School of Computer Science & Engineering

Trustworthy Systems Group

High-Fidelity Specification of Real-World Devices

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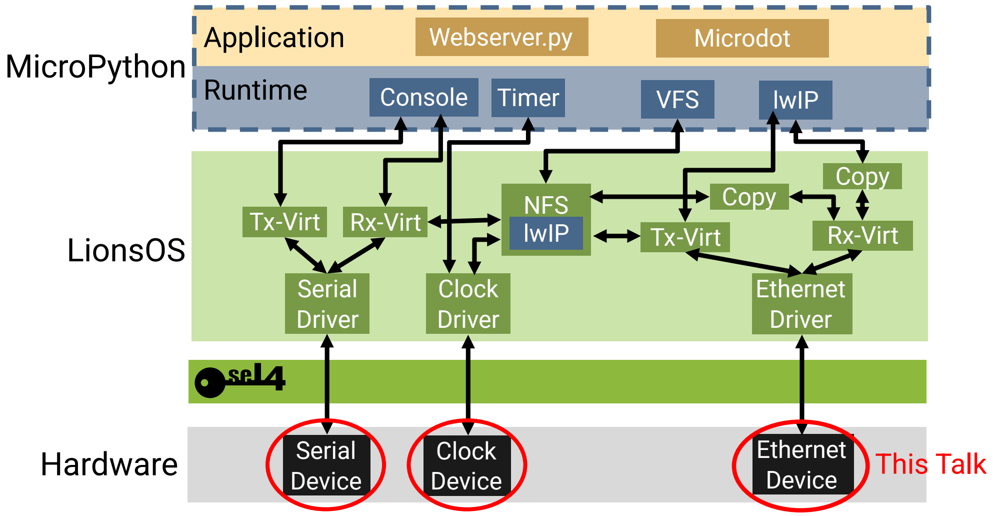
PLOS '25

Background

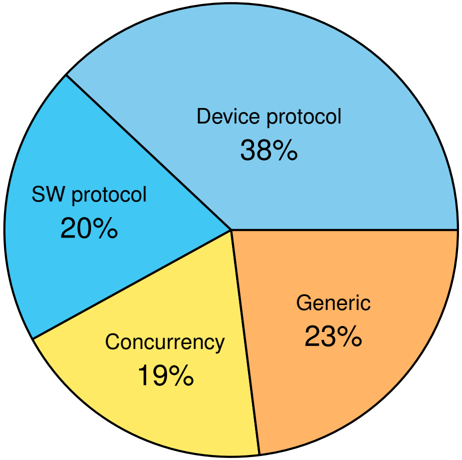
Who Are We?



MicroPython
Application
Webserver.py
Microdot
Runtime
Console
Timer
VFS
lwIP
LionsOS
Copy
Copy
NFS
lwIP
Tx-Virt
Rx-Virt
Tx-Virt
Rx-Virt
Serial Driver
Clock Driver
Ethernet Driver
seL4
Hardware
Serial Device
Clock Device
Ethernet Device
This Talk

Why Drivers?

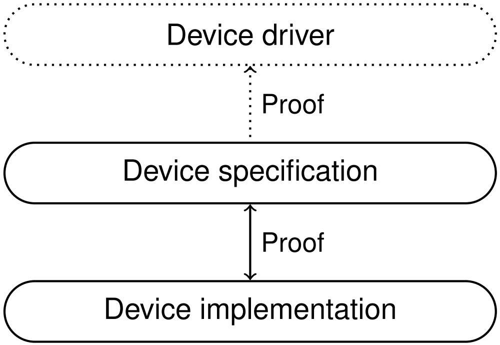
- Device driver bugs are a major source of OS vulnerabilities
  - Cause of majority of Linux CVEs from 2018-2022 [Pohjola et al. 2023]
- Dominant cause of Linux driver bugs is device-protocol violations [Ryzhyk et al. 2009]
  - Without knowledge of the device protocol, formal verification cannot prevent these



Causes of Linux driver bugs (2002–2008)

Aim

- Prevent device-protocol bugs by:
  - Formally specifying device interfaces
  - Verifying these specifications against the device implementation
- Future work: driver verification

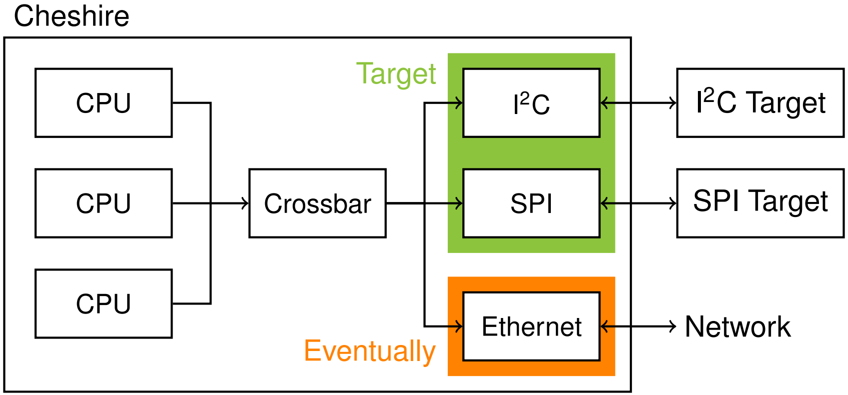


Overview

- Target hardware
- Verification approach
- Specification format
- Application
- Status

Target Hardware

Target Hardware



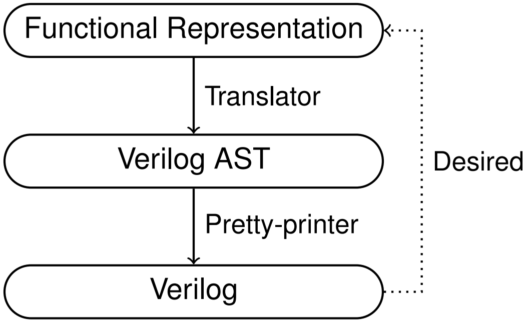
Target Hardware

	Verilog	Driver	HOL spec
I^{2}C	5993	713	1414
SPI	4609	864	1235
Ethernet	3987	641	N/A

Verification Approach

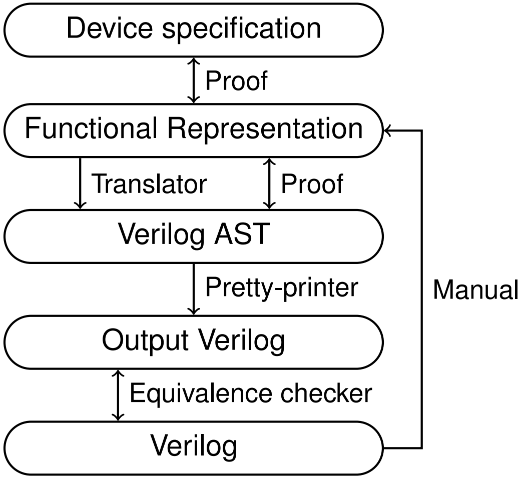
Tools

- HOL4 theorem prover
- HOL4 Verilog formalisation [Lööw and Myreen 2019]:
    - Semantics for Verilog AST
    - Semantics for functional representation
    - Proof-producing translator from functional to AST
    - Pretty-printer for deep embedding
- Problem: need opposite direction



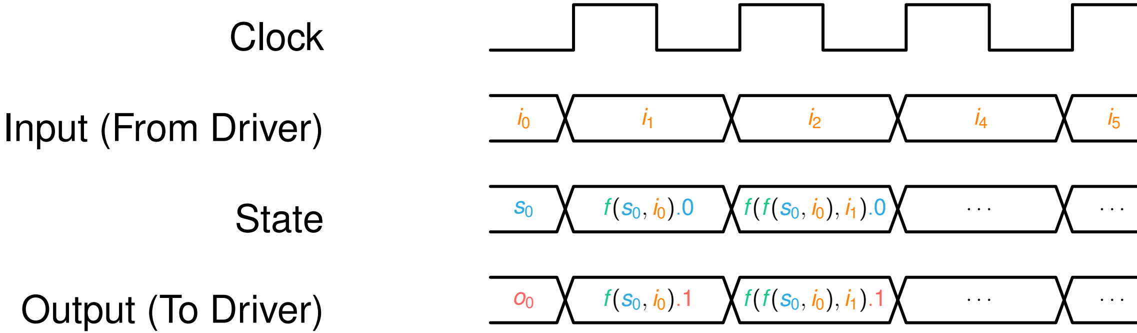
Workflow

- Workaround:
  - Manually translate Verilog to functional representation
  - Translate and export into Verilog
  - Use equivalence-checker (`eqy`) to prove equivalence to original Verilog
- Finally, prove that functional representation refines specification



Specification Format

Specification Format



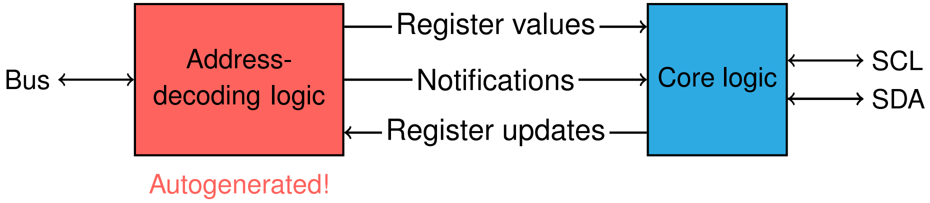
$$f \colon s \to i \to s \times o$$

Non-Determinism

- Model can be non-deterministic
  - Inputs not controlled by driver
  - Underspecification
- *f* only returns one possible state
- Determined by `fnums` - infinite stream of numbers
- To obtain set of all possible states, try all `fnums`

Application to Cheshire

Structure of Cheshire Peripherals



Cheshire Specifications

- Format of Cheshire peripheral specifications:

```
cheshire_run tick read write:
  state -> req option list ->
  ffi_outcome + state # word32 option list
```

- Input instantiated with optional MMIO request
- Output instantiated with response to read requests
- Executes multiple cycles

Cheshire Specifications

```
cheshire_run tick read write:
  state -> req option list ->
  ffi_outcome + state # word32 option list
```

- `tick` represents core logic
- `read`, `write` and `cheshire_run` represent address-decoding logic

Status

Status

	I^{2}C		SPI	
	Address-decoding	Core	Address-decoding	Core
Specification	✓	✓	✓	✓
Functional Representation	✓	✓	✓	WIP
Equivalence-checking	✓	WIP	✓	WIP
Correctness proof	✓	Almost!	✓	WIP

Questions?

Note

UNSW is recruiting OS faculty members - talk to Gernot if you're interested

References

- Pohjola, Johannes Åman et al. (Oct. 2023). “Pancake: Verified Systems Programming Made Sweeter”. In: *Workshop on Programming Languages and Operating Systems (PLOS)*. Koblenz, DE.
- Ryzhyk, Leonid et al. (Apr. 2009). “Dingo: Taming Device Drivers”. In: *EuroSys Conference*. Nuremberg, DE, pp. 275–288.
- Lööw, Andreas and Magnus O. Myreen (2019). “A proof-producing translator for Verilog development in HOL”. In: *Proceedings of the International Workshop on Formal Methods in Software Engineering (FormaliSE@ICSE)*, pp. 99–108.