Error Resilient Systems and Approximate Computing: Conjoined Twins Separated at Birth ?

Karthik Pattabiraman,

Anna Thomas, Jiesheng Wei, Bo Fang, Guanpeng Li and Qining Lu

University of British Columbia (UBC)

http://blogs.ubc.ca/karthik/

What this talk is about

- **Approximate computing**: Exact results don't matter - compromise on correctness
- **Error-Resilient Systems**: Can we produce correct results in the presence of hardware faults ?

What this talk is about

- **Approximate computing**: Exact results don't always matter - compromise on 100% correctness
- **Error-Resilient Systems**: Can we produce acceptable ~~correct~~ results in the presence of hardware faults ?
- **TLDR:** The two fields have evolved independently. Can they be bridged, and learn from each other ?

Error Resilient Systems: History

- **Long history in fault tolerant systems (1960s)**
  - Targeted mission-critical or safety-critical systems such as space missions, finance and healthcare
  - Costs (power/performance) not very important

- **Around 2005, marked change in paradigm**
  - Commodity systems where cost matters
  - Mostly software driven (with hardware support)
  - Error Detectors (UIUC), SWAT (UIUC), SWIFT (Princeton), Shoestring (Michigan) etc.

Approximate Computing: History

- **Long history going back to Von Neumann's notion of probabilistic computing in 1960s**
  - Confined to the circuits or electronic devices level
  - Confined to selected application classes
- **Starting around 2009, adoption of approximate computing at higher levels of the system stack**
  - ERSA (Stanford), Flikker (UBC/Microsoft), Relax (U. Wisconsin), and EnerJ (U. Washington)
  - Main motivation: Energy savings

Similarities between the two fields

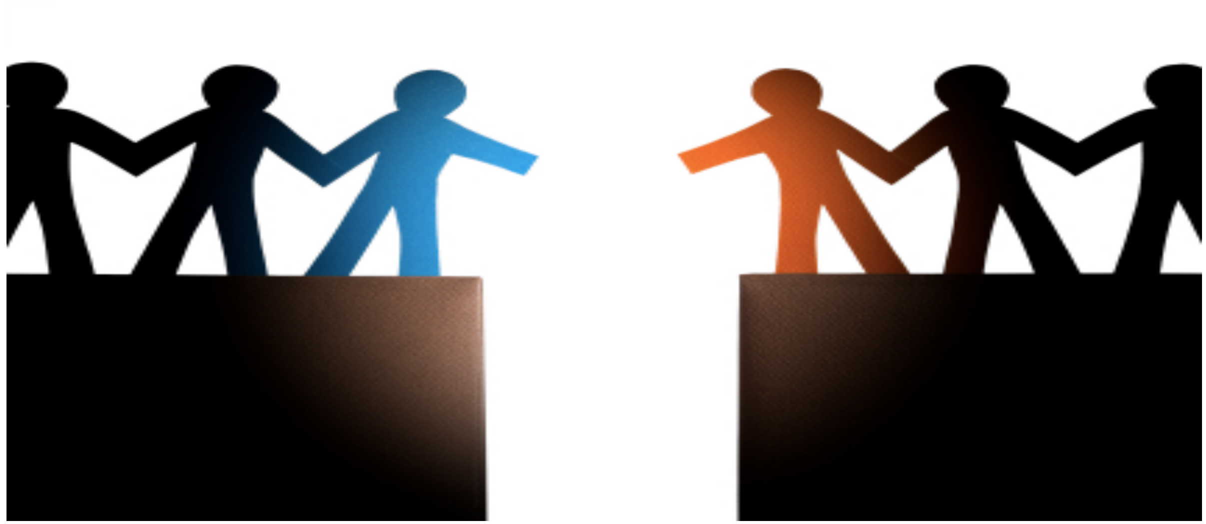
- **Both consider hardware faults, primarily transients**
  - In error resilient systems, faults are introduced by natural phenomena (e.g., cosmic rays, alpha particles)
  - In approximate computing, faults are introduced by deliberate lowering of voltages/frequencies etc.
- **Both fields have notions of partial correctness**
  - In error resilient systems, these are defined by SDCs or Silent Data Corruptions (e.g., SDC rate, coverage of SDCs)
  - In approximate computing, these are defined by application specific fidelity metrics (e.g., Peak Signal to Noise Ratio)

Differences between the two fields

- **Approximate computing assumes that it is possible to control when & where faults occur**
  - E.g., Only in low-refresh DRAM, only in some ALUs
  - Resilient systems assume that the number of fault occurrences is bounded (e.g., one fault per execution)

- **Approximate computing assumes programmers will explicitly mark low (high)-fidelity data/code**
  - Typically through type systems or annotations
  - Resilient systems automate this based on heuristics

Can we bridge this gap ?

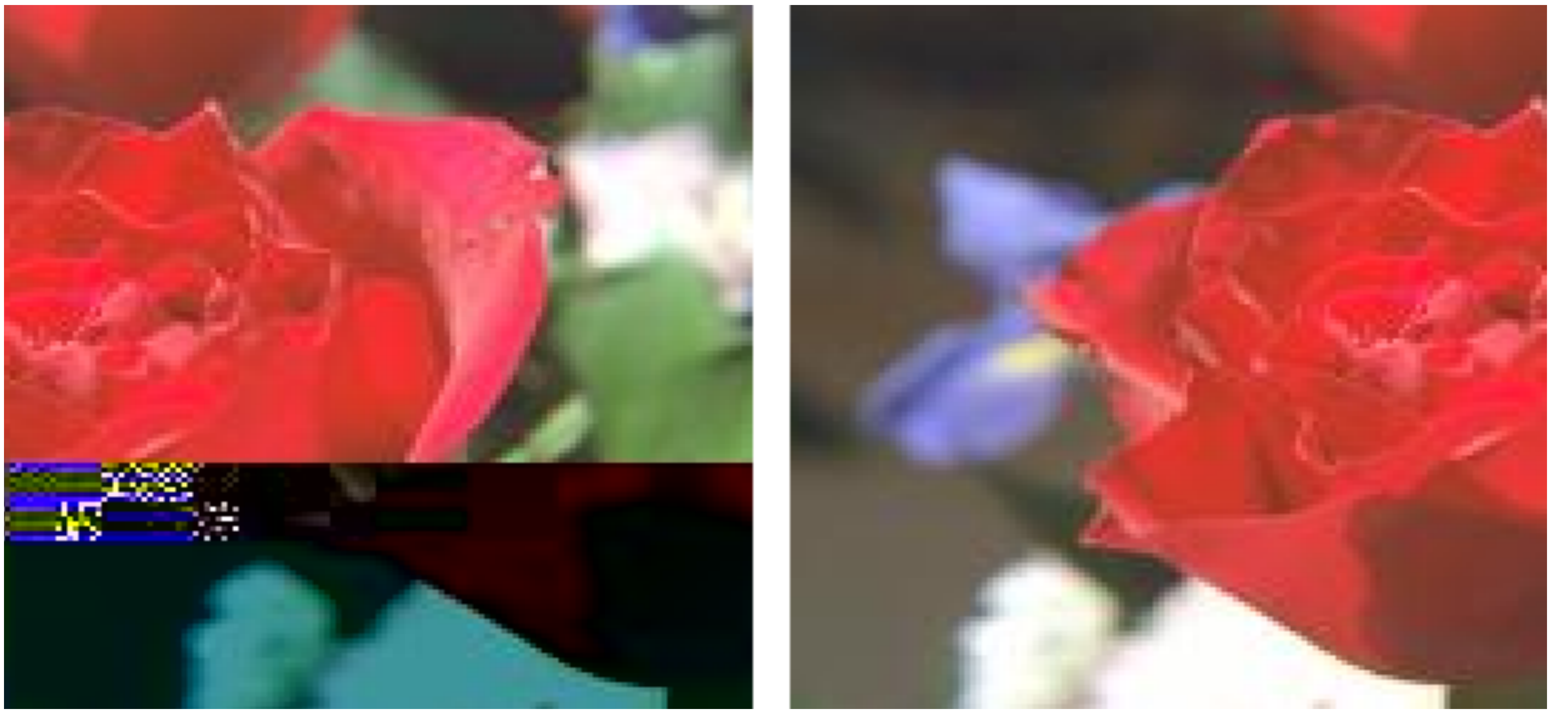


Example of a system that i have worked on

Egregious Data Corruptions (EDCs) in Approximate Computing Applications [DSN’13]

EDCs: What are they ?

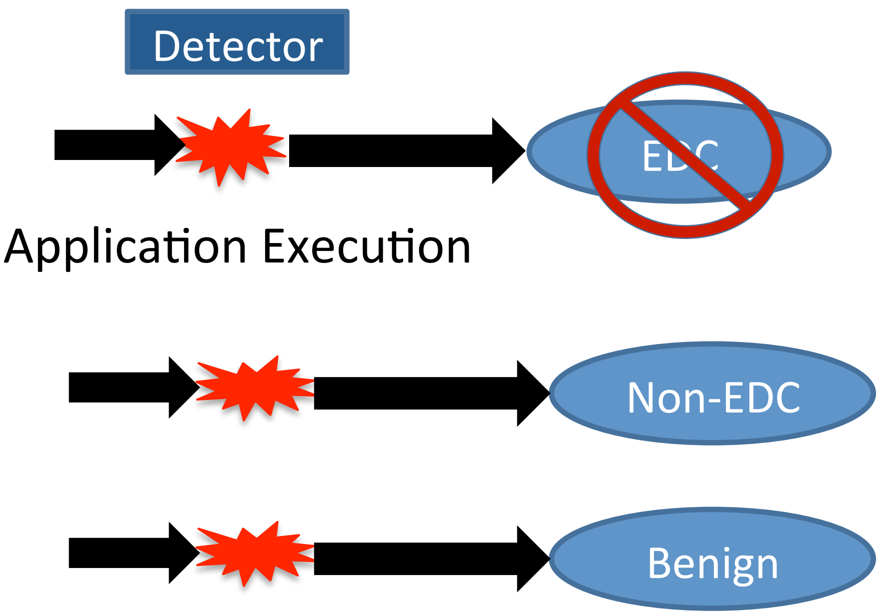
- Large or unacceptable deviation in output

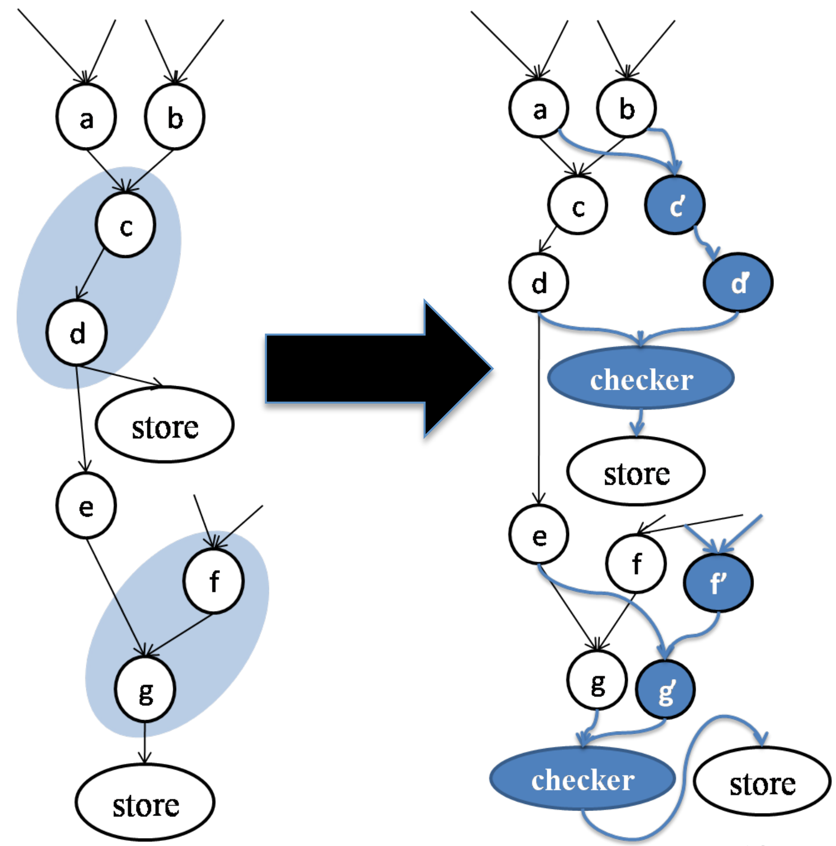


EDC image (PSNR 11.37) Vs. Non-EDC image (PSNR 44.79)

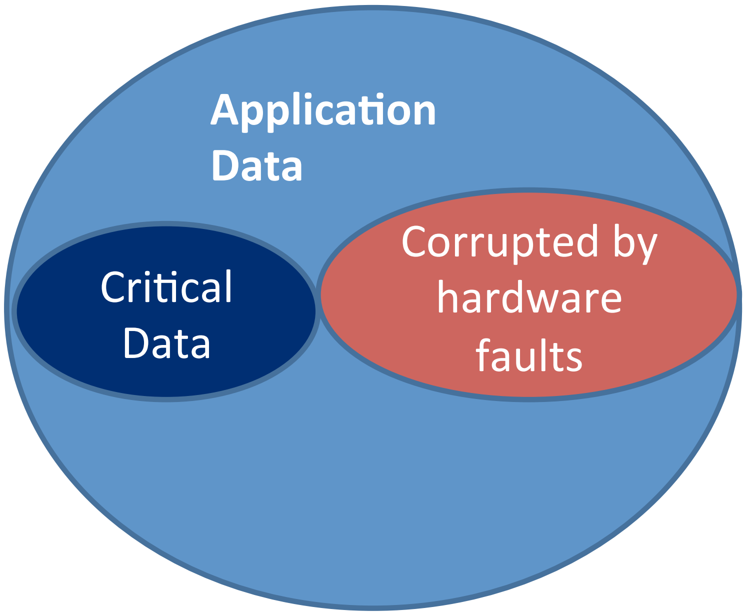
EDCs: Goal

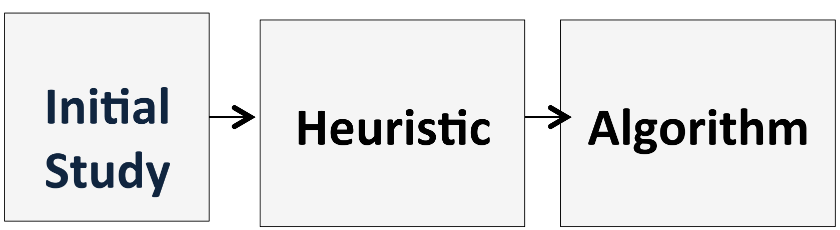
- Selectively detect EDC causing faults, but not others





EDCs: Main Idea

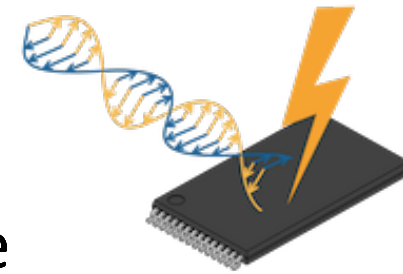




Our prior work: EDCs are caused by corruption of a small fraction of program data [Flikker - ASPLOS'11]

This work: Critical data can be identified using static and dynamic analysis, without any programmer annotations

EDCs: Fault model



- **Transient hardware faults**
  - Caused by particle strikes, supply noise
- **Our Fault Model**
  - Assume one fault per application execution
  - Processor registers and execution units
  - Memory and cache protected with ECC
  - Control logic protected with other methods

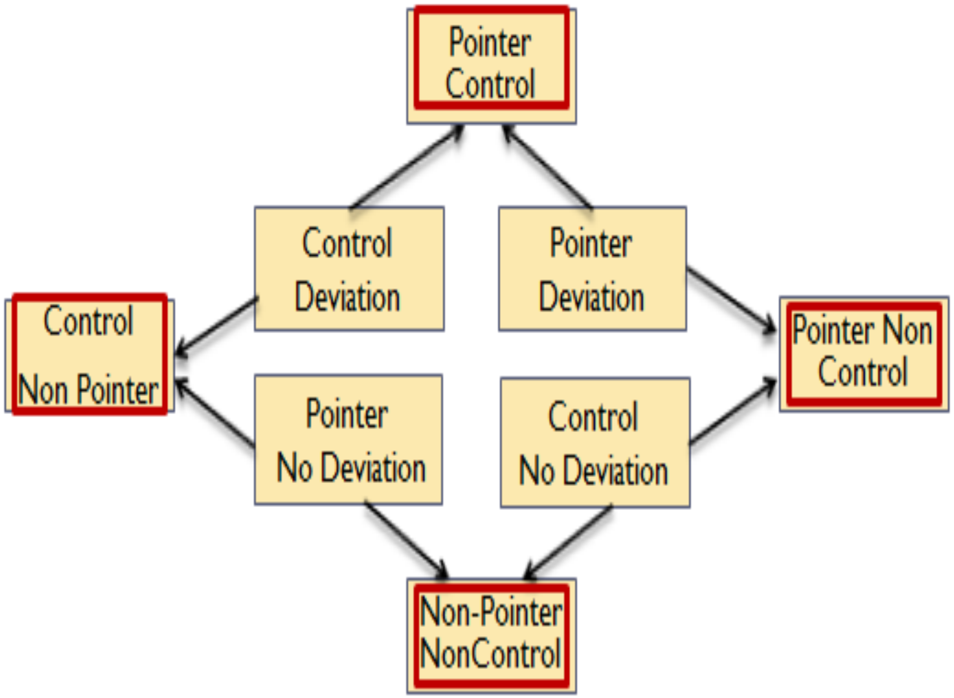
EDCs: Initial Study

- Correlation between program data use & fault outcome

Monitor Control/ Pointer Data

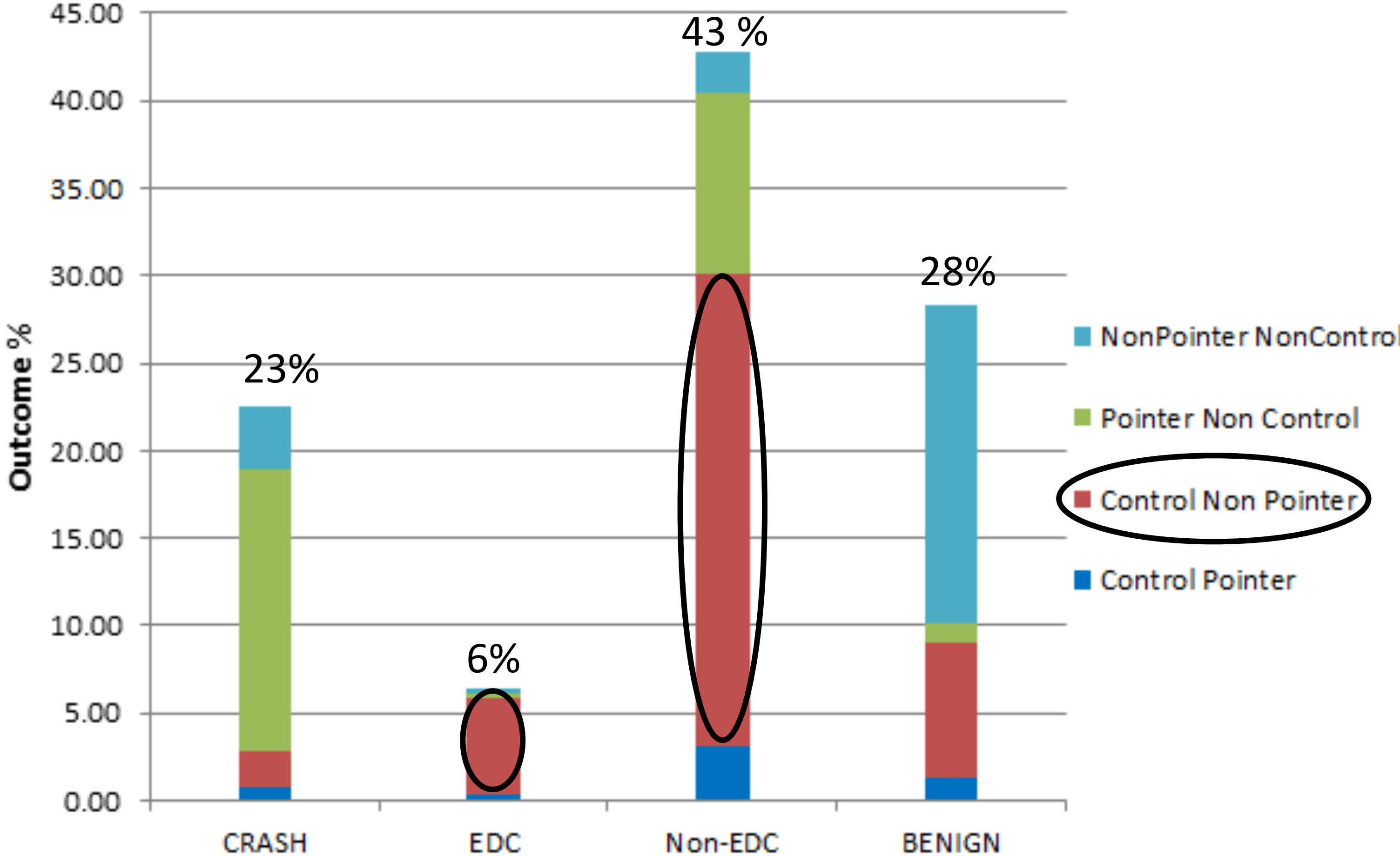
- Instrument code
- Fault Injection

Performed using LLFI fault injector [DSN'14], at the LLVM IR code level



Initial Study → Heuristic → Algorithm

EDCs: Initial Study



EDCs: Example Heuristic

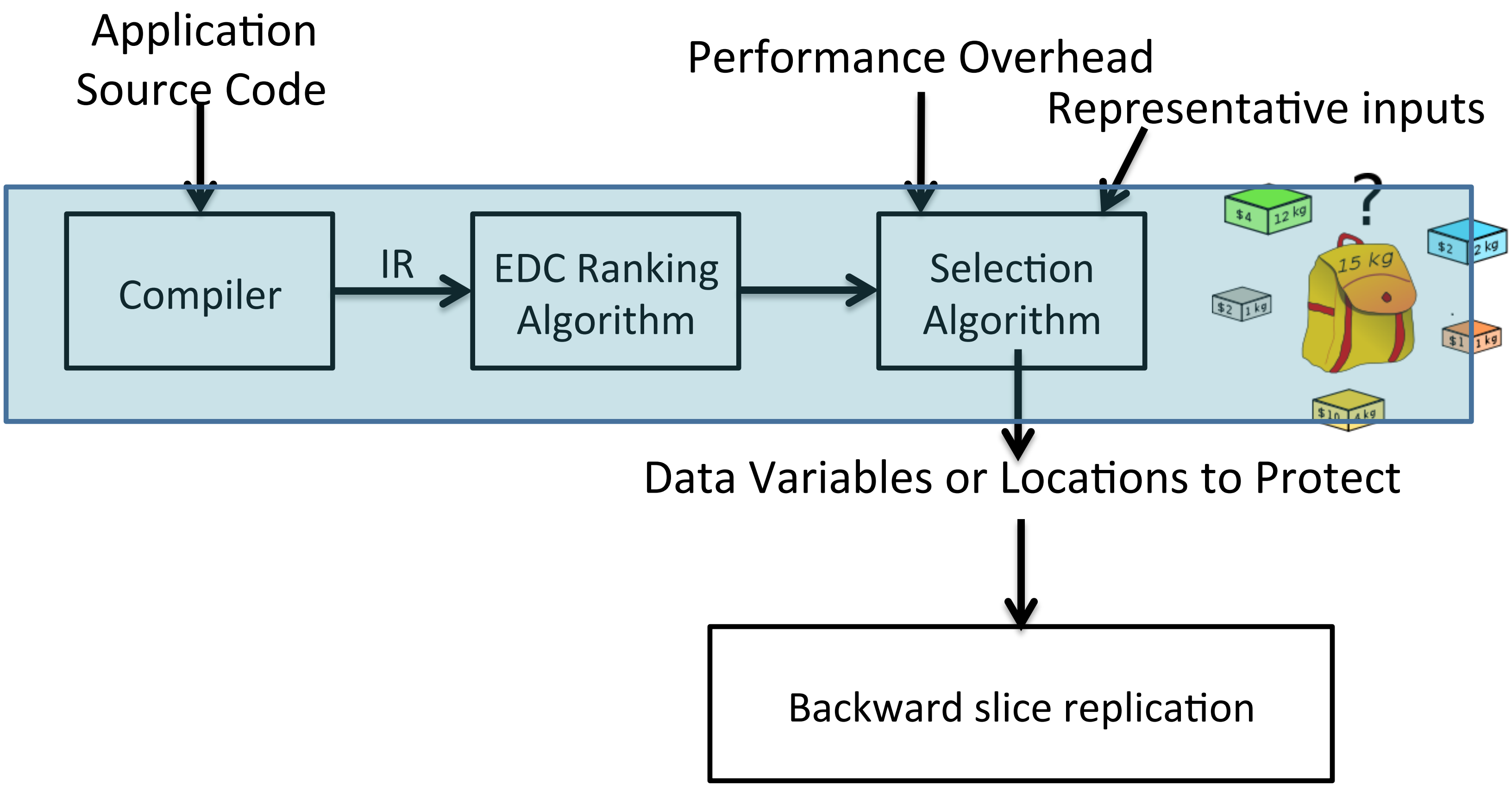
Faults affecting branches with large amount of data within their bodies have a higher likelihood of resulting in EDC outcomes

```
offset) {
   for(j=0; j < height; j++){
     for(i=0; i < width; i++) {
       im1 = (i < 1) ? 0 : i – 1
       …
       …
     }
     if (j + 1 < offset) {
         src += w;
         dst += width; }
   }
}
```

- Fault in offset
- Branch Flip

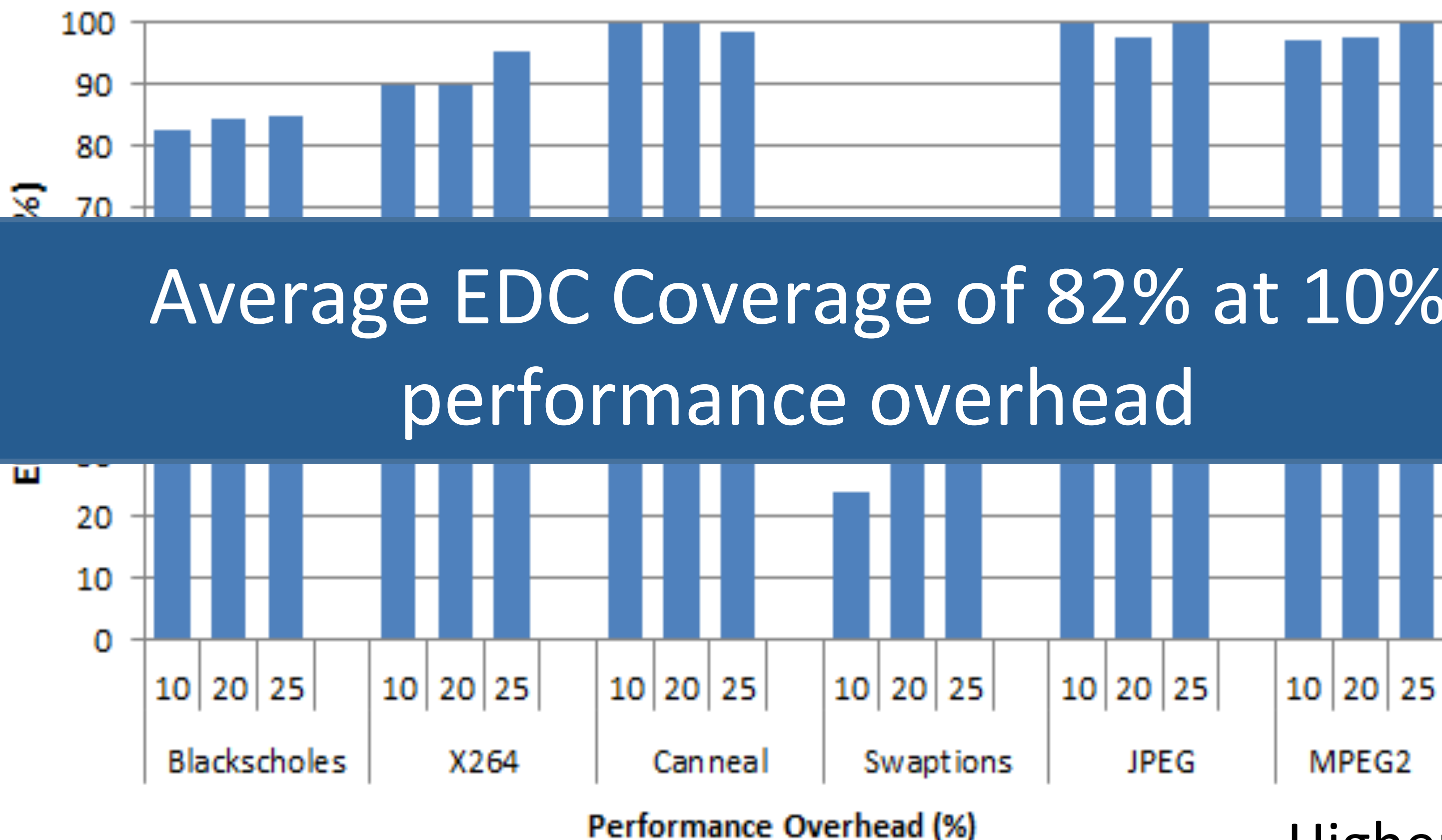
Low EDC Likelihood

EDCs: Algorithm



EDCs: Detection Coverage

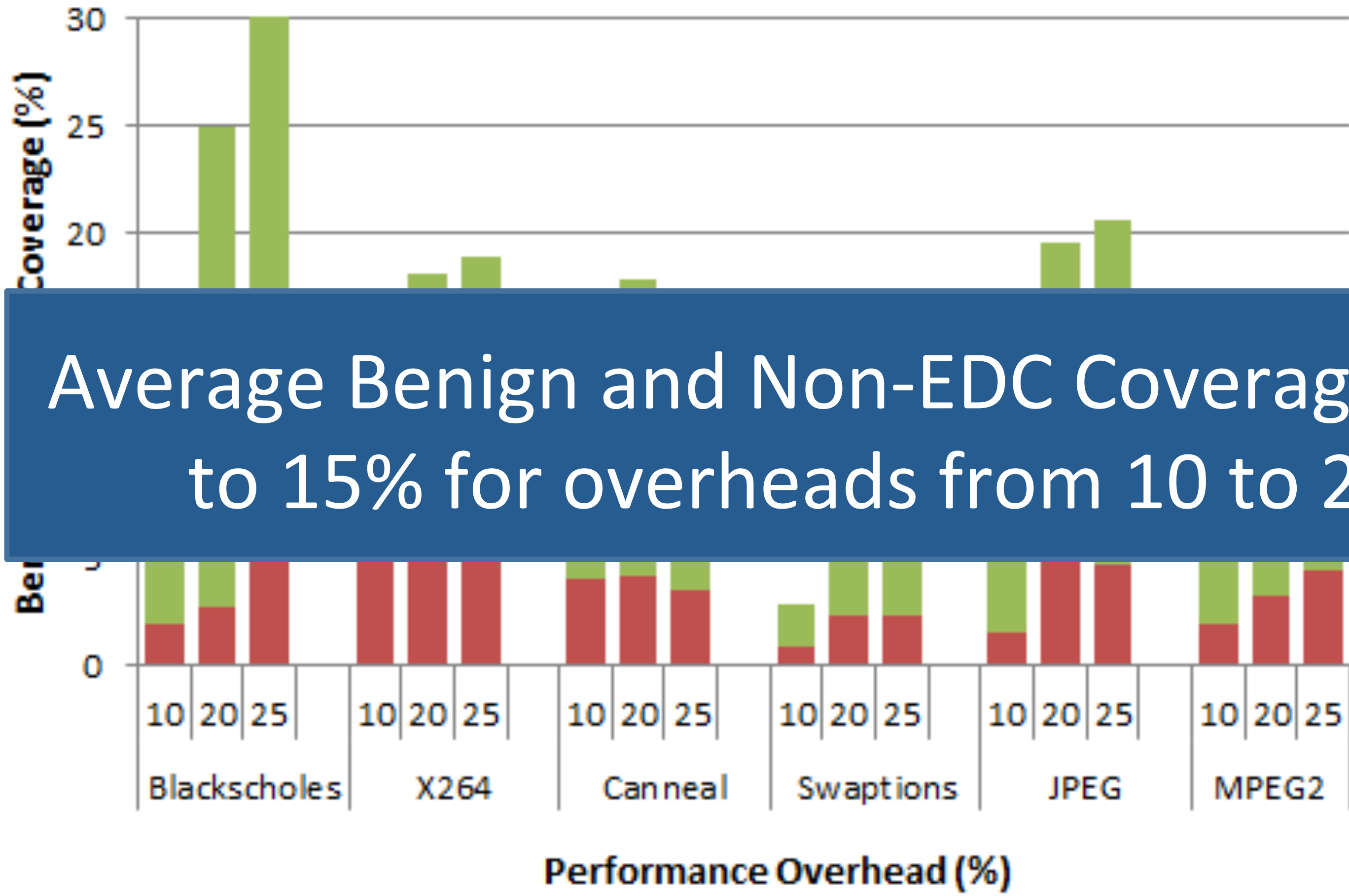
$$EDC\ Coverage = Number\ of\ Detected\ EDCs / Total\ Number\ of\ EDCs$$



Average EDC Coverage of 82% at 10% performance overhead

Higher is better

EDCs: Selectivity



Average Benign and Non-EDC Coverage of 10 to 15% for overheads from 10 to 25%

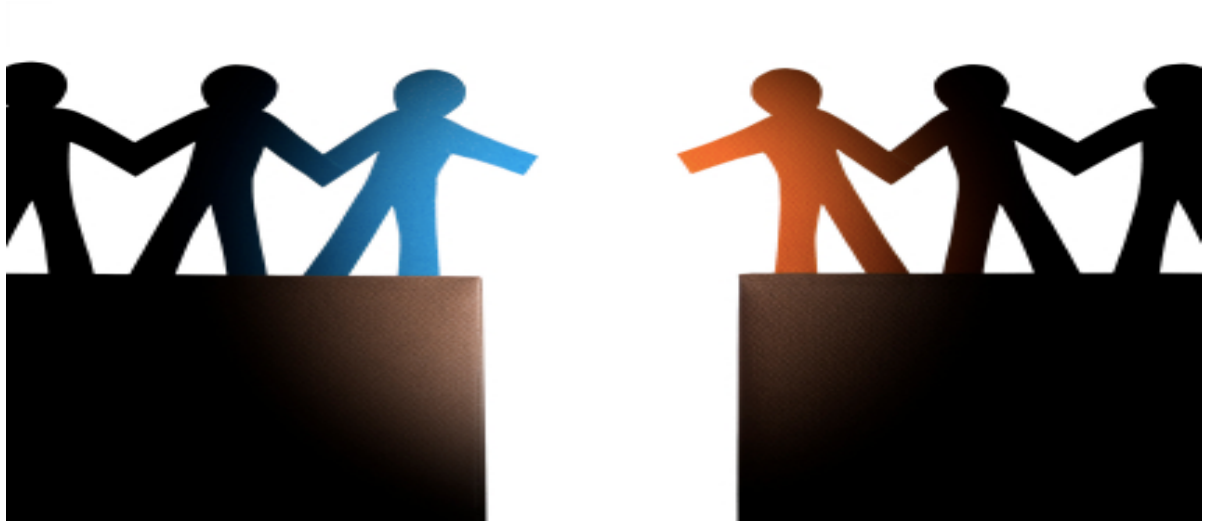
Lower is better

How can the two fields learn from each other ?

- **Approximate computing applications**
  - More generic fault models (more resilient)
  - More automation based on heuristics (say)

- **Error Resilient Systems**
  - Precisely quantify acceptable & unacceptable outcomes using the programmer's help
  - Use of type theory or model checking to reason about whether the protection is adequate or not

Can we bridge this gap ?



Challenges

1. **Different constraints**
2. **Different methodologies**