

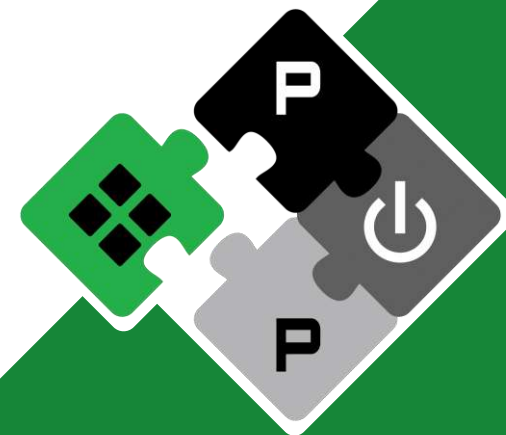
Practical Implementations & Cooperation for Reliable Architectures Using Open-Source Hardware

European Test Symposium (ETS) 2023

Special Session on dependable RISC-V

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PULP Platform

Open Source Hardware, the way it should be!

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pulp-platform.org



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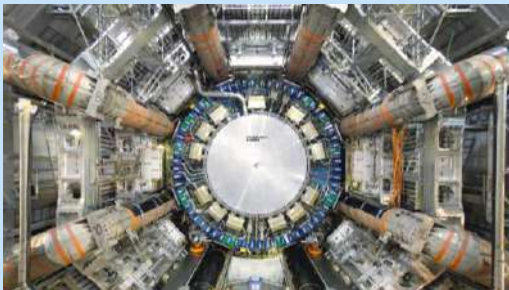
Soft-Error Tolerance – Required in Different Domains



Space Environment



Automotive



Particle Accelerator

And many more...

Open-Source Microcontroller – PULPissimo



pulp-platform / pulpissimo Public

This is the top-level project for the PULPissimo Platform. It instantiates a PULPissimo open-source system with a PULP SoC domain, but no cluster.

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Code Issues 100 Pull requests 2 Actions Projects Security

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bluewww Merge pull request #350 from pulp-platform/x-in-bootrom on Nov 3, 2022 694

View code

README.md

PULPissimo

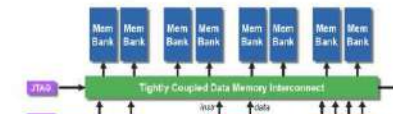
README.md

PULPissimo

Citing

If you are using the PULPissimo IPs for an academic publication, please cite the following paper:

```
@INPROCEEDINGS{8640145,
  author={Schiavone, Pasquale Davide and Rossi, Davide and Pullini, Antonio and
  booktitle={2018 IEEE S0I-3D-Subthreshold Microelectronics Technology Unified (
  title={Quentin: an Ultra-Low-Power PULPissimo SoC in 22nm FDX},
  year={2018},
  volume={},
  number={},
  pages={1-3},
  doi={10.1109/S3S.2018.8640145}}
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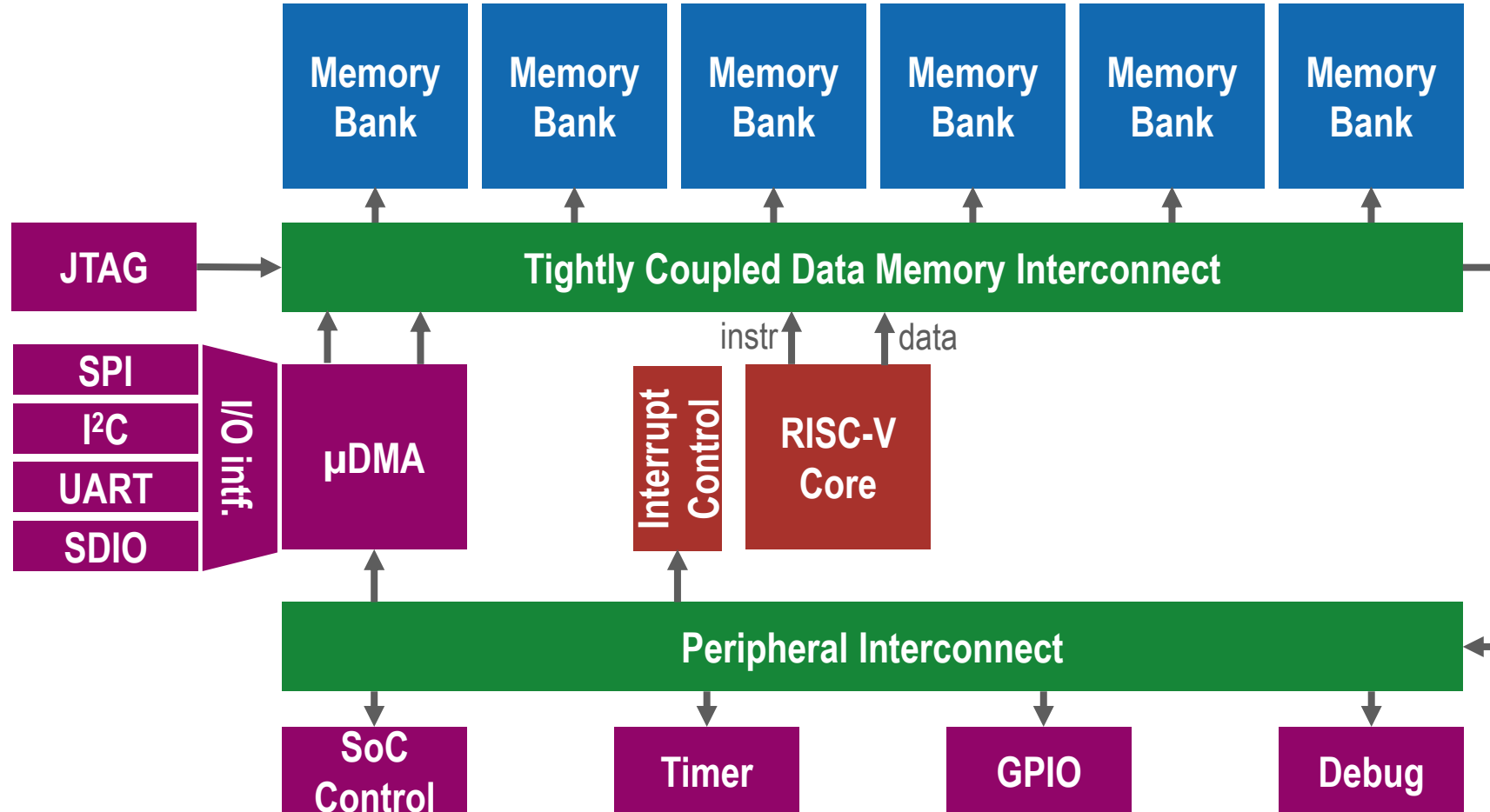


PULPissimo is the microcontroller architecture of the more recent PULP chips, part of the ongoing "PULP platform" collaboration between ETH Zurich and the University of Bologna - started in 2013.

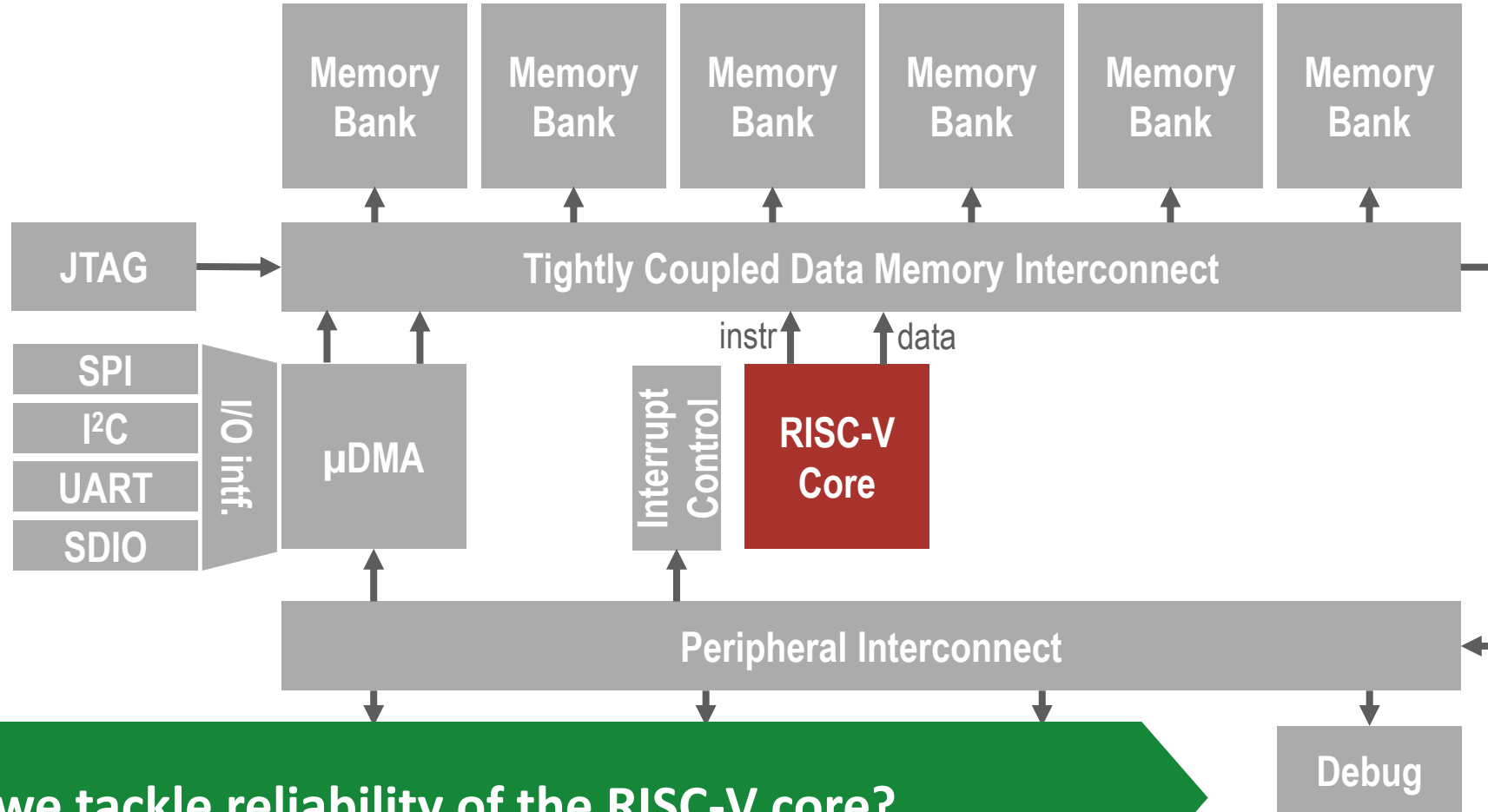


github.com/pulp-platform/pulpissimo

PULPissimo Architecture

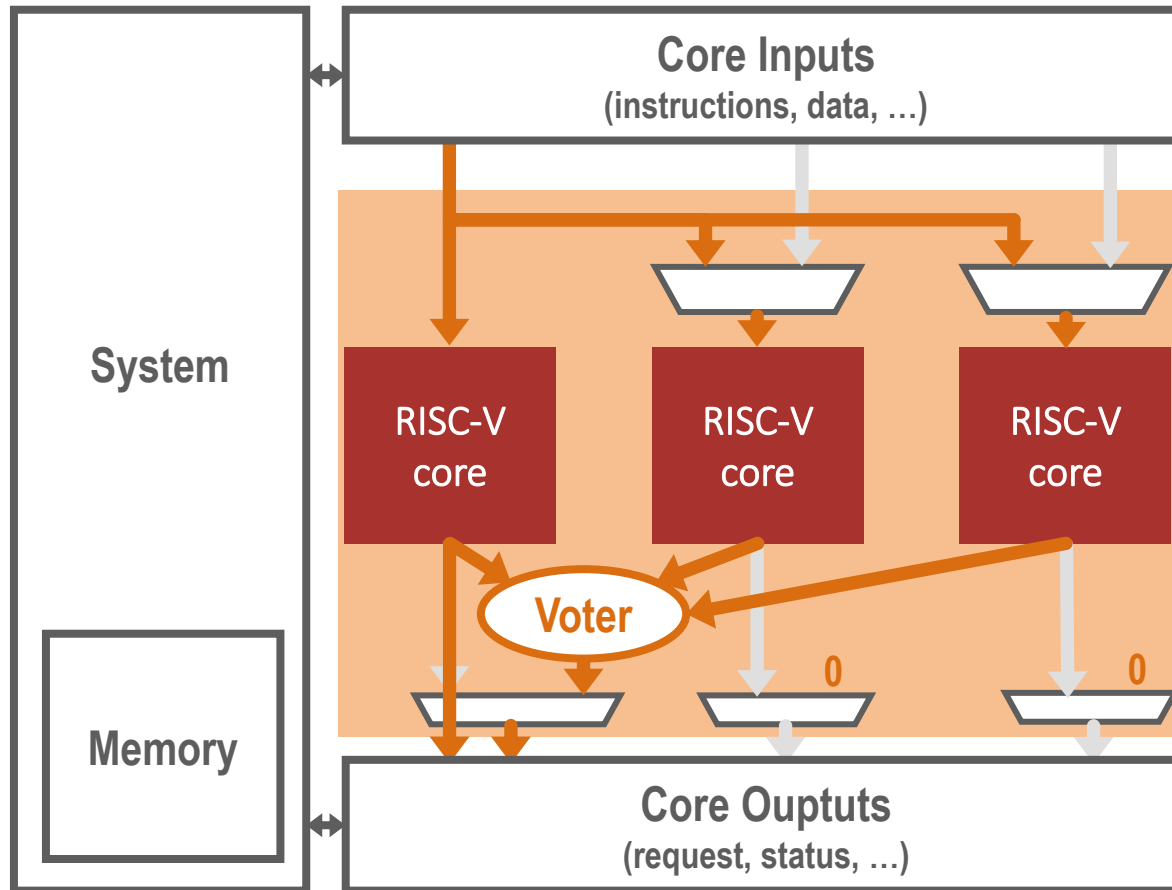


PULPissimo Architecture



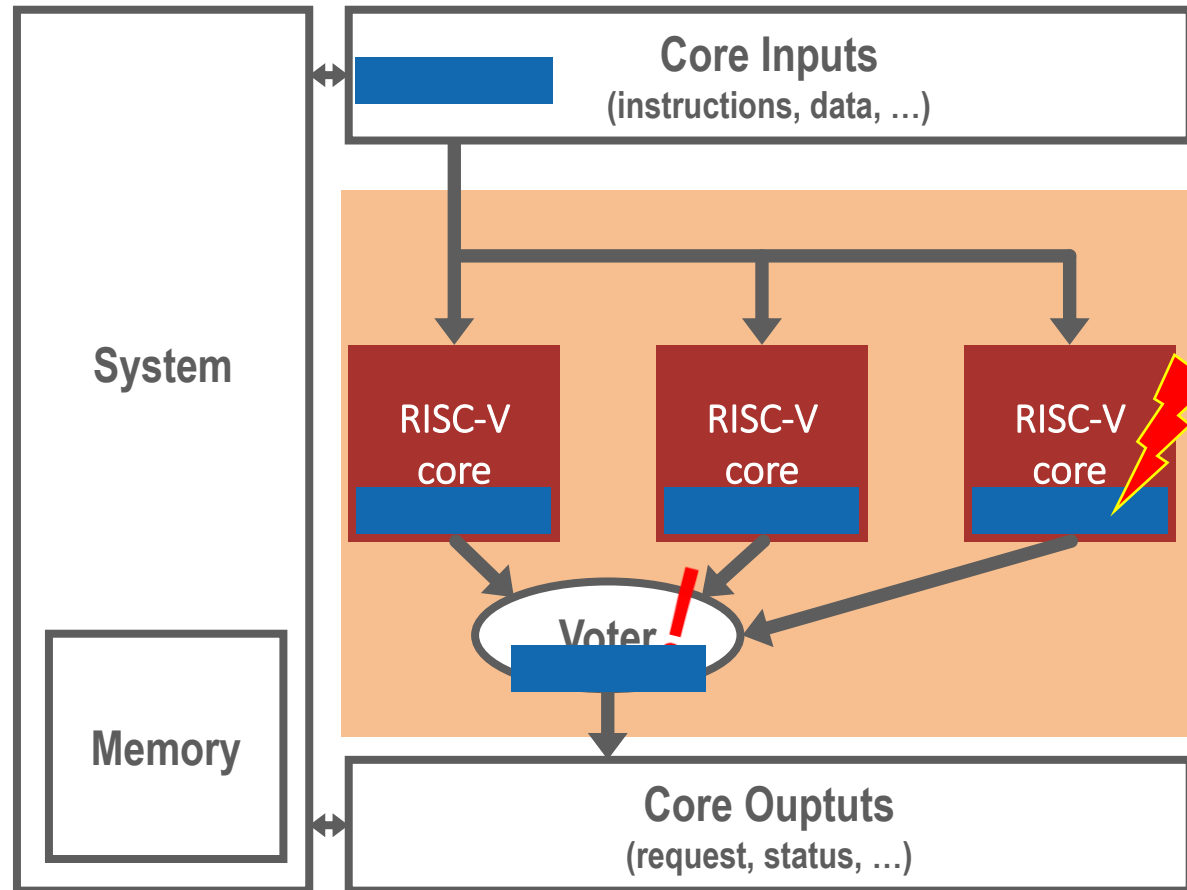
How do we tackle reliability of the RISC-V core?

Reliable Processing Cores



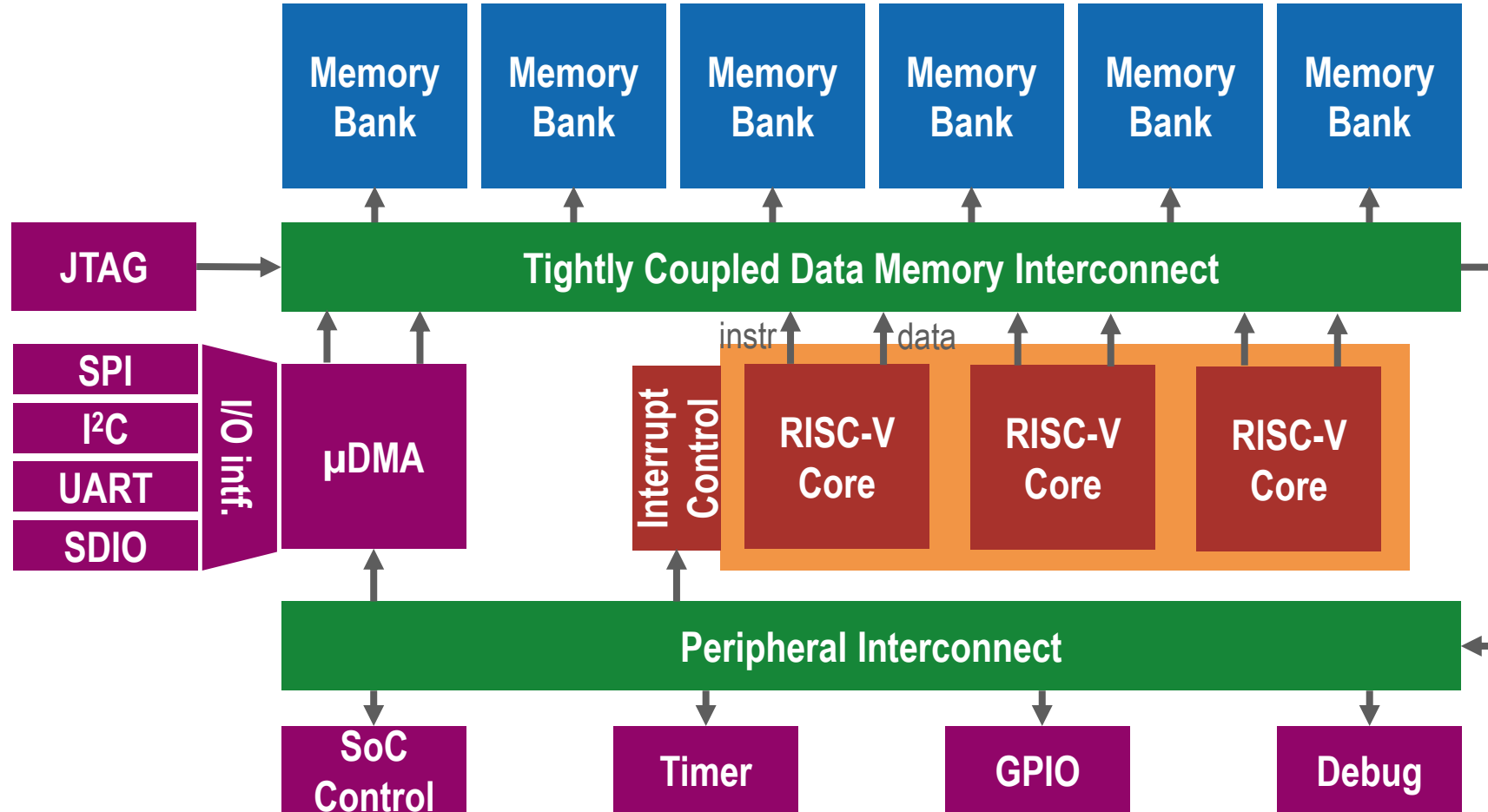
- Replicate Core
→ Triple-Core Lockstep
- Identical Inputs
- Voted Outputs
 - Directly connects any soft error
- Configurable for performance if reliability is not needed
 - **2.96x speedup**

Software Recovery of Triple Modular Redundant Cores

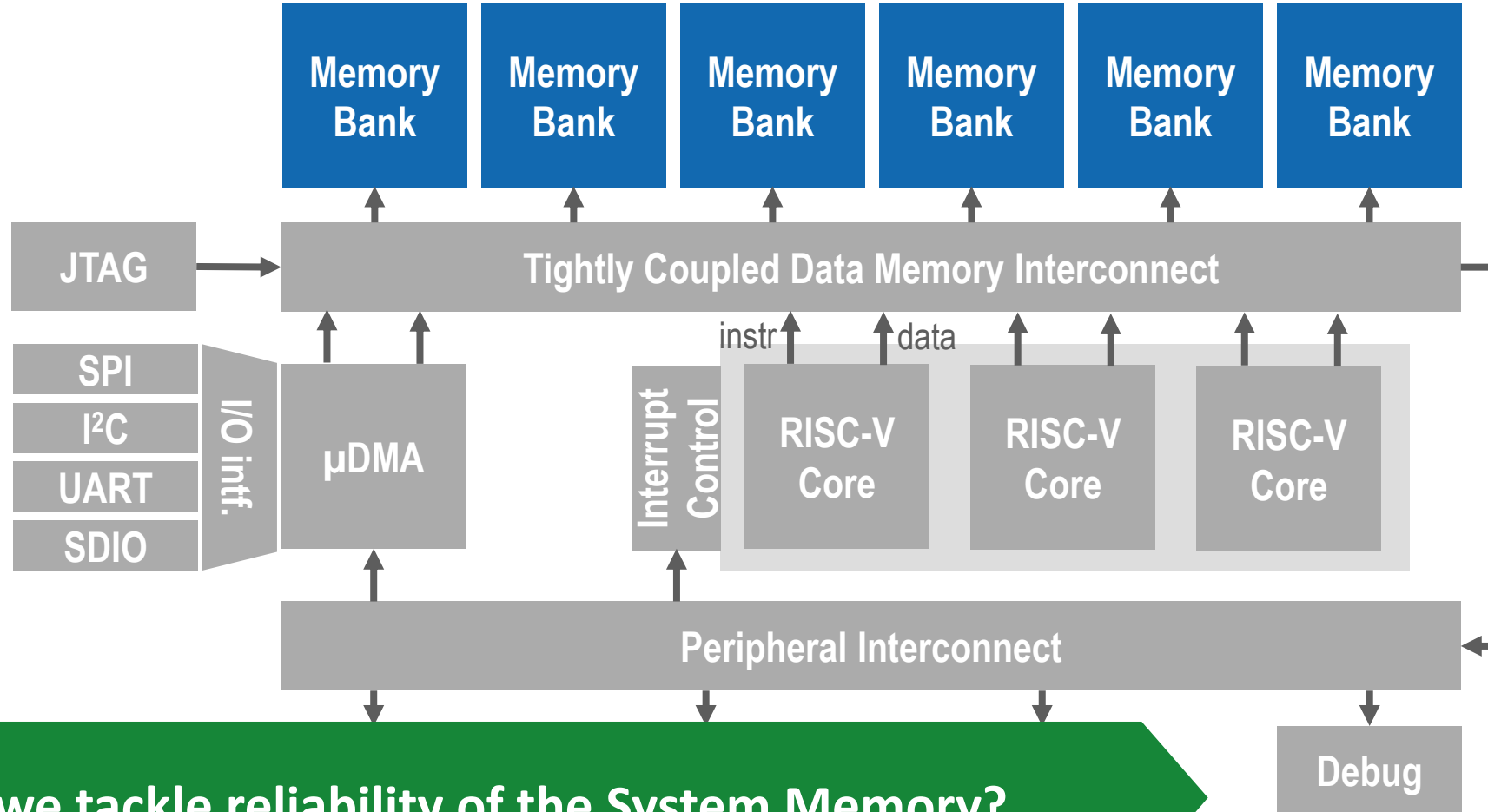


- Radiation causes soft-error
- Error detected by voter
- Core state (RF, PC, CSRs) stored to memory
- Corrected by voter
- Core state loaded back into cores
- Total procedure in ~600 cycles

Trikarenos – PULPissimo with Reliability



Trikarenos – PULPissimo with Reliability



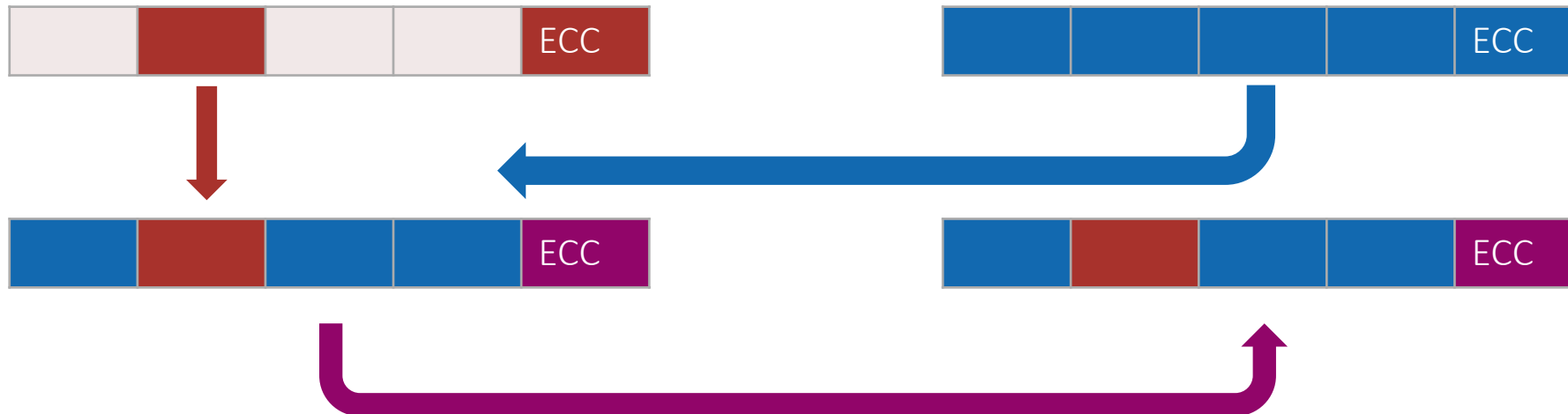
Byte-addressable Memory – ECC Load and Store



Byte Store



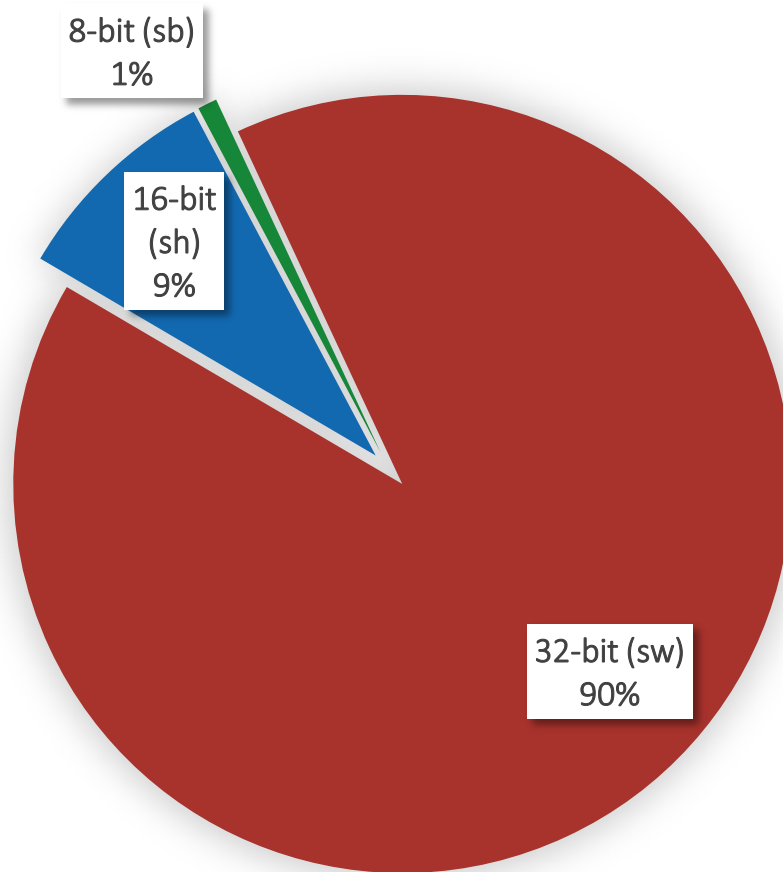
Byte Store with ECC



ECC Load-and-Store – Performance Impact



CoreMark Store Instructions

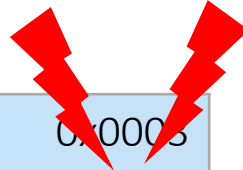


- 32-bit Hsiao ECC word protection
- Directly grant storage
 - Delay following transaction, not current transaction, to shift & reduce impact
- Results: **<1% cycle increase**
 - Various tests, such as 8-bit Matrix-Matrix Multiplication

ECC Scrubber

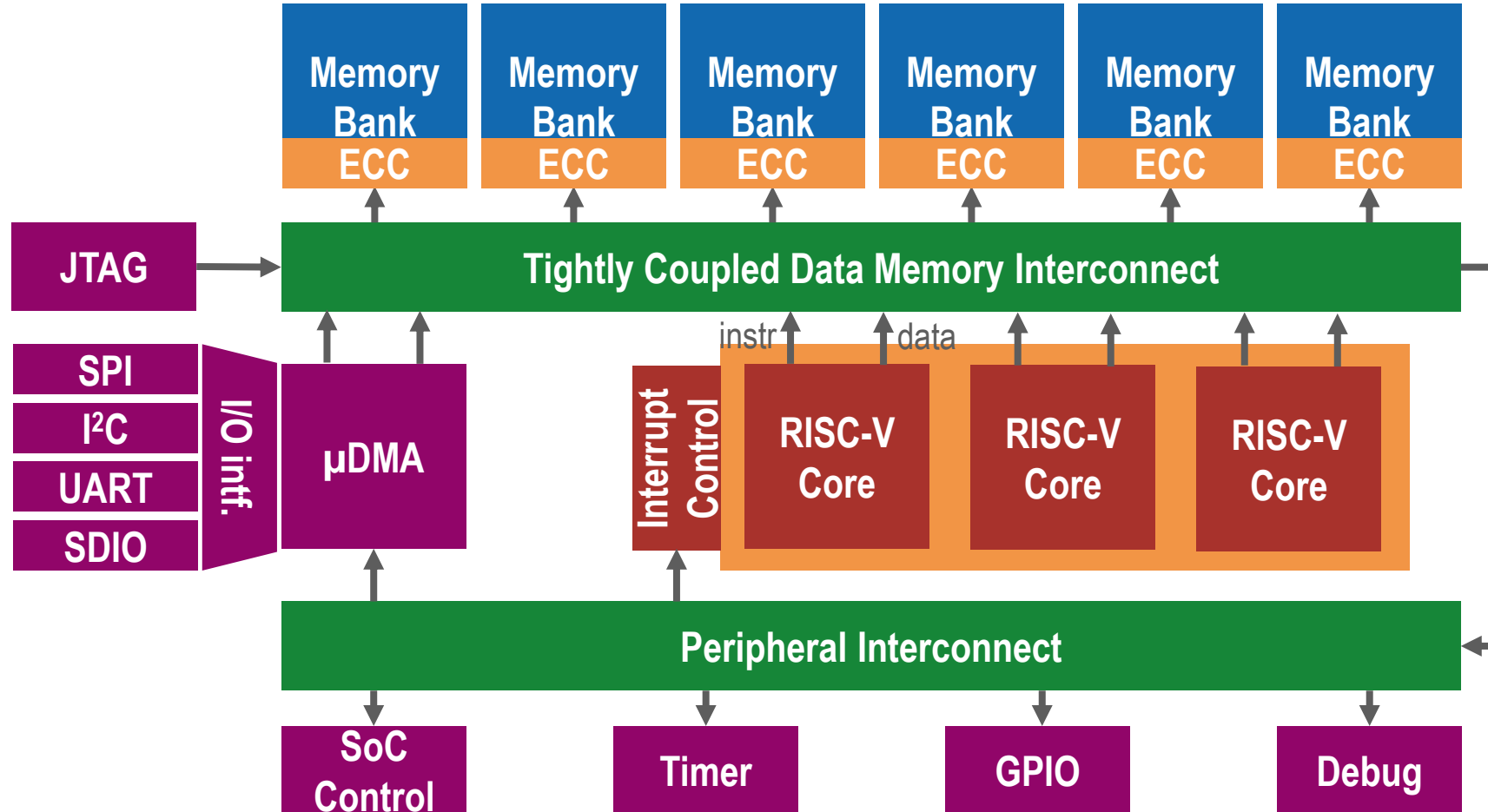


0x0000	0x0001	0x0002	0x0003
0x0004	0x0005	0x0006	0x0007
0x0008	0x0009	0x000A	0x000B
0x000C	0x000D	0x000E	0x000F
0x0010	0x0011	0x0012	0x0013
0x0014	0x0015	0x0016	0x0017
0x0018	0x0019	0x001A	0x001B
0x001C	0x001D	0x001E	0x001F
0x0020	0x0021	0x0022	0x0023
0x0024	0x0025	0x0026	0x0027

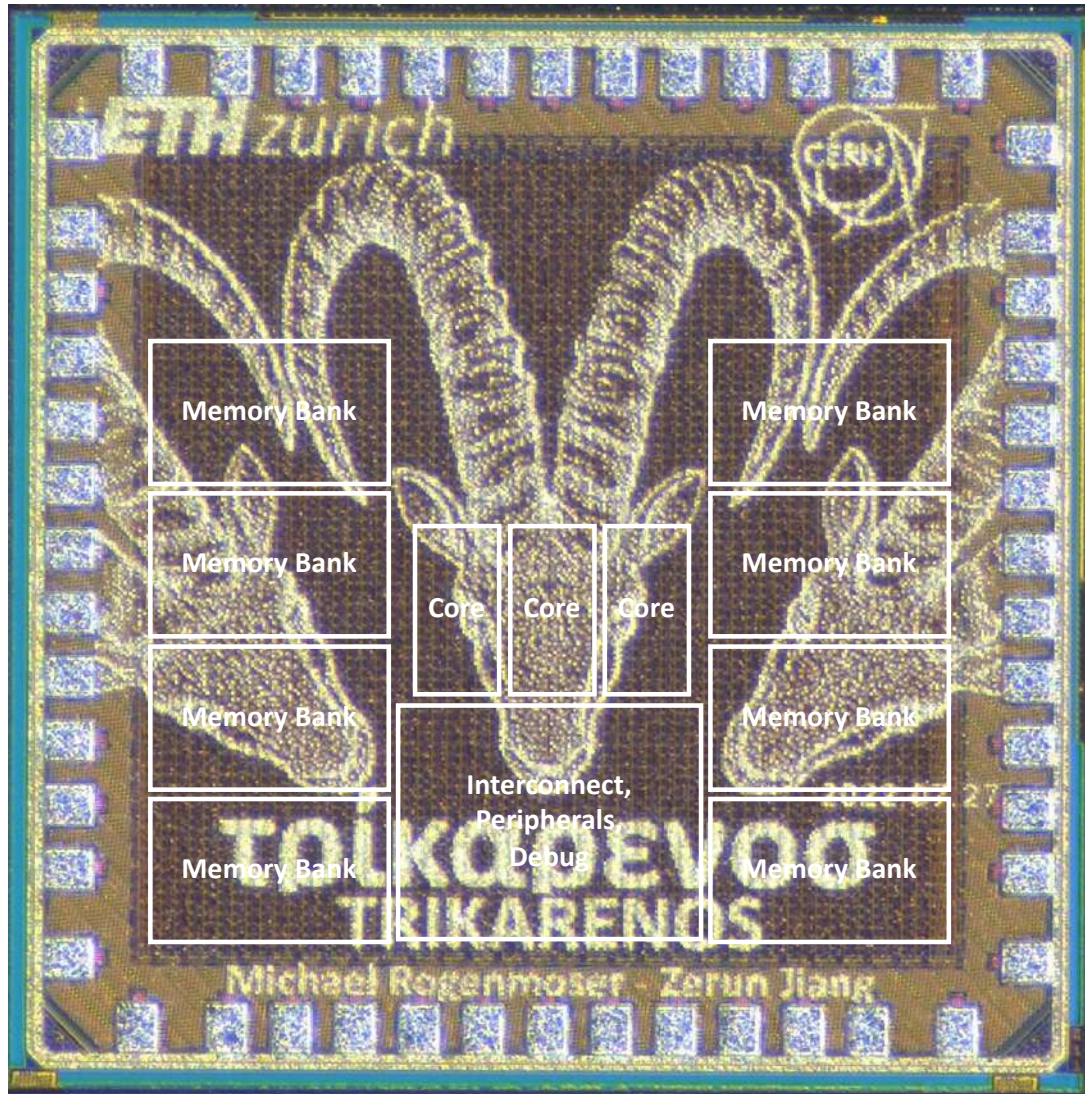


- Multiple errors in a single word lead to unrecoverable errors
- Scan Memory Bank
- Re-write faulty word if error is detected
- Defer permission to external accesses
- Log all corrections (and uncorrectable words)

Trikarenos – PULPissimo with Reliability



Trikarenos – ASIC implementation



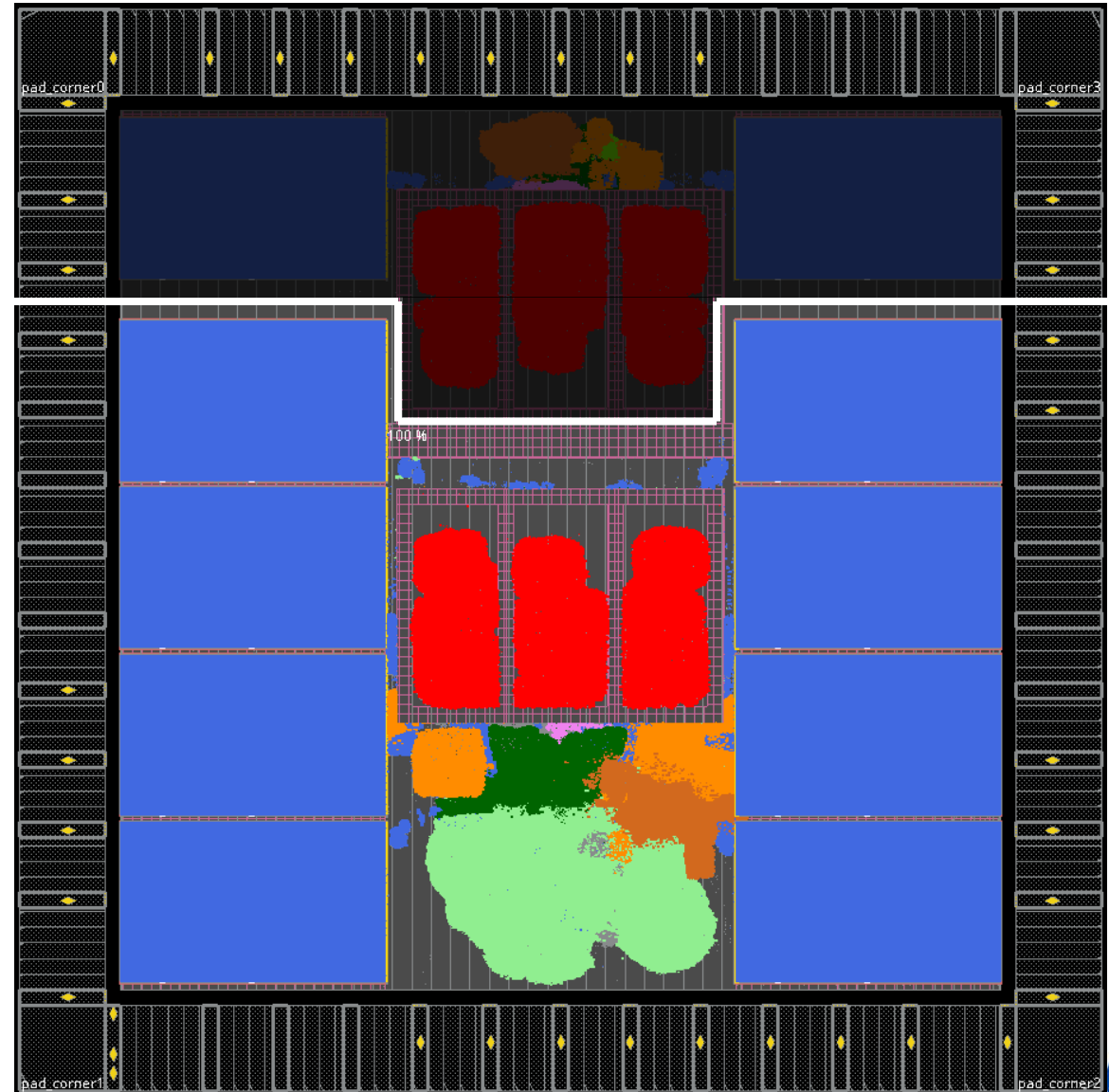
- TSMC 28HPC+
 - Shown to have high TID tolerance
- 2 mm² @250 MHz
- 3 separate Ibex cores
- 256 KiB Memory in 8 word-interleaved banks

Internal structure

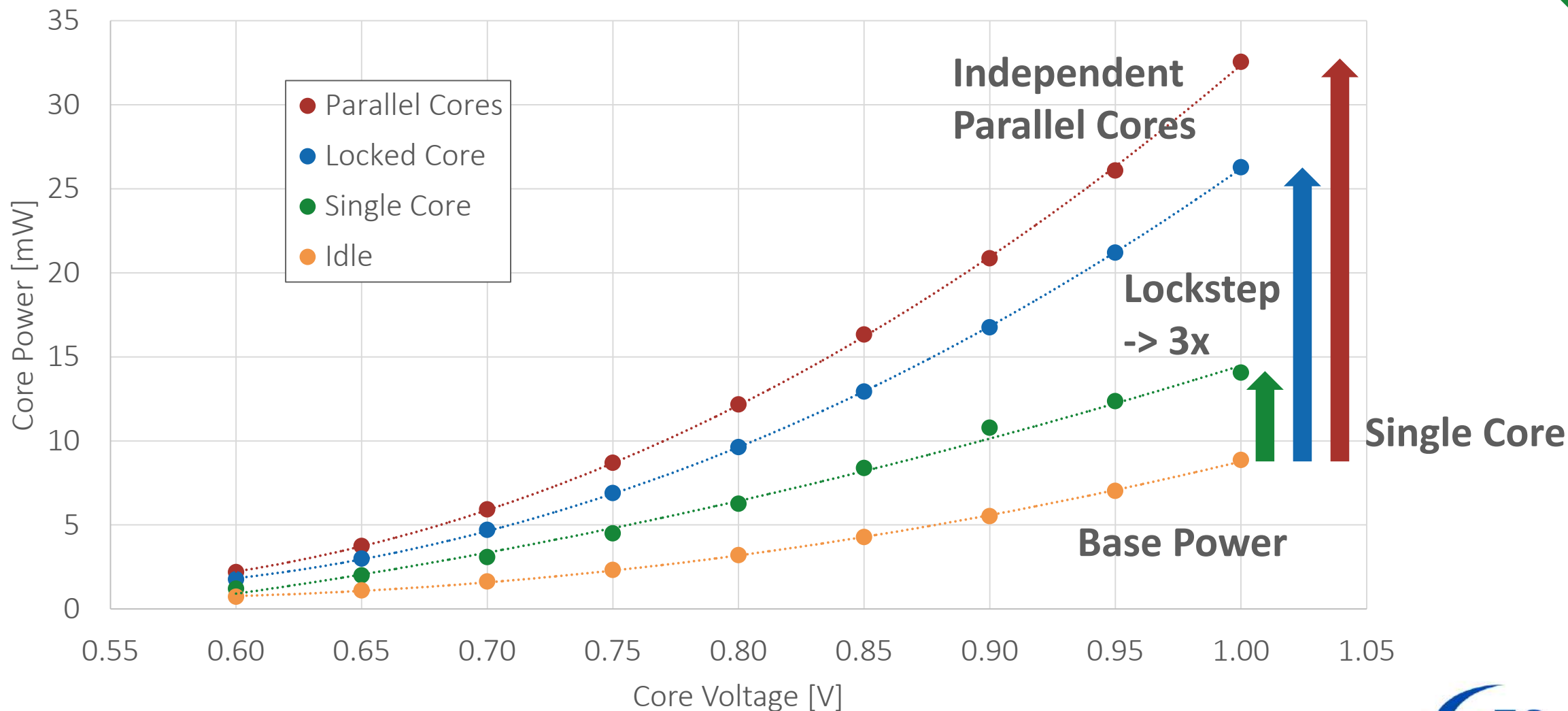
- Spatially separated cores with a keepout zone

- Legend:

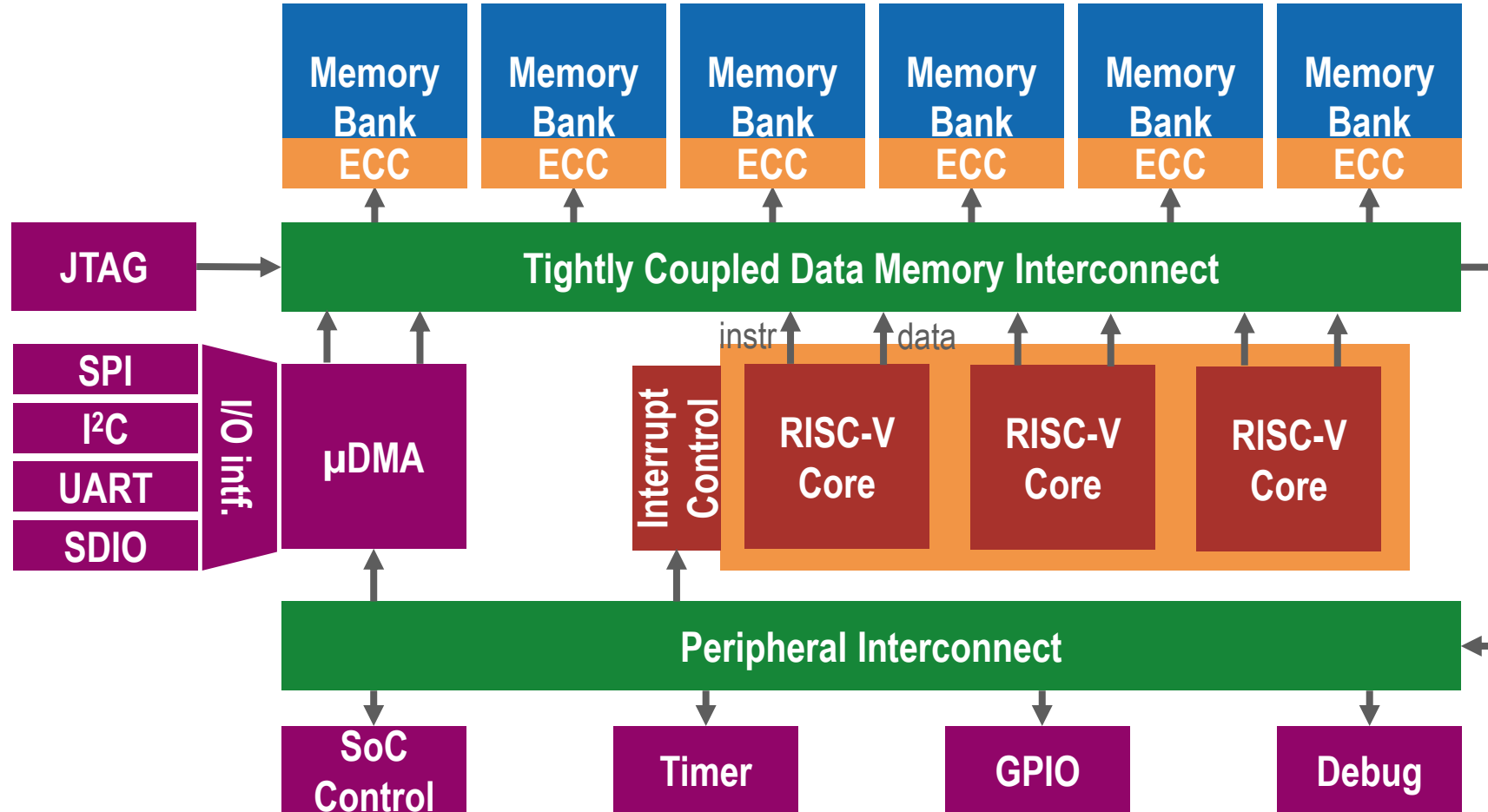
- Cores
- HMR Unit
- Memory (w/ ECC en-/decode)
- Interconnect
- Debugger
- Logging & control registers, ROM, ...
- I/O



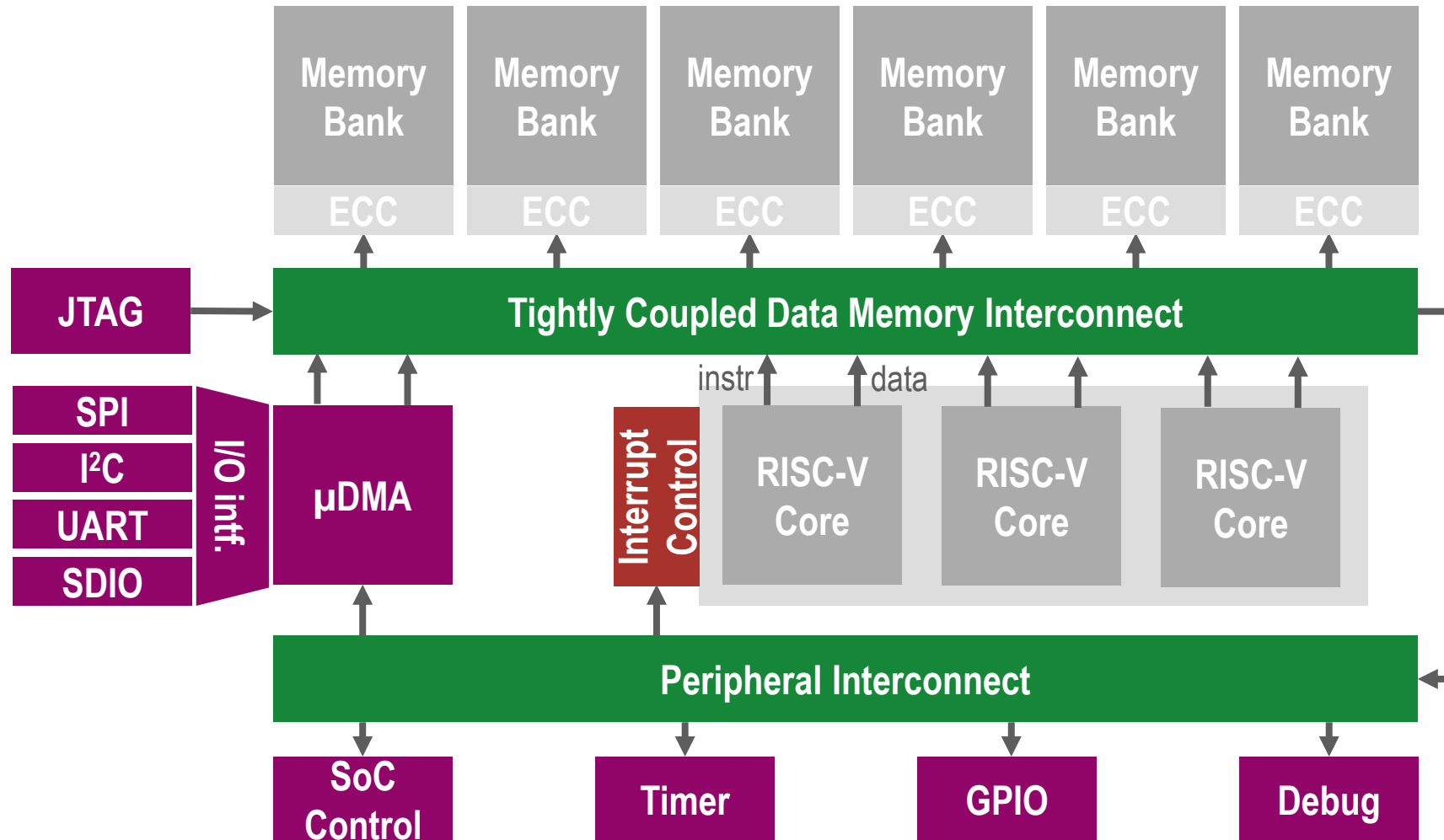
Power Consumption at max Frequency



Open points – PULP is a playground



Open points – PULP is a playground





PULP

Parallel Ultra Low Power

Luca Benini, Ahmad Mirsalari, Alessandro Capotondi, Alessandro Nadalini, Alessandro Ottaviano, Alessio Burrello, Alfio Di Mauro, Andrea Borghesi, Andrea Cossettini, Angelo Garofalo, Arpan Prasad, Chi Zhang, Corrado Bonfanti, Cristian Cioflan, Cyril Koenig, Daniele Palossi, Davide Rossi, Fabio Montagna, Florian Glaser, Francesco Conti, Georg Rutishauser, Germain Haugou, Gianna Paulin, Giuseppe Tagliavini, Hanna Müller, Jannis Schoenleber, Lorenzo Lamberti, Luca Bertaccini, Luca Colagrande, Luca Valente, Maicol Caini, Manuel Eggimann, Manuele Rusci, Marco Bertuletti, Marco Guermandi, Matheus Cavalcante, Matteo Perotti, Mattia Sinigaglia, Michael Rogenmoser, Moritz Scherer, Moritz Schneider, Nazareno Bruschi, Nils Wistoff, Paul Scheffler, Philipp Mayer, Robert Balas, Samuel Riedel, Segio Mazzola, Sergei Vostrikov, Simone Benatti, Thomas Benz, Thorir Ingolfsson, Tim Fischer, Victor Javier Kartsch Morinigo, Victor Jung, Viviane Potocnik, Vlad Niculescu, Xiaying Wang, Yichao Zhang, Yvan Tortorella, Frank K. Gürkaynak, all our past collaborators

and many more that we forgot to mention



<http://pulp-platform.org>



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