Mixed Criticality Systems: Beyond Transient Faults

Abhilash Thekkilakattil, Alan Burns, Radu Dobrin and Sasikumar Punnekkat

MÄLARDALEN UNIVERSITY SWEDEN

UNIVERSITY of York

BITS Pilani K K Birla Goa Campus

Motivation and Contribution

- State of the art of mixed criticality scheduling mainly focuses on WCET overruns

- WCET overruns are one example of transient faults

- We propose an approach for design and scheduling of mixed criticality systems under permanent faults

Introduction

- Mixed criticality scheduling deals with scheduling real-time tasks with varying levels of WCET assurances

- Growing interest in mixed criticality scheduling since Vestal's RTSS'07 paper
  - 230 citations according to Google Scholar
  - Over 200 follow-up papers according to "Mixed Criticality Systems- A Review" (6th ed.) by Burns and Davis

Goals of Mixed Criticality Scheduling

- Enable certification by different certifying authorities
  - Demonstrate timeliness under different WCETs
- Enable efficient utilization of the underlying computing infrastructure
  - Enabling safe sharing of the computing infrastructure
  - Ensuring isolation of critical from less critical tasks

State of the Art Mixed Criticality Scheduling

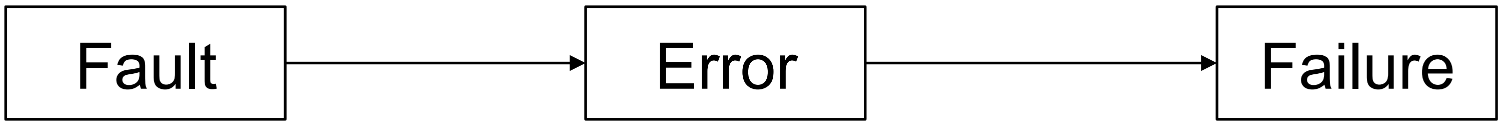
- Criticality monotonic priority ordering
- Adaptive and static scheduling
- Scheduling with virtual deadlines/periods
- Mixed criticality scheduling under faults

The Dependability Perspective

- Dependability
  - Threats
    - Faults
    - Errors
    - Failures
  - Attributes
    - Reliability
    - Safety — Focus of MC scheduling
    - Maintainability
    - Confidentiality
    - Integrity
    - Availability
  - Means
    - Fault tolerance
    - Fault Prevention
    - Fault Removal
    - Fault Forecasting

Avizienis *et al.*, Basic Concepts and Taxonomy of Dependable and Secure Computing, IEEE Transactions of Dependable and Secure Computing, 2004

Faults, Errors and Failures



Fault	Error	Failure
A bit flip	Wrong computed value	Incorrect actuation
WCET overrun	Task deadline miss	High criticality deadline miss

Many different types of faults (except WCET overruns) are not covered by Vestal-like models

Classification of Faults

Faults

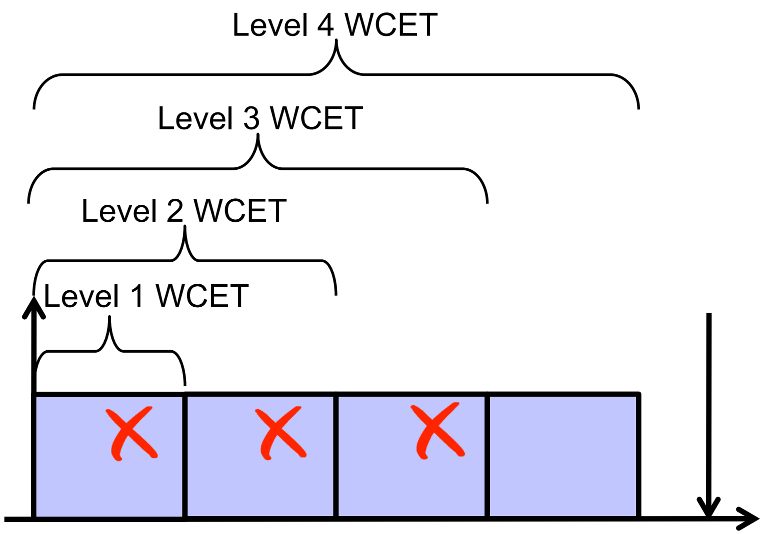
Transient Faults

- Fault whose presence is limited in time
- Examples include bit flips and WCET overruns
- Solution: temporal redundancy e.g., task re-executions

Permanent Faults

- Fault whose presence is continuous in time
- Examples include memory and processor failures
- Solution: spatial redundancy e.g., using additional hardware

Transient Fault Tolerance



- Temporal redundancy: replicate the tasks in time
  - Re-execute the task
  - Execute an alternate task
- The time for re-execution/alternate task execution can be seen as the “extra time” needed in Vestal’s model

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Focus of this paper

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Focus of this Paper

How to design mixed criticality real-time architectures to tolerate permanent faults?

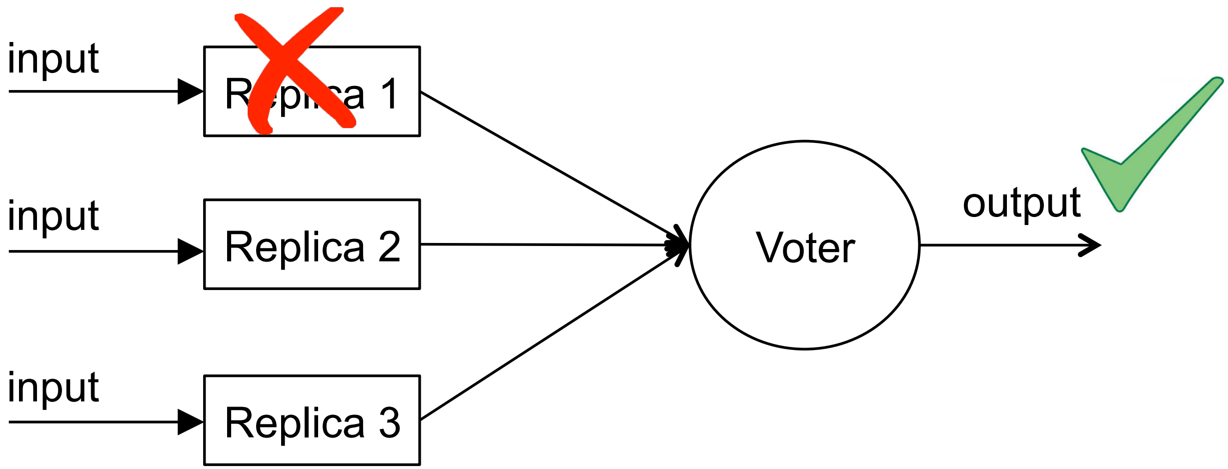
Contribution:

1. Propose a fault coverage based mapping of criticalities
2. Present a taxonomy of fault tolerance mechanisms in the context of mixed criticality systems

Classification of Permanent Faults

- Design Faults
  - Faults due to deficiencies in design and development e.g., manufacturing defects in computers
  - Hardware and software design faults
- Random Faults
  - Faults whose time of occurrence nor the cause can be determined e.g., faults due to wear and tear
- Byzantine faults
  - Faults in which replicas behave arbitrarily differently
  - Worst kind of faults: requires high amount of redundancy

Tolerating Permanent Faults



Requires additional hardware (N-modular paradigm)

- Replicate the tasks on multiple hardware
- Perform voting to determine and mask failures
- Diversity to prevent common cause failures

Goals of Mixed Criticality Scheduling

- Enable certification by different certifying authorities
  - Demonstrate timeliness under different WCETs

Timeliness does not imply certification

Safety standards mandate redundancy for safety

- Enable efficient utilization of the underlying computing infrastructure
  - Enabling safe sharing of the computing infrastructure
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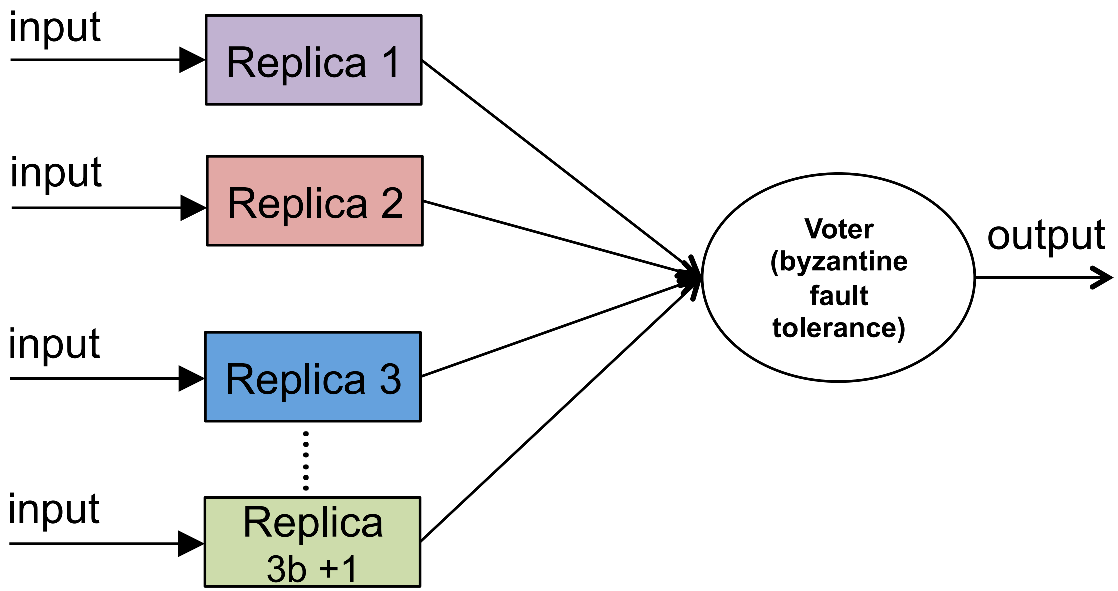
Highest level of "protection" for all tasks?

Mapping Criticalities Based on Fault Coverage

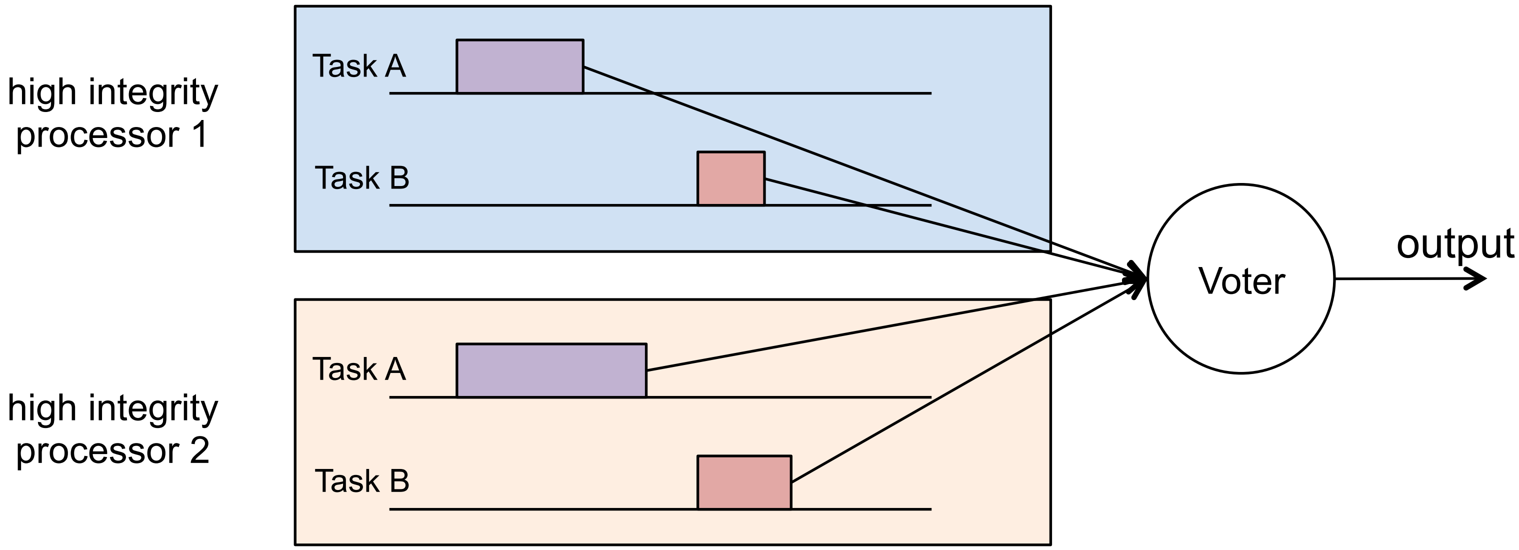
			Design Faults		
Criticality	**Transient Faults**	**Random Faults**	**Software Faults**	**Hardware Faults**	**Byzantine Faults**
High	✓	✓	✓	✓	✓
Medium	✓	✓	✓	✓	✗
Low	✓	✓	✓	✗	✗
Non-critical	*Partially covered*	*Partially covered*	✗	✗	✗

High Criticality Tasks



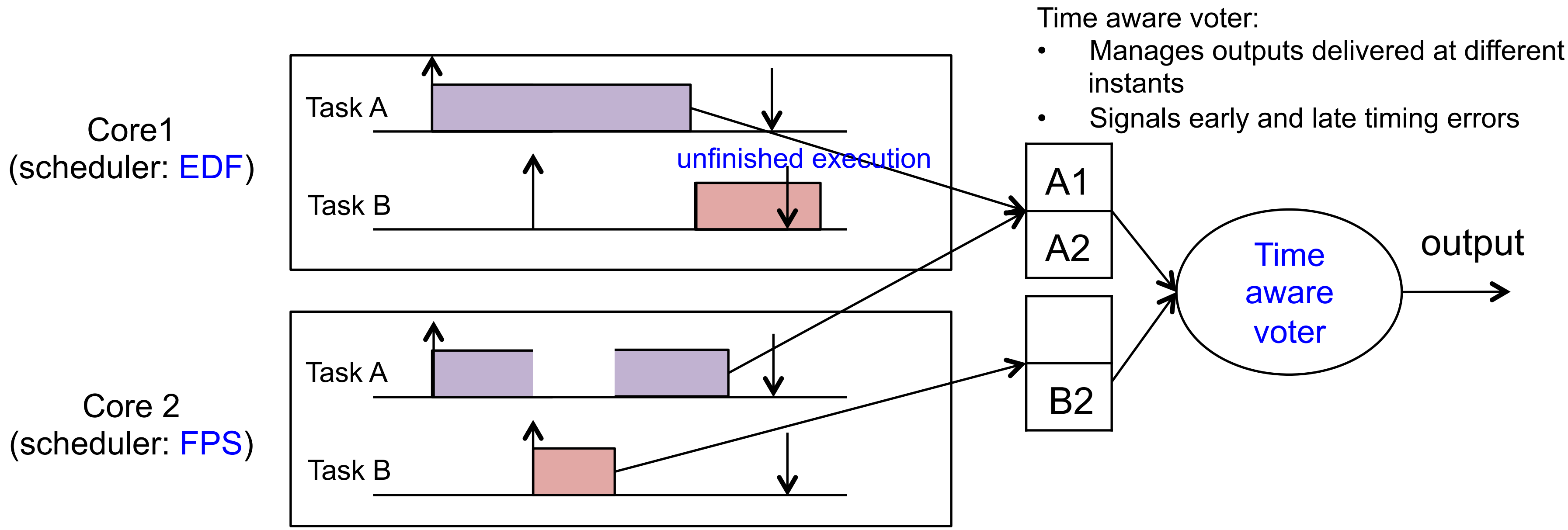
- Dedicated hardware to guarantee isolation
- 3b+1 replicas and byzantine fault tolerance mechanism to tolerate b byzantine faults
- Hardware and Software diversity to protect against design faults

Medium Criticality Tasks



- High integrity hardware that is shared among medium criticality tasks
- Time triggered scheduling and lock-step execution
- Replication for protection against random faults
- Hardware and software diversity for protection against design faults

Low Criticality Tasks



- COTS hardware, e.g., a multicore processor, that is shared among low criticality tasks
- Time aware voter and loose synchronization: less development effort
- Replication for protection against random faults
- Software diversity for protection against software design faults

Non-Critical Tasks

- Scheduled along with low criticality tasks
- Timeliness is guaranteed in the absence of faults
- Discarded upon failures
- Possibility of using existing MC scheduling algorithms
- Guarantees isolation of higher criticality tasks
- Limited form of redundancy can be provided exploiting spare processing capacity

Mapping Criticalities Based on Fault Coverage

			Design Faults		
Criticality	**Transient Faults**	**Random Faults**	**Software Faults**	**Hardware Faults**	**Byzantine Faults**
High	redundancy	redundancy	software diversity	hardware diversity	byzantine fault tolerance
Medium	redundancy	redundancy	software diversity	hardware diversity	✗
Low	redundancy	redundancy	software diversity	✗	✗
Non-critical	Limited redundancy	Limited redundancy	✗	✗	✗

Conclusions

- Approach for design of mixed criticality systems in the context of permanent faults through:
  - Fault coverage based mapping of criticalities
  - Criticality based provisioning of resources
  - Isolation of higher criticality tasks
  - Implicit coverage of WCET overrun faults
- Future Work
  - Methods for efficient allocation of replicas to processors
  - Consideration of safety analysis in the allocation and scheduling of tasks
  - Providing better-than-average service to non-critical tasks

Thank You !

Questions ?