GAMA: Generative Adversarial Multi-Object Scene Attacks

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Abstract

The majority of methods for crafting adversarial attacks have focused on scenes with a single dominant object (e.g., images from ImageNet). On the other hand, natural scenes include multiple dominant objects that are semantically related. Thus, it is crucial to explore designing attack strategies that look beyond learning on single-object scenes or attack single-object victim classifiers. Due to their inherent property of strong transferability of perturbations to unknown models, this paper presents the first approach of using generative models for adversarial attacks on multi-object scenes. In order to represent the relationships between different objects in the input scene, we leverage upon the open-sourced pre-trained vision-language model CLIP (Contrastive Language-Image Pre-training), with the motivation to exploit the encoded semantics in the language space along with the visual space. We call this attack approach Generative Adversarial Multiobject Attacks (GAMA). GAMA demonstrates the utility of the CLIP model as an attacker's tool to train formidable perturbation generators for multi-object scenes. Using the joint image-text features to train the generator, we show that **GAMA** can craft potent transferable perturbations in order to fool victim classifiers in various attack settings. For example, **GAMA** triggers ~16% more misclassification than state-of-the-art generative approaches in black-box settings where both the classifier architecture and data distribution of the attacker are different from the victim. Our code is available here: https://abhishekaich27.github.io/gama.html

1 Introduction

Despite attaining significant results, decision-making of deep neural network models is brittle and can be surprisingly manipulated with adversarial attacks that add highly imperceptible perturbations to the system inputs [1, 2]. This has led to dedicated research in designing diverse types of adversarial attacks that lead to highly incorrect decisions on diverse state-of-the-art classifiers [2–13]. The majority of such adversarial attacks [2, 8–18] has focused on scenes with a single dominant object (e.g., images from ImageNet [19]). However, natural scenes consist of multiple dominant objects that are semantically associated [20–25]. This calls for attack methods that are effective in such multi-object scenes.

A recent body of work in adversarial attacks [26–30] has shown the importance of exploring attack methodologies for real-world scenes (although designed for attacking object detectors). However, such methods are image-specific approaches that are known to have poor time complexity when perturbing large batches of images, as well as poor transferability to unknown models (more details in Section 2) due to their inherent property of perturbing images independently from one another.

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Different from such approaches, *our interest lies in the generative model-based approaches* [10–13] which are distribution-driven and craft perturbations by learning to fool a surrogate classifier for a large number of images. These generative adversarial attacks show stronger transferability of perturbations to unknown victim models and can perturb large batches of images in one forward pass through the generator demonstrating better time complexity [11, 31]. However, these generative attack methods have focused on learning from single-object scenes (*e.g.*, ImageNet in [11–13], CUB-200-2011 [32] in [13]) or against single-object surrogate classifiers (*e.g.*, ImageNet classifiers [33] in [10–13]). When trained against multi-object (also known as multi-label) classifiers to learn perturbations on multi-object scenes, such methods perform poorly as they do not explicitly incorporate object semantics in the generator training (see Table 2 and Table 3). As real-world scenes usually consist of multi-object images, designing such attacks is of importance to victim model users that analyze complex scenes for making reliable decisions *e.g.* self-driving cars [34]. To this end, *we propose the first generative attack approach, called* Generative Adversarial Multi-object scene Attacks or GAMA, *that focuses on adversarial attacks on multi-object scenes*.

Progress in recent vision-and-language (VL) models [35–39] that allow joint modelling of image and text have garnered interest in recent times due to their versatile applicability in various image downstream tasks like inpainting, editing, etc. [40–51]. For the first time in literature, we introduce the utility of a pre-trained open-source framework of the popular VL model named CLIP (Contrastive Language-Image Pre-training) [36] in generating adversarial attacks. Trained on 400 million image-text pairs collected from the internet, CLIP has been shown to provide robust joint representations of VL semantics [40, 46] and strong zero-shot image classification on diverse datasets [36, 44]. This allows us to access diverse

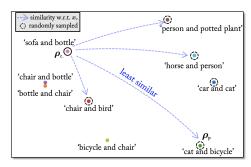


Figure 1: Using CLIP's image-text aligning property, we compute the features of the least similar text description w.r.t. to clean image.

VL features cheaply without any training as end-user. Our proposed GAMA attack employs the CLIP model to exploit the natural language semantics encoded in text features along with the vision features (due to its joint image-text alignment property). Different from prior works, GAMA utilizes CLIP model's extracted knowledge from ~400 million images to maximize the feature differences of perturbed image x_p against two different types of features computed from clean image x_c : (1) features of x_c computed from surrogate models, and (2) features of x_c computed from CLIP's image encoder. Additionally, **GAMA** also guides x_p to contain different features compared to x_c by using features from CLIP's text encoder via a contrastive loss function. For example in Figure 1, consider a clean image x_c with objects "sofa and bottle". Using CLIP's image-text aligning property, we estimate that x_c (with text features ρ_c) is least similar to the text prompt "car and bicycle" (text features ρ_n) among some randomly chosen candidates (indicated by dotted circles). **GAMA** uses ρ_p , created from a contextually consistent classes, to contrast and move the perturbed x_p away from x_c in feature space. Hence, the perturbed image features are comparably robust to data distribution changes in victim models as $\mathcal{G}_{\theta}(\cdot)$ is optimized to create perturbations that differ in features from two different image features. This allows GAMA to launch highly transferable attacks on unseen victim models (see Section 4). To summarize, we make the following contributions in this paper.

- 1. Multi-object scene based generative attack aided by VL models. We propose the first multi-object scene based generative attack, GAMA, that is designed to consider object semantics through vision-and-language models.
- Pre-trained CLIP model as an attacker's tool. We propose the first generative attack on classifiers that utilizes the open-source pre-trained CLIP model as an attacker's tool to train perturbation generators.
- 3. **Extensive Attack Evaluations.** Our extensive experiments on various black-box settings (where victims are multi-label/single-label classifiers and object detectors) show **GAMA**'s state-of-the-art transferability of perturbations (Table 2, 3, 5, 4, 6, and 7). Additionally, we also show that **GAMA** outperforms its baselines in terms of attack robustness when the victim deploys state-of-the-art defenses (Table 8).

Table 1: Characteristic comparison. Here, $f(\cdot)$ denotes the surrogate classifier. x and x_{δ} denote a clean and perturbed image. k denotes output from a specific pre-defined layer of $f(\cdot)$ (different for each method). Better than prior generative attacks [10–13], GAMA leverages multi-modal (text and image) features ρ_{txt} and ρ_{img} extracted from a pre-trained CLIP [36] model for train the perturbation generator. Its learning objective aims to pull $f_k(x_{\delta})$ closer to a dissimilar text embedding ρ_{txt} (w.r.t. x) while pushing it away from $f_k(x)$ and ρ_{img} . Further, GAMA analyzes attack scenarios where the surrogate model is a multi-label classifier with input scenes that usually contain multiple objects.

Attack	Venue	Generator training strategy	Analyzed input scene?
GAP [10]	CVPR2018	maximize difference of $oldsymbol{f}(oldsymbol{x}_{\delta})$ and $oldsymbol{f}(oldsymbol{x})$	single object
CDA [11]	NeurIPS2019	maximize difference of $f(x_\delta)$ - $f(x)$ and $f(x)$	single object
TAP [12]	NeurIPS2021	maximize difference of $f_k(x_\delta)$ and $f_k(x)$	single object
BIA [13]	ICLR2022	maximize difference of $oldsymbol{f}_k(oldsymbol{x}_{\pmb{\delta}})$ and $oldsymbol{f}_k(oldsymbol{x})$	single object
GAMA	Ours	contrast $m{f}_k(m{x}_\delta)$ w.r.t. $m{ ho}_{ ext{ iny txt}}, m{ ho}_{ ext{ iny img}}$ and $m{f}_k(m{x})$	single/ multiple objects

2 Related works

Adversarial attacks on classifiers. Several state-of-the-art adversarial attacks [2, 6, 8–17, 52–60] have been designed to disturb the predictions of classifiers. Broadly these approaches can be categorized into two strategies: instance (or image) specific attacks and generative model-based attacks. Instance specific attacks [2, 6, 8, 9, 14–17, 52–60] create perturbations for every image exclusively. Specifically, these perturbations are computed by querying the victim model for multiple iterations in order to eventually alter the image imperceptibly (e.g. texture level changes to image [60]) to cause its misclassification. Due to this "specific to image" strategy, their time-complexity to alter the decision of a large set of images has been shown to be extremely poor [11, 13, 31]. Furthermore, learning perturbations based on single-image generally restrict their success of misclassification only on the known models [11, 13].

To alleviate these drawbacks, a new category of attack strategies has been explored in [10-13, 61] where a generative model is adversarially trained against a surrogate victim model (in other words, treated as a discriminator) to craft perturbations on whole data distribution. This attack strategy particularly allows one to perturb multiple images simultaneously once the generative model is optimized, as well as enhances the transferability of perturbations to unseen black-box models [10, 11]. For example, Generative Adversarial Perturbations or GAP [10] and Cross-Domain Attack or CDA [11] presented a distribution-driven attack that trains a generative model for creating adversarial examples by utilizing the cross-entropy loss and relativistic cross-entropy loss [62] objective, respectively. Different from these, Transferable Adversarial Perturbations or TAP [12] and Beyond ImageNet Attack or BIA [13] presented an attack methodology to further enhance transferability of perturbations using feature separation loss functions (e.g. mean square error loss) at mid-level layers of the surrogate model. Most of these methods focused on creating transferable perturbations assuming that the surrogate model is trained in the same domain as the target victim model [13]. Further, a mid-level layer is manually selected for each architecture and is also sensitive to the dataset (shown later in Section 4). Similarly, [61] proposes to change image attributes to create semantic manipulations using their disentangled representations via generative models. Most of these generative attacks employed classifiers that operate under the regime that input images include single dominant objects. Some recent attacks [26–30] have focused on analyzing complex images which contain multiple objects, however, they are instance-driven attacks that introduce aforesaid drawbacks of transferability and time complexity. In contrast to these aforementioned works, GAMA is a generative model-based attack designed to craft imperceptible adversarial perturbations that can strongly disrupt both multi-label and single-label classifiers. Moreover, GAMA uses a novel perturbation generation strategy that employs a pre-trained CLIP model [36] based framework to craft highly effectual and transferable perturbations by leveraging multi-modal (image and text) embeddings. We summarize the differences between prior generative attacks and GAMA in Table 1.

Applications of Vision-and-Language (VL) representations. Due to their robust zero-shot performance, joint vision-and-language pre-trained models [35–39] have allowed new language-driven solutions for various downstream tasks [40–51, 63]. The differentiating attribute of using VL models [36], when compared to existing conventional image-based pre-trained models [33], is that they provide high-quality aligned visual and textual representations learnt from large-scale image-text

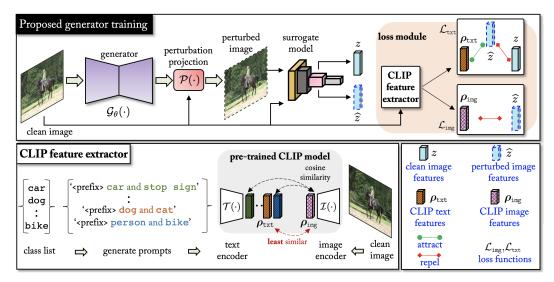


Figure 2: **Overview of GAMA.** The perturbation generator $\mathcal{G}_{\theta}(\cdot)$ crafts a perturbed image (ℓ_{∞} -budget constrained by projection operator $\mathcal{P}(\cdot)$) from the clean image as input. Next, embeddings z from clean image and \hat{z} from perturbed image are extracted from the surrogate model. A pre-trained CLIP model extracts the image embedding ρ_{img} from the clean image and the text embedding ρ_{txt} that is *least* similar to ρ_{img} (see details in Section 3.1). Finally, the loss functions \mathcal{L}_{img} and \mathcal{L}_{txt} utilize these embeddings to optimize the generator weights θ . Loss solely based on a surrogate model not shown here for simplicity. We use a *prefix*='a photo depicts' in all the text prompts following [67].

pairs. In this work, we leverage one such powerful VL framework named CLIP [36] to an adversary's advantage and show its utility in preparing a perturbation generator for formidable attacks across multiple distributions. Employing freely available pre-trained models for tasks other than what they were trained for has been common practice (*e.g.* VGG [64] models in [65, 66], CLIP for domain adaptation of generators in [46]). To the best of our knowledge, the proposed attack is the first to introduce such VL model usage to subvert classifier decisions.

3 Proposed Attack Methodology: GAMA

Problem Statement. Our goal is to train a generative model $\mathcal{G}_{\theta}(\cdot)$ (weights θ) from a training distribution of images with multiple-objects. Once θ is optimized, $\mathcal{G}_{\theta}(\cdot)$ can create perturbations on diverse types (multi-object or otherwise) of input images that can lead to misclassification on an unknown victim classifier. Suppose we have access to a *source* dataset \mathcal{D} consisting of N training samples from C number of classes, with each sample/image possibly consisting of multiple object labels, i.e., multi-label images. Each i^{th} sample in \mathcal{D} is represented as $\mathbf{x}^{(i)} \in \mathbb{R}^{H \times W \times T}$ (with height H, width W, and channels T) containing labels $\mathbf{y}^{(i)} = [y_1^{(i)}, \cdots, y_C^{(i)}] \in \mathcal{Y} \subseteq \{0, 1\}^C$. More specifically, if sample $\mathbf{x}^{(i)}$ is associated with class c, $y_c^{(i)} = 1$ indicates the existence of an object from class c in $\mathbf{x}^{(i)}$. Further, we have access to a surrogate multi-label classifier trained on \mathcal{D} denoted as $\mathbf{f}(\cdot)$ which is employed to optimize the perturbation generator $\mathcal{G}_{\theta}(\cdot)$'s weight θ . For ease of exposition, we drop the superscript i in further discussion.

3.1 Adversary Equipped with Pre-Trained CLIP

We aim to train a generator $\mathcal{G}_{\theta}(\cdot)$ that learns to create perturbations from its observations by fooling a surrogate classifier $f(\cdot)$ during its training phase. Now, as $\mathcal{G}_{\theta}(\cdot)$ learns to create perturbations δ in accordance to $f(\cdot)$, it is bounded by the features extracted from $f(\cdot)$ in order to contrast x and x_{δ} (e.g. final-layer logits in [10, 11] or mid-level features [12, 13]). In this work, we explore a case where we have access to a pre-trained vision-and-language model like CLIP that can be utilized as a loss network to train $\mathcal{G}_{\theta}(\cdot)$. Our motivation for using CLIP is to exploit its joint text and image matching property and compute two embeddings: clean image embedding extracted from the image encoder and a dissimilar text embedding extracted from the text encoder. Specifically, we aim to encode

the contextual relationships between multiple objects in the natural scene via language derivatives. We next describe **GAMA**'s method and present a novel strategy to use CLIP's model to train $\mathcal{G}_{\theta}(\cdot)$. Note that we assume each image contains two co-occurring classes for creating text prompts, mainly restricted due to computation of co-occurrence matrices of dimension $C \times C$ available for multi-label datasets. As we will see later, co-occurrence matrices allow us to discard pairs of classes that would not occur in real-world scenarios.

GAMA Overview. Before training $\mathcal{G}_{\theta}(\cdot)$, we first compute a text embedding matrix $A_{\text{txt}} = [\rho_1, \rho_2, \cdots, \rho_N] \in \mathbb{R}^{N \times K}$ with $\rho_n \in \mathbb{R}^K$ (explained in detail later) using the CLIP text encoder $\mathcal{T}(\cdot)$. Here, K is the embedding size of output from $\mathcal{T}(\cdot)$. During training $\mathcal{G}_{\theta}(\cdot)$, we start by feeding the clean image x to the CLIP image encoder $\mathcal{I}(\cdot)$ and computing an image embedding $\rho_{\text{img}} = \mathcal{I}(x) \in \mathbb{R}^K$. Next, a particular vector $\rho_{\text{txt}} \in \mathbb{R}^K$ from A_{txt} is retrieved that is least similar to ρ_{img} . Then, we feed x to $\mathcal{G}_{\theta}(\cdot)$ and create x_{δ} while ensuring it to be under given perturbation ℓ_{∞} budget ϵ using the perturbation projection operator $\mathcal{P}(\cdot)$. These clean and perturbed images are then fed to the surrogate classifier $f(\cdot)$ to extract K-dimensional embeddings at specific kth layer, denoted by $f_k(x)$ and $f_k(x_{\delta})$ respectively. Finally, the aforementioned quadruplet embeddings $(\rho_{\text{txt}}, \rho_{\text{img}}, f_k(x), f_k(x_{\delta}))$ are used to compute a contrastive learning based CLIP text embedding-guided loss $\mathcal{L}_{\text{txt}}(\rho_{\text{txt}}, f_k(x), f_k(x_{\delta}))$ and a regression learning based CLIP image embedding-guided loss $\mathcal{L}_{\text{img}}(\rho_{\text{img}}, f_k(x_{\delta}))$ to compute the final objective \mathcal{L} . We also include a loss function that further maximizes the difference between $f_k(x)$ and $f_k(x_{\delta})$ solely from the surrogate classifier's perspective. This loss \mathcal{L} is minimized to update the weights of the generator θ . The whole GAMA paradigm is illustrated in Figure 2 and summarized in Algorithm 1. The details of loss objectives \mathcal{L}_{img} and \mathcal{L}_{txt} (with text embedding matrix A_{txt}) are discussed next.

CLIP text embedding-guided loss (\mathcal{L}_{txt}). Let $z=f_k(x)$ and $\widehat{z}=f_k(x_\delta)$. The CLIP framework inherently learns the text and vision embedding association via a contrastive learning regime [36, 68], constraining the feature embeddings of the input image and its counterpart language description to be as similar as possible. Different from CLIP's image embedding ρ_{img} , CLIP's text embedding ρ_{txt} allows us to look beyond the pixel-based features. More specifically, CLIP's vision-and-language aligning ability allows us to utilize *text* features to craft transferable image perturbations. Hence, we can optimize $\mathcal{G}_{\theta}(\cdot)$ to create perturbed images x_δ that do not follow the same text embedding alignment as their clean image counterpart x. In order to cause this text misalignment, we create a triplet of embeddings where the anchor \widehat{z} is pushed away from z while pulling it closer to a text embedding ρ_{txt} that is least associated or similar to a clean image x. To compute this triplet, the following two steps are performed.

- Before training, compute A_{txt} . The goal is create a dictionary or matrix of text embeddings which can be utilized to retrieve ρ_{txt} during optimization of $\mathcal{G}_{\theta}(\cdot)$. Firstly, we generate language derivatives or text prompts using classes of source distribution. This means we only need to know all the available C classes in \mathcal{D} but not their specific association with x. Secondly, with assumption that each clean image x is associated with two classes, we can generate C^2 text prompts and create a matrix A_{txt} of size $C^2 \times K$. For example, if classes 'cat', 'dog', 'person' and 'boat' exist in D, then one can create text prompts such as "a photo depicts cat and dog" or "a photo depicts person and boat" (see Figure 1 for 10 random examples extracted from CLIP's 'ViT-B/16' model using Pascal-VOC's classes). Here, the part of the text prompt underlined is a recommended 'prefix' common to all text prompts as suggested in [67]. However, such A_{txt} can contain embeddings from prompts that are generated from classes that do not exist in real life. To circumvent this, we utilize an object co-occurrence matrix $\mathcal{O} \in \mathbb{R}^{C \times C}$ (a binary matrix) to estimate the co-occurrence relationships between classes. Computed from the training data set containing C classes, O is first initialized with a matrix containing only zeros. Then, an element \mathcal{O}_{ij} (ith row and jth column of \mathcal{O}) is set to 1 if objects from classes y_i and y_j appear together at least in one image. Computing such co-occurrence information is a common practice in multi-object downstream problems [26, 27, 69– 72]. We use \mathcal{O} provided by [69]. Using such a co-occurrence matrix, we only create text prompts from a pair of classes that occur together according to \mathcal{O} . This leads to a text embedding matrix of size A_{txt} of size $\|\mathcal{O}\|_0 \times K$ where $\|\mathcal{O}\|_0$ denotes total non-zero elements.
- During training, compute ρ_{txt} . CLIP's training objective allows it to push the embeddings of associated image-text pairs closer compared to non-matched pairs. We leverage this property to compute the least similar text embedding ρ_{txt} w.r.t. image embedding ρ_{img} . During each training

epoch, we randomly sample B candidates $[\rho_1, \rho_2, \cdots, \rho_B]$ from A_{txt} and estimate ρ_{txt} as follows:

$$\rho_{\text{txt}} = \min[\text{cs}(\rho_{\text{img}}, \rho_1), \text{cs}(\rho_{\text{img}}, \rho_2), \cdots, \text{cs}(\rho_{\text{img}}, \rho_B)]$$
 (1)

Here, $cs(\cdot)$ denotes cosine similarity. Next, we force \hat{z} to align with ρ_{txt} while misaligning with z. This is implemented as contrastive learning [73, 74] objective as follows.

$$\mathcal{L}_{\text{txt}} = \min_{\boldsymbol{\theta}} \ ^{1}/\kappa \left(\|\widehat{\boldsymbol{z}} - \boldsymbol{\rho}_{\text{txt}}\|_{2}^{2} + \left[\alpha - \|\widehat{\boldsymbol{z}} - \boldsymbol{z}\|_{2}\right]_{+} \right)$$
(2)

where $\alpha > 0$ is the desired margin between clean and perturbed image embedding, and $[v]_+ = \max(0, v)$. \mathcal{L}_{txt} pulls away embeddings of \boldsymbol{x} and \boldsymbol{x}_{δ} by making them keep a margin α while pushing dissimilar embeddings $\hat{\boldsymbol{z}}$ and $\boldsymbol{\rho}_{\text{txt}}$ closer than the given margin.

CLIP image embedding-guided loss (\mathcal{L}_{img}). Due to CLIP's learning on ~400 million internet retrieved images from diverse categories and its consequential strong zero-shot image recognition performance over different distributions [36, 41], we argue that its image encoder $\mathcal{I}(\cdot)$ outputs an embedding that has captured attributes of input image with distinct generalized visual features. **GAMA** leverages this to our advantage, and maximizes the difference between \hat{z} and CLIP's image encoder's embedding for clean image ρ_{img} . The aim of such an objective is to increase the transferability strength of $\mathcal{G}_{\theta}(\cdot)$ perturbations using the generalized features computed from $\mathcal{I}(\cdot)$. This is envisioned using a regression learning based loss described as follows:

$$\mathcal{L}_{img} = \min_{\boldsymbol{\theta}} - \left(\frac{1}{K} \| \boldsymbol{\rho}_{img} - \widehat{\boldsymbol{z}} \|_{2}^{2} \right)$$
 (3)

Final Learning Objective (\mathcal{L}). Loss functions \mathcal{L}_{img} and \mathcal{L}_{tax} are finally added to a surrogate model loss \mathcal{L}_{surr} that minimizes the cosine similarity of z and \hat{z} [13]. Choice of layer k is dependent on feature outputs of the CLIP model employed. All embeddings are normalized before computing the loss functions.

$$\mathcal{L} = \min_{\mathbf{A}} \ \left(\mathcal{L}_{\text{surr}} + \mathcal{L}_{\text{img}} + \mathcal{L}_{\text{txt}} \right) \tag{4}$$

Overall, $\mathcal{L}_{\text{surr}}$ maximizes the difference between x and x_{δ} from surrogate $f(\cdot)$'s perspective, while \mathcal{L}_{ing} and \mathcal{L}_{txt} enhance its transferability using CLIP's perspective.

Attack evaluation. We assume that the attacker has no knowledge of victim classifier $g(\cdot)$ and its data distribution \mathcal{D}_t . Further, there is a perturbation budget of ϵ defined by an ℓ_∞ norm. To launch an attack, we input a clean image x_t from target dataset \mathcal{D}_t to optimized $\mathcal{G}_{\theta}(\cdot)$ and craft imperceptible perturbations δ_t in order to alter the decision space of the target victim classifier $g(\cdot)$ (pre-trained on \mathcal{D}_t). Mathematically, this can be represented as $y_t \neq \hat{y}_t$ where, $y_t = g(x_t)$ and $\hat{y}_t = g(x_t + \delta_t)$ with $\|\delta_t\|_\infty \leq \epsilon$. We can cause following attack scenarios after training $\mathcal{G}_{\theta}(\cdot)$ against $f(\cdot)$ on \mathcal{D} :

- Scenario 1: an attack termed white-box if $f(\cdot) = g(\cdot)$ and $\mathcal{D} = \mathcal{D}_t$
- Scenario 2: an attack termed black-box if either $f(\cdot) \neq g(\cdot)$ or $\mathcal{D} \neq \mathcal{D}_t$

A real-world attack is generally modeled by *Scenario 2* as an adversary would not have the knowledge of victim model $g(\cdot)$'s architecture, its training data distribution \mathcal{D}_t and the task it performs e.g. single-label classification, multi-label classification, or object detection, etc. The perturbations that make an attack successful in *Scenario 2* should be highly transferable.

4 Experiments

In this section, we analyze the strength of **GAMA** under diverse practical attack settings. We also perform an ablation analysis of **GAMA**, test the attack robustness against various defenses ([76, 77], median blurring, context-consistency check), as well performance of attacks on different architecture designs. *Note that* we provide more black-box attack results in the supplementary material.

Baselines. As there are no prior works for generative attacks that learn on multi-object scenes using multi-label classifiers, we define our baselines by adapting existing state-of-the-art generative attacks summarized in Table 1. Specifically, the cross-entropy loss in GAP [10] and CDA [11] is replaced with binary cross-entropy loss to handle the prediction of multiple labels during training.

Training Details. We use the multi-label datasets PASCAL-VOC [78] and MS-COCO [79] to train

Algorithm 1: GAMA pseudo-code

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Input: distribution \mathcal{D}, batch size B, perturbation \ell_{\infty} bound \epsilon
Input: surrogate classifier f(\cdot), CLIP-encoders for text \mathcal{T}(\cdot) and image \mathcal{I}(\cdot)
Output: optimized perturbation generator \mathcal{G}_{\theta}(\cdot)'s weights \theta

1 Randomly initialize \theta. Load (as well as freeze) f(\cdot), \mathcal{T}(\cdot) and \mathcal{I}(\cdot) with respective pre-trained weights
2 Create text embeddings matrix A_{\text{txt}} from \mathcal{T}(\cdot) as described in Section 3.1
3 repeat
4 | Input x to \mathcal{I}(\cdot) and get \rho_{\text{img}}
5 | Randomly sample B vectors from A_{\text{txt}} and get least similar text embedding \rho_{\text{txt}} w.r.t. \rho_{\text{img}}
6 | Input clean image x (from \mathcal{D}) to f(\cdot) and compute mid-level embedding f_k(x)
7 | Input x to \mathcal{G}_{\theta}(\cdot) and project it within bound \epsilon using \mathcal{P}(\cdot) to obtain x_{\delta}
8 | Input x_{\delta} to f(\cdot) and compute mid-level embedding f_k(x_{\delta})
9 | Compute loss \mathcal{L} by Equation (4) and minimize it to update \theta using Adam [75]
10 until convergence
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generators for the baselines and our method. Unless otherwise stated, perturbation budget is set to $\ell_{\infty} \leq 10$ for all experiments. We chose the following surrogate models $f(\cdot)$ (Pascal-VOC or MS-COCO pre-trained multi-label classifiers): ResNet152 (Res152) [80], DenseNet169 (Den169) [81], and VGG19 [64]. For the CLIP model, we use the 'ViT-B/16' framework [36]. See supplementary material for more training details.

Inference Metrics. We measure attack performances on multi-label classifiers using hamming score (%) defined in [82, 83]. For evaluations on single-label classifiers and object detectors, we use top-1 accuracy (%) and bbox_mAP_50 \in [0, 1] metric, respectively. A lower score indicates better attack. Best results are in **bold**. For reference, accuracy on clean images is provided as 'No Attack'.

4.1 Results and Analysis

All trained perturbation generators (trained only on multi-label datasets) are extensively evaluated under following victim model settings.

- White-box and black-box (multi-label classification, different model than $f(\cdot)$): We evaluate the attacks in white-box and black-box settings on six victim multi-label classifiers (VGG16, VGG19, ResNet50 (Res50), Res152, Den169, and DenseNet121 (Den121)) in Table 2 and Table 3 (white-box attacks are marked with cell color). We outperform all baselines in the majority of cases, with an average absolute difference (w.r.t. closest method) of \sim 13 percentage points (pp) for Pascal-VOC and \sim 4.46pp for MS-COCO.
- Black-box (single-label classification): We evaluate the attacks in a black-box setting with various single-label classifiers for CIFAR10/100 [84] (coarse-grained tasks [13]), CUB-200-2011 (CUB) [32], Stanford Cars (Car) [85], and FGVC Aircrafts (Air) [86] (fine-grained tasks [13]) in Table 6, and ImageNet [87] (50K validation set) in Table 4 and Table 5. Following [13], the victim models of coarse-grained tasks are taken from [88], fine-grained task models (Res50, SENet154 (SeNet), and SE-ResNet101 (se-Res101) [89]) from [90], and six ImageNet models from [33]. Here, we beat our closest baseline in all cases by ~13.33pp for Pascal-VOC and ~5.83pp for MS-COCO on six ImageNet models. Note that the ImageNet results also demonstrate the drop in performance of TAP [12] and BIA [13] attacks that show close to 0% top-1 accuracy when $\mathcal{G}_{\theta}(\cdot)$ is trained on ImageNet on the attacker side [12, 13]. We hypothesize that such a drop in performance is due to sensitivity to the dataset of the manually selected mid-level layer of $f(\cdot)$ used by the attacker. We observe a similar trend when attacking non-ImageNet distributions as suggested by BIA [13] in coarse and fine-grained tasks in Table 6. In this case, GAMA beats the prior attacks by average ~13.33pp when $\mathcal{G}_{\theta}(\cdot)$ is trained with Pascal-VOC.
- Black-box (Object detection): We also evaluate a difficult black-box attack with state-of-the-art MS-COCO object detectors (Faster RCNN with Res50 backbone (FRCN) [91], RetinaNet with Res50 backbone (RNet) [92], DEtection TRansformer (DETR) [93], and Deformable DETR (D²ETR) [94]) in Table 7, available from [95]. It can be observed that **GAMA** outperforms its competitors when $\mathcal{G}_{\theta}(\cdot)$ is trained with Pascal-VOC.

Table 2: Pascal-VOC \rightarrow Pascal-VOC Table 3: MS-COCO \rightarrow MS-COCO Method VGG16 VGG19 Res50 Res152 Den169 Den121 Method VGG16 VGG19 Res50 Res152 Den169 Den121 No Attack 82.51 83.18 80.52 83.12 83.74 83.07 82.69 No Attack 65.80 66.48 65.64 67.95 67.59 66.39 66.64 53.45 GAP [10] 19.64 16.60 72.95 76.24 66.50 GAP [10] 8.31 10.61 39.49 48.00 41.00 38.12 30.92 26.16 24.77 CDA [11] 20.52 61.40 65.67 70.33 62.67 51.12 CDA [11] 6.57 8.57 37.38 43.56 38.41 35.59 28.34 TAP [12] 19.26 66.95 66.95 68.65 64.51 51.84 TAP [12] 3.45 25.77 20.05 21.15 17.68 6.14 29.56 BIA [12.53 14.00 BIA [4.01 30.76 GAMA 6.11 5.89 41.17 45.57 53.11 44.58 32.73 GAMA 3.59 3.75 27.13 30.43 24.60 18.54 GAP [10] 56.93 56.20 65.58 72.26 69.54 65.95 GAP [10] 42.59 45.41 53.75 54.18 52.54 49.94 CDA [11] 41.07 47.60 53.84 47.22 67.50 59.65 52.81 CDA [11] 30.16 37.79 42.83 45.13 49.24 44.93 41.68 58.24 49.74 71.55 67.75 59.56 54.35 TAP [12] 52.92 56.52 53.61 64.56 TAP [12] 24.34 25.94 29.40 24.13 35.58 33.06 28.74 BIA [13] 45.34 51.98 50.27 61.05 22.73 36.06 32.41 BIA [13] 22.76 28.64 22.16 24.52 29.85 **27.31** 33.99 **27.42** 33.43 GAMA 33.42 39.42 32.39 20.46 49.76 49.54 37.49 GAMA 30.62 23.04 31.30 32.77 GAP [10] 59.55 62.09 68.60 72.81 76.09 68.64 GAP [10] 38.15 40.84 24.98 CDA [11] 52.28 53.75 59.65 67.23 69.60 67.37 61.64 CDA [11] 39.39 41.19 46.34 50.82 43.42 44.63 44.29

62.57 58.85

52.66

54.01

58.97 55.77

49.19

Table 4: Pascal-VOC \rightarrow ImageNet

48.83

58.48 48.52

TAP [12]

BIA [13]

58.55 58.14 63.42 53.77 56.15 63.33

Table 5: MS-COCO \rightarrow ImageNet

15.73 13.57

40.22

20.90 24.69 26.72

28.82

23.01 27.01

TAP [12]

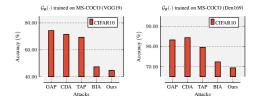
BIA [13]

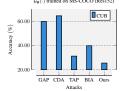
27.73 32.75 29.59 34.65

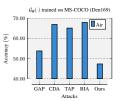
$f(\cdot)$	Method	VGG16	VGG19	Res50	Res152	Den121	Den169	Average	£()	Method	VGG16	VGG19	Res50	Res152	Den121	Den169	Average
J (*)	No Attack	70.15	70.94	74.60	77.34	74.22	75.74	73.83	$f(\cdot)$	No Attack	70.15	70.94	74.60	77.34	74.22	75.74	73.83
	GAP [10]	24.44	21.64	63.65	67.84	63.09	65.47	51.02		GAP [10]	15.55	15.06	49.50	56.07	47.65	53.49	39.55
19	CDA [11]	13.83	11.99	47.32	53.92	46.81	52.24	37.68	19	CDA [11]	13.05	12.59	46.77	52.58	43.55	50.03	36.42
NGG.	TAP [12]	06.70	07.28	50.94	57.36	47.68	53.43	37.23	99	TAP [12]	02.33	02.93	19.28	35.20	19.45	23.42	17.10
>	BIA [13]	04.20	04.73	48.63	57.65	45.94	53.37	35.75	۶	BIA [13]	02.51	03.09	29.72	43.98	30.37	36.53	24.36
	GAMA	03.07	03.41	22.32	34.04	24.51	30.35	19.61		GAMA	02.01	02.57	19.99	35.21	26.26	32.98	19.83
	GAP [10]	34.04	34.67	52.85	61.61	58.09	59.24	50.08		GAP [10]	22.98	24.41	32.74	32.35	39.56	44.11	32.69
22	CDA [11]	29.33	34.88	44.28	46.05	46.91	51.62	42.17	es152	CDA [11]	35.69	39.40	51.75	54.84	53.55	58.92	49.02
Rest	TAP [12]	33.25	37.53	41.18	42.14	50.96	56.45	43.58		TAP [12]	13.29	12.46	23.44	21.11	35.14	41.29	24.45
~	BIA [13]	22.82	27.44	34.66	36.74	45.48	51.26	36.40	×	BIA [13]	14.98	14.98	25.40	21.98	34.11	37.62	24.84
	GAMA	16.43	17.02	21.93	17.07	31.63	30.57	22.44		GAMA	17.94	19.16	24.57	17.24	29.67	30.57	23.19
	GAP [10]	42.79	45.01	57.79	65.42	63.02	65.31	56.55		GAP [10]	30.50	30.79	40.82	51.12	41.03	37.46	38.62
8	CDA [11]	36.67	37.51	52.30	61.78	54.68	57.85	50.13	69	CDA [11]	35.75	36.69	50.45	57.43	51.23	52.44	47.33
Den169	TAP [12]	28.92	30.19	38.36	50.92	45.88	40.78	39.17	EII	TAP [12]	21.45	26.45	27.30	45.76	30.83	25.34	29.52
ă	BIA [13]	26.12	27.42	37.06	51.30	40.63	37.56	36.68	Ã	BIA [13]	20.91	25.01	37.16	50.65	34.71	23.38	31.97
	GAMA	18.16	20.93	28.04	41.85	26.11	21.67	26.12		GAMA	06.94	10.63	10.97	21.60	13.92	08.22	12.04

Table 6: Pascal-VOC → Coarse (CIFAR10/100) and Fine-grained (CUB, Car, Air) tasks

	Method	CIFAR10	CIFAR100	CUB	CUB	CUB	Car	Car	Car	Air	Air	Air	Avaraga
$oldsymbol{f}(\cdot)$	Methou	[88]	[88]	Res50	SeNet	se-Res101	Res50	SeNet	se-Res101	Res50	SeNet	se-Res101	Average
	No Attack	93.79	74.28	87.35	86.81	86.54	94.35	93.36	92.97	92.23	92.05	91.90	89.60
	GAP [10]	73.58	39.10	78.94	79.79	80.41	82.33	85.71	87.19	81.19	81.82	79.99	77.27
19	CDA [11]	70.40	44.68	54.76	64.74	68.99	70.87	75.64	81.78	42.87	74.38	77.20	66.02
VGG19	TAP [12]	73.18	35.41	72.42	74.39	73.94	78.40	77.08	84.59	78.91	78.94	75.52	72.98
×	BIA [13]	59.82	27.84	68.31	65.64	73.70	75.61	67.90	81.83	75.88	66.13	76.75	67.22
	GAMA	53.85	24.94	53.52	62.19	66.93	60.08	69.11	78.95	45.51	43.71	63.37	56.56
	GAP [10]	69.80	41.06	64.96	80.01	81.77	72.62	86.02	87.53	84.28	84.64	85.48	76.19
Res152	CDA [11]	77.60	49.43	65.38	71.52	71.63	73.04	76.52	79.54	66.61	72.73	60.10	69.46
	TAP [12]	70.92	38.39	48.60	73.20	76.10	69.02	86.62	81.94	74.65	80.68	83.20	71.21
≊	BIA [13]	67.54	36.43	51.17	70.64	71.63	70.85	82.85	80.21	72.94	80.20	81.01	69.58
	GAMA	69.53	38.57	27.67	64.77	64.79	59.18	74.27	80.50	59.71	69.10	65.77	61.26
	GAP [10]	83.25	56.08	64.70	78.15	76.77	80.65	85.95	86.74	81.79	84.40	85.03	78.50
69	CDA [11]	84.34	58.03	61.75	73.40	71.75	84.21	85.57	84.58	78.97	82.24	78.22	76.64
Den169	TAP [12]	86.77	58.67	54.04	64.45	62.31	76.13	81.35	82.91	34.02	76.66	76.75	68.55
ă	BIA [13]	85.20	55.21	47.95	58.18	56.02	55.88	73.65	72.30	62.47	72.97	70.39	64.56
	GAMA	78.27	46.80	33.57	57.44	63.24	49.31	70.65	75.14	48.48	62.95	70.15	59.63







(a) Custom architecture (both from [88])

(b) Standard architecture (left: Res50, right: se-Res101)

Figure 3: **Transferability on types of victim model designs.** GAMA shows potent transferring attacks to victim networks that were custom designed (Figure 3(a)) and that contain standard blocks like Residual blocks [80] (Figure 3(b)).

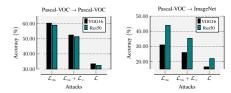


Figure 4: Ablation analysis of loss objective. We analyze the contribution due to the introduction of each loss function \mathcal{L}_{img} and \mathcal{L}_{txt} towards the final objective \mathcal{L} , both in same distribution (*left*) and different distribution (*right*). The surrogate model is Res 152.

Table 7: Pascal-VOC → MS-COCO Object Detection task

$f(\cdot)$	Method	FRCN	RNet	DETR	$\mathbf{D}^2\mathbf{ETR}$	Average
J (·)	No Attack	0.582	0.554	0.607	0.633	0.594
	GAP [10]	0.424	0.404	0.360	0.410	0.399
19	CDA [11]	0.276	0.250	0.208	0.244	0.244
VGG19	TAP [12]	0.384	0.340	0.275	0.320	0.329
>	BIA [13]	0.347	0.318	0.253	0.281	0.299
	GAMA	0.234	0.207	0.117	0.122	0.170
	GAP [10]	0.389	0.362	0.363	0.408	0.380
25	CDA [11]	0.305	0.274	0.256	0.281	0.279
Res152	TAP [12]	0.400	0.348	0.288	0.350	0.346
~	BIA [13]	0.321	0.275	0.205	0.256	0.264
	GAMA	0.172	0.138	0.080	0.095	0.121

Performance on Type of Architectures. In Figure 3, we further study the transferability of attacks depending on the type of victim architecture: *standard* which follow the standard modules like Residual blocks [80] to build the classifier, and *custom* where the victim classifier doesn't adhere to a specific pattern of network modules. In both cases, **GAMA** consistently maintains better attack rates than other attacks. This shows convincing transferability of perturbations crafted from **GAMA**'s $\mathcal{G}_{\theta}(\cdot)$ under diverse black-box settings. We provide additional results in the supplementary material.

Robustness of Attacks against Defenses. To analyze the robustness of all the methods, we launch misclassification attacks ($\mathcal{G}_{\theta}(\cdot)$ trained on MS-COCO with the surrogate model as Den169) when the victim deploys input processing based defense such as median blur with window size as 3×3 , and Neural Representation purifier (NRP) [76] on three ImageNet models (VGG16, Res152, Den169). From Table 8(a) and Table 8(b), we can observe that the attack success of **GAMA** is better than prior methods even when the victim pre-processes the perturbed image before making decisions. In Figure 8(c), we observe that Projected Gradient Descent (PGD) [77] assisted Res50 is difficult to break with **GAMA** performing slightly better than other methods. Finally, motivated by [96], we analyze an output processing defense scenario where the victim can check the context consistency of predicted labels on perturbed images using the co-occurrence matrix \mathcal{O} . In particular, if a perturbed image is misclassified showing co-occurrence of labels not present in \mathcal{O} , we term this as a detected attack. Otherwise, we call it an undetected attack. To measure this performance, we first compute the co-occurrence matrix \mathcal{O}_{δ} by perturbing all the test set images and estimate its precision w.r.t. ground-truth \mathcal{O} . To check for attacks that have high precision value p and high misclassification rate, we calculate a 'context score' (higher is better) that is a harmonic mean of p and misclassification rate (1-accuracy). We show the attack performance against this context consistency check in Figure 8(d) for both Pascal-VOC and MS-COCO averaged over all surrogate models under white-box attacks. Clearly, **GAMA** presents itself as the best *undetected* attack compared to prior works.

Ablation Analysis. We dissect the contribution of each loss function in our proposed loss objective of Equation (4) in Figure 4 where $\mathcal{G}_{\theta}(\cdot)$ is trained with Pascal-VOC with Res152 surrogate model. We analyze the attack transferability to different victim models (VGG16, Res50). We observe that the introduction of each loss objective (*left* to *right*) increases the strength of the attack both in the same distribution (Pascal-VOC) as the attacker and in the unknown distribution (ImageNet) on both victim classifiers. Finally, we visualize some perturbed image examples crafted by **GAMA** in Figure 5.

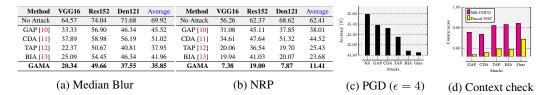


Table 8: Robustness Analysis against various defenses. Our proposed attack GAMA consistently shows better performances compared to baselines in scenarios where the victim deploys attack defenses.



Figure 5: **Qualitative Examples.** We show some clean (*top*) and perturbed (*bottom*) images from **GAMA**. Best viewed in color/zoomed.

5 Conclusion

In this paper, we propose a new generative attack **GAMA** that can learn to create perturbations against multi-object scenes. For the first time in generative attack literature, we show the utility of a pretrained vision-and-language model CLIP to optimize effectual perturbation generators. Specifically, CLIP's joint text and image aligning property allow us to use natural language semantics in order to handle the multi-object semantics in the input scene to be perturbed. To demonstrate **GAMA**'s efficiency, we perform extensive experiments that show state-of-the-art attacks across a wide range of black-box victim models (multi-label/single-label classifiers, and object detectors). We also evaluate the robustness of our attacks against various defense mechanisms. As part of our future works, we will explore more complex methodologies to employ vision-language models both for adversarial attacks and defense systems.

6 Limitations and Societal Impacts

Limitations. The pre-trained CLIP model 'ViT-B16' outputs a 512-dimensional embedding that restricts us to compare the features extracted from the surrogate model in our losses of the same size. Another limitation of our method is the use of co-occurrence matrices to extract the right pair of classes that exist together in real-world scenes. In this paper, we make an assumption that text prompts are created using two classes that exist together according to the co-occurrence matrix of size $C \times C$ (for C classes in the data distribution). However, we can also use a triplet of classes that exist together in an input scene which would need a co-occurrence tensor of size $C \times C \times C$. Computing such a huge tensor would be tedious to cover all the images provided in the train set (usually in the order of thousands).

Societal Impacts. Adversarial attacks are designed with the sole goal to subvert machine decisions by any means available. Our attack approach shows one such method where a benign open-sourced vision-language model can be utilized by an attacker to create potent perturbations. This demonstrates the need for the victim to prepare for constantly evolving attacks that may cause major harm in real-world systems (*e.g.* person re-identification [97]). We believe that our work can help further propagate research into designing efficient and robust models that do not break down to attacks built upon multi-modal (in our case, text-image) features. Future researchers should also be aware of video generative models [98, 99] that can be used to create adversarial attacks for ubiquitous video classifiers built on the success of vision-language models.

Acknowledgement. This material is based upon work supported by the Defense Advanced Research Projects Agency (DARPA) under Agreement No. HR00112090096. Approved for public release; distribution is unlimited.

Supplementary material for "GAMA: Generative Adversarial Multi-Object Scene Attacks"

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We present additional analysis of GAMA in the following sections to investigate its attack capabilities under various settings, including black-box embedding visualizations w.r.t. TAP [12], impact of different types of CLIP models, performance with ensemble of surrogate models. We also demonstrate GAMA's transfer attack strength in comparison to prior methods under difficult black-box transfer attacks including in different multi-label distribution, object detection, and robustness of perturbations when victim uses defense mechanisms to minimize classifier performance deterioration. All experiments are done with perturbation budget $\ell_{\infty} \leq 10$.

A Additional Analysis on GAMA

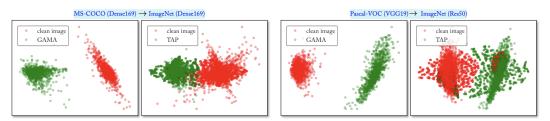


Figure 1: **Embedding visualization. GAMA** uses the CLIP extracted text and image embeddings to craft highly transferable adversarial examples. This can be seen in above embedding visualizations where **GAMA**'s perturbed images lie convincingly farther away from the clean images with better margins compared to TAP [12]. Left and right plots show perturbed image embeddings (both on random 1000 ImageNet images) when $\mathcal{G}_{\theta}(\cdot)$ is trained with MS-COCO and Pascal-VOC respectively. Surrogate and victim models are given in parenthesis.

Black-box Setting Embedding Visualization. To demonstrate the phenomenon that GAMA learns to create potent perturbations compared to prior works, we perform Principal Components Analysis (PCA) of perturbed images extracted from GAMA and TAP [12] in Figure 1 when the $\mathcal{G}_{\theta}(\cdot)$ is trained with MS-COCO and Pascal-VOC. We choose PCA visualization as it preserves the global differences of high dimensional data in low dimensional regimes [100, 101]. Clearly, in an unseen distribution (ImageNet [87]), features obtained from GAMA's perturbed images significantly differ from those of clean images in comparison to TAP [12].

Impact of Different CLIP models. We analyze the impact of different open-source pre-trained CLIP models provided by Open-AI in Table 1 (surrogate model as Res152), both for the same domain and different domain transfer attacks. We observe that the CLIP frameworks with vision encoders with image transformers [102] (ViT-L/14, ViT-B/32, ViT-B/16) as their backbone perform better in our proposed setting than those with the vision encoders as convolutional networks (RN50, RN101). We attribute this to the effectual representation capability of transformers [102].

Table 1: Impact of CLIP model on GAMA

(a) Pascal-VOC \rightarrow Pascal-VOC

(b) Pascal-VOC \rightarrow ImageNet

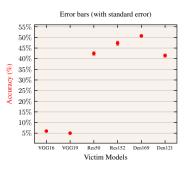
	VGG16	VGG19	Res50	Res152	Den169	Den121		VGG16	VGG19	Res50	Res152	Den121	Den169
No Attack	82.51	83.18	80.52	83.12	83.74	83.07	No Attack	70.15	70.94	74.60	77.34	74.22	75.74
RN50	8.83	15.25	64.37	67.24	70.53	69.13	RN50	3.13	2.06	46.25	52.01	49.33	45.91
RN101	21.74	9.45	60.56	68.53	67.01	66.17	RN101	2.93	2.41	42.73	56.16	46.67	45.97
ViT-L/14	43.35	49.89	45.08	43.30	54.23	51.53	ViT-L/14	16.63	20.04	26.41	23.18	31.10	32.53
ViT-B/32	10.58	15.18	67.07	70.34	69.14	68.02	ViT-B/32	3.90	2.81	49.61	54.41	48.02	46.41
ViT-B/16	6.12	5.89	41.17	45.57	53.11	44.58	ViT-B/16	3.07	3.41	22.32	34.04	24.51	30.35

Random Runs with Error Bars. We report the mean, and standard error in Table 2 along with the error bar plot (with mean and standard error). We can observe that **GAMA** maintains its performance with random seed values over various runs. Here, $\mathcal{G}_{\theta}(\cdot)$ was trained on Pascal-VOC with VGG19 as a surrogate.

Effect of Surrogate Ensemble. We analyze the results when all the surrogates (VGG19, Res152, and Den169) are employed together to train the perturbation generator $\mathcal{G}_{\theta}(\cdot)$ using **GAMA**. As can be seen in Table 3 and Table 4 (ensemble denoted as All), we do not observe any significant advantage in results when using multiple surrogates. This same observation has been noted by TAP

Table 2: Pascal-VOC \rightarrow Pascal-VOC (s.e. = standard error)

Table 2.	i ascai- v	$OC \rightarrow I a$	scar- v O	C (s.c. –	Standard	ciroi)
	VGG16	VGG19	Res50	Res152	Den169	Den121
No Attack	82.51	83.18	80.52	83.12	83.74	83.07
Run 1	5.86	5.18	45.43	50.88	52.61	43.44
Run 2	6.00	4.99	42.30	47.54	49.82	40.82
Run 3	6.08	4.88	40.71	46.64	50.31	42.73
Run 4	5.95	5.15	42.28	45.52	51.46	40.92
Run 5	6.01	4.84	41.47	45.77	49.33	39.47
mean	5.98	5.01	42.44	47.27	50.70	41.47
s.e.	0.035	0.067	0.800	0.966	0.590	0.711



[12] as well. We hypothesize that the mid-level features from multiple surrogates may not introduce complementary features to learn comparatively powerful perturbations than single classifier based surrogates.

Table 3: Ensemble comparison: VOC→VOC

$f(\cdot)$	VGG16	VGG19	Res50	Res152	Den169	Den121	Average
VGG19	6.11	5.89	41.17	45.57	53.11	44.58	32.74
Res152	33.42	39.42	32.39	20.46	49.76	49.54	37.49
Den169	44.25	52.89	48.83	53.25	45.00	50.96	49.19
All	16.46	21.67	51.97	58.52	54.51	58.20	43.55

Table 4: Ensemble comparison: COCO→COCO

$f(\cdot)$	VGG16	VGG19	Res50	Res152	Den169	Den121	Average
VGG19	3.59	3.75	27.13	30.43	24.60	21.77	18.54
Res152	24.52	27.73	30.62	23.04	31.30	27.31	27.42
Den169	10.40	13.47	19.30	23.46	8.65	10.29	14.26
All	10.08	10.75	23.83	35.23	29.57	30.45	23.32

Table 5: COCO → COCO Object Detection

B Additional Results w.r.t. Baselines

Black-box Setting (Object Detection). We evaluate a black-box transfer attack with state-of-the-art MS-COCO object detectors (Faster RCNN with Res50 backbone (FRCN) [91], RetinaNet with Res50 backbone (RNet) [92], DEtection TRansformer (DETR) [93], and Deformable DETR (D²ETR) [94]) in Table 5, provided by [95]. It can be observed that **GAMA** beats the baselines when $\mathcal{G}_{\theta}(\cdot)$ is trained with MS-COCO in the majority of scenarios.

$f(\cdot)$	Method	FRCN	RNet	DETR	$\mathbf{D}^2\mathbf{ETR}$	Average
J (*)	No Attack	0.582	0.554	0.607	0.633	0.594
	GAP [10]	0.347	0.312	0.282	0.304	0.311
19	CDA [11]	0.370	0.347	0.312	0.282	0.327
VGG 19	TAP [12]	0.130	0.120	0.099	0.104	0.113
۶	BIA [13]	0.266	0.229	0.185	0.211	0.223
	GAMA	0.246	0.214	0.134	0.155	0.187
	GAP [10]	0.187	0.145	0.097	0.108	0.134
22	CDA [11]	0.322	0.301	0.237	0.274	0.283
Res152	TAP [12]	0.167	0.151	0.087	0.123	0.132
×	BIA [13]	0.152	0.144	0.101	0.121	0.129
	GAMA	0.154	0.128	0.086	0.100	0.117
	GAP [10]	0.308	0.261	0.201	0.213	0.245
69	CDA [11]	0.325	0.293	0.238	0.255	0.277
Den169	TAP [12]	0.181	0.155	0.126	0.147	0.152
Ď	BIA [13]	0.265	0.236	0.185	0.214	0.225
	GAMA	0.078	0.064	0.037	0.047	0.056

Black-box Setting (Multi-Label Classification). We

perform a black-box transfer attack on different multi-label domain than that of $\mathcal{G}_{\theta}(\cdot)$'s training set: Pascal-VOC \to MS-COCO in Table 6 and MS-COCO \to Pascal-VOC in Table 7. We outperform all baselines in the majority of cases, with an average absolute difference (w.r.t. closest method) of \sim 5 percentage points (pp) for Pascal-VOC \to MS-COCO, and \sim 13.5pp for MS-COCO \to Pascal-VOC.

Table 6: Pascal-VOC → MS-COCO

	Tac	ne o: i	ascai-	- VOC	$\rightarrow N$	15-CO	CO	
e()	Method	VGG16	VGG19	Res50	Res152	Den169	Den121	Average
$f(\cdot)$	No Attack	65.80	66.49	65.64	67.94	67.60	66.39	66.64
	GAP [10]	20.14	20.61	54.12	58.71	53.68	50.87	43.02
19	CDA [11]	18.87	15.93	41.96	48.09	47.62	42.74	35.86
VGG19	TAP [12]	7.84	10.03	45.96	48.46	43.40	39.76	32.57
۶	BIA [13]	8.56	10.06	41.32	49.07	46.03	40.60	32.60
	GAMA	2.92	3.83	23.37	28.26	22.07	17.69	16.35
	GAP [10]	32.90	33.63	46.70	54.18	53.71	51.40	45.41
22	CDA [11]	27.28	32.25	41.32	44.59	48.33	45.10	39.81
Res152	TAP [12]	31.68	37.33	36.09	36.85	47.77	45.59	39.22
~	BIA [13]	26.99	29.83	33.86	35.35	45.87	41.70	35.59
	GAMA	21.43	28.59	29.54	24.95	32.92	29.89	27.89
	GAP [10]	42.64	44.07	50.14	57.48	57.01	53.16	50.75
69	CDA [11]	39.60	39.13	44.85	53.07	50.01	47.52	45.69
Den169	TAP [12]	38.96	40.87	40.86	47.01	28.67	40.62	39.50
ă	BIA [13]	31.86	37.59	37.98	44.93	28.25	36.15	36.13
	GAMA	26.43	32.64	32.30	38.88	22.06	30.62	30.49

Table 7: MS-COCO → Pascal-VOC

Method VGC16 VGC19 Res50 Res152 Den169 Den121	
No Attack S2.51 S3.18 S0.52 S3.12 S3.74 S3.07 GAP [10] 17.07 15.01 61.14 67.17 69.30 63.04 GDA [11] 15.23 13.19 58.81 63.80 67.43 62.23 TAP [12] 15.35 12.74 42.12 42.52 48.61 42.23 BIA [13] 8.10 8.82 52.85 55.82 63.05 56.58 GAMA 6.60 7.08 44.16 49.20 57.49 52.52 GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	Average
B CDA [11] 15.23 13.19 58.81 63.80 67.43 62.23 TAP [12] 15.35 12.74 42.12 42.52 48.61 42.23 BIA [13] 8.10 8.82 52.85 55.82 63.05 56.58 GAMA 6.60 7.08 44.16 49.20 57.49 52.52 GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	82.69
Feature TAP [12] 15.35 12.74 42.12 42.52 48.61 42.23 BIA [13] 8.10 8.82 52.85 55.82 63.05 56.58 GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	48.78
GAMA 6.60 7.08 44.16 49.20 57.49 52.52 GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	46.78
GAMA 6.60 7.08 44.16 49.20 57.49 52.52 GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	33.93
GAP [10] 27.09 28.45 45.91 37.28 58.07 51.28	40.87
	36.17
CDA [11] 53.45 55.82 64.68 64.12 70.74 65.04	41.34
in CB11[11] 55:15 55:02 01:00 01:12 70:71 05:01	62.31
CDA [11] 53.45 55.82 64.68 64.12 70.74 65.04 TAP [12] 42.21 41.26 41.02 35.35 58.99 54.77	45.60
BIA [13] 37.04 36.46 44.91 36.12 54.60 49.95	43.18
GAMA 36.86 40.62 38.23 23.52 48.56 48.03	39.30
GAP [10] 48.37 46.35 58.04 60.73 52.89 57.83	54.03
CDA [11] 58.51 58.20 67.61 69.73 67.26 65.88	64.53
CDA [11] 58.51 58.20 67.61 69.73 67.26 65.88 TAP [12] 46.83 47.88 46.98 57.68 44.95 43.99 BIA [13] 42.14 49.84 54.47 62.05 48.75 50.91	48.05
BIA [13] 42.14 49.84 54.47 62.05 48.75 50.91	51.34
GAMA 19.68 20.29 23.22 33.57 26.33 16.37	23.25

Robustness Analysis. We launch misclassification attacks ($\mathcal{G}_{\theta}(\cdot)$ trained on Pascal-VOC with the surrogate model as Den169) when the victim uses input processing based defense such as median blur with window size as 3×3 (Table 8(a)), and Neural Representation purifier (NRP) [76] (Table 8(b)) on three ImageNet models (VGG16, Res152, Den169). We can observe that the attack success of

GAMA is better than prior methods even when the victim pre-processes the perturbed image. Further, in Figure 8(c), we see that Projected Gradient Descent (PGD) [77] assisted Res50 is difficult to break with **GAMA** performing slightly better than other methods.

Table 8: **Robustness Analysis against various defenses. GAMA** consistently shows better robustness in cases where victim uses attack defenses ($\mathcal{G}_{\theta}(\cdot)$ trained on Pascal-VOC). 'NA' in Figure 8(c) denotes 'No Attack'.

Evaluation of adversarial images on CLIP. We evaluated CLIP (as a "zero-shot prediction" model) on the perturbed images from Pascal-VOC and computed the top two associated labels in Figure 2 using CLIP's image-text aligning property. Specifically, we used the whole class list of Pascal-VOC and computed the top-2 associated labels both for clean and perturbed images. We can observe the perturbations change the labels associated with the clean image.



Figure 2: Evaluation of adversarial images on CLIP. Surrogate model is VGG19 trained on Pascal-VOC.

Mid-layer selection from surrogate model for training perturbation generator. Our mid-layer from surrogate model is chosen based on the embedding size of CLIP: e.g. if the embedding size of the CLIP encoder is 512, we select the layer from the surrogate model that outputs 512 dimension features. In comparison, prior state-of-the-art generative attack TAP [12] manually searches for the optimal layer from the surrogate model to train the perturbation generator (see *Limitations* in Section 4.6 in their paper [12]). In particular, finding the optimal mid-layer (that gives the best attack results) requires searching over each block of M layers (which is around an average of M=5 layers [12]) for each surrogate model. Hence to find the best layer to train a perturbation generator for a particular model, the computation time cost for such an exhaustive search will be MN GPU hours where Nis the total training time (in GPU hours) per layer. Moreover, our analysis shows this layer might not result in best attack results when the training data distribution varies and would require a manual search for all the different combinations of surrogate model and data distributions. Such a search is very time-consuming, impractical, and clearly not scalable. Finally, directly using TAP's suggested layer is not possible because the embedding size doesn't match that of CLIP, and would require us to introduce embedding modifications mechanisms (e.g. Principal Component Analysis (PCA), t-distributed stochastic neighbor embedding (t-SNE)) leading to an unreasonable increase in training time for every epoch. Note that if we do not consider the manual search of an optimal layer from the surrogate model to train the perturbation generator, then the proper baseline on ImageNet would be CDA [11]. As evident throughout our analysis, we convincingly outperform them on all settings.

C Implementation Details

We use two multi-label datasets to stimulate the scenario of multi-object scenes: Pascal-VOC (training set: trainval from 'VOC2007' and 'VOC2012', testing set: 'VOC2007_test') and MS-COCO (training set: train2017, testing set: val2017). We follow prior works [11, 13] for the generator network for $\mathcal{G}_{\theta}(\cdot)$. To stabilize the training, we replace all the ReLU [103] activation functions with Fused Leaky ReLU [104] activation function (negative slope = 0.2, scale = $\sqrt{2}$). We use a margin $\alpha = 1.0$ for the contrastive loss. All our training setup uses ViT-B/16 as the CLIP model. We use Adam optimizer [75] with a learning rate 0.0001, batch size 16, and exponential decay rates between 0.5 and 0.999. All images were resized to 224×224 . Training time was observed to be \sim 1 hr for Pascal-VOC dataset (10 epochs) and \sim 10 hrs for MS-COCO dataset (5 epochs) on one NVIDIA GeForce RTX 3090 GPUs. PyTorch is employed [105] in all code implementations.

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