Exploiting Hybrid Modular Redundancy in RISC-V Based Multicore Clusters for Space Computing

Yvan Tortorella, Michael Rogenmoser, Francesco Conti, Luca Benini

<yvan.tortorella, f.conti, luca.benini>@unibo.it, <michaero, lbenini>@iis.ee.ethz.ch

ThalesAlenia Space — a Thales / Leonardo company

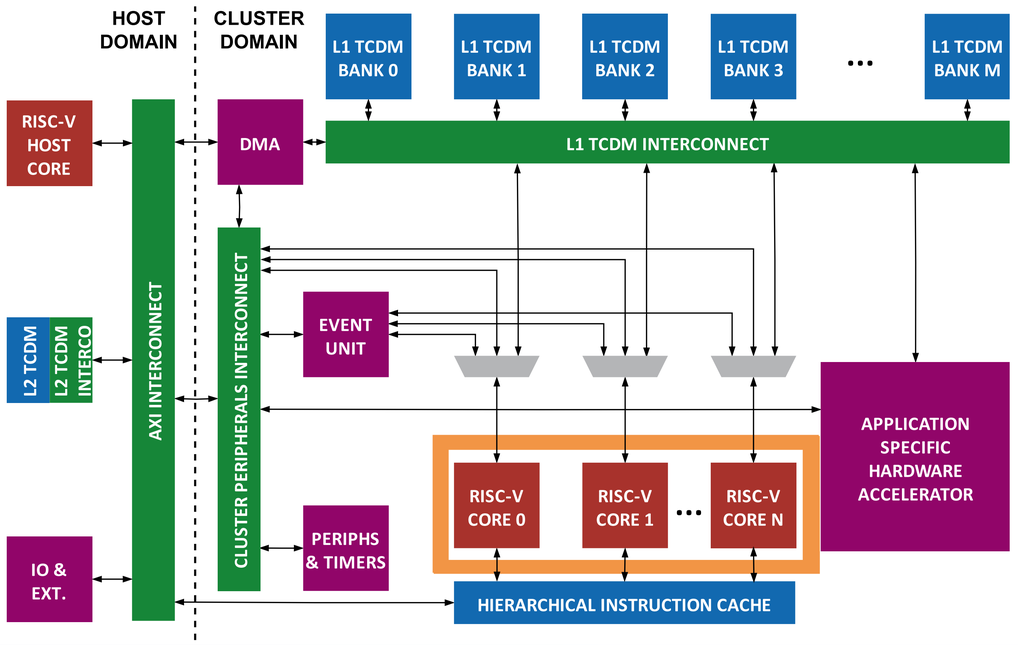
Motivation

- Increasing demand for **processing** capabilities **in space**
  - **ESA** and **NASA** also looking at **RISC-V**
- **Cosmic rays** affect onborad computers
  - Single Event Upsets/Transients (**SEU/Ts**), Transient Faults (**TFs**)
- **TF**s can only be **mitigated** -> HW/SW aproaches
- **Open-source** platforms enable research and development in this direction
- **PULP**: open-source **hardware and software**

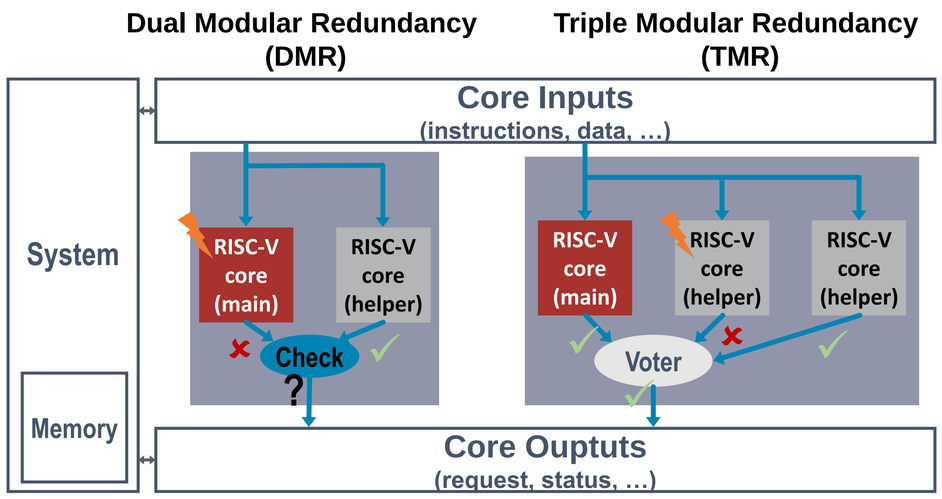
PULP Cluster

PULP (Parallel Ultra-Low-Power): **RISC-V**-based **multicore** computing cluster for energy-efficient execution of parallel workloads.

How to **protect** it for **applications in space**?



Protecting the cores: Redundant Grouping



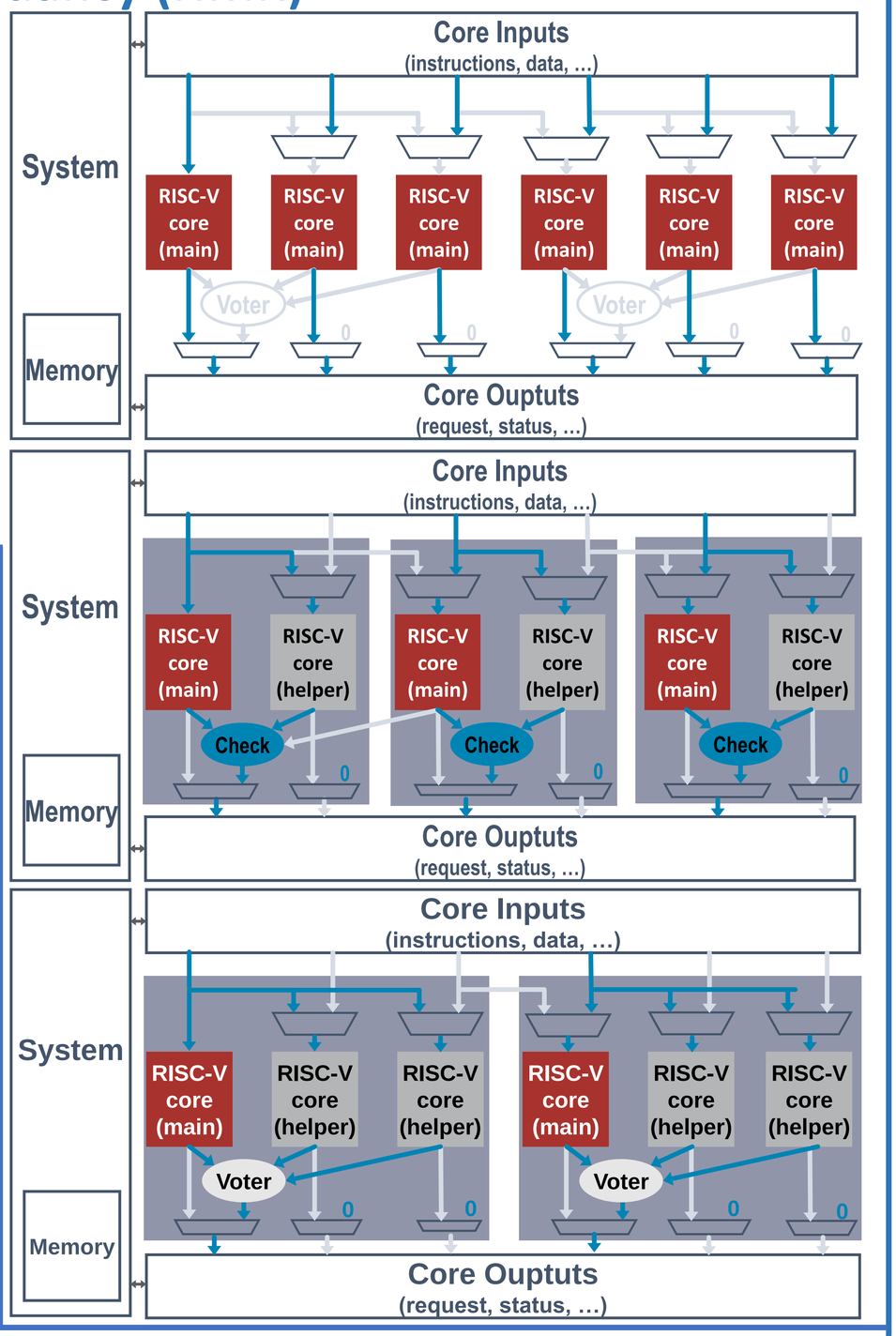
TMR: low performance, high reliability, quick recovery
DMR: better performace, lower reliability, slower recovery

How to chose? Why not both?

Hybrid Modular Redundancy (HMR)

Runtime configurable cluster supporting **multiple** redundant groupings through an advanced **split-lock** mechanism:

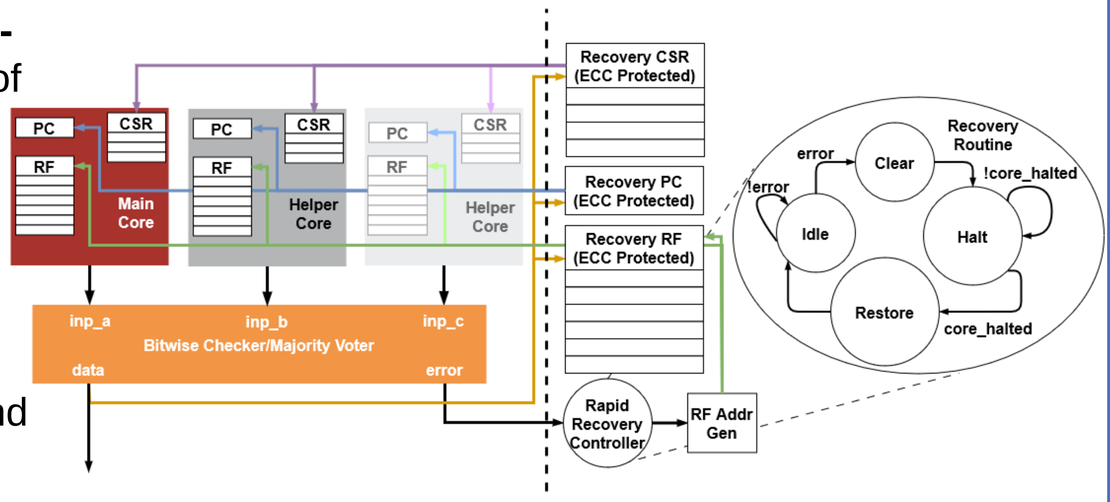
- **Independent** mode: no reliablity, best performance
- **DMR** mode: good reliability, good performance
- **TMR**: high reliability, worst performance



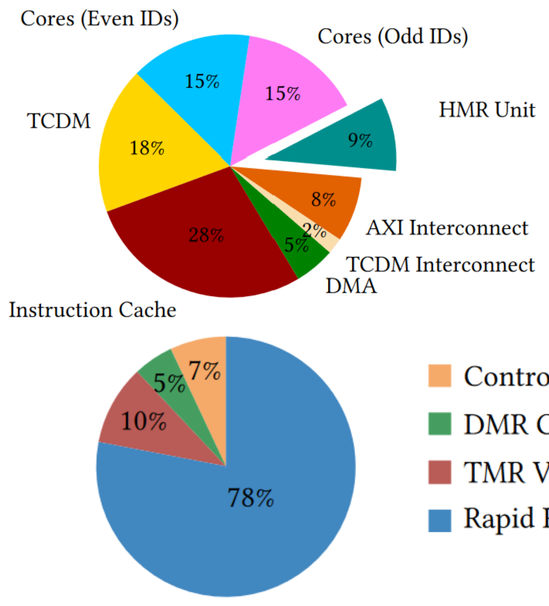
Rapid Recovery: shared hardware extension

HMR cluster featuring **ECC-protected backup** copies of the cores' status **registers**

- Cycle-by-cycle backup
- **Quick and predictable** recovery also in **DMR**
- Real-time recovery (**24 cycles**)!
- Shared between TMR and DMR



Results



	DMR	TMR	DMR Rapid Recovery	TMR Rapid Recovery
Recovery Latency [cycles]	Application dependant	363	24	24
Mode Switching [cycles]	703	598	603	515

PULP Cluster Area [mm²]		Overhead
Baseline	0.604	-
DMR	0.605	0.3%
TMR	0.608	0.7%
HMR	0.612	1.3%
With Rapid Recovery		
DMR	0.654	8.4%
TMR	0.657	8.8%
HMR	0.660	9.4%

			base	DMR	TMR	DMR-R	TMR-R
						Rapid Recovery	
MatMul Performance		[MOPS @ 430 MHz]	1165	617	414	617	414
SW-based MatMul Performance		*[MOPS @ 430 MHz]*	*1165*	*576*	*351*	-	-
CFFT Performance		[MOPS @ 430 MHz]	989	531	385	531	385
Recovery Latency		[cycles]	-	-	363	24	24
Mission-Critical	entry	[cycles]	-	534	410	397	310
	exit main		-	22	23	22	23
	exit help		-	147	165	184	182
Performance	entry	[cycles]	-	134	82	125	82
	exit		-	373	311	183	94