

Resampled Datasets Are Not Enough: Mitigating Societal Bias Beyond Single Attributes

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Abstract

We tackle societal bias in image-text datasets by removing spurious correlations between protected groups and image attributes. Traditional methods only target labeled attributes, ignoring biases from unlabeled ones. Using text-guided inpainting models, our approach ensures protected group independence from all attributes and mitigates inpainting biases through data filtering. Evaluations on multi-label image classification and image captioning tasks show our method effectively reduces bias without compromising performance across various models. Specifically, we achieve an average societal bias reduction of 46.1% in leakage-based bias metrics for multi-label classification and 74.8% for image captioning.

1 Introduction

Models trained on biased data can develop prediction rules based on spurious correlations (i.e., associations devoid of causal relationships), perpetuating and amplifying harmful stereotypes (Zhao et al., 2017). For example, image captioning models may generate gendered captions by associating gender with depicted activities (Zhao et al., 2023), location (Hendricks et al., 2018), or objects (Wang and Russakovsky, 2021). Dataset-level bias mitigation aims to reduce spurious correlations between labeled image attributes (e.g., teddy bear) and protected groups (e.g., woman). Resampling approaches balance the co-occurrence of each attribute with each group (Agarwal et al., 2022; Wang et al., 2020b). However, models can still exploit correlations between groups and sets of attributes (e.g., man with {dog, pizza, couch}), even when individual attributes are balanced (Zhao et al., 2023). Moreover, spurious correlations extend to unlabeled attributes, which current strategies do not address—e.g., gender disparities in image color

statistics (Meister et al., 2023) or the person-to-object spatial distances (Wang et al., 2020a).

While equal group distributions in real-world datasets are challenging to achieve, generative text-to-image models now enable targeted image modifications (Rombach et al., 2022; Brooks et al., 2023; Couairon et al., 2023). For example, bias detection methods alter image subjects’ appearance to assess counterfactual fairness (Joo and Kärkkäinen, 2020) or model bias (Smith et al., 2023; Brinkmann et al., 2023). However, manipulating individuals’ appearances without consent raises significant ethical and privacy concerns (Andrews et al., 2023; Yew and Xiang, 2022; Sobel, 2020; Ramaswamy et al., 2021a; Orekondy et al., 2018; Oh et al., 2016).

To address these challenges, we create training datasets with text-guided inpainting (Rombach et al., 2022), ensuring attribute distributions are independent of protected groups. Using masked person images and text prompts, we generate counterfactual images by inpainting only the masked regions, addressing ethical concerns of altering non-consensual persons and ensuring equal representation of protected groups across attributes. We introduce data filters to mitigate biases from generative text-guided inpainting models (Bianchi et al., 2023; Cho et al., 2023; Bansal et al., 2022; Luccioni et al., 2023), evaluating images based on adherence to prompts, preservation of attributes and semantics, and color fidelity, validated by human evaluators. Unlike prior work (Wang et al., 2019, 2020b; Zhao et al., 2023; Agarwal et al., 2022), training on our counterfactual data decorrelates both labeled and unlabeled attributes from protected groups without impacting model performance. Comprehensive evaluations show our approach significantly reduces prediction rules based on spurious correlations in multi-label classification and image captioning across various architectures (e.g., ResNet-50 (He et al., 2016), Swin Transformer (Liu et al., 2021)), datasets (COCO (Lin et al., 2014), Open-

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Figure 1: (a) Predicted objects by baseline ResNet-50 and with bias mitigation, i.e., over-sampling (Wang et al., 2020b) versus our method. (b) Generated captions by baseline ClipCap and with bias mitigation, i.e., LIBRA (Hirota et al., 2023) versus our method. Incorrect predictions, possibly affected by gender-object correlations, are in red.

Images (Krasin et al., 2017)), and protected groups (gender, skin tone). Our key contributions are summarized as follows:

- Introducing a framework for generating synthetic training datasets with group-independent image attribute distributions.
- Proposing data filtering to mitigate biases introduced by generative inpainting models.
- Conducting quantitative experiments, demonstrating significant bias reduction in classification and captioning tasks compared to baselines.
- Identifying limitations of training on combined real and synthetic datasets, emphasizing the need for cautious synthetic data augmentation.

1.1 Related Work

Societal bias in datasets, characterized by demographic imbalances leading to spurious correlations, has been extensively studied (DeVries et al., 2019; Birhane et al., 2024; Birhane and Prabhu, 2021; Birhane et al., 2021; Wang et al., 2020a; Meister et al., 2023). These biases persist and can be exacerbated by multi-label classifiers (Zhao et al., 2017; de Vries et al., 2019; Wang et al., 2019) and image captioning models (Zhao et al., 2021; Hendricks et al., 2018; Hirota et al., 2022), disproportionately impacting historically marginalized groups such as women and individuals with darker skin tones (Garcia et al., 2023; Ross et al., 2020).

Two common approaches to bias mitigation are dataset-level and model-level. Dataset-level approaches leverage generative adversarial networks (GANs), counterfactual training dataset augmentation, and resampling. GANs create synthetic

images to balance datasets and mitigate spurious correlations (Ramaswamy et al., 2021b; Sattigeri et al., 2019; Sharmanska et al., 2020), counterfactual data augmentation generates alternative scenarios to address biases (Kaushik et al., 2019; Wang and Culotta, 2021), and resampling balances the co-occurrence of attributes and protected groups (Agarwal et al., 2022; Wang et al., 2020b). Model-level approaches reduce bias through corpus-level constraints (Zhao et al., 2017), adversarial debiasing (Wang et al., 2019; Hendricks et al., 2018; Tang et al., 2021; Alvi et al., 2018), domain discriminative/independent training (Wang et al., 2020b), modified loss functions (Lin et al., 2017; Cui et al., 2019; Sagawa et al., 2019), and model output editing (Hirota et al., 2023). However, despite these advancements, existing mitigation methods focus on single labeled attributes, which can inadvertently increase models’ reliance on spurious correlations between protected groups and combinations of attributes (Zhao et al., 2023) or unlabeled attributes (Meister et al., 2023).

Recent progress in text-to-image generative models has enabled targeted image manipulation (Romach et al., 2022; Brooks et al., 2023; Couairon et al., 2023), which can help address bias in multimodal datasets. Nonetheless, these models have also been shown to perpetuate harmful stereotypes (Mandal et al., 2023; Zhang et al., 2023; Wang et al., 2023a; Struppek et al., 2022; Ungless et al., 2023; Naik and Nushi, 2023; Seshadri et al., 2023; Friedrich et al., 2023). In contrast to prior bias mitigation work, we use text-guided inpainting to generate synthetic training datasets that ensure

equal representation of protected groups across all attribute combinations, whether labeled or unlabeled. To mitigate inpainting biases, we propose data filters, producing higher quality and less biased synthetic data. We go beyond previous work focused solely on gender bias mitigation (Joo and Kärkkäinen, 2020; Smith et al., 2023; Brinkmann et al., 2023) by also addressing skin tone biases.

2 Method

We create training datasets with group-independent image attribute distributions by using masked person images and text prompts with an off-the-shelf diffusion model, as outlined in Figure 2.

2.1 Resampled Datasets Are Not Enough

We denote an image by $x \in \mathcal{X}$, a protected group by $g \in \mathcal{G}$, and an image attribute by $a \in \mathcal{A}$. A spurious correlation exists if $p_{\mathcal{X}}(a | g) \neq p_{\mathcal{X}}(a)$, indicating biases in the data. Resampling aims to remove these biases by adjusting the sampling process so that $p_{\mathcal{X}}(a | g) = p_{\mathcal{X}}(a)$ for all g (de Vries et al., 2019; Wang et al., 2020b). This is done using a limited set of labeled attributes $\mathcal{O} \subset \mathcal{A}$, where attributes a are drawn from a distribution $q(a)$ over \mathcal{O} and groups g are drawn from a uniform distribution $u(g)$ over \mathcal{G} such that $\mathcal{X}' = \{x \sim p_{\mathcal{X}}(x | g, a) | a \sim q(a), g \sim u(g)\}$. This ensures $p_{\mathcal{X}'}(a | g) = q(a)$ for $a \in \mathcal{O}$ and $g \in \mathcal{G}$. However, this method has a limitation: it does not account for a being an unlabeled attribute or a combination of labeled and unlabeled attributes, making it difficult to sample x from $p_{\mathcal{X}}(x | g, a)$ due to insufficient information about a . In short, while resampling can reduce biases, it is not always enough, especially when dealing with unlabeled or mixed attributes.

2.2 Text-Guided Inpainting

Suppose $\mathcal{D} = \{(x_i, \omega_i, a_i, t_i^{(g)}) | 1 \leq i \leq n\}$ is a training set, where $x \in \mathbb{R}^d$ is an image, $\omega \in [0, 1]^d$ is a person mask, a is a labeled image attribute, a combination of labeled attributes, or an unlabeled attribute, and $t^{(g)}$ is a text prompt containing a protected group-specific word g . To create a dataset with group-independent image attribute distributions, we utilize a text-guided inpainting model (Rombach et al., 2022). This model, guided by $t^{(g)}$, inpaints ω in x with a synthetic person from protected group g described in $t^{(g)}$. For each tuple in \mathcal{D} , we generate $m \in \mathbb{N}^+$ versions for each

$g \in \mathcal{G}$, resulting in $m \cdot |\mathcal{G}|$ samples:

$$\mathcal{D}_{\text{synthetic}} = \{(x_i^{(j,g')}, \omega_i, a_i, t_i^{(g')}) | 1 \leq i \leq n, g' \in \mathcal{G}, 1 \leq j \leq m\}, \quad (1)$$

where $x_i^{(j,g')}$ denotes the j -th inpainted version of $x_i \in \mathcal{X}$ for g' and $t_i^{(g')}$ the modified text prompt where g in $t_i^{(g)}$ is replaced with g' .

2.3 Societal Bias Data Filtering

Text-to-image generative models often perpetuate societal biases, portraying certain groups stereotypically, such as depicting women in brighter clothing (Bianchi et al., 2023; Cho et al., 2023; Bansal et al., 2022; Luccioni et al., 2023). Since these biases remain largely unaddressed (Smith et al., 2023; Brinkmann et al., 2023), we set $m > 1$ in Equation (1) to generate multiple variations for each group. We propose filters to select the least biased inpainted images, evaluating images based on adherence to text prompts, preservation of attributes and semantics, and color fidelity. Specifically, for each tuple (i, g') , we select the highest quality and least biased version among the m versions to create a training dataset:

$$\mathcal{S}_{\text{synthetic}} = \{(x_i^{(j^*,g')}, \omega_i, a_i, t_i^{(g')}) \in \mathcal{D}_{\text{synthetic}} | \forall (i, g'), j^*\}, \quad (2)$$

where $j^* = \arg \min_j \sum_k c_k \cdot r(s_k^{(i,j,g')})$, $c_k \in \mathbb{R}$ are weights assigned to filters s_k , $s_k^{(i,j,g')}$ is the score obtained from applying filter s_k to image $x_i^{(j,g')}$ for group g' , and $r(s_k^{(i,j,g')})$ is the rank of the score for (i, g') in descending order, with lower ranks indicating less bias. Here, $x_i^{(j^*,g')}$ is the selected inpainted image for tuple (i, g') that minimizes the sum of the ranks of the weighted filter scores, with j^* representing the index of the selected candidate image for tuple (i, g') .

Rather than creating an entire dataset of synthetic samples, we can augment \mathcal{D} :

$$\mathcal{S}_{\text{augment}} = \mathcal{D} \cup \{(x_i^{(j^*,g')}, \omega_i, a_i, t_i^{(g')}) \in \mathcal{D}_{\text{synthetic}} | \forall (i, g' \neq g), j^*\}. \quad (3)$$

The condition $g' \neq g$ ensures that we only add inpainted images to \mathcal{D} for groups different from those originally present in x_i . In contrast to resampling, $\mathcal{S}_{\text{synthetic}}$ and $\mathcal{S}_{\text{augment}}$ ensure $p_{\mathcal{X}'}(a | g) = p_{\mathcal{X}}(a)$ for all $g \in \mathcal{G}$ without making assumptions about \mathcal{A} . Our proposed filters are introduced below.

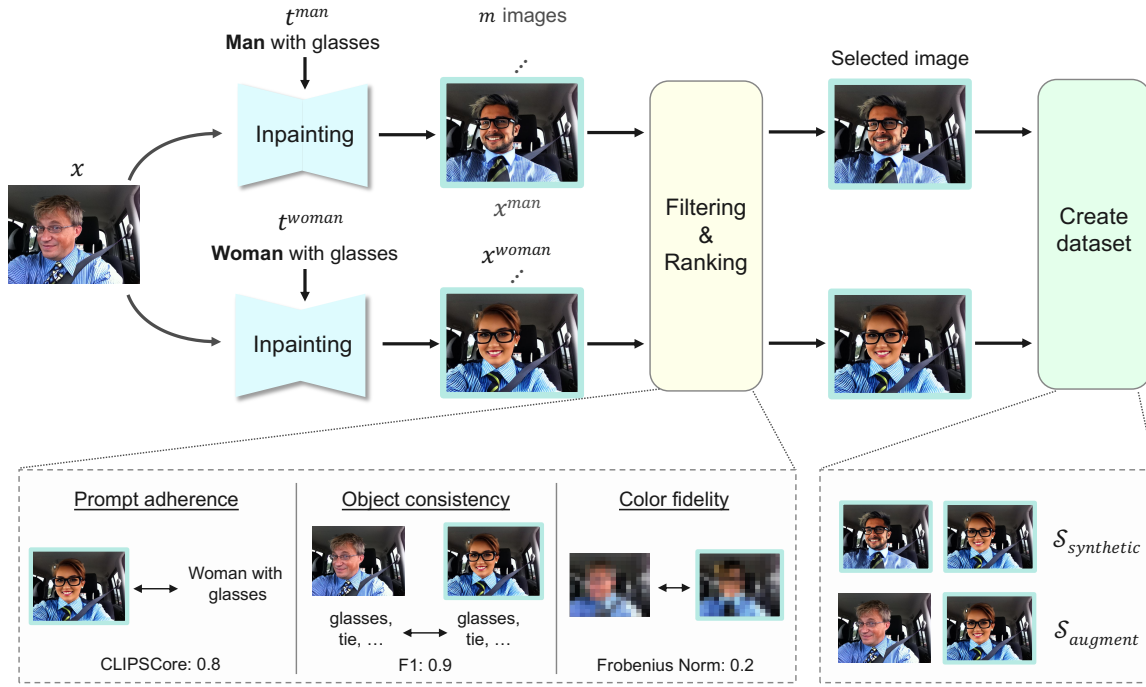


Figure 2: Overview of our pipeline for binary gender as a protected attribute. Original images are inpainted to synthesize diverse groups, maintaining consistent context. Synthesized images (highlighted in blue) are ranked using filters to select high-quality, unbiased samples (Module: Filtering & Ranking). Selected images are then used to construct datasets with group-independent image attribute distributions (Module: Create dataset).

Prompt Adherence. To evaluate the semantic alignment between $x_i^{(j,g')}$ and $t_i^{(g')}$, we use CLIPScore (Hessel et al., 2021), which computes the cosine similarity between their CLIP embeddings (Radford et al., 2021). Formally,

$$s_{\text{prompt}}^{(i,j,g')} = \phi(x_i^{(j,g')}) \cdot \psi(t_i^{(g')}) \in [-1, 1], \quad (4)$$

where ϕ and ψ are CLIP’s vision and text encoders, respectively. If $s_{\text{prompt}}^{(i,j,g')} > s_{\text{prompt}}^{(i,j',g')}$, then $x_i^{(j,g')}$ better reflects the content described in $t_i^{(g')}$.

Object Consistency. To prevent the introduction of spurious correlations, such as generating objects not mentioned in $t_i^{(g')}$ or reinforcing stereotypes (Bianchi et al., 2023; Cho et al., 2023; Bansal et al., 2022), we assess the object similarity between predicted objects in $x_i^{(j,g')}$ and x_i . Concretely, we compute the F1 score (Sokolova et al., 2006) using a pretrained object detector (Zhou et al., 2022), denoted η :

$$s_{\text{object}}^{(i,j,g')} = \text{F1}[\eta(x_i^{(j,g')}), \eta(x_i)] \in [0, 1]. \quad (5)$$

If $s_{\text{object}}^{(i,j,g')} > s_{\text{object}}^{(i,j',g')}$, then $x_i^{(j,g')}$ better preserves the integrity of the original unmasked scene in x_i .

Color Fidelity. Generative models can introduce subtler biases (Bansal et al., 2022; Bianchi et al., 2023), including those related to color (Meister et al., 2023). Addressing color biases is crucial as color choices can implicitly carry cultural or gendered connotations. To mitigate this, we down-sample $x_i^{(j,g')}$ and x_i to 14×14 pixels to focus on color rather than fine details, then measure the color difference using the Frobenius norm:

$$s_{\text{color}}^{(i,j,g')} = \|(x_i^{(j,g')})_{\downarrow 14 \times 14} - (x_i)_{\downarrow 14 \times 14}\|_{\text{F}}^{-1}. \quad (6)$$

If $s_{\text{color}}^{(i,j,g')} > s_{\text{color}}^{(i,j',g')}$, then $x_i^{(j,g')}$ has better color fidelity to the original unmasked scene in x_i .

3 Experiments

Building on prior research (Zhao et al., 2017; Wang et al., 2019; Zhao et al., 2023; Hendricks et al., 2018; Zhao et al., 2021; Tang et al., 2021; Hirota et al., 2024), we evaluate our synthetic dataset creation method on multi-label image classification and image captioning tasks using quantitative metrics, human studies, qualitative comparisons, and effectiveness analysis. Evaluations are conducted on test sets of real data.

Implementation Details. We inpaint the largest person in the image based on bounding box size,

	ResNet-50			Swin-T			ConvNeXt-B		
	mAP	Ratio	Leakage	mAP	Ratio	Leakage	mAP	Ratio	Leakage
Original	<u>66.4</u>	6.3	13.4	72.8	4.0	14.3	76.3	4.6	18.2
Adversarial	63.3	—	3.3	67.8	—	4.4	69.6	—	4.7
DomDisc	57.4	4.1	15.4	65.4	4.6	16.8	68.8	4.5	19.1
DomInd	60.4	2.8	10.4	67.9	3.8	11.4	72.6	5.9	15.0
Upweight	64.9	9.1	8.3	71.5	6.3	9.8	75.0	5.6	12.9
Focal	66.1	6.3	12.0	<u>72.2</u>	3.8	13.3	<u>76.2</u>	3.8	16.2
CB	63.0	4.3	10.9	69.6	3.5	12.3	<u>73.8</u>	3.5	14.7
GroupDRO	64.1	3.0	11.4	70.8	<u>1.5</u>	12.6	75.3	4.2	16.4
Over-sampling	62.6	3.8	9.7	69.9	2.6	10.5	73.5	3.4	13.7
Sub-sampling	58.3	<u>2.0</u>	12.2	64.4	1.8	11.6	66.3	<u>2.2</u>	18.2
$\mathcal{S}_{\text{augment}}$ (Ours)	66.9	4.6	8.1	72.8	3.1	10.5	76.3	<u>2.2</u>	11.3
$\mathcal{S}_{\text{synthetic}}$ (Ours)	66.0	1.1	<u>7.5</u>	71.9	1.4	<u>8.4</u>	75.5	1.2	<u>8.2</u>

Table 1: Classification performance and gender bias scores of ResNet-50, Swin-T, and ConvNeXt-B backbones on COCO. Ratio is inapplicable to Adversarial due to its gender prediction module for mitigation. **Bold** and underline represent the best and second-best, respectively. For an unbiased model, Ratio = 1 and Leakage = 0.

	ClipCap				BLIP-2				Transformer			
	M	CS	Ratio	LIC	M	CS	Ratio	LIC	M	CS	Ratio	LIC
Original	29.1	<u>75.1</u>	2.5	2.2	29.5	75.1	5.7	4.7	<u>26.9</u>	<u>71.5</u>	4.7	4.7
LIBRA	28.9	74.9	6.5	<u>0.5</u>	29.0	75.4	6.3	1.9	27.4	73.4	6.7	2.3
Over-sampling	28.6	74.7	3.2	3.5	28.7	74.1	3.8	3.0	26.2	70.6	4.1	1.6
Sub-sampling	28.0	74.0	<u>1.4</u>	4.1	28.3	74.5	<u>1.4</u>	3.2	25.0	69.7	<u>2.0</u>	3.9
$\mathcal{S}_{\text{augment}}$ (Ours)	<u>29.0</u>	75.0	2.5	1.7	<u>29.4</u>	<u>75.3</u>	2.9	3.8	26.2	71.1	<u>2.6</u>	<u>1.5</u>
$\mathcal{S}_{\text{synthetic}}$ (Ours)	28.5	75.3	1.3	0.3	29.3	75.0	1.2	<u>2.5</u>	25.7	70.9	1.4	0.5

Table 2: Captioning quality and gender bias scores of ClipCap, BLIP-2, and Transformer backbones on COCO. M and CS denote METEOR and CLIPScore. **Bold** and underline represent the best and second-best, respectively. For an unbiased model, Ratio = 1 and LIC = 0.

and if the second largest person exceeds 55,000 pixels, we also inpaint that region, using the person label for COCO. For image generation, we create $m = 30$ inpainted images per group (e.g., woman, man) using guidance scales of 7.5, 9.5, and 15.0 to ensure diversity. Filter weights are set to 1 (i.e., $c_k = 1$ for all k), contributing equally. Results are based on five models trained with different random seeds. More details are in Appendices A and B.

3.1 Multi-Label Classification

Experimental Setup. We focus on gender bias using the COCO dataset, retaining only images with gender-specific terms (e.g., woman, man) in their captions. This results in 28,487/13,487 train/test samples. We focus on objects co-occurring with these terms, yielding 51 objects. ResNet50, Swin Transformer Tiny (Swin-T), and ConvNext models are fine-tuned using early stopping. Performance is assessed using mean average precision (mAP). Bias is quantified using leakage and ratio. Leakage measures how much the model’s predictions amplify the group’s information com-

pared to the ground truth. A gender classifier $f_g(y)$, predicting gender group g from input y (i.e., set of objects), is trained on a training set $\mathcal{T} = \{(y, g)\}$. For the test set \mathcal{T}' , the model’s leakage score is:

$$\text{LK}_M = \frac{1}{|\mathcal{T}'|} \sum_{(y,g) \in \mathcal{T}'} f_g(y) \mathbb{1} \left[\arg \max_{g'} f_{g'}(y) = g \right] \quad (7)$$

The leakage score for the original dataset, LK_D , is similarly computed. The final leakage is $\text{Leakage} = \text{LK}_M - \text{LK}_D$. Higher leakage indicates greater model exploitation of protected group information. Ratio measures the exploitation of attribute information for group prediction. By masking individuals in test images and measuring the bias in group predictions (e.g., #man-to-#woman ratio), deviations from a ratio of 1 indicate attribute exploitation. We report $\text{Ratio} = \max(r, r^{-1})$, where r is the observed ratio. This captures the magnitude of deviation from unbiased predictions consistently.

We compare our method with existing bias mitigation techniques, including dataset-level methods (Over-sampling (Wang et al., 2020b), Sub-sampling (Agarwal et al., 2022)) and model-level

methods such as adversarial debiasing (Wang et al., 2019) (Adversarial), domain-independent training (Wang et al., 2020b) (DomInd), domain discriminative training (Wang et al., 2020b) (DomDisc), loss upweighting (Byrd and Lipton, 2019) (Upweight), focal loss (Lin et al., 2017) (Focal), class-balanced loss (Cui et al., 2019) (CB), and group DRO (Sagawa et al., 2019) (GroupDRO). Additional results on the OpenImages dataset and skin tone bias mitigation are provided in Appendix B.1, demonstrating consistent conclusions.

Results. Results are shown in Table 1. Our method, $\mathcal{S}_{\text{synthetic}}$, achieves the best balance by significantly improving both ratio and leakage while maintaining a high mAP. Specifically, $\mathcal{S}_{\text{synthetic}}$ achieves a near-ideal ratio of 1.1, low leakage of 7.5, and an mAP of 66.0 for ResNet-50, with similar trends observed for Swin-T and ConvNeXt-B.

Adversarial debiasing achieves lower leakage scores by removing gender information from intermediate representations. However, this method reduces mAP, indicating that object information may also be inadvertently removed. Over-sampling and sub-sampling methods address class imbalance but at the cost of model performance. Sub-sampling, in particular, reduces the ratio compared to over-sampling but results in worse mAP and increased leakage. This is likely due to the loss of diversity and information in the training data, which forces the model to rely more on the remaining features, increasing the influence of protected attributes.

In contrast, $\mathcal{S}_{\text{synthetic}}$ generates diverse, high-quality synthetic samples, effectively balancing bias and variance. This approach avoids the pitfalls of other methods, resulting in superior performance metrics. While $\mathcal{S}_{\text{augment}}$ performs similarly to the original dataset, it performs worse in terms of ratio and leakage compared to $\mathcal{S}_{\text{synthetic}}$.

3.2 Image Captioning

Experimental Setup. Using the COCO dataset (Section 3.1), we benchmark captioning models ClipCap, BLIP-2, and Transformer, which are fine-tuned using early stopping. Performance is evaluated with METEOR and CLIPScore. Bias is quantified using LIC and ratio, where LIC is a leakage-based metric that assesses the generation of group-stereotypical captions compared to ground-truth captions (i.e., y is a caption in Equation (7)), and predicted group-related terms (e.g., woman) in captions used to compute ratio.

Bias mitigation baselines include dataset-level methods (Over-sampling, Sub-sampling) and the current state-of-the-art model-level method LIBRA (Hirota et al., 2023). LIBRA is a model-agnostic debiasing framework designed to mitigate bias amplification in image captioning by synthesizing gender-biased captions and training a debiasing caption generator to recover the original captions. Detailed results for skin tone bias mitigation, along with fine-tuning specifics, are provided in Appendix B.2, showcasing the generalizability of our approach.

Results. Results are shown in Table 2. Our method, $\mathcal{S}_{\text{synthetic}}$, significantly improves both ratio and LIC while maintaining high METEOR and CLIPScore values. Specifically, $\mathcal{S}_{\text{synthetic}}$ achieves a near-ideal ratio of 1.3, low LIC of 1.2, and a METEOR score of 29.3 for BLIP-2, with similar trends observed for ClipCap and Transformer.

While LIBRA effectively reduces LIC, it shows an increase in the ratio metric, indicating a trade-off between debiasing effectiveness and caption quality. Over-sampling and sub-sampling methods result in varying degrees of performance. Sub-sampling showed improved bias metrics compared to over-sampling but results in worse METEOR scores, especially for the Transformer model.

As in the multi-label classification task, we observe that although $\mathcal{S}_{\text{augment}}$ significantly reduces bias compared to using the original dataset, there is a significant gap between it and $\mathcal{S}_{\text{synthetic}}$ in terms of bias mitigation.

3.3 Analysis of Synthetic Artifacts

Recent studies show that text-to-image models introduce synthetic artifacts in images, which models may exploit (Qraitem et al., 2023; Corvi et al., 2023; Wang et al., 2023b). Our observations in Sections 3.1 and 3.2 suggest that bias persists with $\mathcal{S}_{\text{augment}}$, which augments the dataset with counterfactual images to balance group distributions. We hypothesize that $\mathcal{S}_{\text{augment}}$ may lead to shortcut learning due to spurious correlations between minoritized groups and inpainted artifacts. In contrast, $\mathcal{S}_{\text{synthetic}}$ distributes artifacts equally across all groups, avoiding this issue.

To test this, we create a test set by inpainting random body parts using COCO-WholeBody annotations (Jin et al., 2020). Given an image, its caption, and body part annotations (e.g., left hand, right hand, head), we randomly select a body part, create

	ResNet-50			Swin-T			ClipCap			BLIP-2		
	Ratio _{orig}	Ratio _{inp}	Δ	Ratio _{orig}	Ratio _{inp}	Δ	Ratio _{orig}	Ratio _{inp}	Δ	Ratio _{orig}	Ratio _{inp}	Δ
Original	3.5	3.0	14.3	3.1	2.6	16.1	2.3	2.5	8.7	2.3	2.4	4.4
$\mathcal{S}_{\text{augment}}$	3.7	1.5	59.5	3.2	0.6	81.3	2.5	0.8	68.0	2.3	1.8	21.7
$\mathcal{S}_{\text{synthetic}}$	1.9	1.8	5.3	2.1	2.0	4.8	1.7	1.6	5.9	1.8	1.7	5.6

Table 3: Comparison of the original (Ratio_{orig}) and inpainted (Ratio_{inp}) versions of the COCO test set. The relative difference is denoted by $\Delta = 100 \cdot \left| \frac{\text{Ratio}_{\text{orig}} - \text{Ratio}_{\text{inp}}}{\text{Ratio}_{\text{orig}}} \right| \%$. A larger Δ signifies a greater change.

	Object	Color	Skin	Gender	CS
$s_{\text{prompt}} + s_{\text{object}} + s_{\text{color}}$	0.57	0.46	0.29	0.95	75.3
$s_{\text{prompt}} + s_{\text{object}}$	0.49	0.50	0.20	0.99	74.8
$s_{\text{prompt}} + s_{\text{color}}$	0.45	0.56	0.21	0.94	75.2
$s_{\text{object}} + s_{\text{color}}$	<u>0.53</u>	<u>0.52</u>	0.20	0.96	74.8
s_{prompt}	0.32	0.46	0.26	<u>0.97</u>	75.1
s_{object}	0.36	0.43	0.25	0.95	74.5
s_{color}	0.52	0.50	0.30	0.95	74.6
No filter	0.09	0.07	0.18	0.94	74.6

Table 4: Human evaluation and captioning quality (CLIPScore, CS in short) for each filter combination. Higher values indicate better alignment with original images. **Bold** and underline represent the best and second-best score for each metric.

a mask using the Segment Anything Model (Kirillov et al., 2023), and perform inpainting with the caption as a prompt. We evaluate the consistency of ratios between the original and synthetic test sets; a gap indicates the exploitation of synthetic artifacts for gender prediction.

Table 3 presents scores for multi-label classification (ResNet-50, Swin-T) and image captioning (ClipCap, BLIP-2). The table includes the ratio of gender predictions (#man-to-#woman) for the original test set (Ratio_{orig}) and the inpainted test set (Ratio_{inp}), along with the relative difference (Δ) between these ratios. Results show a significant shift in gender predictions with $\mathcal{S}_{\text{augment}}$ -trained models. Despite identical gender ratios in the original and inpainted test sets (both set at 2.3), models trained with $\mathcal{S}_{\text{augment}}$ predict woman much more frequently for the inpainted test set, indicated by the large relative differences. In contrast, models trained solely on synthetic data ($\mathcal{S}_{\text{synthetic}}$) show minimal relative differences, indicating consistent gender predictions across original and inpainted test sets.

Figure 3 shows examples of synthetic images and predictions by ClipCap (trained on $\mathcal{S}_{\text{augment}}$ or $\mathcal{S}_{\text{synthetic}}$). The examples demonstrate inconsistent gender predictions with $\mathcal{S}_{\text{augment}}$; specifically, the model tends to predict woman for the inpainted test images, evidencing exploitation of synthetic artifacts.

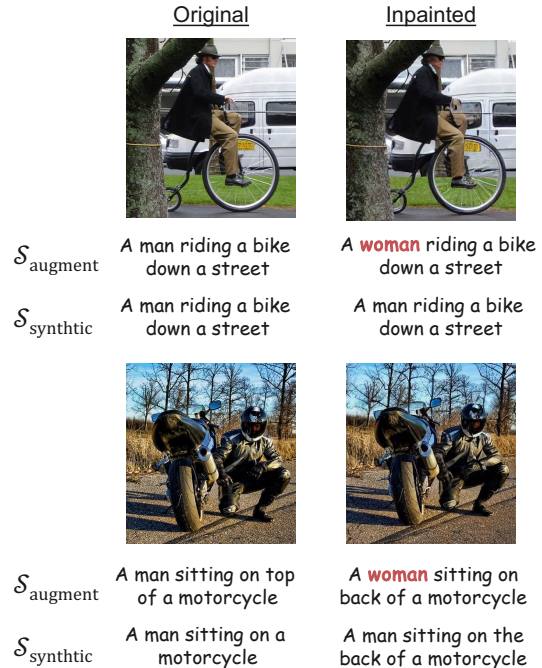


Figure 3: Predicted captions for the original (left) and inpainted (right) test images.

3.4 Human Filter Evaluation

We conduct human evaluations on Amazon Mechanical Turk (Turk, 2012) to evaluate the effectiveness of our filters, aiming to determine if our filters prevent additional biases from inpainting models and ensure high-quality images. For 300 randomly selected original images, we analyze inpainted images chosen by each filter combination. Evaluations focus on the similarity of 1) held/nearby objects, 2) object color, and 3) skin tone compared to the original images. Workers assess differences between original and synthetic images for objects and their color, and selected skin tone classes using the Monk Skin Tone Scale (Schumann et al., 2023; Monk, 2023). Additionally, workers verify accurate gender depiction through a sentence gap-filling exercise (e.g., “A ____ with a dog.”), where they must choose a protected group term to complete the sentence. More details are in Appendix B.3.

For the evaluation of the similarity of objects and their colors, scores are computed as the proportion



Figure 4: Best/worst inpainted images for each filter in Section 2.3 and their combination (overall).

of times the inpainted images are rated as similar. Regarding the skin tone and gender evaluations, the scores are calculated as the proportion of matching responses from workers between the original and inpainted images. All the scores range from 0 to 1.

Table 4 summarizes the human evaluation and captioning performance of ClipCap trained on $\mathcal{S}_{\text{synthetic}}$ (CS), with images selected by each filter. Notably, using all filters consistently received higher ratings across most criteria. In contrast, randomly selecting images without any filtering often leads to synthetic images differing significantly from the originals. This indicates that our filters are effective in mitigating additional biases introduced by the inpainting model. Furthermore, CLIPScore shows that using all filters improves captioning performance, highlighting its effectiveness in selecting higher-quality images.

3.5 Inherited Biases

To further discuss the potential biases introduced by the models used in our method, we conduct several assessments. First, for the object detector, we run Detic (Zhou et al., 2022) on both real and synthetic images, achieving similar mAP scores of 32.0 for real images and 32.3 for synthetic images, indicating consistent performance. Second, addressing biases in CLIP, we acknowledge the potential biases inherent in the model. However, our use of object- and color-based filters helps mitigate these biases. Additionally, image classification and captioning results verify that our method effectively reduces gender and skin tone biases. Lastly, for the inpainting model, our filters effectively remove

synthetic images that deviate from the prompt, alter color statistics, or introduce undescribed objects, as shown in Table 4. These assessments confirm that our method successfully mitigates biases without compromising performance.

3.6 Qualitative Results

We present qualitative examples of bias mitigation by applying our method ($\mathcal{S}_{\text{synthetic}}$) in Figure 1. The results show that training models on $\mathcal{S}_{\text{synthetic}}$ produces less biased outputs. For instance, in the classification task, the baseline ResNet-50 model and the over-sampling model incorrectly predict tie, due to its frequent co-occurrence with man in the training set. In contrast, $\mathcal{S}_{\text{synthetic}}$ results in a gender bias-free prediction. Image captioning results further validate our approach. The baseline ClipCap model and LIBRA model generate the man-stereotypical word skateboard, whereas our method correctly predicts the object frisbee.

In Figure 4, we also present the best and worst inpainted images for each filter (prompt adherence, object consistency, and color fidelity), as well as their combination (overall). The results demonstrate each filter’s effectiveness, and combining them selects a high-quality image that closely resembles the original. For instance, the image judged worst by the object consistency filter lacks the object the man is holding, while the color fidelity filter’s worst image shows significant color changes in the man’s clothing. Combining these filters helps select an inpainted image that minimizes additional bias and closely matches the original.

4 Conclusion

We present a dataset-level bias mitigation pipeline that effectively reduces gender and skin tone biases by ensuring group-independent attribute distribution using synthetic-only images. Our findings indicate that mixing real and synthetic images introduces spurious correlations, underscoring the need for caution when augmenting datasets with synthetic data. Our work highlights the potential of synthetic data in bias mitigation and suggests further exploration into optimizing synthetic data generation and integration techniques for increased bias reduction.

Limitations

Binarized Group Classes and Intersectional Bias Analysis. While acknowledging that gender and skin tone exist on a spectrum, our data limitations necessitated a focus on binarized groups (i.e., man, woman). Our focus on gender and skin tone biases was driven by:

- Prevalence in Literature: Gender and skin tone biases have been extensively investigated in previous works, providing a robust foundation for our study (Zhao et al., 2017; Wang et al., 2019; Zhao et al., 2023, 2021).
- Availability of Annotations: Current datasets primarily include annotations for gender and skin tone, limiting our ability to extend to other attributes (Zhao et al., 2021).

However, our method can be extended to handle intersectional attributes (e.g., gender and skin tone) by inpainting with combinations of attributes (e.g., {woman, darker-skinned}, {woman, lighter-skinned}, {man, darker-skinned}, {man, lighter-skinned}). We leave this extension for future work to ensure a more comprehensive and inclusive analysis of biases.

Risks of Using Pre-trained Models. As discussed in Section 3.5, the pre-trained models employed in our framework (e.g., inpainting model, object detector) may introduce inherent biases. While our analysis in Section 3.5 confirmed that these models do not adversely affect our method based on our evaluations, it is possible that some biases were not detected. Specifically, we propose the following steps for future work:

- Developing and integrating additional filtering techniques to detect and mitigate subtle biases.
- Exploring the use of less biased models, such as debiased versions of CLIP (Berg et al., 2022).

Residual Bias. Our experimental results demonstrated that our method significantly mitigates societal bias compared to existing methods. However, bias is not completely eliminated (e.g., leakage is not zero). Future work could explore further debiasing by optimizing the weight of each filter (currently, all filters are equally weighted), introducing additional filters, and combining our method with existing bias mitigation techniques (e.g., focal loss).

Extending to Additional Protected Groups. Due to a lack of annotations for other protected attributes, our focus in this paper is on gender and skin tone biases. Nevertheless, our pipeline is applicable to various protected attributes, such as age (e.g., “A woman with a dog” → “An elderly woman with a dog”). Future research should explore the application of our method to additional protected attributes.

Ethics Statement

Our research involves the manipulation of image data to mitigate societal bias, raising important ethical considerations. We address these concerns by creating synthetic images that completely inpaint over identifiable individuals, thereby respecting privacy and consent without altering their appearance. Our approach aims to promote fairness and equity by ensuring diverse and unbiased representation in image datasets. We acknowledge the potential biases inherent in the pre-trained models used and have implemented filters to mitigate these biases as much as possible. Future work should continue to explore ethical guidelines and safeguards to ensure the responsible use of generative models in research.

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A Method Details

A.1 Image Generation Settings

Selection of People for Inpainting. Following the previous works (Zhao et al., 2021; Misra et al., 2016), we apply inpainting to a person with the largest bounding box. In addition, if the second largest person’s box is larger than 55,000 pixels, the region is also inpainted. For COCO, we do this by using the person label and corresponding bounding boxes. For OpenImages, we use person-bounding boxes presented in More Inclusive Annotations for People (MIAP) annotations (Schumann et al., 2021), then we generate person masks within the boxes using Segment Anything Model (Kirillov et al., 2023).

Parameters of Image Generation. In Section 2.2, we generate $m = 30$ inpainted images for each group (e.g., {woman, man} for binary gender). When generating the images, we use three different guidance scale parameters (7.5, 9.5, and 15.0) to generate diverse inpainted images (i.e., generating 10 images for each guidance scale). We use 6 NVIDIA A100-PCIE-40GB GPUs, resulting in a total of 72 hours to finish synthesizing images.

A.2 Visual examples of inpainted images & failure cases

We show the visual examples of the inpainted images after filtering in Figure 5 (for binary gender) and Figure 6 (for binary skin tone). The examples show that the inpainted images depict the target groups (e.g., woman and darker-skinned), keeping the rest fixed. In some cases, artifacts are noticeable, which enables us to identify synthetic images (e.g., the details of the faces are not clear), but they do not affect the downstream performance, as shown in the main paper.

B Experimental Settings and Additional Results

B.1 Multi-Label Classification

Datasets. We use COCO (Lin et al., 2014) and OpenImages (Krasin et al., 2017). Following previous works (Zhao et al., 2017, 2023), we focus on attributes co-occurring with woman or man more than 100 times and remove person-related classes (e.g., person class), resulting in 51 and 126 attributes for COCO and OpenImages, respectively. The list of the attributes is as follows:

COCO: {sink, refrigerator, laptop, surfboard, vase, bottle, remote, donut, motorcycle, car, chair, suitcase, tv, knife, fork, couch, bus, toothbrush, bicycle, tie, clock, microwave, teddy bear, frisbee, spoon, dog, truck, bench, backpack, skis, horse, sandwich, bed, handbag, umbrella, pizza, book, dining table, traffic light, banana, potted plant, tennis racket, cat, sports ball, kite, cake, wine glass, bowl, cup, oven, cell phone}.

OpenImages: {goggles, building, cloud, smile, tree, sunglasses, light, t-shirt, glasses, water, forehead, wall, sky, tire, roof, road, wheel, vehicle, land vehicle, car, tie, furniture, microphone, suit, clothing, fence, jeans, trousers, shirt, footwear, flooring, outerwear, coat, ceiling, floor, jacket, table, house, couch, mammal, hat, shoe, sports uniform, baseball (sport), cap, baseball cap, bag, drawing, sun hat, musical instrument, baby, window, door, sweater, lake, chair, tableware, bottle, drink, handwriting, paper, food, tent, concert, drum, guitar, glove, sports equipment, blazer, art, painting, dress, flower, sneakers, screenshot, watercraft, beach, animal, grass family, plant, soil, desk, poster, bus, computer, personal computer, watch, mountain, helmet, bicycle helmet, bicycle wheel, bicycle, curtain, dance, football, ball (object), soccer, wedding dress, jewellery, bride, office building, laptop, toddler, shorts, hiking, fashion accessory, fedora, swimming, swimwear, camera, playground, weapon, ship, statue, boat, fast food, flag, soft drink, book, auto part, snow, carnivore, dog, horse, motorcycle, pole dance}.

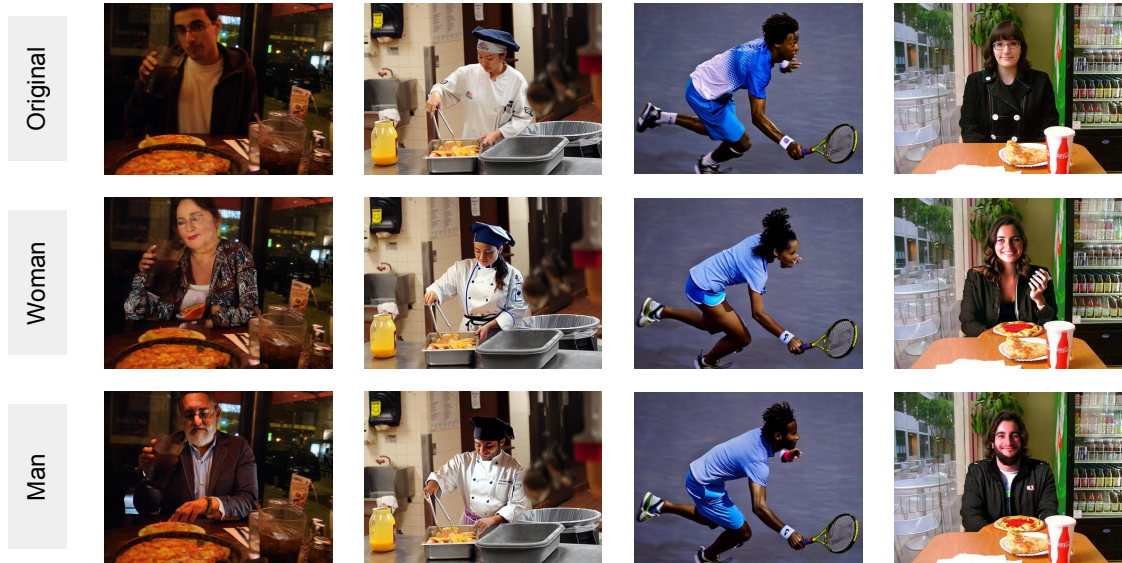


Figure 5: Examples of inpainted images for binary gender.

	ResNet-50			Swin-T			ConvNeXt-B		
	mAP	Ratio	Leakage	mAP	Ratio	Leakage	mAP	Ratio	Leakage
Original	<u>42.3</u>	5.2	18.9	<u>45.3</u>	4.3	20.9	<u>46.0</u>	5.0	22.7
Adversarial	37.5	—	8.3	40.8	—	11.3	40.4	—	12.3
DomDisc	40.7	3.7	20.6	43.6	4.6	22.1	42.9	4.1	21.9
DomInd	40.3	3.7	19.1	42.7	3.5	20.2	43.4	2.6	22.0
Upweight	41.3	6.5	<u>13.1</u>	44.7	5.8	17.9	45.3	7.4	18.0
Focal	43.0	4.6	18.7	45.4	4.4	21.3	45.4	4.0	22.3
CB	40.5	5.2	18.0	42.6	3.9	19.8	43.9	4.6	21.5
GroupDRO	<u>42.3</u>	4.2	18.9	45.1	4.2	20.9	46.1	3.4	22.5
Over-sampling	38.5	3.3	15.0	41.1	4.0	<u>16.1</u>	41.7	5.2	18.4
Sub-sampling	38.3	<u>2.2</u>	18.3	41.2	<u>2.1</u>	19.8	39.8	2.8	21.7
$\mathcal{S}_{\text{augment}}$ (Ours)	42.0	1.9	16.0	44.9	<u>2.4</u>	18.0	45.5	2.6	19.0
$\mathcal{S}_{\text{synthetic}}$ (Ours)	41.4	1.1	14.6	44.4	2.0	17.6	44.7	1.3	<u>17.9</u>

Table 5: Classification performance and gender bias scores of ResNet-50, Swin-T, and ConvNeXt-B backbones on OpenImages. Ratio is inapplicable to Adversarial due to its gender prediction module for mitigation. **Bold** and underline represent the best and second-best, respectively. For an unbiased model, Ratio = 1 and Leakage = 0.

Training. The models (ResNet-50 (He et al., 2016), Swin-T (Liu et al., 2021), and ConvNeXt-Base (Liu et al., 2022)) are initialized with ImageNet (Russakovsky et al., 2015) pre-training, and fine-tuned with early stopping using a validation set split from the training set (20% of the training set). The optimizer is Adam (Kingma and Ba, 2015), batch size is 32, and a learning rate is 1×10^{-5} . For binary gender, the classification layers predict both protected groups (i.e., {woman, man}) and object classes. For binary skin tone, the models only predict object classes as ground-truth skin tone labels are not available.

Results for OpenImages. We show the complete results of the experiments in the main paper: gender bias on OpenImages (Table 5). The results show

that all the insights described in the main paper are consistent across the datasets.

Results for skin tone bias. Previous bias mitigation methods face a significant limitation, requiring protected group labels for all training set samples (Zhao et al., 2017; Wang et al., 2019; Agarwal et al., 2022). They typically focus on gender as a protected attribute due to its prevalence in captions (Misra et al., 2016), allowing for label inference through gender-related terms. In contrast, $\mathcal{S}_{\text{synthetic}}$ applies to attributes without labels, such as skin tone. We use our pipeline (excluding the color fidelity filter, as we aim to modify skin tone) on binary skin tone categories (i.e., $\mathcal{G} = \{\text{darker-skinned}, \text{lighter-skinned}\}$) using COCO. We evaluate skin tone bias using *leak-*

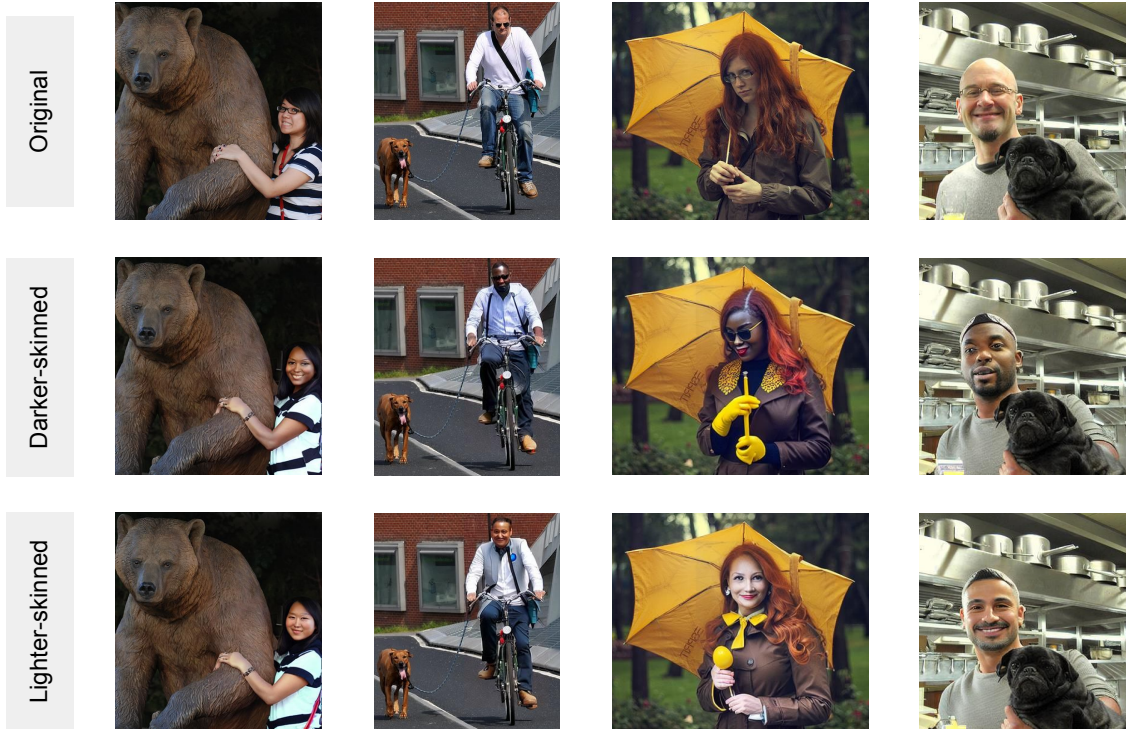


Figure 6: Examples of inpainted images for binary skin tone.

	ResNet-50		Swin-T		ConvNeXt-B	
	mAP	Leakage	mAP	Leakage	mAP	Leakage
Original	65.8	3.2	72.2	7.1	75.9	7.2
$\mathcal{S}_{\text{synthetic}}$ (Ours)	65.2	2.3	71.4	3.7	74.5	5.9

Table 6: Classification performance and skin tone bias scores of ResNet-50, Swin-T, and ConvNeXt-B backbones on COCO. **Bold** represents the best. For an unbiased model, Ratio = 1 and Leakage = 0.

age only since *ratio* requires models to predict protected groups, and there are no skin tone annotations for the COCO training set. Results are shown in Table 6, demonstrating consistent conclusions with gender bias.

B.2 Image Captioning

Training. We benchmark three captioning models: ClipCap (Mokady et al., 2021), BLIP-2 (Li et al., 2023), and Transformer (i.e., the Transformer-based encoder-decoder model composed of Vision Transformer (Dosovitskiy et al., 2021) and GPT-2 (Radford et al., 2019)). As with multi-label classification, we train the models with early stopping. Specifically, for ClipCap, we follow the official implementation regarding the training settings. For BLIP-2 and Transformer, we use the implementation in Hugging Face (Wolf et al., 2020). We use the AdamW optimizer (Loshchilov and Hutter, 2019) with a learn-

ing rate of $2 \times 10^{-6}/1 \times 10^{-4}$ and batch size of 8/64 for BLIP-2 and Transformer, respectively.

Results for skin tone. We show the results of the experiments for skin tone bias mitigation in Table 7. The results show that the insights in the main paper are mostly consistent across the protected groups.

B.3 Human Filter Evaluation

In Figures 7 to 9, we present example tasks for human evaluation conducted on Amazon Mechanical Turk (AMT) (Turk, 2012). This evaluation assesses how well each combination of filters identifies desirable inpainted images. Figure 7 shows the user interface for evaluating the similarity of held/nearby objects and their colors between the original (left) and inpainted (right) images. Figure 8 asks workers to select a skin tone class using the Monk Skin Tone Scale (Schumann et al., 2023; Monk, 2023). We conduct this evaluation on both original and inpainted images and compute

	ClipCap			BLIP-2			Transformer		
	M	CS	LIC	M	CS	LIC	M	CS	LIC
Original	29.4	75.3	4.6	27.1	73.9	2.2	27.0	71.5	5.3
$S_{\text{synthetic}}$ (Ours)	29.1	75.4	3.7	26.8	73.6	2.0	26.5	71.0	4.7

Table 7: Captioning quality and skin tone bias scores of ClipCap, BLIP-2, and Transformer backbones on COCO. M and CS denote METEOR and CLIPScore. **Bold** represents the best. For an unbiased model, Ratio = 1 and LIC = 0.

the degree of agreement between them. Figure 9 verifies if *perceived* gender is accurately depicted—according to the AMT worker—in the inpainted images through gap-filling, where workers must choose a protected group term to complete the sentence. Each assignment pays \$0.07, with a total participant compensation of approximately \$2,000.

C Image Attribution

All images in this paper are sourced from the COCO dataset (Lin et al., 2014), which is publicly available at <https://cocodataset.org>. These images are used for non-commercial academic purposes in accordance with their respective licenses.

Image License Details. Detailed information on the licensing of each image used in the figures of this paper is provided below:

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Figure 2

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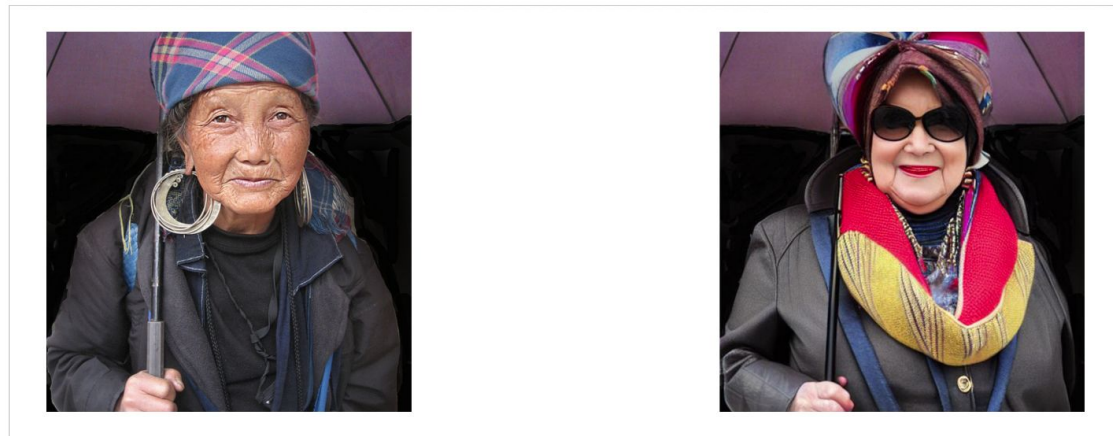
Figure 4

- Title: LANCE JAMES AND DOGS
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Please compare the target person (right) with the reference person (left) and answer the questions below.



Q1. Is the target person similar to the reference person? Focus only on **type** of clothing worn by the persons and the **type** of objects they are holding/touching.

Has significant discrepancies Has minor discrepancies or identical objects

Q2. Is the target person similar to the reference person? Focus only on the **color** of the clothing worn by the people and the **color** of the objects they are holding/touching.

Has significant discrepancies Has minor discrepancies or indistinguishable colors

Submit

Figure 7: Evaluation of *perceived* object and color similarity between original and inpainted images on AMT.

Figure 5 (second from the left)

- Title: 091022-F-7797P-006
- Photographer: Offutt Air Force Base
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Figure 5 (second from the right)

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- Photographer: Kyle T.
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Figure 5 (right)

- Title: 022
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Figure 6 (left)

- Title: Bear & I @ San Diego Zoo
- Photographer: tammylo
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Figure 6 (second from the left)

- Title: Loop hem eruit!
- Photographer: FaceMePLS
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Figure 6 (second from the right)

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Figure 6 (right)

- Title: Raoul in the kitchen!
- Photographer: pug freak
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Figures 7 to 9

- Title: Hmong Woman
- Photographer: Elliot Margolies
- Source URL: <https://www.flickr.com/photos/41597157@N00/8298673953>
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Please answer the following question about the image below.



Q. What is the skin tone of the person? If you are not sure, then select "Unsure".

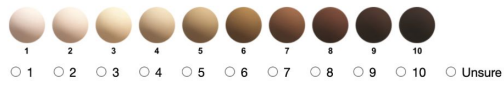


Figure 8: Evaluation of *perceived* skin tone using the Monk Skin Tone Scale on AMT.

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Please compare the image and description, and answer the following questions.



An older ___ with large earrings holding a purple umbrella

Q. Choose the best word to complete the sentence. If you are not sure, then select "Unsure".

- Woman / she / her / hers Man / he / him / his Unsure

Submit

Figure 9: Evaluation of *perceived* gender depiction accuracy in inpainted images on AMT.