Transform-Triggered Adversarial Examples

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Abstract

Deep neural networks are vulnerable to adversarial attacks, yet most existing attack research focuses on adversarial examples that induce fixed, static mispredictions. In this work, we instead exploit a dynamical adversarial manifold that depends on image transforms, which are a group of functions commonly used for data augmentation, preprocessing, and deployment. We incorporate image transforms into the adversarial optimization process, such that at test-time the same transforms, when applied under malicious conditions, act as triggers that induce diverse adversarial behaviors. For the first time, we demonstrate adversarial perturbations that exhibit metamorphic properties, producing different attack outcomes under different transforms. Our study shows that this transform-dependent vulnerability consistently exists across multiple deep network architectures (e.g., CNNs and transformers), computer vision tasks (e.g., image classification and object detection), and a broad range of commonly used image transforms. Additionally, to further motivate its real-world relevance, we extend our transform-dependent formulation to a camera-in-the-loop setting, demonstrating its effectiveness under challenging physical conditions. In summary, we introduce a novel and controllable paradigm for adversarial attack deployment, exposing a previously overlooked and structurally inherent vulnerability in deep neural networks.

1 Introduction

Adversarial attacks pose well-known threats to deep networks, and have traditionally been studied through the lens of human-visually imperceptible perturbations that can deceive models into misclassifying inputs Goodfellow et al. (2015); Kurakin et al. (2016); Wang et al. (2021); Zhu et al. (2024); Li et al. (2024); Guo et al. (2025). In real cases, inputs can undergo different transforms due to physical environment variations, such as changes in viewpoint, lighting conditions, and acquisition pipelines, with little to no perceptual change. Prior work has attempted to make adversarial examples robust to such variations by optimizing attack objectives as expectation over a distribution of transforms. For instance, the expectation over transformation (EOT) framework Athalye et al. (2018) seeks transform-invariant attacks that are robust to various image transforms. Image transforms are also utilized to enhance blackbox transferability of adversarial examples Zhu et al. (2024); Li et al. (2024); Guo et al. (2025). More recently, TPatch Zhu et al. (2023) moves beyond passively modeling naturally occurring transformations and studies controllable activation: a physical adversarial patch remains benign under normal imaging, but is activated when an attacker injects an acoustic signal into the inertial sensors of an autonomous vehicle system, inducing a specific motion blur that triggers a single attack outcome. ~~All of these existing adversarial paradigms, with or without utilizing image transforms,~~Yet across these existing paradigms: transform-invariant, transform-transferable, or trigger-activated, which are image transforms primarily used to preserve, transfer, or activate an attack, rather than to condition distinct malicious outcomes. Consequently, each optimized perturbation ultimately aims to achieve a single fixed malicious behavior on the victim model, as summarized in Tab. 1.

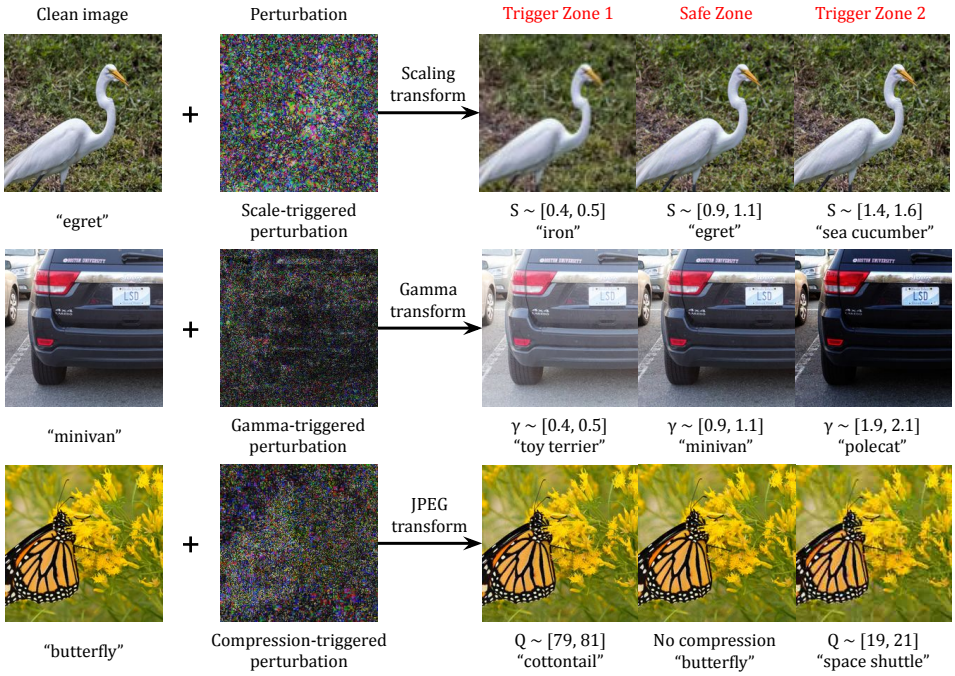

Figure 1: Visual examples of transform-triggered adversarial examples against classifiers. A single adversarial perturbation added to clean image can offer multiple attack effects for the desired image present conditions. *First row*: Targeted attacks are triggered by scaling around $0.5\times$ and $2\times$, with clean label around $1\times$. Scaled images in the first row will have different sizes after scaling, but we present their resized versions for better display. *Second row*: Attacks triggered with $\gamma \sim 0.5 \pm 0.1, 2 \pm 0.1$ in gamma correction, while providing the clean label with $\gamma \sim 1 \pm 0.1$. *Third row*: Attacks triggered with JPEG image compression quality factor $Q \sim 80 \pm 1$, 20 ± 1, while providing the clean label with no compression. *The perturbation in all examples is bounded by* $\ell_\infty \leq 8$*; the magnitude is amplified* $30\times$ *for better visualization.*

Table 1: Comparison of adversarial paradigms in terms of adversarial goals, treatment of transforms, role of transform variations, and induced behaviors. Our adversarial examples condition on transforms, which are then playing a trigger role to controllably induce multi-malicious behaviors.

Paradigm	Goal	Transform Treatment	Variation Role	Induced Behavior
Standard (Madry et al., 2018)	Deception	Not modeled	–	Single target
EOT (Athalye et al., 2018)	Invariance	Marginalized	Nuisance	Single target
Transform-transferable	Transfer	Marginalized	Nuisance	Single target
TPatch (Zhu et al., 2023)	Activation	Conditioned	Trigger	Single target
Ours	Multi-target control	Conditioned	Trigger	Multi-target

In this work, we identify a previously unexplored adversarially vulnerable manifold that consistently exists in deep networks. Within this manifold, a single post-optimized adversarial example can exhibit multiple adversarial behaviors as it undergoes different transforms at test-time. We aim to systematically characterize this dynamical property of adversarial examples, which we term Transform-Triggered Adversarial Examples. We present visual examples of these adversarial examples in Fig. 1, showcasing how a single perturbation can lead to diverse target labels conditioned on the transforms. In this paradigm, stealthiness is achieved beyond the visually imperceptible perturbation: ~~and can also achieved~~ the perturbation is optimized to keep adversarial effects ~~by optimizing adversarial effects to~~ remain "benign" under normal conditions (e.g., getting the correct label at scales near $1\times$), while targeted attacks are triggered for a desired set of transform parameters (e.g., scales below or above $0.9 - 1.1\times$). Unlike existing adversarial paradigms, which seek invariance to transforms or seek invariance to blackbox models, our work reveals a fundamentally different

threat model: a single, carefully crafted perturbation can induce a range of targeted attacks, each selectively triggered by transforms that images undergo in traditional imaging and processing pipelines. This transform-triggered behavior offers new attack dimensions beyond additive perturbations; the attack is no longer triggered solely by the presence of an added perturbation (Xiao et al., 2018) or applied transform (Zhu et al., 2023), but instead by the dual control of an additive perturbation and its associated transform.

We demonstrate that transform-triggered adversarial examples widely exist across modern deep network architectures (e.g., CNNs and transformers) for a wide range of image transforms. To further demonstrate the robustness of such attacks in the physical domain, we construct a display–camera hardware pipeline that enables the deployment, capture, and optimization of transform-triggered adversarial examples through a noisy real-world environment. This setup further supports that our transform-triggered attacks are not merely precision artifacts due to input transformations, but are desired malicious behaviors purposely introduced with our proposed formulation.

We summarize our main contributions as follows.

- We introduce transform-triggered adversarial examples, a novel class of adversarial examples that can induce multiple targeted attacks.
- We showcase the versatility and utility of the proposed adversarial examples through extensive experiments across models, computer vision tasks, and transforms. Our experiments demonstrate that a single perturbation can trigger diverse adversarial behaviors in a controllable manner.
- We demonstrate physical attacks with transform-triggered adversarial examples through a camera-in-the-loop pipeline. Our results show that the transform-triggered adversarial examples are not merely artifacts of digital precision, but that they represent a robust feature space that persists even when transforms are physically induced.

Our work questions the fundamental assumption in adversarial machine learning — that an input example is either benign or adversarially perturbed. We demonstrate that adversarial perturbations can encode metamorphic properties that exhibit as benign or adversarial based on transforms applied to the input.

2 Related Work

2.1 Adversarial attacks and defenses

Adversarial attacks were initially introduced as visually imperceptible perturbations, capable of causing false predictions in untargeted attacks or inducing desired misclassifications in targeted attacks Goodfellow et al. (2015); Moosavi-Dezfooli et al. (2017). Adversarial vulnerabilities have been found across various neural architectures (e.g., CNN, transformer), and tasks (e.g., classification, object detection) Xie et al. (2017); Mahmood et al. (2021). In conventional paradigms, a single optimized perturbation can achieve a (single) fixed attack outcome, offering limited control over adversarial effects. Likewise, existing defenses operate under the assumption that an input is either benign or adversarial, without considering dynamic adversarial behaviors Raff et al. (2019); Dong et al. (2019). A recent step toward controllable adversarial behavior is TPatch Zhu et al. (2023), a physical adversarial patch that remains benign under normal conditions but is activated when the attacker injects an acoustic signal into the camera's inertial sensors, inducing a specific motion-blur trigger. TPatch demonstrates that conditional, trigger-based activation of adversarial behavior is feasible, but operates with a single trigger and a single target behavior in a specific physical-attack scenario. In contrast, our work aims to characterize a previously overlooked structural property of deep networks: that a *single* imperceptible perturbation can encode *multiple* targeted behaviors, each conditionally activated at the post-optimization stage by ordinary image transforms encountered in standard imaging and preprocessing pipelines, without any attacker-side hardware. ~~Unlike existing work, we introduce a new level of controllability, allowing a single perturbation to induce multiple, transform-driven attack effects. This approach not only expands the adversarial landscape but also effectively bypasses common defenses.~~

2.2 Image transformation in adversarial attacks

In adversarial attack literature, image transforms have primarily been leveraged for two purposes: (i) Generating transform-invariant adversarial examples that remain effective under input corruptions and physical environment variations (EOT) Athalye et al. (2018); Kurakin et al. (2018); Lennon et al. (2021), as well as transferable adversarial examples that remain effective across models other than the surrogate used during attack generation Zou et al. (2020); Wang et al. (2021; 2023); Xie et al. (2019); Dong et al. (2019); Lin et al. (2020). This line of work seeks robust adversarial examples that provide consistent attack effects under various conditions~~.~~, and is the setting in which the EOT formulation underlying our optimization (and TPatch's) was originally introduced. (ii) Generating adversarial examples via simple geometric transforms Pei et al. (2017); Chen et al. (2020); Zhu et al. (2024); Li et al. (2024). This line of work optimizes over transformation parameter, so that a slightly transformed image causes misprediction. While these methods provide new attacks against deep networks through simple image transforms, the attacks are limited to certain transformation parameters, may change the image semantic content Xiao et al. (2018), or may cause deviation from natural image color distribution Chen et al. (2020). In contrast, our work exploits the more general and diverse image transformations, covering spatial, photometric, and compression transformations to craft adversarial perturbations capable of dynamically altering their effects based on the transform trigger applied.

3 Methodology

We study a class of adversarial examples whose malicious behavior is conditionally activated by image transforms. Unlike conventional adversarial examples that induce a fixed misprediction, the adversarial effect here is *triggered* by specific transform parameters, while remaining benign under others.

3.1 Problem statement

Suppose f denotes a trained model, $x \in \mathbb{R}^{H\times W\times 3}$ an input image with ground-truth label y, and δ an additive perturbation constrained within an ℓ_p-norm ball $\|\delta\|_p \le \varepsilon$. We denote $\tau(\cdot;\theta)$ as an image transform (e.g., rotation, scaling, or perspective), with $\theta \in \Theta$ as the transform parameters. We further assume (and require) that applying such transforms to clean images should preserve semantic content and output of a properly trained model; that is,

$$f(\tau(x;\theta)) \approx y, \quad \forall \theta \in \Theta. \tag{1}$$

Importantly, Eq. 1 defines the scope of our work: Θ is chosen to keep clean transformed images semantically recognizable and to avoid transform-induced collapse in clean accuracy, as summarized in Tab. 12. Thus, observed failures are primarily attributable to the adversarial perturbation rather than the transform alone.

Definition 1 (Transform-Triggered Adversarial Example)**.** Given a model f, an input x with label y, and a transform $\tau(\cdot;\theta)$, a perturbation δ is *transform-triggered* if we have two disjoint parameter sets Θ_{safe} and Θ_{trigger} such that

$$f\big(\tau(x+\delta;\theta)\big) = \begin{cases} y, & \forall\, \theta \in \Theta_{\text{safe}}, \\ y^\star, & \forall\, \theta \in \Theta_{\text{trigger}},\ y^\star \neq y. \end{cases}$$

This definition formalizes adversarial perturbations whose effect is dormant under normal conditions but activated when specific transform triggers are applied. Our main objective is to find δ that deceive the model to predict desired target labels $y^\star$ under different transform triggers in digital and physical attacks.

3.2 Proposed method

Optimization objective. To synthesize desired perturbations for digital attacks, we incorporate the transform in the adversarial optimization process. We consider a set of transform parameters $\boldsymbol{\theta} = \{\theta_i\}_{i=1}^N$ and corresponding target labels $\mathbf{y}^\star = \{y_i^\star\}_{i=1}^N$, each $(\theta_i, y_i^\star)$ pair specifies the desired model behavior under transform θ_i. For certain parameters, $y_i^\star$ may coincide with the ground-truth label y, enforcing benign behavior.

We seek a single perturbation δ that satisfies all specified behaviors by solving the following optimization problem:

$$\min_{\delta} \sum_{i=1}^{N} \mathcal{L}\big(f(\tau(x+\delta;\theta_i)),\, y_i^\star\big) \text{ s.t. } \|\delta\|_p \le \varepsilon, \tag{2}$$

where $\mathcal{L}$ denotes the task loss (e.g., cross-entropy for classification). At test-time, the input examples $x+\delta$, or $\tau(x+\delta;\theta_i),\ \theta_i \in \Theta_{\text{safe}}$ should appear "benign" (i.e., $f\big(\tau(x+\delta;\theta)\big) = y$). When applying a transform with trigger parameters $\theta_i \in \Theta_{\text{trigger}}$, the corresponding adversarial behaviors will be activated.

Robustness to parameter variations. To ensure robustness against small deviations in transform parameters, we adopt an expectation-over-transform (EOT) formulation Athalye et al. (2018). Instead of optimizing for discrete parameters, we optimize over neighborhoods around each target parameter:

$$\min_{\delta} \sum_{i=1}^{N} \mathbb{E}_{\theta_i \sim \mathcal{N}_r(\bar{\theta}_i)} \mathcal{L}\big(f(\tau(x+\delta;\theta_i)),\, y_i^\star\big) \text{ s.t. } \|\delta\|_p \le \varepsilon, \tag{3}$$

where $\mathcal{N}_r(\bar{\theta}_i)$ denotes a uniform distribution over parameters within radius r of some predefined $\bar{\theta}_i$ (for all i). This formulation yields perturbations that remain effective over continuous ranges of transform parameters in digital and physical attacks and improves transferability to blackbox models, consistent with prior observations that transforms enhance adversarial generalization Xie et al. (2019); Lin et al. (2020); Wang et al. (2021).The full step-by-step optimization procedure for synthesizing transform-triggered adversarial examples in the digital setting is given in algorithm 1.

Transform functions. To enable gradient-based optimization, we assume the transform function $\tau(\cdot;\theta)$ is differentiable (or approximately differentiable) with respect to the input. This allows computing gradients via the chain rule: $\nabla_\delta \mathcal{L} = \frac{\partial \mathcal{L}}{\partial f}\frac{\partial f}{\partial \tau}\frac{\partial \tau}{\partial \delta}$. Moreover, transforms are assumed to be deterministic with respect to θ, ensuring that adversarial behavior is desirably induced by the θ rather than presenting stochastic effects.

3.3 Physical attacks with hardware-in-the-loop

To further demonstrate that our proposed method generates robust adversarial examples, we incorporate an explicit imaging forward model $\mathcal{W}$ in the optimization problem as

$$\min_{\delta} \sum_{i=1}^{N} \mathop{\mathbb{E}}_{\theta_i \sim N_r(\bar{\theta})} \mathcal{L}(f(\mathcal{W}(\tau(x+\delta;\theta_i))), y_i^\star) \text{ s.t. } \|\delta\|_p \le \varepsilon. \tag{4}$$

The forward operator $\mathcal{W} : \mathbb{R}^{H\times W\times 3} \to \mathbb{R}^{H\times W\times 3}$ models the mapping of a physical planar scene to the digital captured image. We assume that the perturbed and transformed image can be represented as a planar scene $\tau(x+\delta;\theta_i) \in \mathbb{R}^{H\times W\times 3}$. In our experiments, we use a monitor to represent the planar scene that undergoes different transformations before being captured by a camera.

Let us represent $\mathbf{p}$ and $\mathbf{s}$ as proxies for $\tau(x+\delta,\theta)$ and $\mathcal{W}(\tau(x+\delta,\theta))$ in equation 4, where $\mathbf{p} \in \mathbb{R}^{H\times W\times 3}$ represents a physical planar scene and $\mathbf{s} \in \mathbb{R}^{H\times W\times 3}$ represents the digital sensor image. By representing $\mathbf{s} = \mathcal{W}(\mathbf{p})$, we assume that the $H \times W$ color digital image imparts a corresponding Nyquist sampling on the physical plane. In practice, a complete imaging model may need to represent different stages: "scene $\to$ optics $\to$ sensor $\to$ ISP". We approximate this pipeline using three major parameterized steps: (i) the geometric map between the scene and sensor planes, represented using a homography matrix H; (ii) the camera color response, represented using a color–correction matrix $W \in \mathbb{R}^{3\times 3}$; and (iii) intensity-dependent sensor and environment noise $\mathbf{n} \in \mathbb{R}^{H\times W\times 3}$. We can represent the mapping between the physical planar scene $\mathbf{p}$ and the digital sensor image $\mathbf{s}$ using the following model:

$$\mathbf{s}(u,v) = W[\mathbf{p}\left(H^{-1}(u,v)\right)] + \mathbf{n}(u,v), \tag{5}$$

where (u,v) represents spatial coordinates of each pixel in the sensor image and $W[\cdot]$ performs a matrix-vector operation on the three color channels.

Algorithm 1 Optimization procedure of Transform-triggered adversarial examples (digital space)

Require: Clean image x, model f, transform τ, parameter-target pairs $\{(\bar{\theta}_i, y_i^*)\}$

Initialize $\delta \leftarrow 0$
while not converged **do**
  for each pair i **do**
    Sample $\theta_i \sim \mathcal{N}_r(\bar{\theta}_i)$
  end for
  $L \leftarrow \sum_i \mathcal{L}\big(f(\tau(x+\delta;\theta_i)), y_i^*\big)$ ▷ Eqn. (3)
  $\delta \leftarrow \delta - \alpha \cdot \text{sign}(\nabla_\delta L)$ ▷ PGD step
  $\delta \leftarrow \text{clip}(\delta, -\varepsilon, \varepsilon)$
end while
return δ

Algorithm 2 Optimization procedure of Transform-triggered adversarial examples (physical space)

Require: Digital image x, captured image $\tilde{x}$, model f, transform τ, parameter-target pairs $\{(\bar{\theta}_i, y_i^*)\}$

Initialize $\delta \leftarrow 0$
while not converged **do**
  for each pair i **do**
    Sample $\theta_i \sim \mathcal{N}_r(\bar{\theta}_i)$
  end for
  $\tilde{x} \leftarrow$ `Capture_image` ▷ Hardware process
  $L \leftarrow \sum_i \mathcal{L}\big(f(\mathcal{W}(\tau(\tilde{x}+\delta;\theta_i))), y_i^*\big)$ ▷ Eqn. (4)
  $\delta \leftarrow \delta - \alpha \cdot \text{sign}(\nabla_\delta L)$ ▷ PGD step
  $\delta \leftarrow \text{clip}(\delta, -\varepsilon, \varepsilon)$
  `Display_image` $(x+\delta)$ ▷ Hardware process
end while
return δ

The model in equation 5 offers a differentiable approximation of the imaging model and allows us to use gradient-based optimization through the physical forward model. Utilizing the chain rule, the gradient w.r.t. the input perturbation δ can be represented as $\nabla_\delta \mathcal{L}(f(\mathcal{W}(\tau(\mathbf{x}+\delta;\theta))), y^\star) = \frac{\partial \mathcal{L}}{\partial f}\frac{\partial f}{\partial \mathcal{W}}\frac{\partial \mathcal{W}}{\partial \tau}\frac{\partial \tau}{\partial \delta}$. Notably, due to the hardware memory-disconnection introduced by $\mathcal{W}$, the Jacobians $\frac{\partial \mathcal{L}}{\partial f}\frac{\partial f}{\partial \mathcal{W}}$ and $\frac{\partial \mathcal{W}}{\partial \tau}\frac{\partial \tau}{\partial \delta}$ are computed separately in the memory instead of directly calling `autograd` (which is a common operation for gradient computation in modern machine learning packages Paszke et al. (2017)). We include the step-by-step processing and optimization procedures of our hardware setup in algorithm 2. This hardware-in-the-loop modeling closes the gap between purely digital attacks and physically realizable adversarial examples, allowing us to validate transform-triggered adversarial examples effectiveness under the real-world environments.

4 Experiments

In this section, we first evaluate transform-triggered adversarial examples across diverse image transforms and model architectures. We then demonstrate the generalization of our formulation to object detection, highlighting its practical relevance. Finally, we extend our results from digital to a physical display–camera pipeline, showing that multi-targeted attack behaviors remain robustly partitioned under real-world noise and capture artifacts.

4.1 Experiment setup

Models and dataset. We utilize pretrained image classification models from Pytorch Torchvision Paszke et al. (2017), which provides models pretrained on ImageNet dataset Deng et al. (2009) for a variety of families and architectures. Models are trained with data augmentation techniques including random cropping, rotation, flipping, and color jittering, so that they align with our assumption in Eq. (1). We sample models from different families that cover Convolutional Neural Networks (CNNs) and Vision Transformers (ViT): {`VGG-19-BN`, `ResNet-50`, `DenseNet-121`, `InceptionV3`, `MobileNet-v2`, `ViT-L-16`, `ViT-L-32`, `Swin-T`}. We use 1000 ImageNet-like RGB images from the NeurIPS'17 challenge Brain (2017), which has the same label space as ImageNet, all images are in the size of 224×224.

Our threat model and attack setup. We consider targeted, transform-triggered adversarial attacks, which are more challenging than untargeted ones and directly align with our formulation. The attacker is assumed to have whitebox access to the victim model during optimization and knowledge of sets of transforms that input may undergo in real model deployment. The goal is to induce distinct, attacker-specified target labels conditioned on these transforms when the perturbed image is processed under corresponding transform parameters. In the main paper, we evaluate a simplified setup optimizing $N = 3$ transform-target pairs

Table 2: Transform-dependent targeted ASR (%) ↑ against classifiers over the range of selected parameters. A higher ASR value indicates better attack performance. The adversarial perturbation budget for this experiment is $\varepsilon = 8$.

Transform parameter	Classifier model							
	VGG19	ResNet50	Dense121	Incv3	Mobv2	ViT-L16	ViT-L32	Swin-T
$S \sim [0.4, 0.6]$	95.80	87.20	88.20	61.90	96.40	68.70	61.00	99.70
$S \sim [0.9, 1.1]$	99.90	98.70	98.20	83.10	100.0	75.50	68.40	100.0
$S \sim [1.4, 1.6]$	99.90	99.60	99.60	80.30	99.80	75.90	68.70	100.0
Average	98.53	95.17	95.33	75.10	98.73	73.37	66.03	99.90
$\sigma \sim [0.4, 0.6]$	100.0	99.90	99.80	95.40	99.80	97.40	91.70	100.0
$\sigma \sim [1.4, 1.6]$	98.70	98.90	97.90	75.40	95.80	77.60	66.20	98.90
$\sigma \sim [2.9, 3.1]$	97.10	98.90	94.40	65.70	94.20	65.60	53.80	99.10
Average	98.60	99.23	97.37	78.83	96.60	80.20	70.57	99.33
$\gamma \sim [0.4, 0.6]$	99.90	100.0	99.90	93.10	99.90	99.00	93.30	99.80
$\gamma \sim [0.9, 1.1]$	100.0	96.20	99.90	95.10	99.90	97.60	91.90	100.0
$\gamma \sim [1.9, 2.1]$	100.0	91.00	99.70	93.70	99.70	93.60	85.30	99.70
Average	99.97	95.73	99.83	93.97	99.83	96.73	90.17	99.83
$Q \sim [19, 21]$	96.10	87.70	91.70	73.40	86.90	66.60	72.70	83.40
$Q \sim [49, 51]$	99.10	96.20	96.70	80.90	95.20	81.90	83.00	96.20
$Q \sim [79, 81]$	99.40	98.40	99.20	87.00	97.90	87.80	82.20	99.80
Average	98.20	94.10	95.87	80.43	93.33	78.77	79.30	93.13

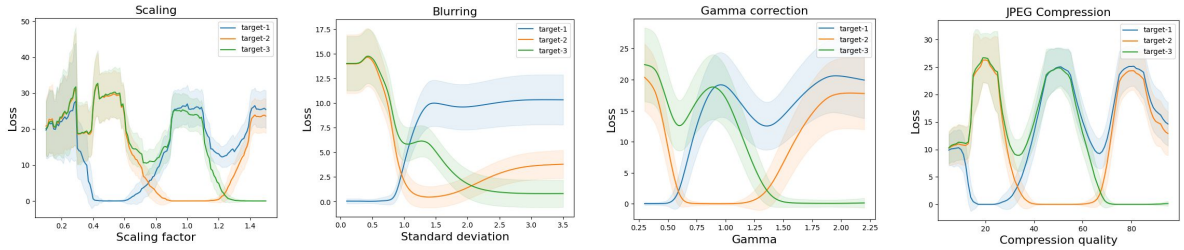

Figure 2: Loss landscape of the `ResNet50` over transform parameter values. Small loss values indicate successful targeted attacks within the correspond transform parameter ranges. The shaded regions represent the standard deviation of each curve. Perturbation are generated to deceive model providing three target labels for three transform parameter ranges: $S \sim \{[0.4, 0.6], [0.9, 1.1], [1.4, 1.6]\}$, $\sigma \sim \{[0.4, 0.6], [1.4, 1.6], [2.9, 3.1]\}$, $\gamma \sim \{[0.4, 0.6], [0.9, 1.1], [1.9, 2.1]\}$, $Q \sim \{[19, 21], [49, 51], [79, 81]\}$, same as Table 2. This figure indicates that 1) different transforms have various smoothness for the transform-triggered objective, 2) multiple attack targets can be controllably triggered by desired transform parameters, and 3) attacks remain effective when parameter is sampled outside of the ranges used in optimizations.

$\{\bar{\theta}_i\}_{i=1}^3$ and $\{y_i^\star\}_{i=1}^3$, where target labels are randomly sampled from ImageNet. We provide stress tests for larger N in section 5.1. Optimization is performed using PGD with 500 iterations and step size $\alpha = 5 \times 10^{-4}$, which we found sufficient for convergence.

Evaluation metrics. We evaluate the transform-triggered adversarial examples effectiveness using the Attack Success Rate (ASR). Specifically, for a perturbed image transformed as $\tau(\mathbf{x}+\delta; \theta_i)$, we check whether the prediction matches target label y_i^* (i.e., success if $f(\tau(\mathbf{x}+\delta; \theta_i)) = y_i^*$). We report ASR for each transform parameter $\bar{\theta}_i$ over $N_r(\bar{\theta}_i)$, where $N_r(\bar{\theta}_i)$ includes series of θ samples generated with a small sampling rate (detailed in section 4.2), and we report ASR averages over all samples within $N_r(\bar{\theta}_i)$ for each $\bar{\theta}_i$.

4.2 Attacks against classifiers

We present transform-triggered examples under four image transforms commonly applied in real-world scenarios: geometric transforms (scaling, blurring) and photometric transforms (gamma correction, JPEG compression). For each transform, we select three parameters $\{\bar{\theta}_i\} \in \Theta_{\text{trigger}}$ following **two concrete criteria:** (i) covering a representative spectrum of deployment conditions: unaltered, mildly transformed, and heavily transformed inputs (illustrated qualitatively in Fig. 1); and (ii) preserving model accuracy on clean samples at each $\bar{\theta}_i$ so that the Eq. (1) assumption holds and observed adversarial behavior is attributable to the objective Eq. (3) rather than transform-induced degradation to the model (accuracies on transformed clean examples are reported in Tab. 12, Appendix C).

For scaling, we use factors $S \in [0.5, 1.0, 1.5]$. For blurring, we fix the Gaussian kernel size to 5×5 and vary $\sigma \in [0.5, 1.5, 3.0]$. For gamma correction, we select $\gamma \in [0.5, 1.0, 2.0]$, and for JPEG compression, we use quality levels $Q \in [20, 50, 80]$. To generate $N_r(\bar{\theta}_i)$, we define a neighborhood with an interval radius of $r = 0.1$ for scaling, blurring, gamma correction, and $r = 1$ for JPEG compression. This results in the following parameter ranges: scaling $S \sim \{[0.4, 0.6], [0.9, 1.1], [1.4, 1.6]\}$, blurring $\sigma \sim \{[0.4, 0.6], [1.4, 1.6], [2.9, 3.1]\}$, gamma correction $\gamma \sim \{[0.4, 0.6], [0.9, 1.1], [1.9, 2.1]\}$, and JPEG compression $Q \sim \{[19, 21], [49, 51], [79, 81]\}$.

Tab. 2 summarizes the ASR for transform-triggered attacks across three target labels and corresponding parameter ranges. These results show consistent targeted attacks success on whitebox CNN and ViT models, demonstrating the effectiveness of transform-triggered adversarial examples. These attacks, optimized via Eq. (3), retain their effectiveness under small parameter variations (also indicated in Fig. 2). Their transferability to blackbox and defended models is further explored in section A.1. Fig. 2 visualizes the adversarial loss landscape of ResNet50 across four transforms, with loss evaluated over a grid of transform parameters (sampling rate 0.1 for S, σ, γ, and 1 for Q). The three colors represent distinct target labels, with solid lines indicating average loss and shaded areas denoting standard deviation. As seen, minimum loss values align with the intended transform parameter ranges, confirming that adversarial examples successfully embed targeted attacks triggered by specific transformations. Notably, scaling and JPEG are more sensitive to parameter variations, while blurring and gamma correction exhibit greater smoothness.

4.3 Attacks against object detectors

To demonstrate the practicality of transform-triggered examples, we design transform-selective hiding threat model in compatible with our objectives. We present more threat models against detectors in Sec. E. Here, We first outline the setups, followed by a discussion of the threat model and results.

Models and dataset. For object detection, we use pretrained models from `MMDetection` Chen et al. (2019) on the COCO 2017 dataset Lin et al. (2014), and generate adversarial examples using the same dataset. Our model selection covers diverse architectures: one-stage detector (`YOLOv3` Redmon & Farhadi (2018)), two-stage detectors (`Faster R-CNN` Ren et al. (2015), Grid R-CNN Lu et al. (2019)), and a ViT-based model (DETR Carion et al. (2020)).

Table 3: Transform-selective hiding attack success rate (ASR) for trigger zone and accuracy (ACC) for safe zone. Higher ASR and ACC indicate better performance. The attack is selectively triggered within the desired range of enhancement transform parameters. Our attack consistently hides objects under image enhancement transforms while preserving detectability in unaltered or minimally enhanced images.

Θ	Zoom-in				Deblurring				Gamma correction			
	Faster	YOLOv3	GRID	DETR	Faster	YOLOv3	GRID	DETR	Faster	YOLOv3	GRID	DETR
Θ_{trigger}	89.41	95.22	84.62	53.79	78.92	85.17	72.37	51.03	79.88	89.10	72.13	53.46
Θ_{safe}	94.36	99.03	93.25	77.02	92.43	91.78	88.84	71.53	89.49	91.78	82.50	65.96

Threat model: transform-selective hiding. In this threat model, we maintain the same attacker knowledge assumptions described in section 4.1, aim to hiding all detectable objects when a level of image enhancement is applied that potentially discloses sensitive information, and preserve detectability in unaltered or minimally enhanced images (consistent criteria as in section 4.2), enabling privacy protection and strategic information control. For instance, surveillance footage can obscure sensitive objects upon enhance-

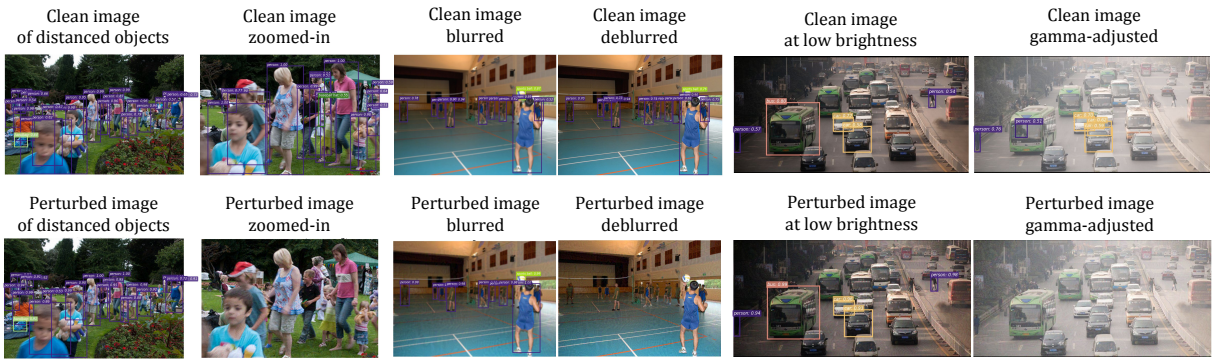

Figure 3: Visualization of the enhancement transform-triggered hiding attacks on YOLOv3. While objects in the enhanced clean images are being detected, after adding transform-triggered perturbations (with tiny magnitude level $\|\delta\|_\infty \leq 10$), detectors fail when the enhancement transform is applied, motivate the utility on preventing sensitive information disclosure in remote sensing or public surveillance systems.

ment, preventing unauthorized recognition while maintaining visibility in unaltered conditions. Similarly, in satellite imaging, critical targets can be concealed under specific enhancements, controlling detectability based on operational needs. We stress that transform-selective hiding is a representative instantiation: our formulation more broadly supports transform-conditioned behaviors depending on the security needs.

Results. We consider attacking zoom-in (i.e., scaling + centered cropping) with $S \sim [2.0, 2.5]$, blurring with $\sigma \sim [0.0, 0.7]$, and gamma correction with $\gamma \sim [0.5, 0.9]$ to simulate these enhancement scenarios. Outside of attack ranges, which we consider as safe ranges, we keep the detectability of objects and report accuracy. Tab. 3 show that the attack is selectively triggered within the desired range of enhancement transform parameters, with overall ASR above 50% over attack ranges and high ACC over safe ranges. Our attack consistently hides objects when different image enhancement transforms are heavily applied, while preserving detectability in unaltered or minimally enhanced images. The examples in Fig. 3 show that objects are selectively hidden in predefined attack ranges in three enhance transforms, meanwhile, over safe range the detection results remain identical to original clean image. We provide animated visual examples of these attack scenarios in the submitted supplementary material.

4.4 Hardware-in-the-loop experiments

In this section, we further evaluate transform-triggered adversarial examples in a physical setup created using a planar display and a DSLR camera. Our goal is to verify that a single perturbation can reliably induce multiple adversarial behaviors under different transforms in physical attacks and that the transform-triggered behaviors are desired and targeted rather than precision artifacts introduced by transform functions. As described in equation 5, we represent the imaging model using a combination of homography, color correction, and noise calibration. We include the diagram of our hardware-in-the-loop attack pipeline, and a picture of the built physical setup, in Fig. 4.

Implementation details. We display perturbed images on a `BenQ BL2780 27" 1080p (1920×1080)` monitor and capture them using a Nikon Z30 camera (lens: `NIKKOR Z DX 16-50mm f/3.5-6.3 VR`; manual mode, aperture `f/5.6`, ISO 100, shutter 1/60 s; working distance: ∼60 cm). The captured images are then fed to the model loaded in memory.

We estimate the homography matrix, H, by registering four markers at image corners across physical and captured digitial images. We estimate W using 1000 pairs of RGB vectors, randomly sampled from the matching pixels in the images captured by the camera and the corresponding values stored in the memory.

Image classification. We follow the same experiment setup as described in Sec. 4.2. We sampled 100 images from ImageNet-1K and four pretrained classifiers from `TorchVision`. For each image instance, we select a target label for the original view and a different target label for the transformed version. We

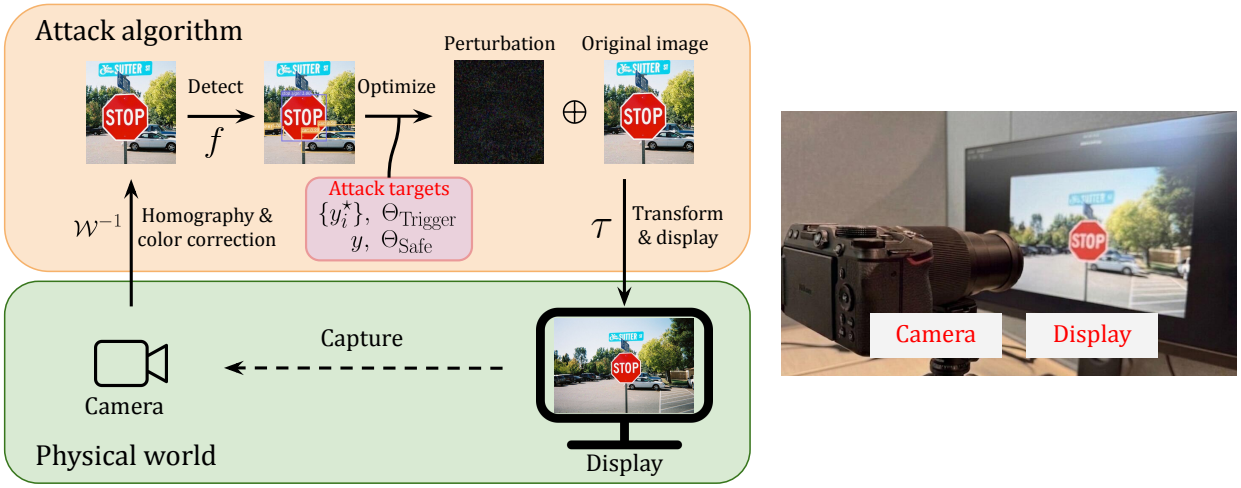

Figure 4: The diagram of hardware-in-the-loop pipeline and a picture of our built camera-display setup. In physical world, We display transformed adversarial example on a planer display, then capture the adversarial with a DSLR camera. The captured images are then fed to the model loaded in the memory, optimize with transform-trigger adversarial example formulation.

optimized for two target attacks for Zoom (zoom factor $\{1.0, 1.2\}\times$), Blur (Gaussian kernel $\sigma = 0.1, 1.0$), and Gamma ($\gamma = 0.7, 1.0$) transforms. Tab. 4 summarizes the results. We first report classification accuracy on non-perturbed images and the ASR of the standard PGD paradigm (one fixed target, no transform) as a contextual reference for our physical pipeline under benign and conventional threats. We then report the ASR of transform-triggered examples, computed as the average targeted success across the two transforms optimized per image. We observe that transform-triggered examples maintain substantially higher success: for zoom, up to 72.5% ASR (`DenseNet121`) vs. 23% on `VGG19`; for blur, $55-72\%$, and for gamma adjustments, $52-72\%$. The trend is consistent across architectures, which demonstrates that incorporating the transform-dependency in the optimization provides physically-realizable effects.

Table 4: Physical attacks on image classifiers using transform-triggered adversarial examples across three image transforms. Our proposed transform-triggered formulation creates robust and physically realizable adversarial examples.

Model	Classification Accuracy (↑)	Attack Success Rate (↑)			
		PGD	Zooming	Blurring	Gamma
VGG19	69.00	100.0	96.00	95.00	96.00
ResNet50	73.00	99.00	95.00	96.00	92.00
Dense121	69.00	100.0	98.00	99.00	98.00
ViT-L16	83.00	100.0	94.00	93.00	91.00

Object detection. We further evaluate a real-world zoom-triggered attack on `Faster R-CNN` using stop sign images from COCO. We learn additive perturbation, δ, that is localized within the stop sign region and optimized to produce two mutually incompatible outcomes: (i) original to minor zoom (1.0–1.4× as Θ_{safe}) should detect the stop sign; (ii) moderate to strong zoom (1.5–2.0× as Θ_{trigger}) should trigger the hiding attack (i.e., not detect the stop sign). To emulate real physical zoom rather than digital cropping, we display the perturbed image and change the distance between the camera and the monitor. Representative captured frames are shown in Fig. 5 and videos will be included in the supplementary material. The detector outputs follow the transform-triggered logic enforced by optimization: the stop sign is detected in the 1—1.4× zoom range; whereas, all proposals are suppressed in the 1.5–2.0× zoom range and the stop sign is not detected by the model. Note that "car" is detected at all zoom levels, which is the desired attack effect in our setup.

Figure 5: Physical attacks on object detector `Faster R-CNN` using zoom trigger. These images are captured by a DSLR camera while displaying adversarial examples on a monitor. The first row shows the camera-captured adversarial examples and their detections in "safe zoom", where objects are detected. The second row shows camera-captured adversarial examples and their detection with "trigger zoom", where targeted attack is triggered and target object (stop sign) is hidden.

These results demonstrate that models can be deceived to produce targeted outputs for the same physical object depending solely on the applied transforms. Furthermore, our results demonstrate physically-realistic transform-triggered adversarial attacks in object detection, which is significantly more challenging than classifiers.

5 Discussion

5.1 Capacity limit of a single perturbation

Given that our attack can embed multiple transform-dependent targeted behaviors into a single perturbation, a natural question is: *"How many transform-triggered targets can one perturbation support?"* To empirically probe this limit, we conduct a stress test with up to $N = 25$ targets on three representative models from section 4.2: ResNet50, InceptionV3, and ViT-L-16. We use scaling, blurring, gamma correction, and JPEG compression as transform triggers. For each transform, we initialize the parameter sequence with $\theta_1 = 0.5$ for scaling, blurring, and gamma correction, and $\theta_1 = 20$ for JPEG compression. Additional trigger parameters are then appended with an adaptive step size until reaching $N = 25$. Each newly added parameter θ_i is assigned a randomly sampled ImageNet target label $y_i^\star$.

This stress test imposes N transform-conditioned target constraints on one bounded perturbation:

$$f(\tau(x+\delta;\theta_i)) = y_i^\star, \qquad i = 1,\dots,N, \qquad \|\delta\|_p \le \varepsilon. \tag{6}$$

Given an evaluation set $\mathcal{D}$, we summarize performance by the empirical average targeted ASR:

$$\mathrm{ASR}_N(\delta) = \frac{1}{N|\mathcal{D}|}\sum_{i=1}^{N}\sum_{x\in\mathcal{D}} \mathbf{1}[f(\tau(x+\delta;\theta_i)) = y_i^\star]\,. \tag{7}$$

Thus, increasing N directly increases the number of target constraints that the same perturbation must satisfy under the fixed budget ε. Empirically, as Fig. 6 shows, the average targeted ASR decreases as N increases, but the degradation rate depends strongly on both the transform and the victim architecture. Scaling and JPEG compression sustain higher ASR under larger N, while blurring and gamma correction

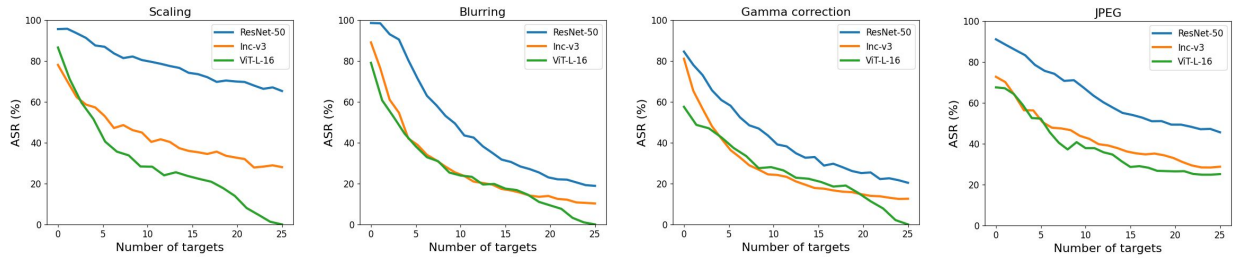

Figure 6: Average targeted ASR vs the number of embedded targets N across scaling, blurring, gamma correction, and JPEG compression. As N increases, the average ASR drop for fixed perturbation budget.

degrade more rapidly. This trend is consistent with the loss landscapes in Fig. 2: sharper and more separable transform-dependent losses allow finer partitioning of the transform space, whereas smoother losses create wider overlapping trigger regions and reduce the number of distinguishable target behaviors. Architecture also affects the capacity: ResNet50 accommodates more transform-target pairs, whereas ViT-L-16 shows the smallest capacity among the tested models. This suggests that capacity is governed not only by the transform itself, but also by the model-dependent geometry of the decision boundary under transformed inputs. Finally, the perturbation budget ε provides a direct constraint: a larger ε expands the feasible perturbation set and may support more target constraints, but at the cost of increased visibility.

Overall, the empirical capacity of a single perturbation depends jointly on: N, smoothness of transform functions, victim architecture, and perturbation budget. A formal capacity theory relating these factors to the maximum number of embeddable targets remains an important direction for future work.

5.2 Practical threat scenarios

Transform-triggered adversarial examples suggest a practical threat model for vision systems with known or partially known image processing pipelines. In real deployments, digital inputs to the models are typically produced after an image signal processing (ISP) pipeline that includes transforms such as denoising, gamma correction, resizing, and compression. These transforms are often deterministic or configuration-dependent once the camera model, software stack, or deployment setting is fixed. An attacker with knowledge of the acquisition or ISP pipeline could therefore optimize a perturbation whose malicious behavior is conditionally activated under targeted ISP transforms while remaining benign under others.

Prior work partially supports this threat model in the visible-patch regime. TPatch (Zhu et al., 2023) studies an active trigger mechanism in which an attacker injects an acoustic signal into the MEMS gyroscope of an autonomous vehicle to induce false motion readings; the Optical Image Stabilization (OIS) module then applies enhancement transforms into the captured image, which activates the adversarial patch. Our work generalizes this threat: ordinary image transforms widely present in sensing and preprocessing pipelines can themselves act as implicit triggers, and be exploited for injecting multiple malicious behaviors. This makes transform-triggered adversarial examples relevant for evaluating robustness across real-imaging scenarios, such as heterogeneous cameras, compression settings, and preprocessing configurations — dynamical scenarios that conventional adversarial examples cannot capture.

6 Conclusion

We introduce a framework for transform-triggered adversarial examples that expose a previously overlooked dynamical vulnerability in deep networks. Conventional adversarial examples induce a single, static failure mode. Our method can generate adversarial examples that can produce multiple, targeted adversarial behaviors triggered by image transforms. Extensive experiments across architectures and tasks show that these attacks enable precise, transform-dependent mispredictions. Our hardware-in-the-loop experiments further confirm that the adversarial examples remain effective in physical attacks, indicating a robust feature-space phenomenon beyond digital artifacts. Our proposed method can potentially be beneficial for sensitive operations where perturbations remain benign under normal viewing and imaging conditions but suppress sensitive content under adverse conditions, enabling transform-triggered privacy or safety control.

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Appendix

In this appendix, in section A, we first present additional evaluations for transform-triggered adversarial examples, including blackbox transfer of our examples, ~~increasing number of transform-target pairs for transform-triggered adversarial examples,~~ adaptation to alternative optimization methods, and more challenging label selections. In section B, we extend transform-triggered adversarial examples to additional image transforms: view-perspective and flipping beyond those discussed in the main paper. In section C, we provide an accuracy evaluation of the classifier models used in our main experiments (section 4.2) as a model accuracy reference under input transforms, validating the assumption in Eq. (1). Finally, we provide computational resource in section D, and additional visual examples of transform-triggered adversarial examples on classifiers and detectors for reference, in sections E and F.

A Additional evaluation

In this section, we first analyze the impact of increasing the number of transform-target pairs to stress test the capacity of adversarial perturbations in embedding transform-dependent targets in section 5.1. Next, we explore alternative optimization algorithms beyond PGD for generating transform-triggered adversarial examples in section A.4. Additionally, we evaluate attacks on more challenging label selection for attack optimization in section A.5.

A.1 Transfer test on blackbox and defended models

Blackbox transferability. In our formulation, post-optimized transform-triggered adversarial examples are functions of transform parameters ($x^\star = \tau(x + \delta; \theta)$), enabling query-efficient blackbox attacks. Since

only model outputs are accessible in the blackbox setup, we query blackbox models with transformed versions of perturbed images $\tau(x+\delta;\theta)$ over $N_r(\bar{\theta}_i)$, with three queries per image at maximum, which is a negligible query cost. For an adversarial example $x+\delta$ generated for a surrogate model, we sample transform parameters θ from the neighborhoods used in Tab. 2, i.e., $N_r(\bar{\theta}_i)$. The goal is to find a transform parameter $\theta_i^\star$ such that the adversarial example $\tau(x+\delta;\theta_i^\star)$ deceives the blackbox model:

$$\text{Find } \theta_i^\star \quad \text{s.t.} \quad f_{\text{bb}}(\tau(x+\delta;\theta_i^\star)) = y_i^\star;\ \theta_i^\star \in N_r(\bar{\theta}_i). \tag{8}$$

We conduct a uniform search over $N_r(\bar{\theta}_i)$ with a sampling interval of 0.1, leading to three queries per transform parameter (e.g., $\{0.4, 0.5, 0.6\}$ for $S = 0.5$). An attack is successful if a transformed adversarial example forces the blackbox model to predict the target label.

Tab. 5 presents the transfer attack success rates under both targeted and untargeted setups. As a reference, we compile transfer attacks BPA (Xiaosen et al., 2023), SU (Wei et al., 2023), and ILPD (Li et al., 2024). By introducing multi-targets in the adversarial optimization, our method achieves comparable ASR to recent techniques without specialized adaptation. Scale- and blur-triggered attacks achieve high success in both targeted and untargeted setups. For untargeted attacks, we use the ground-truth label (y) as the target in Eq. (3) for all transform parameters θ_i and switch the objective from minimization to maximization. Because all N targets collapse to the single y, the multi-target sum in Eq. (3) reduces to a single expectation over the union of transform neighborhoods, recovering the EOT objective Athalye et al. (2018) as a special case of our formulation. An untargeted attack is success when δ-perturbed input to a blackbox model f_{bb} satisfies:

$$\text{Find } \theta_i^\star \quad \text{s.t.} \quad f_{\text{bb}}(\tau(x+\delta;\theta_i^\star)) \neq y;\ \theta_i^\star \in N_r(\bar{\theta}_i). \tag{9}$$

Scale-triggered adversarial examples exhibit slightly better transferability than blur-triggered ones. Targeted success is higher for larger scaling factors, while untargeted success occurs more frequently at smaller scaling factors. ~~These findings highlight that leveraging image transforms and embedding multi-targets improves blackbox transferability, demonstrating the effectiveness of our attacks.~~We provide an ablation study in section A.2 that disentangles the individual contributions of transform function and multi-target optimization to blackbox transferability.

Attacks against defended models. To further evaluate the effectiveness of the transform-triggered adversarial examples, we assess their performance on four defense methods: HGD Liao et al. (2018), Randomized Smoothing (RS) Cohen et al. (2019), JPEG compression (JPEG) Guo et al. (2018) and NPR Naseer et al. (2020). We follow the untargeted setup in a recent transfer attacks BPA Xiaosen et al. (2023), generate whitebox attacks with perturbation budget $\varepsilon = 8$, against four defenses applied to the ResNet50 model. In Tab. 6, we report these untargeted ASRs averaged over all the transform parameters. Our attack archives overall better performance than BPA Xiaosen et al. (2023) on the same benchmark. These results suggest that transform-triggered examples can bypass existing defense methods by leveraging the transform space.

Table 5: Blackbox transfer evaluation under untargeted and targeted settings, adversarial perturbation budget is $\varepsilon = 8$. Our scale-triggered attacks achieve comparable untargeted ASRs and higher targeted ASRs under the same setting as the most recent transfer attacks. Furthermore, the transfer attacks maintain transform-triggered attack properties as targeted ASRs present.

Methods	Untargeted ASR (%) ↑					Targeted ASR (%) ↑				
	Surrogate	Blackbox model				Surrogate	Blackbox model			
	ResNet50	VGG19	Dense121	Incv3	Mobv2	ResNet50	VGG19	Dense121	Incv3	Mobv2
BPA Xiaosen et al. (2023)	99.40	60.96	70.70	35.36	68.90	100.0	31.02	43.82	15.34	39.00
ILPD Li et al. (2024)	83.96	**88.10**	**90.68**	64.70	-	-	-	-	-	-
Logit-SU Wei et al. (2023)	-	-	-	-	-	-	41.30	45.70	1.10	-
$S \sim [0.4, 0.6]$	88.00	80.10	81.10	**96.90**	**86.80**	99.60	39.10	40.00	12.10	31.50
$S \sim [0.9, 1.1]$	98.30	86.70	77.50	62.60	81.00	99.90	**62.80**	61.40	28.80	56.10
$S \sim [1.4, 1.6]$	99.90	85.40	83.90	58.90	85.10	100.0	59.50	**67.80**	**33.10**	**60.00**
$\sigma \sim [0.4, 0.6]$	99.80	64.40	69.40	53.50	65.60	100.0	32.60	42.20	19.10	35.00
$\sigma \sim [1.4, 1.6]$	99.80	85.40	84.60	73.70	83.80	99.90	43.90	52.60	23.40	35.40
$\sigma \sim [2.9, 3.1]$	99.60	86.80	85.50	76.30	85.00	99.90	41.90	50.40	22.50	33.80

Table 6: Results of untargeted ASR (%) ↑ against defense methods, perturbation budget is $\varepsilon = 8$.

Attack method	Defense method			
	HGD	RS	JPEG	NPR
BPA	23.96	14.00	22.52	14.08
Scaling (ours)	56.20	53.43	34.90	39.70
Blurring(ours)	57.73	63.67	57.80	52.43
Gamma(ours)	48.67	65.43	52.27	53.57

A.2 Ablation on multi-target objective transferability

In this section, we provide an ablation study answering the question: *does the transform-triggered objective with multiple targets yield more blackbox-transferable adversarial examples?* To disentangle the roles of the *transform function* and the *multi-target* objective, we formulate three distinct objectives and optimize a separate set of adversarial examples for each. Objective 1 (Obj. 1) corresponds to Eq. (3), where we assign $N = 3$ random targets $y_i^\star$ to parameters $\bar{\theta}_i$, yielding adversarial examples under a *transform with multi-target* formulation. Obj. 2 corresponds to EOT, solving $\max_\delta \sum_{i=1}^{N} \mathcal{L}\big(f(\tau(x+\delta;\theta_i)),\, y\big)$, as a *transform with single-target* formulation. Obj. 3 corresponds to $\min_\delta \sum_{i=1}^{N} \mathcal{L}(f(x+\delta), y_i)$, as a *multi-target without transforms* formulation. All objectives are subjective to (s.t.) the visibility constraint $\|\delta\|_\infty \leq 8$.

Following the untargeted setup in section A.1 that utilizes ResNet50 as surrogate and evaluate the blackbox untargeted ASR (Eq. (9)) with adversarial examples generated from solving Obj. 1,2 and 3. The ablation in Tab. 7 reveals that transform function is the primary driver of transferability: Obj. 3 (multi-target without transforms) consistently yields the lowest blackbox ASR, while Obj. 2 (transforms with a single target) performs comparably to or above Obj. 1. This is consistent with prior findings that input diversity enhances transfer (e.g., DIM (Xie et al., 2019), SIM (Lin et al., 2020), Admix (Wang et al., 2021)), and confirms that the transferability gains in Tab. 5 stem from transform-based input augmentation rather than the multi-target objective itself.

Table 7: Ablation study separating the effects of multi-target optimization and transform function on blackbox transferability. We report untargeted ASR (%) for scale and blur transforms, with examples generated on the surrogate and evaluated on blackbox models. The transform-involved, single-target objective (Obj. 2, equivalent to EOT) yields the most transferable adversarial examples.

Adversarial objective				Untargeted ASR (%) ↑				
				Surrogate	Blackbox model			
Trigger	Obj.	Transform	Multi-target	ResNet50	VGG19	Dense121	Incv3	Mobv2
Scale	1	✓	✓	96.50	69.90	69.90	88.00	81.70
	2	✓	✗	95.40	**84.00**	**80.83**	**88.10**	**84.30**
	3	✗	✓	96.70	63.40	64.70	86.80	75.60
Blur	1	✓	✓	99.50	64.50	72.90	72.80	74.20
	2	✓	✗	99.70	**78.87**	**79.83**	**67.80**	**78.10**
	3	✗	✓	99.70	64.20	66.80	69.60	70.20

Importantly, this result is expected and does not conflict with contribution of this work, as transferability and transform-triggered multi-target behavior are different properties of adversarial examples. Obj. 2 achieves marginally better transfer because it concentrates the entire perturbation budget on a single target, whereas Obj. 1 must partition that budget across N targets and splitting the optimization effort onto achieving distinct targeted attacks. We remind the reader that our contribution is not in maximizing blackbox transfer but in identifying and characterizing a new whitebox phenomenon: embedding multiple conditionally-activated behaviors within one perturbation, which Obj. 2 cannot achieve by design. That Obj. 1 retains competitive transfer despite this added constraint further supports the robustness of the transform-dependent phenomenon.

A.3 ~~Increasing the Number of Targets~~

~~Given what we introduced in this work that multiple targeted attacks can be embedded within a single perturbation through image transforms, a natural question arises: *"How many transformation-dependent targets can be embedded in one attack perturbation?"* To explore this, we conduct a study on three models sampled from section 4.2: ResNet50, InceptionV3, and ViT-L-16, using scaling, blurring, gamma correction, and JPEG compression as transformations. We initialize the transform parameter sequence with 0.5 for scaling, blurring, and gamma correction, and 20 for JPEG compression. Additional θ_i values are iteratively appended using an adaptive step size until reaching a maximum of 25 samples. For each newly appended θ_i, we assign a randomly sampled label from ImageNet label space as target $y_i^\star$.~~

~~The ASR trends in Fig. 6 show that as the number of samplings increases, the ASR drop rate varies across models and transformations. Scaling and JPEG compression demonstrate a higher capacity to embed multiple targeted attacks compared to blurring and gamma correction, this is consistent with the sensitivity indicate by loss landscape discussed in section 4.2. Among the tested models, ResNet-50 accommodates more transform-target pairs, whereas ViT-L-16 exhibits the smallest capacity.~~

A.4 Adaptation with other optimization algorithms

In our main paper, we primarily solve transform-triggered adversarial examples using PGD Madry et al. (2018) for simplicity. However, in principle, these attacks can be generated with other optimization methods. Here, we evaluate the adaptability of transform-triggered adversarial examples using commonly used methods, including FGSM Goodfellow et al. (2015), MIM Dong et al. (2018), and C&W Carlini & Wagner (2017), and compare their performance with PGD.

Tab. 8 presents the average ASR for scale-dependent targeted attacks under the same settings as Tab. 2 in the main text. Among tested optimization algorithms, MIM, C&W, and PGD are sufficient to solve Eq. (3) and achieve high ASR, while the single-step FGSM is insufficient.

Table 8: Average scale-triggered ASRs (%) ↑ with different attack optimization methods, perturbation budget $\varepsilon = 8$. PGD offers overall better ASR among all optimization methods.

Attack method	ResNet50	VGG19	Dense121	Incv3
FGSM Goodfellow et al. (2015)	0.13	0.13	0.07	0.10
C&W Carlini & Wagner (2017)	85.90	90.73	90.77	60.50
MIM Dong et al. (2018)	92.80	96.77	94.83	**83.10**
PGD (Tab. 2)	**96.06**	**98.83**	**97.10**	82.08

A.5 More challenging attack targets

In section 4.2 of the main text, we initially employed a random selection process to choose three distinct classes from the set of 1000 ImageNet classes as our target labels, denoted as $\{y_i^\star\}_{i=1}^3$. Here, we maintain the consistent setup as section 4 (i.e., datasets, models, hyperparameters), and opt to target label section as the ***three least-likely labels*** extracted from the probability vectors converted from logits.

In this continuation, we evaluate the Adversarial Success Rate (ASR) under these modified attack settings, as presented in Tab. 9. This evaluation demonstrates the efficacy of our attack formulation even when faced with the challenge of targeting the least-likely labels.

B More transforms

Conceptually, transform-triggered attack formulation applies to any differentiable and deterministic image transforms, as discussed in the main paper section 3. Here, we extend our adversarial formulation to two

Table 9: ASR evaluation of transform-triggered attacks using 3 most least-likely labels as targets (challenging target selection). Higher value indicates better attack performance. The perturbation budget is $\varepsilon = 8$.

Transform parameter	Classifier model ASR(%) ↑							
	VGG19	ResNet50	Dense121	Incv3	Mobv2	ViT-L-16	ViT-L-32	Swin-T
$S = 0.5$	98.60	89.60	92.10	77.70	96.20	81.70	65.40	99.40
$S = 1.0$	100.0	99.70	99.70	91.00	100.0	95.40	85.80	100.0
$S = 1.5$	100.0	99.40	99.00	82.50	99.80	91.80	78.00	100.0
Average	99.53	96.23	96.93	83.73	98.67	89.63	76.40	99.80
$\sigma = 0.5$	100.0	99.80	99.90	90.60	99.80	94.40	88.70	100.0
$\sigma = 1.5$	99.30	96.90	98.20	77.70	95.80	74.80	65.60	98.90
$\sigma = 3.0$	99.40	95.60	98.20	74.50	94.20	71.20	55.90	99.10
Average	99.57	97.43	98.77	80.93	96.60	80.13	70.07	99.33
$\gamma = 0.5$	100.0	99.60	99.80	91.90	99.90	98.40	90.90	99.80
$\gamma = 1.0$	100.0	99.90	100.0	90.70	99.90	94.40	88.00	99.70
$\gamma = 2.0$	100.0	99.60	99.70	89.10	99.70	85.60	76.80	99.90
Average	100.0	99.70	99.83	90.57	99.83	93.47	85.23	99.80
$Q = 20$	84.20	89.00	65.60	62.20	82.90	79.60	73.70	83.00
$Q = 50$	95.80	97.00	88.70	74.40	95.20	86.00	79.70	96.60
$Q = 80$	98.80	98.90	96.00	79.50	97.90	88.80	79.40	99.80
Average	92.93	94.97	83.43	72.03	92.00	84.80	77.60	93.13

additional geometric transforms as examples — flipping and perspective transforms, to further demonstrate its flexibility.

B.1 Flip-triggered attack

In our examination of flip-triggered attacks, we explore three specific targeted scenarios designed to activate upon the network's receipt of images subjected to vertical flip, horizontal flip, and no flip (retaining their original orientation) as inputs. The findings, as detailed in Tab. 10, reveal a notable efficacy of these flip-triggered attacks, achieving an ASR of 90% across the majority of evaluated models.

Table 10: Flip-triggered targeted attack success rate (ASR). ASRs are reported at each target flip version of image and average over all three flipping methods. Higher value indicates better attack performance. The perturbation budget is $\varepsilon = 8$. Below is the model classification accuracy (ACC) evaluation over flipped clean images without perturbation.

Flip method	Classifier model							
	VGG19	ResNet50	Dense121	Incv3	Mobv2	ViT-L-16	ViT-L-32	Swin-T
ASR (%) ↑								
None	100.0	99.70	99.90	92.10	100.0	93.40	85.50	100.0
Horizontal	100.0	99.90	99.80	91.70	100.0	92.80	87.20	100.0
Vertical	100.0	99.80	99.90	97.70	100.0	96.10	91.40	100.0
Average	100.0	99.80	99.87	93.83	100.0	94.10	88.03	100.0
ACC (%) ↑								
None	100.0	100.0	100.0	100.0	87.60	100.0	100.0	96.00
Horizontal	93.20	94.20	96.20	80.60	87.90	98.30	96.40	96.10
Vertical	55.00	57.40	62.00	39.30	53.10	72.80	54.80	78.00
Average	82.73	83.87	86.07	73.30	76.20	90.37	83.73	90.03

B.2 View perspective-triggered attack

Here, we introduce perspective-triggered attacks to mimic the variability encountered when taking photos from different angles. We categorize these variations into three predefined perspectives: viewing the subject from the front, from above, and from below, labeled as perspectives 1, 2, and 3, respectively. Specifically, perspective 1 maintains the image in its original state, illustrating a front-facing viewpoint. Perspective 2

Table 11: Perspective-triggered targeted attack success rate (ASR). ASRs are reported at each target flip version of image and average over all three flipping methods. Higher value indicates better attack performance. The perturbation budget is $\varepsilon = 8$. Below is the model classification accuracy (ACC) evaluation over perspective transformed clean images without perturbation.

Perspective	Classifier model							
	VGG19	ResNet50	Dense121	Incv3	Mobv2	ViT-L-16	ViT-L-32	Swin-T
				ASR (%) ↑				
1	100.0	99.70	100.0	92.90	100.0	96.70	91.30	100.0
2	99.80	99.20	99.40	87.70	100.0	83.30	71.30	99.90
3	99.90	99.50	99.10	92.50	100.0	83.80	69.20	100.0
Average	99.90	99.47	99.50	91.03	100.0	87.93	77.27	99.97
				ACC (%) ↑				
1	90.80	93.20	94.50	79.90	87.90	92.70	89.90	96.10
2	72.10	72.10	73.50	53.00	65.30	87.80	79.30	91.30
3	73.60	75.40	74.10	57.90	63.50	87.50	78.20	92.10
Average	78.83	80.23	80.70	63.60	72.23	89.33	82.47	93.17

simulates a downward view by transforming the image axis from {(0,0), (223,0)} to {(56,56), (168,56)}, and perspective 3 simulates an upward view by altering the image axis from {(0,223), (223,223)} to {(56,168), (168,168)}.

The results, as noted in Tab. 11, demonstrate the effectiveness of these perspective-triggered attacks, with targeted strategies achieving an overall ASR of over 90% when images are presented from these varied perspectives.

C Accuracy evaluations

In section 4.2 of our main paper, we presented targeted attacks designed to exploit vulnerabilities specific to scaling, blurring, gamma correction, and JPEG compression. To distinguish the adversarial effects from mere consequences of image transformations, we evaluate Attack Success Rate (ASR) across a diverse set of models: {`VGG-19-BN, ResNet50, DenseNet-121, InceptionV3, ViT-L-16, ViT-L-32, Swin-T`}.

To further investigate model sensitivity to transformations, Tab. 12 reports classification accuracy on clean images subjected to the same transformations used in attack generation. While most models maintain high accuracy (e.g., over 80%), one architecture, `InceptionV3`, exhibits notable sensitivity, with accuracy dropping to 69.70%. We mitigate this influence in our experiment by experimenting on sufficiently diverse set of models, and image transformations, and dataset contains larger number of instances, following similar principle to prior adversarial works that utilize image transformation for adversarial examples generation discussed in section 2.2.

D Memory and computation resources

We used a single NVIDIA RTX 2080Ti (12 GB) for all the experiments. Average times for generating $\{3, 5, 10\}$ target attacks are $\{2.61, 4.29, 8.67\}$ sec/image, with EOT over 3 samples for each $\bar{\theta}_i$ in Eq.(3). The cost scales roughly linearly with N since each iteration computes one forward-backward pass per transform-target pair. Within each pair, EOT sampling (drawing multiple θ samples from $\mathcal{N}_r(\bar{\theta}_i)$) adds a constant factor per pair. In practice, we found that modest neighborhood sizes ($r = 0.1$) with a few samples suffice for robust trigger zones (as confirmed by the smooth loss valleys in Fig. 2), so the EOT overhead is small relative to the multi-target cost.

Table 12: Clean accuracy (ACC) evaluation over selected classification models. Higher value indicating lower classification error introduced by the image transformation.

Transform parameter	Classifier model							
	VGG19	ResNet50	Dense121	Incv3	Mobv2	ViT-L-16	ViT-L-32	Swin-T
$S = 0.5$	66.00	69.20	62.20	29.30	56.10	89.10	83.00	78.30
$S = 1.0$	100.0	100.0	100.0	100.0	87.90	100.0	100.0	96.10
$S = 1.5$	87.80	90.40	92.00	79.80	83.60	97.80	96.40	92.50
Average	84.60	86.53	84.73	69.70	75.87	95.63	93.13	88.97
$\sigma = 0.5$	94.20	95.80	96.90	91.50	88.10	98.30	96.90	94.70
$\sigma = 1.5$	71.00	76.50	78.30	67.00	60.30	88.20	81.90	81.10
$\sigma = 3.0$	64.60	74.10	75.80	61.10	58.50	85.90	78.40	79.10
Average	76.60	82.13	83.67	73.20	68.97	90.80	85.73	84.97
$\gamma = 0.5$	91.90	92.30	95.80	85.00	82.80	94.40	92.70	93.70
$\gamma = 1.0$	100.0	100.0	100.0	100.0	87.90	100.0	100.0	96.10
$\gamma = 2.0$	90.90	90.70	92.80	80.60	82.40	91.80	88.60	95.00
Average	94.27	94.33	96.20	88.53	84.37	95.40	93.77	94.93
$Q = 20$	71.30	78.20	84.10	68.90	69.80	81.70	83.30	65.90
$Q = 50$	82.10	86.10	89.60	75.50	77.10	87.50	88.00	82.30
$Q = 80$	87.30	89.50	92.10	78.00	84.80	91.20	89.40	89.00
Average	80.23	84.60	88.60	74.13	77.23	86.80	86.90	79.07

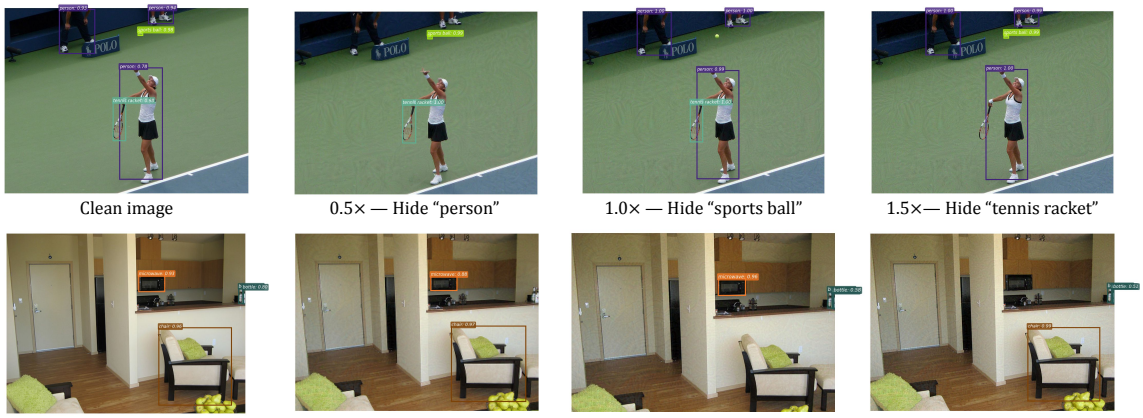

Figure 7: Visualization of scale-triggered selective hiding attack against YOLOv3. The first column shows detection results on the original clean image, while the following columns present perturbed images scaled with factors $S \in \{0.5, 1.0, 1.5\}$ (perturbation $\|\delta\|_\infty \leq 10$). *Note that scaled images will have different sizes after scaling, but we present their resized versions for better display.*

E More threat models against object detector

Beside the transform-selective hiding threat model discussed in Sec. 4.3, here we present another **threat model: object-selective hiding.** We design a scenario where specific object classes are hidden when images are displayed at different scales, simulating real-world applications such as privacy-preserving surveillance or content-adaptive filtering. For example, certain sensitive objects (e.g., license plates or faces) could be concealed at lower resolutions in public monitoring systems, while critical details remain visible at higher resolutions for authorized analysis. In this setup, we use images containing three distinct classes and aim to hide objects from one of these classes for each transform parameter. We focus on scaling with factors $S \in \{0.5, 1.0, 1.5\}$. The attack conceals objects from class A at 0.5×, class B at 1.0×, and class C at 1.5×. ASR is measured as the ratio of successfully hidden objects in the detections for each scaled input.

Tab. 13 show that on most of R-CNN-based detectors, the scale-triggered attacks are successfully triggered when adversarial examples scale to the predefined image size, with average ASR over 66%. In Fig. 7, we

Table 13: Quantitative evaluation of scale-triggered selective hiding attack success rate (ASR) over object detection models. The higher value indicates better attack performance. Our attack formulation is generalizable to more complex object detection task.

Scaling factor	Detector model ASR (%) ↑ $\|\delta\|_\infty \leq 10$					Detector model ASR (%) ↑ $\|\delta\|_\infty \leq 20$				
	Faster	YOLOv3	FCOS	GRID	DETR	Faster	YOLOv3	FCOS	GRID	DETR
$S = 0.5$	53.85	97.39	71.61	54.44	11.91	60.26	97.39	76.39	67.22	17.16
$S = 1.0$	65.71	95.10	69.38	58.89	11.95	72.76	98.04	79.26	68.52	23.61
$S = 1.5$	90.71	32.35	100.0	86.11	41.26	96.15	40.98	100.0	97.78	52.18
Average	70.09	74.95	80.33	66.48	21.71	76.39	78.80	85.22	77.84	30.98

showcase successful examples of object-selective hiding. The scale-triggered perturbations effectively obscure the targeted class when the perturbed image is resized to the predefined scaling factors used in transform-aware optimization, demonstrating precise control over object concealment.

F More visual examples

For enhanced qualitative evaluation, we offer additional visual examples showcasing successful transform-triggered adversarial examples against image classification models in Fig. 8 and Fig. 9. Moreover, we present further examples of object-selective hiding attacks against object detection models in Fig. 10, Fig. 11, and Fig. 12. For transform-selective hiding attacks against detectors, which we demonstrate as a defense mechanism against image enhancement (Fig. 3 in the main text). In the supplementary material, we include animations in `.gif` format to illustrate how object detectability changes dynamically under different enhancement transformations.

Attacks against classifiers. The examples in Fig. 8 and Fig. 9 illustrate that with imperceptible noise perturbation, an image can be misclassified as multiple target labels when subjected to specific image transformations.

Attacks against detectors. In the scenario of object-selective hiding attacks, consider the images in the first row of Fig. 10 as an illustration. It demonstrates that in the clean image, objects labeled as three distinct categories (*person, ski*, and *snowboard*) are detected. However, upon adding scale-triggered perturbations, objects labeled as one of these categories become hidden in three differently scaled versions of perturbed images, as depicted in the titles: 0.5× — *Hide "person"*, 1.0× — *Hide "ski"*, and 1.5× — *Hide "snowboard"*.

In the scenario of transform-selective hiding attacks, we simulate image enhancement processes—zoom-in, deblur, and gamma correction—applied to raw images initially presented as distant scenes, blurry images, or low-light conditions. The animations included in the submission illustrate the effectiveness of our transform-triggered examples: objects remain detectable in unaltered images but become concealed when the images undergo enhancement. This demonstrates the perturbation's ability to selectively obscure objects under specific transformations while preserving detectability close to the original, non-perturbed state.

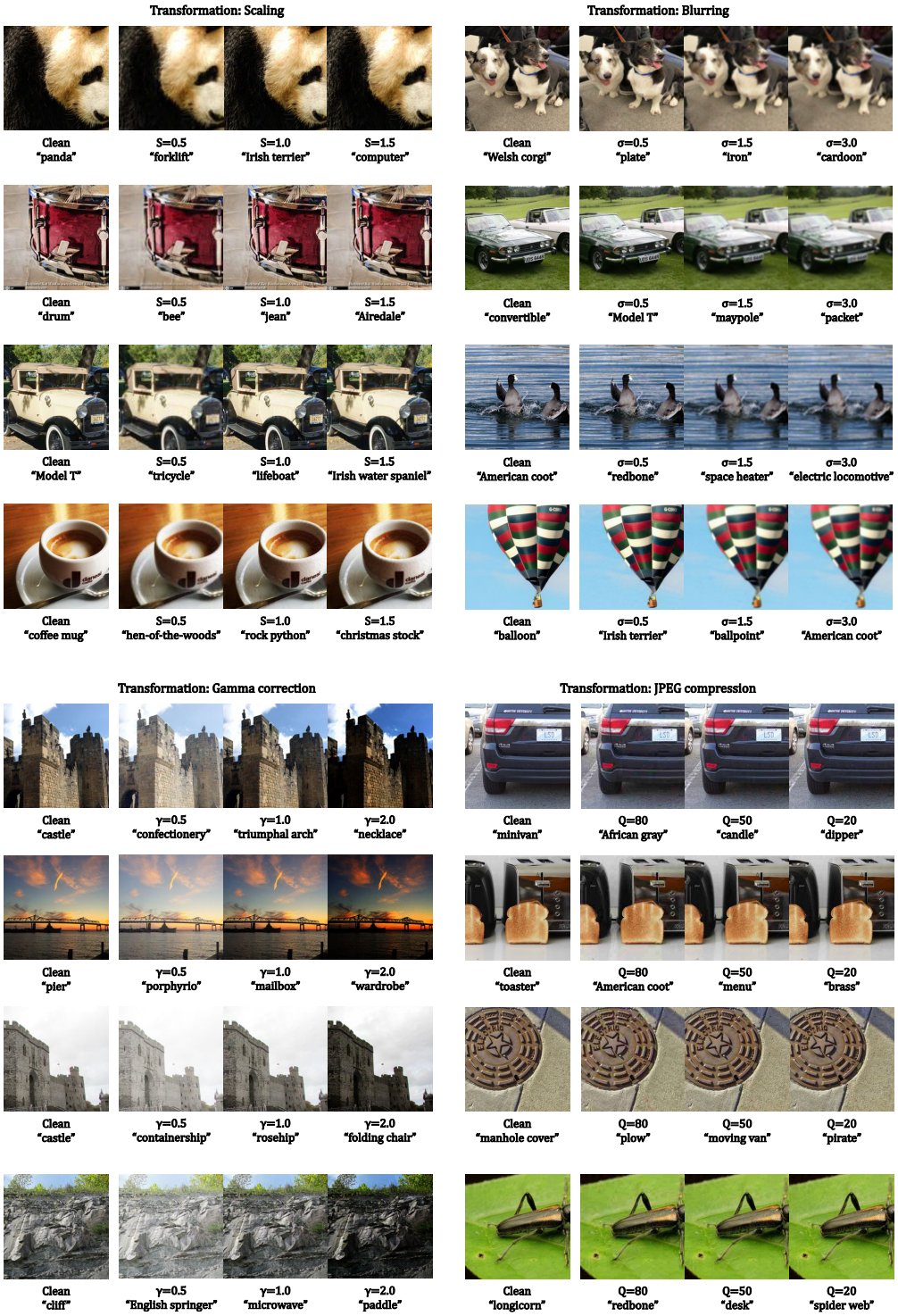

Figure 8: Visualize examples for transform-dependent attacks against image classifiers. In this figure, we show visual effects of clean image and the perturbed images transformed with different parameters.

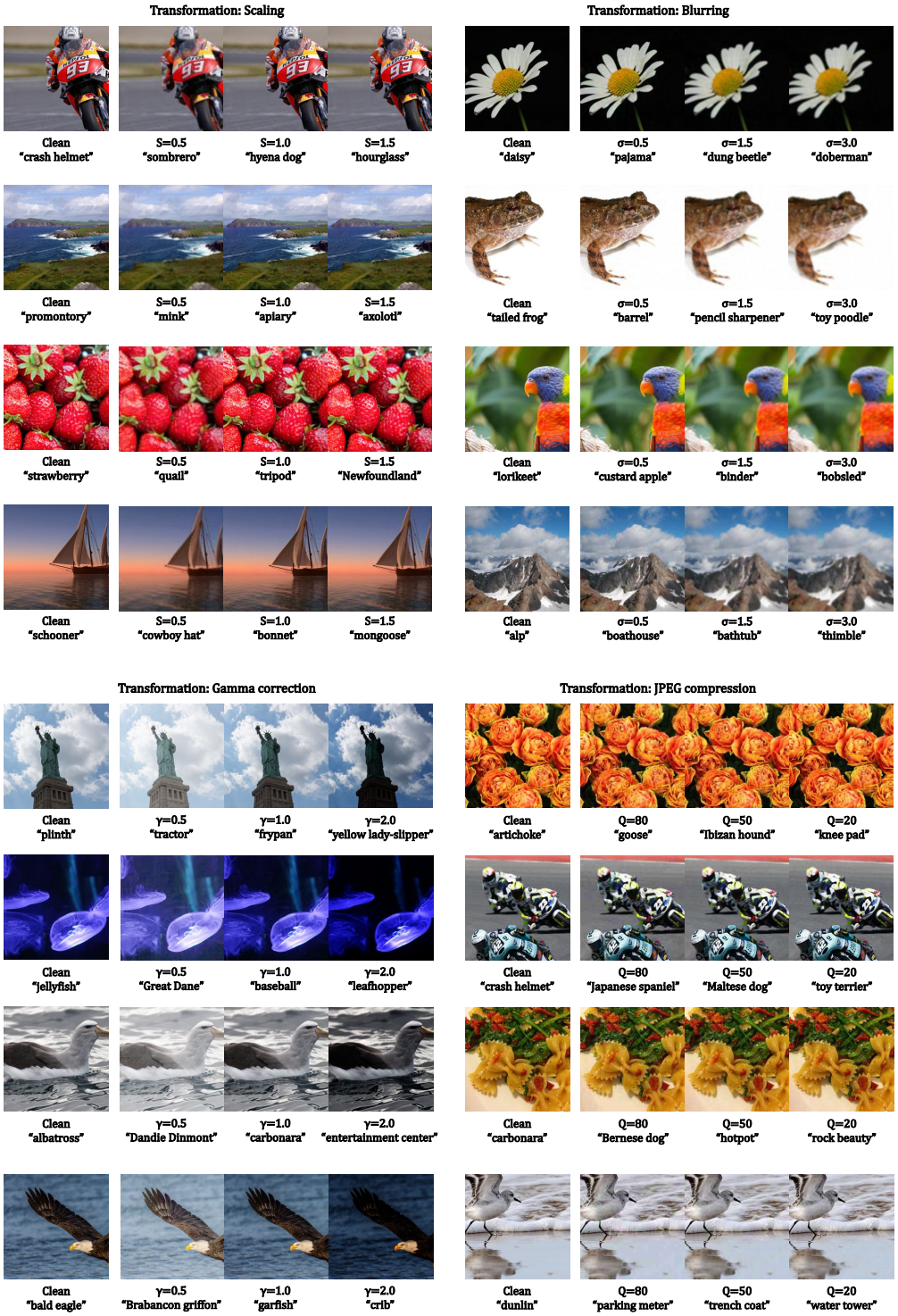

Figure 9: Visualize examples for transform-dependent attacks against image classifiers. In this figure, we show visual effects of successful attacks under different image transformations with different transform parameters.

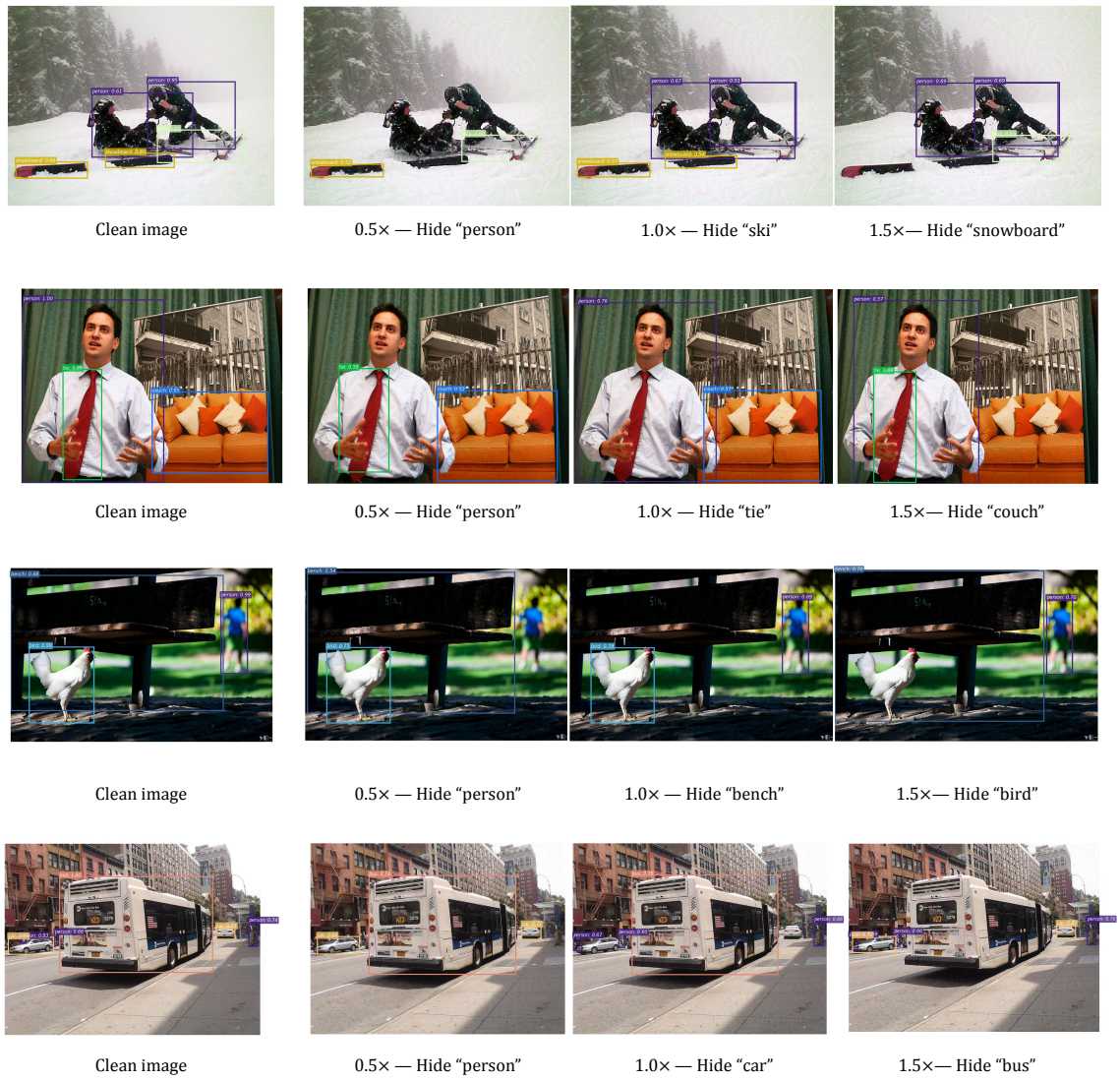

Figure 10: Visualize examples of scale-dependent selective hiding attacks against object detection model `FCOS`. From top to button, `ImageIDs: 000000142790, 000000170099, 000000197870, 000000338625`. Note, images labeled as $0.5, 1.5\times$ are in resolutions different from the original image, and they are resized to the same size for better display.

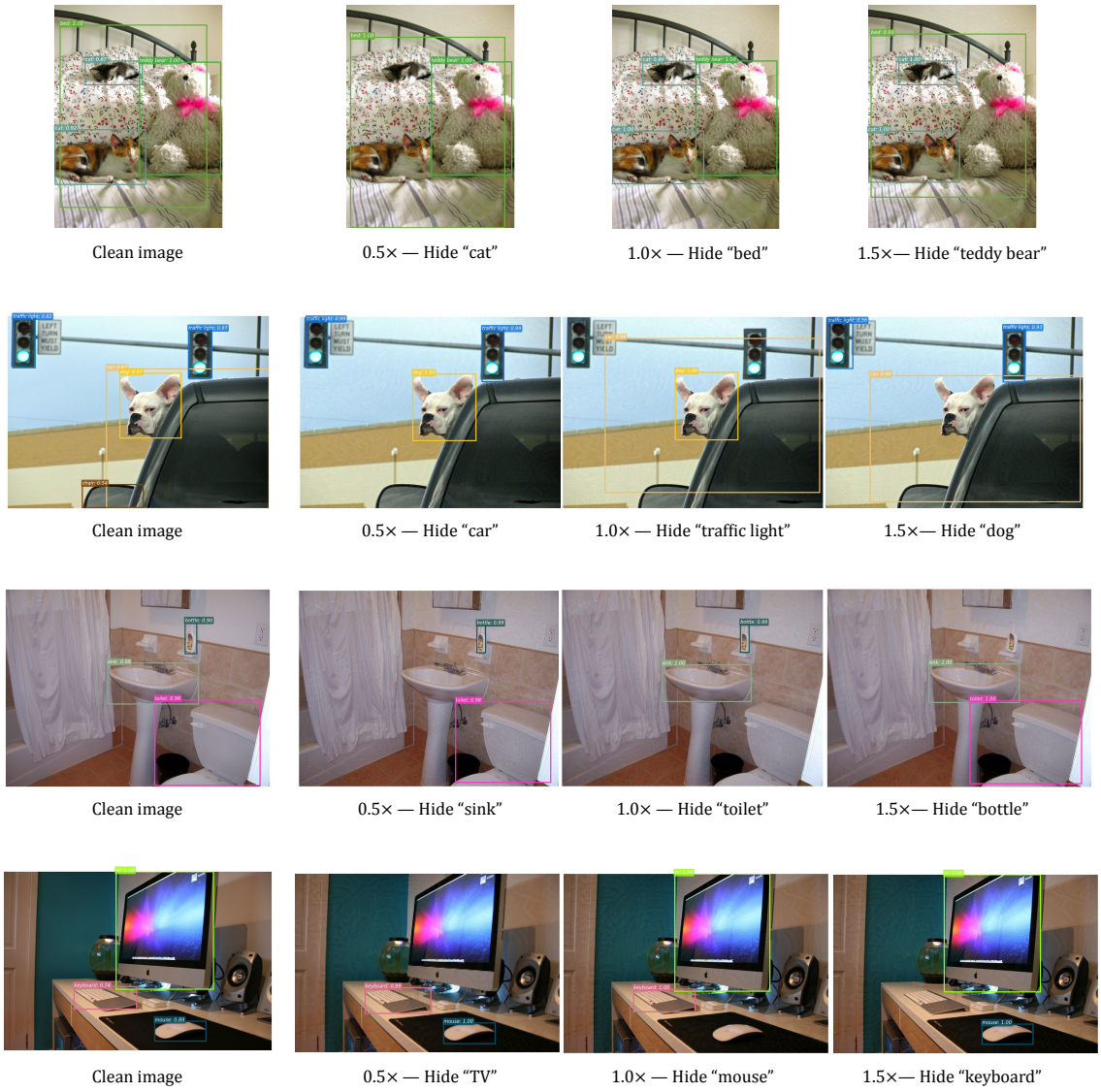

Figure 11: Visualize examples of scale-dependent selective hiding attacks against object detection model `YOLOv3`. From top to button, `ImageIDs: 000000478393, 000000076417, 000000167898, 000000186282`. Note, images labeled as $0.5, 1.5\times$ are in resolutions different from the original image, and they are resized to the same size for better display.

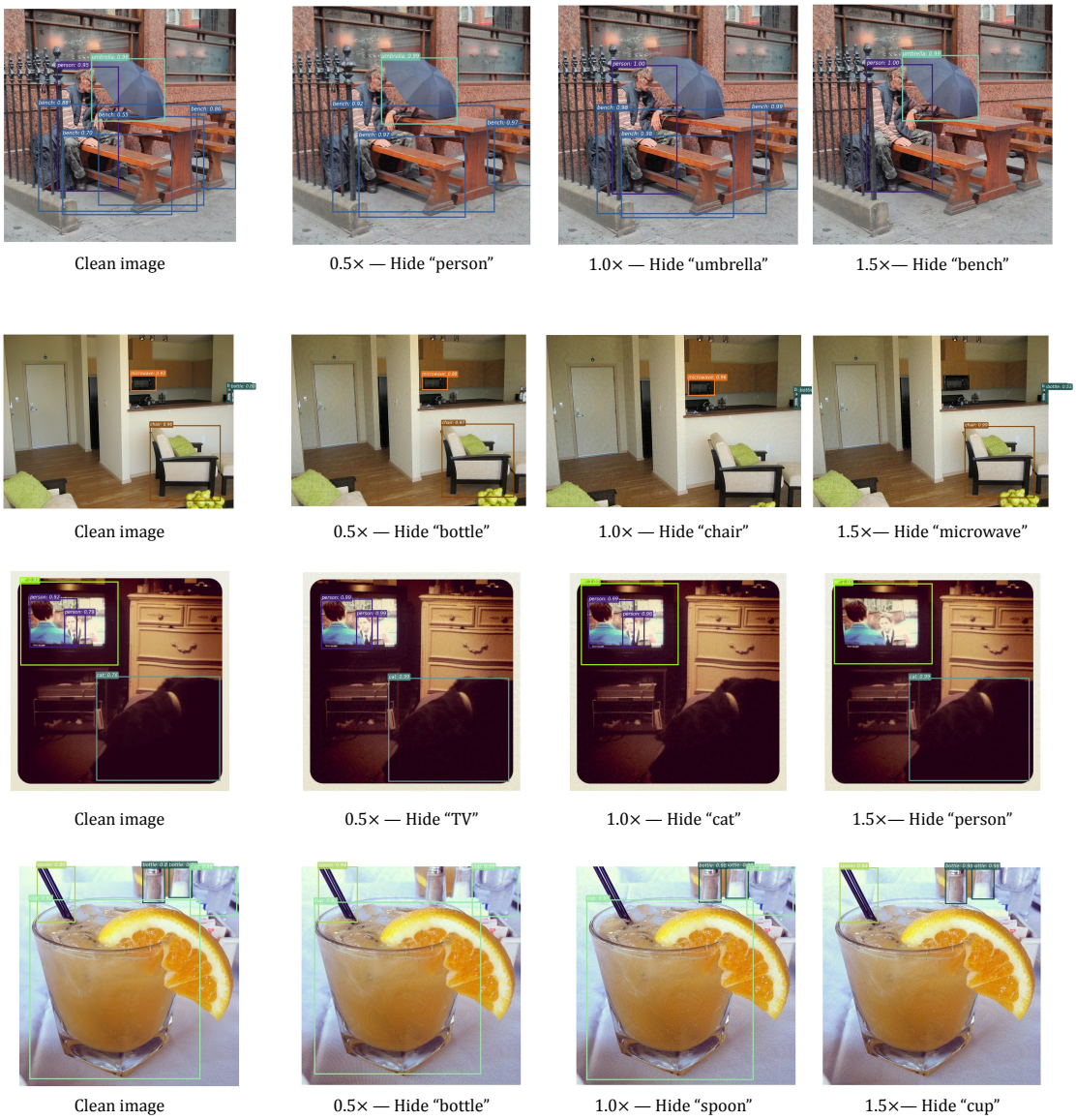

Figure 12: Visualize examples of scale-dependent selective hiding attacks against object detection model `Faster R-CNN`. From top to button, `ImageIDs: 000000455157, 000000488075, 000000169076, 000000463283`. Note, images labeled as $0.5, 1.5\times$ are in resolutions different from the original image, and they are resized to the same size for better display.