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Hardware-Level Security for the IoT

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Outline

- Background, IoT, Hardware/Software, Threats/Risks
- Hardware-level security
- PUFs
- Anomaly detection
- Summary

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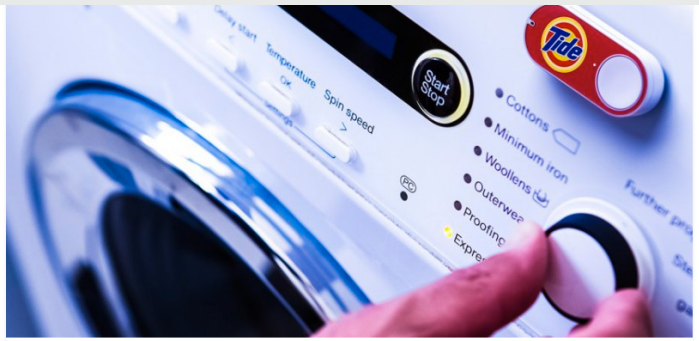
IoT / Embedded Systems

- Not desktop / server systems:
  - 20-30 year lifetimes
  - May be safety-critical
    - automotive
    - medical
  - Access to private networks
  - Limited resources


ANDY GREENBERG SECURITY 07.21.15 6:00 AM

HACKERS REMOTELY KILL A JEEP ON THE HIGHWAY—WITH ME IN IT

wired.com



Amazon Dash Button: IoT Risk in Your Home or Not?

July 10, 2016 Christopher Isak

techacute.com

IoT Security Foundation

iotsecurityfoundation.org

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How is hardware different to software?

- Hardware exists in the real world
  - Physical access allows side-channel attacks
- Implementation is not the same as design
  - Timing
  - Energy
- Every device is unique
  - Variability
- But "Hardware is the root of trust"

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Threats / Risks

- Physical access
  - Power supply monitoring
  - Changing environment
- Trojans
  - The supply chain is long and not well understood
  - What *exactly* is on your chip?
- Remote hacking
  - Buffer overflow -> root shell
- Loss of data
- Privacy
- Remote control
- Denial of service

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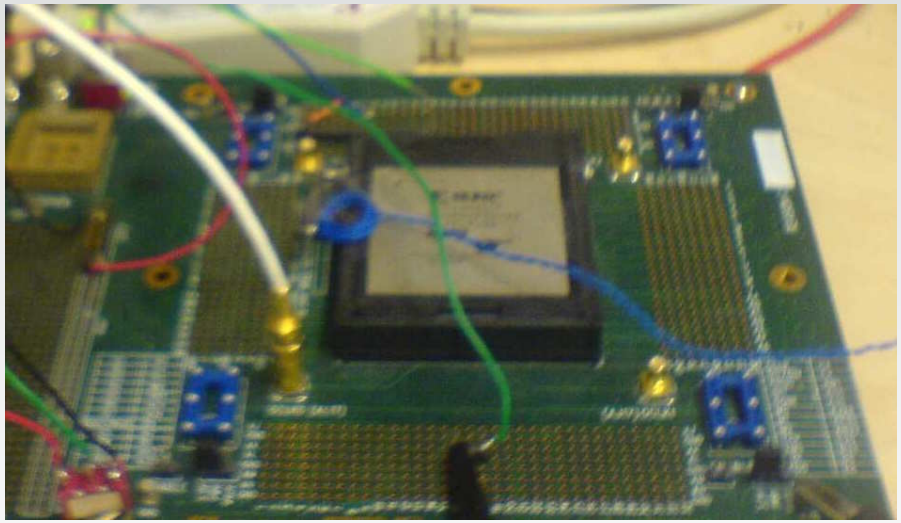
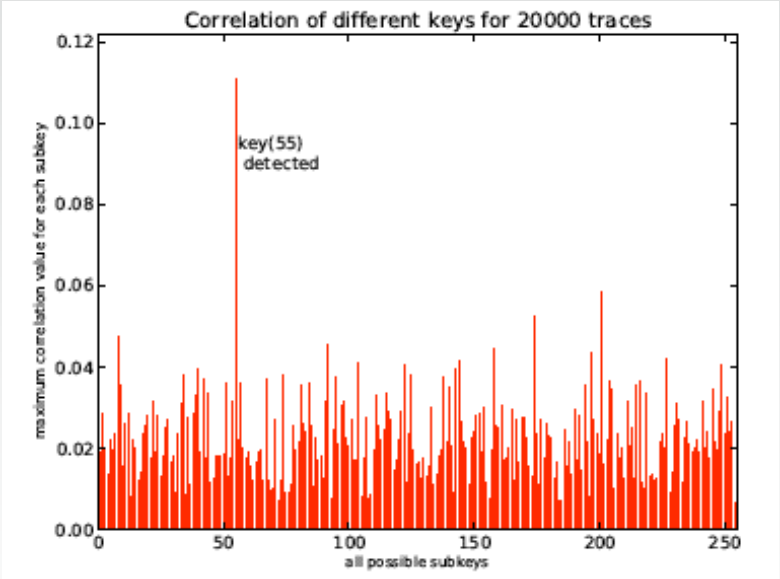
Side-Channel Attacks on Crypto

- Example: Differential Power Analysis
  - AES on FPGA
  - Simple probe





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Security at Hardware-level

- Physical Uncloneable Functions (PUFs)
  - Exploit variability between ICs to give a "fingerprint"
  - Key generation
  - Authentication
- On-chip monitoring
  - Anomaly Detection

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PUFs

- Ring Oscillators
  - Exploit variability in frequency
- SRAM
  - Use start-up values – random, but repeatable
- Need to be on-chip (CMOS)
- Need ECC
- Long term reliability
- Can be hacked by Machine Learning attacks

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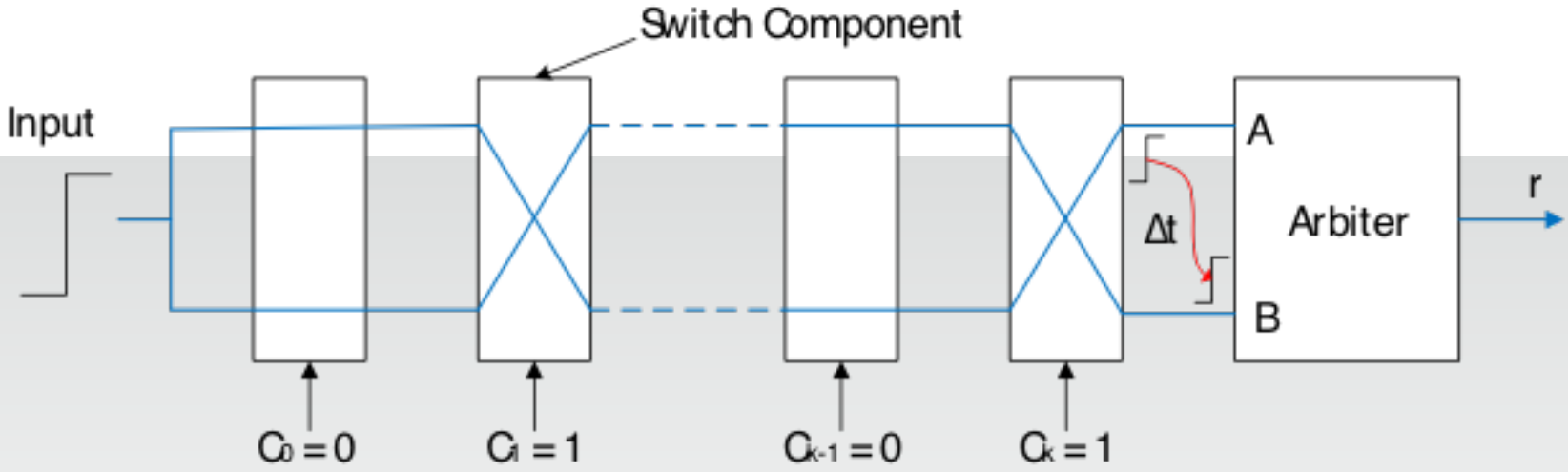
Arbiter PUF

- Exploit differences in signal paths to get unique bit patterns



- C is a key – apply different values to get a set of responses
- Low cost (power, area), but vulnerable to Machine Learning

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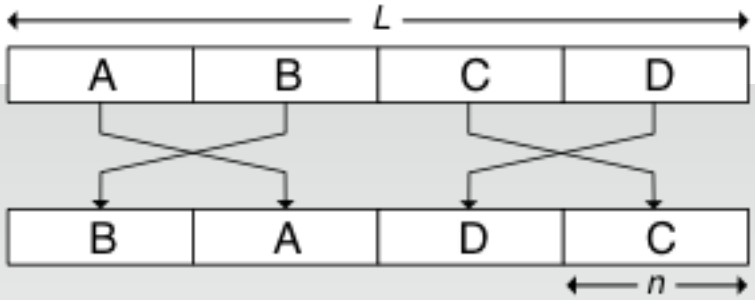
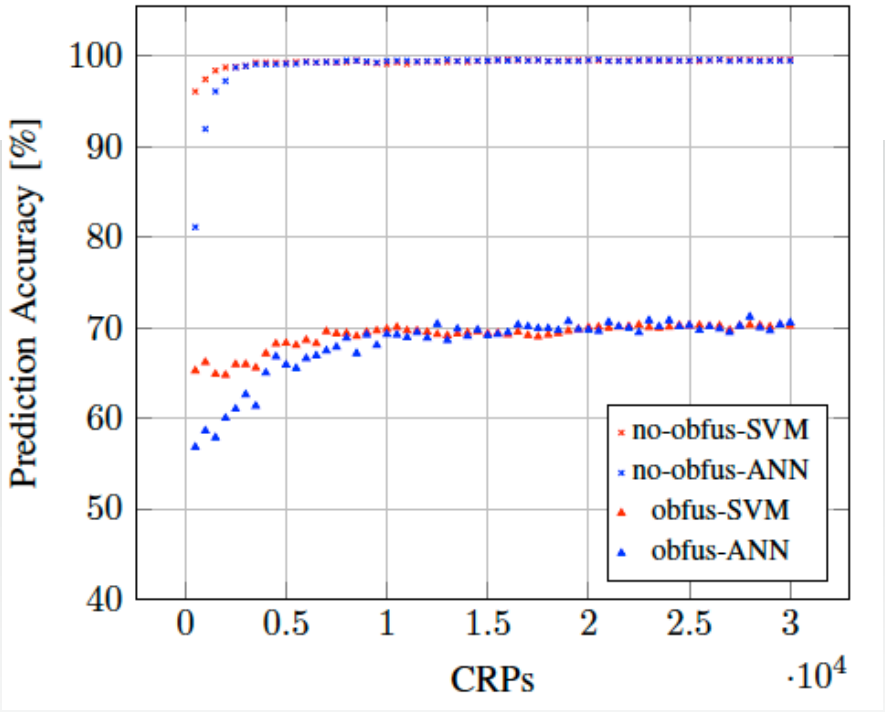
Arbiter PUF Obfuscation

- Simple permutations can significantly reduce predictability.



- 50% predictability is ideal



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On-Chip Anomaly Detection

- Hypothesis: Embedded systems do predictable things
- Therefore anomalous behaviour occurs because something bad has happened
  - Reliability problem
    - One-off (radiation) or gradual (ageing)
  - Security problem
    - Sudden, sustained
- May be able to react much more quickly in hardware than in software

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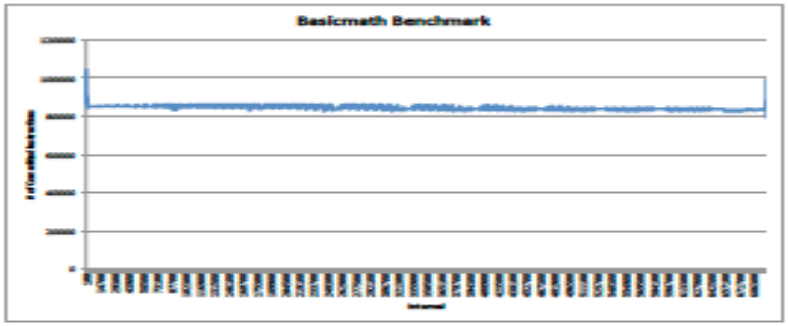
Normal Behaviour

- Different programs have patterns

Committed Instructions:



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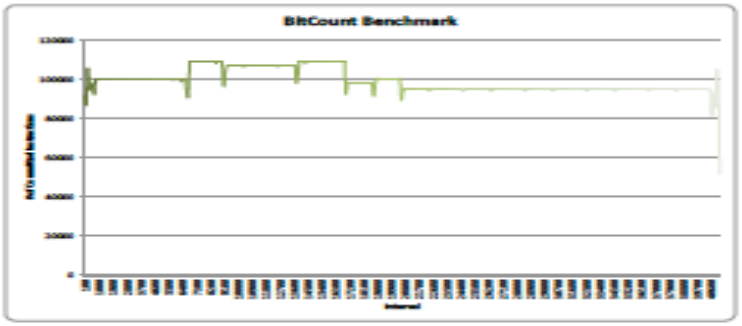

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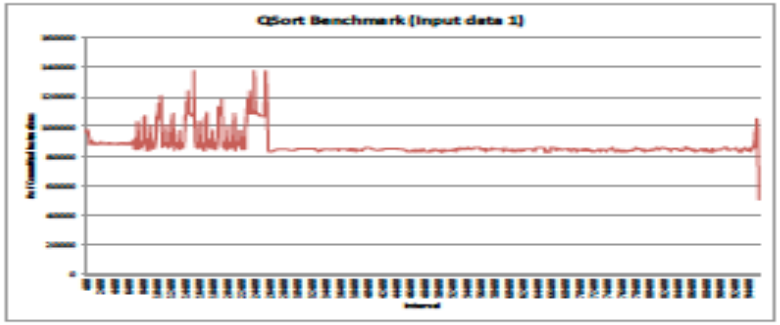

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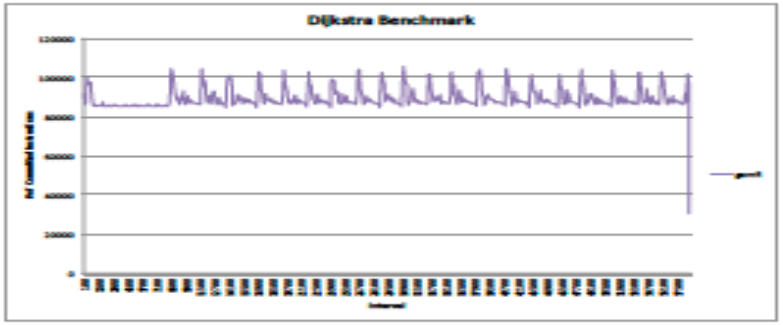

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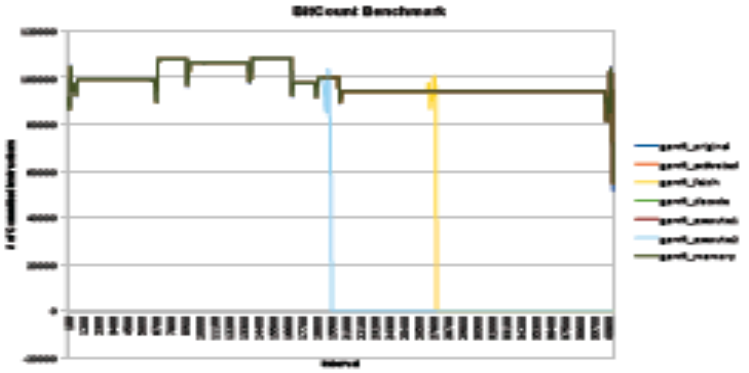
Anomalous Behaviour

- Injected faults (not attacks)

(a)



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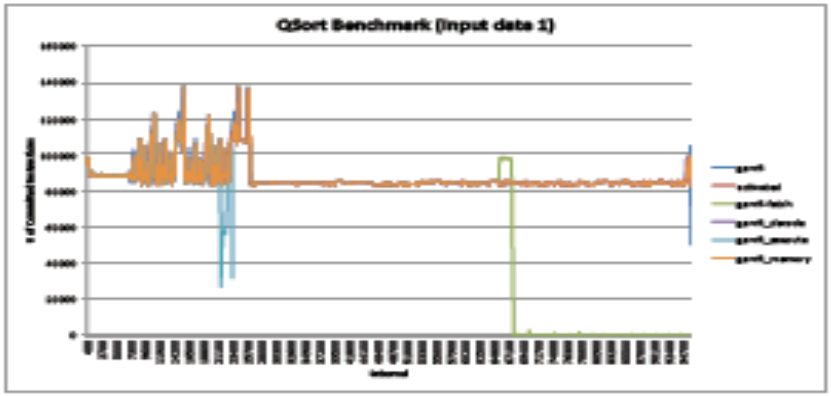

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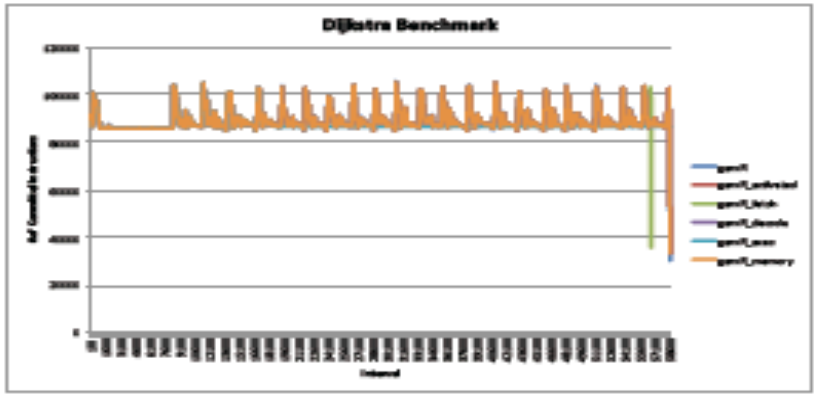

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Anomaly Detection

- Security anomaly may cause different types of unusual behaviour
  - Program Counter has unusual pattern
  - Cache Miss rate suddenly increases
  - Temperature suddenly rises

On-Chip Detection

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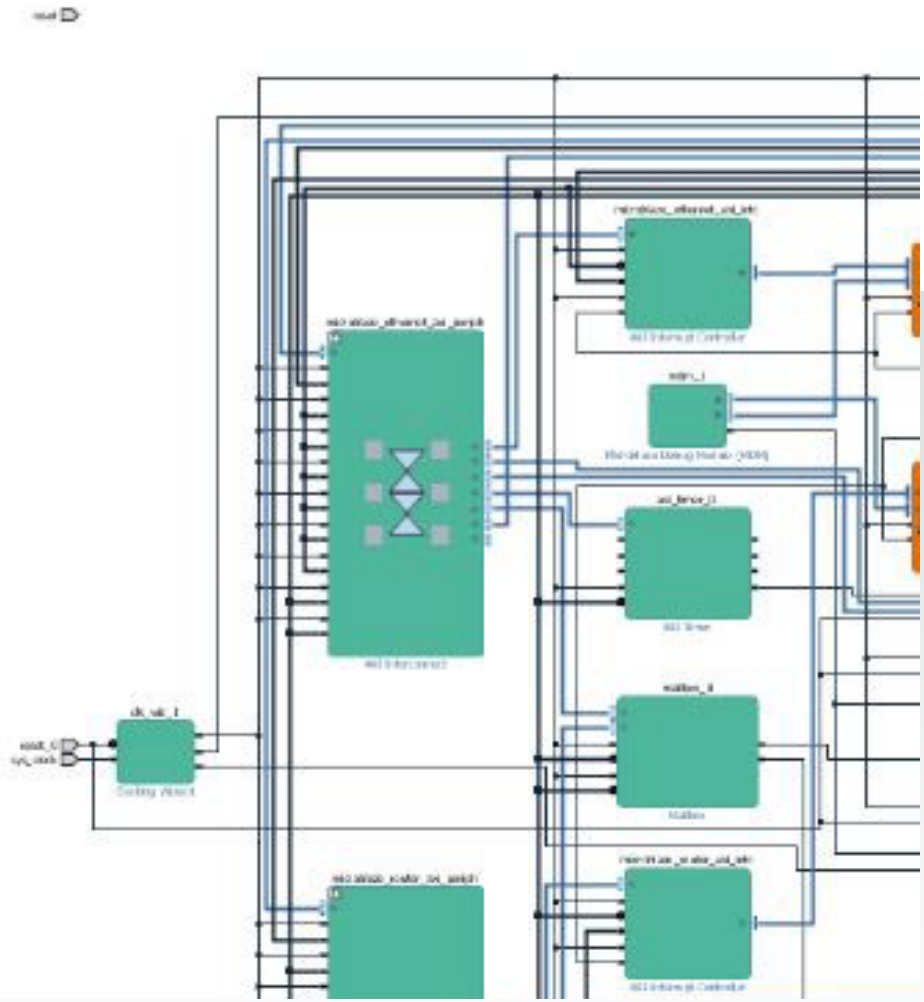

- Xilinx Microblaze
- Implemented a new Vivado Block
- Features AXI peripherals

Data Model

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Implemented as a deterministic alternative to a sparse matrix

- **Advantages**
  - Deterministic
  - Using ‘chunks’ of the program counter which
    the size
  - Implements tally to keep track of how many
    path is accessed which allows ‘unlikely path’ d
- **Disadvantages**
  - Larger space requirement
    - Map can be optimised off-chip with kn
      the program execution
  - Still using the program counter
    - Only map branch instructions

Learning

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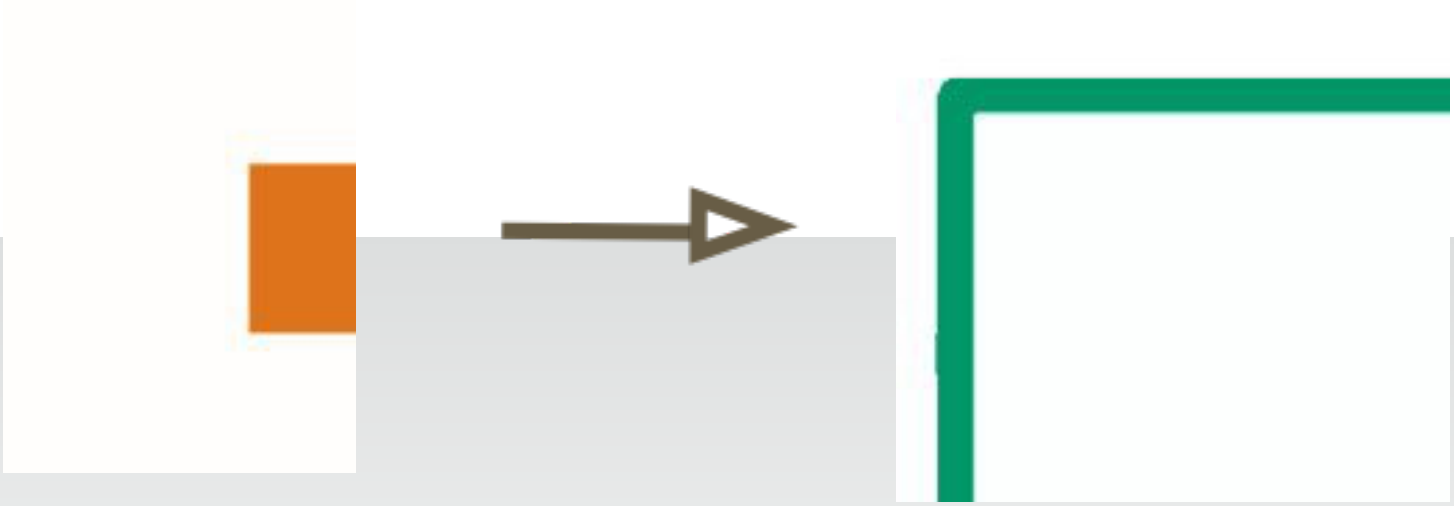

On-chip only

- Cannot construct model in real time in learning mode
- Not enough memory on chip to store for later processing

With PC

- Much more memory available
- More processing power to construct model
- Device cannot independently produce a new model to deal with changes in program e.g. updates

Learning

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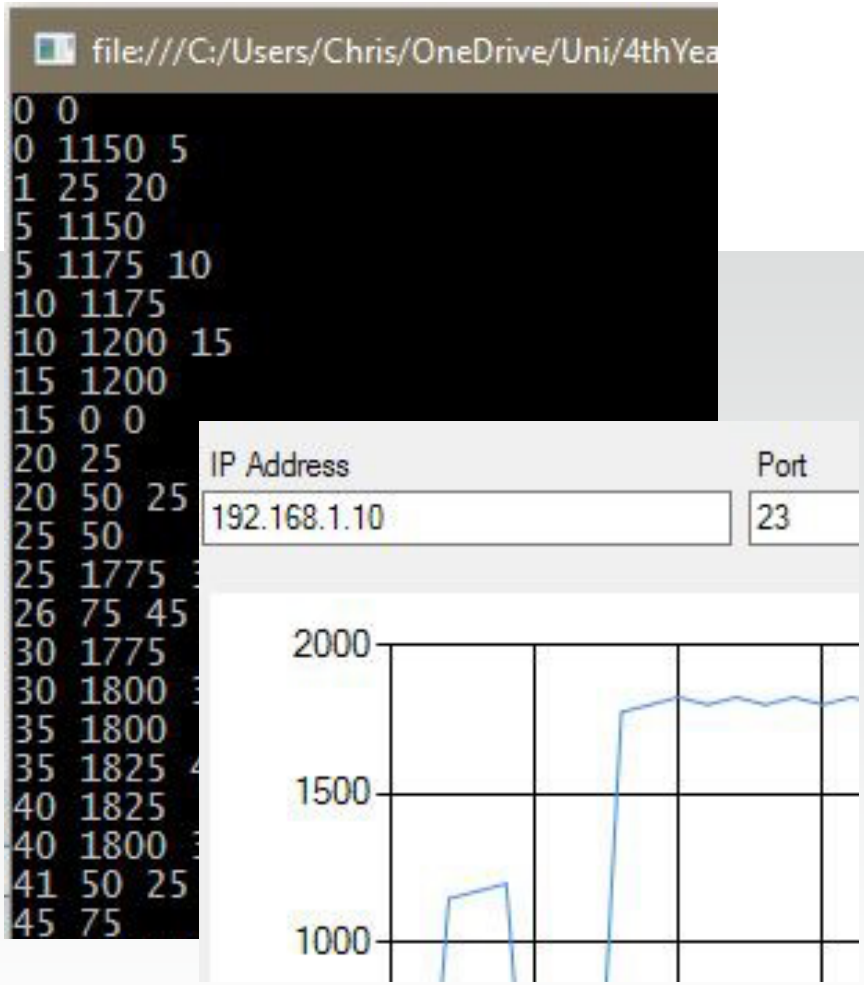
- Implemented a second microblaze processor on the FPGA which outputs the trace data to a PC via Ethernet.
- An AXI peripheral added to buffer program counter values.
- PC program developed to log the received data
- Data then transmitted back to the device and then processed to save the directed graph in memory.
- PC can also implement more complex model algorithms and enable more rapid prototyping.



IoT Exemplar

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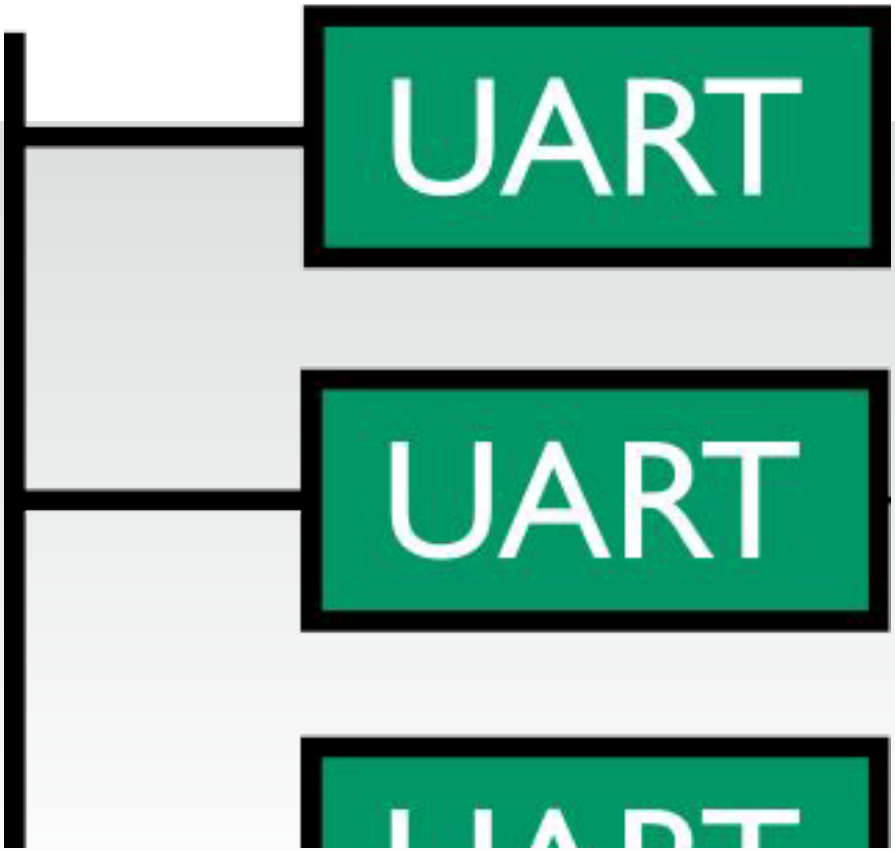

Evaluation

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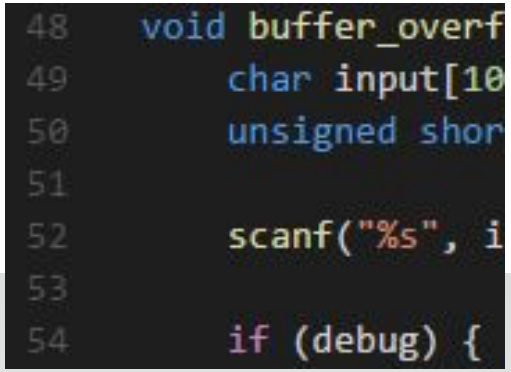
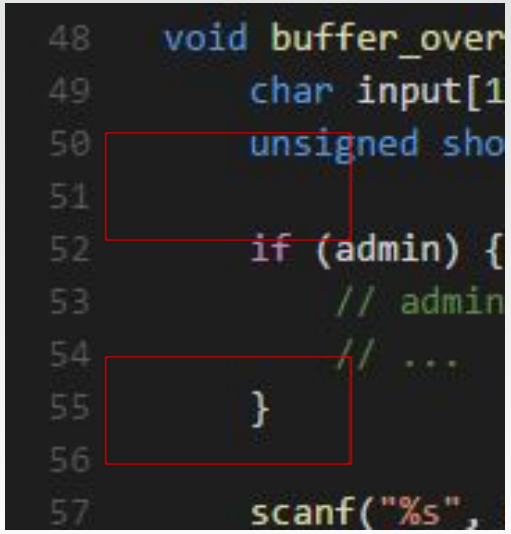
1. **Timing**
   - Does the algorithm run in real time with the processor?
2. **Hardware Size**
   - How much space on the FPGA does the anomaly detection hardware consume?
3. **Power Consumption**
   - How much additional power is consumed by the extra hardware?
4. **User Complexity**
   - What additional equipment is required to configure and run the detector?
5. **Defensive Capabilities**

Attacks that...

- Modify the execution of the program
  - Entirely new execution
  - Known execution in an unknown pattern
- Crash the program
- Change the output of the program





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Summary

- Hardware has different characteristics to software
- PUFS – Exploit variability in manufacturing
- Anomaly detection – different types of threats; faster, different response

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Acknowledgements

- PUFs – Mohd Syafiq Mispan, Dr Basel Halak
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