School of Computer Science & Engineering

**Trustworthy Systems Group**

# High-Fidelity Specification of Real-World Devices

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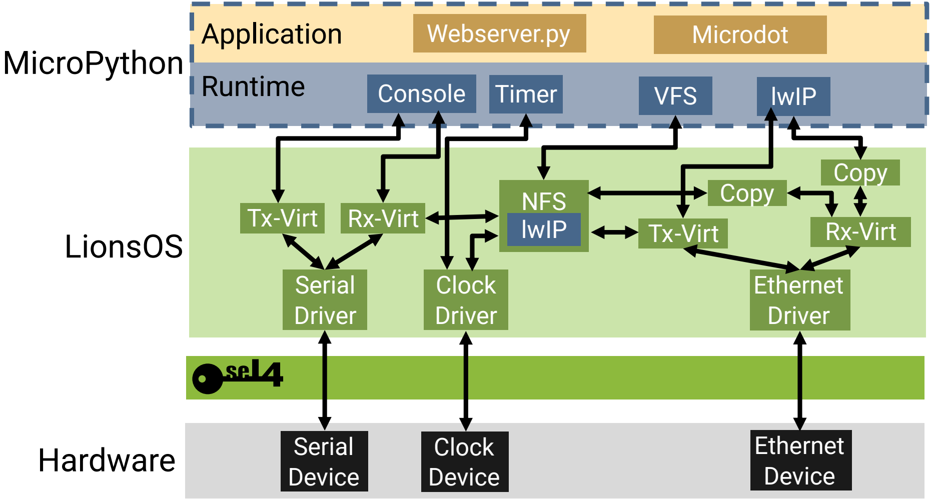
[1]UNSW Sydney [2]PlanV GmbH [3]University of Wisconsin - Madison

**PLOS ’25**

# Background

# Who Are We?


MicroPython
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Microdot
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Timer
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lwIP
LionsOS
Tx-Virt
Rx-Virt
NFS
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Clock Driver
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sel4
Hardware
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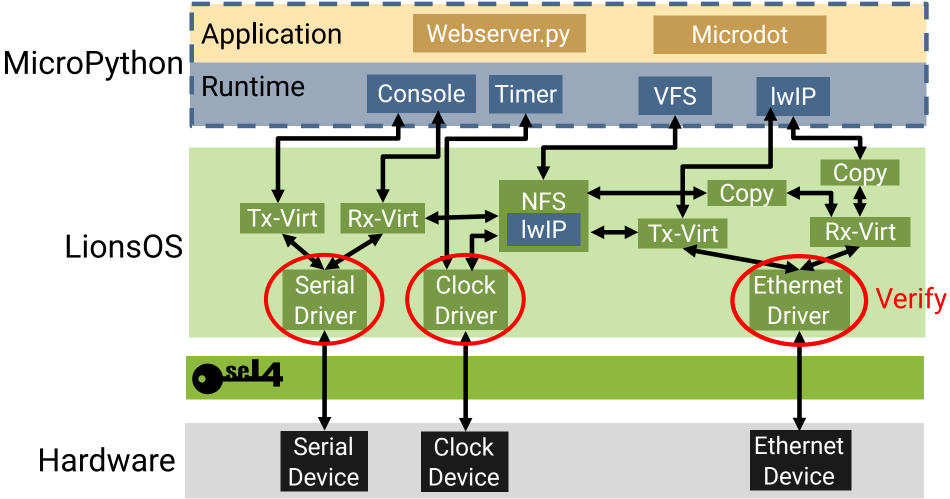

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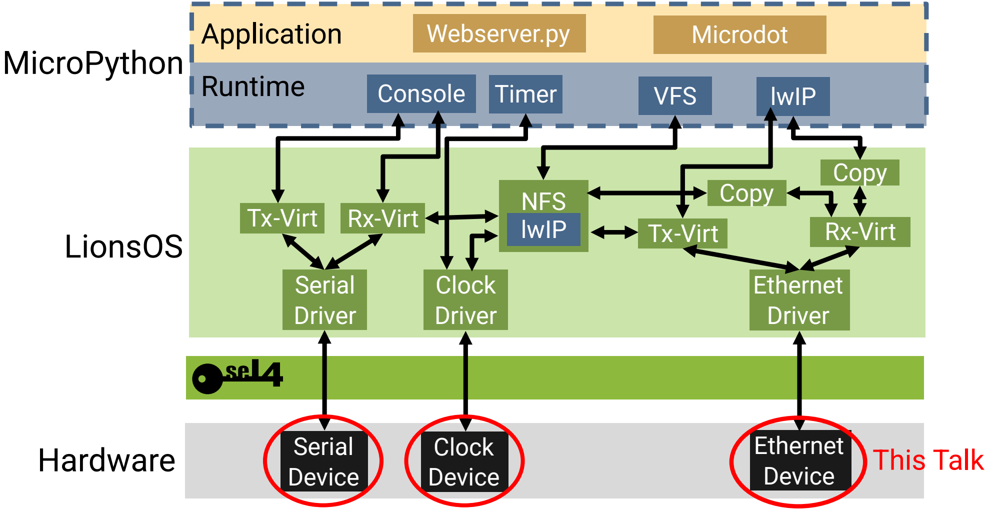

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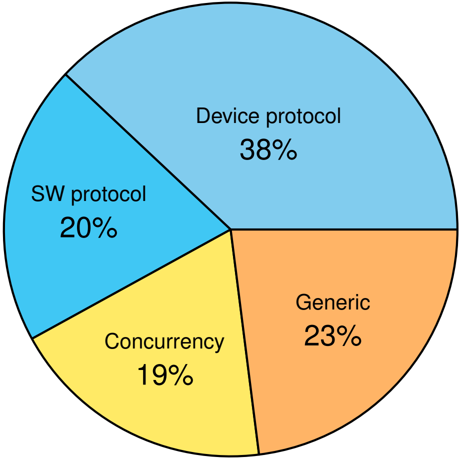
- Dominant cause of Linux driver bugs is device-protocol violations [Ryzhyk et al. 2009]




*Causes of Linux driver bugs (2002–2008)*

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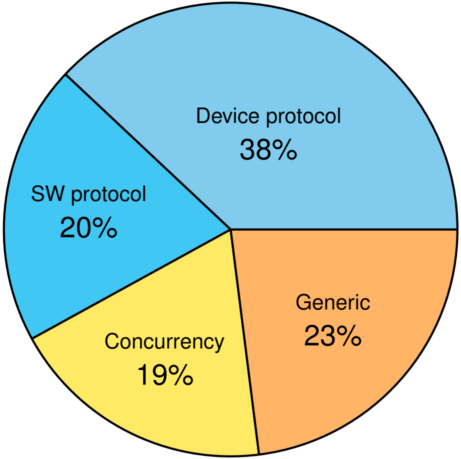
  - Cause of majority of Linux CVEs from 2018-2022 [Pohjola et al. 2023]
- Dominant cause of Linux driver bugs is device-protocol violations [Ryzhyk et al. 2009]
  - Without knowledge of the device protocol, formal verification cannot prevent these

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Device specification

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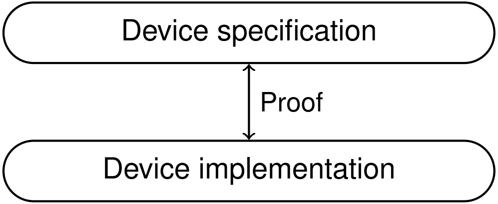
  - Verifying these specifications against the device implementation



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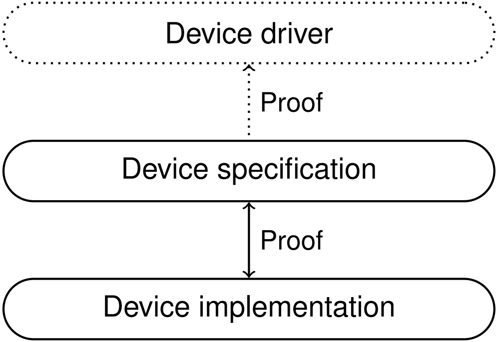
  - Formally specifying device interfaces
  - Verifying these specifications against the device implementation
- Future work: driver verification



# Overview

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

# Target Hardware

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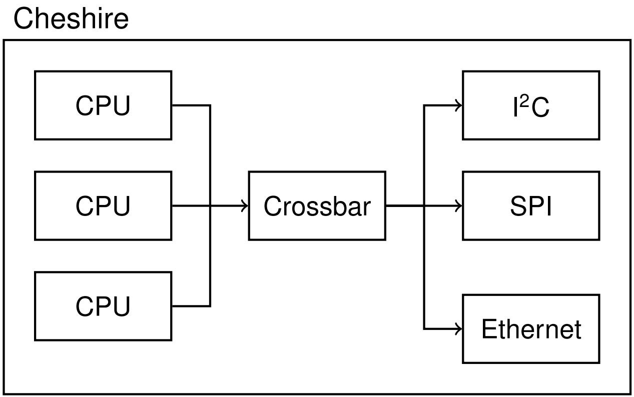

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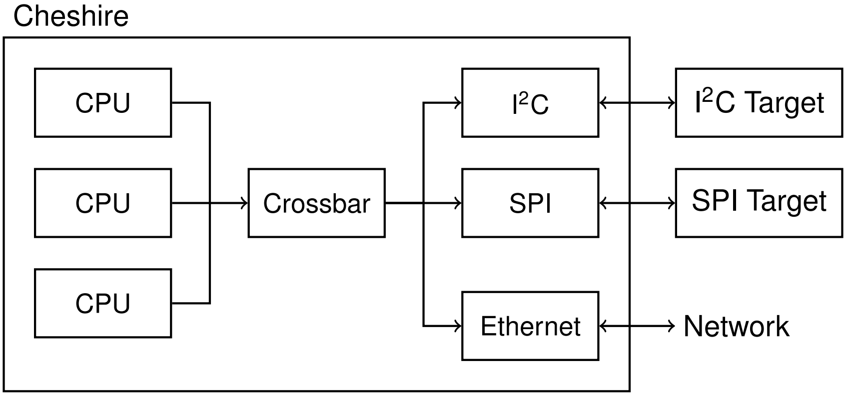

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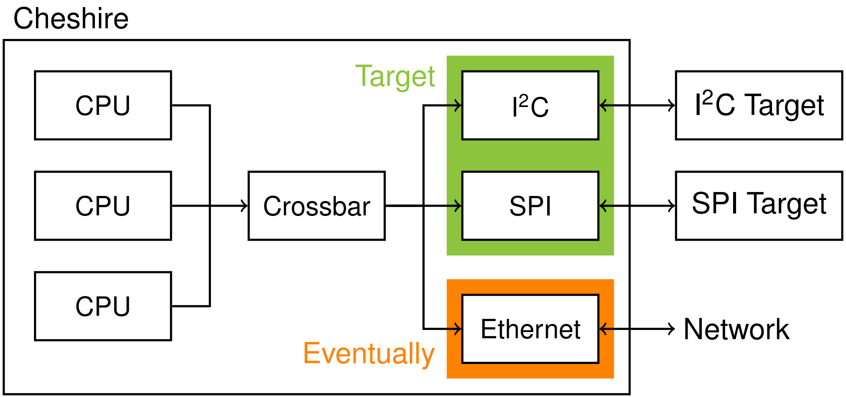

# Target Hardware

| | Verilog | Driver | HOL spec |
|---|---|---|---|
| **I$^2$C** | 5993 | 713 | 1414 |
| **SPI** | 4609 | 864 | 1235 |
| **Ethernet** | 3987 | 641 | N/A |

# Verification Approach

# Tools

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Functional Representation

Verilog AST

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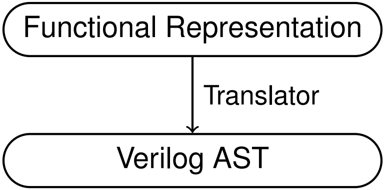

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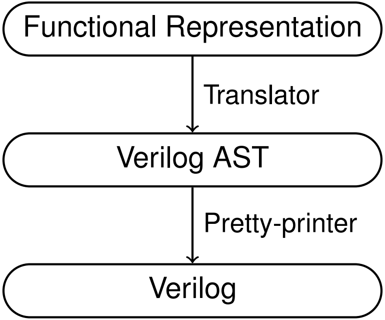

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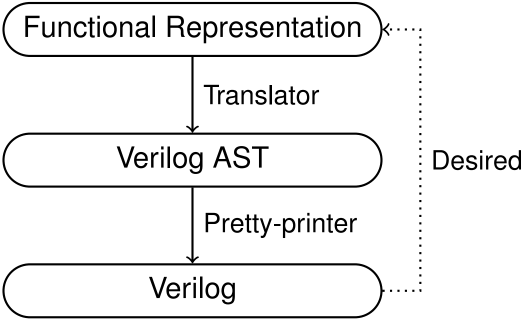
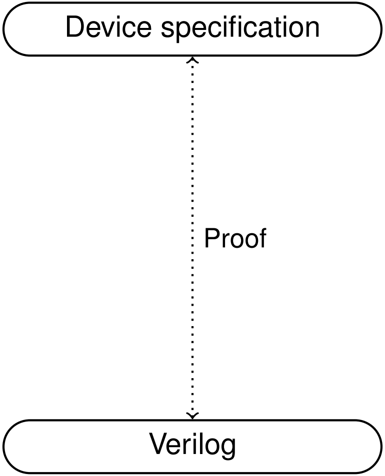
- Problem: need opposite direction



# Workflow

- Workaround:



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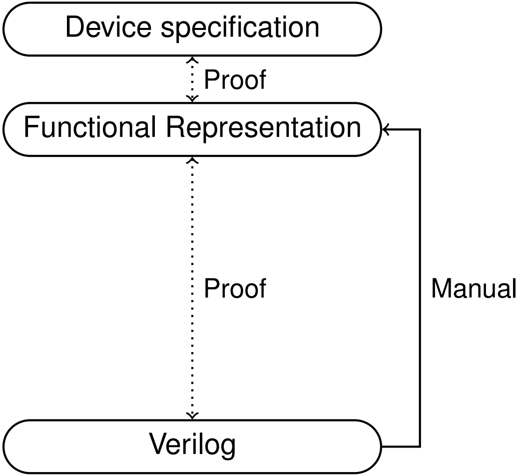

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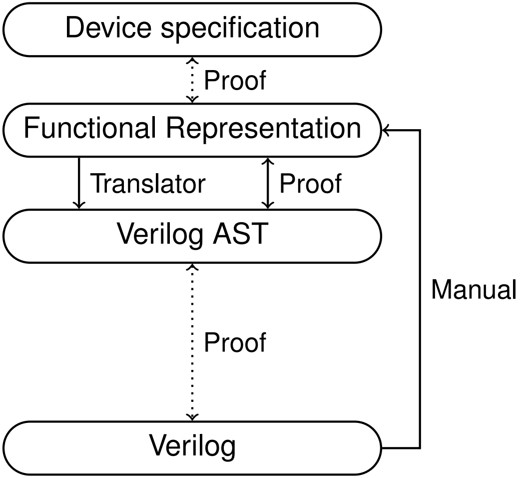

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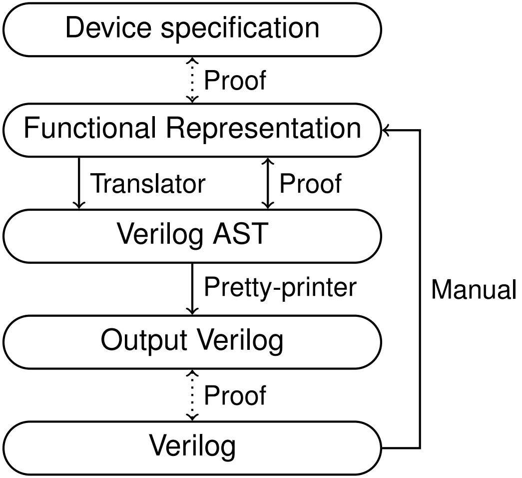

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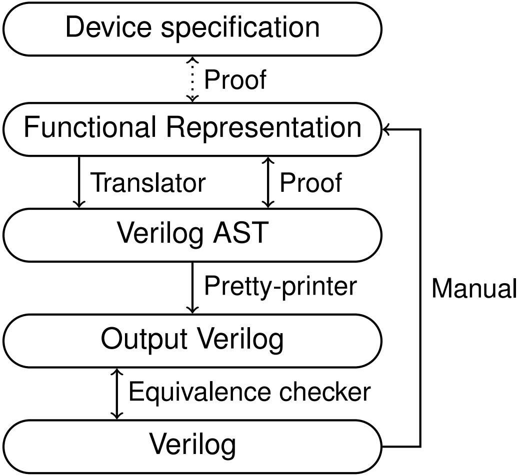

# Workflow

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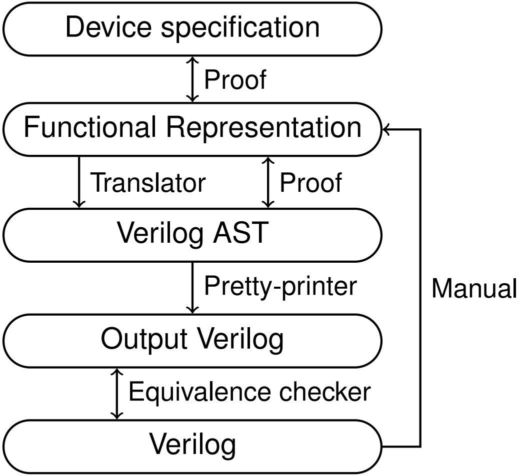
- Finally, prove that functional representation refines specification



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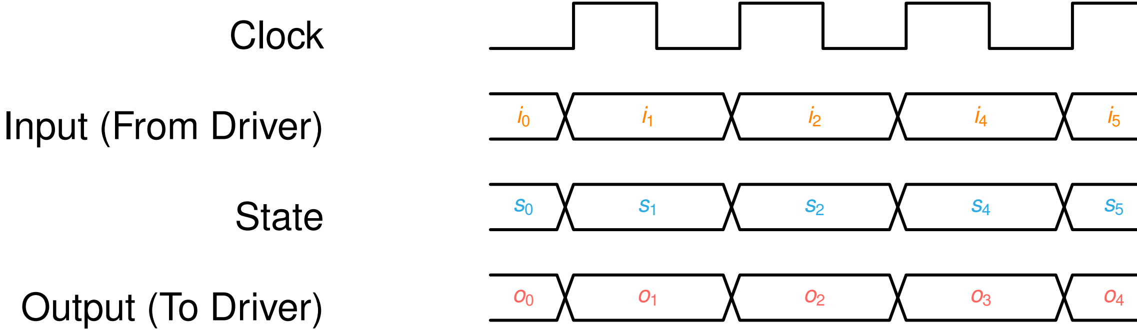

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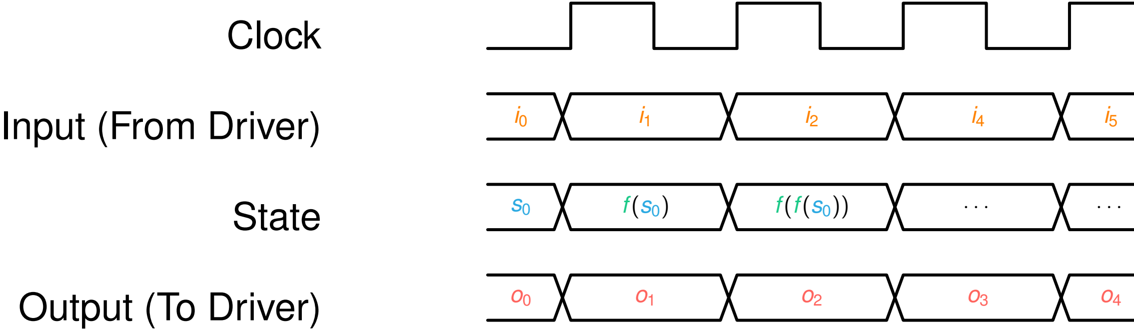

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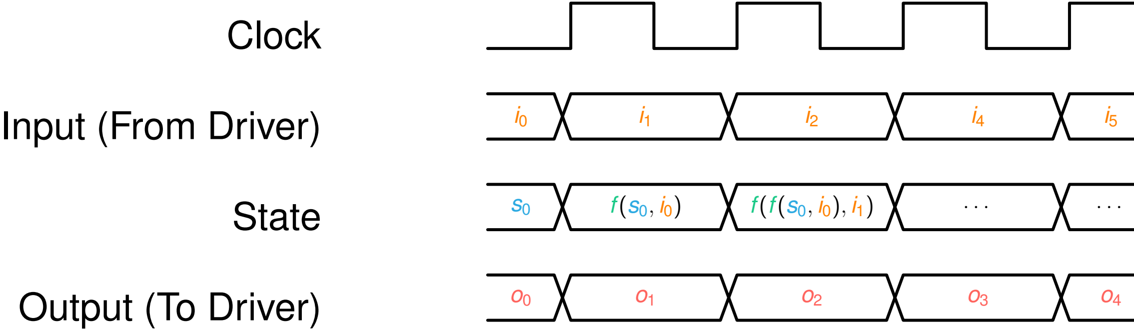

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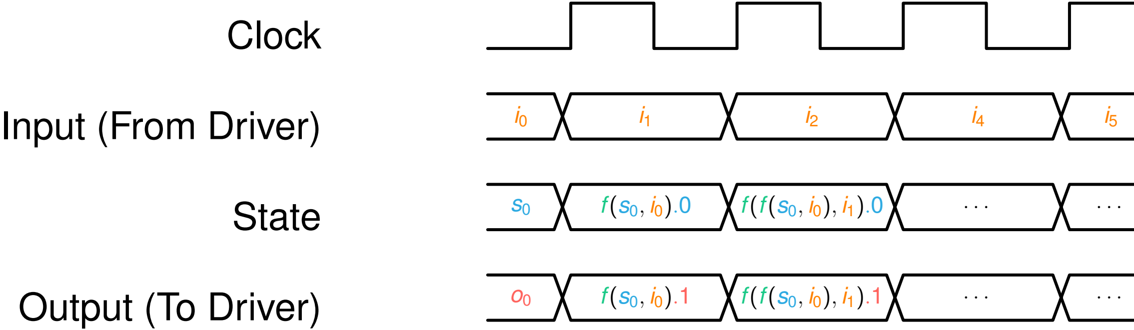

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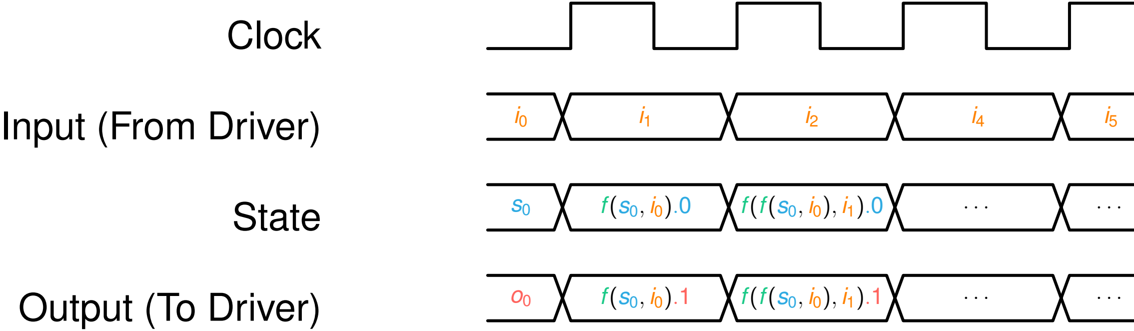


$$f : s \to i \to s \times o$$

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- *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

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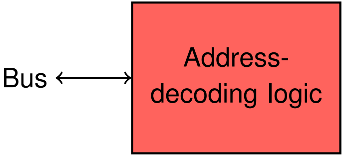


 

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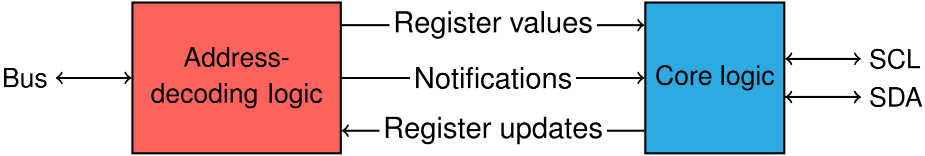

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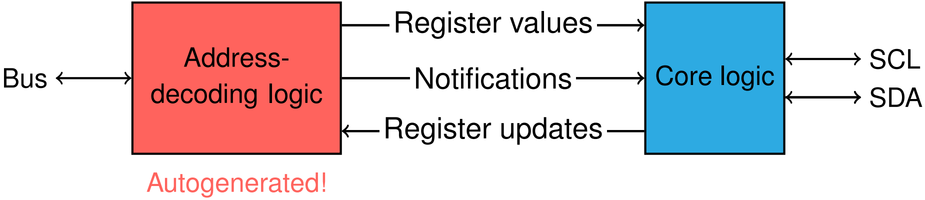

# Cheshire Specifications

- Format of Cheshire peripheral specifications:

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cheshire_run tick read write:
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- Input instantiated with optional MMIO request
- Output instantiated with response to read requests
- Executes multiple cycles

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

# Status

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| | $I^2C$ | | 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.