A Tunable, Software-based DRAM Error Detection and Correction Library for HPC

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Motivation

- Silent Data Corruption (SDC) → undetected soft errors that result in corruption in storage (Processor, Cache, Disks, RAM, etc)
- SDC faults may manifest themselves as bit-flips in memory
  - Some bit-flips are not correctable or even detected even with hardware ECC protection
  - Exacerbating this situation, when SDC goes undetected, applications continue to run while reporting **invalid** results
    - This is a severe problem for today's large-scale simulations
- Server class hardware supports ECC; one common form provides single error correct, double error detect (SECDEC)
- Non-server class hardware provides no protection
- **Today there is no generic way to protect applications without ECC**
- **Even with ECC, hardware SECDEC protection fails you when 3 or more bit flips occur**
- SDC events are expected to grow dramatically as chip density, heat generation, and core counts increase in larger HPC systems

LIBSDC: A software-based solution

- **Idea:** Provide SDC protection in software by tracking accesses to memory regions and ensuring their integrity before an application uses that region's data
- For each region of memory choose one or both:
  - *Hashes*: Detect memory corruption via hash mismatches
  - *ECC/Hamming Codes*: Correct some SDCs, even if hardware ECC failed to detect them
- Application-independent and transparent
  No code changes required for applications
- Using the MMU provides a granularity of a single page for a region

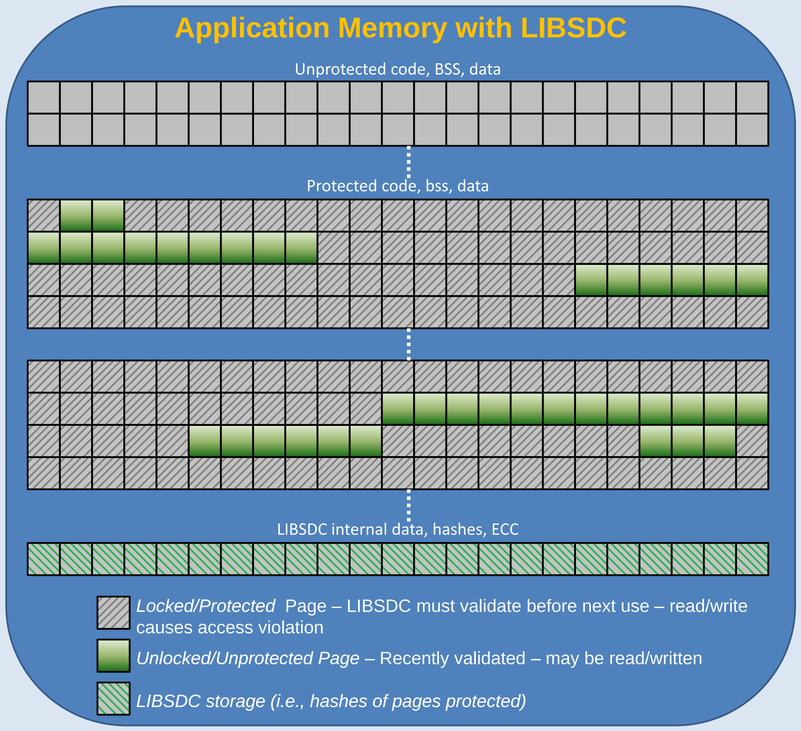
Method	SHA1 Hashing (4KB pages)	72/64 Hamming Codes (ECC)
Storage Overhead	0.49%	12.5%

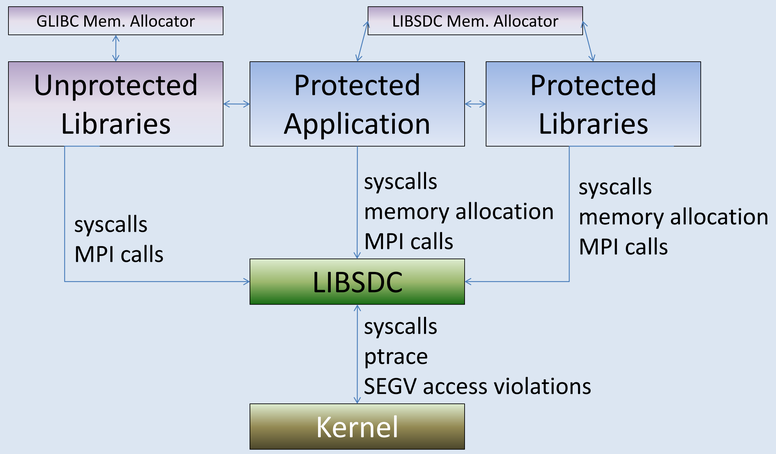
Tuning

- ***Max-unlocked:*** Adjust the maximum number of pages to be allowed "unlocked" at a time. Ideally set at the number of pages in an application's working-set during runtime
- ***Hash or ECC:*** Choose if you desire SDC detection and/or correction
- **Memory to protect:** Choose or combine:
  - Application's heap, bss, data, and/or code
  - Other linked libraries (optionally include or exclude)

Implementation

- Page tracking is accomplished with **mprotect** (removing read/write)
  - Each new page access triggers an access violation which allows LIBSDC to monitor application activity (SEGV handler)
  - Swap out unlocked pages upon reach max-unlocked
- Permission changes break many libraries
  - Syscalls will fail if passed protected pointers
    - *ptrace* is used to intercept all syscalls and unprotect pointers within syscall parameters
  - MPI implementations will fail with protected pointers, too
    - LIBSDC's MPI profiling layer wrappers unprotect passed buffers
  - Separate memory allocators prevent unprotected libraries from sharing virtual addresses in the same page as protected data





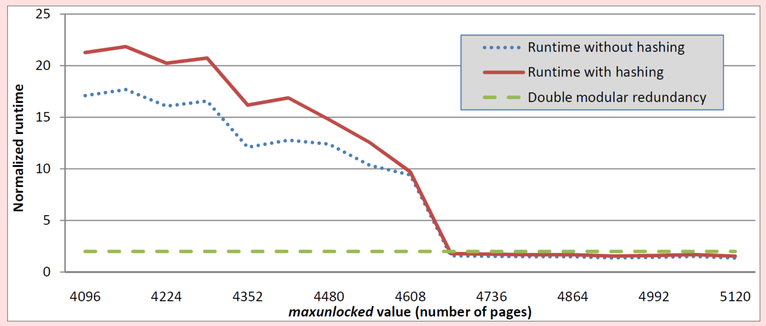
Memory Verification

```
On page request (inital read or write):
  If page is locked:
    Perform hash of page
    Compare current hash with previously stored known-good hash
    If any inconsistency found:
      Notify the presence of SDC and report location
      Terminate application / Rollback to previous checkpoint
    Mark page as unlocked (mprotect)

On page lock:
  Calculate new hash of entire page
  Storage hash in separate location
  Mark page as locked (mprotect)
```

HPCCG Results

- HPCCG – A Sandia Natl. Labs kernel conjugate gradient solver from the Mantevo Miniapps
- 256 processes on a 768x8x8 matrix
  - AMD Opteron 6128 (Magny Core) – 16 cores per node
  - 32GB RAM per node
  - 40Gbit/s Infiniband



- Ideal max-unlocked around 4096-5120 to match working-set size
- **On average, about 15% of overhead spent on page hashing**
- **53% overhead vs baseline when tuned with optimal max-unlocked**

Future Work

- Recent related work has shown (Ferreira, SC11) page hashing on GPUs can greatly reduce the overhead spent hashing on the CPU
- Replace LIBSDC's FIFO policy of unlocked pages with a smarter frequency-based algorithm
- Investigate using kernel page tables/invalid bit to reduce the overhead incurred from frequent use of mprotect (TLB flushes may be responsible for much overhead)

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