Comprehensive Verification of the RISC-V Memory Management Unit: Challenges and Solutions

Authors

Huda Sajjad
Verification Engineer
10xEngineers
Lahore, Pakistan

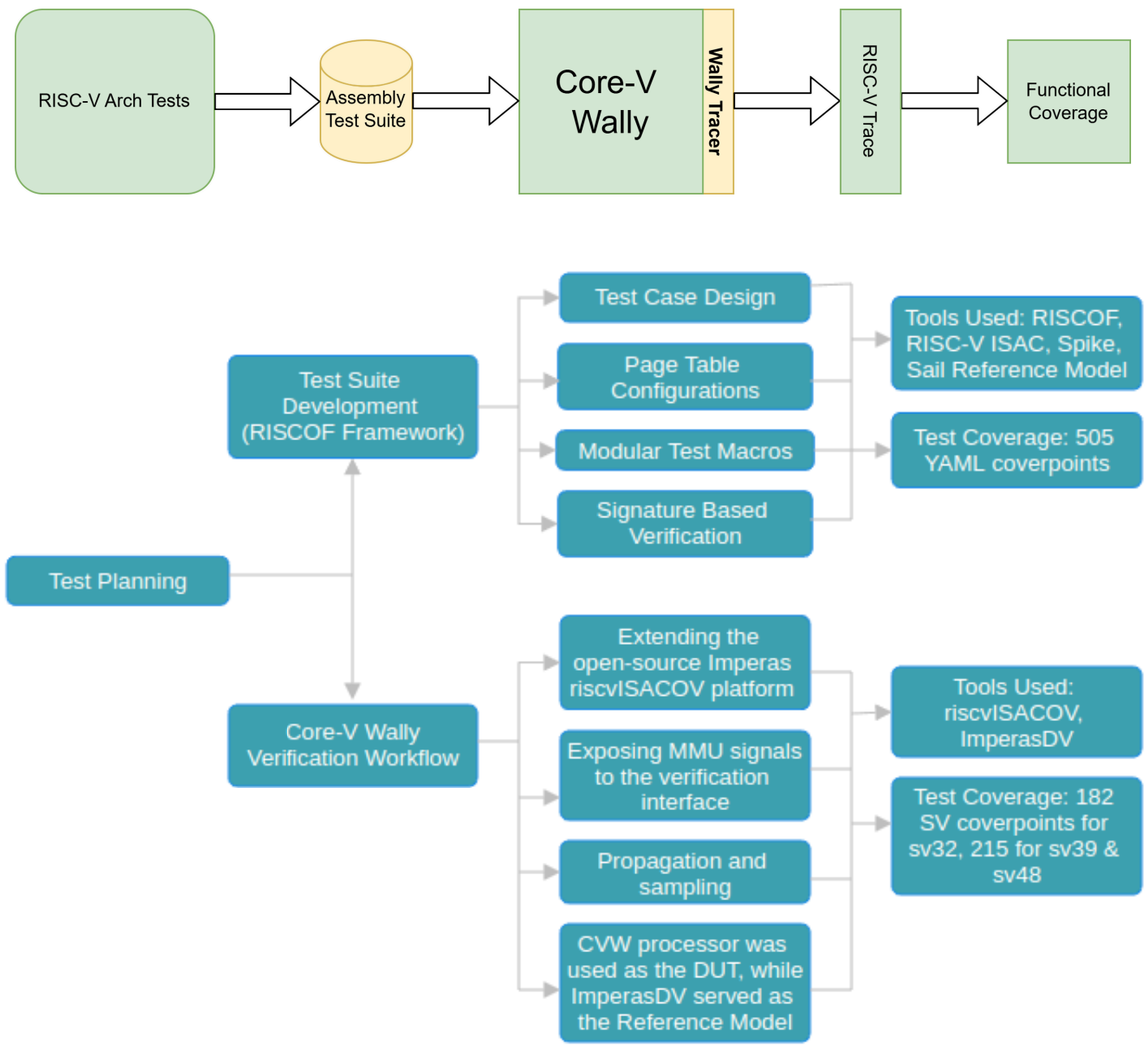
Hammad Bashir
Verification Engineer
10xEngineers
Lahore, Pakistan

Yazan Hussnain
Design Engineer
10xEngineers
Lahore, Pakistan

Fatima Saleem
Sr. Design Engineer
10xEngineers
Lahore, Pakistan

Introduction

The Memory Management Unit (MMU) enables virtual address translation, memory protection, and multitasking. Ensuring compliance with the RISC-V Privileged ISA is crucial for interoperability. However, its configurability—supporting multiple paging schemes and superpage translations—poses significant verification challenges, especially in open-source cores where edge cases and ambiguities can cause critical flaws.



Test Planning

✅ Unified DV Plan for all MMU configurations
✅ Key Verification Areas:

- PTE Permission Bits – Tested across all page table levels in supervisor & user modes.
- Global Mappings & satp Register – Ensures correct address translation and ASID handling.
- Virtualization in Machine Mode
- TVM Bit Functionality
- Supervisor Access to U-Mode Pages
- MXR (Make eXecutable Readable)

Results/Findings

This work was implemented and validated on Core-V Wally, a 5-stage pipelined processor supporting configurations from RV32E to a full RV64GC application processor. The proposed test suite successfully uncovered a critical bug in the MMU through the reserved_pte_s_mode test. The bug caused Core-V Wally to fail in triggering a page fault when accessing memory regions mapped by Page Table Entries (PTEs) with reserved RWX encoding (pte.W=1 and pte.R=0), violating the RISC-V Privileged ISA specification.

Conclusion

✅ Enhanced verification framework for RISC-V MMUs
✅ Discovered a major flaw in Core-V Wally's MMU implementation
✅ Improved compliance testing for open-source processor designs

Our methodology strengthens MMU validation for open-source RISC-V cores, ensuring better reliability and compliance.

Visit 10xE' website for more info

SCAN ME