SC20

Everywhere we are | more than hpc.

GPU-Trident: Efficient Modeling of Error Propagation in GPU Programs

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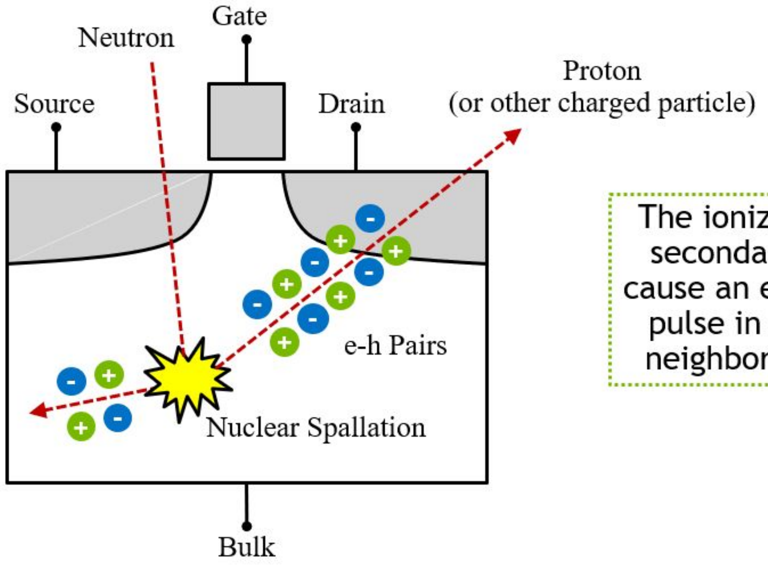
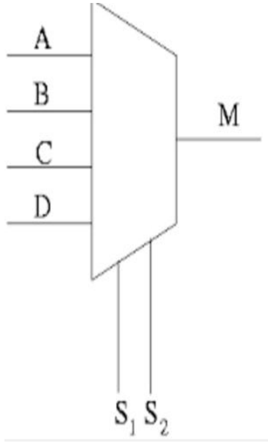
Soft Errors



The ionizing track left by secondary particles can cause an erroneous current pulse in one or multiple neighboring transistors.



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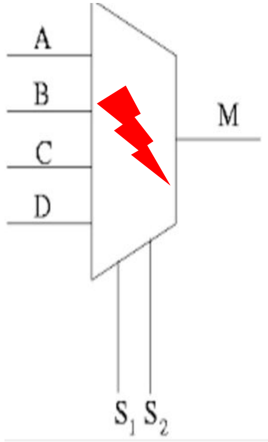

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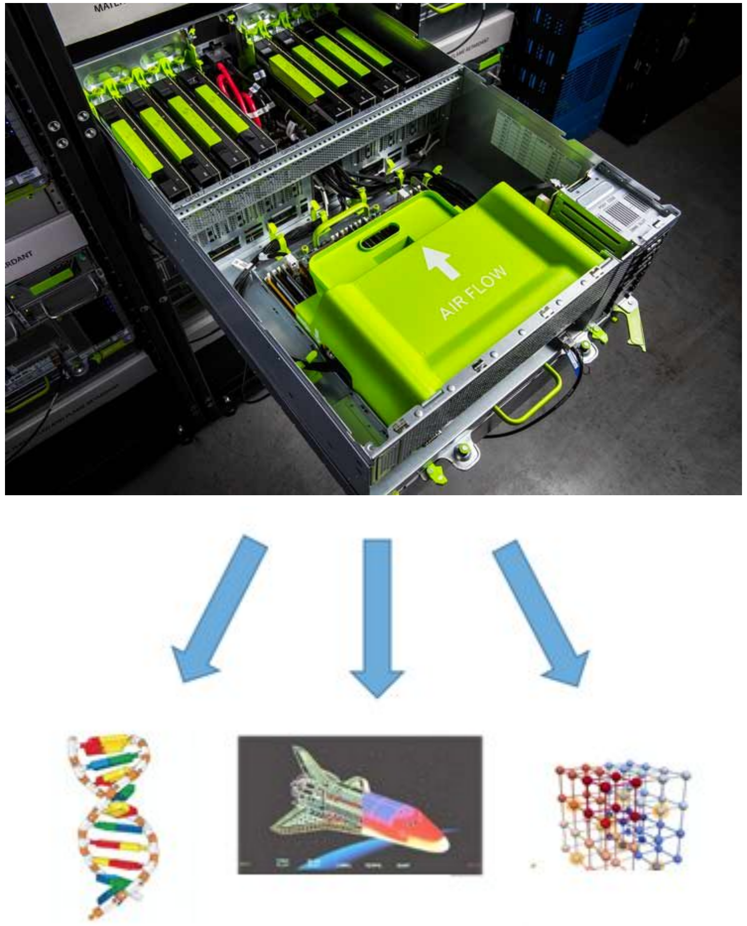
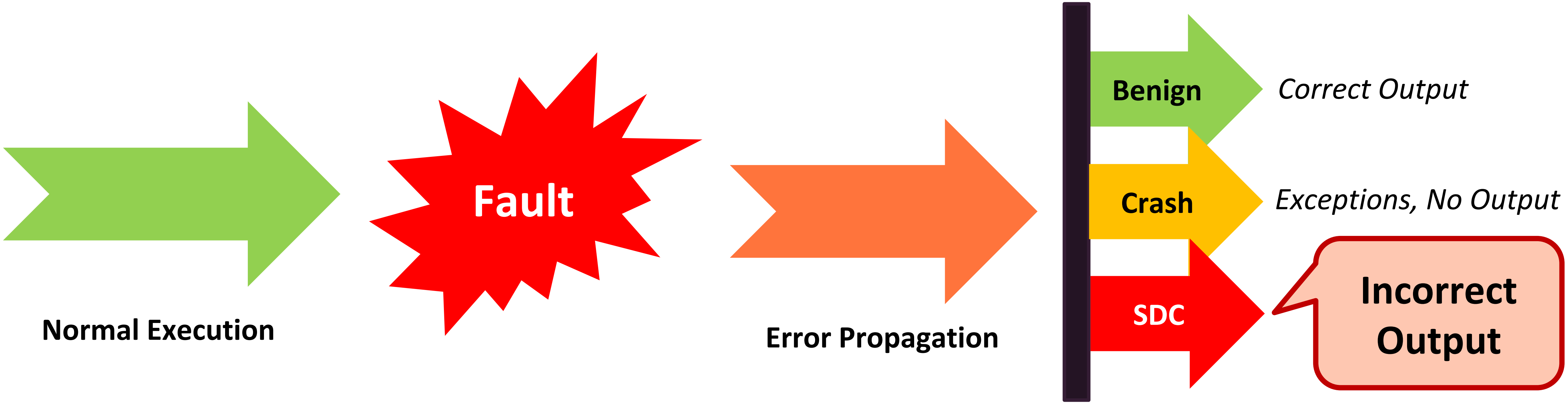


Silent Data Corruption (SDC)

e.g. Amazon S3 Incident



Traditional Solutions

- Error Correction Code (ECC)
- Hardware means
  - **Circui**

    Waste … i.e.,

    betwe

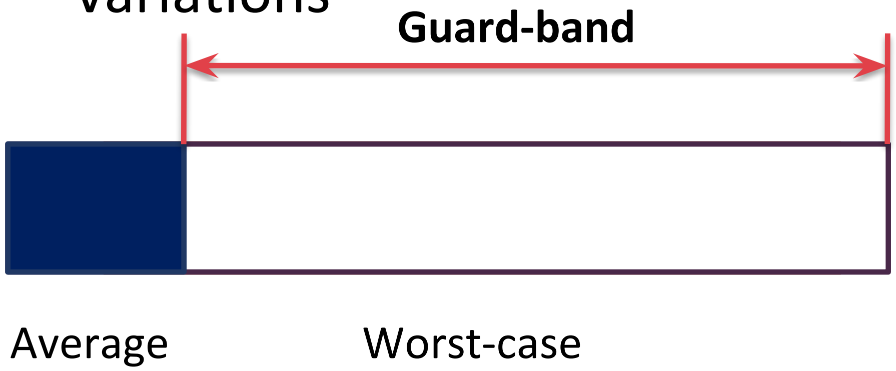
    worst-case widens due to

    variations

    …gy

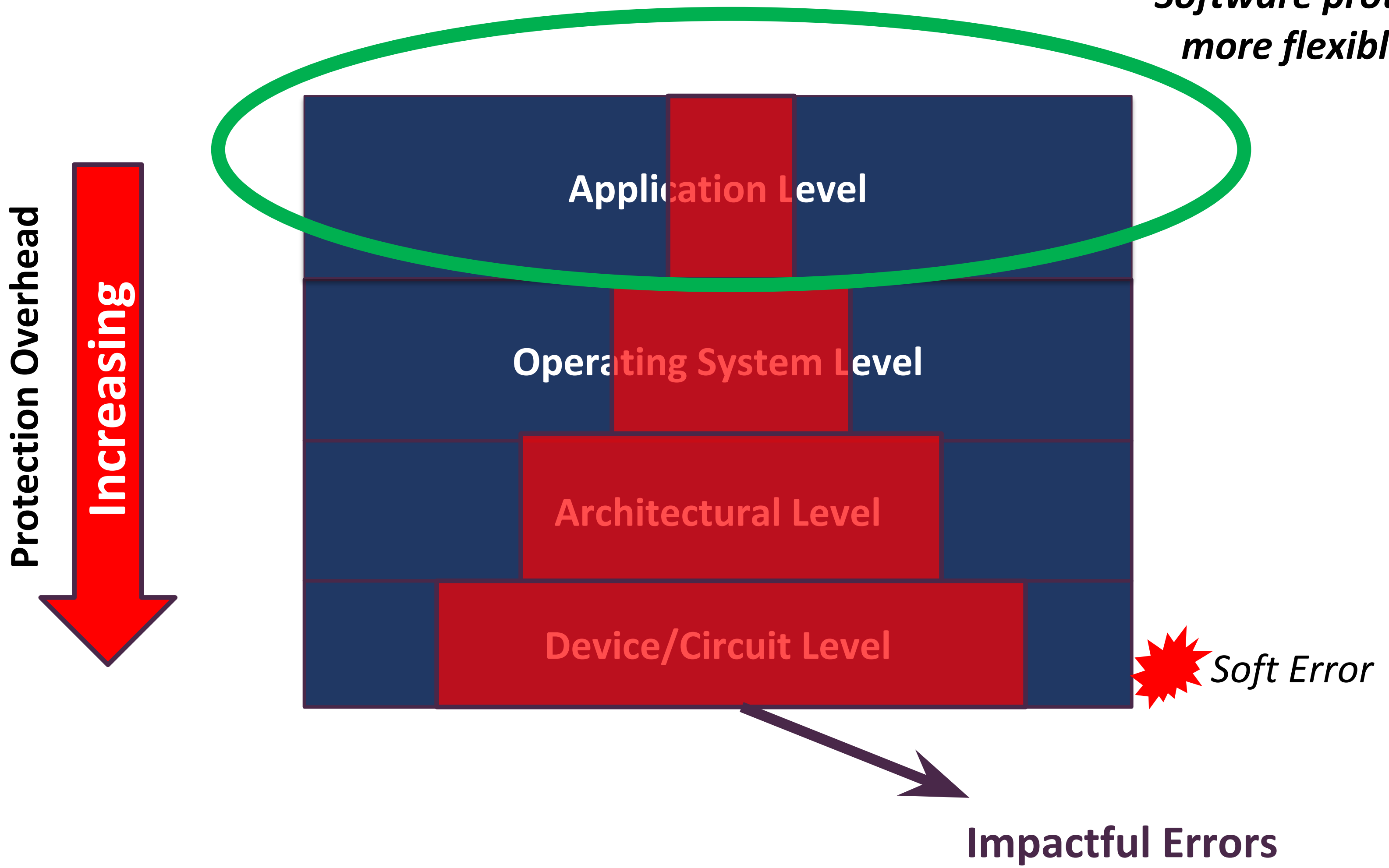
    consumption

Very expensive to deploy in practice!

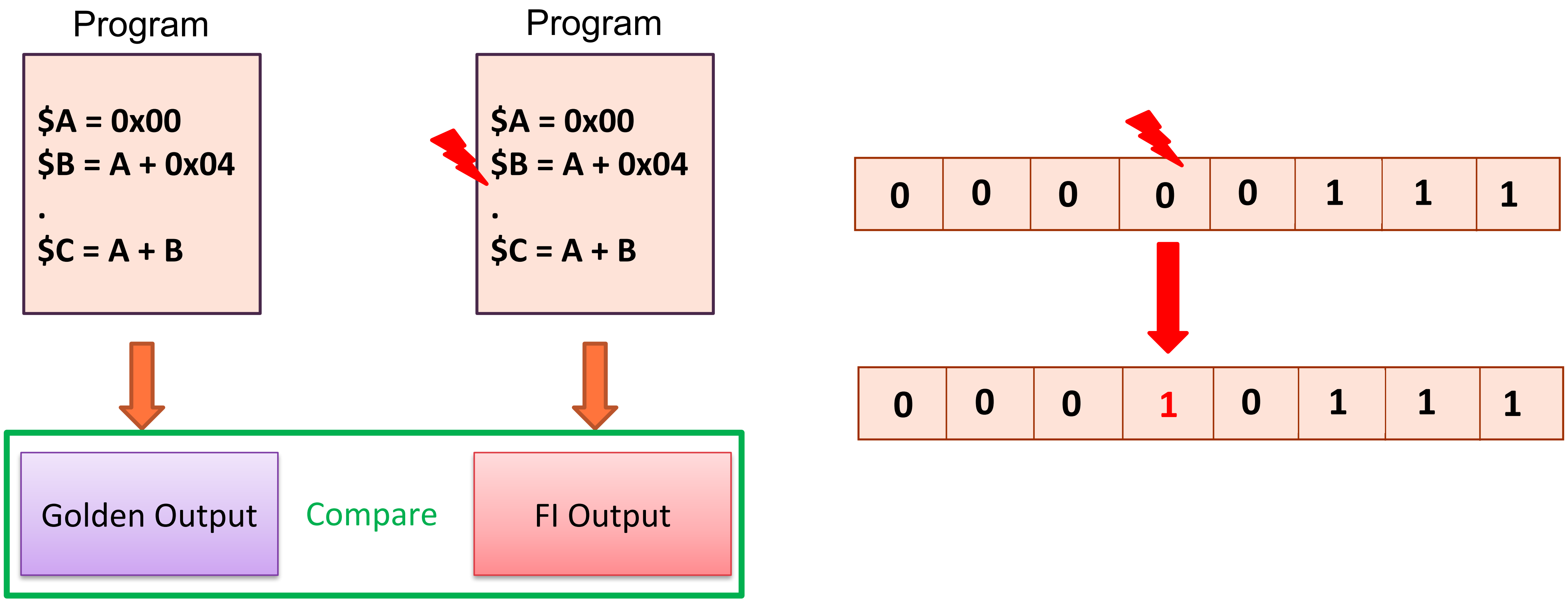


Software Solutions

Software protection techniques are more flexible and cost-effective!



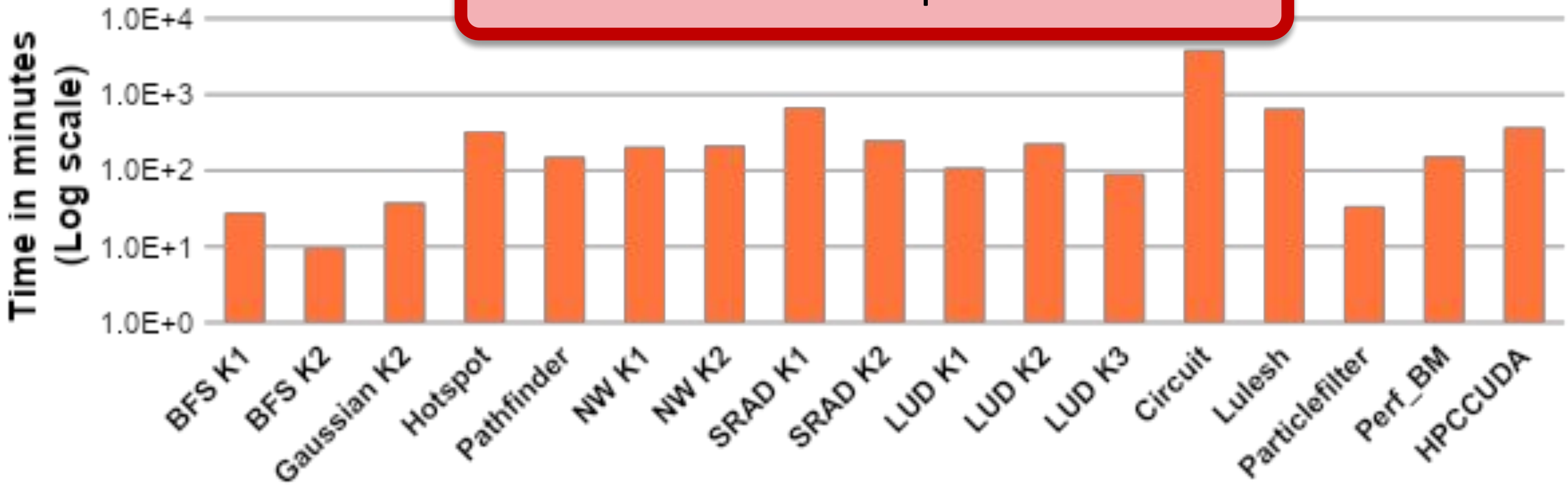
Fault Injection



FI injection – Overhead

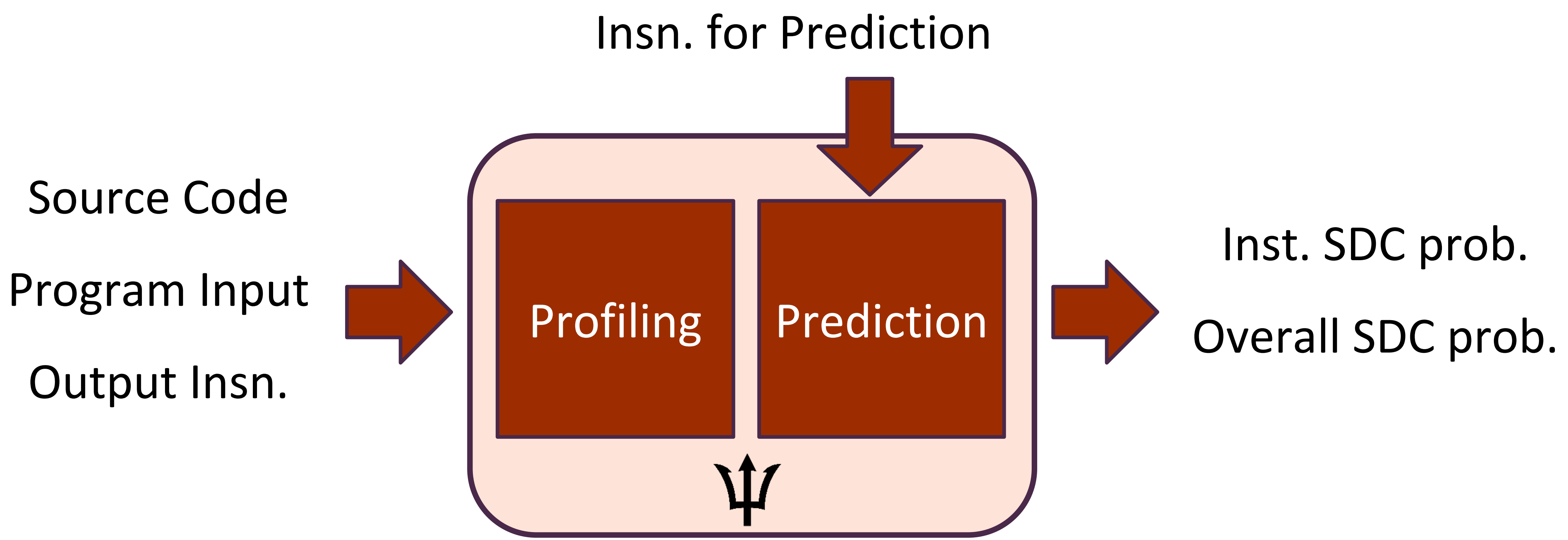
- GPU-Qin [ISPASS’14, Fang], LLFI-GPU [SC’16,Li], SASSIFI [ISPASS’17, Hari]
- Highly inefficient, as it has to be repeated if application is updated

~7 hrs. for 100 faults per instruction



*Timings obtained from our experiments using LLFI-GPU, other works report similar timings

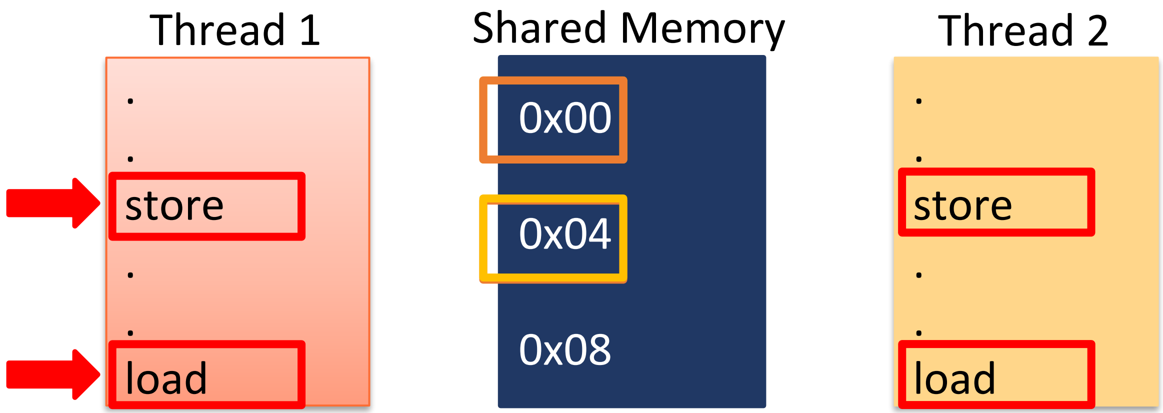
Trident – for CPU (DSN'18, Li)



GPU - Challenges

- Execution of GPU applications is inherently multi threaded
- Threads frequently communicate with each other

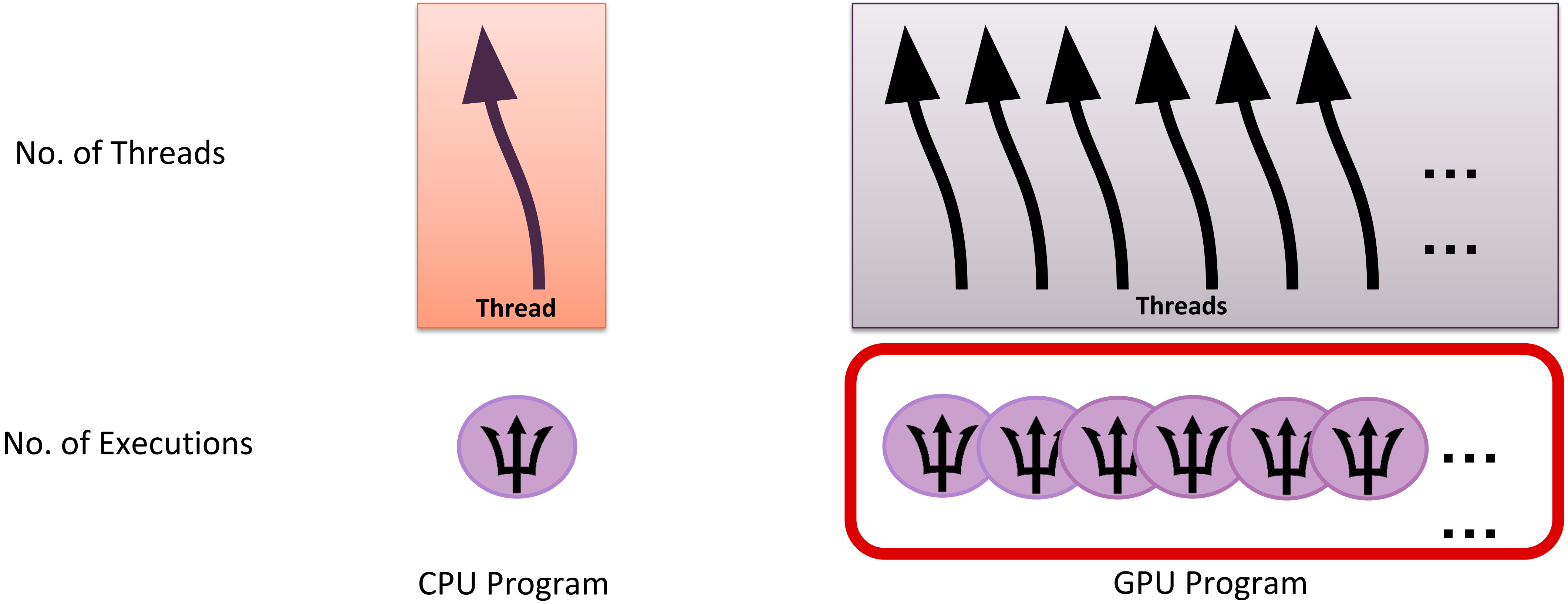
Interleaving dependencies complicate error propagation



[SC’16, Li]

GPU - Challenges

- *Average of ~5 years, Max 17 years*
- > 5GB, data to be profiled in Circuit
- *Inaccuracies in model accumulate*



Challenges - Summary

1. Tracking error across threads

2. Huge amount of states to profile

3. Accumulation of inaccuracies

Challenges - Summary

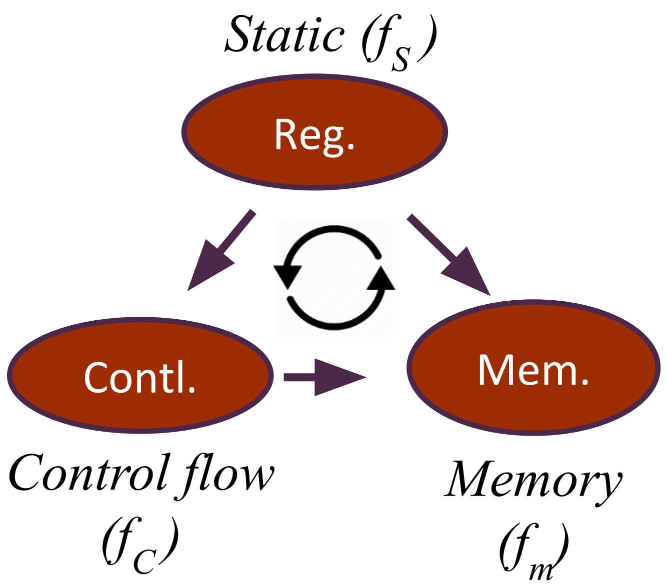
1. Tracking error across threads

2. Huge amount of states to profile

f_m

3. Accumulation of inaccuracies

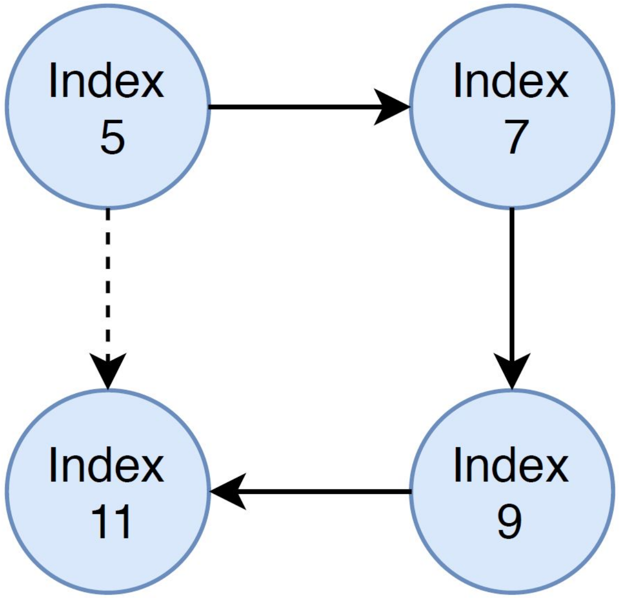
f_c, f_s



Updating f_m

- f_m constructs a memory dependency graph between instructions.
- We construct graph of whole kernel, instead of individual threads.

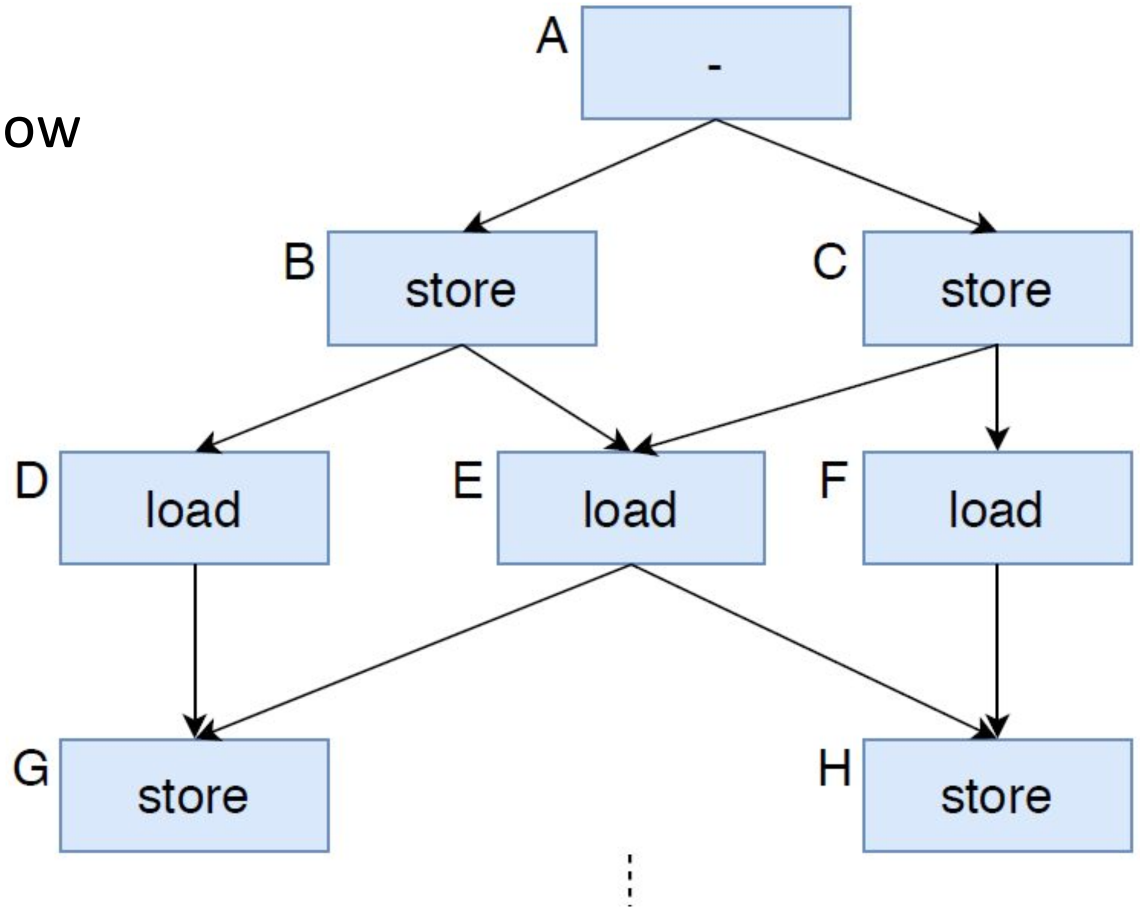
```
__global__ void staticReverse(int *d, int n)
{
  __shared__ int s[64];
  int t = threadIdx.x;
  int tr = n-t-1;
  s[t] = d[t];
  __syncthreads();
  d[t] = s[tr];
}
```



Constructing the dependency graph

- Memory dependency, based on control-flow
- Limited possible control-flows

Solution: *Sample threads with unique control-flows for profiling e.g. 3,840 out of 592,640 threads profiled for Pathfinder*



Challenges

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f_m

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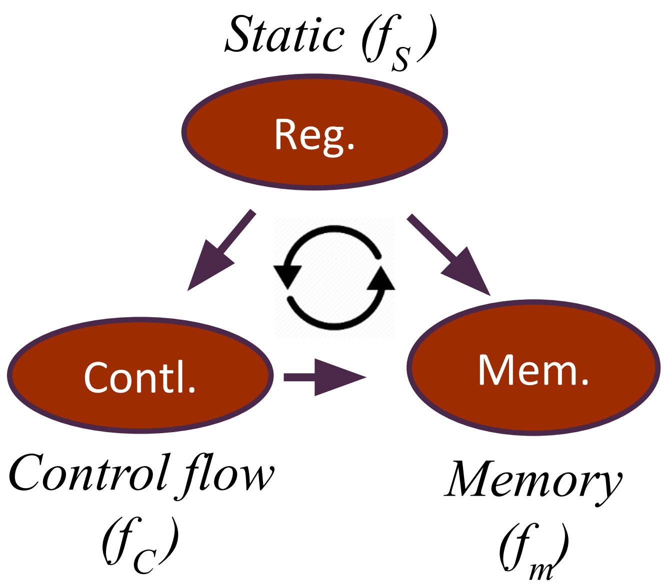
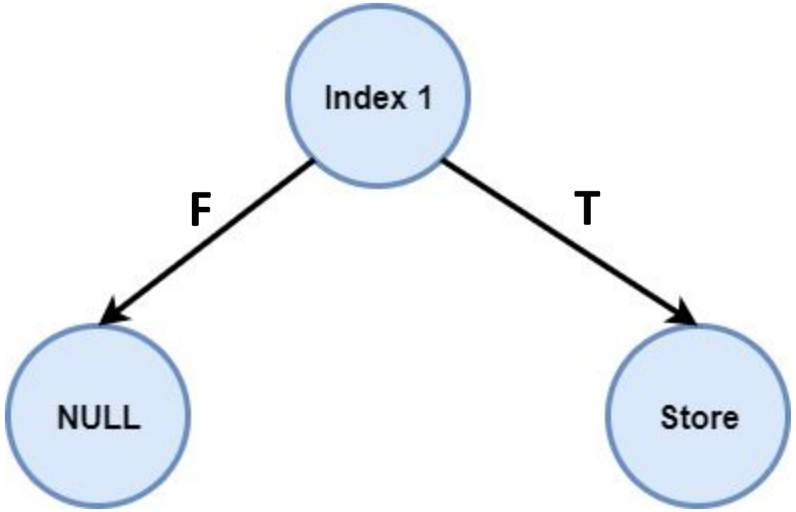
f_c, f_s



Lucky Stores

- If a memory contains the same data we want to store in it
- Missing that store won't result in any SDC



Solution: *Update f_c to modify propagation probability of comparisons dominating output stores.*

Challenges

1. Tracking error across threads

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f_m

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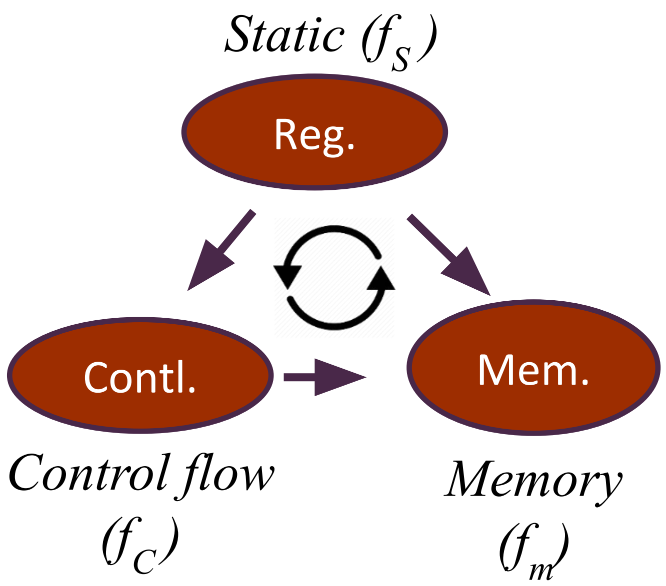
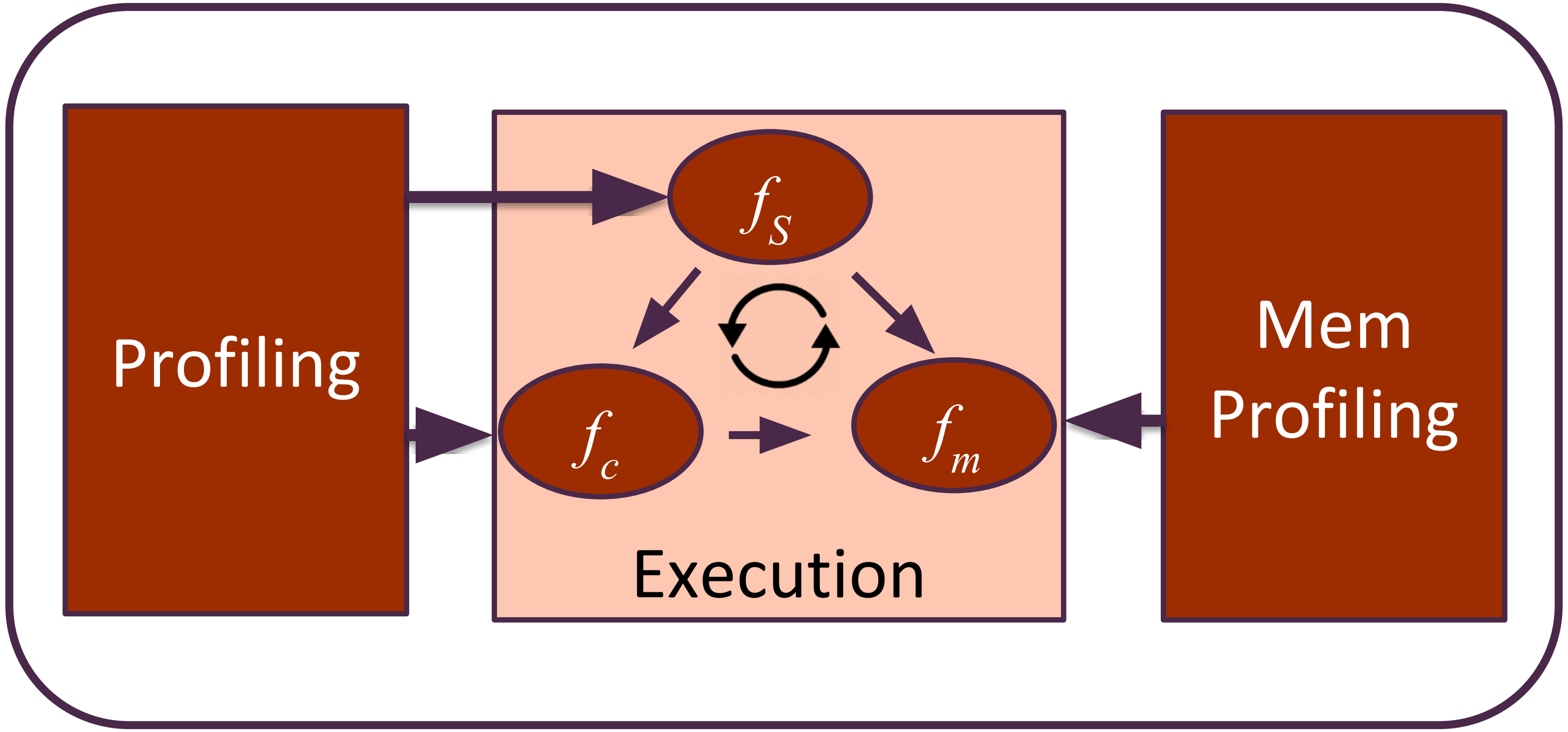
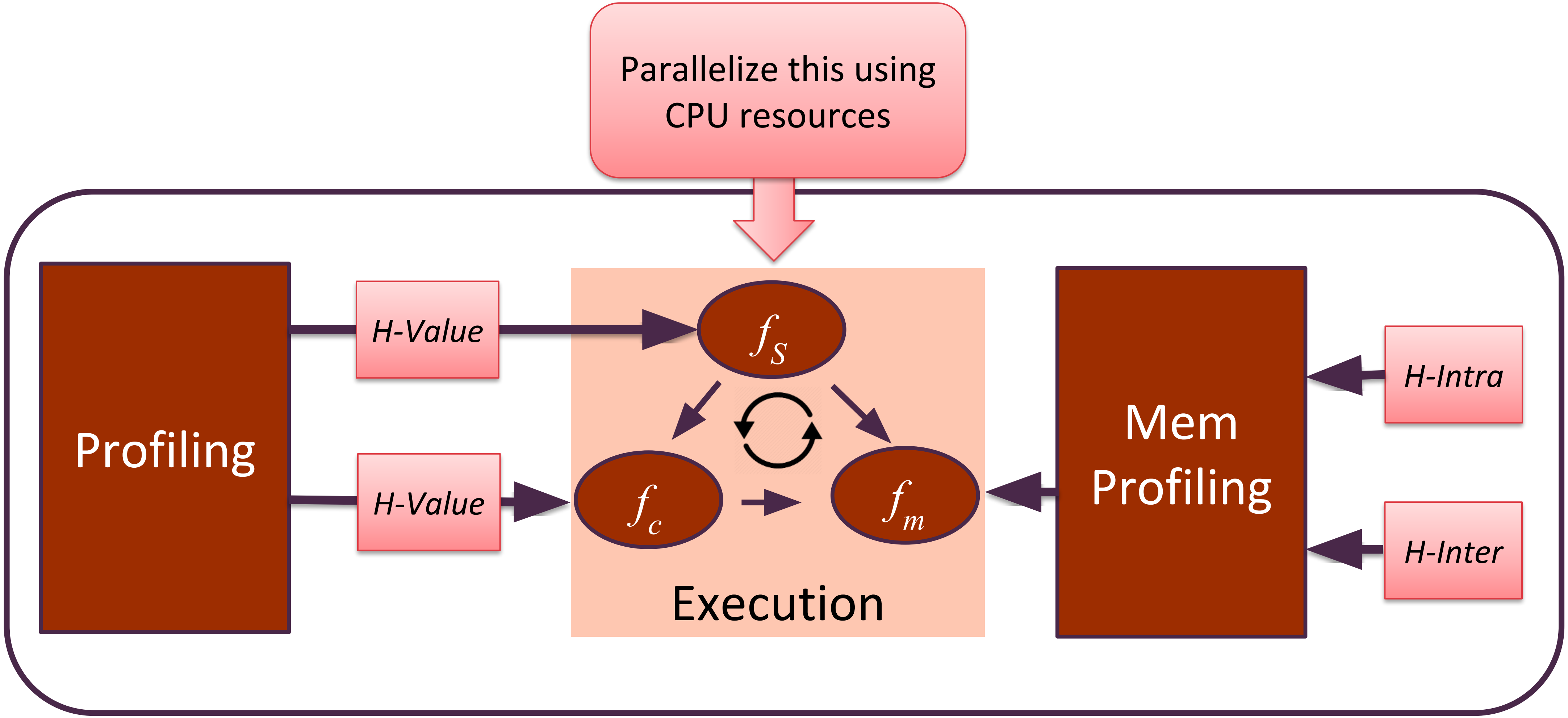
f_c, f_s



Trident - Workflow



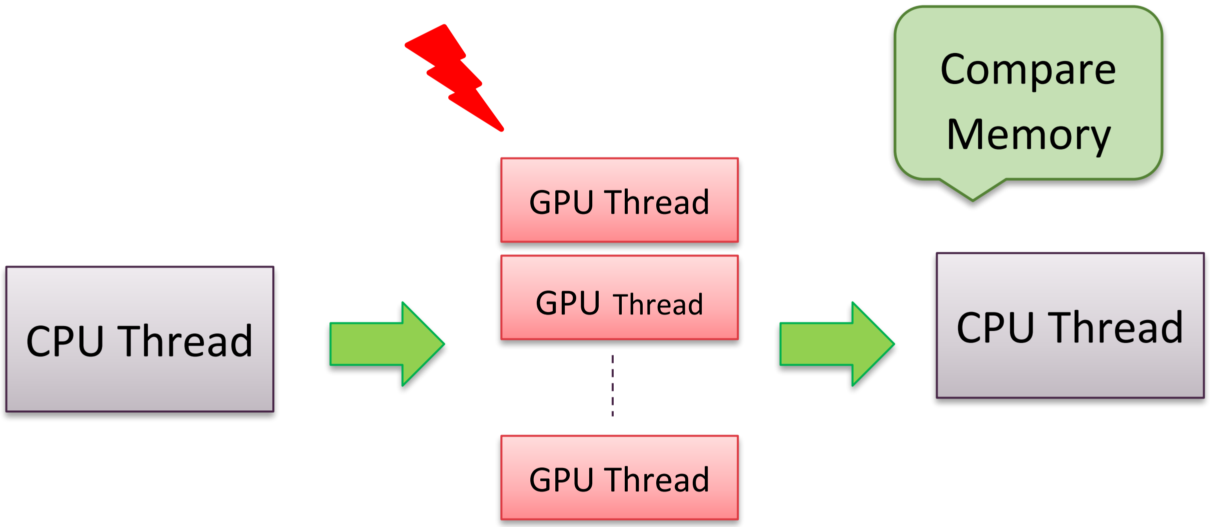
GPU-Trident - Workflow



Experiments - Overview

- GPU-Trident: A set of LLVM passes, driven by python scripts
  URL: https://github.com/DependableSystemsLab/GPU-Trident
- Use LLFI-GPU for FI and use it as a baseline
- Predict SDC probability with GPU-Trident, compare with FI
- Evaluate GPU-Trident for 17 kernels (Rodinia and OSS HPC) at
  - Kernel level
  - Instruction level

FI in GPU applications



$A = 0x00
$B = A + 0x04
.
$C = A + B

Evaluating Kernel SDC probability

T1	*T2*		*Tn*
\$A = 0x00 \$B = A + 0x04 . \$C = A + B	\$A = 0x00 \$B = A + 0x04 . \$C = A + B	. . .	\$A = 0x00 \$B = A + 0x04 . \$C = A + B

0	0	0	1	0	1	1	1

5,000 random FI trials per kernel

Evaluating Instruction SDC probability

T1

$A = 0x00
$B = A + 0x04
.
$C = A + B

T2

$A = 0x00
$B = A + 0x04
.
$C = A + B

...

Tn

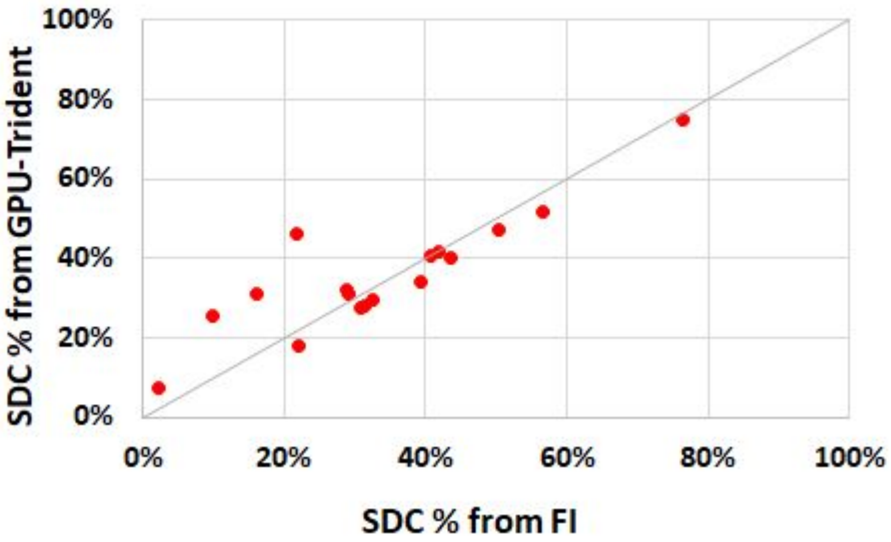
$A = 0x00
$B = A + 0x04
.
$C = A + B

0	0	0	1	0	1	1	1

100 random FI trials per instruction

Accuracy - Summary

- Mean absolute error for kernel SDC is **5.7%** (Trident has error of **4.75%**)



- Pearson correlation coefficient for kernel SDC is **0.88** (Without outliers **0.99**)

- Average Pearson correlation coefficient for instructions is **0.83**

Scalability - Summary

- Kernel SDC probability

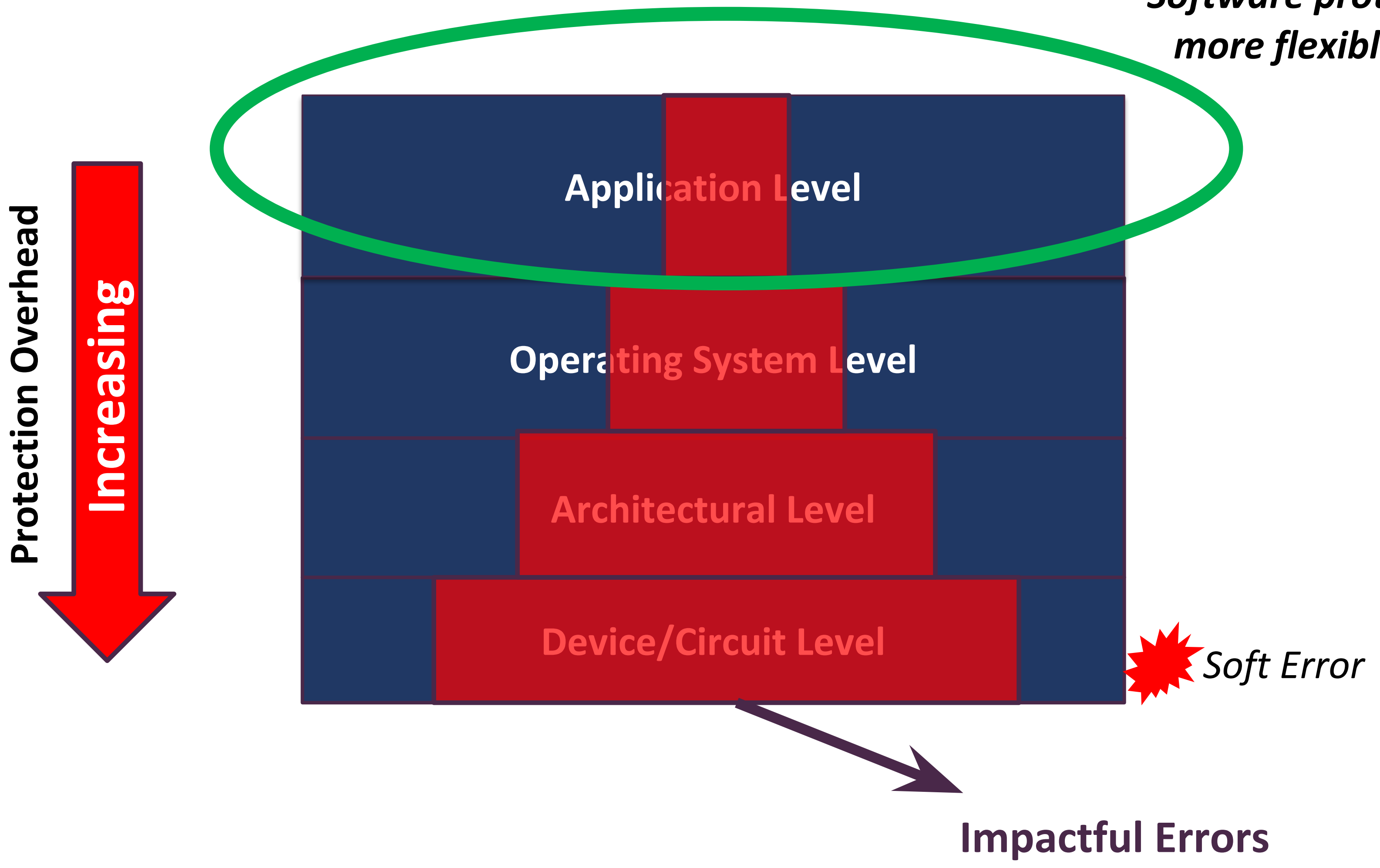
FI trials	Speed up
1000	11x
3000	33x
5000	55x

- Instruction SDC probability
  - GPU-Trident is **2 orders of magnitude (~100x)** faster than FI
  - FI takes **7 hrs**, while GPU-Trident takes less than **5 minutes**

GPU-Trident needs to construct model once, while each FI trials requires an application run

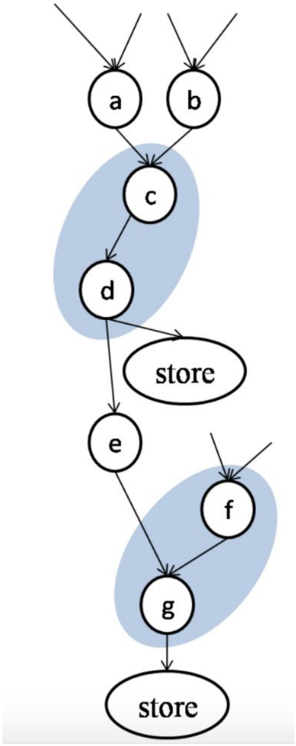
Software Solutions

Software protection techniques are more flexible and cost-effective!

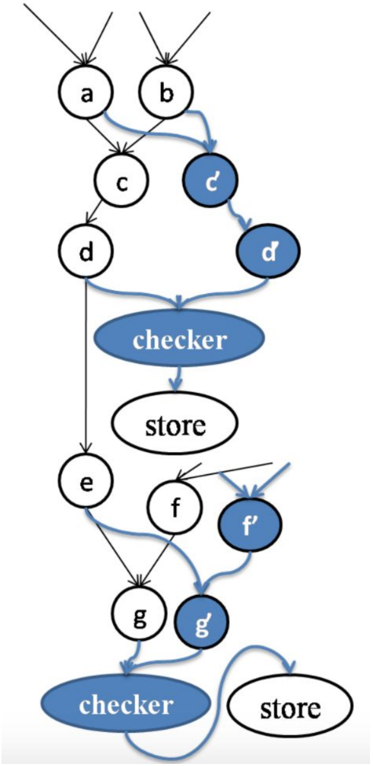


Selective Instruction Duplication

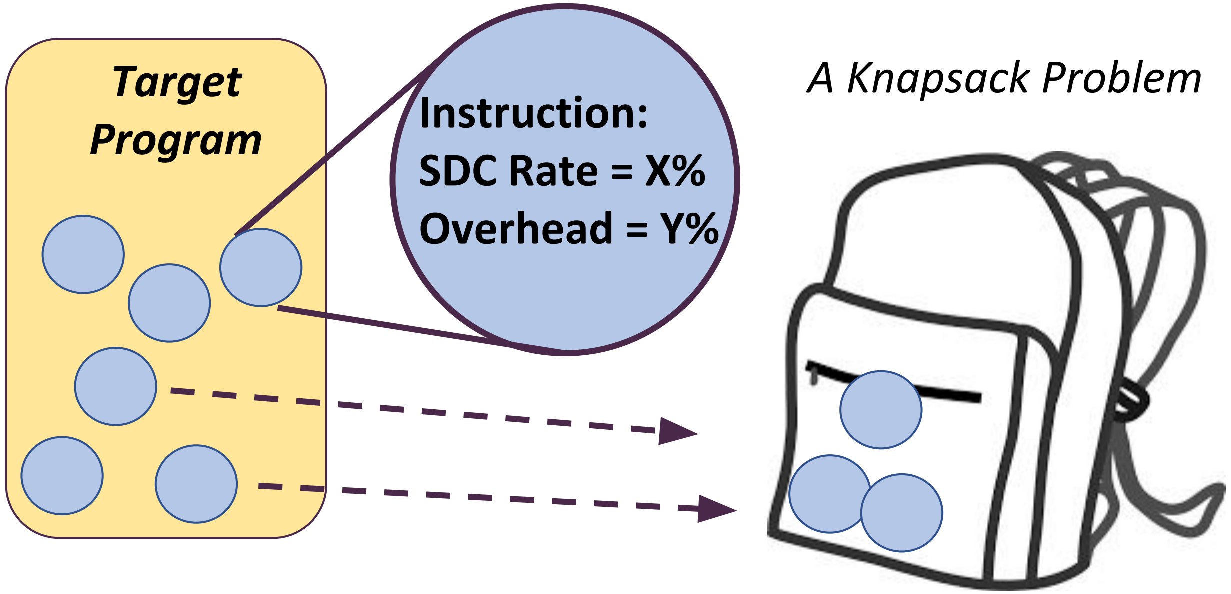
- Proposed by [DAC’09, Reddi], [ASPLOS’10, Feng], [CGO’16, Laguna]



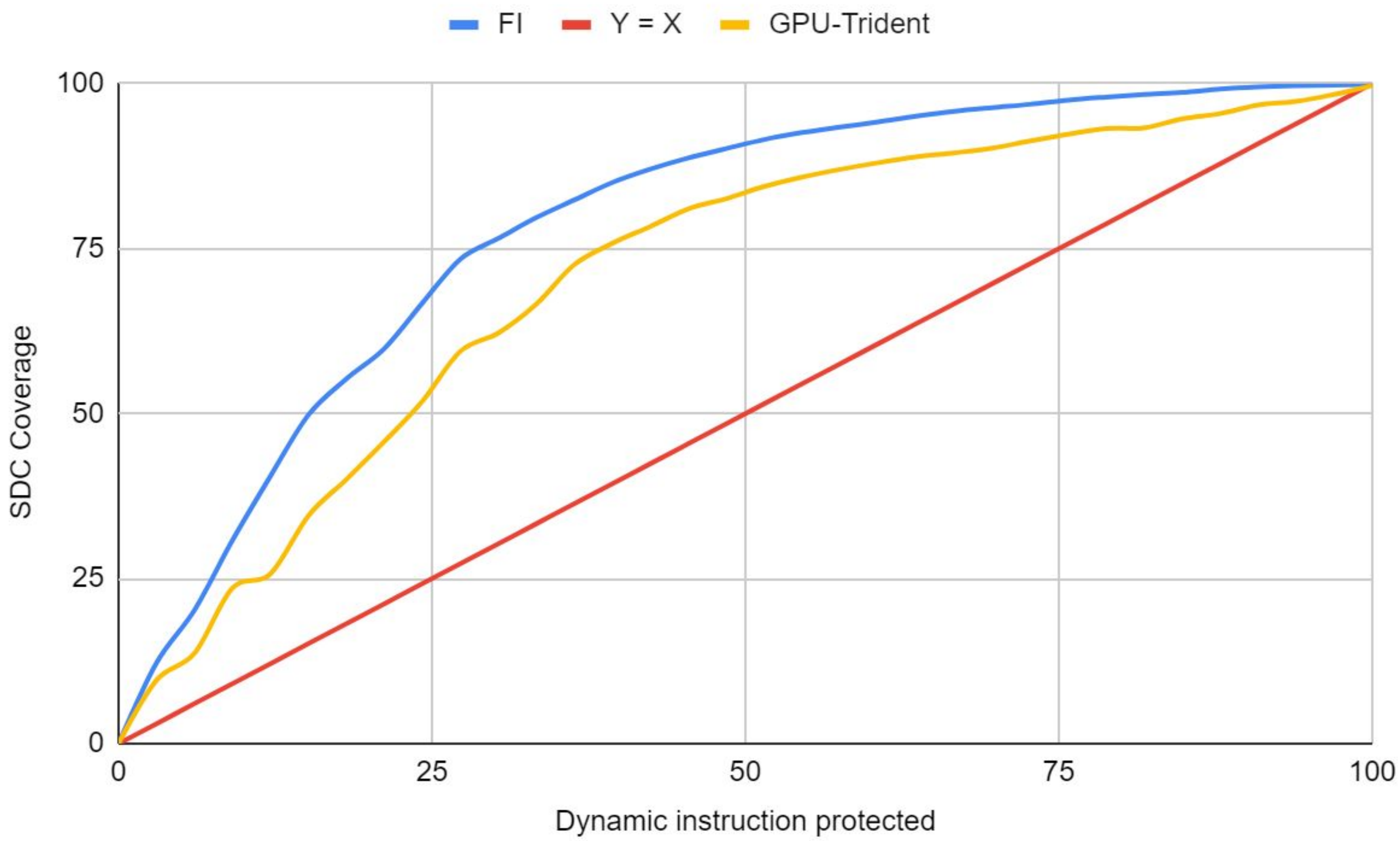
Instruction Sequence



Instruction Duplication



Selective Instruction Duplication



Summary

- Modeling error propagation in GPU applications is challenging due to *scale* and *inaccuracy*
- We develop heuristics, based on *memory access* and *data patterns*
- Experiments show our techniques are *accurate* and *scalable*
- *GPU-TRIDENT: Efficient Modeling of Error Propagation in GPU Programs (https://github.com/DependableSystemsLab/GPU-Trident)*
- *For questions: arehman.anwer1@gmail.com*