

Formal Verification of Neural ODE for Safety Evaluation in Autonomous Vehicles

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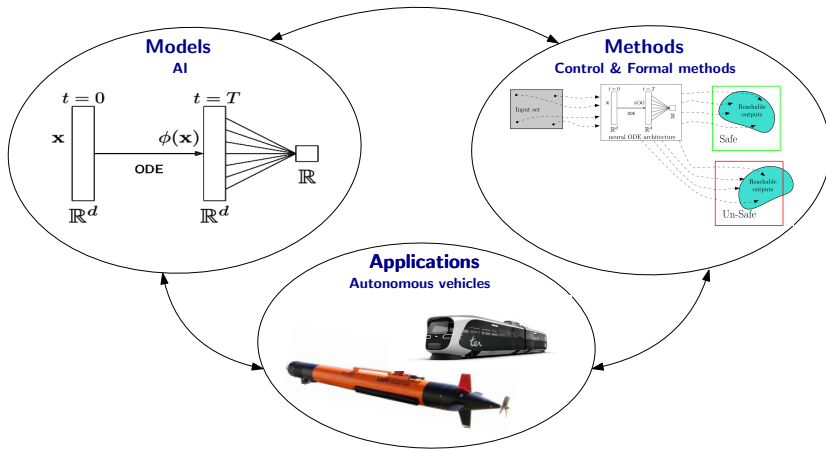
January 20th 2026, Singapore



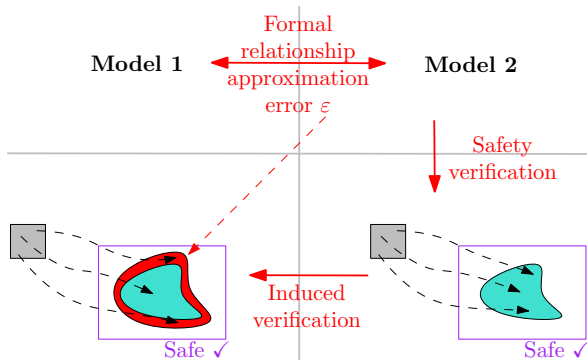
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PhD Interdisciplinarity



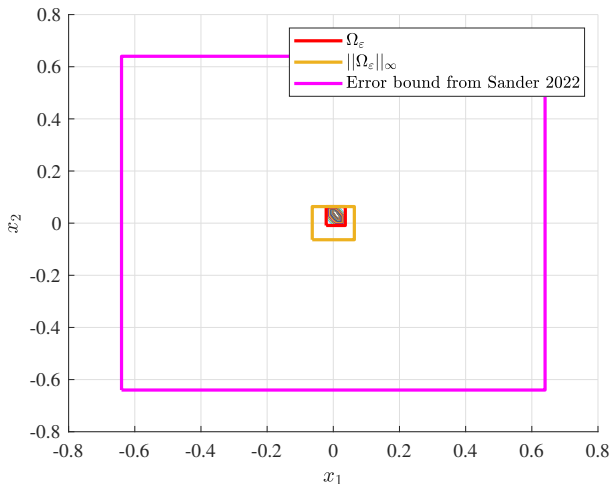
R.D 1: Formal relations between discrete and continuous neural models



CAV 2025 Symposium on AI  Verification

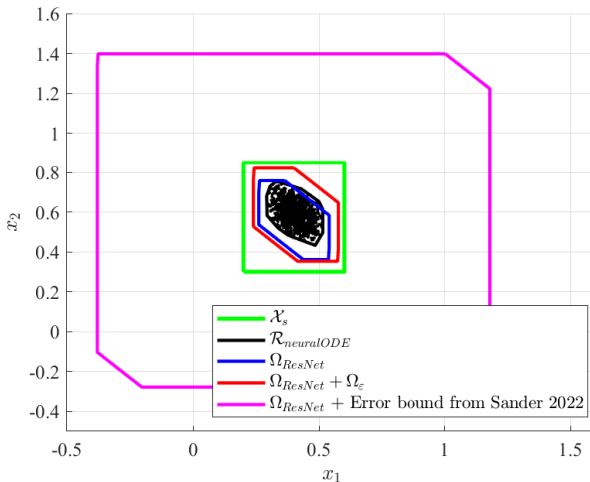
Error Bounding

- Rigorous error bound (ε) between neural ODE and ResNet
- Tighter $\Omega_\varepsilon < \mathbf{16 \text{ million times} \times SOTA}$



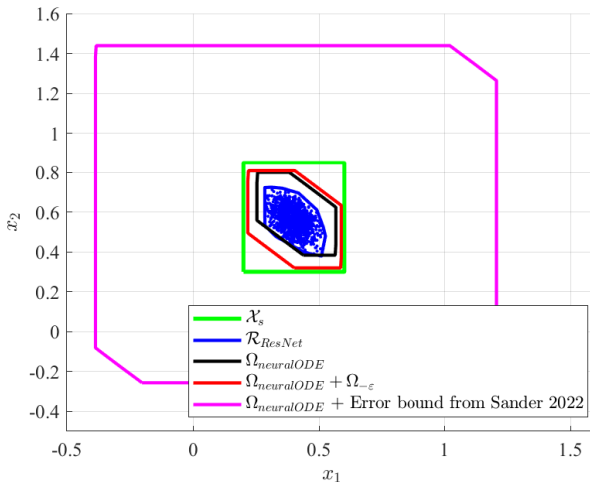
Verification Proxy

- Verifying neural ODE based on ResNet

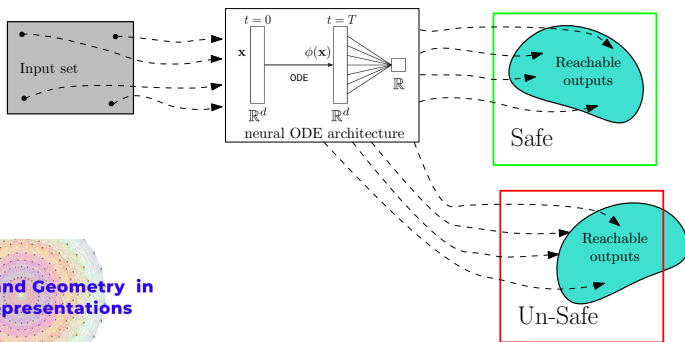


Verification Proxy

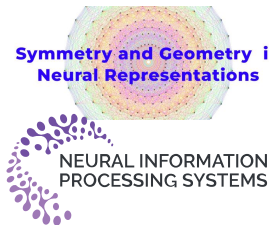
- Verifying **ResNet** based on neural ODE



R.D 2: Reachability Analysis of neural ODE

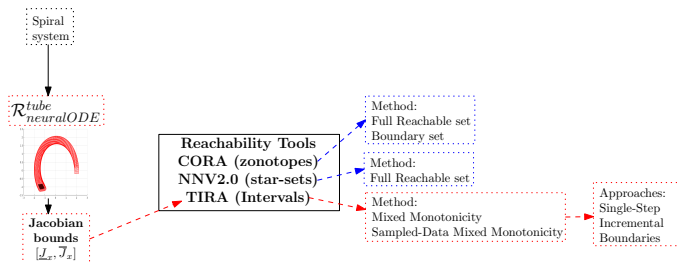


**Symmetry and Geometry in
Neural Representations**



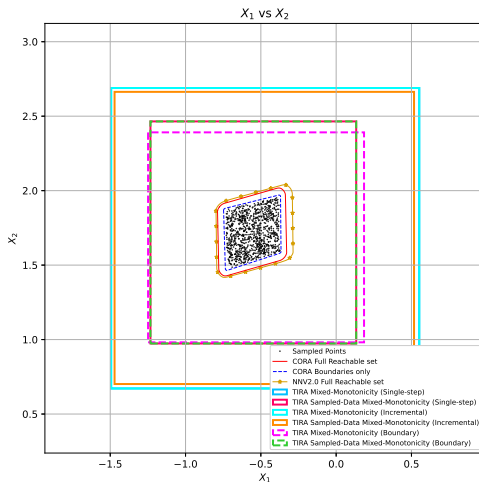
Reachability Approaches

- Tools: CORA (zonotopes) - NNV2.0 (star-sets) - **TIRA (intervals)**
- Methods: Continuous-Time Mixed Monotonicity and Sampled-Data Mixed Monotonicity
- Approaches: Single-step - Incremental - Boundary

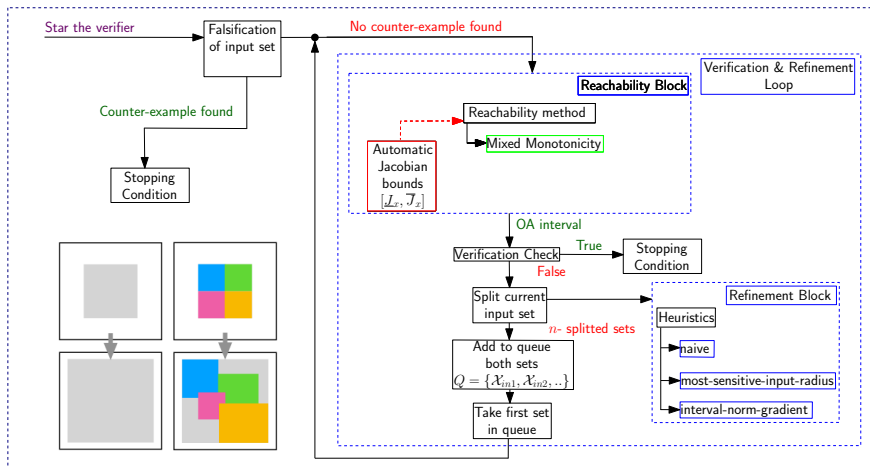


Reachability Approaches

- Sound over-approximations, albeit at the cost of tightness

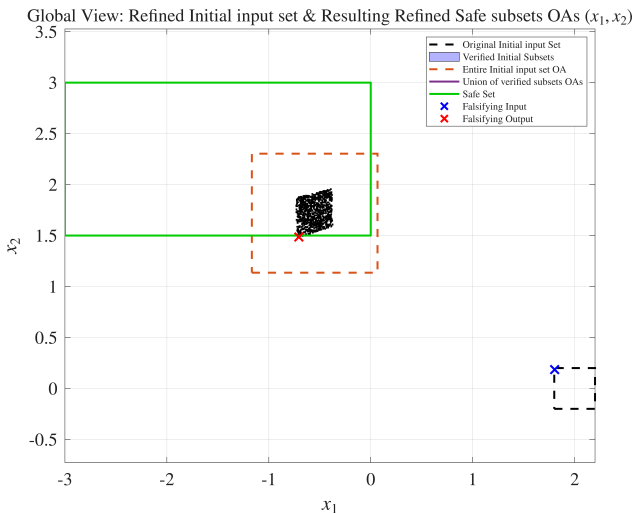


R.D 3: Verification toolbox for neural ODE



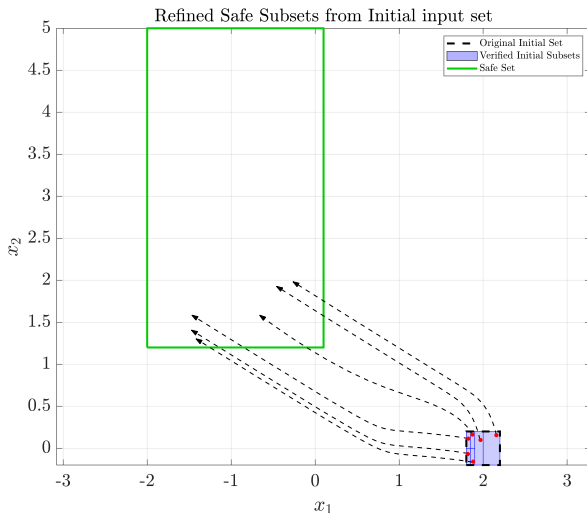
Iterative refinement

- Falsified case

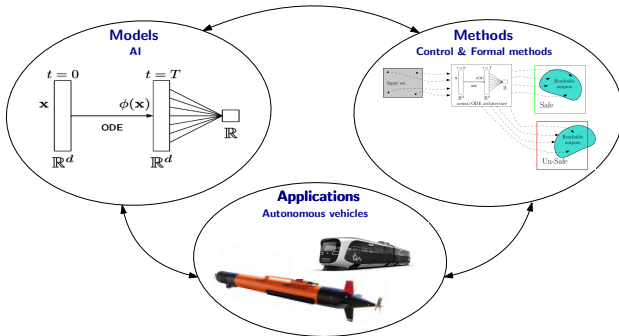


Iterative refinement

- Refined case

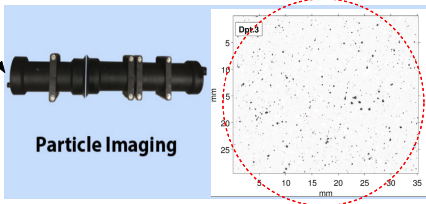


Applications

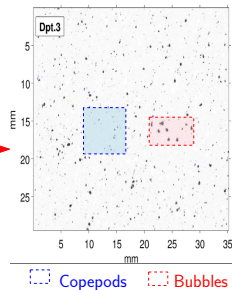


Autonomous Underwater Vehicles (AUV)

- Robustness Verification for ROI from in situ images



neural ODE
Verifier



References

-  Meyer, P.J., Devonport, A., Arcak, M.: Interval reachability analysis: Bounding trajectories of uncertain systems with boxes for control and verification. Springer Nature (2021)
-  Sayed, A.S.: Formal verification of neural ode for safety evaluation in autonomous vehicles. In: AAI-26 Doctoral Consortium (2026), <https://hal.science/hal-05375718>
-  Sayed, A.S., Meyer, P.J., Ghazel, M.: Bridging neural ode and resnet: A formal error bound for safety verification. In: International Symposium on AI Verification. pp. 97–114. Springer (2025)
-  Sayed, A.S., Meyer, P.J., Ghazel, M.: Mixed monotonicity reachability analysis of neural ode: A trade-off between tightness and efficiency. In: NeurIPS Workshop on Symmetry and Geometry in Neural Representations (2025), <https://www.arxiv.org/abs/2510.17859>

Thank You!

Questions? $\Rightarrow$ **Poster WS57**

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