Legible Robot Motion from Conditional Generative Models

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Motivation

Can we develop an end-to-end method that directly learns legible motion from offline demonstrations?

Legible Robot Motion [1]
- Intent expressive
- Improved safety
- Faster task completion

Learning from Demonstrations [2]
- Safe offline training
- Non-expert programming
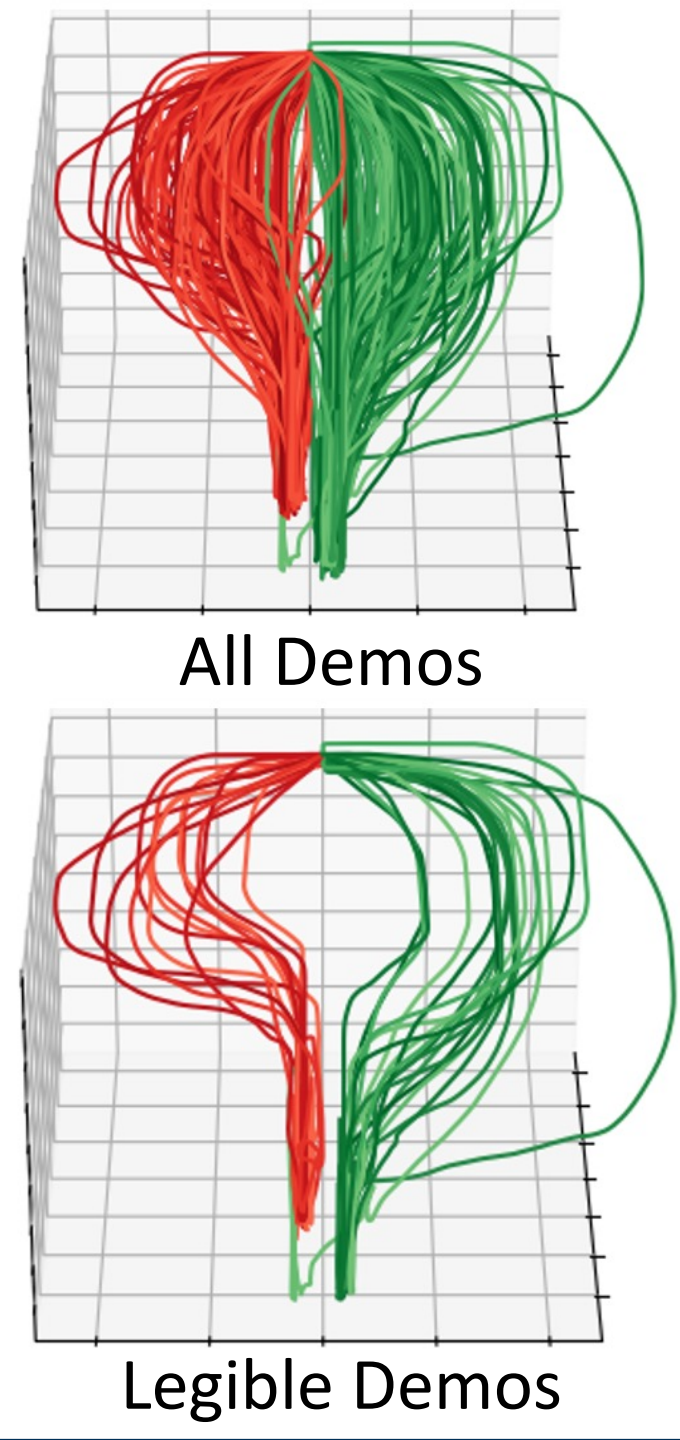- Highly scalable

Experiment

Training Dataset
- 280 multi-modal demonstrations of successful block lifts
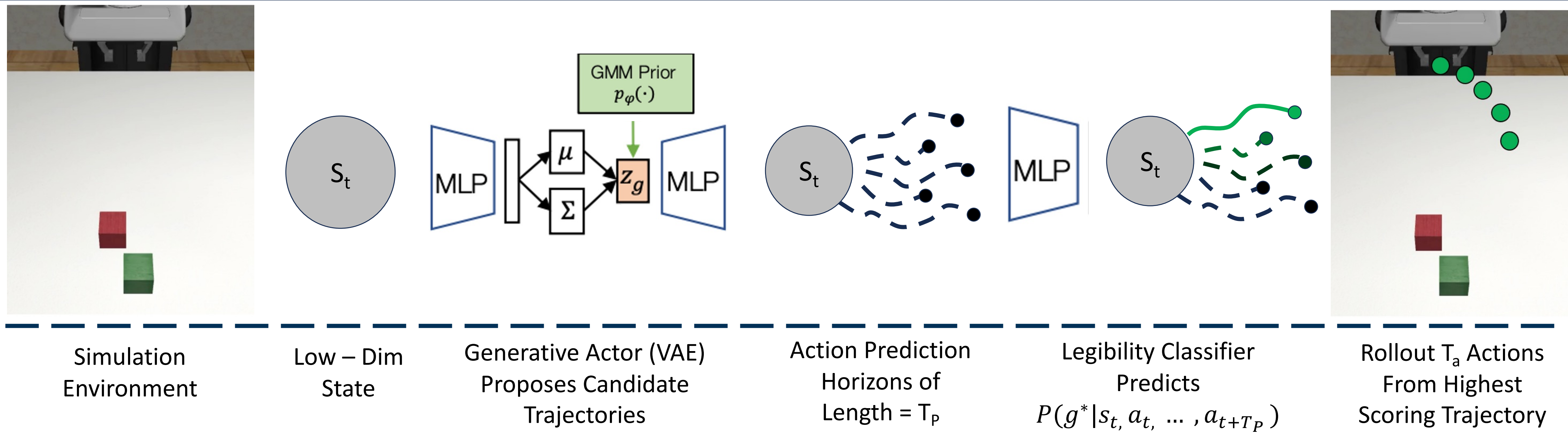
Generative Algorithms Evaluated
- Variational Auto-Encoder (VAE)
- Goal Conditioned VAE (G-VAE)
- *Generative Legible Motion Model (GLMM)*

Independent Variables
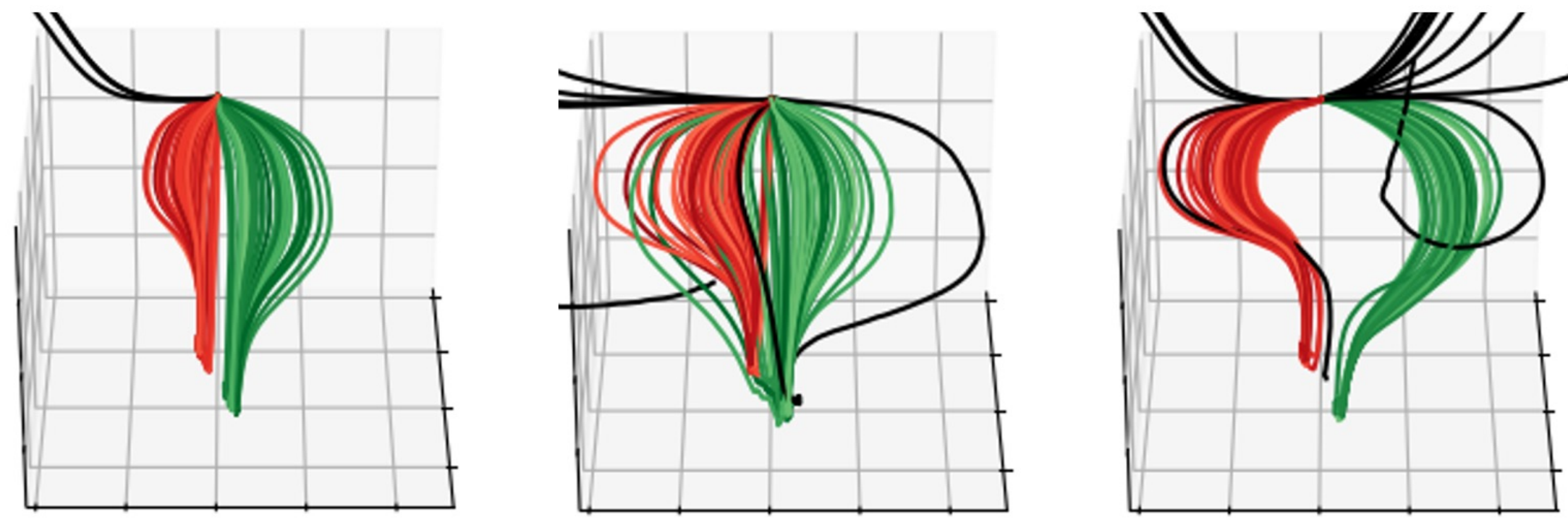- Success Rate
- Legibility

All Demos

Legible Demos

Generative Legible Motion Model

GMM Prior $p_\varphi(\cdot)$

S_t · MLP · μ · Σ · z_g · MLP · S_t · MLP · S_t

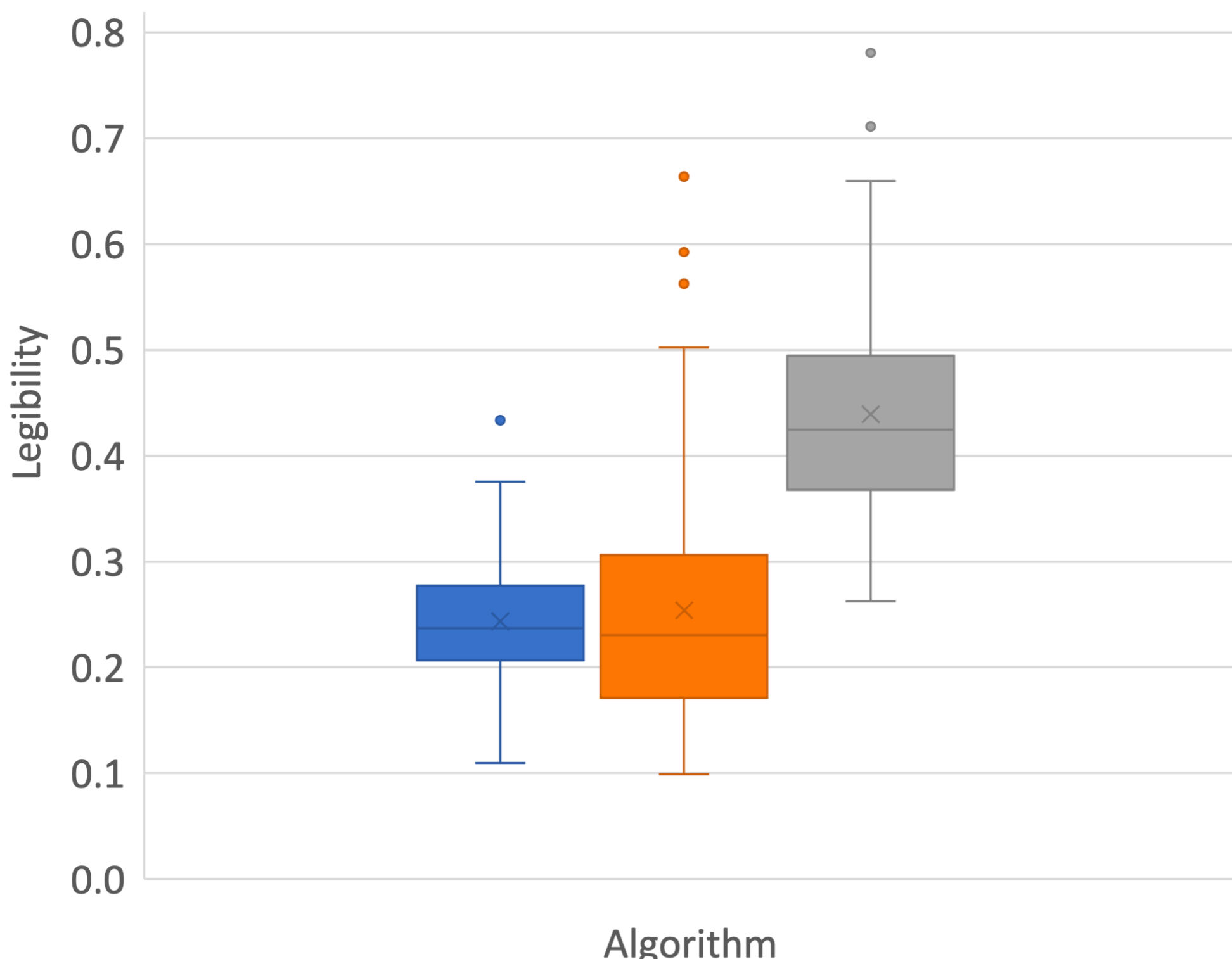| Simulation Environment | Low − Dim State | Generative Actor (VAE) Proposes Candidate Trajectories | Action Prediction Horizons of Length = T_P | Legibility Classifier Predicts $P(g^*|s_t, a_t, \dots, a_{t+T_P})$ | Rollout T_a Actions From Highest Scoring Trajectory |

Results

100 Rollouts of Trained Agents

VAE
97% Success

G-VAE
93% Success

GLMM
86% Success

— Picked Up Red   — Picked Up Green   — Failure

Evaluating Legibility [3]

$$L(\xi_{S \to G^*}) = \sum_{s_i \in \xi_{S \to G^*}} \sum_{\{g \in G : g \neq g^*\}} \frac{||g - s_i||_2}{i}$$

■ VAE ■ G-VAE ■ GLMM
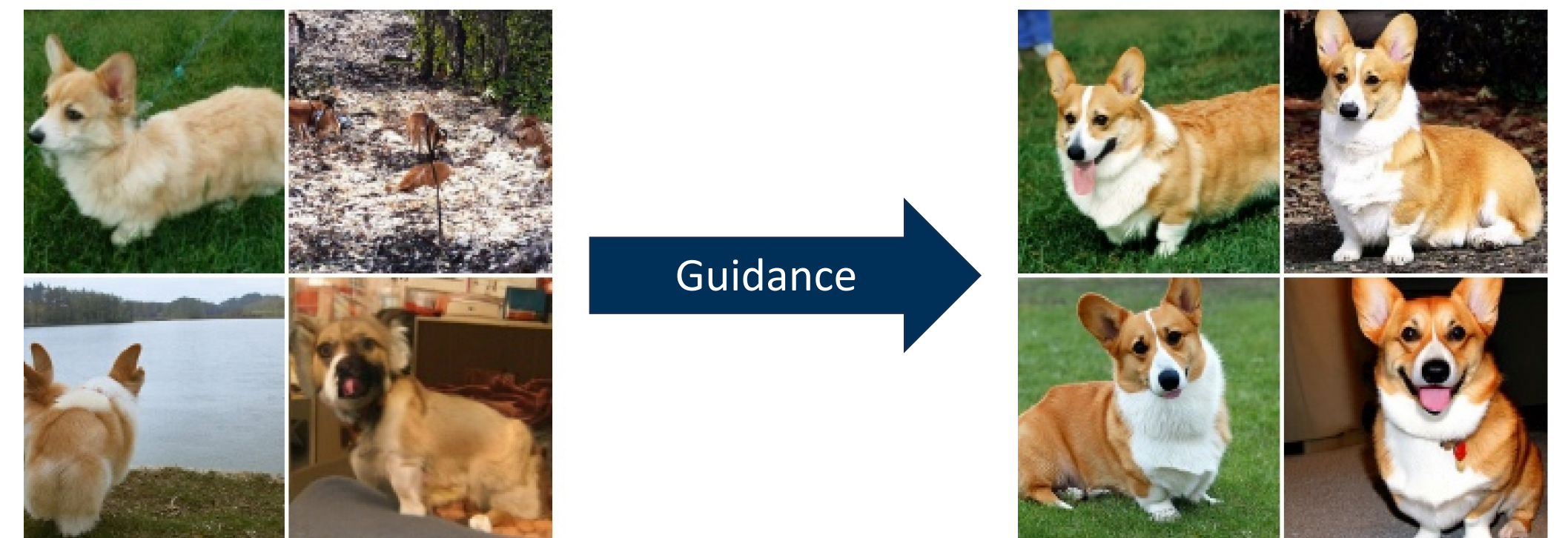
(box plot: y-axis Legibility 0.0–0.8, x-axis Algorithm)

Conclusions

The implicit classifier guidance afforded by GLMM optimizes for legibility, but at the cost of success rate.

Parallels to Image Generation

Unguided Corgi Image Generation

Guidance

Generation with Classifier-Free Guidance [4]

| Image Guidance | Enhances class specific characteristics Improves quality at the cost of diversity |
| Action Guidance | Selects goal specific states Improves legibility at the cost of success rate |

Next Steps

- Implement a legibility classifier conditioned on continuous goal states
- Measure performance of diffusion models with guidance
- Run experiment on more complex tasks
- Directly evaluate how GLMM affects an observer's ability to predict the robot's goal state

References

[1] Dragan, A. D., Lee, K. C., and Srinivasa, S. S. Legibility and predictability of robot motion. In 2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), pp. 301–308. IEEE, 2013.
[2] Ravichandar, H., Polydoros, A. S., Chernova, S., and Billard, A. Recent advances in robot learning from demonstration. Annual review of control, robotics, and autonomous systems, 3:297–330, 2020.
[3] Zhao, X., Fan, T., Wang, D., Hu, Z., Han, T., and Pan, J. An actor-critic approach for legible robot motion planner. In 2020 IEEE International Conference on Robotics and Automation (ICRA), pp. 5949–5955. IEEE, 2020.
[4] Ho, J. and Salimans, T. Classifier-free diffusion guidance. arXiv preprint arXiv:2207.12598, 2022.

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