Finger Finder: A Low-Energy Peak Detection Accelerator for Capacitive Touch Controllers

Third Workshop on Computer Architecture Research with RISC-V (CARRV 2019)
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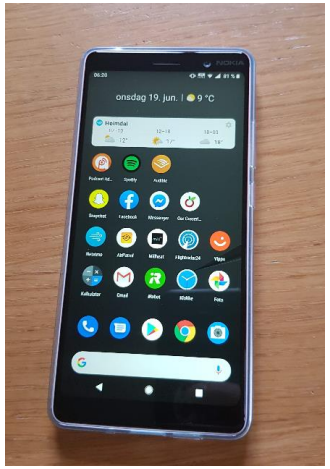
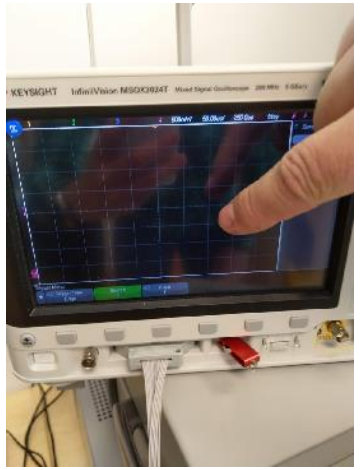
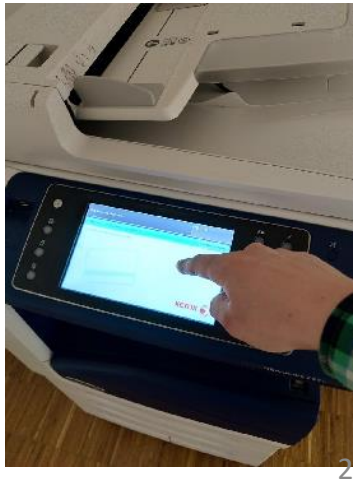
Touch screens everywhere

Home

Work

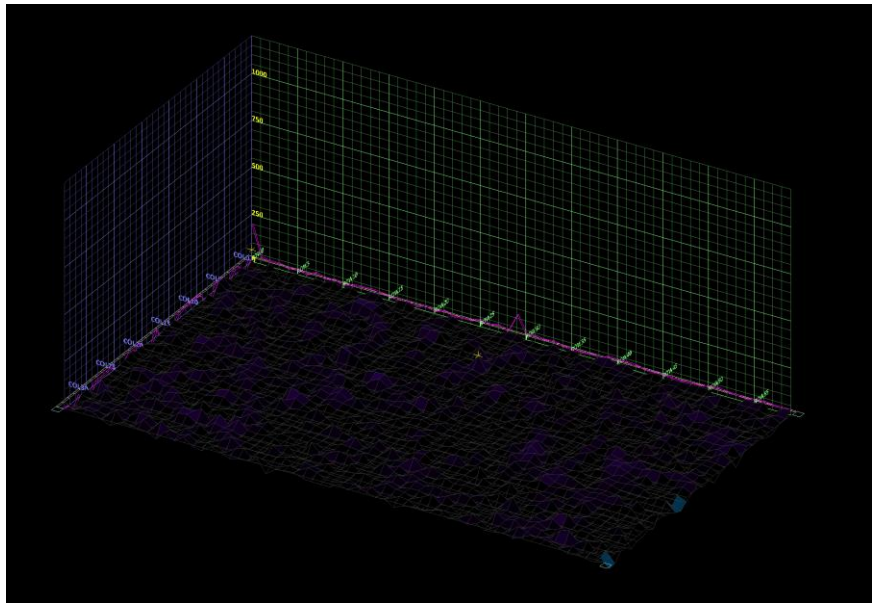




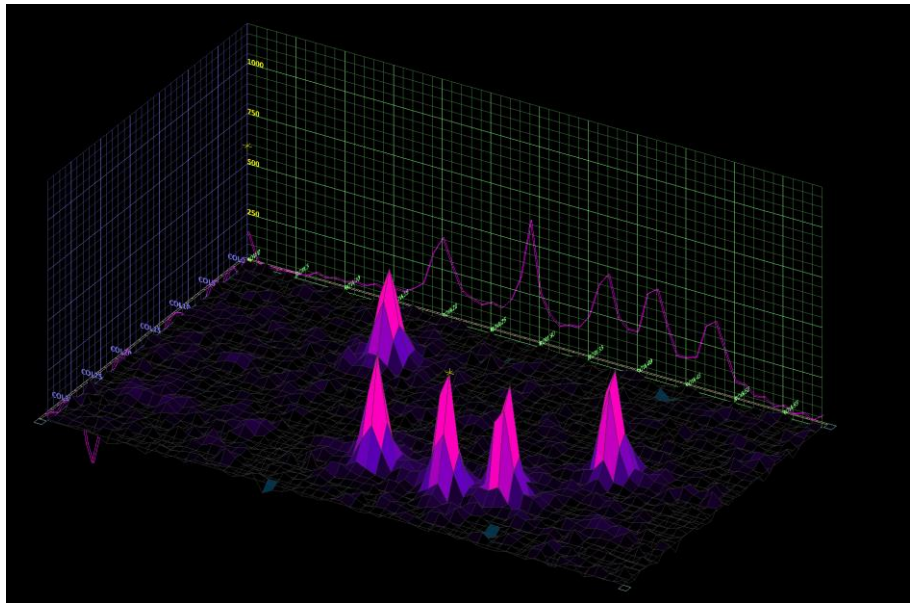


Touch screen controllers, process touch or sleep

- Peak detection is the first algorithm run on the acquired touch screen image



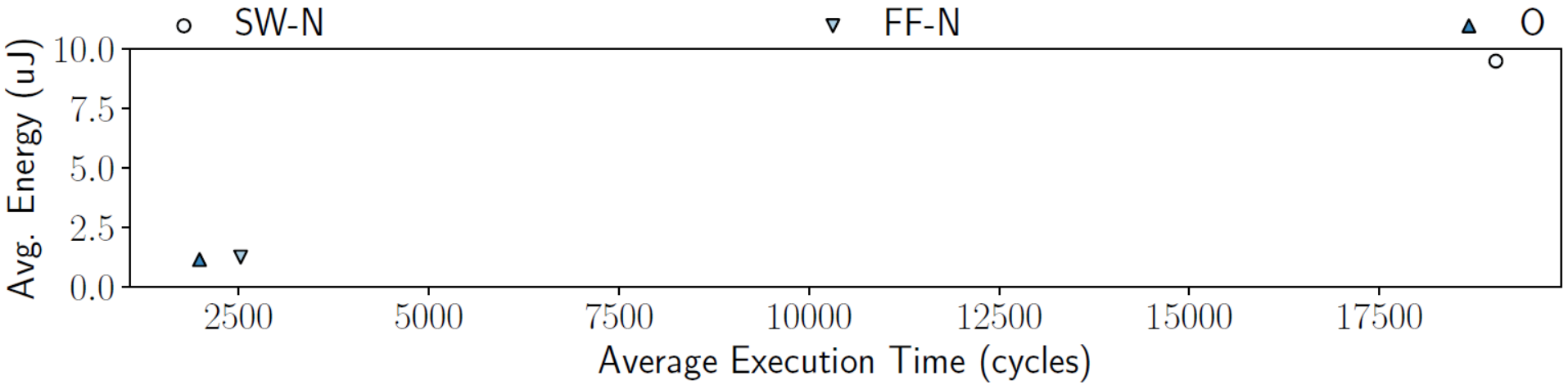
Go to sleep



Process touch

Touch screens, Finger Finder

- Finger finder (FF-N) HW accelerator
  - Compared to the best compiled C-code solution, FF-N reduces the energy consumption with 86%
  - 9.5% above a theoretical lower bound for energy consumption

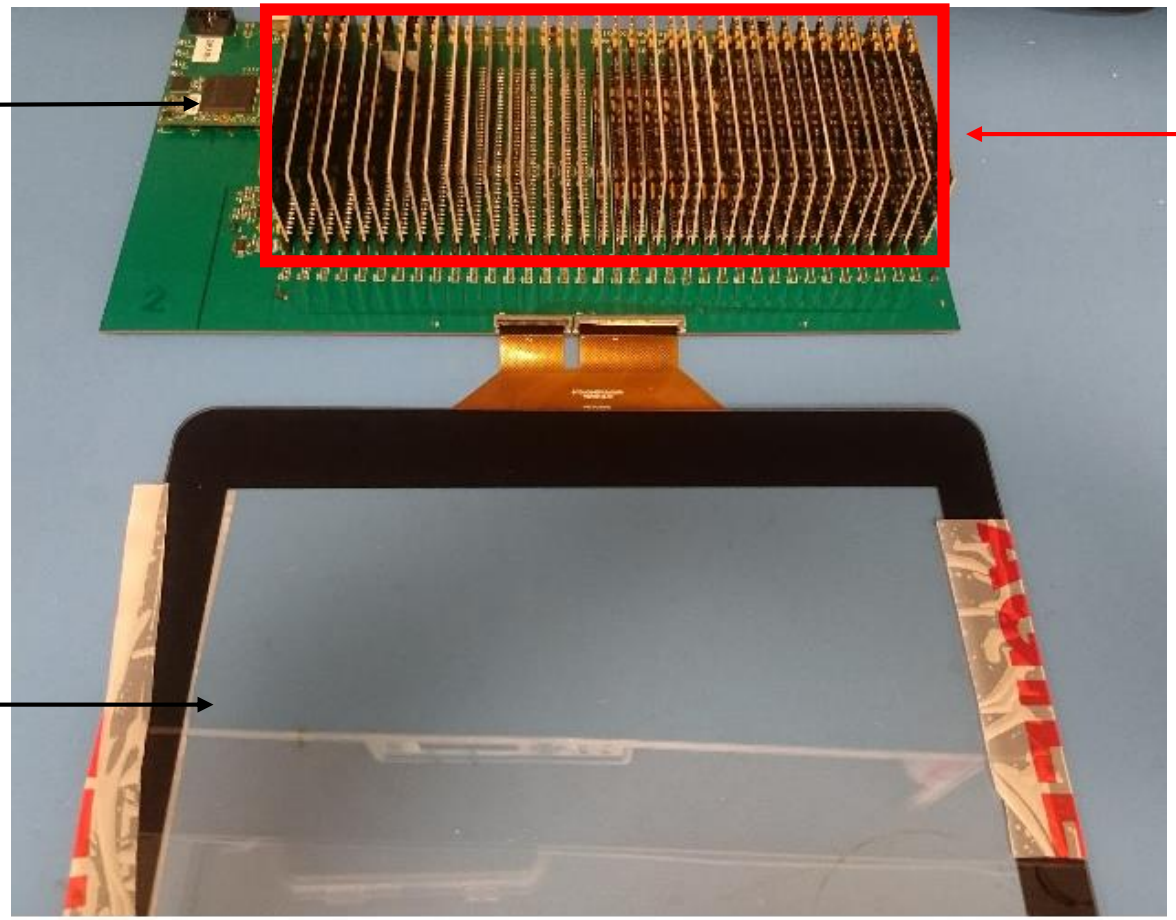


Outline

- **Introduction**
- Peak detection in SW
- Finger Finder

Why make a touch screen controller ASIC?

FPGA with CPU, IO and custom DSP



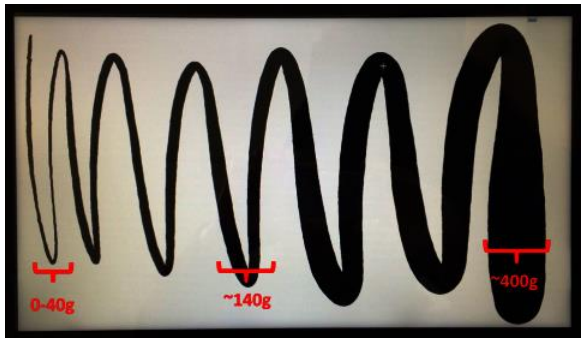
Analog front-end daughter cards

Touch screen

aXiom touch screen controller

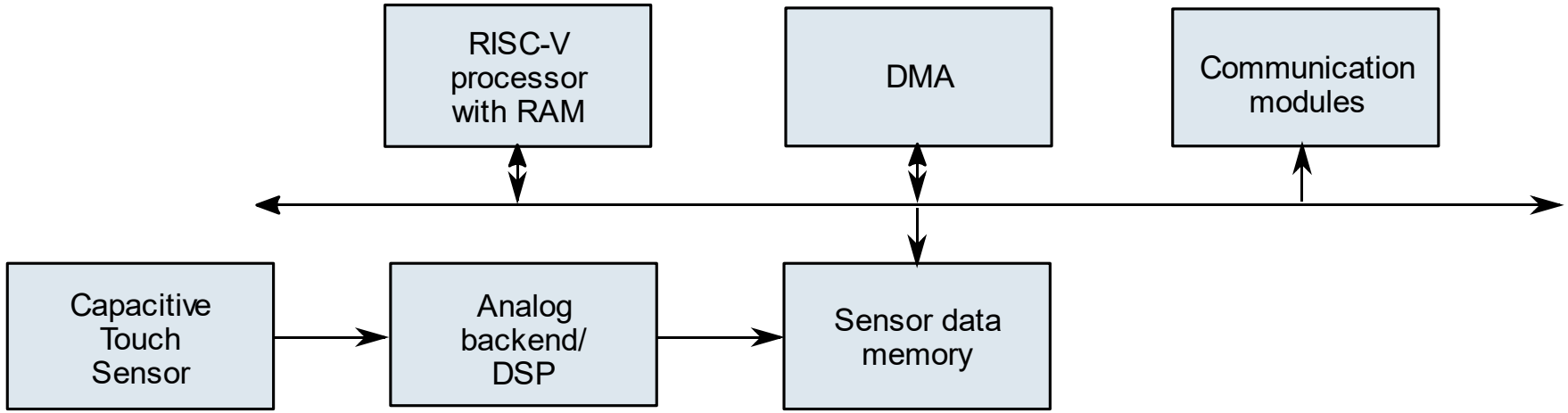
MyWo AS - designing high performance touch controllers

- Targeting industrial and automotive applications
  - Noisy environments require higher SnR
  - 3D touch
  - Force sensing
  - Haptics feedback
- Need a 32-bit CPU with mul+div



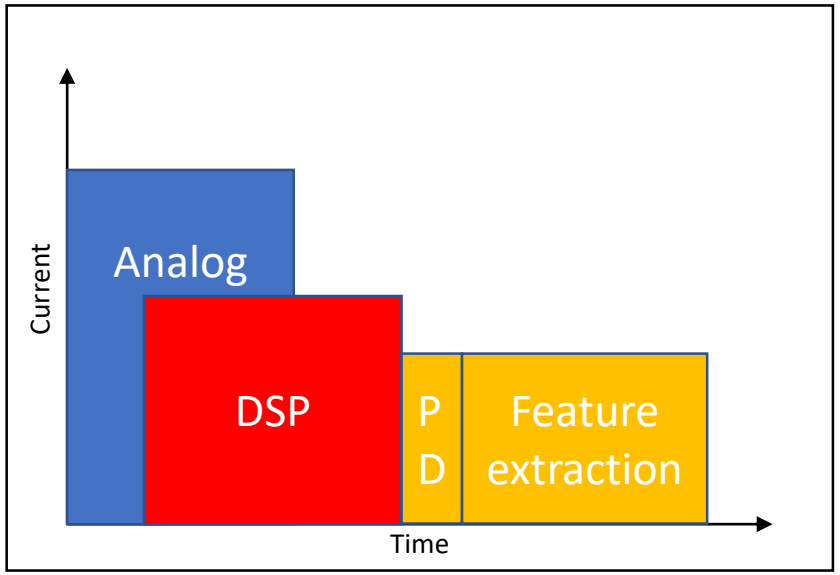
Why using RISC-V in the MyWo touch screen controller?

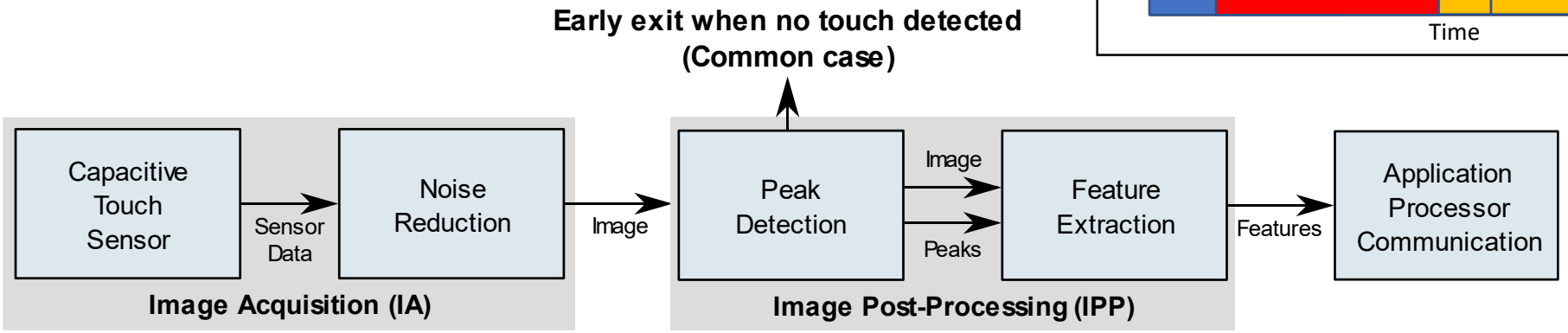
- Using the Rocket Chip generator
  - Speed
  - Cost
  - Flexibility
  - Design time



Reducing power consumption in touch controllers

- Periodically scans the touch screen
- Analog dominates first
- Then digital when processing
- Go to sleep quickly





Why peak detection?

- Selected when we had the FPGA prototype
  - The feature extraction was not complete
  - Peak detection dominated the image post-processing
    - The CPU ran at half of the speed of the aXiom chip
  - The analog current consumption was not known
- Many devices run the touch controller when the screen is off
  - Knock to wake up
  - Gestures to perform functions while off

Outline

- Introduction
- **Peak detection in SW**
- Finger Finder

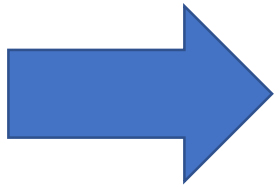
Peak detection

- Detect local maxima in a 2D image
  - Above a noise threshold
  - Peak if center is greater or equal to neighbors

1	4	2	1
5	9	8	4
3	7	7	6
2	3	5	8

- If one or more of the neighbor nodes are equal to the center peak, increment the center
  - Avoiding a large number of peaks for plateaus

1	4	2
5	9	8
3	7	9



1	4	2
5	10	8
3	7	9

Peak detection algorithms, SW-N

- The naive implementation:

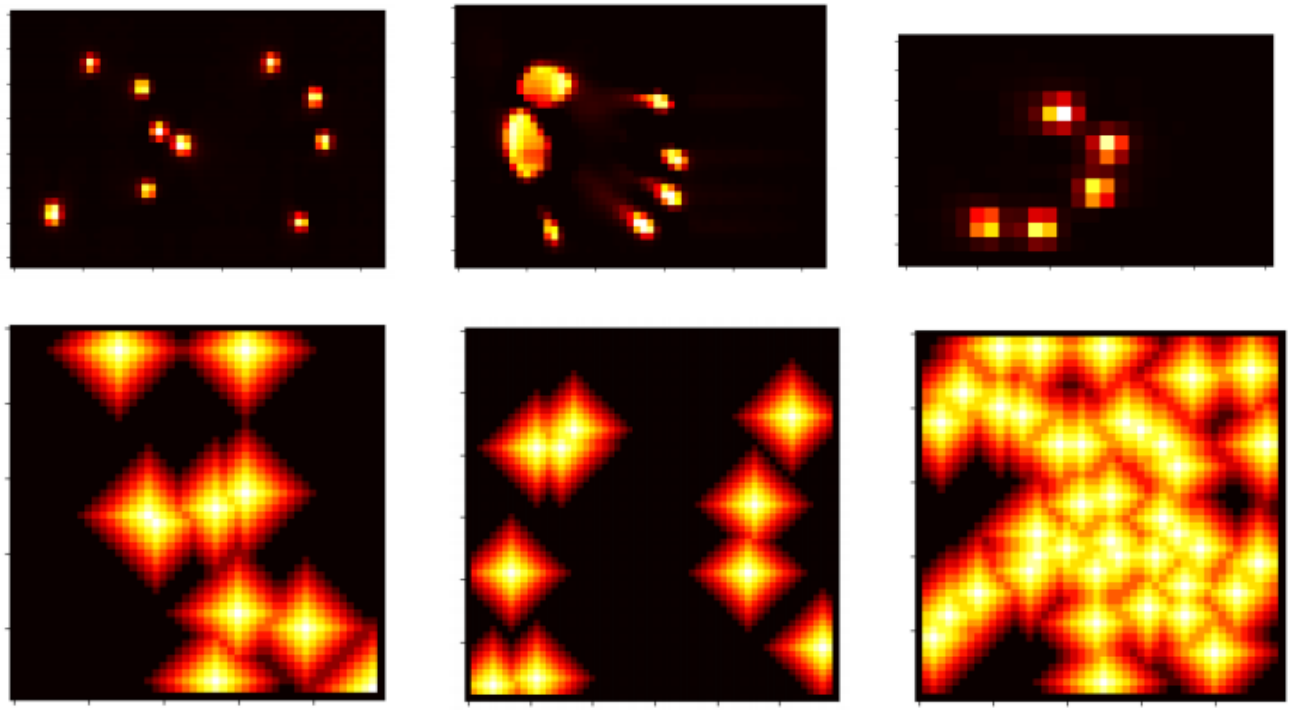
```
for (Down = DownOffset; (Down <= (Max_Down -1)) && (TotalPeaksFound < MaxPeaks); Down++)
{
    for (Across = AcrossOffset; Across <= (Max_Across -1); Across++)
    {
      if ((RawData[Down][Across] >= MinimumSignal) &&
          (RawData[Down+0][Across-1] <= RawData[Down][Across]) &&
          (RawData[Down+0][Across+1] <= RawData[Down][Across]) &&
          (RawData[Down-1][Across+0] <= RawData[Down][Across]) &&
          (RawData[Down+1][Across+0] <= RawData[Down][Across]) &&
          (RawData[Down-1][Across-1] <= RawData[Down][Across]) &&
          (RawData[Down-1][Across+1] <= RawData[Down][Across]) &&
          (RawData[Down+1][Across-1] <= RawData[Down][Across]) &&
          (RawData[Down+1][Across+1] <= RawData[Down][Across]) )
        {
```

Peak detection algorithms, SW-C, SW-N16, SW-T

- Three other software algorithms were developed:
  - SW-C will cache the 8 neighbor nodes to reduce the number of memory loads
  - SW-T will only keep the cache updated if the current node is over the threshold
  - SW-N16 tries to take advantage of the 16-bit values stored in a 32-bit RAM and reads two and two values for each load
    - Otherwise similar to SW-N
- Theoretical lower bound
  - O (Oracle) loads a node from RAM and knows if it is a peak or not.

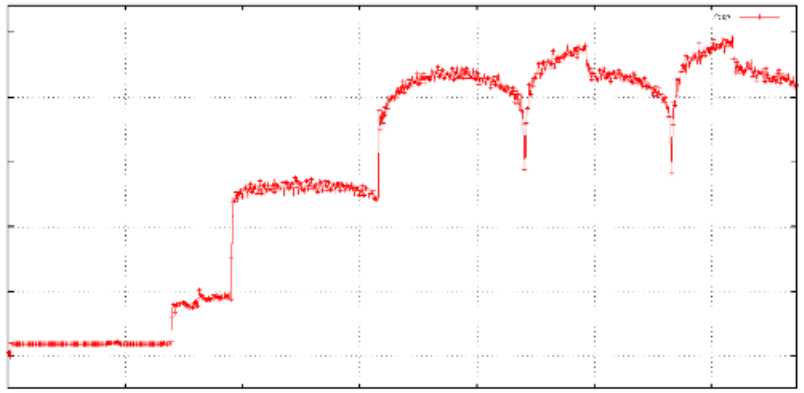
Test patterns

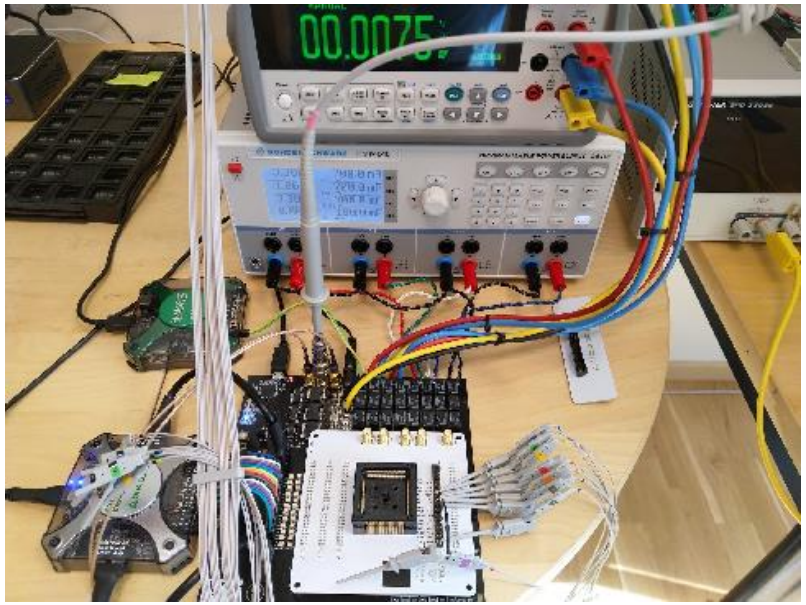
- 70 test patterns
  - 31 acquired from the FPGA prototype
  - 39 synthetically generated patterns



Test method

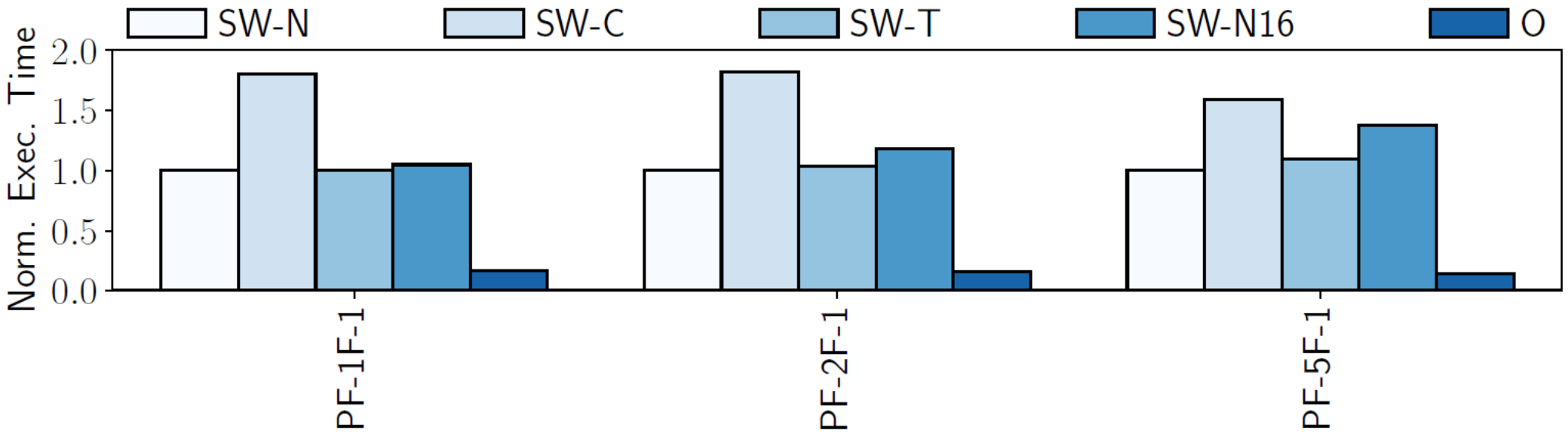
- Test method
  - Simulated on the aXiom chip RTL code
  - RTL current estimation tool
- Measured the actual current consumption on the aXiom prototype
  - Compared against the simulated





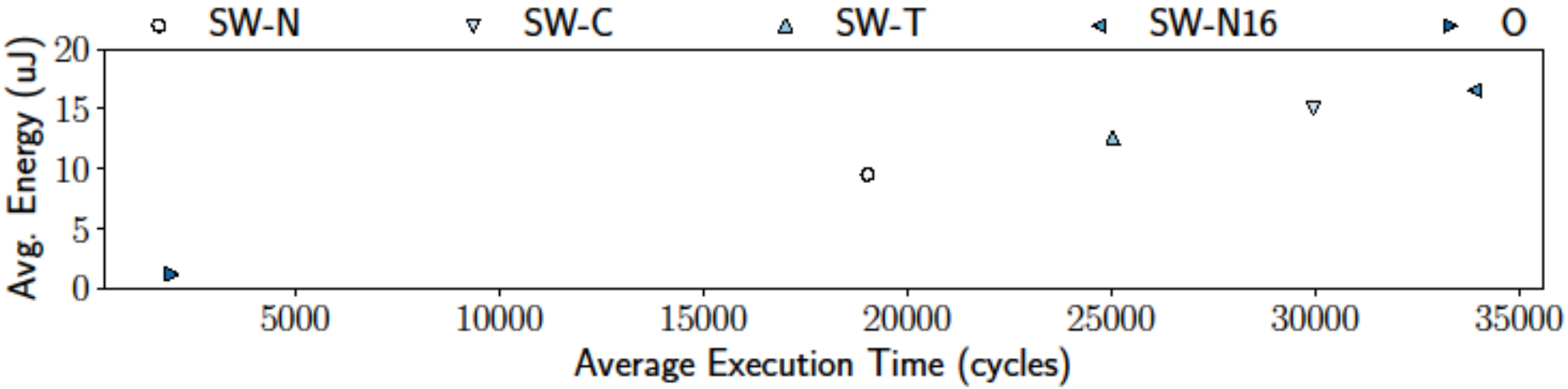
SW results

- The results are data dependent



SW results

- The SW-N algorithm performs best overall
  - The SW-C algorithm is impacted by keeping alive the cache all the time
  - The SW-T and SW-N16 algorithms performs worse when there are nodes over the threshold



- Simulated current consumption correlates with the measured

Outline

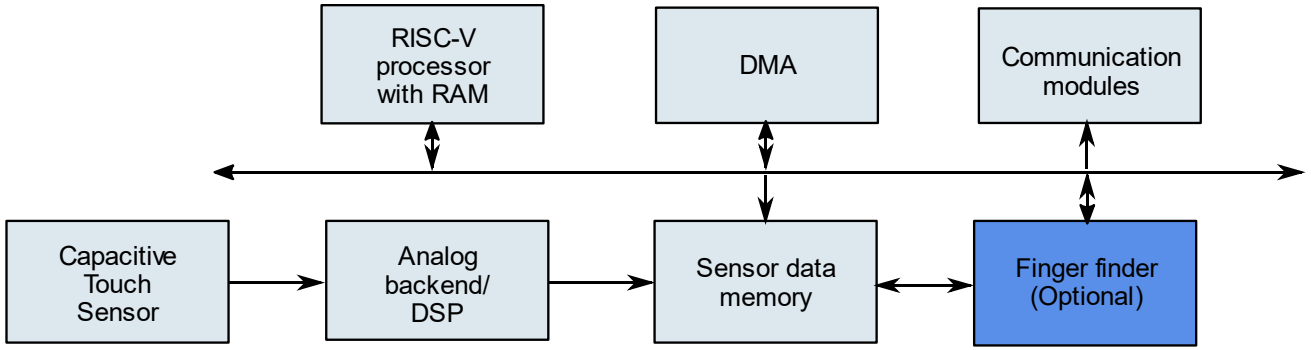
- Introduction
- Peak detection in SW
- **Finger Finder**

Assembly optimizing, RoCC or HW accelerator?

- Looked into assembly optimizing the code

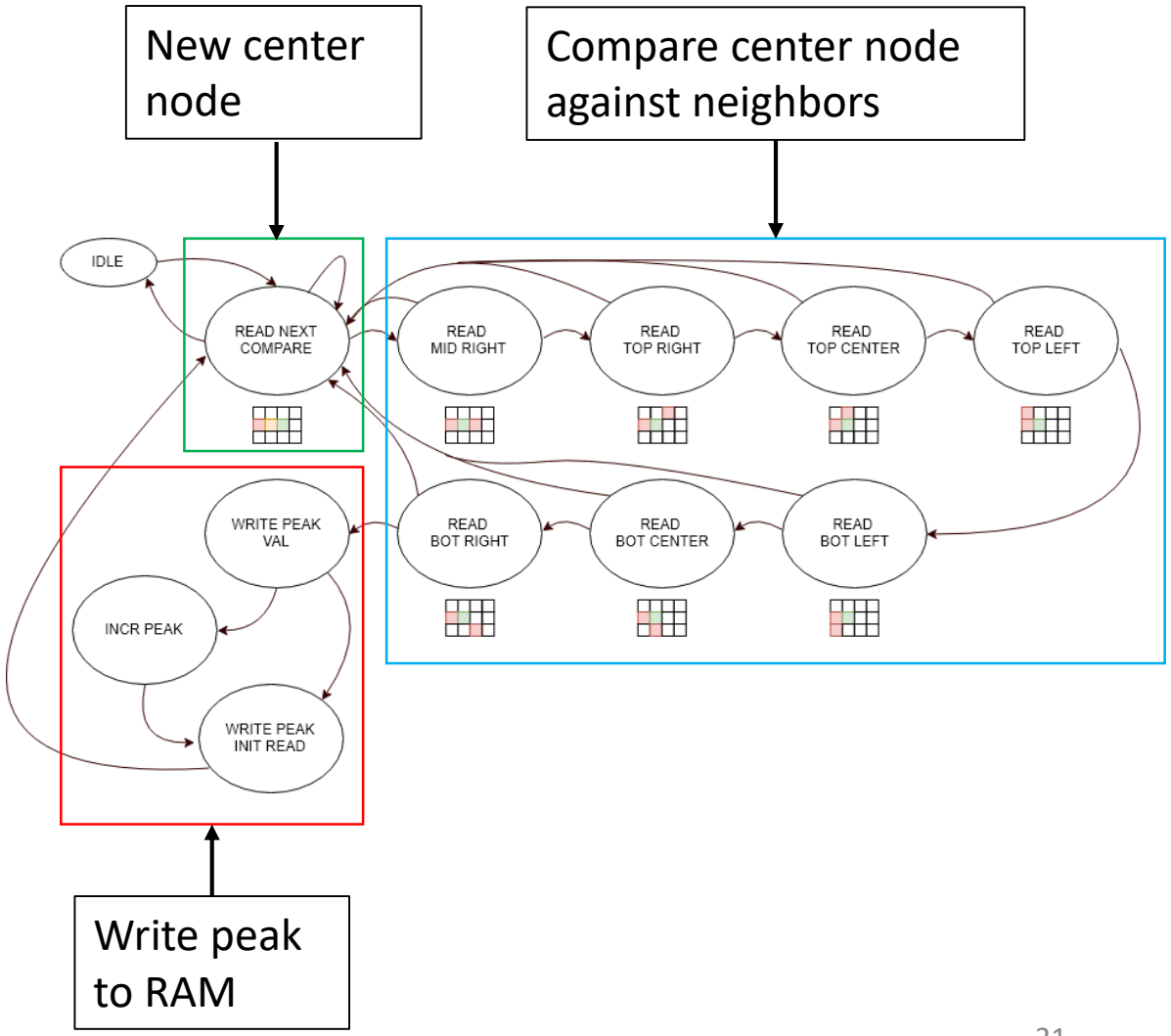
```
400001ea:       43d4                    lw      a3,4(a5)
400001ec:       fea6eae3                bltu    a3,a0,400001e0 <FindPeaks+0x80>
400001f0:       0007a803                lw      a6,0(a5)
400001f4:       ff06e6e3                bltu    a3,a6,400001e0 <FindPeaks+0x80>
400001f8:       0087a303                lw      t1,8(a5)
```

- Looked into making a Rocket Custom Coprocessor via the RoCC interface
- Decided to go for a HW accelerator tied to the sensor data memory



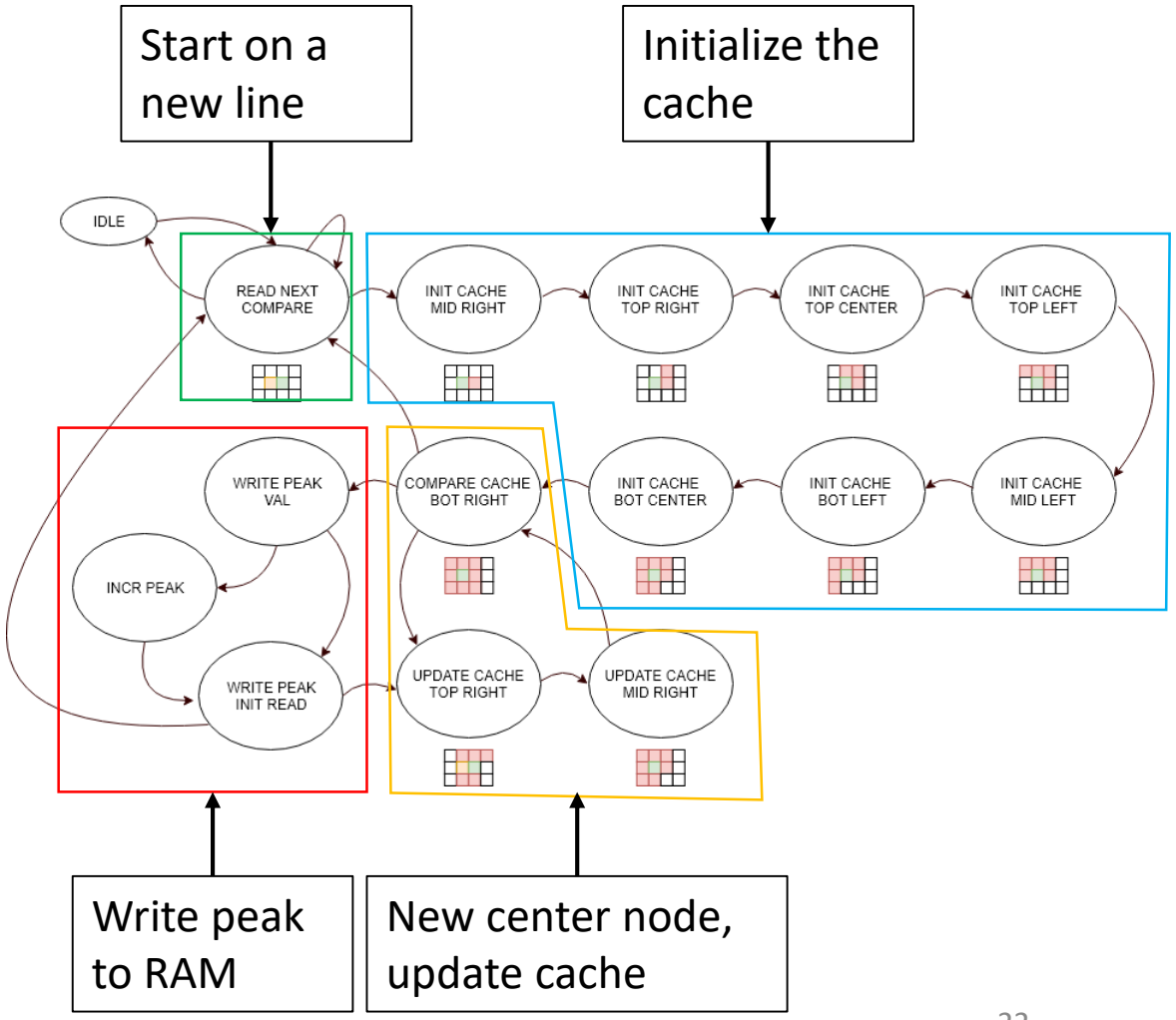
Peak detection algorithms, FF-N

- Implemented the SW-N algorithm as a FSM with direct access to the sensor node data RAM
- When a peak is found the FSM writes the location to a list of peaks in the RAM



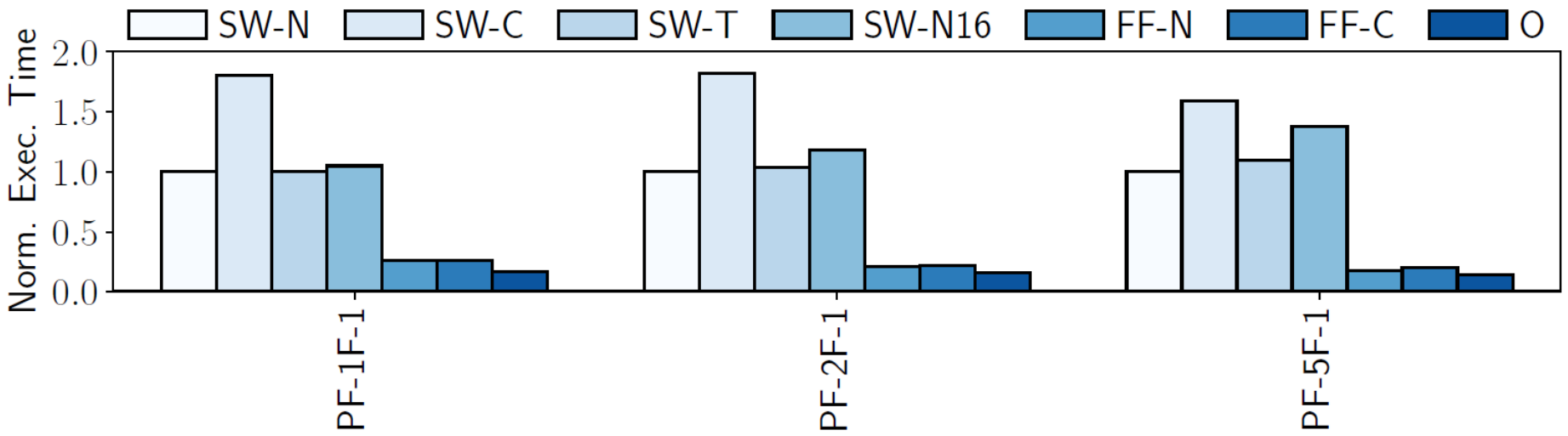
Peak detection algorithms, FF-C

- The FF-C accelerator stores all 8 neighbors in a register bank
  - When going to a new center node the register bank is shifted and three new values are loaded into the bank



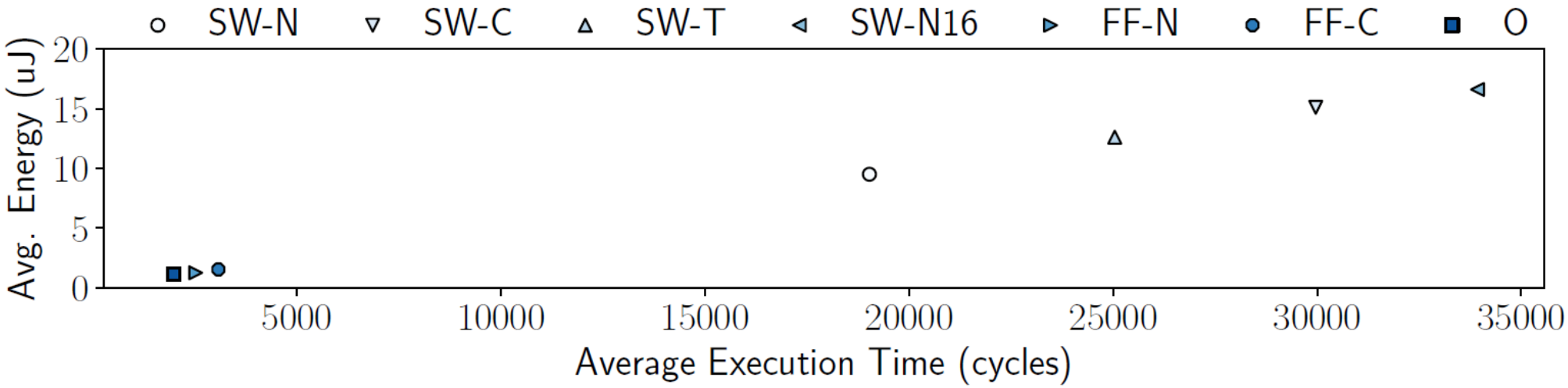
Final results

- Finger finder (FF-N) has the best performance



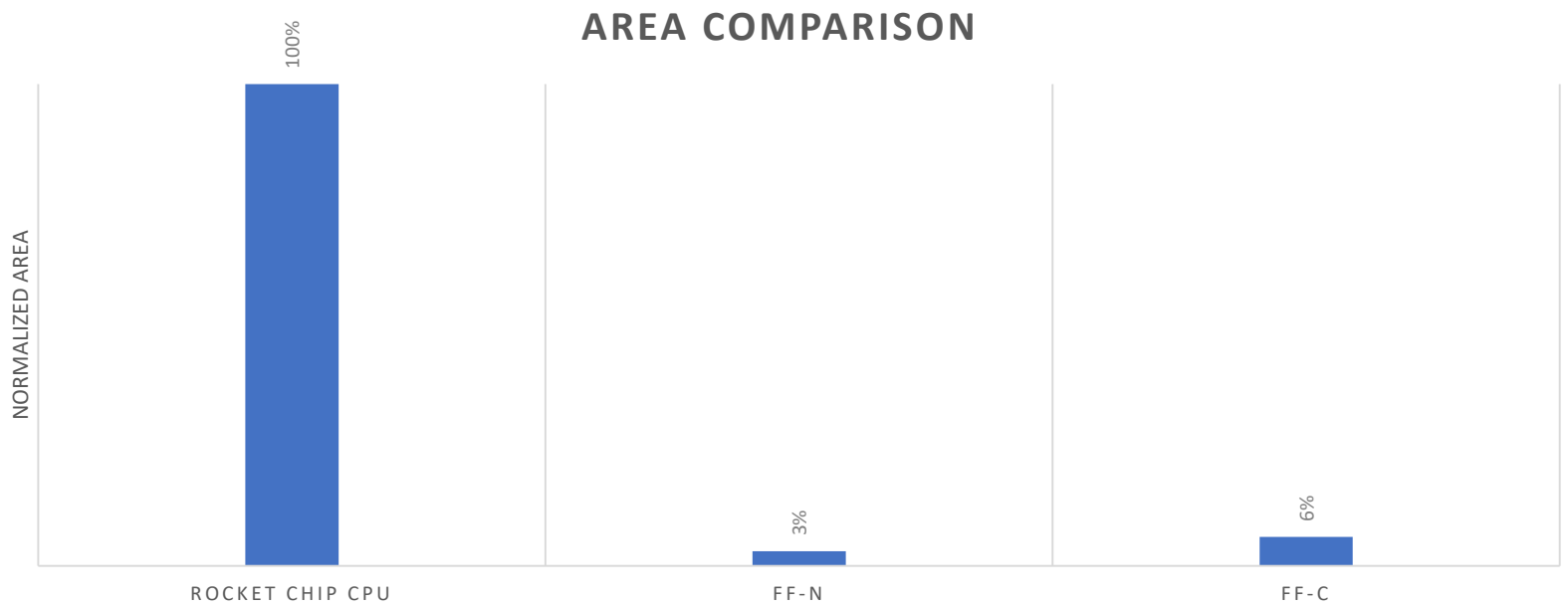
Final results

- Compared SW-N, FF-N reduces the energy consumption with 86%
- 9.5% above the oracle (O)



Final results

- Area impact is small
  - No changes in critical path



Conclusions

- Of the software algorithms, the naïve implementation performs best
- With the Finger Finder HW accelerator we can speed up the peak detection and reduce the power consumption considerable compared to the best SW algorithm

Thank you

Any questions?

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