Experience Report: An Application-specific Checkpointing Technique for Minimizing Checkpoint Corruption

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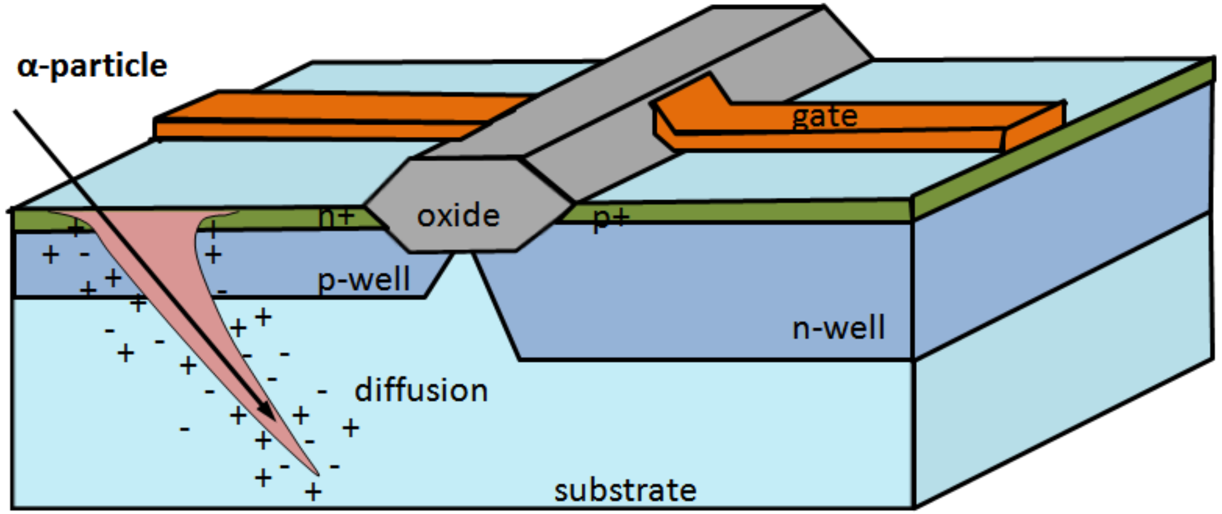
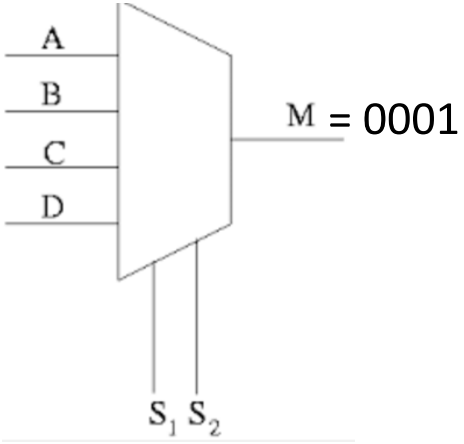
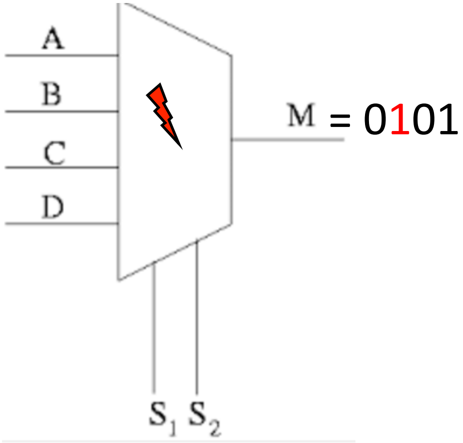
Soft Errors

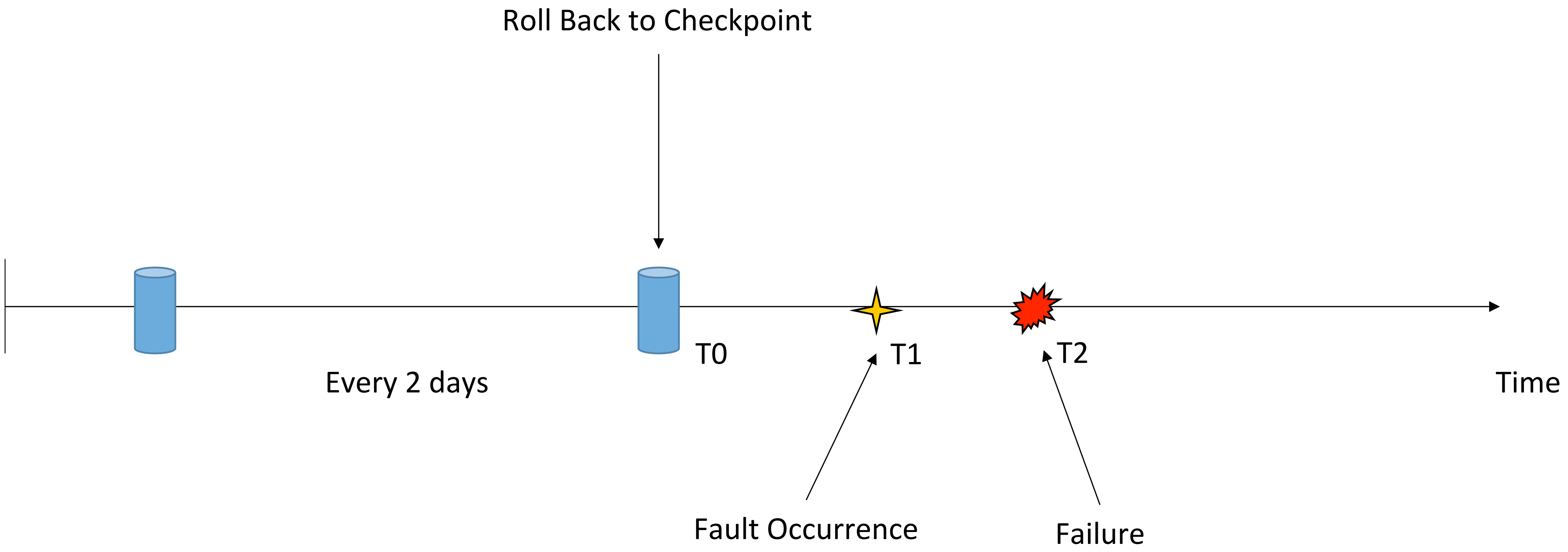
Bauman, T-DMR[1]







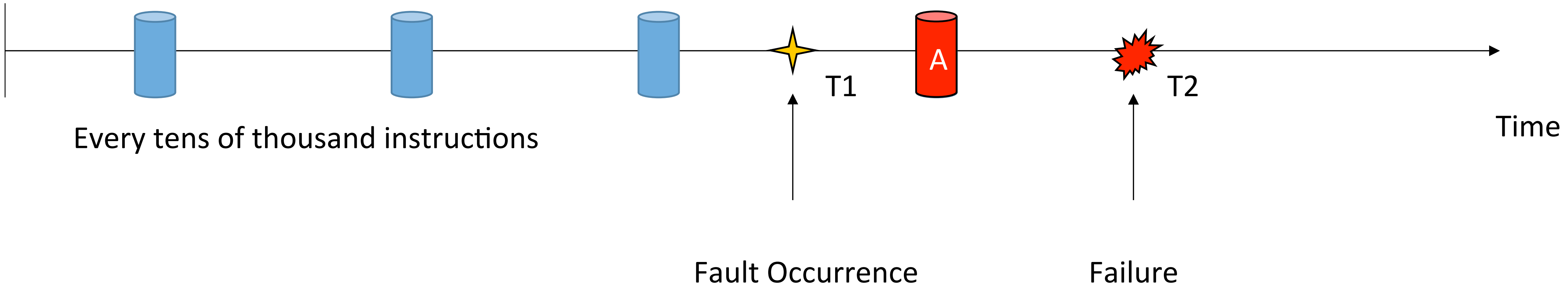
Traditional Checkpoint



Checkpoint at High Frequency

ReVive[2]
SafetyNet[3]

System is unrecoverable!

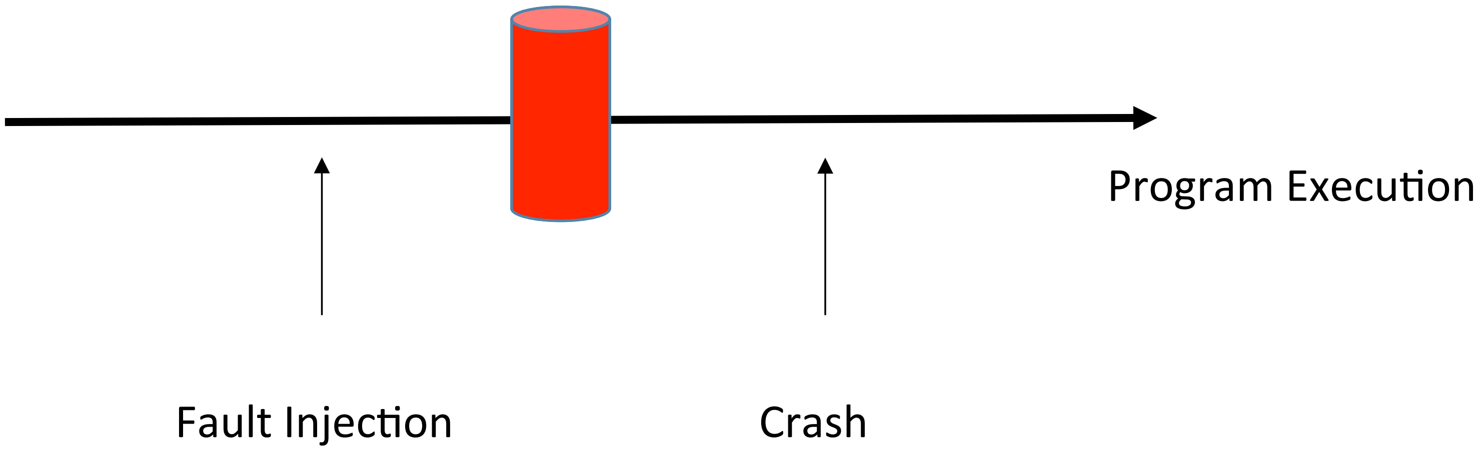


Fault Model

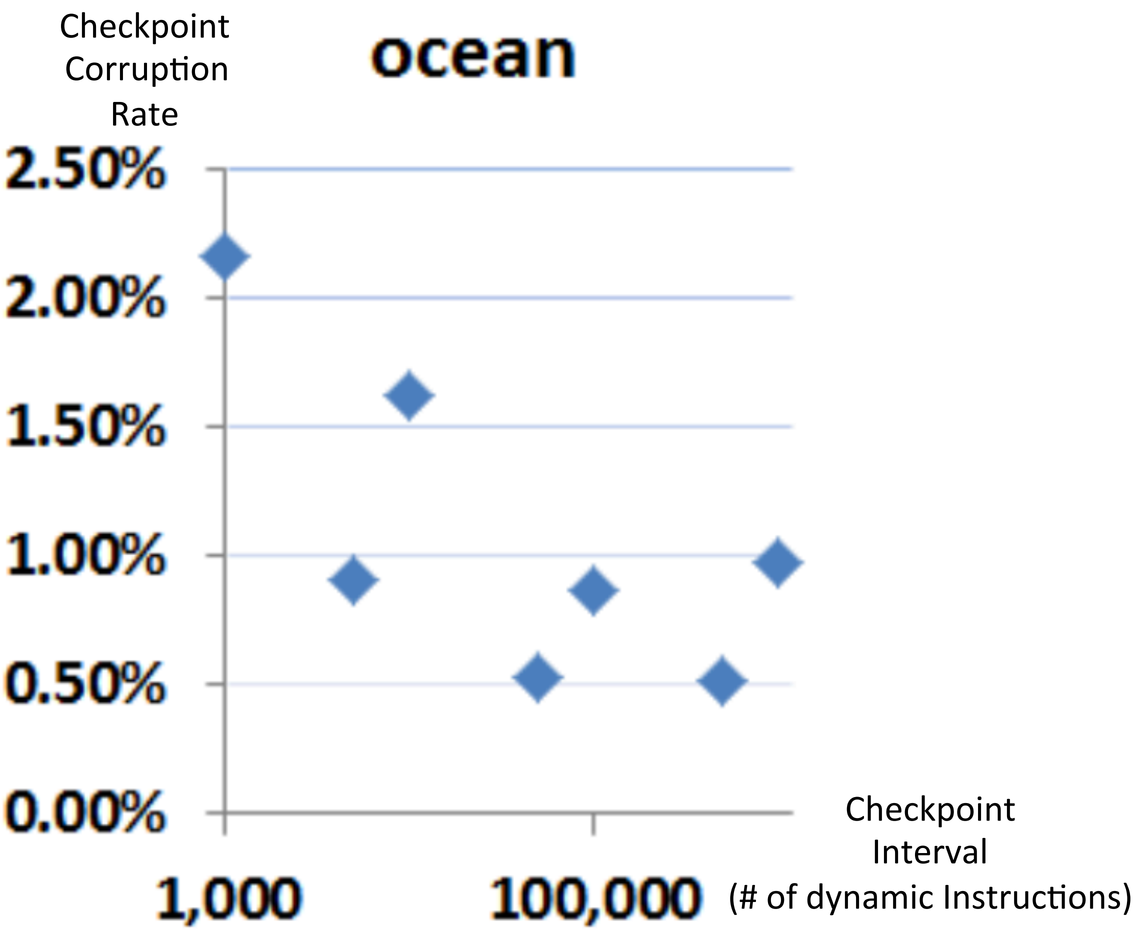
- Transient errors occurred in computation components
- Memory and cache protected with ECC
- Single-bit flip
- Crash-causing faults

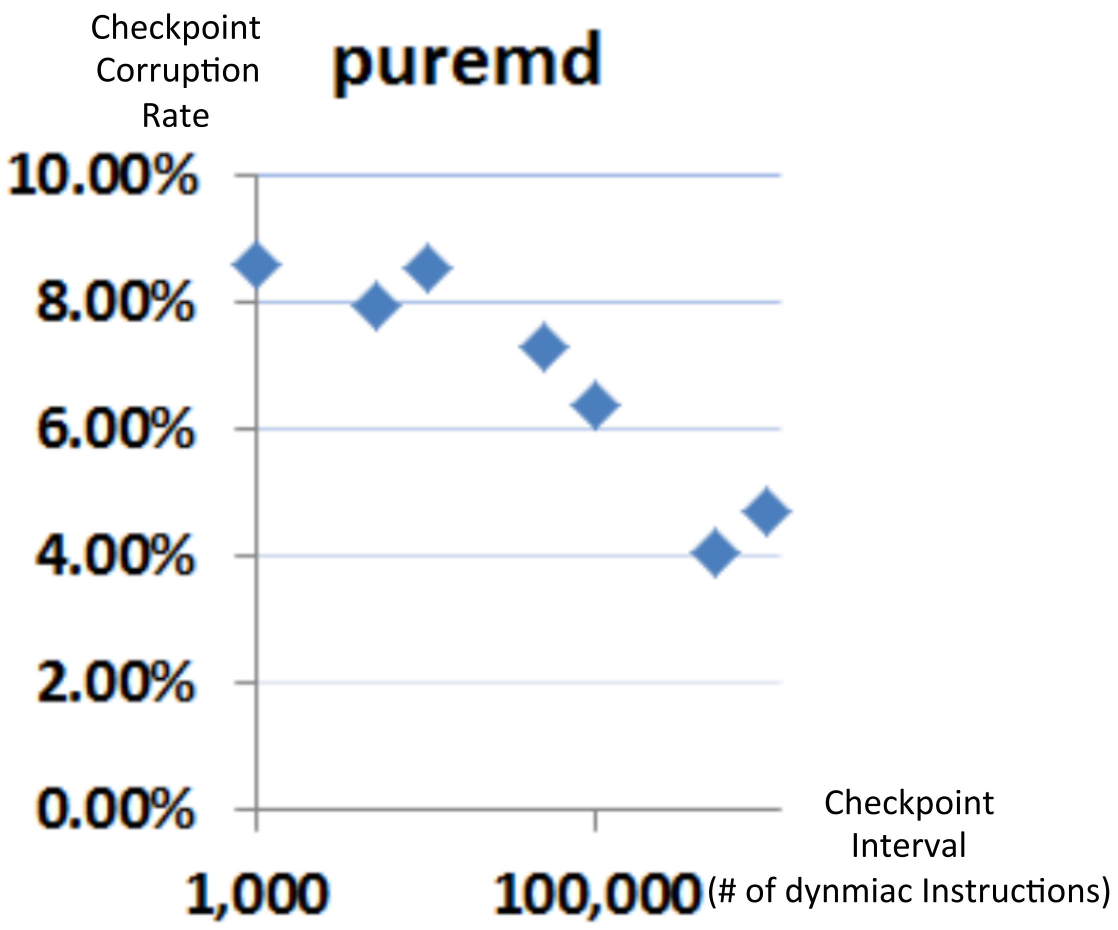
Checkpoint

- Periodic checkpoint system
- Saves all architectural states



Checkpoint Corruption





Traditional Method: DMR

Dual Modular Redundancy (DMR)

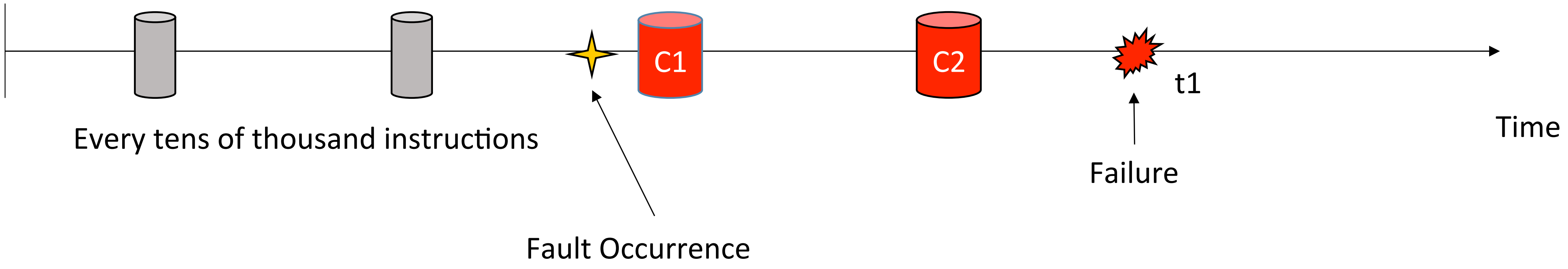
- Run 2 copies in program
- Compare for divergence

Too much energy consumption!

Traditional Method: Dual-checkpoint Scheme

Wang et.al. at TDSC [4]
Aupy et.al. at PRDC [5]

- Checkpoints still corrupted at high frequency
- Takes additional memory space



Our Goal

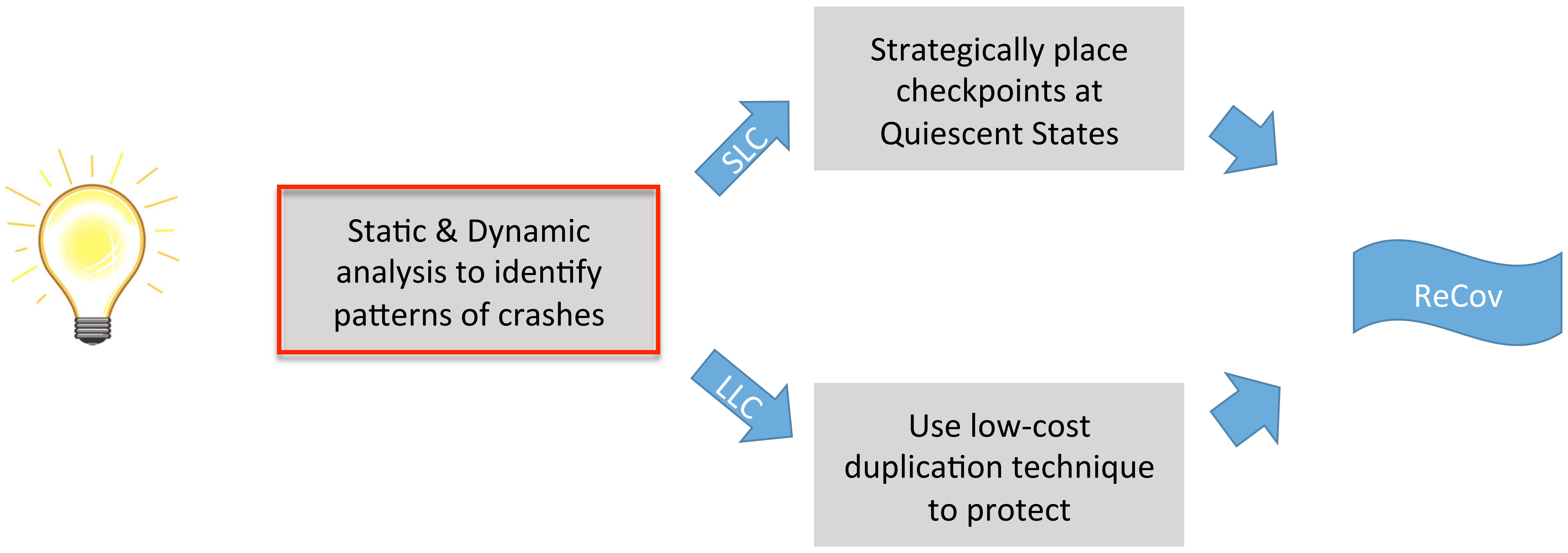
- Keep single checkpoint
- Minimize checkpoint corruptions

Challenges

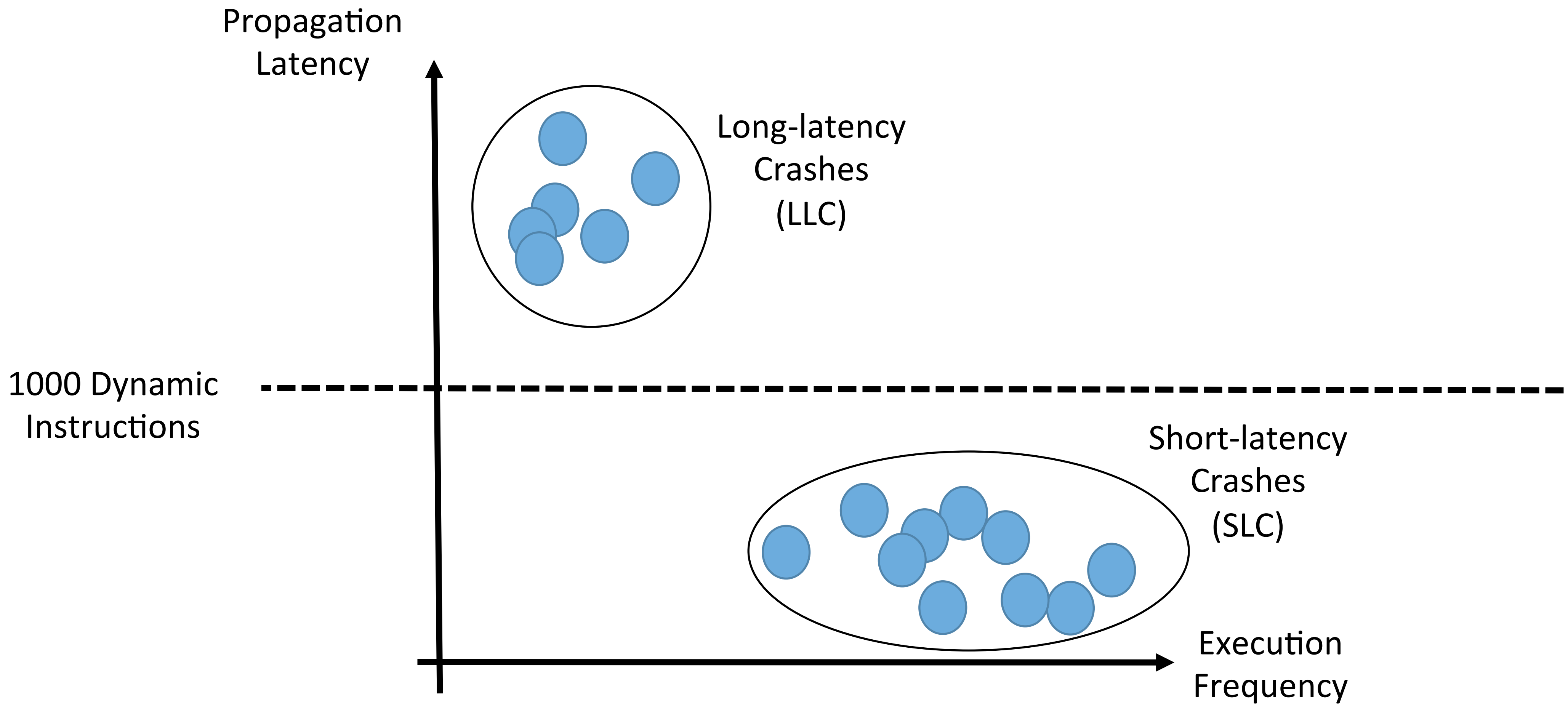
- Fault propagations are application-specific

- Difficult to reason about error propagation (Huge state space)

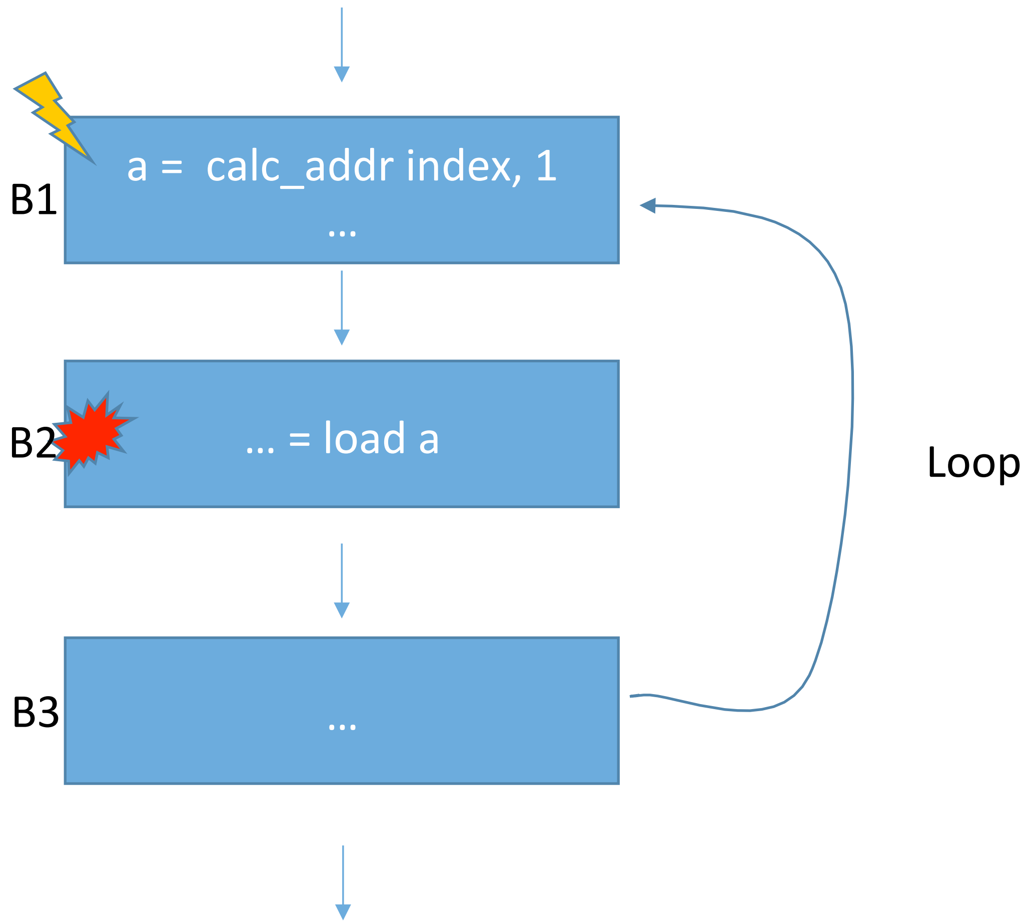
Our Approach



Crashes Leading to Checkpoint Corruptions



SLC Leading to Checkpoint Corruption

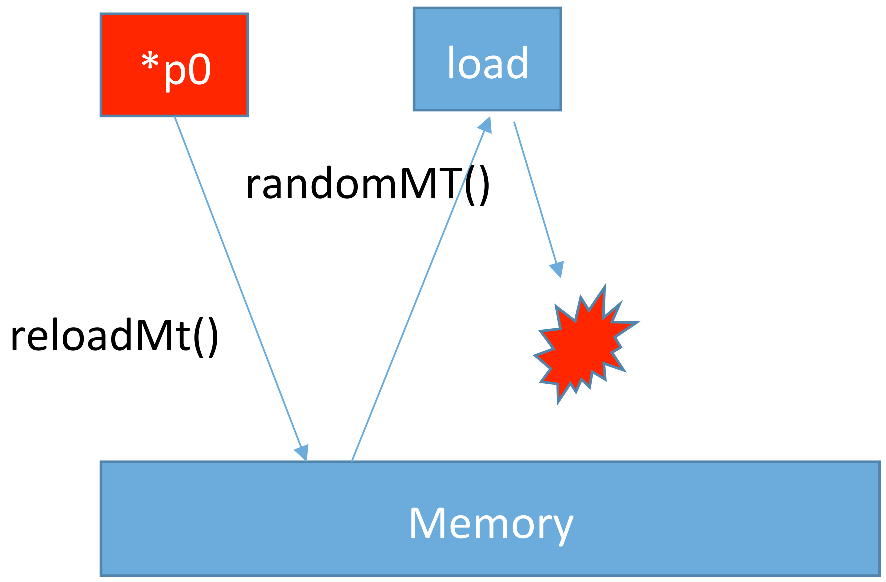


LLC Leading to Checkpoint Corruption

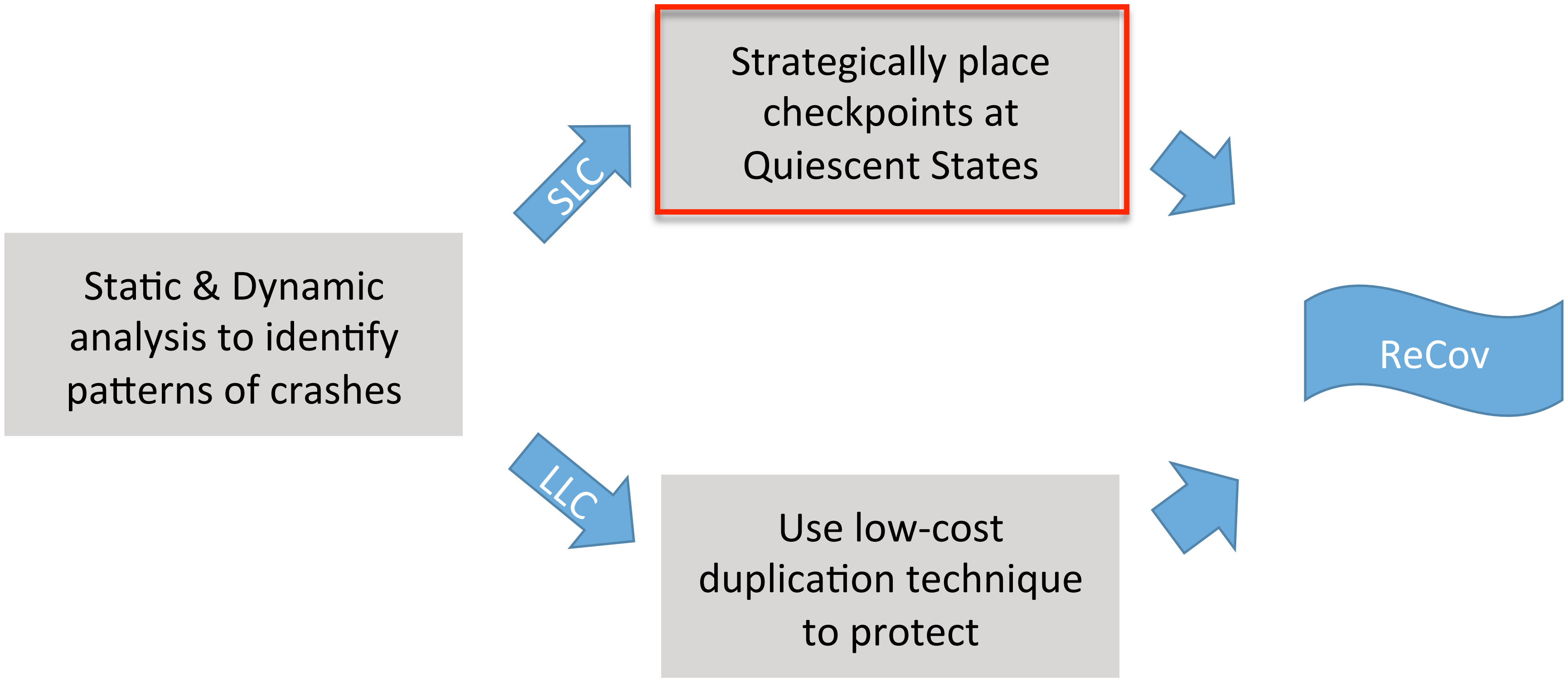
Our work at DSN[4]

```
static unsigned int state[N+1];
static unsigned int *next;
...
unsigned int reloadMT(void)
{
  ...
  register unsigned int *p0 = state;
  next = state+1;
  ...
  *p0++ = *pM++ ^ ... ;
  ...
}
...
unsigned int randomMT(void)
{
  unsigned int y;
  ...
  y  = *next++;
  ...
}
...
```

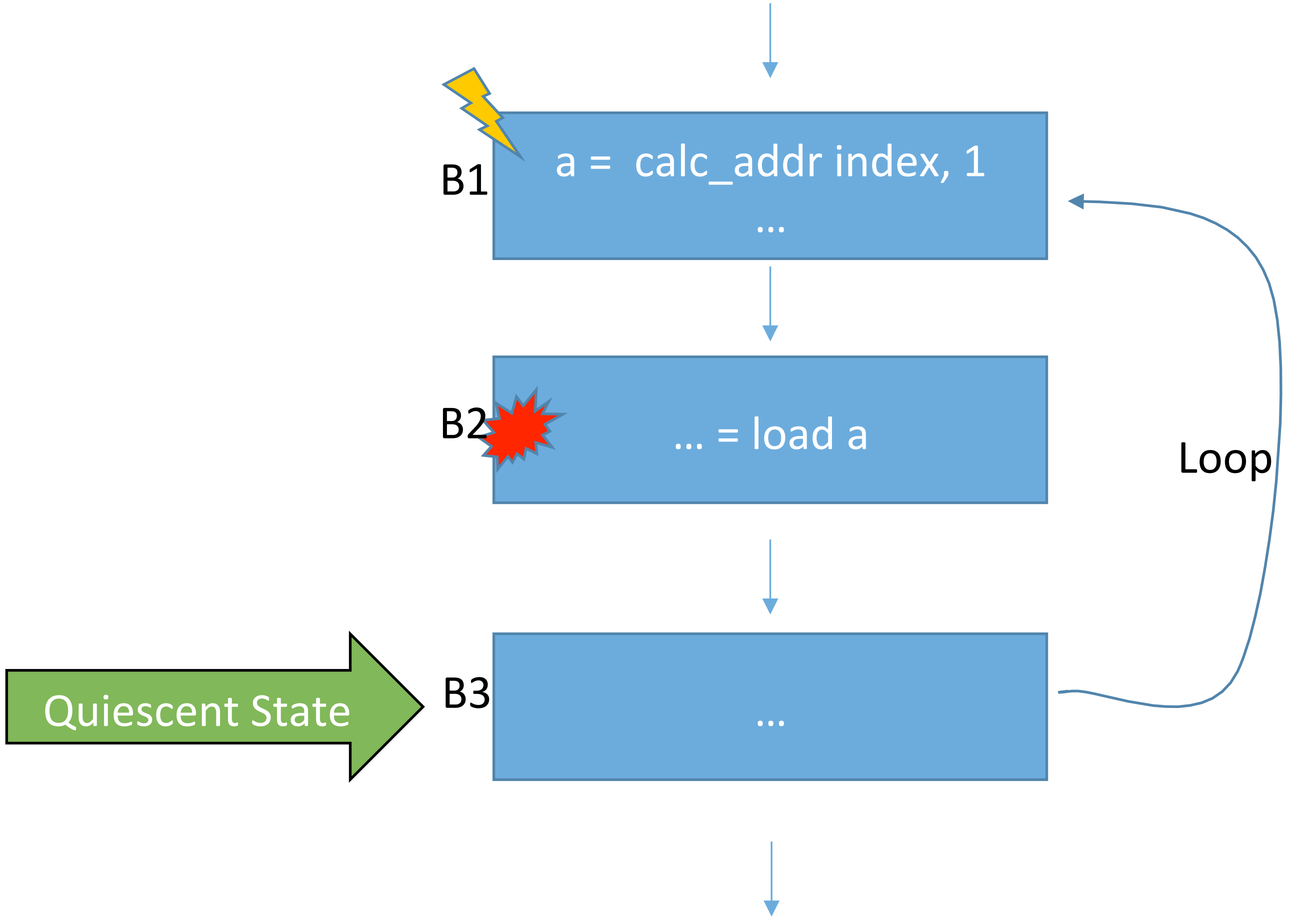
[From sjeng program]



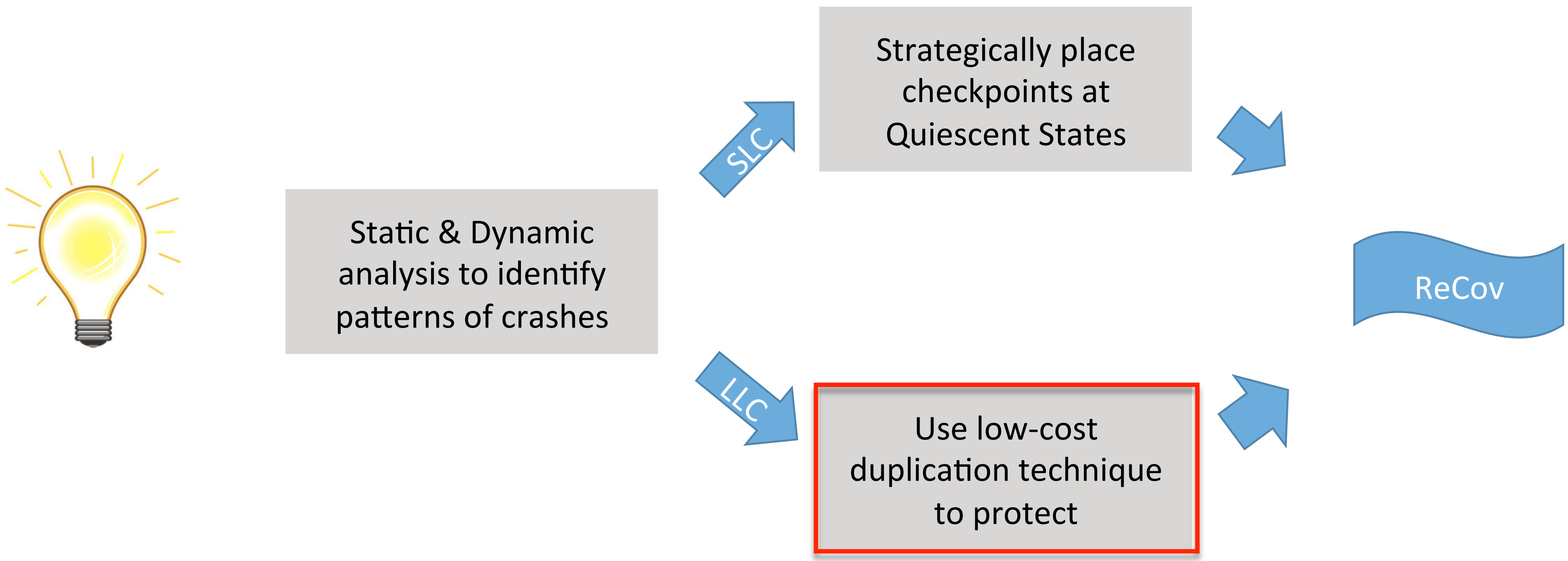
Our Approach



Quiescent States for SLCs

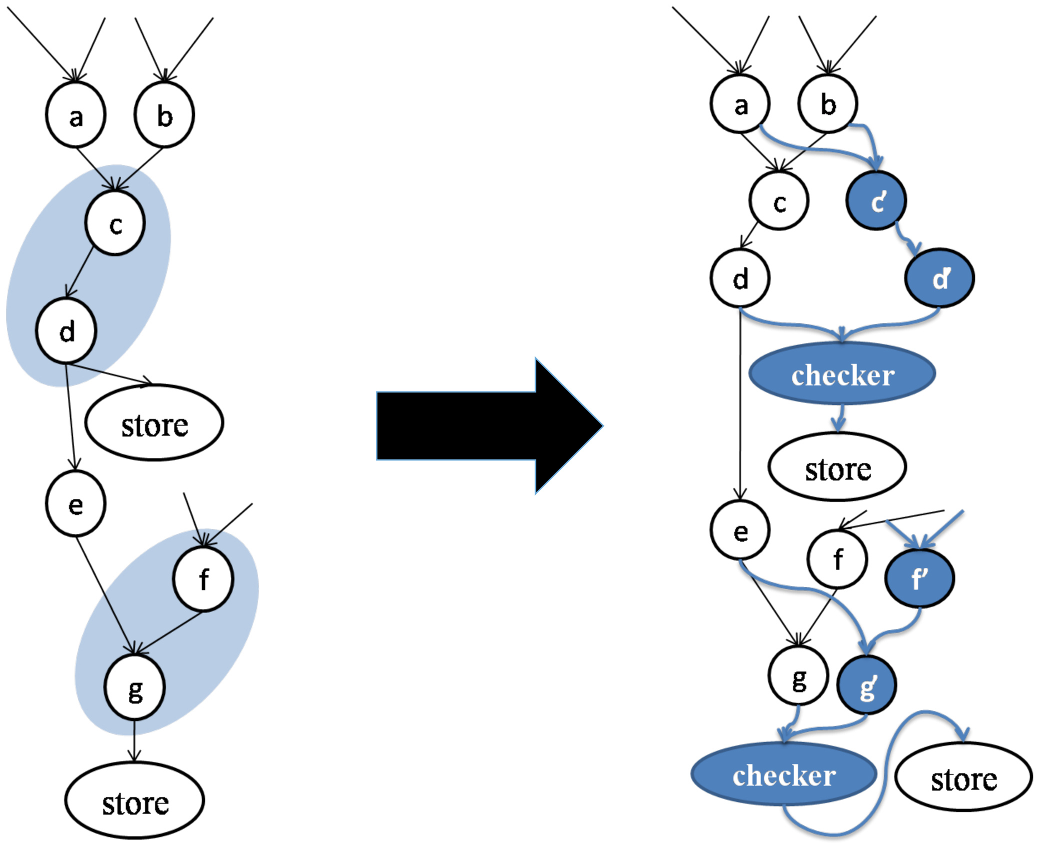


What We Do


Static & Dynamic analysis to identify patterns of crashes
SLC
Strategically place checkpoints at Quiescent States
LLC
Use low-cost duplication technique to protect
ReCov

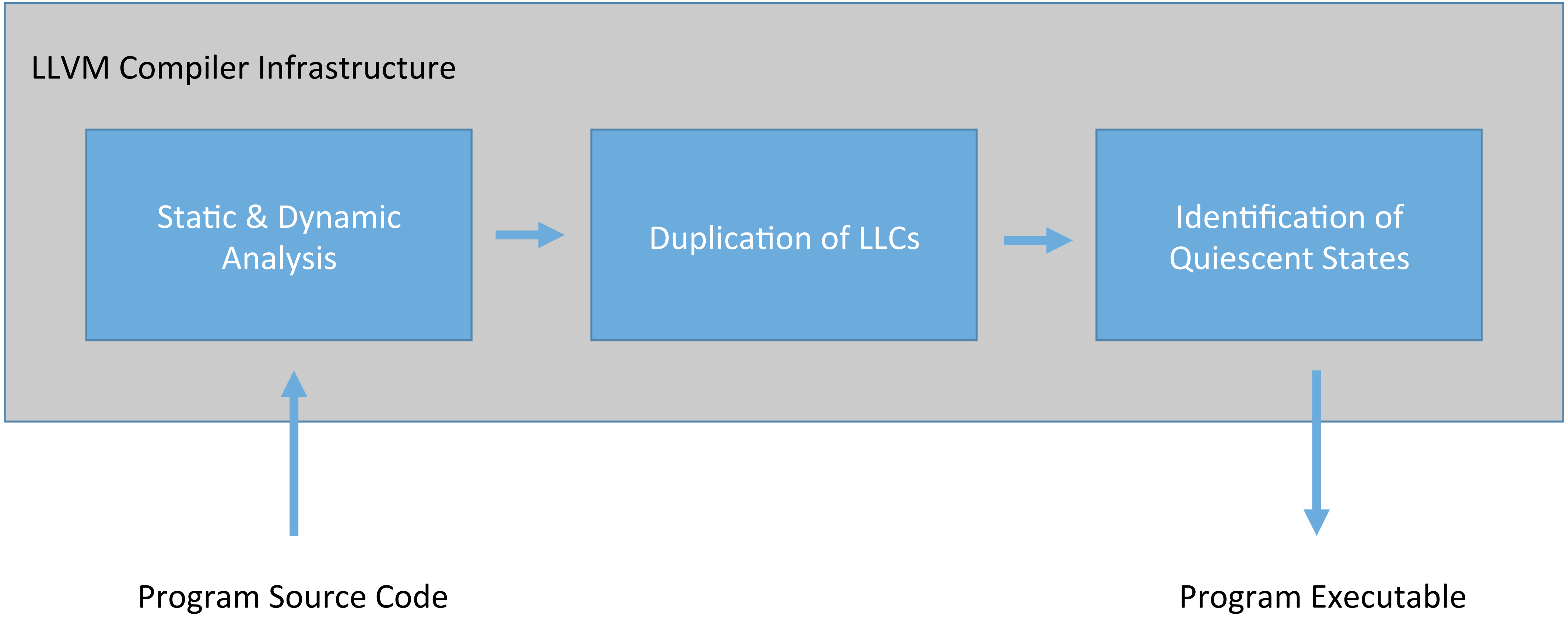
Protection of LLCs

Duplicate backward slices of chosen instructions and insert a checker at the end



ReCov

Download: https://github.com/DependableSystemsLab/ReCov



Research Questions

RQ1:
How much does ReCov reduce the checkpoint corruption?

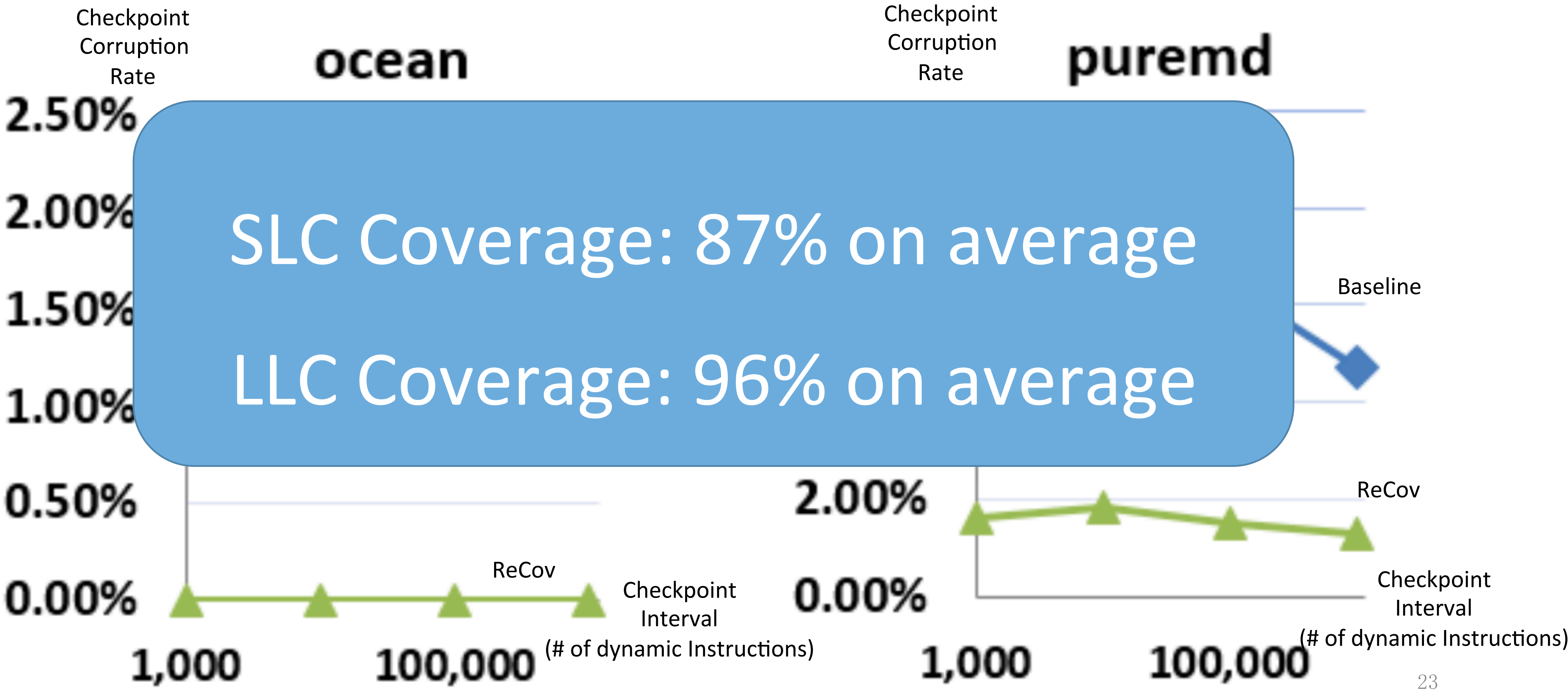
RQ2:
What are the performance overheads incurred by ReCov?

RQ3:
How much reduction in unavailability does ReCov provide?

Experiment

- Benchmarks
  - 8 applications from 4 suites: Parsec, Parboil, SPLESH-2 & SPEC
  - 2 open source applications: PureMD and Hercules
- 5 applications for our initial study, 10 in total for evaluation
- Periodic single checkpoint scheme as baseline
- 3000 Fault Injections per checkpoint interval(Error Bar: 0.06% - 0.6%)
- LLVM Fault Injector (LLFI) -> https://github.com/DependableSystemsLab/LLFI

ReCov: Minimize Checkpoint Corruption



SLC Coverage: 87% on average

LLC Coverage: 96% on average

RQs

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How much does ReCov reduce the checkpoint corruption?

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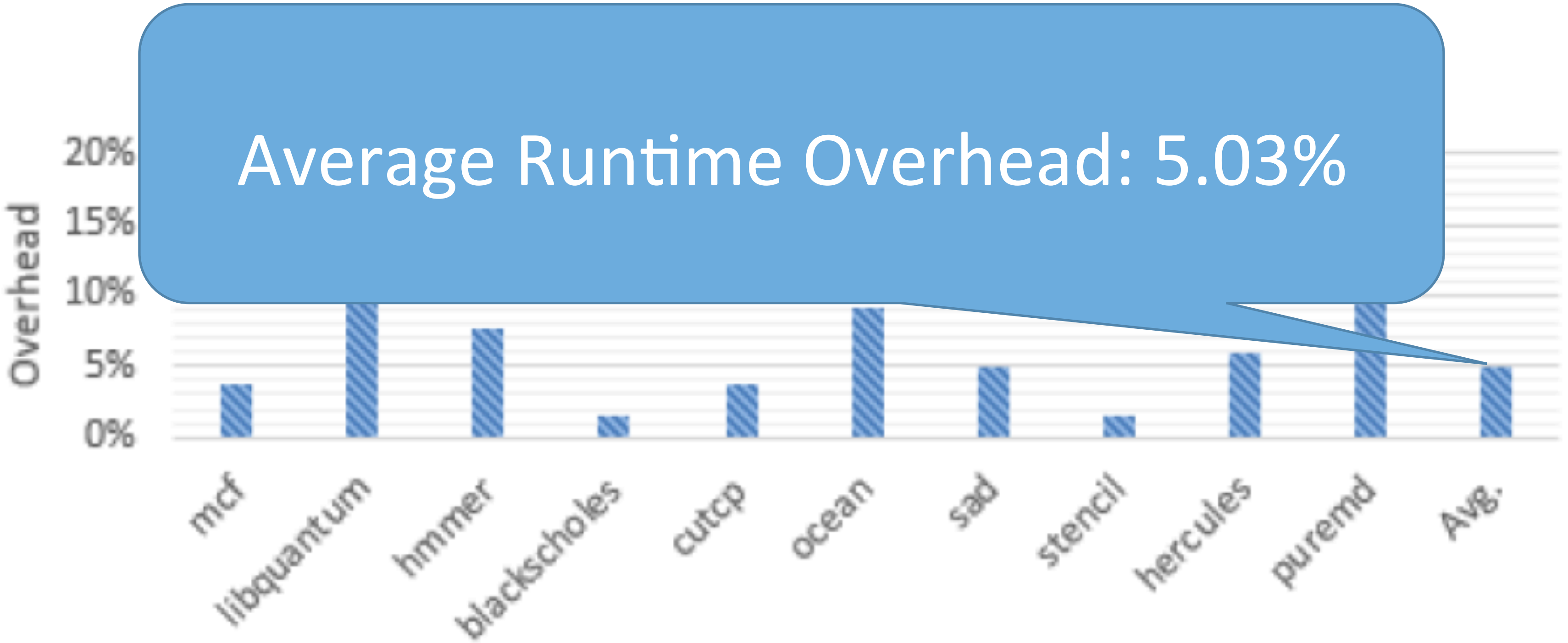
Protection of LLCs

Amount of dynamic instructions protected: 9.44% on average



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Unavailability

$$Availability = \frac{MTTF}{(MTTF+MTTR)}$$

Unavailability = 1 - Availability

- 8.25 times reduction compared to baseline
- 6.2 times reduction compared to dual-checkpoint

Summary

- Checkpoint corruptions are non-negligible at high-frequency checkpointing
- 2 patterns leading to checkpoint corruptions: SLC & LLC
- Quiescent states to place SLC to avoid checkpoint corruptions
- Protection of LLCs: ~5% overhead
- ReCov: Single checkpoint scheme that reduces ~8 times unavailability

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https://github.com/DependableSystemsLab/ReCov