Optimized digital design flow for embedded sensor applications using high level synthesis

Savino Bellopede, Marco Castellano, Ugo Garozzo
Digital Designer
STMicroelectronics

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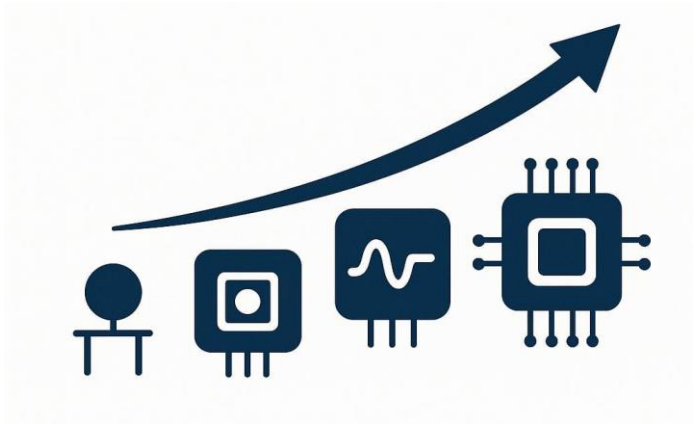
Motivation

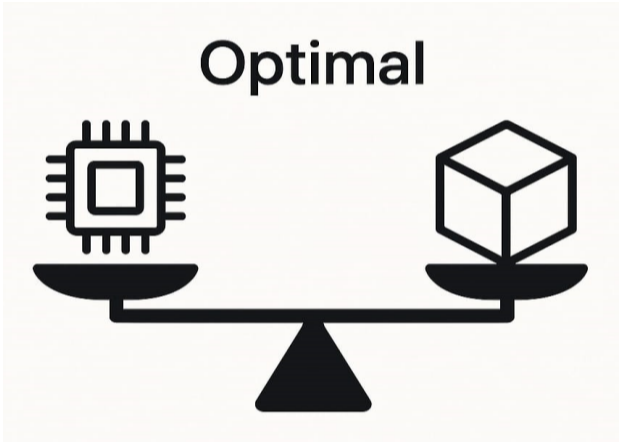
Sensors are evolving

From data to embedded applications



Algorithm quality/accuracy and area occupation

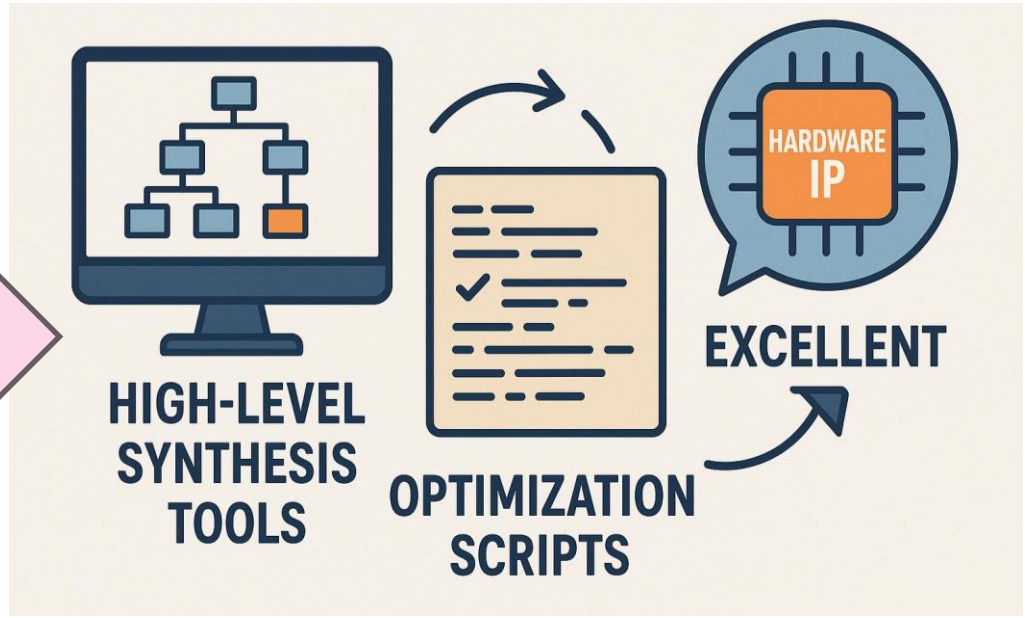
Best compromise between algorithm quality/accuracy and area occupation



Timelines & time to market

Project timelines are often very tight

Idea



Advantages of synergistic use of high-level synthesis tools and optimization scripts:

- HW implementation tool: HLS Catapult
- SW optimization tool: Python

The Synergy tool for best in-sensor embedded algorithms

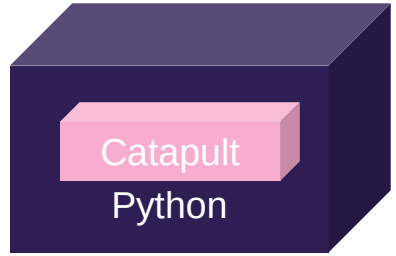
Enhanced productivity	Improved design quality	Integration and scalability	Resource management

Build a best-in-class embedded algorithm

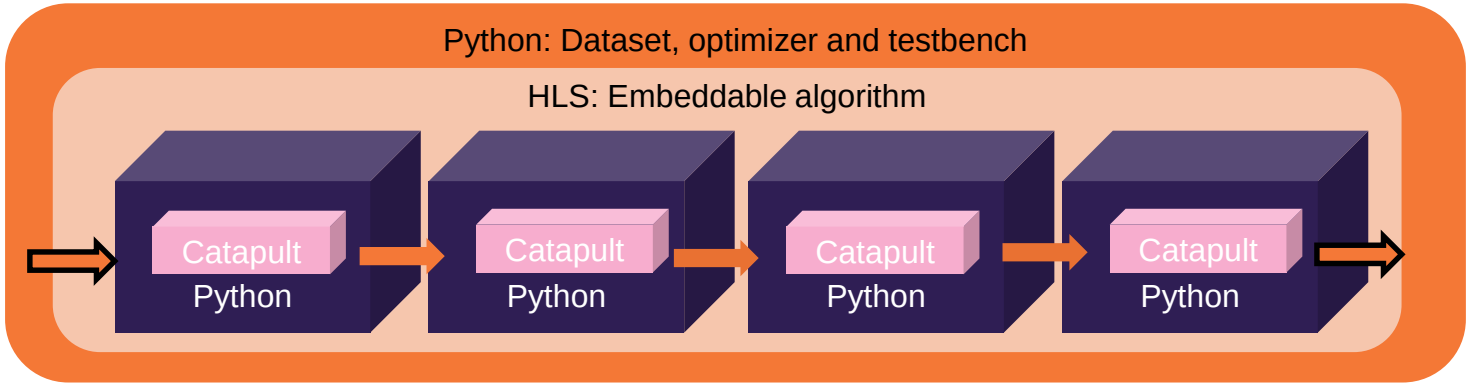
First pillar: basic bricks
Go up and down from algorithm to implementation and back

Second pillar: the chain
Embed an algorithm as a chain of basic bricks

Third pillar: the flow
Create a flow that uses the synergy of Catapult and python to find the best tradeoff between latency accuracy and area

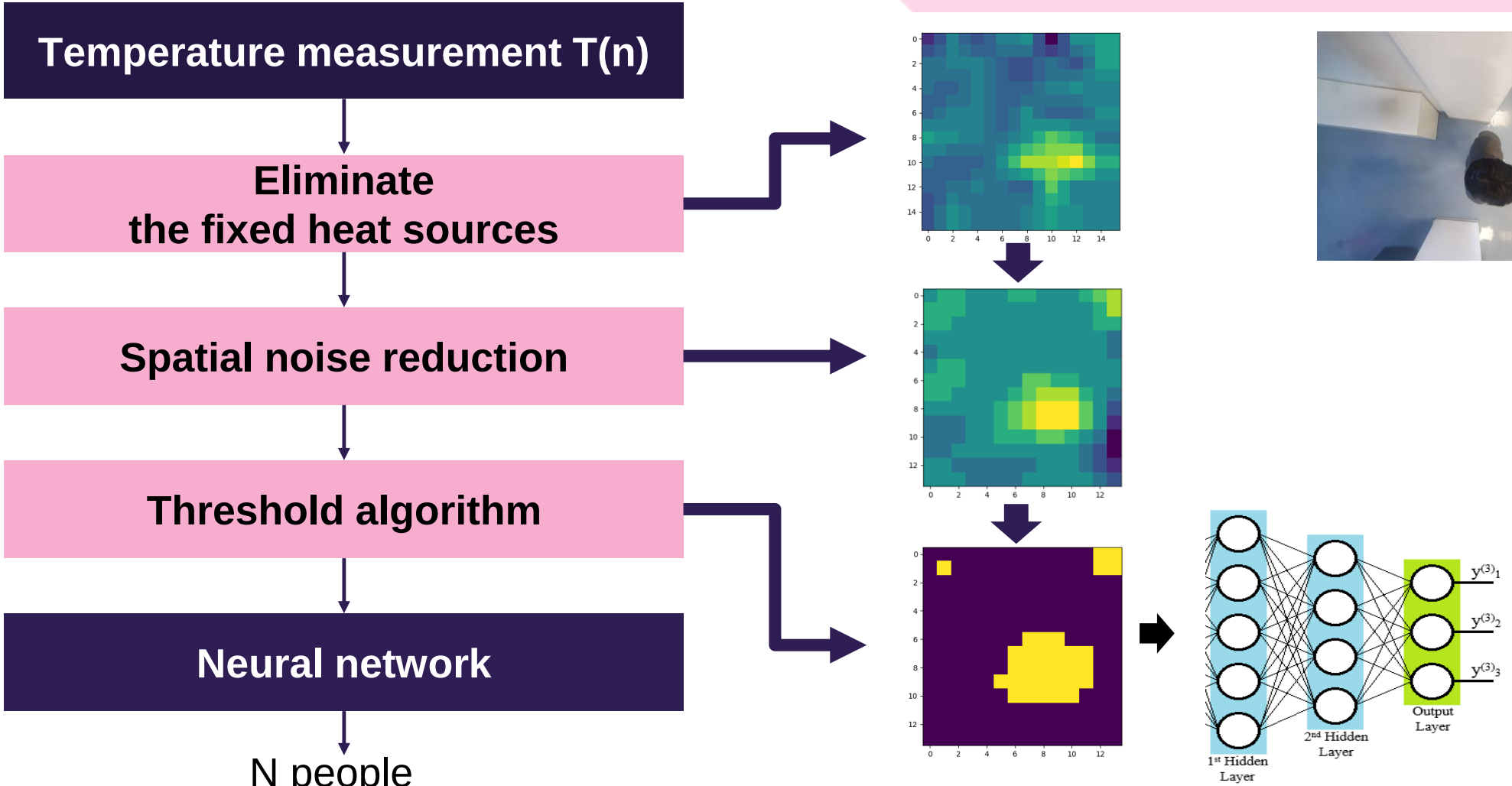


Basic bricks model



Evidence: people counting

Algorithm as chain of basic bricks



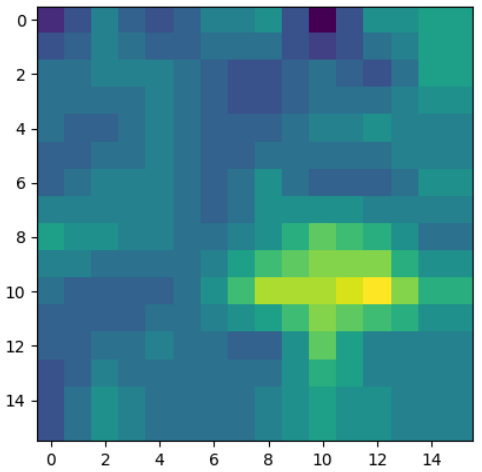
Brick1: eliminate fixed heat sources

- The infrared array data collected by a thermal sensor has background noise.
- This has a great impact on the detection and estimation accuracy.
- An Exponentially Weighted Moving Average (EWMA) filter is a simple and effective technique for smoothing data and reducing noise

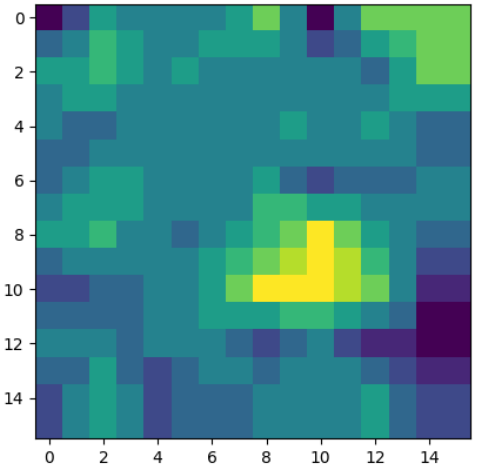
$$EWMA(t) = \sigma F(t) + (1 - \sigma) EWMA(t - 1)$$

$$\sigma = \frac{2}{N + 1}$$

- Possible implementations:
  - MUL EWMA
  - SHIFT EWMA



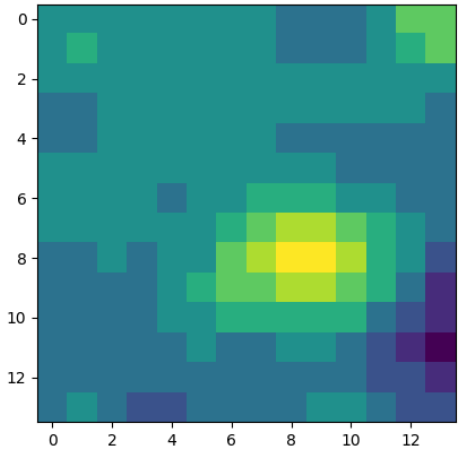
Original frame



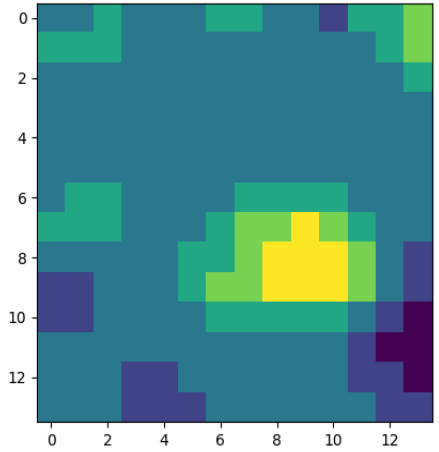
Frame data after noise reduction

Brick2: spatial filter

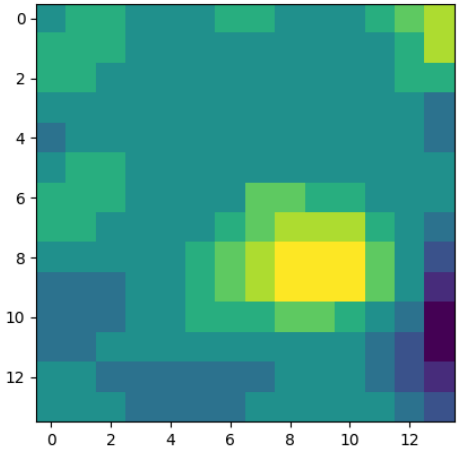
- Random noise in infrared array data can significantly affect the quality of the thermal images.
- Potential sources:
  - sensor electronics
  - background radiation
  - environmental factors
- Possible implementations:
  - Average filter
  - Median filter
  - Gaussian filter



Average filter



Median filter

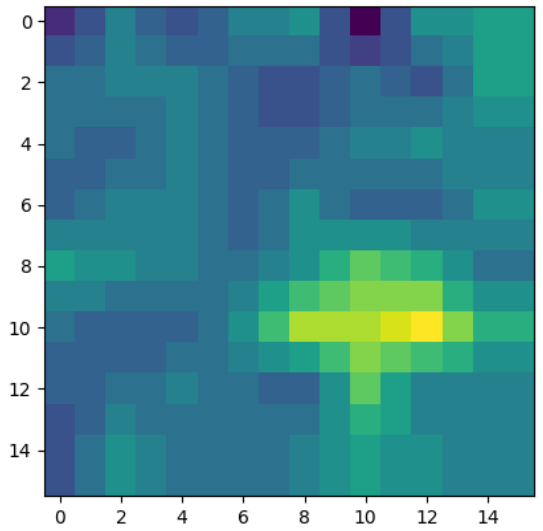


Gaussian filter

Brick3: threshold algorithm

- This algorithm separates the foreground region from the background region

- Possible implementations:
  - Fixed threshold algorithm
  - Median threshold algorithm



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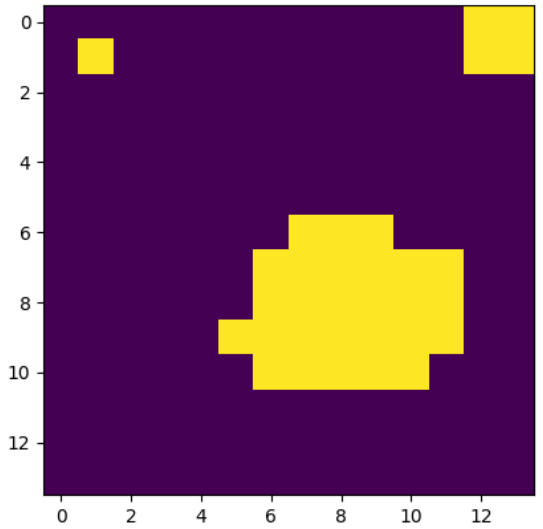
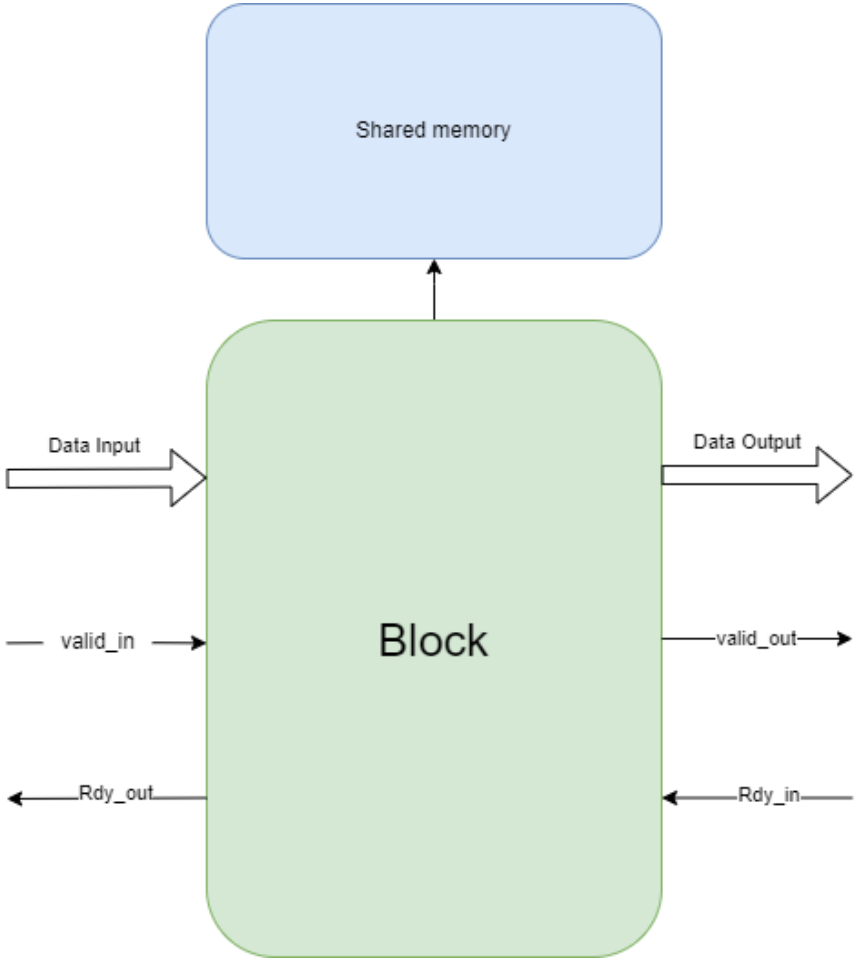


Frame data after DSP chain

Protocol for bricks connections

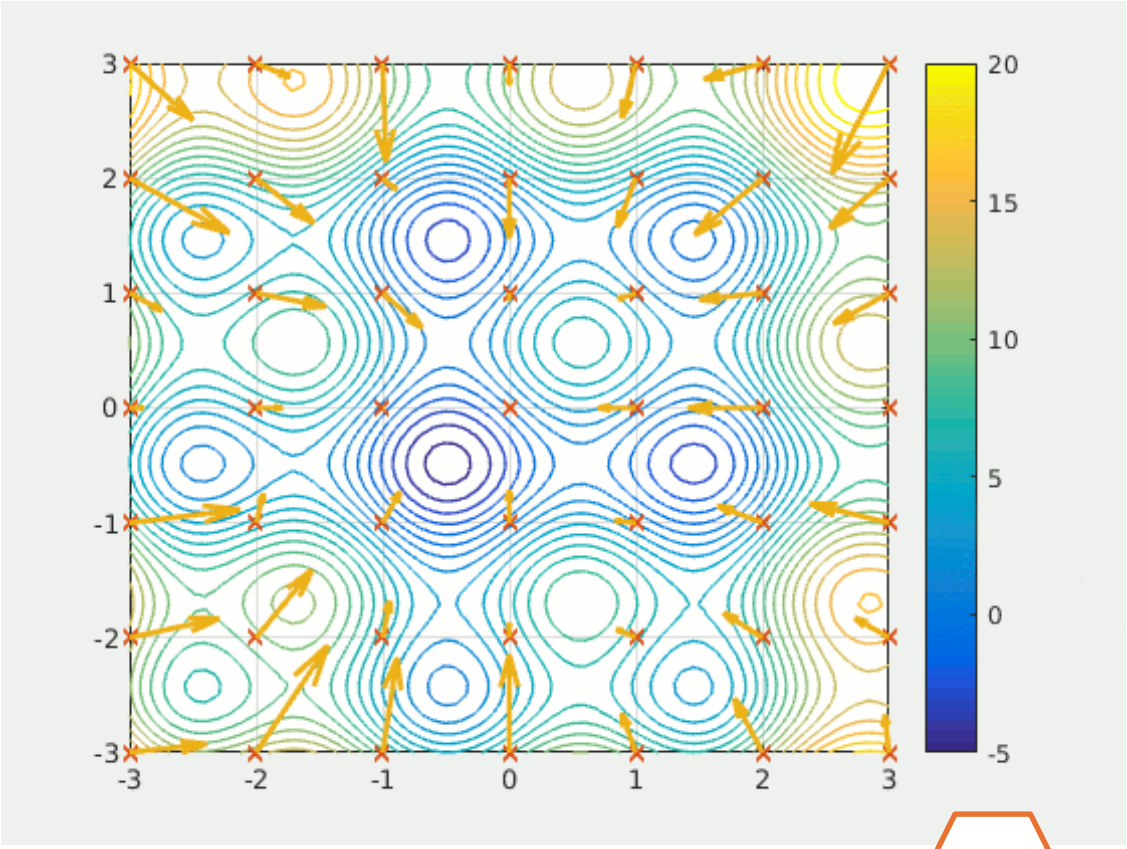


Signals for brick communication:

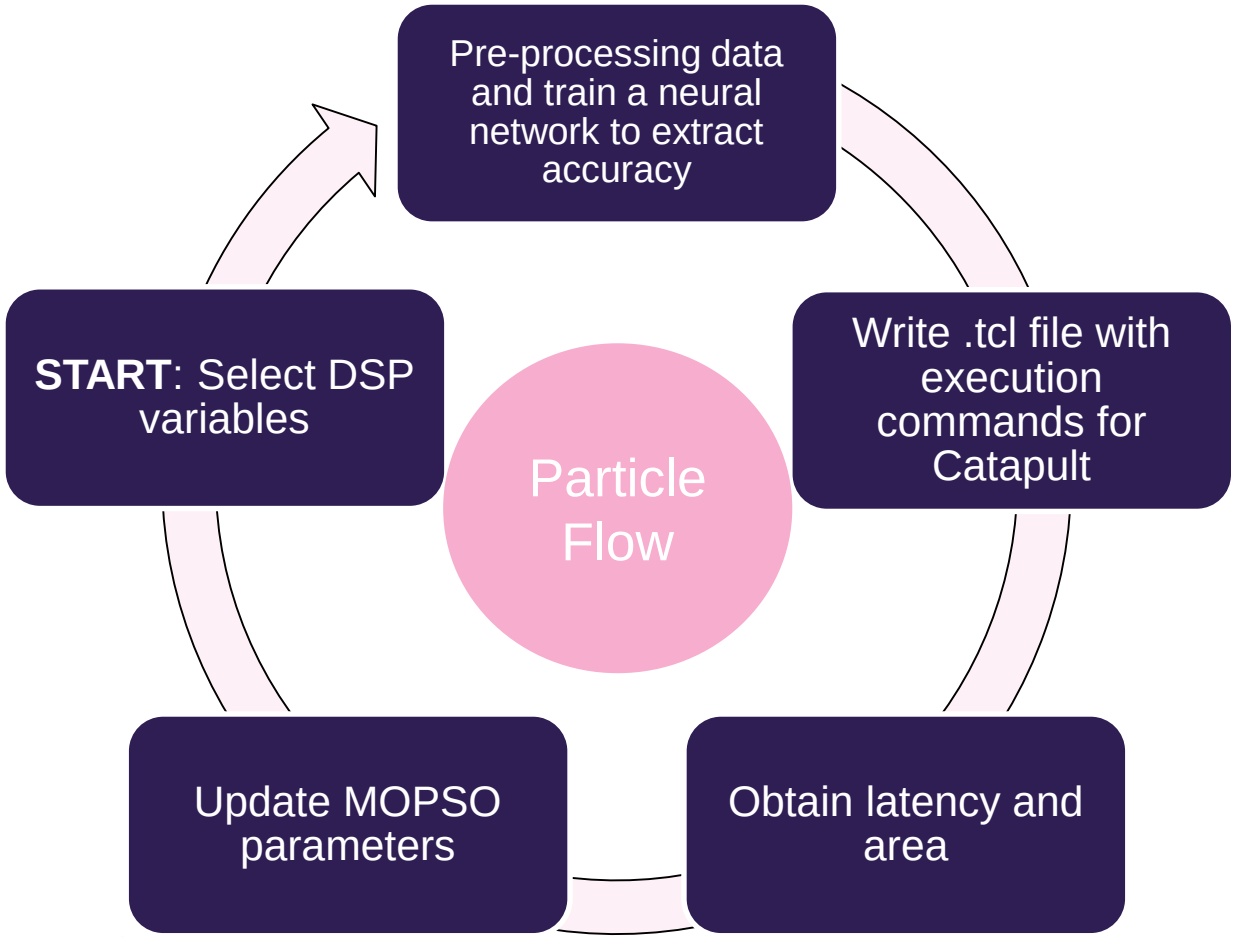
- **Valid:** Driven by the source when data output is ready
- **Ready:** Active high, driven by the target when the data is correctly received
- **Data_input/Data_output:** can be stored in shared memory or directly connected to the next block

Multi-objective Particle Swarm Optimization (MOPSO)

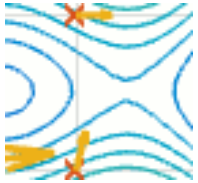
- **Particle Swarm Optimization (PSO)**: Optimizes a problem by iteratively improving a candidate solution.
  - Solves a problem by having a population of candidate solutions, so called particles
  - Each particle's movement is influenced by:
    - Its local best-known position
    - Guided toward the best-known positions in the search-space
- **Multi-objective Particle Swarm optimization:** Extension of the standard PSO to handle optimization problems involving multiple objectives



Optimization flow



- In a MOPSO algorithm we can select:
  - Particles number(number of x)
  - Iterations number(number of ->)



- These particles are moved around in the search-space

Variables	Description
Spatial filter	Type of spatial filter[average, gaussian or median filter]
Threshold algorithm	Type of threshold algorithm [Fixed or median threshold]
K	Additive constant threshold algorithm
N	Widow size in EWMA filter

- **Goal**: find the best trade-off among
  - Accuracy
  - Area
  - Latency

Implementation results

- Clock frequency: 16 MHz
- Technology: CMOS 130nm

Results			Parameters			
Accuracy(%)	Latency cycles	Area (kum2)	K(additive constant threshold)	N(windows average)	Spatial filter	Thr algorithm
90	415	56	3	4 (IIR SHIFT)	Gaussian	Simple
89	412	47	2	17 (IIR MUL)	Median	Median
86	355	36	3	16 (IIR SHIFT)	Median	Simple
87	564	35	2	18 (IIR MUL)	Average	Simple
92	621	45	2	20 (IIR MUL)	Average	Median
93	416	51	2	20 (IIR MUL)	Gaussian	Median

Latency

Area

Accuracy

Conclusions

- A new approach **merging the Python and Catapult** worlds
- **Goal**: to implement the best embedded algorithms on sensors
- **The time** required to design complex algorithms is **hugely reduced**
- A test case has shown a very good result in fast prototyping

For these reasons, this methodology is widely used in the development of our algorithms, allowing us to be fast and competitive in the market.

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