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INVESTIGATING THE LIMITATIONS OF PVF FOR REALISTIC PROGRAM VULNERABILITY ASSESSMENT

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Motivation

Software development today:

- How fast does my program run?
- How much energy does it consume?
- How many software errors does it contain?

Software development in the future:

- Which functions are most vulnerable against certain hardware errors?
- Should I use implementation A or B of a certain algorithm?
- Which impact will compiler optimizations have on my program's vulnerability?

Vulnerability Analysis Today

Hardware vulnerability analysis: Architectural Vulnerability Factor (AVF)[1]

- Established technique
- Requires both application and hardware model
- Hardware model out of reach in practical SW development

[1] Mukherjee et al.: *A systematic methodology to compute the architectural vulnerability factors for a high-performance microprocessor*, IEEE MICRO 2003

[2] Sridharan, Kaeli: *Eliminating microarchitectural dependency from architectural vulnerability*, HPCA 2009

Vulnerability Analysis Today

Hardware vulnerability analysis: Architectural Vulnerability Factor (AVF)[1]

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Software-only analysis: Program Vulnerability Factor (PVF)[2]

- Replace hardware with an abstract model
- Requires application knowledge only

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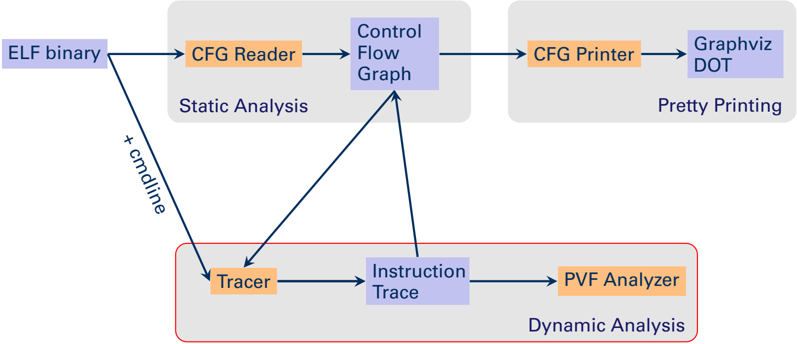
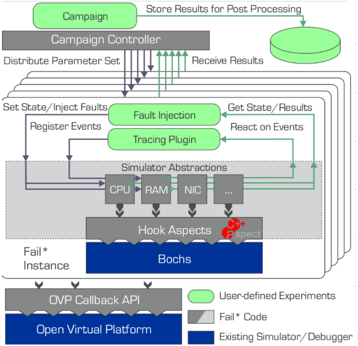
PVF Analysis for x86



Source code: `https://github.com/TUD-OS/PVFAnalyzer`

FAIL/*: Fault Injection

- Framework for performing FI campaigns[3]
- Interchangeable hardware model: Bochs/x86
- Benefit: real distribution of errors for a given platform



[3] H. Schirmeier, M. Hoffmann, R. Kapitza, D. Lohmann, and O. Spinczyk: FAIL/*: *Towards a versatile fault-injection experiment framework*, ARCS 2012

Experiment Setup

Application:

- `nanojpeg` JPEG decoder
- Decode a small JPEG image into bitmap
- GCC 4.4.5, fully optimized $\rightarrow$ 3.7 million instructions

Fault Injection:

- FI campaign using FAIL/*
- Flip every bit in every used register once and record outcome
- Runtime: about a week on fairly large cluster

PVF Analysis:

- Analysis of a single trace
- Same fault model as for FI
- Runtime: a couple of minutes on my laptop

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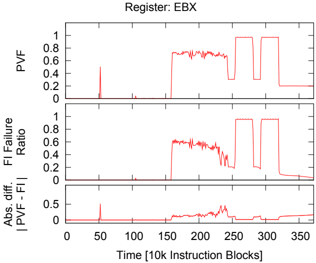
Initial Results

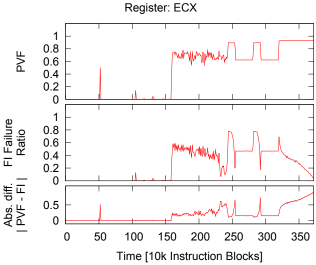
- Program run split into blocks of 10,000 instructions
- For each block: compare computed PVF and fault ratio from FI experiments
- Question: What do we consider a fault?
  - Program crashes
  - Infinite loops
  - Silent data corruption



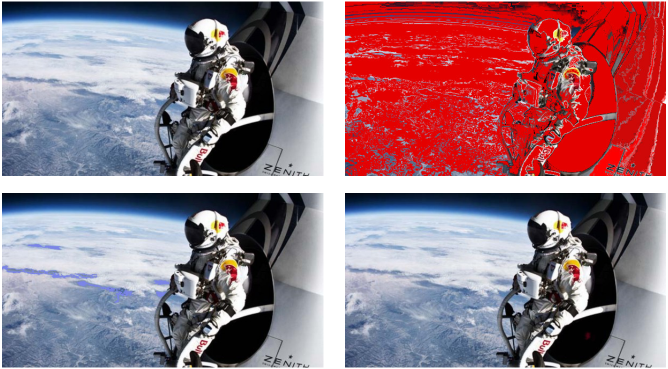
Observation #1: PVF is a fairly good prediction of the fault rate if we consider all SDC to be faults.

Understanding PVF-FI Deviations

1. FI works on bit granularity, PVF analyses registers
2. PVF does not analyze bit masking etc. operations
3. PVF analysis stops on block boundaries – no propagation of fault state for more than 10,000 instructions



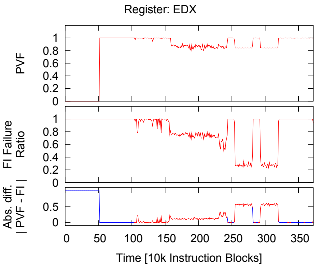
Corrupted data?



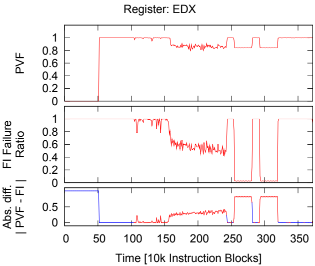
Observation #2: Not all data corruption can be considered equally faulty.

Considering Data Quality

All SDC are failures:



PSNR threshold = 20:



Incorporating Quality Into PVF?

- Similar results for an analysis of H.264 video decoding: control data (high fault rate) vs. payload data (low fault rate)[4]
- Compiler extension:
  - `reliable` and `unreliable` data modifiers
  - Special protection (encoding / redundancy) for `reliable` data

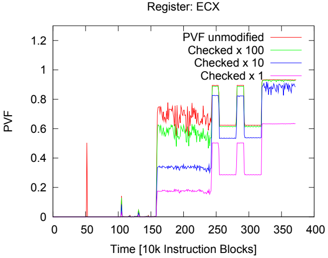
Observation #3: Using reliability annotations, the compiler can determine the reliability level of a hardware resource and propagate this information to a PVF analyzer.

[4] A. Heinig, M. Engel, F. Schmoll, and P. Marwedel: *Improving transient memory fault resilience of an H.264 decoder*, STMEDIA 2010

Modeling the Effect of FT methods

- $PVF(app)$ models probability of a fault affecting execution
- Replicated execution (e.g., RMT): tolerates faults $\frac{n}{2} - 1$ independent faults

  $PVF_{rep}(app) := PVF(app)^{\frac{n}{2}}$
- Encoded processing:
  - Checksummed data, periodic checking
  - Limit PVF analysis to smaller periods



Now What?

PVF seems promising, but is not there yet.

- We need to incorporate data quality information.
- Compiler support: propagate resource vulnerability information to PVF analyzer.
- Analysis of different fault models
  - Original PVF: register and ALU errors
  - How about memory bit flips, decoding errors, ...?

PVF will never fully replace full-featured FI campaigns.

- Analysis of complex applications and fault models
- Strong limitation: Abstract hardware model