mSWAT: Low-Cost Hardware Fault Detection and Diagnosis for Multicore Systems

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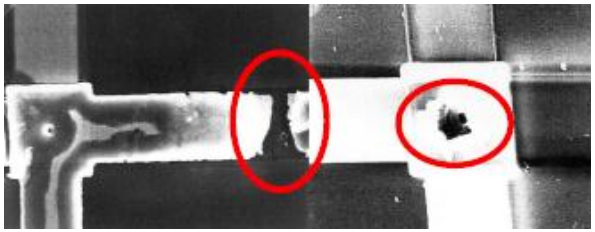
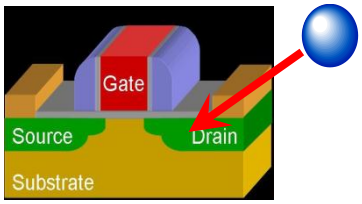
Motivation

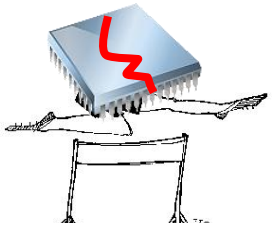
- **Hardware will fail in-the-field due to several reasons**



Wear-out
(Devices are weaker)



Transient errors
(High-energy particles)



Design Bugs

… and so on

⇒Need in-field detection, diagnosis, repair, and recovery

- **Reliability problem pervasive across many markets**
  - **Traditional redundancy solutions (e.g., nMR) too expensive**

⇒ Need low-cost solutions for multiple failure sources

* **Must incur low area, performance, power overhead**

SWAT: Low-Cost Hardware Reliability

SWAT Observations

- **Need handle only hardware faults that propagate to software**
- **Fault-free case remains common, must be optimized**

SWAT Approach

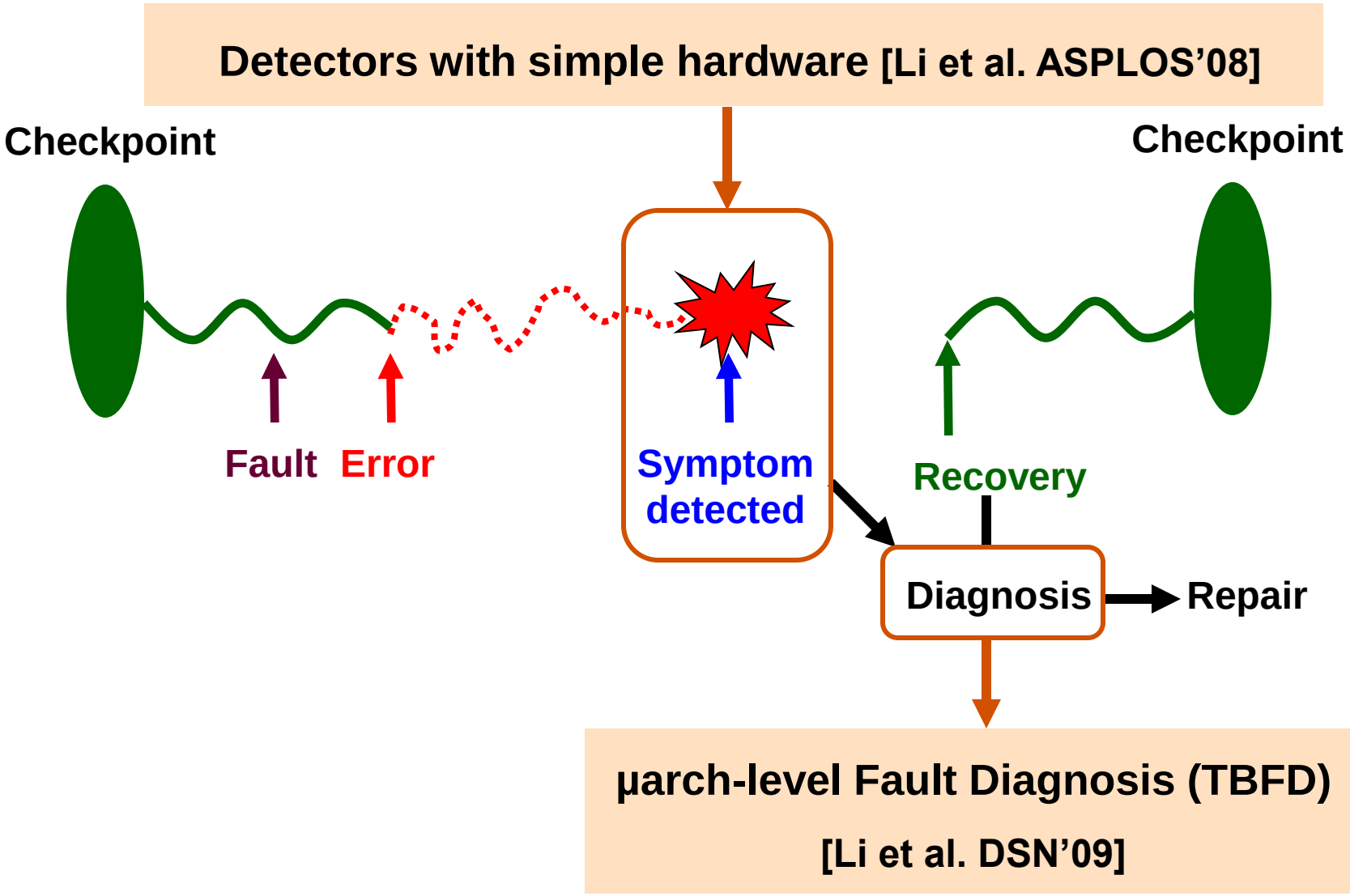
⇒ Watch for software anomalies (symptoms)

Zero to low overhead "always-on" monitors

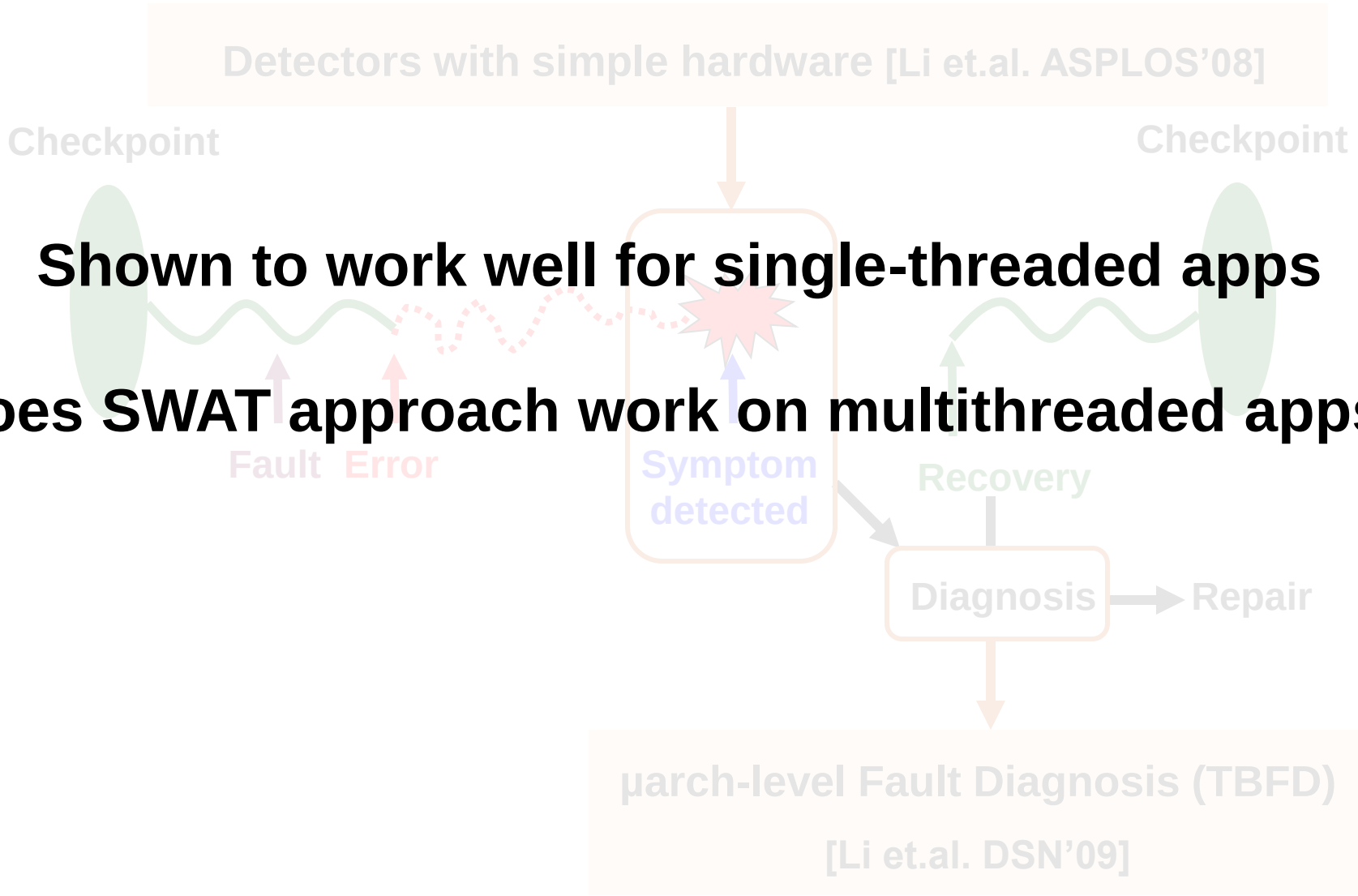
Diagnose cause after symptom detected

May incur high overhead, but rarely invoked

SWAT Framework Components



Challenge

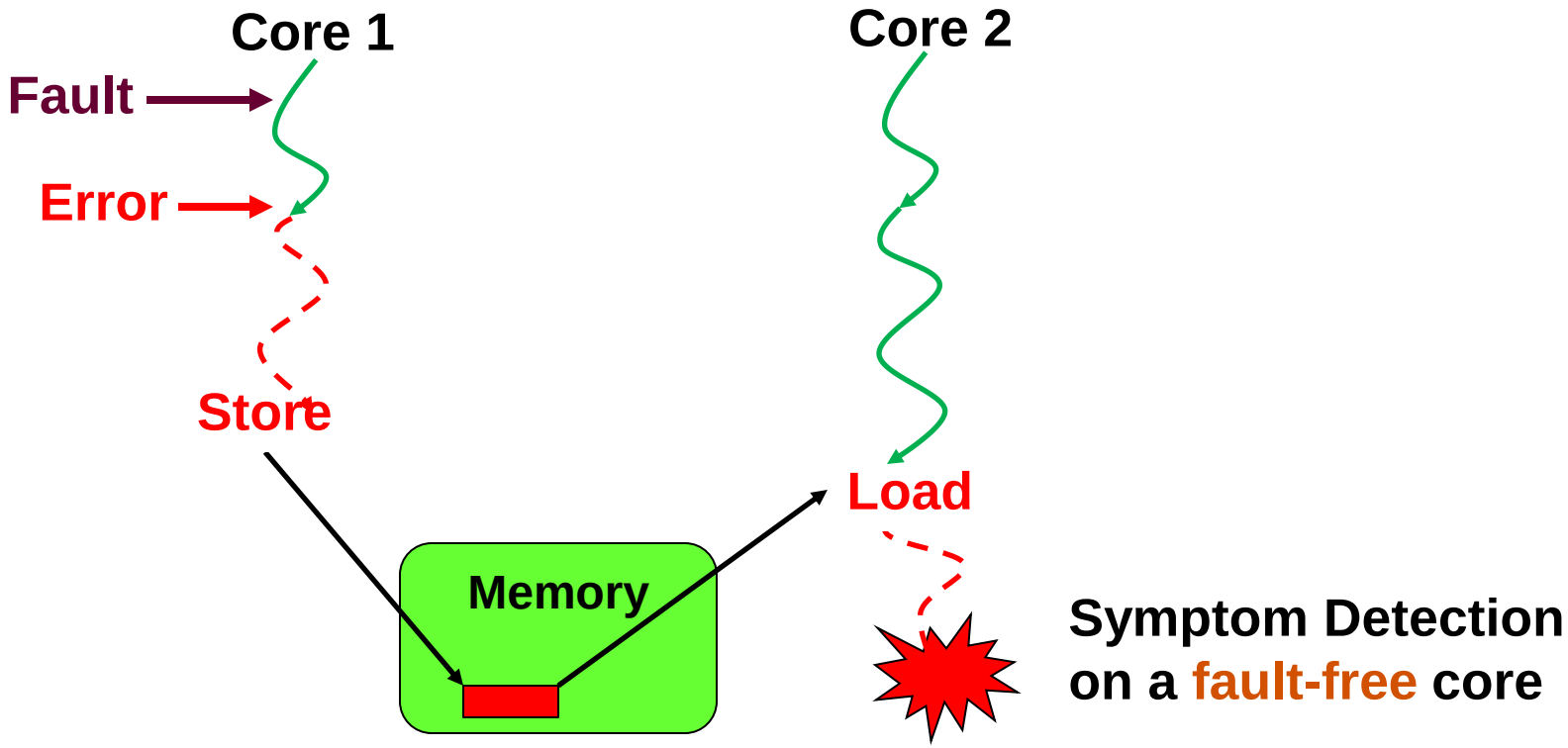


Shown to work well for single-threaded apps

Does SWAT approach work on multithreaded apps?

Challenge: Data sharing in multithreaded apps

- **Multithreaded apps share data among threads**



- **Does symptom detection work?**
- **Symptom causing core may not be faulty**
  - **How to diagnose faulty core?**

Contributions

- **Evaluate SWAT detectors on multithreaded apps**
  - **Low Silent Data Corruption rate for multithreaded apps**
  - **Observed symptom from fault-free cores**

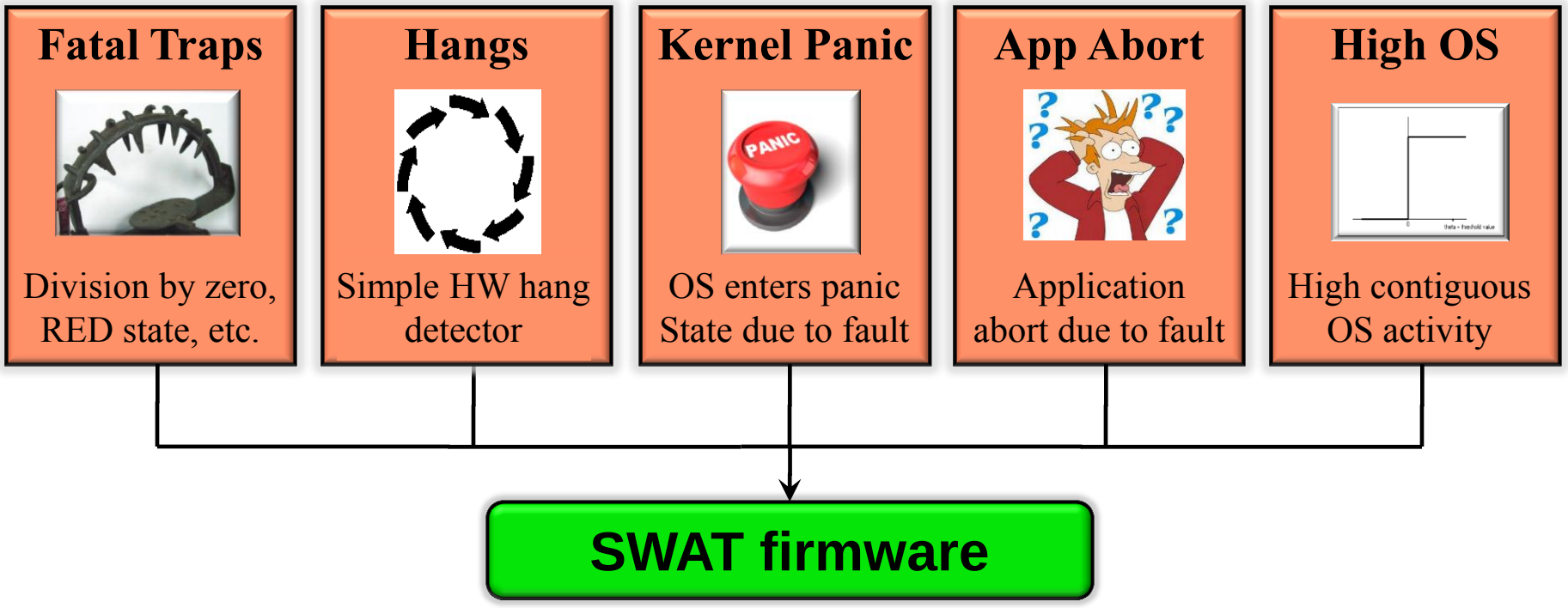
- **Novel fault diagnosis for multithreaded apps**
  - **Identifies the faulty core despite error propagation**
  - **Provides high diagnosability**

Outline

- Motivation
- **mSWAT Detection**
- **mSWAT Diagnosis**
- **Results**
- **Summary and Future Work**

mSWAT Fault Detection

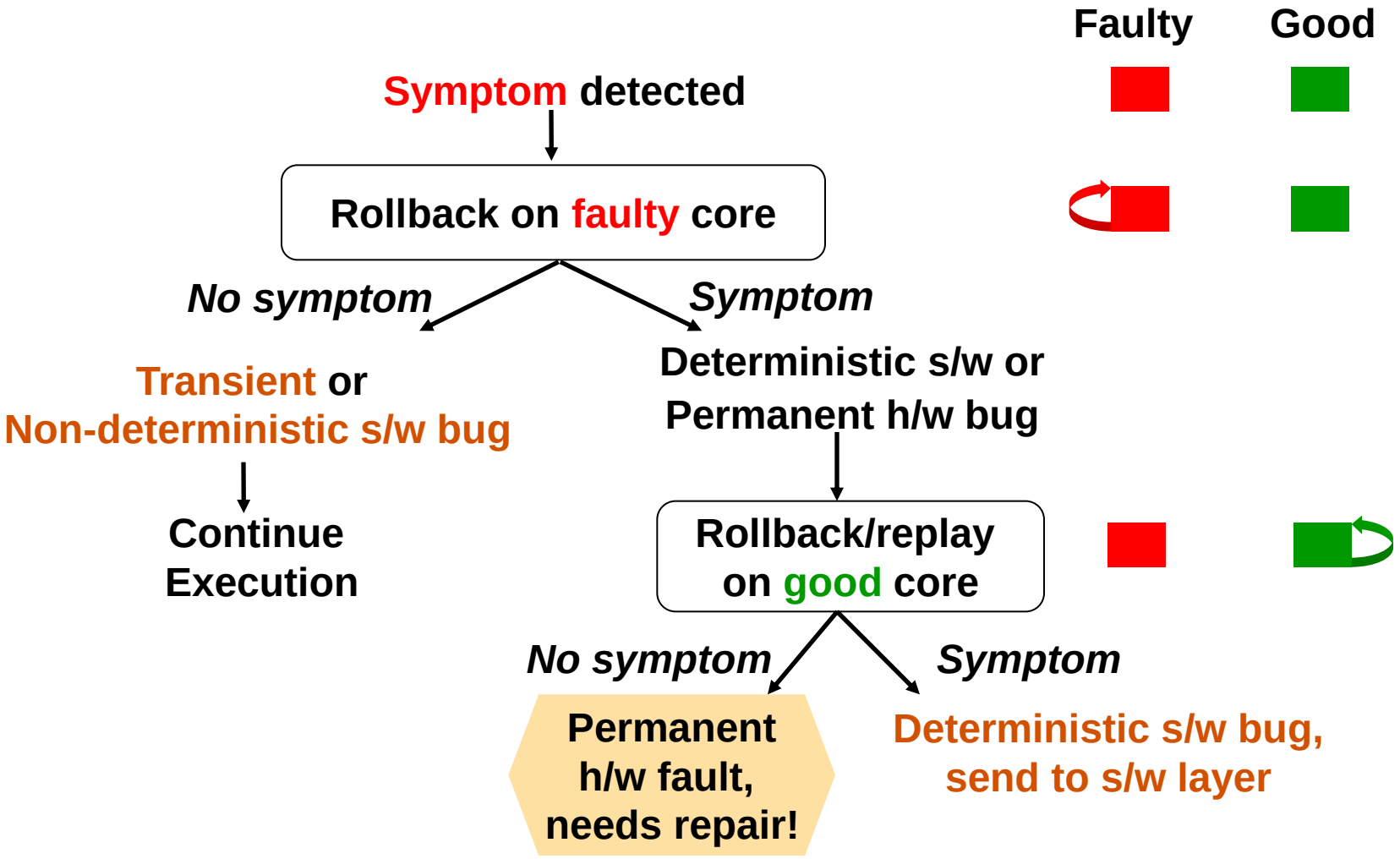
- **SWAT Detectors:**
  - **Low-cost monitors to detect anomalous sw behavior**
  - **Incur near-zero perf overhead in fault-free operation**



- **Symptom detectors provide low Silent Data Corruption rate**

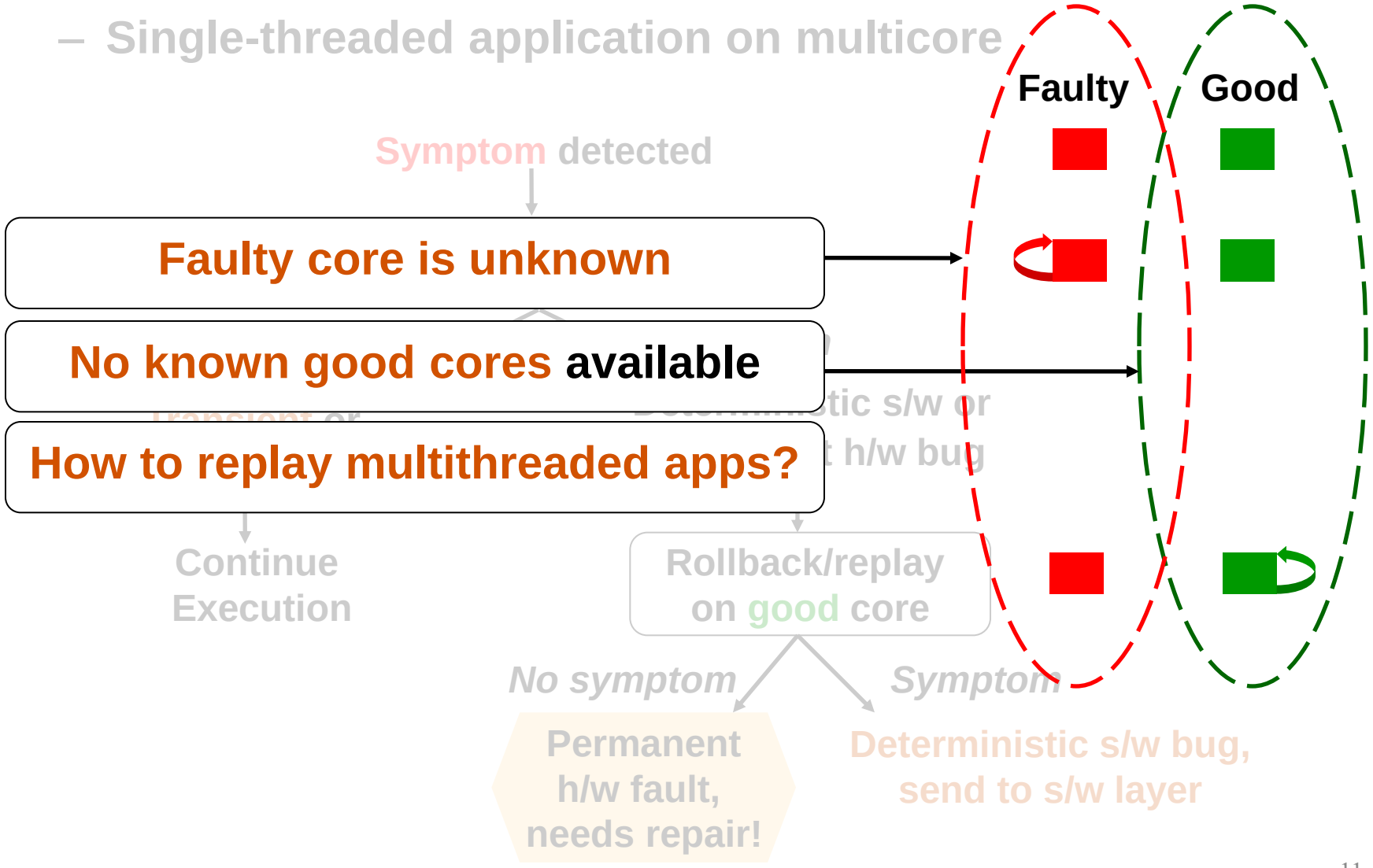
SWAT Fault Diagnosis

- **Rollback/replay on same/different core**
  - **Single-threaded application on multicore**



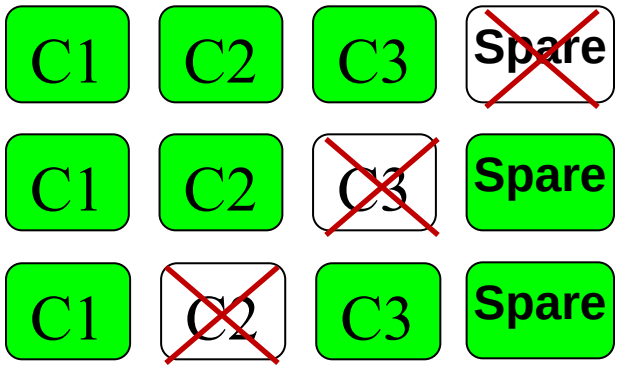
Challenges

- Rollback/replay on same/different core
  - Single-threaded application on multicore



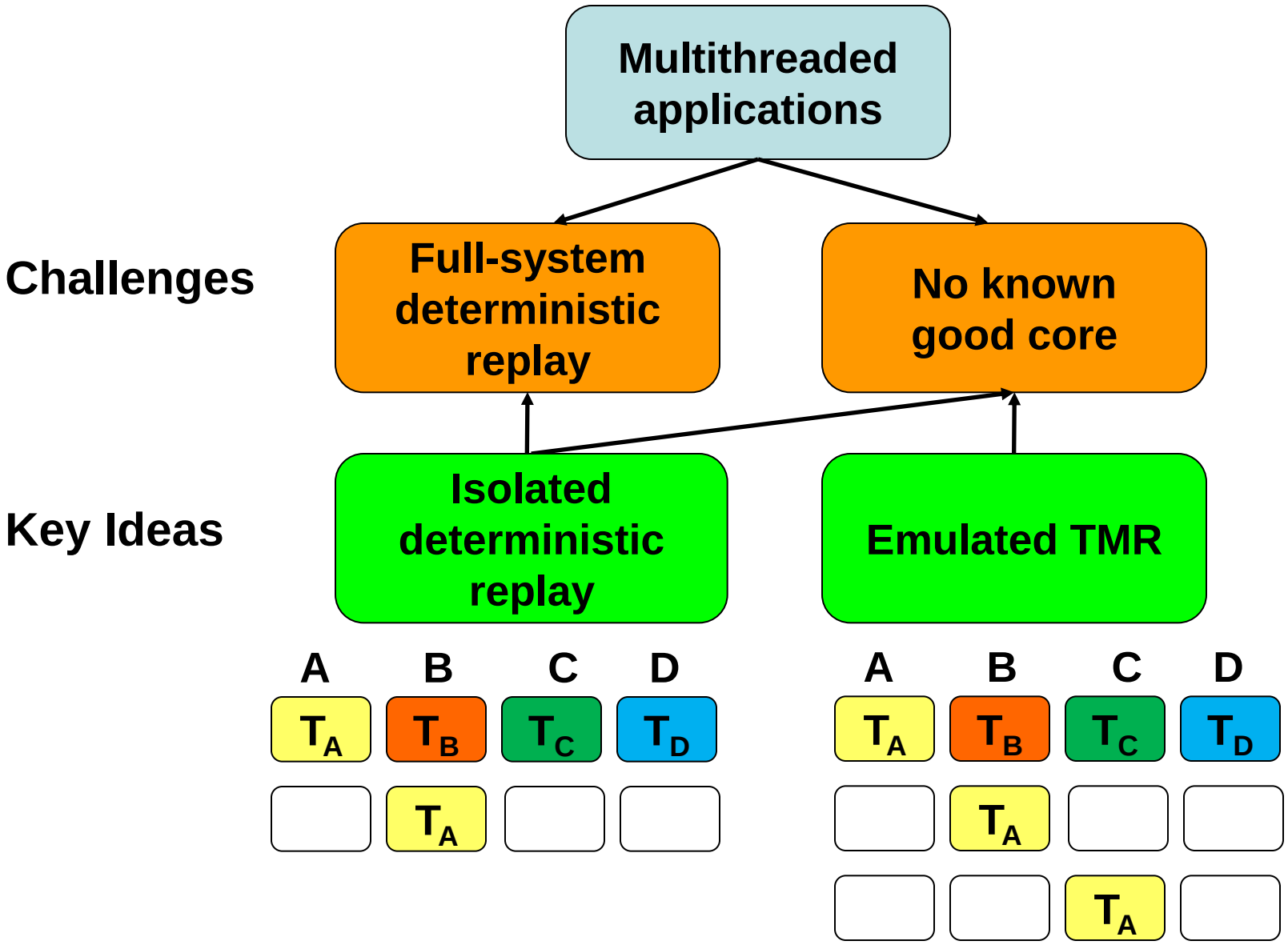
Extending SWAT Diagnosis to Multithreaded Apps

- **Assumptions: In-core faults, single core fault model**
- **Naïve extension – N known good cores to replay the trace**
  - **Too expensive – area**
  - **Requires full-system deterministic replay**
- **Simple optimization – One spare core**



  - **Not scalable, requires N full-system deterministic replays**
  - **High hardware overhead – requires a spare core**
  - **Single point of failure – spare core**

mSWAT Diagnosis - Key Ideas



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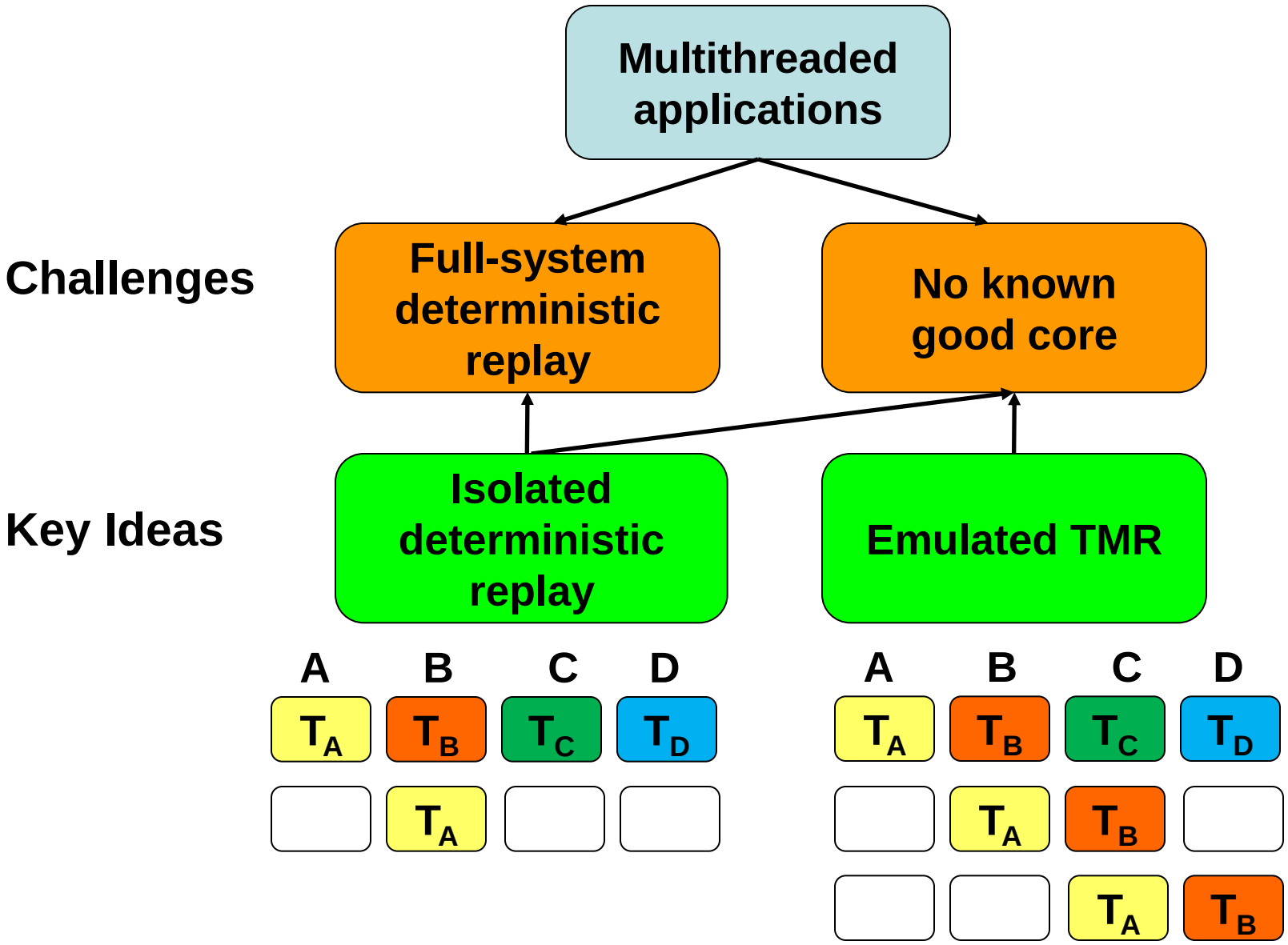
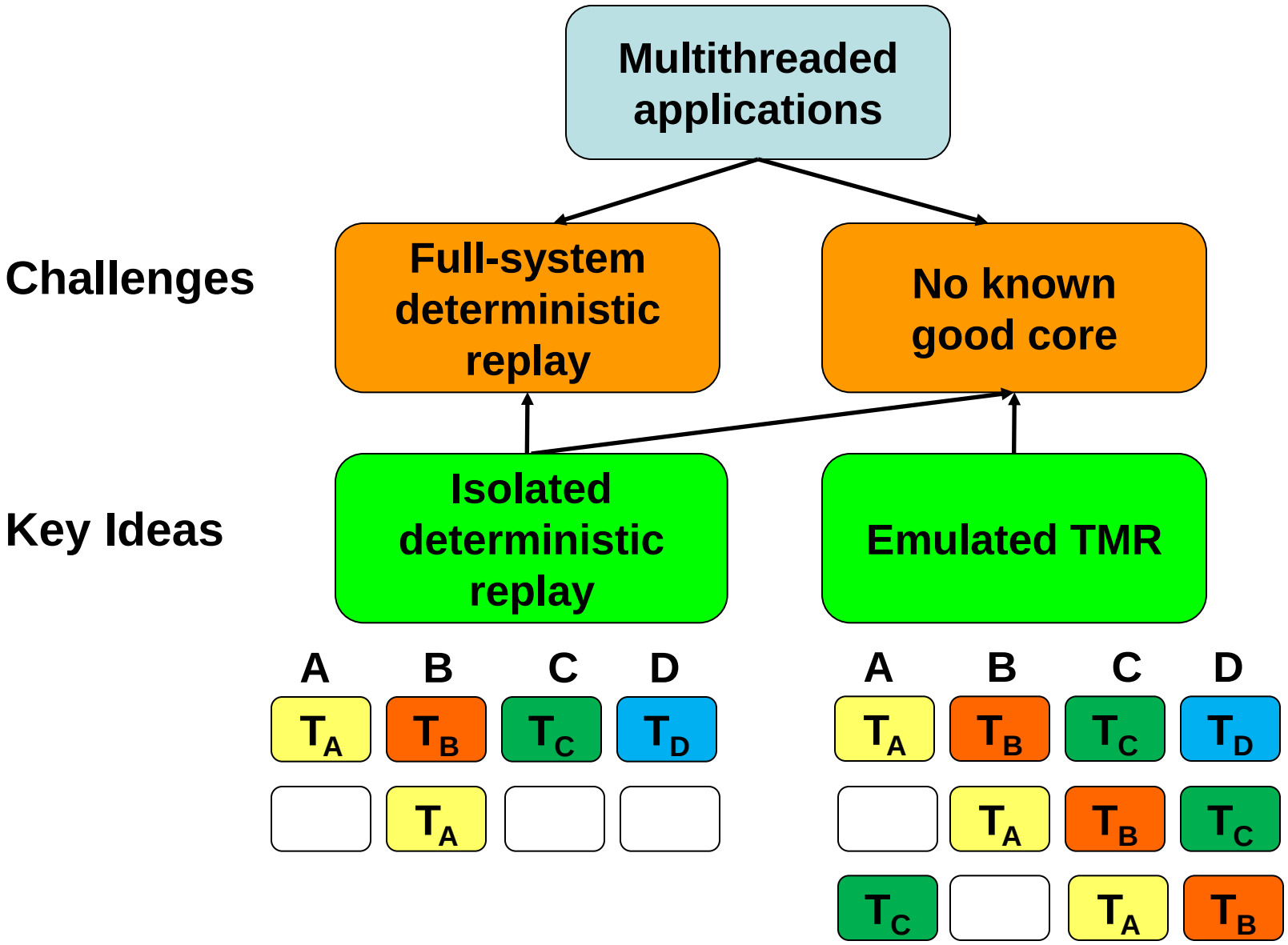


mSWAT Diagnosis - Key Ideas



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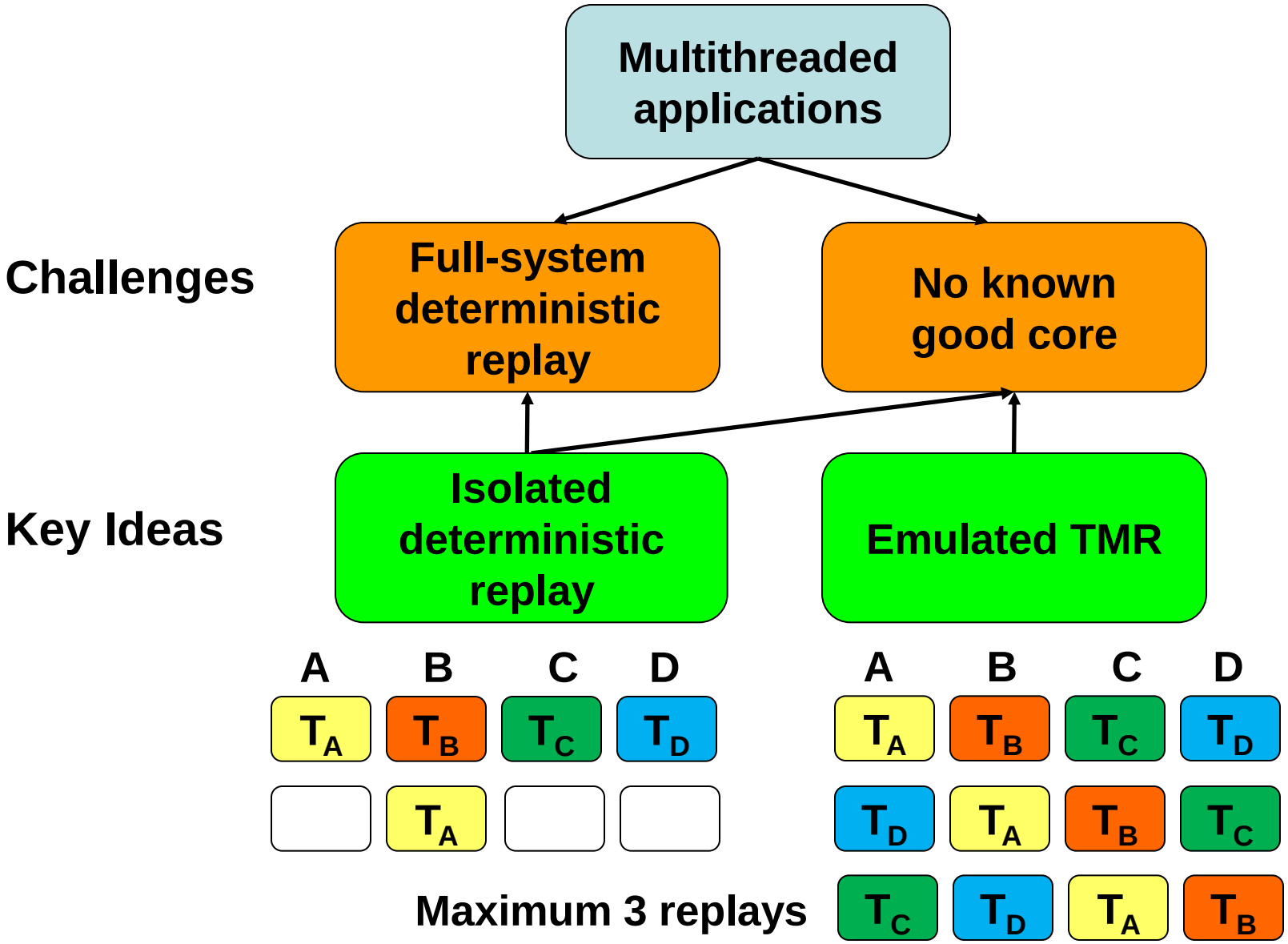
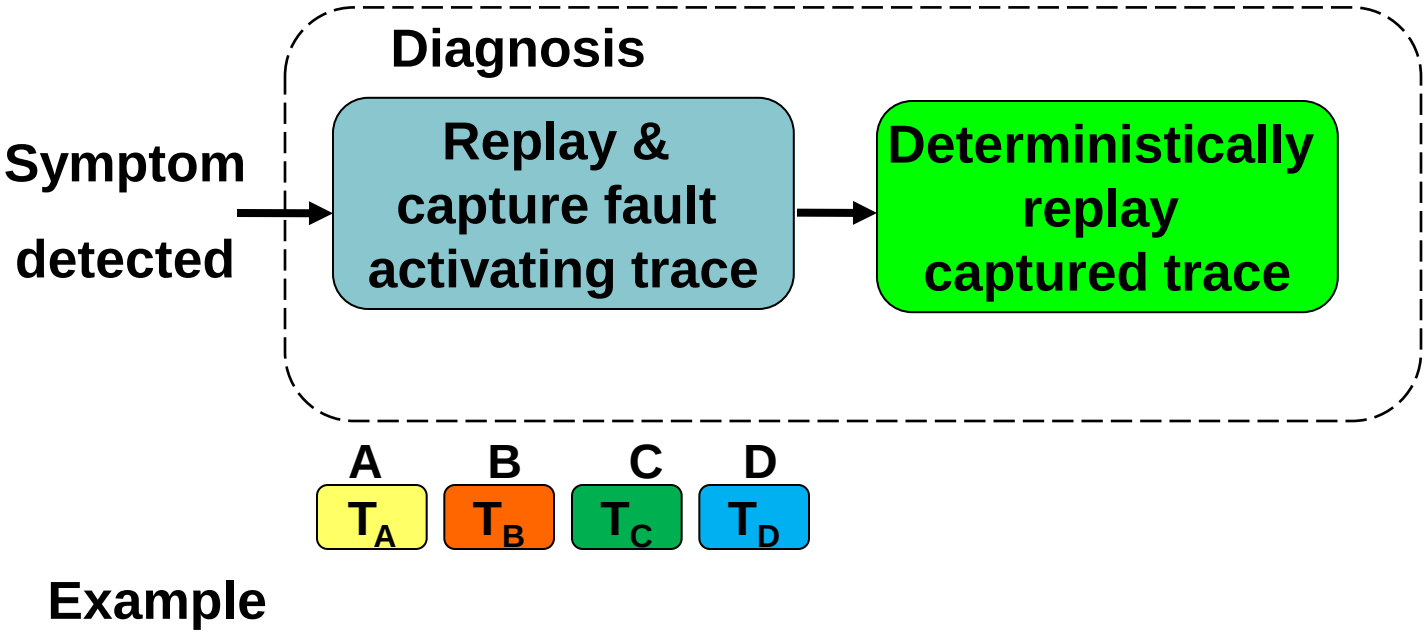


Multicore Fault Diagnosis Algorithm Overview



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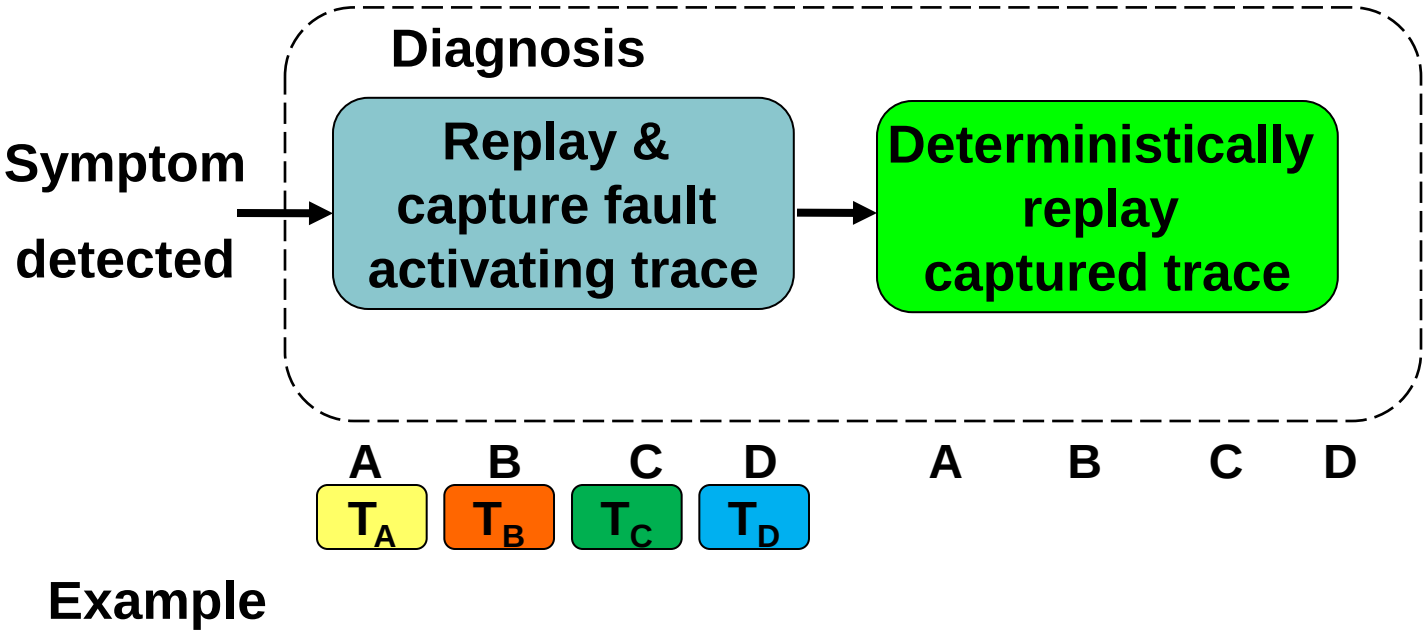
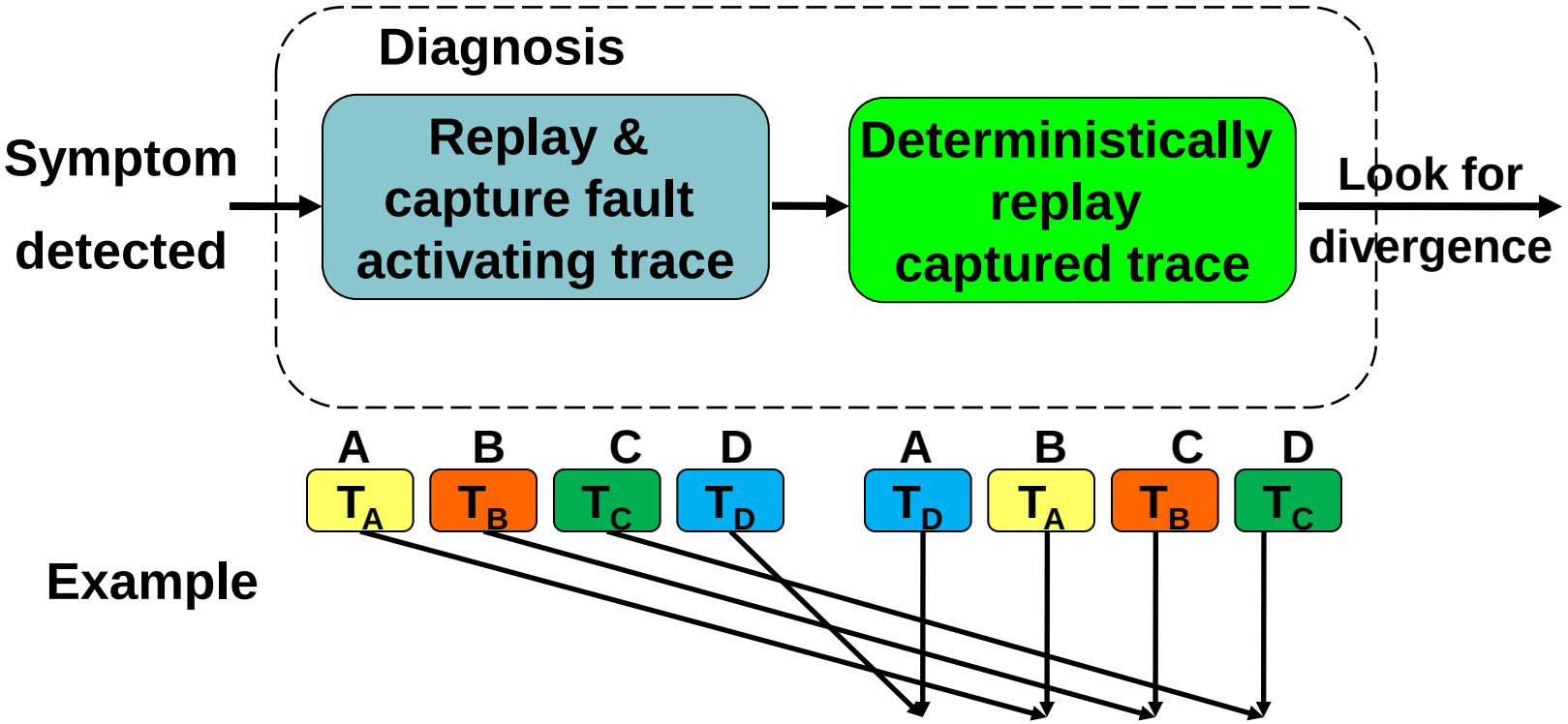


Example

Multicore Fault Diagnosis Algorithm Overview



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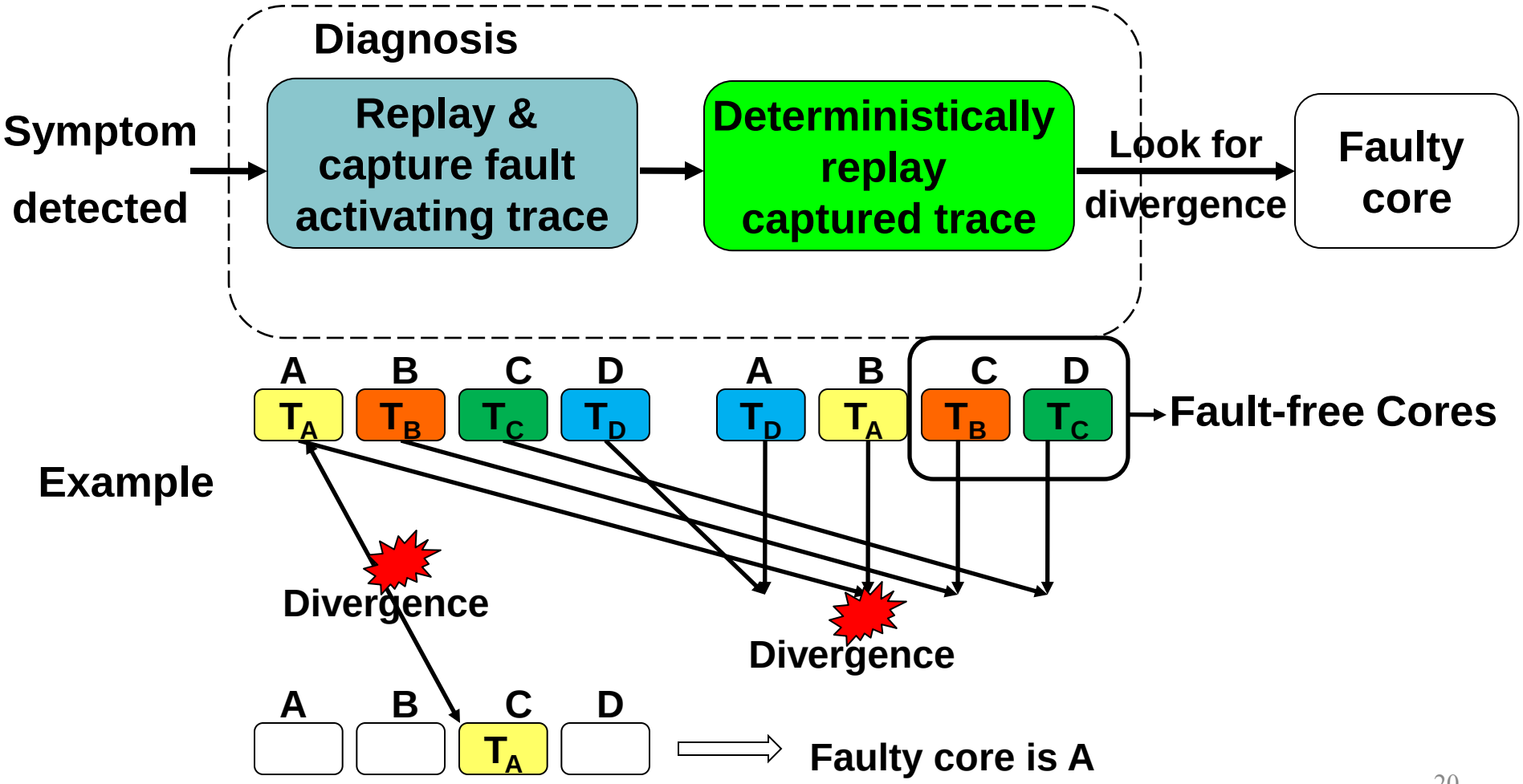
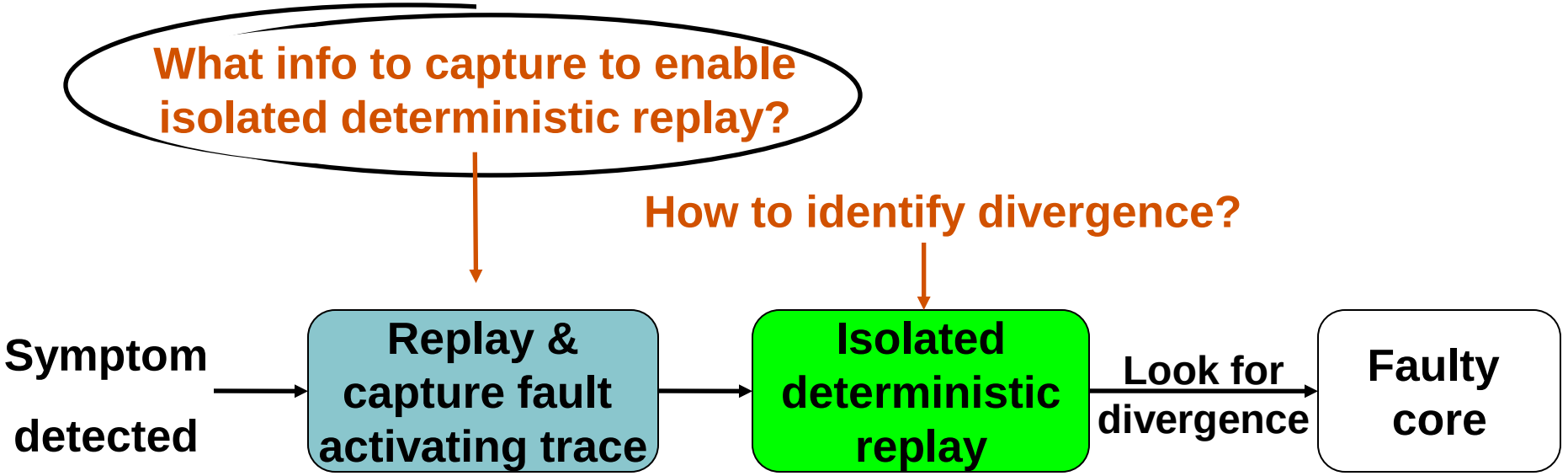
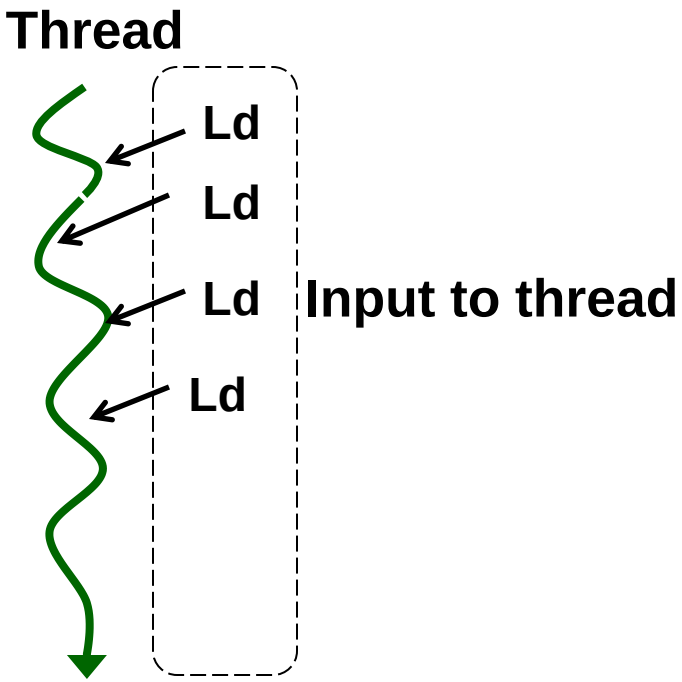


Digging Deeper



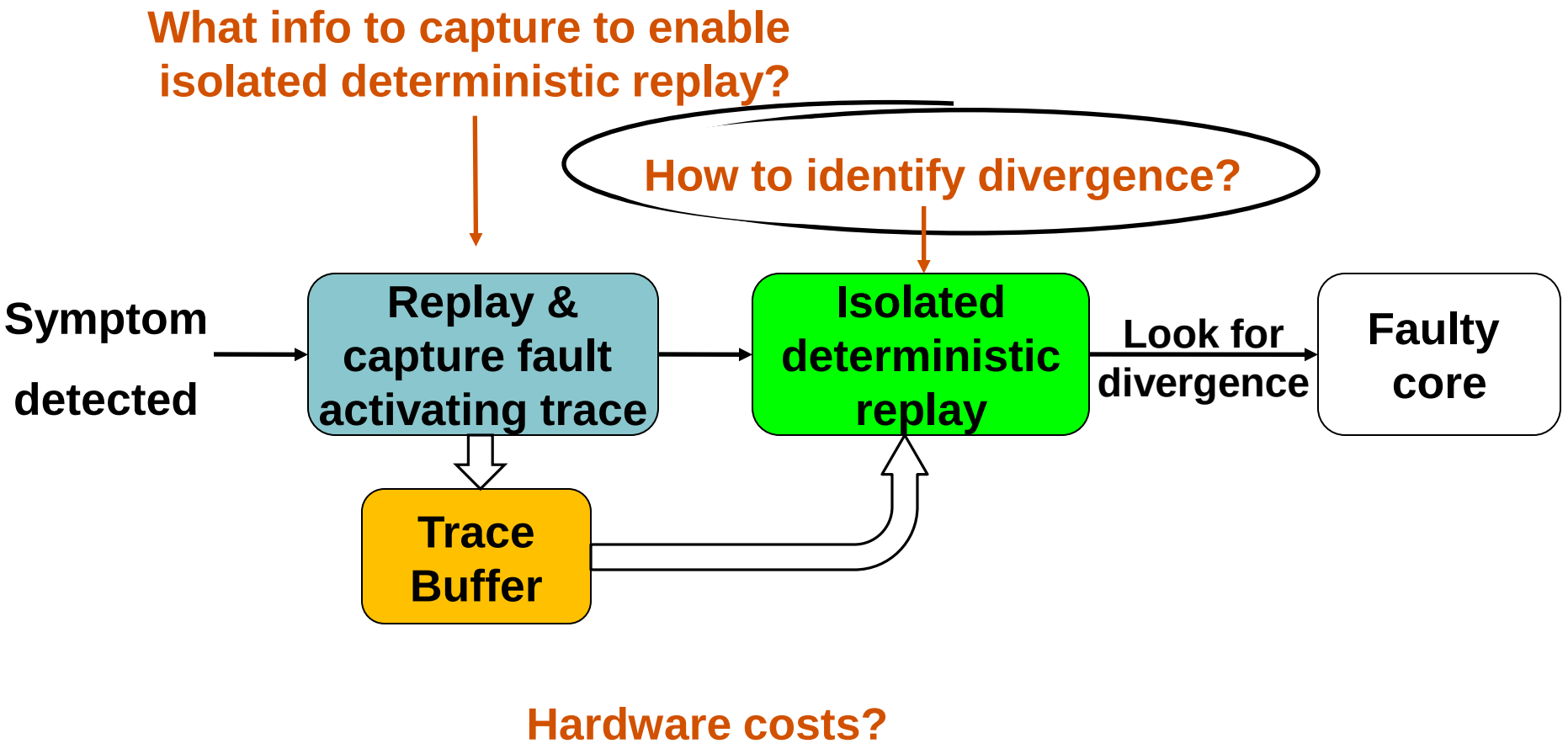
Hardware costs?

Enabling Isolated Deterministic Replay



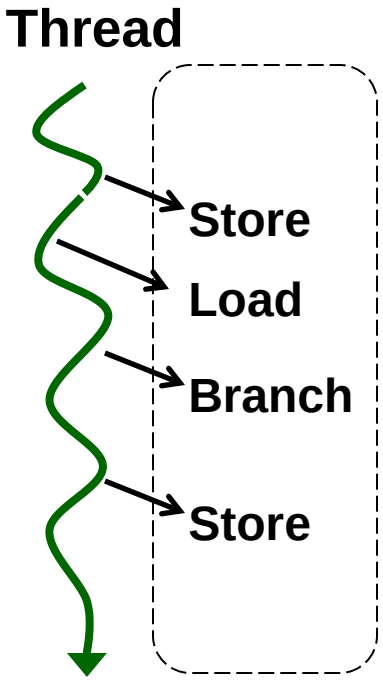
- **Recording thread inputs sufficient – similar to BugNet**
  - **Record all retiring loads values**

Digging Deeper (Contd.)



Identifying Divergence

- Comparing all instructions ⇒ Large buffer requirement
- Faults corrupt software through memory and control instrns
  - Capture memory and control instructions



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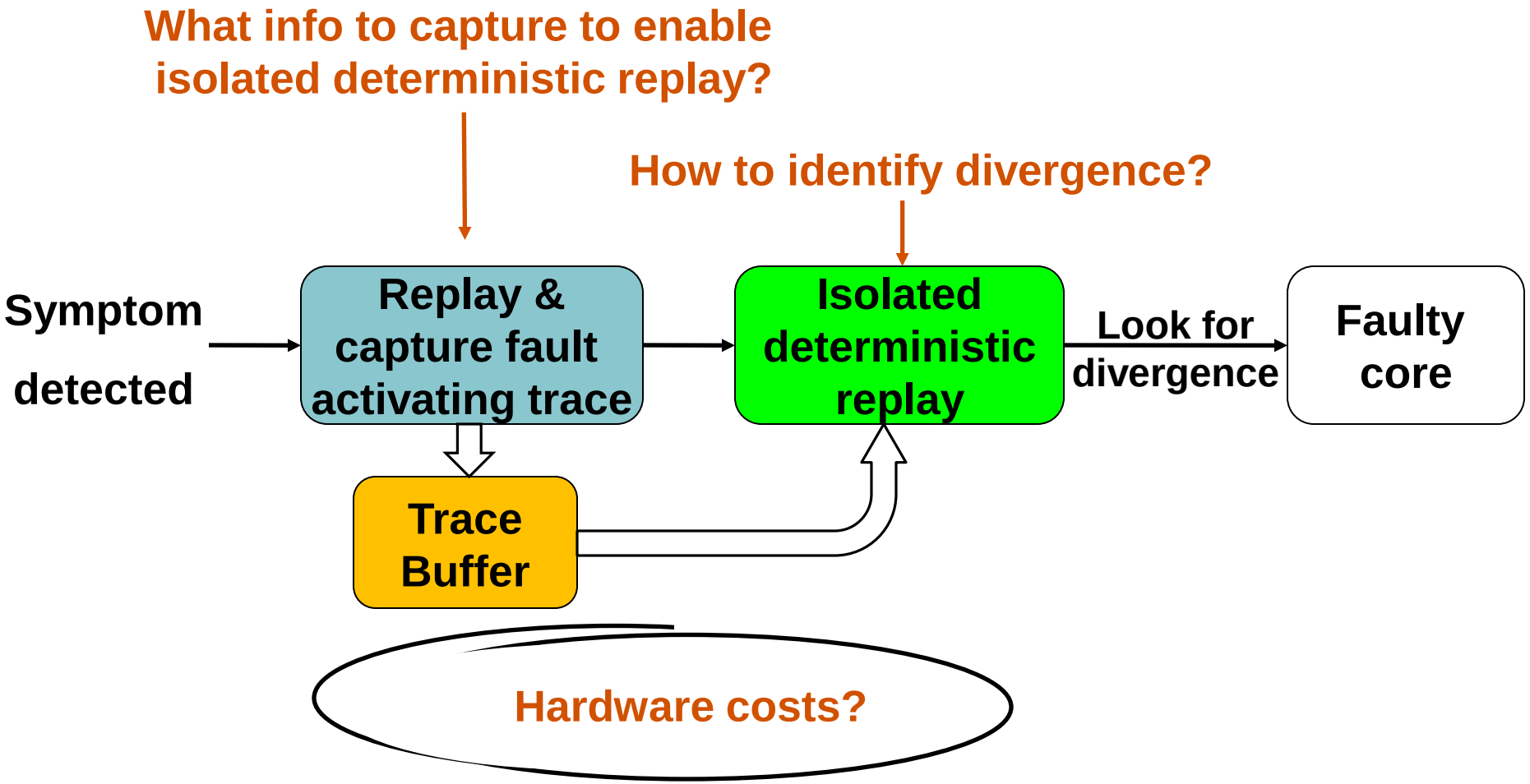
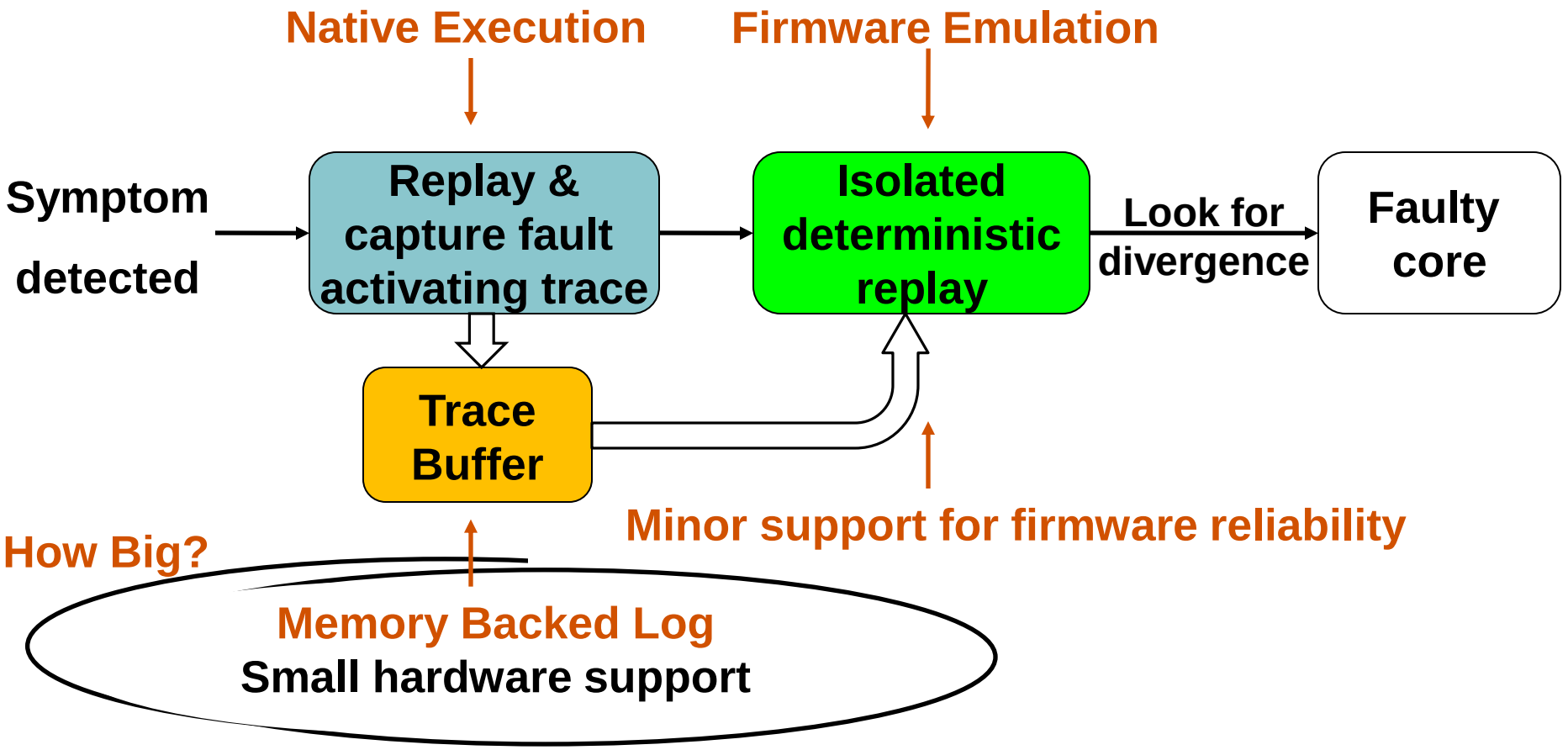


Hardware Costs



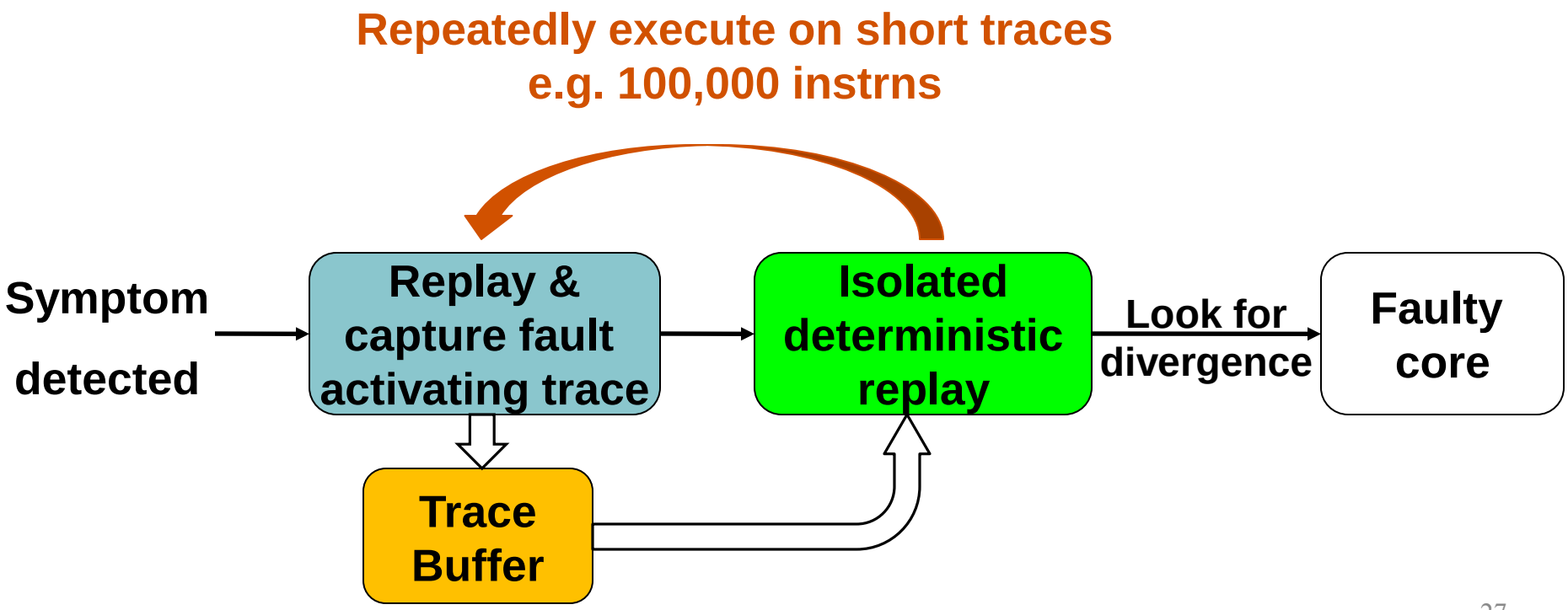
What if the faulty core subverts the process?

Key Idea: On a divergence two cores take over

Trace Buffer Size

- **Long detection latency ⇒ large trace buffers (8MB/core)**
  - **Need to reduce the size requirement**

  ⇒ Iterative Diagnosis Algorithm



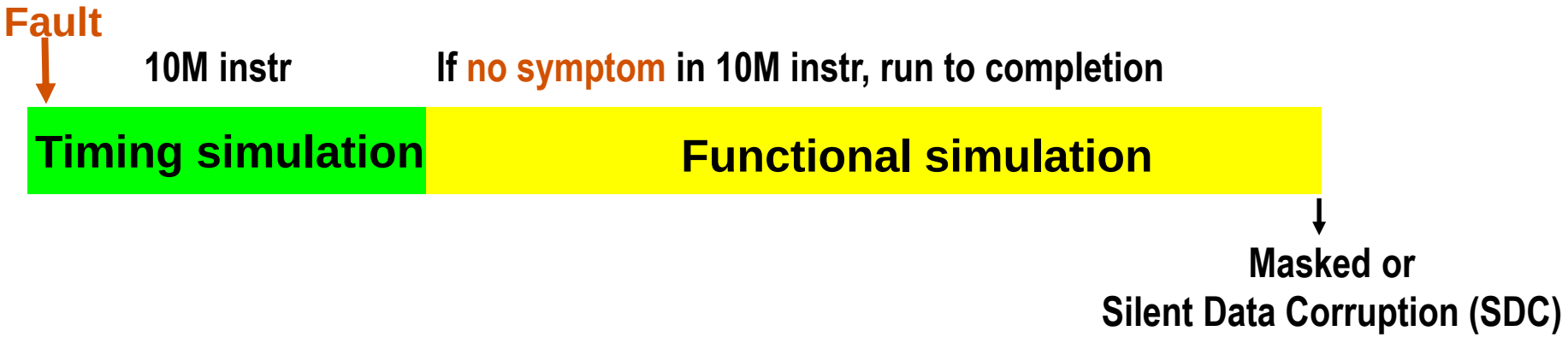
Experimental Methodology

- **Microarchitecture-level fault injection**
  - **GEMS timing models + Simics full-system simulation**
  - **Six multithreaded applications on OpenSolaris**
    - **4 Multimedia apps and 1 each from SPLASH and PARSEC**
  - **4 core system running 4-threades apps**

- **Faults in latches of 7 μarch units**
  - **Permanent (stuck-at) and transients faults**

Experimental Methodology

Detection:

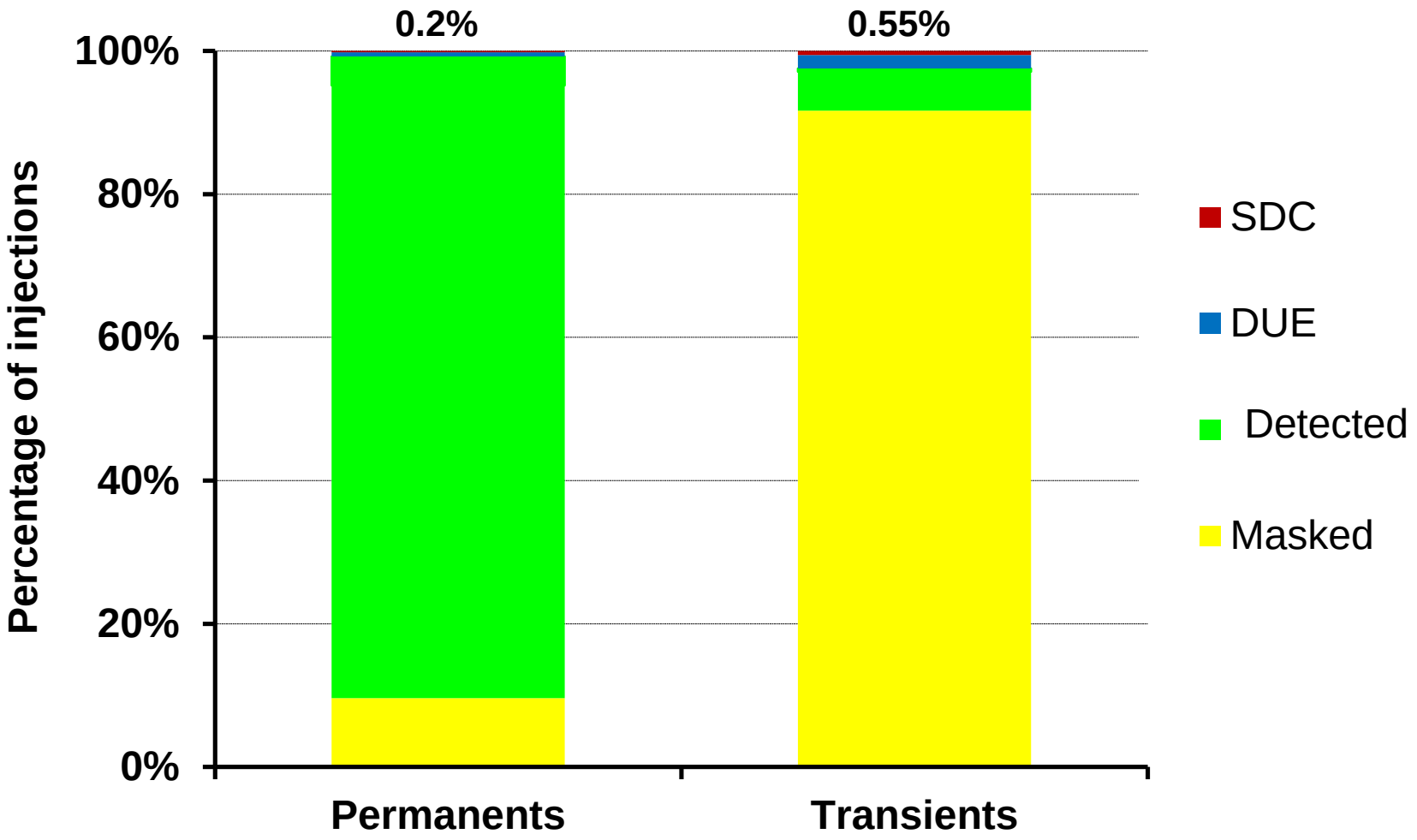


- **Metrics: SDC Rate, detection latency**

Diagnosis:

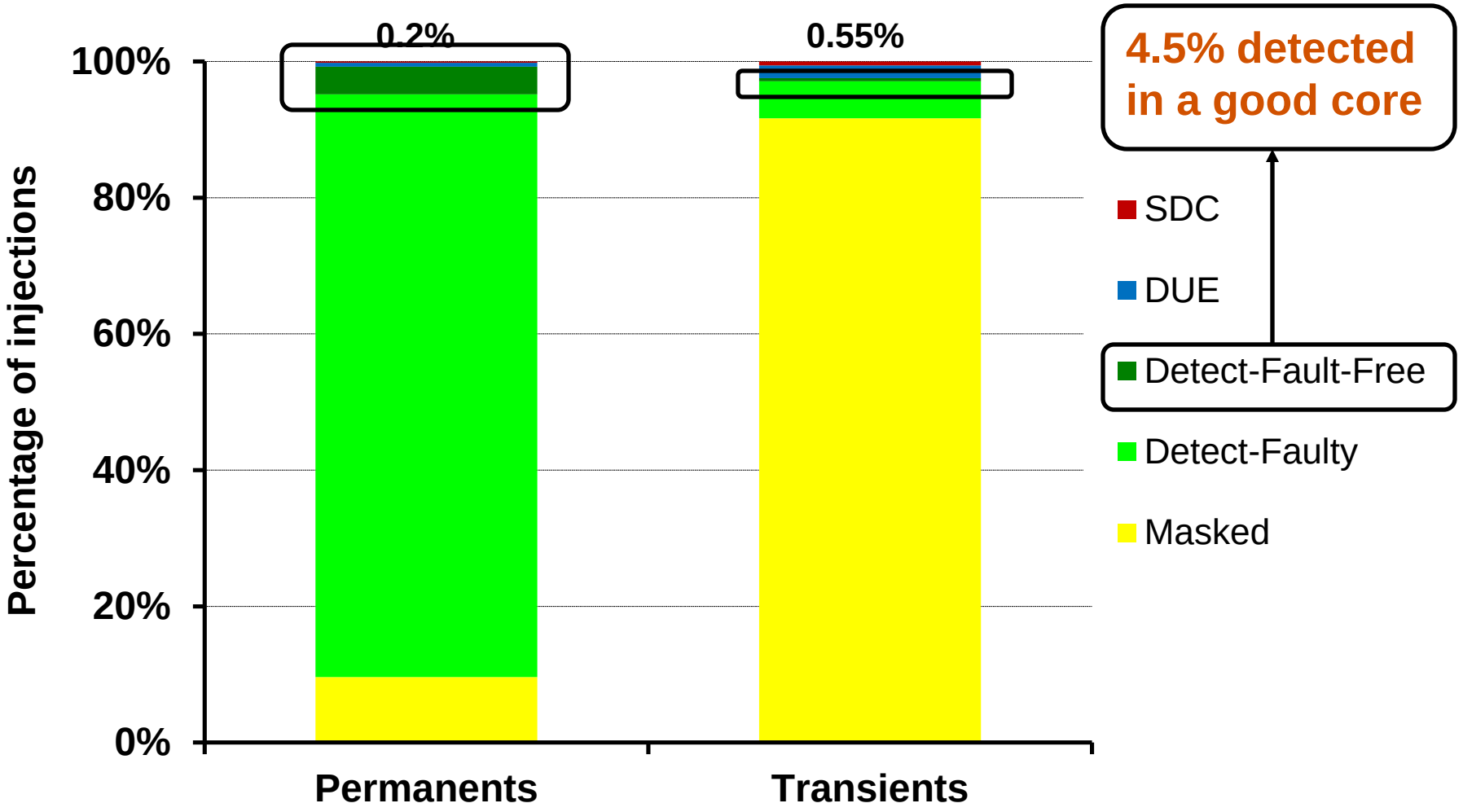
- **Iterative algorithm with 100,000 instrns in each iteration**
  - **Until divergence or 20M instrns**
- **Deterministic replay is native execution**
  - **Not firmware emulated**
- **Metrics: Diagnosability, overheads**

Results: mSWAT Detection Summary



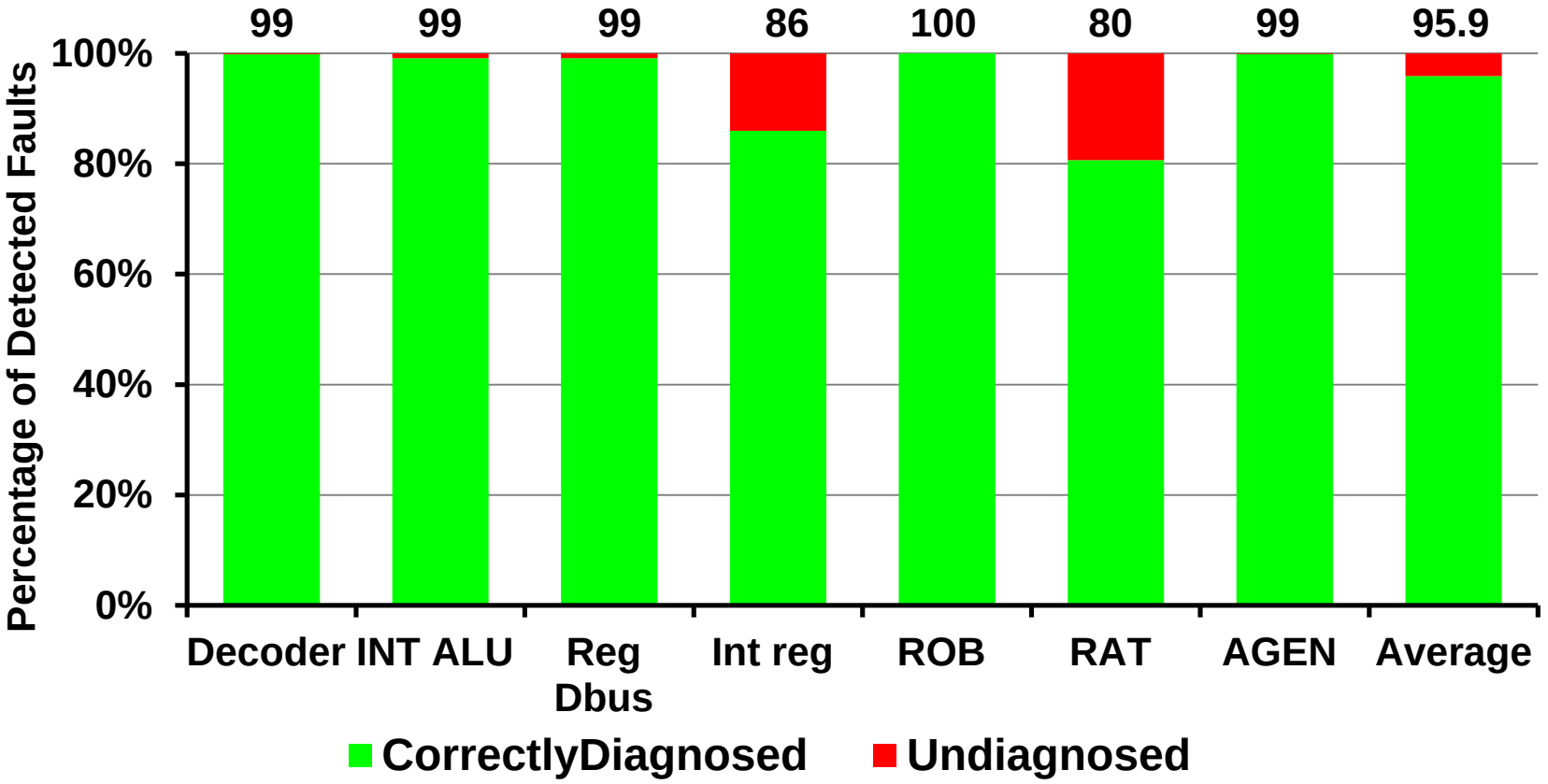
- **SDC Rate: Only 0.2% for permanents & 0.55% for transients**
- **Detection Latency: Over 99% detected within 10M instrns**

Results: mSWAT Detection Summary



- **SDC Rate: Only 0.2% for permanents & 0.55% for transients**
- **Detection Latency: Over 99% detected within 10M instrns**

Results: mSWAT Diagnosability



- **Over 95% of detected faults are successfully diagnosed**
- **All faults detected in fault-free core are diagnosed**
- **Undiagnosed faults: 88% did not activate faults**

Results: mSWAT Diagnosis Overheads

- **Diagnosis Latency**
  - **98% diagnosed <10 million cycles (10ms in 1GHz system)**
  - **93% were diagnosed in 1 iteration**
    - **Iterative approach is effective**

- **Trace Buffer size**
  - **96% require <400KB/core**
    - **Trace buffer can easily fit in L2 or L3 cache**

mSWAT Summary

- **Detection: Low SDC rate, detection latency**
- **Diagnosis – identifying the faulty core**
  - **Challenges: no known good core, deterministic replay**
  - **High diagnosability with low diagnosis latency**
  - **Low Hardware overhead - Firmware based implementation**
  - **Scalable – maximum 3 replays for any system**
- **Future Work:**
  - **Reducing SDCs, detection latency, recovery overheads**
  - **Extending to server apps; off-core faults**
  - **Validation on FPGAs (w/ Michigan)**