ABSTRACT

As digital systems become increasingly complex, verifying their correctness before fabrication is a critical challenge. Industrial hardware designs often require checking multiple properties, whose complexities are unknown beforehand. This calls for a well-defined verification planning strategy to manage complexity and resource constraints within limited timeframes.

Multi-Property Verification (MPV) is particularly demanding, as it formally proves numerous properties over a single design. To scale effectively, MPV requires an intrinsic verification planning layer—a dynamic orchestration mechanism that handles property grouping, ordering, engine tuning, and reusing proven results to accelerate verification. Traditional MPV approaches rely on static planning, where the verification flow is fixed upfront. These methods lack adaptability and often fail when property complexity varies during execution. This thesis introduces intrinsic planning techniques to improve MPV efficiency and scalability. The key strategies include:

- **Dynamic Property Ordering**: The thesis first introduces a real-time adaptive approach to reorder properties on the fly during verification using statistical feedback from the proof engine. It identifies key computable features and defines metrics to optimize property ordering.
- **ML-Assisted Property Ordering and Sweeping**: The thesis enhances dynamic ordering through machine learning for feature analysis and ranking. In this work, we propose a sweeping mechanism to handle inconclusive goals efficiently, improving overall MPV performance.
- **Property Clustering and Selective Invariant Sharing**: In our third contribution, we investigate property clustering and selective invariant sharing to enhance multi-property verification. These techniques improve efficiency by grouping related properties based on clause and variable overlap while selectively reusing meaningful invariants. Additionally, we incorporate counterexample trace storage to facilitate efficient reuse.
- **Property Ordering and Frame Clause Reuse**: This work proposes a sequential MPV approach that reuses frame clauses across properties and

begins verification of goals from the last frame of the already proven set of properties. This reduces duplication and improves solver performance.

- **Automated Testbench Generation using PSS**: Our last contribution presents a simulation-driven framework that auto-generates constrained-random test benches and cover properties based on the Portable Test and Stimulus Standard (PSS), validated on practical RTL designs.

Together, these methods significantly enhance the performance of formal and simulation-based verification on complex designs.

Keywords: Multi-Property Verification, Property Ordering, Property Clustering, Property Sweeping, Invariant Sharing, Frame Clause Reuse, Model Checking, Portable Stimulus, Constraint Random Test Benches.