Karlsruhe Institute of Technology

Provably Safe Neural Network Controllers via Differential Dynamic Logic

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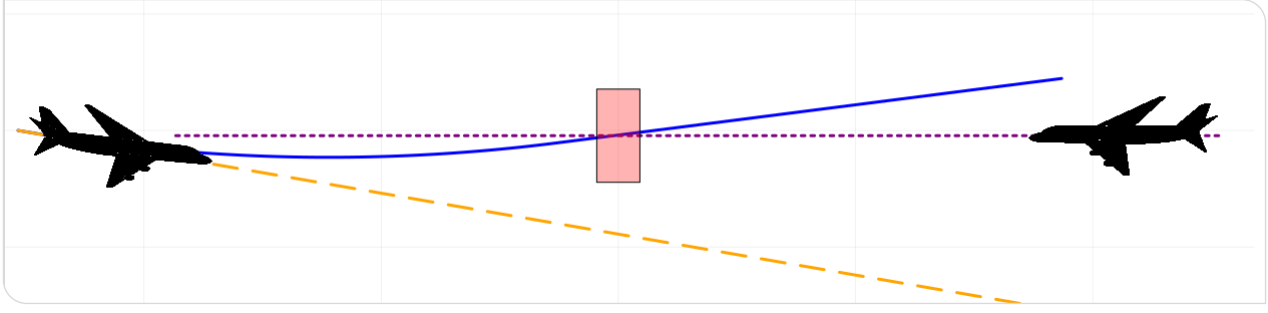
Samuel Teuber, Stefan Mitsch, André Platzer | 2024



Background

Differential Dynamic Logic

- Program Logic to reason about Cyber-Physical Systems
- Proves **infinite time-horizon** safety for **control envelopes**

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Open-Loop Neural Network Verification

- Analysis of Neural Network **in isolation**
- Usually supports **linear constraints** with very **simple structure**

Objective

Given:

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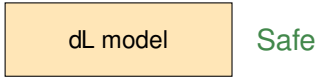
Question:

If we **replace** the control envelope α_{ctrl} by the NN g,
does the resulting system retain the same safety guarantees?

Provably Safe Neural Network Controllers



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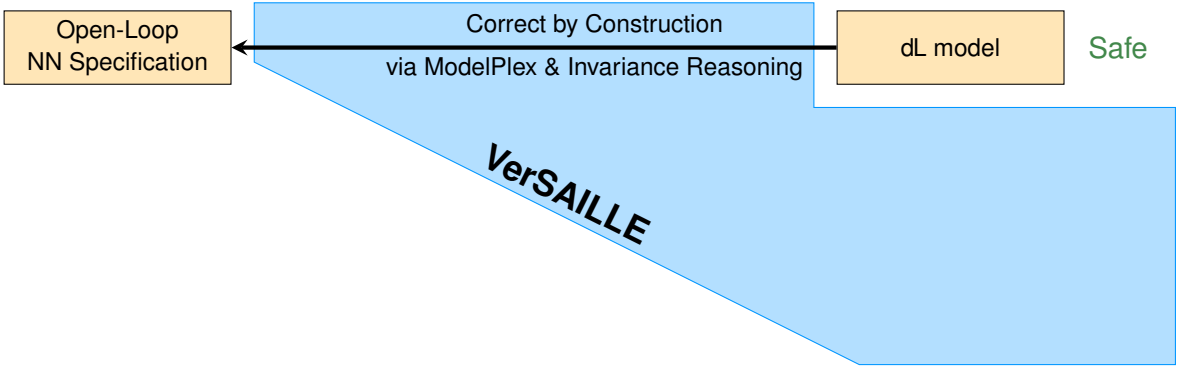

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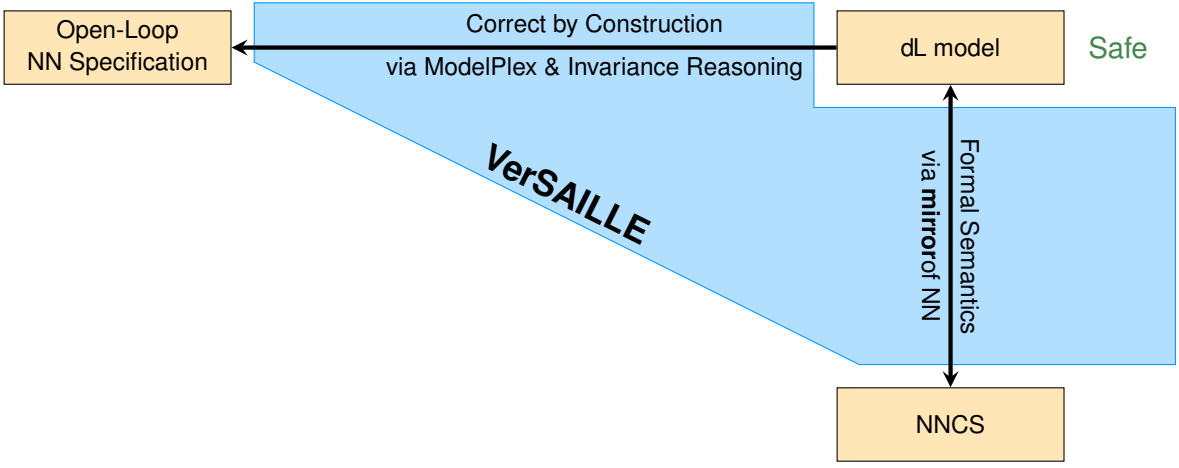

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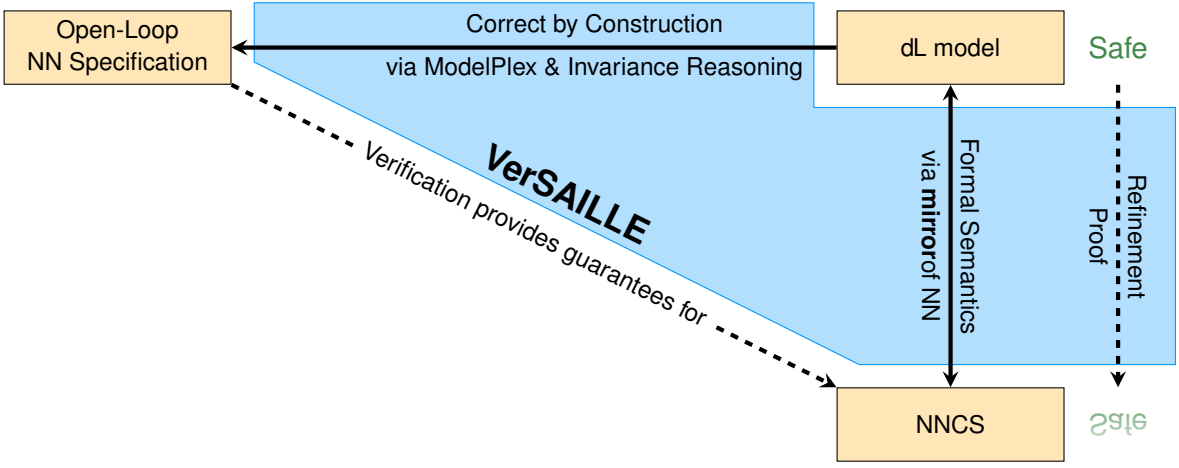
Provably Safe Neural Network Controllers via $d\mathcal{L}$
Institute of Information Security and Dependability (KASTEL)

Provably Safe Neural Network Controllers



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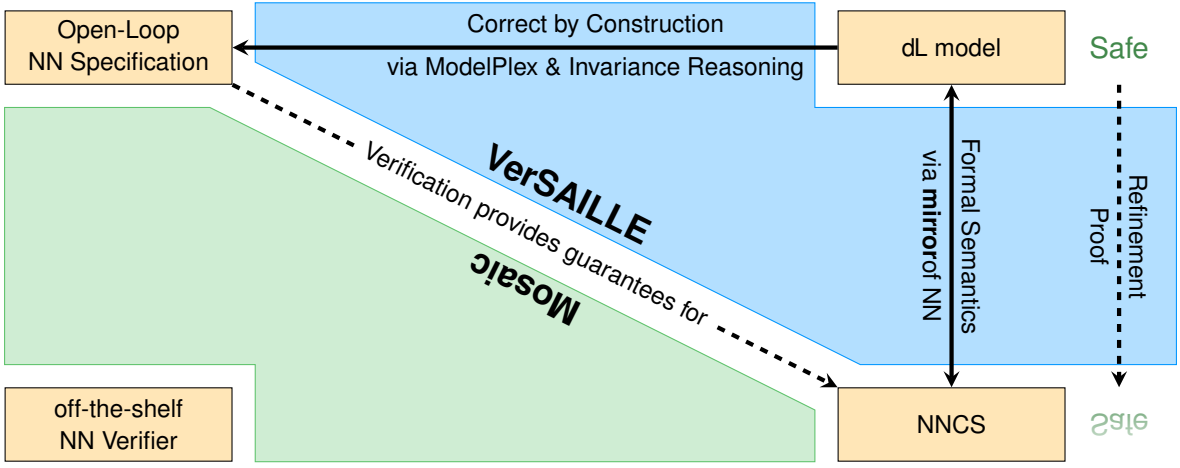

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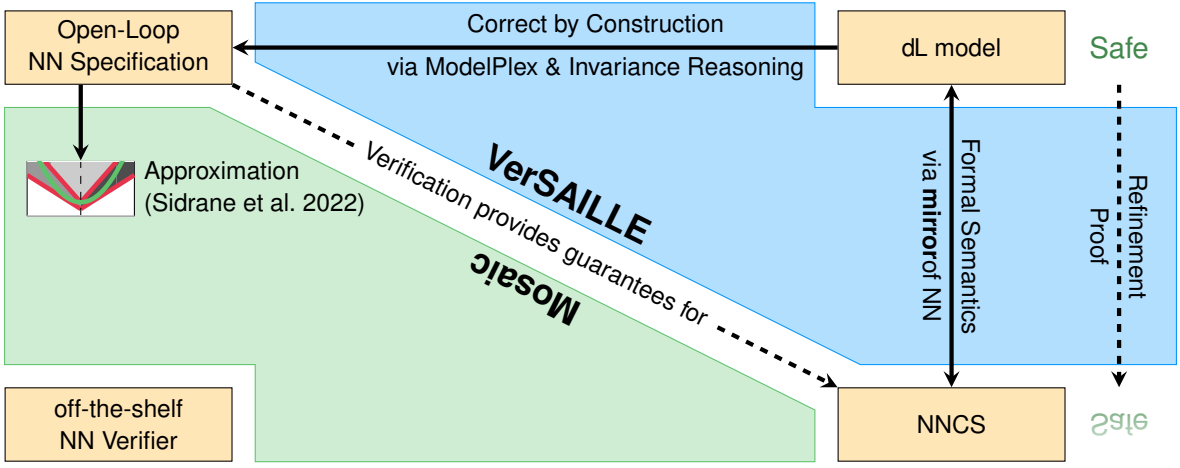

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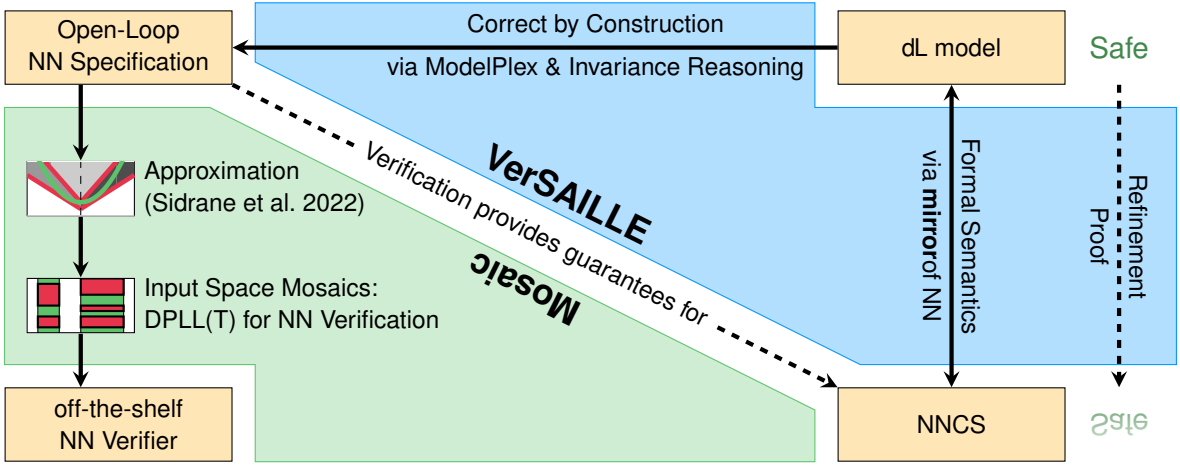

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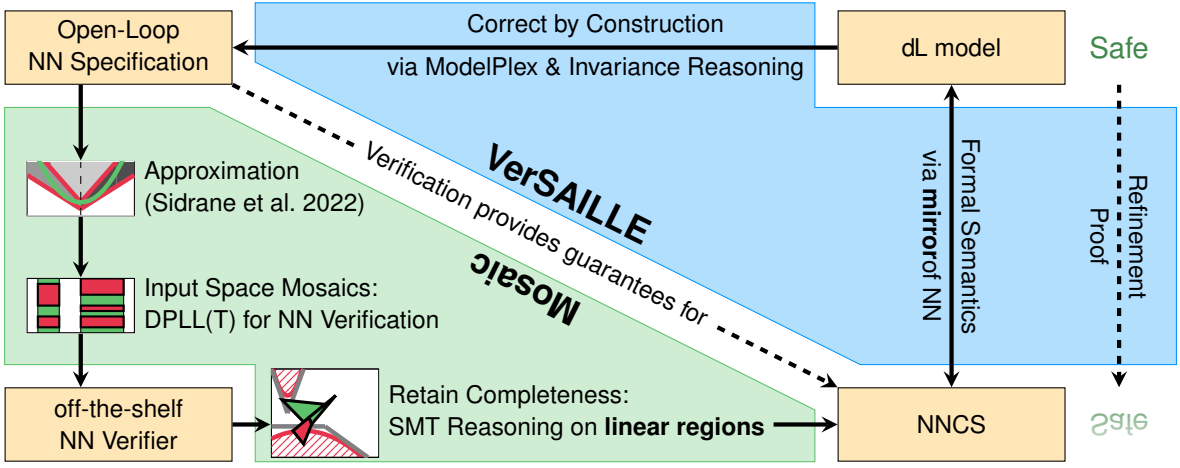

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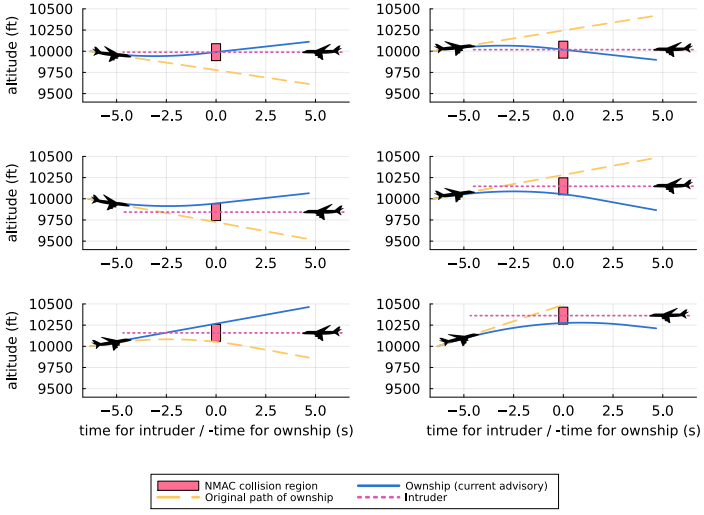
Analysis of Vertical Airborne Collision Avoidance



Networks **and** dL formalization **from prior literature**
(Julian and Kochenderfer 2019; Jeannin et al. 2017)

Result

- 6 out of 8 NNs **unsafe**
- Other NNs safe for **intruder in level flight**
  (but found crashes for non-level flight intruder)

References I

[1] Jean Baptiste Jeannin et al. “A formally verified hybrid system for safe advisories in the next-generation airborne collision avoidance system”. In: *International Journal on Software Tools for Technology Transfer* 19.6 (2017), pp. 717–741. ISSN: 14332787. DOI: 10.1007/s10009-016-0434-1. URL: https://doi.org/10.1007/s10009-016-0434-1.

[2] Kyle D. Julian and Mykel J. Kochenderfer. “Guaranteeing Safety for Neural Network-Based Aircraft Collision Avoidance Systems”. In: *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*. 2019, pp. 1–10. DOI: 10.1109/DASC43569.2019.9081748.

[3] Chelsea Sidrane et al. “OVERT: An algorithm for safety verification of neural network control policies for nonlinear systems”. In: *Journal of Machine Learning Research* 23.117 (2022), pp. 1–45.