, buoyant and playful, dance in the air above her, enhancing her smile with a whimsical charm.

A vast, green meadow stretches endlessly, under a brilliant blue sky dotted with a handful of fluffy white clouds. This idyllic scene exudes a sense of whimsical joy and carefree happiness, inviting a playful and cheerful mood.

In the backdrop of this serene scene lies a boundless expanse of lush green grass under a vivid blue sky dotted with a smattering of white clouds. At the heart of this idyllic setting stands a joyous little girl, clad in a plaid shirt, her hands clutching a string of buoyant pink balloons that dance in the air. This moment captures a snapshot of blissful joy and playful spirit, framed by nature's sprawling beauty.