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BENCHMARKING GENERATIVE AI MODELS FOR DEEP LEARNING TEST INPUT GENERATION

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SERICS
SECURITY AND RIGHTS IN THE CYBERSPACE

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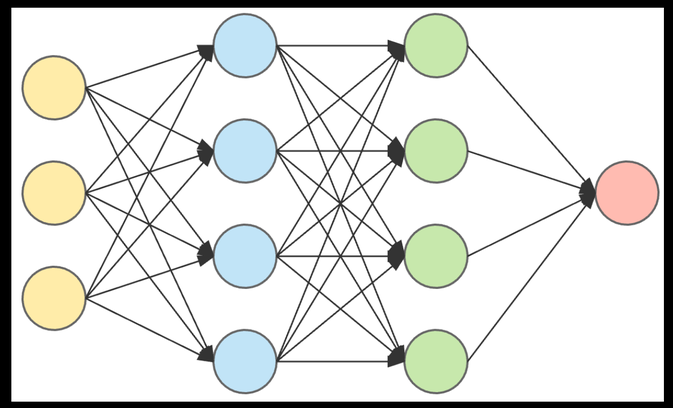
DNN ASSESSMENT

ORIGINAL DATASET



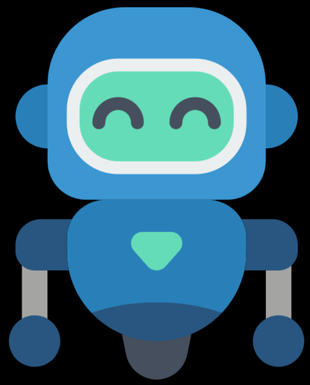
DNN UNDER TEST

ACC = 0.95

PERFORMANCE METRIC

Problem: What is the performance of a DNN for inputs beyond its original dataset?

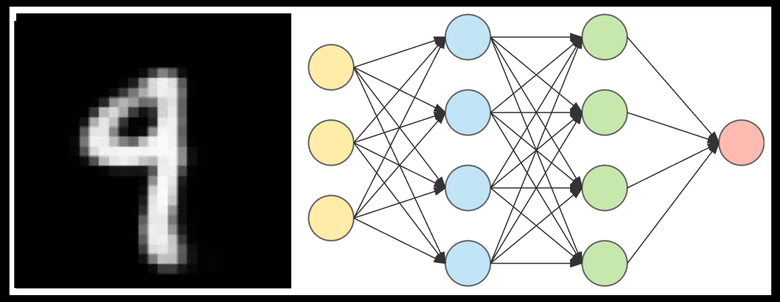
AUTOMATED TEST INPUT GENERATION FOR DNNS



TEST GENERATOR

Target Label

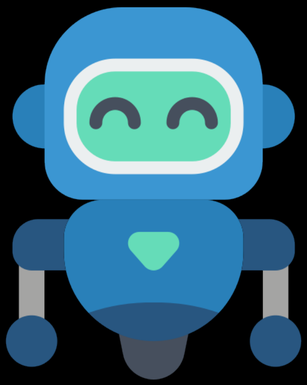
9



Predicted Label

4 ✗

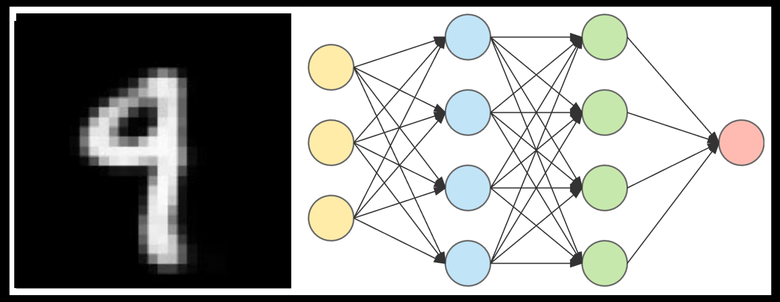
AUTOMATED TEST INPUT GENERATION FOR DNNS



TEST GENERATOR

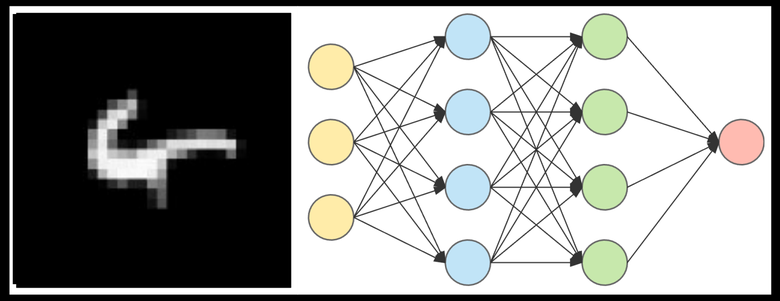
Target Label

9



Predicted Label

4 ✗



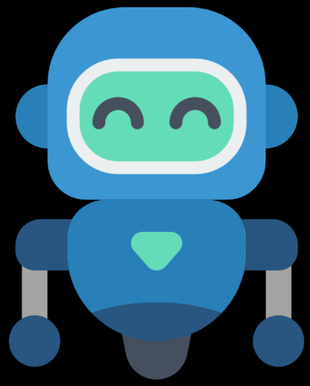
Predicted Label

4 ✗

Problem #1:

invalid inputs, not recognisable by domain experts in the input domain

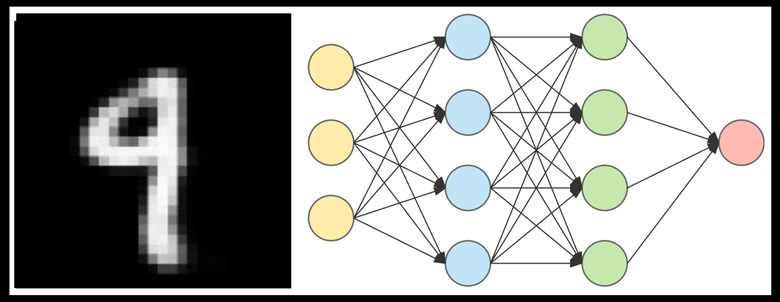
AUTOMATED TEST INPUT GENERATION FOR DNNS



TEST GENERATOR

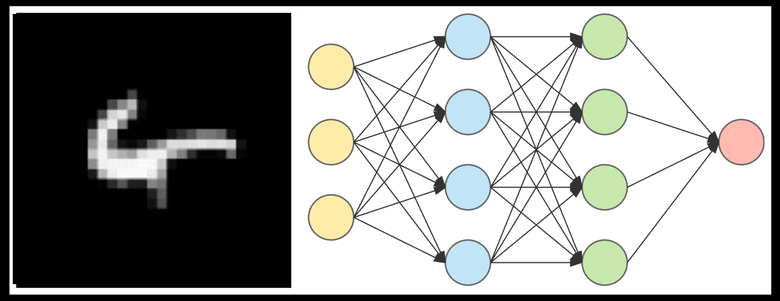
Target Label

9



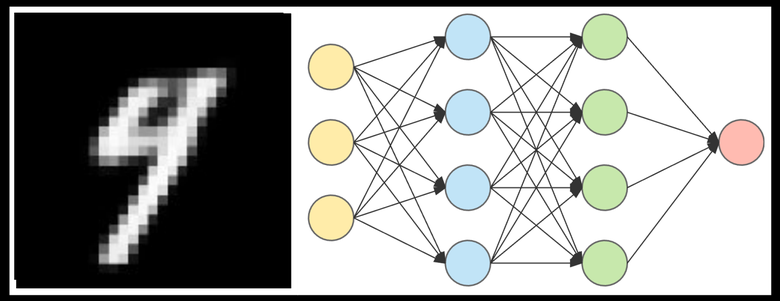
Predicted Label

4 ✗



Predicted Label

4 ✗



Predicted Label

4 ✗

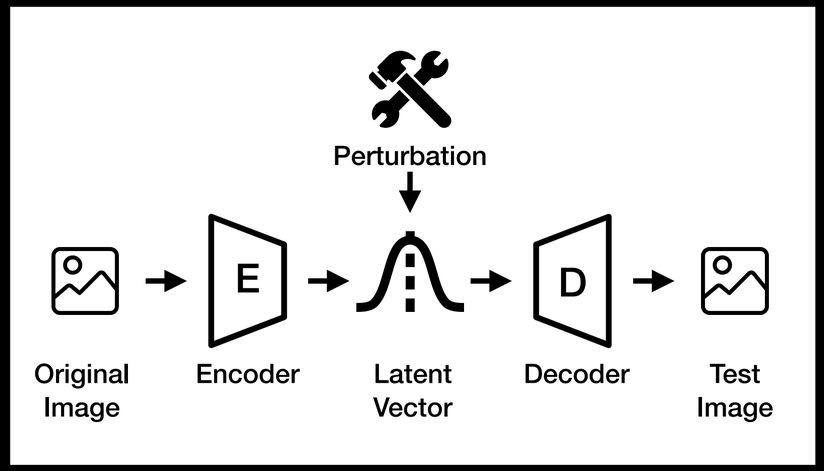
Problem #1:

invalid inputs, not recognisable by domain experts in the input domain

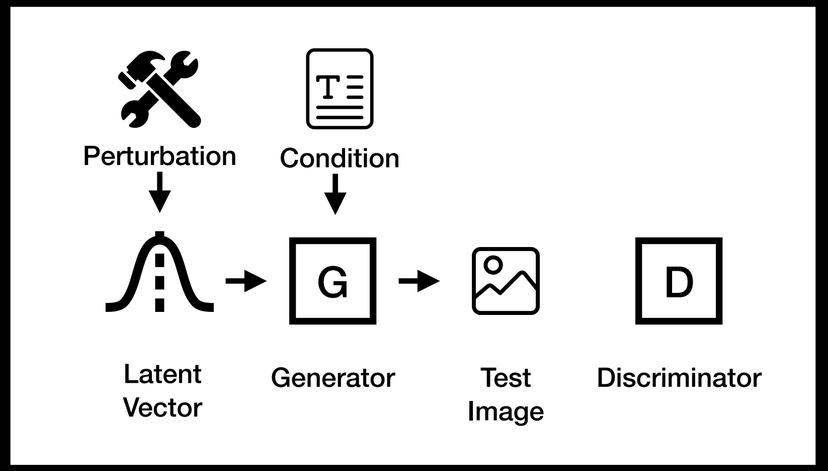
Problem #2:

original label is not preserved

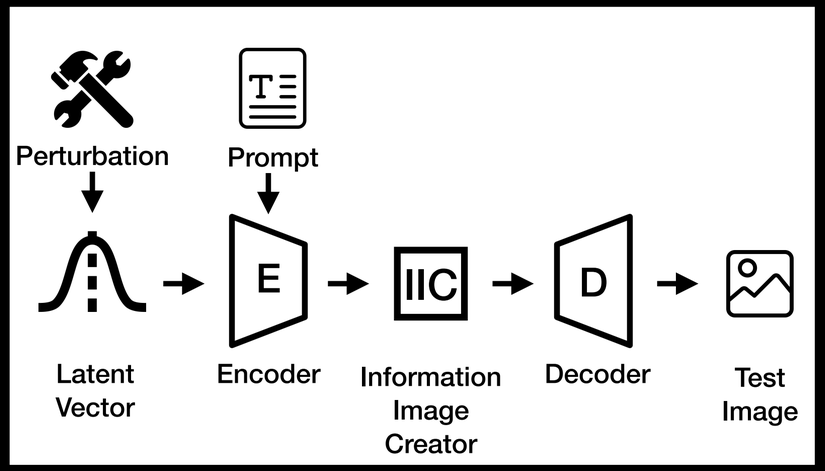
GENERATIVE AI MODELS



Variational AutoEncoder (VAE)

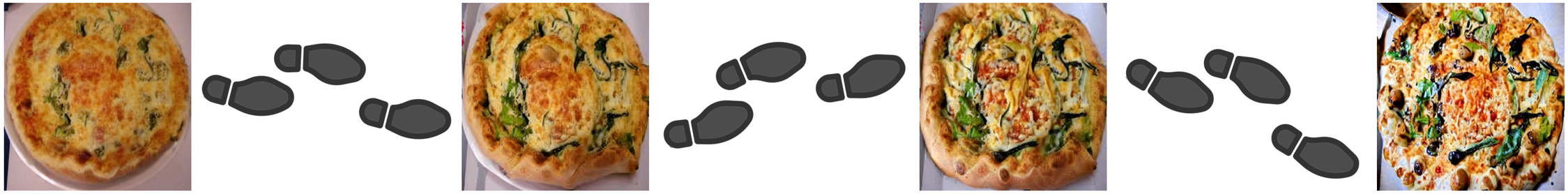


Generative Adversarial Network (GAN)



Diffusion Model (DM)

RANDOM WALK IN THE LATENT SPACE



GENETIC ALGORITHM

Seed Generation

Population

VAE: Image fed to the Encoder

GAN: Sample from target distribution + target label

DM: Sample from target distribution + prompt

GENETIC ALGORITHM

Seed Generation

Population

Crossover and Mutation in the Latent Space

Mutation: Random Latent Walk

Crossover: One-Point Crossover of Latent Vectors

Constraint: Clamping Vectors to Target Distribution

GENETIC ALGORITHM

Seed Generation

Population

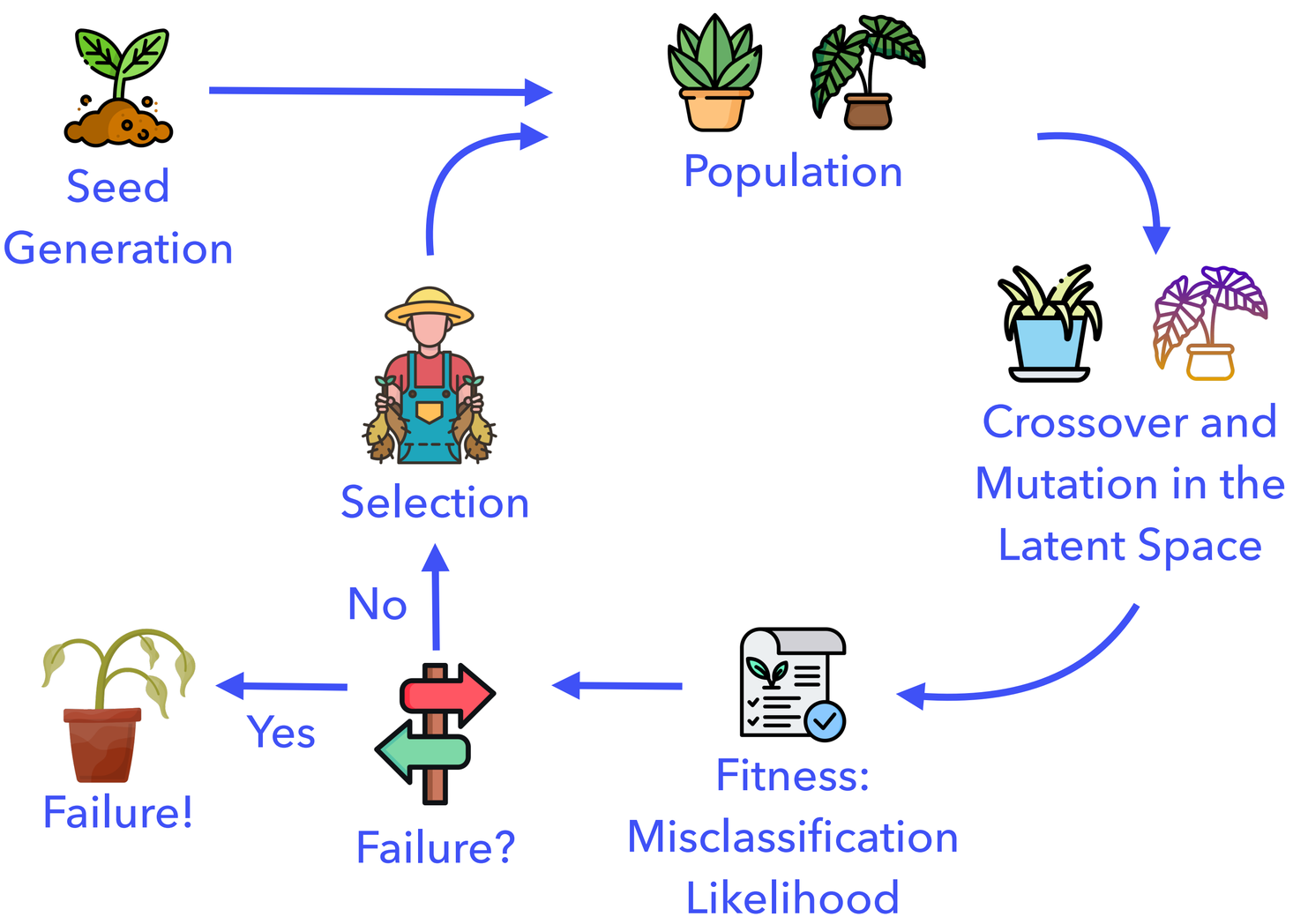
Crossover and Mutation in the Latent Space

Fitness: Misclassification Likelihood

Evaluation of generated images on the DNN under test

Compares confidence assigned to the target class VS other classes

GENETIC ALGORITHM



Termination Conditions

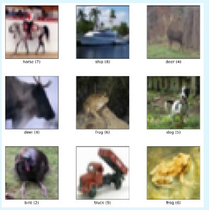
Misclassification detected

Search budget exhausted

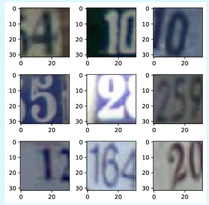
EVALUATION BENCHMARK

DATASETS

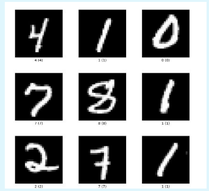
Imagenet



CIFAR-10



SVHN



MNIST

Complexity

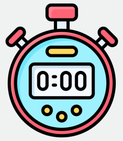
Generative AI models

Genetic Algorithm

DNN Under Test

SETUP

Small VS large perturbation step



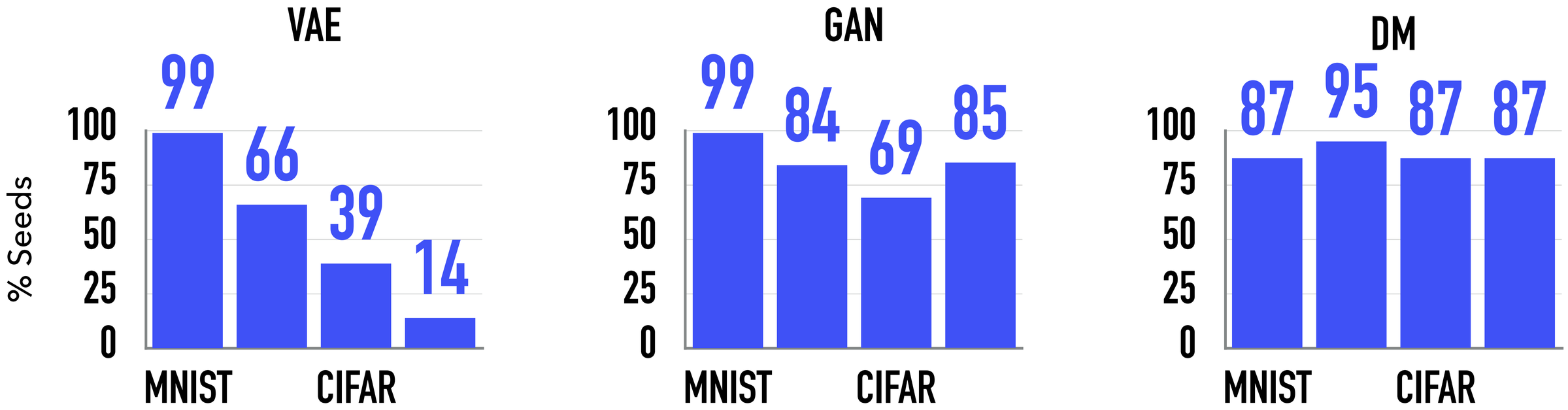
Fixed search budget

METRICS

Effectiveness:
Valid label-preserving misclassification -inducing inputs

Efficiency:
Iterations

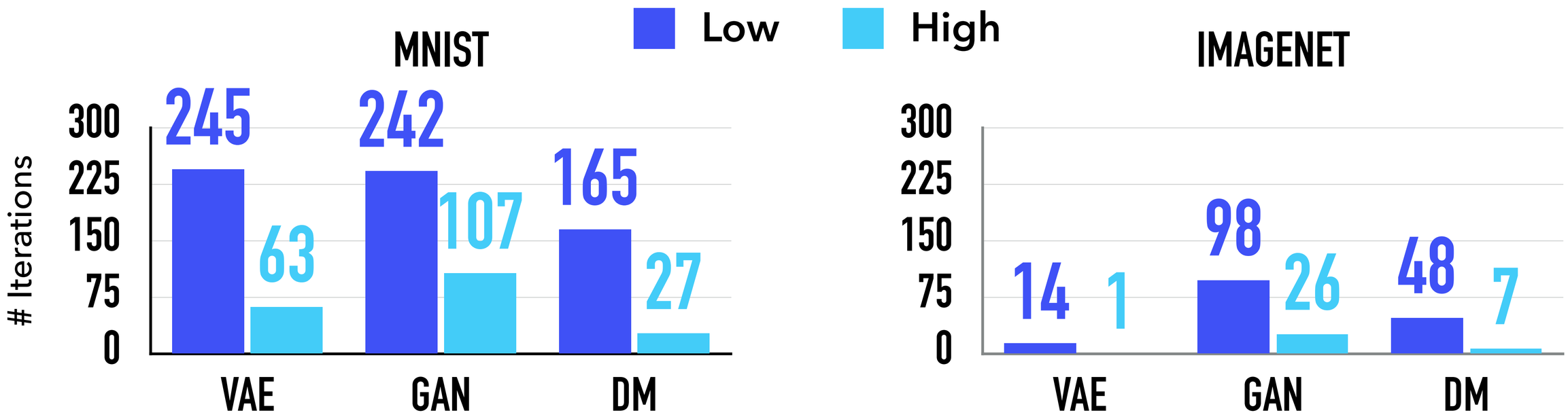
SEED GENERATION



VAE performance declined as dataset complexity increased

GAN and DMs consistently achieved high accuracy in seed generation, regardless of complexity

ITERATIONS TO TRIGGER A FAILURE



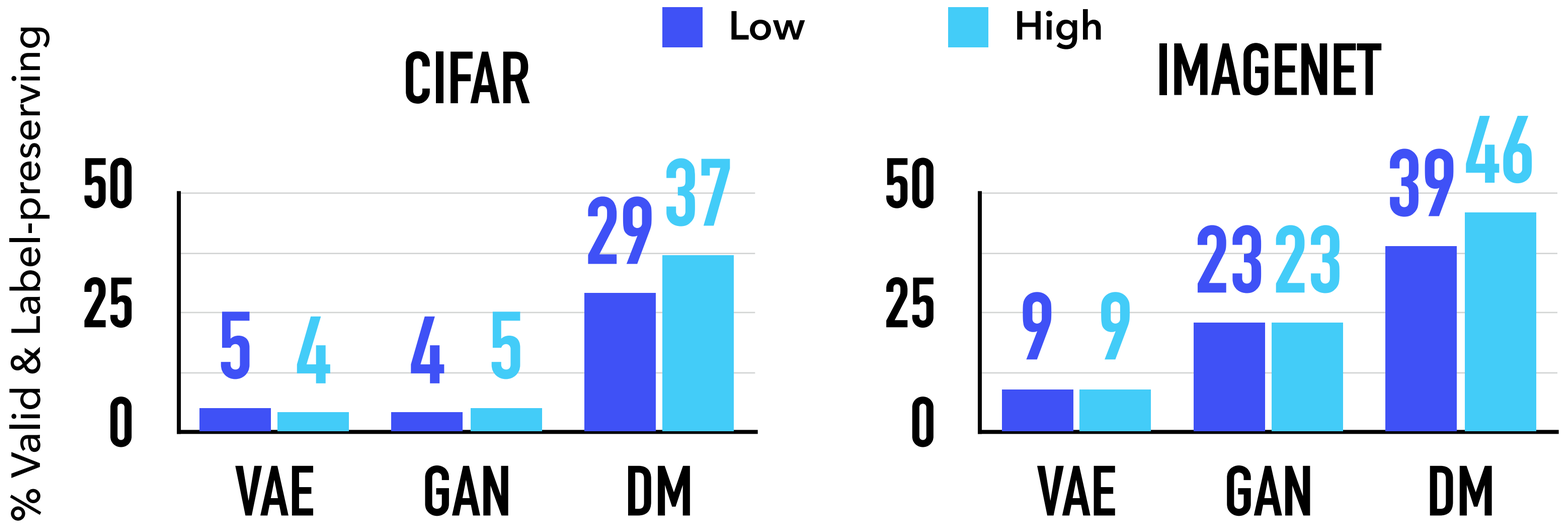
VAEs need less iterations than other GenAI models for complex datasets, while DMs are the most efficient for simpler datasets

Increased perturbations reduce the number of iterations

VALIDITY AND LABEL PRESERVATION

364 Human assessors from

amazon mechanical turk



DMs excel at generating valid misclassification-inducing inputs for complex datasets like CIFAR-10 and ImageNet

KEY INSIGHTS

- Diffusion Models excel in complex tasks, but their superior performance comes at a higher cost

INFERENCE TIME 10X HIGHER FOR DM VS VAE

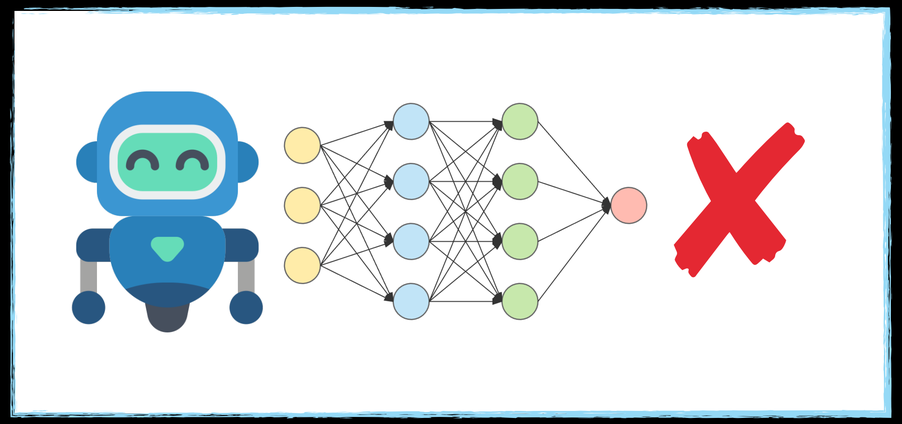
- Larger perturbation extents speed up test generation without compromising input validity or label preservation

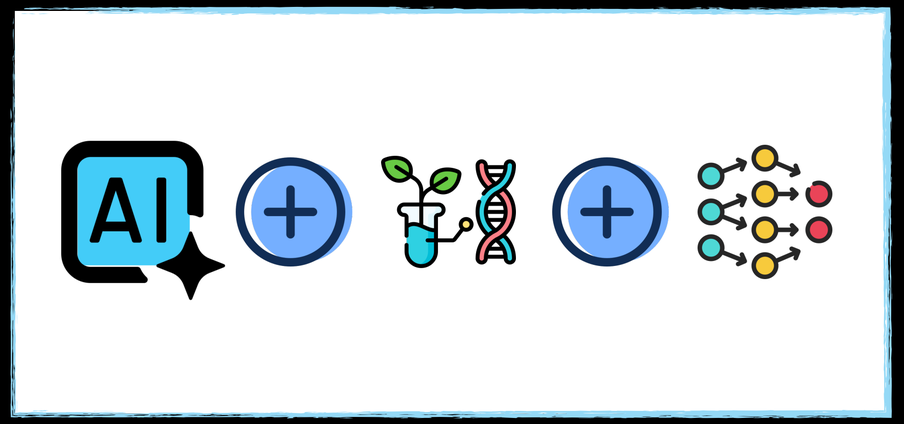
DMS UP TO 10X MORE EFFICIENT FOR IMAGENET AND SVHN

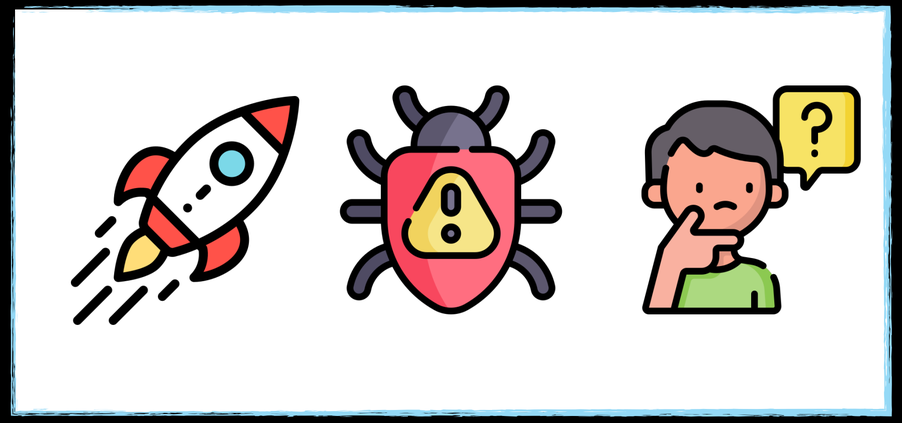
- Latent vectors should be carefully constrained and carefully manipulated

AT MOST ONLY 15% MISCLASSIFICATIONS FOR SVHN ARE VALID AND PRESERVE THE LABEL

BENCHMARKING GENERATIVE AI MODELS FOR DEEP LEARNING TEST INPUT GENERATION







Icons from www.flaticon.com

EXTRA SLIDES

TABLE II

CHARACTERISTICS OF THE GENAI MODELS: LATENT VECTOR SIZE, TRAINING TIME UNTIL CONVERGENCE, AVERAGE INFERENCE TIME.

Dataset	**Model**	**LV size**	t_{train} **(min)**	t_{infer} **(ms)**
MNIST	VAE [49]	400	6	0.27
	GAN [50], [51]	100	9	0.7
	DM [52]	16384	405	960.68
SVHN	VAE [53]	800	93	4.07
	GAN [50], [51]	100	86	1.75
	DM [52]	16384	572	1213.49
CIFAR-10	VAE [53]	1024	423	2.51
	GAN [50], [51]	100	450	1.73
	DM [52]	16384	362	1903.29
ImageNet	VAE [54]	512	2521	11.92
	GAN [55]	128	21600	20.68
	DM [52]	16384	30	1945.77

TABLE III

COMPARISON BETWEEN GENAI TIGS ACROSS DIFFERENT DATASETS AND MUTATION EXTENTS IN TERMS OF VIABLE SEEDS, MISCLASSIFICATION-INDUCING INPUTS, NUMBER OF ITERATIONS TO GENERATE FAILURE, INPUT VALIDITY, AND LABEL PRESERVATION. THE BEST RESULTS ARE HIGHLIGHTED IN BOLD, WHILE THE UNDERLINED VALUES ARE NOT STATISTICALLY DIFFERENT FROM THE BEST.

Dataset	Pert. Step (δ_{init})	Model	% Seeds	% Misclass. (#)	# Iterations	% Validity (#)	% Preserved (#)
MNIST	Low	VAE	**99**	4.04 (4)	245.41	50.00 (2)	**100.00** (2)
		GAN	**99**	8.08 (8)	242.05	**75.00** (6)	83.33 (5)
		DM	87	**50.57** (**44**)	**164.61**	45.45 (**20**)	30.00 (**6**)
	High	VAE	**99**	**100.00** (**99**)	62.92	**73.74** (**73**)	49.32 (36)
		GAN	**99**	96.97 (96)	107.46	69.79 (67)	**62.69** (**42**)
		DM	87	**100.00** (87)	**26.77**	40.23 (35)	34.29 (12)
SVHN	Low	VAE	66	50.00 (33)	178.20	**51.52** (17)	41.18 (7)
		GAN	84	42.86 (36)	182.22	30.56 (11)	45.45 (5)
		DM	**95**	**69.47** (**66**)	**131.04**	39.39 (**26**)	**57.69** (**15**)
	High	VAE	66	**100.00** (66)	27.00	**39.39** (26)	30.77 (8)
		GAN	84	98.81 (83)	39.00	36.14 (**30**)	**50.00** (**15**)
		DM	**95**	**100.00** (**95**)	**13.23**	23.16 (22)	18.18 (4)
CIFAR-10	Low	VAE	39	82.05 (32)	118.90	53.13 (17)	29.41 (5)
		GAN	69	66.67 (46)	140.32	45.65 (21)	19.05 (4)
		DM	**87**	**89.66** (**78**)	**85.63**	**60.26** (**47**)	**61.70** (**29**)
	High	VAE	39	**100.00** (39)	19.51	30.77 (12)	33.33 (4)
		GAN	69	**100.00** (69)	25.78	31.88 (22)	22.73 (5)
		DM	**87**	**100.00** (**87**)	**14.18**	**62.07** (**54**)	**68.52** (**37**)
ImageNet (Teddy Bear)	Low	VAE	14	**100.00** (14)	**13.57**	78.57 (11)	**81.82** (9)
		GAN	85	**100.00** (85)	98.27	74.12 (63)	36.51 (23)
		DM	**87**	98.85 (**86**)	48.45	**91.86** (**79**)	49.37 (**39**)
	High	VAE	14	**100.00** (14)	**1.36**	**100.00** (14)	**64.29** (9)
		GAN	85	**100.00** (85)	26.38	83.53 (71)	32.39 (23)
		DM	**87**	**100.00** (**87**)	6.63	94.25 (**82**)	56.10 (**46**)
ImageNet (Pizza)	Low	VAE	25	**100.00** (25)	**12.96**	92.00 (23)	91.30 (21)
		GAN	**99**	88.00 (87)	172.88	88.51 (**77**)	46.75 (36)
		DM	73	97.26 (71)	83.60	**98.59** (70)	**92.86** (**65**)
	High	VAE	25	**100.00** (25)	**2.60**	80.00 (20)	75.00 (15)
		GAN	**99**	**100.00** (99)	47.93	86.87 (**86**)	51.16 (44)
		DM	73	**100.00** (73)	12.53	**100.00** (73)	**86.30** (**63**)

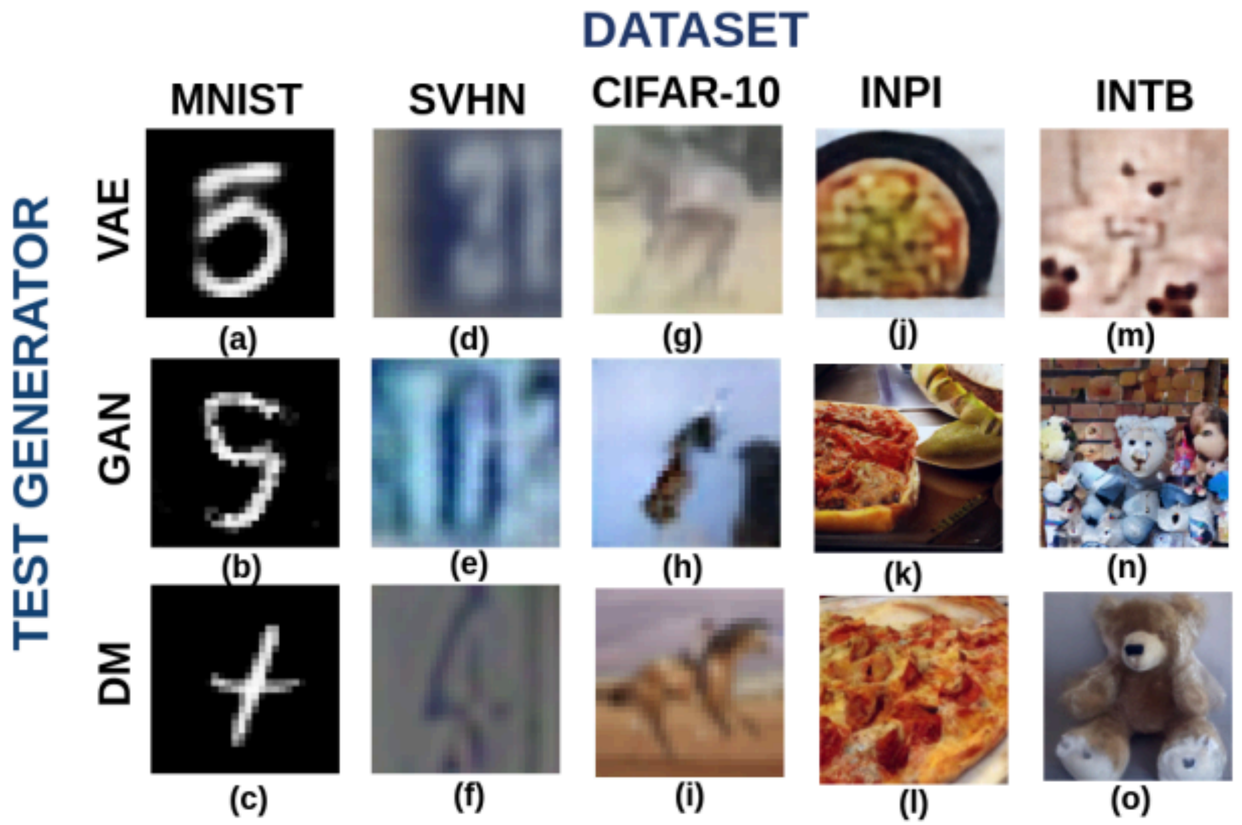


Fig. 3. Misclassification-inducing images generated by GenAI TIGs