Understanding Measurement Perturbation in Trace-Based Data

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Joint work with

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Motivation

- Instrument code to understand system behavior
  - Profile basic blocks, methods
  - Trace hardware & software metrics
- Instrumentation can perturb the system's behavior
- How does perturbation impact the ability to reason about system behavior?

Background

- NSF Grant "Understanding the Performance of Modern Systems"
  - Amer Diwan (U of Colorado Boulder)
  - Mike Mozer (U of Colorado Boulder)
  - Peter Sweeney (IBM Research)
- Vertical profiling
  - Trace-based data
  - Reason across software and hardware components
- General belief
  - Low overhead => low perturbation

    Overhead is instruction or cycle perturbation!

Methodology

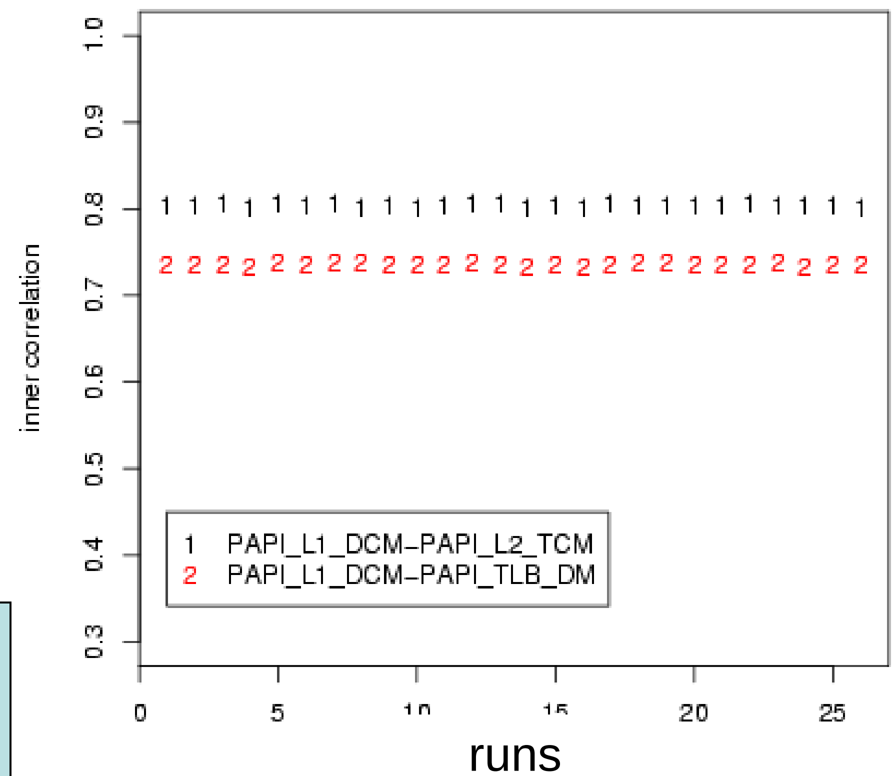
- Reason about metrics
  - Statistical correlation computes trend between two metrics
    - e.g. L1 and L2 misses
  - Compare correlation score before and after instrumentation

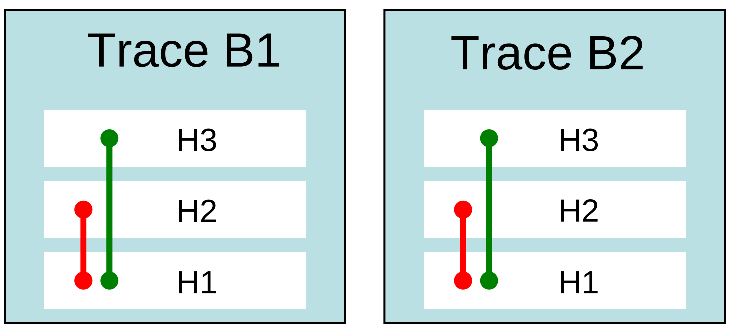
Infrastructure

- Extended CIL to instrument C programs
- Two types of instrumentation
  - Low level: hardware metrics
    - E.g. Cache misses, instructions executed, cycles
  - High level: software metrics
    - E.g. method calls, update global variable
- Periodically collect metric values
  - Use *settimer*
  - 10 to 100's millisecond intervals
  - reads counters and writes their values to disk

Reality Check

- sjeng (SPEC CPU2006)
- Multiple runs collecting same metrics
- Graph correlation of pairs of metrics within a trace
- Minimal perturbation across runs





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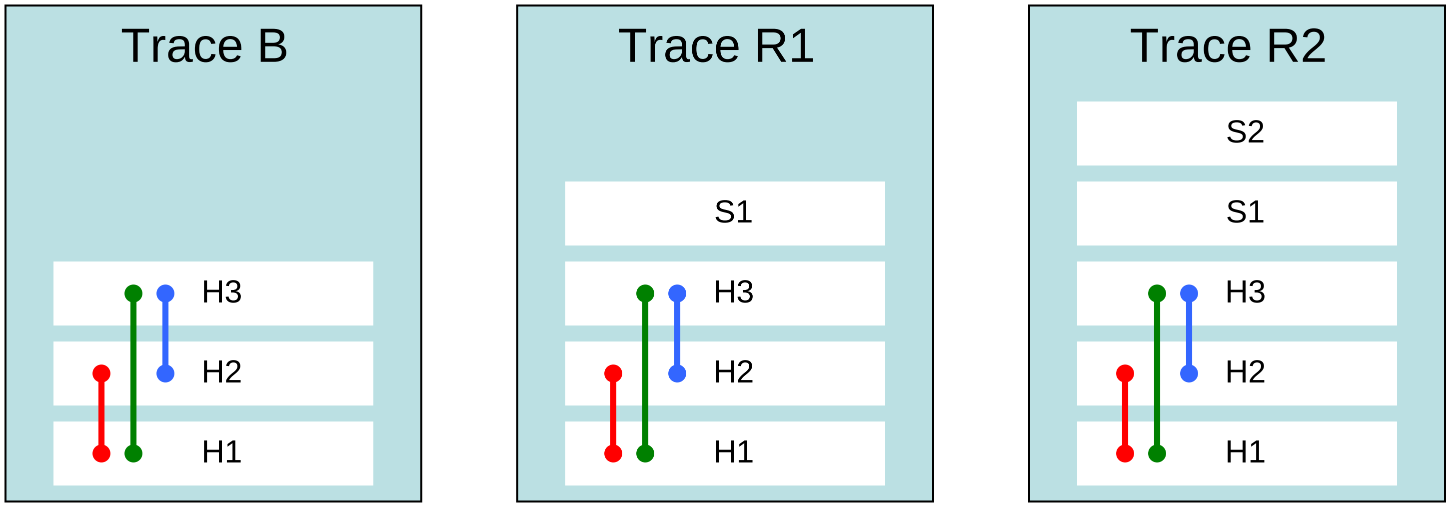
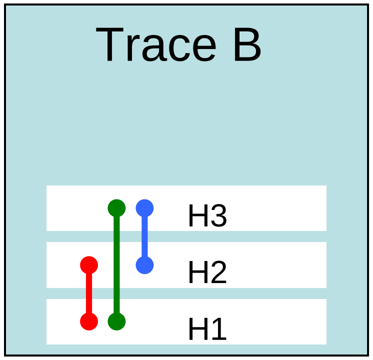
Inner Perturbation

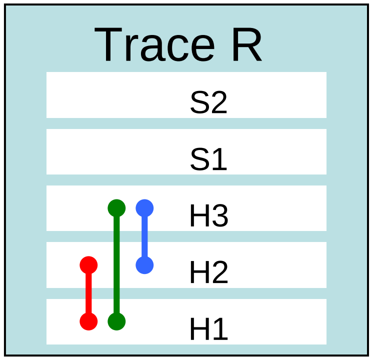


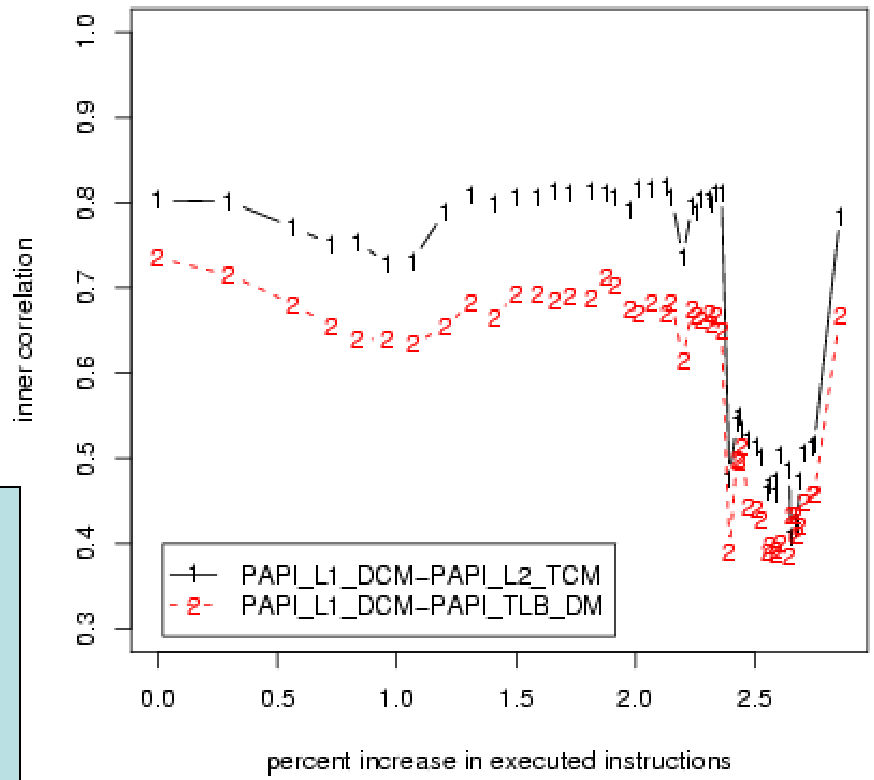
- Correlate pairs of metrics within a trace
- Compare *inner* correlation scores across traces
  - E.g. compare corr(B.H1, B.H2) with corr(R.H1, R.H2)
- Observe how correlation changes as additional instrumentation is added

Significant Inner Perturbation

- sjeng (SPEC CPU2006)
- Multiple runs collecting different software metrics
- Graph inner correlation scores of hardware metrics as instrumentation is added
- Same metrics as “Reality Check”
- Significant inner perturbation
- Small increase in instructions executed < 3%
- But recovers

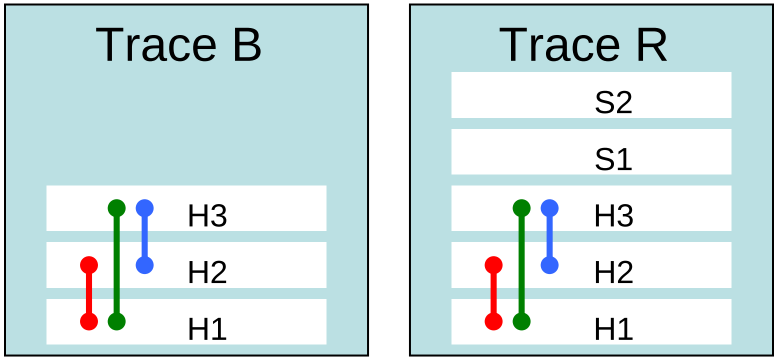


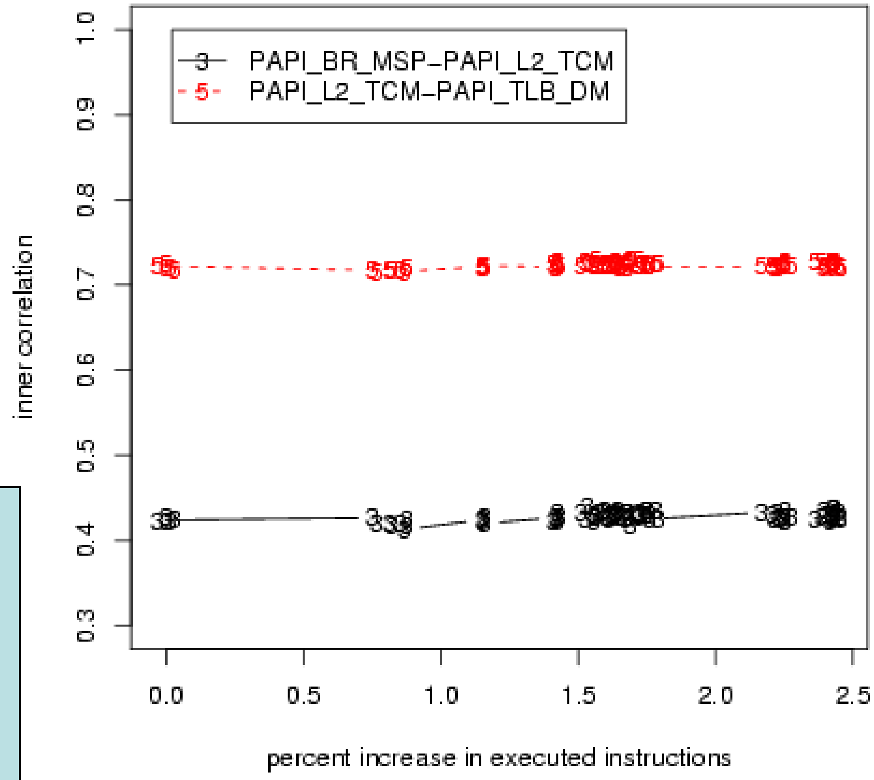




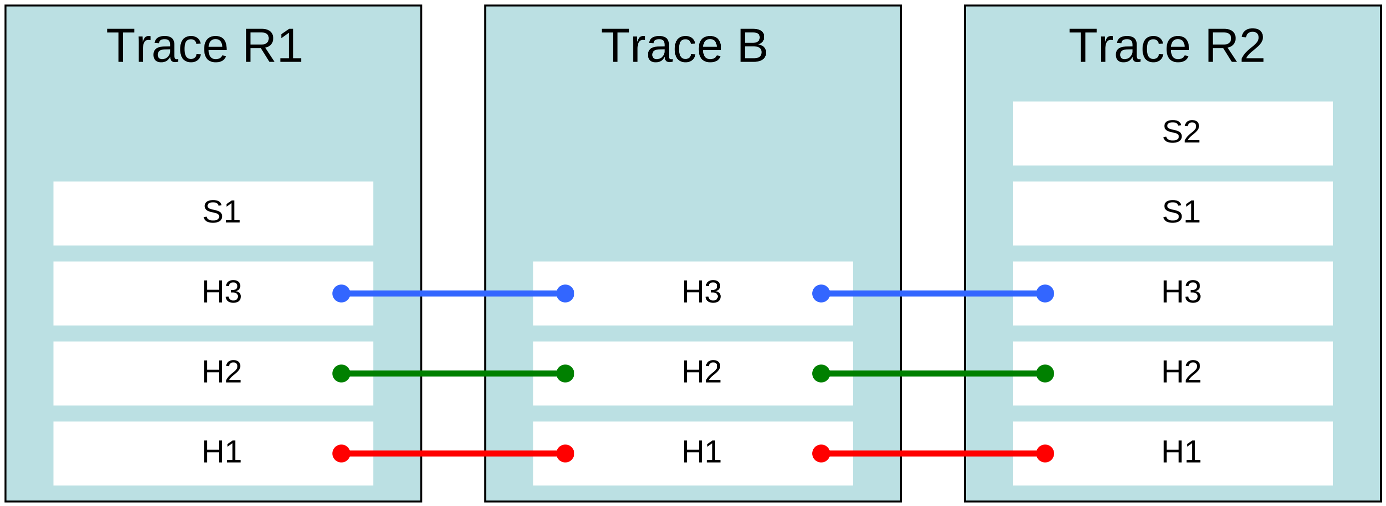
Minimal Inner Perturbation

- bzip (SPEC CPU2006)
- Multiple runs collecting different software metrics
- Graph inner correlation scores of hardware metrics as instrumentation is added
- Minimal inner perturbation
- Inner perturbation is benchmark specific





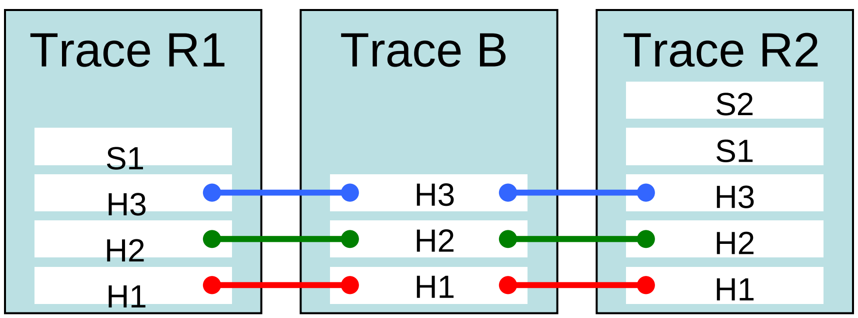
Outer Perturbation

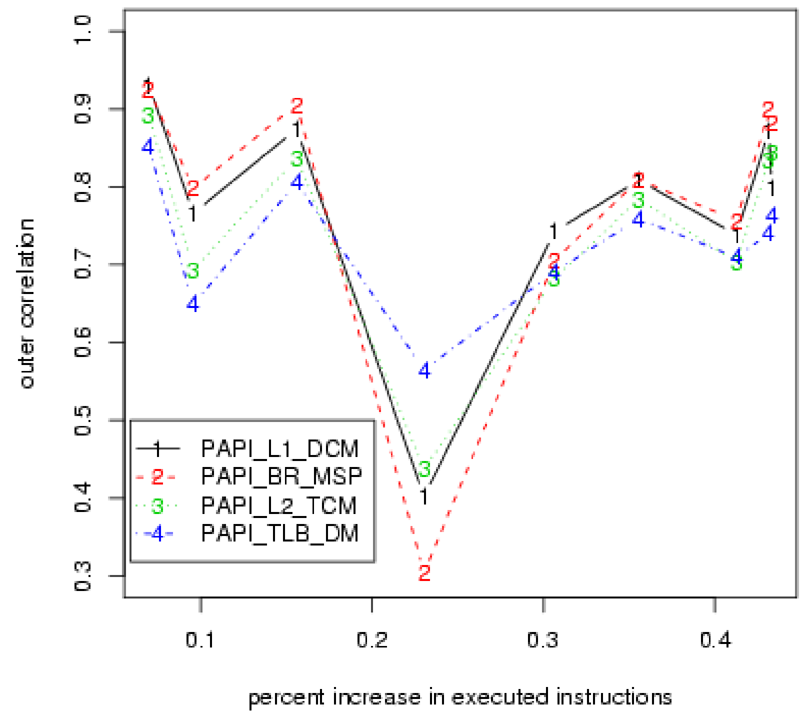


- Correlate same metric in baseline and in another trace
- Compare *outer* correlation scores across pairs of traces
  - E.g. compare corr(B.H1, R1.H1) with corr(B.H1, R2.H1)
- Observe how correlation changes as additional instrumentation is added
- Assumes technique to align traces
  - We use DTW

Significant Outer Perturbation

- Sim-outorder with gcc as input
- Multiple runs collecting different software metrics
- Graph outer correlation of hardware metrics as instrumentation is added
- Significant outer perturbation
- But recovers

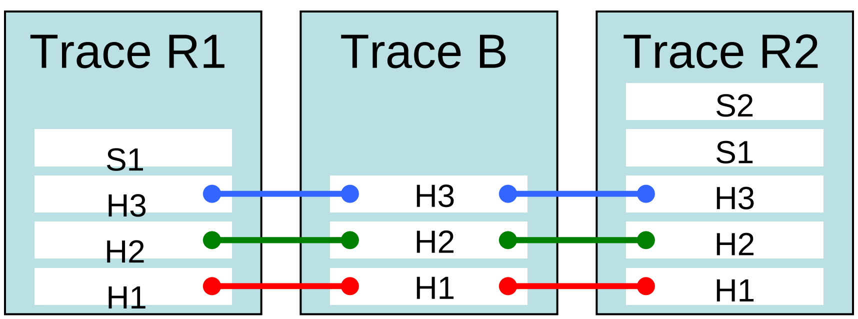


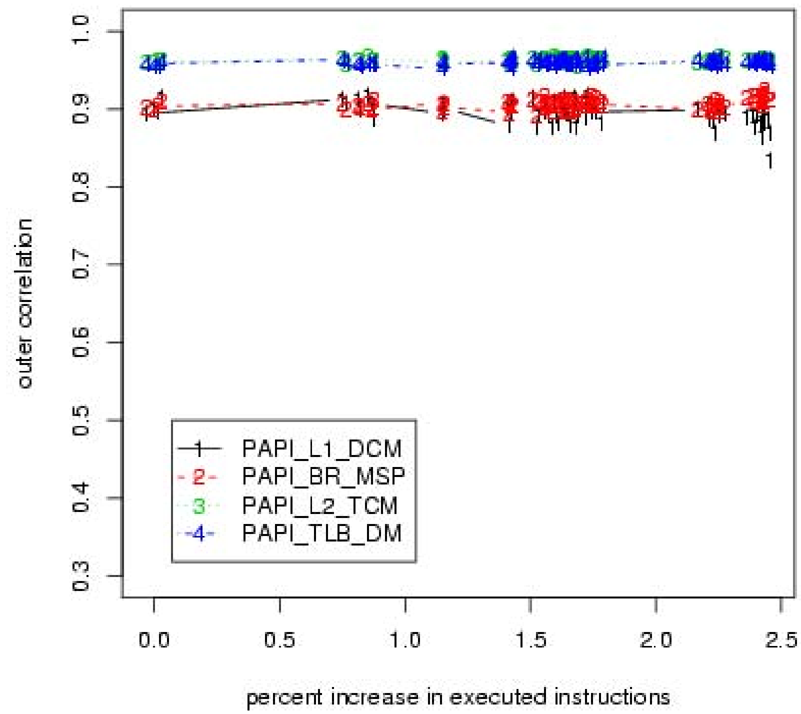


Minimal Outer Perturbation

- bzip (SPEC CPU2006)
- Multiple runs collecting with different metrics
- Graph outer correlation of hardware metrics as instrumentation is added
- Minimal outer correlation
- Outer perturbation is benchmark

  specific





Conclusions

- Low overhead !=> low perturbation
  - Minimal instrumentation overhead can result in significant perturbation
    - Less than 3% increase in executed instructions prevented reasoning about metrics within or across traces
- Perturbation is application specific
- Perturbation is not monotonic
  - Additional instrumentation may increase or decrease perturbation!
  - Makes impact of instrumentation hard to predict
- This is a starting point for a more in depth study!

Related Work

- Perturbation measurement [Daigle et al.]
  - Operational definition of perturbation
    - Aggregate runtime slowdown as function of instrumentation
- Perturbation management [Maloney]*
  - Use perturbation model to eliminate perturbation effects from a trace
    - Only as good as model
      - Difficult to model out-of-order superscalar machines
    - Overall program run time

Questions

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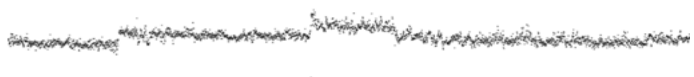
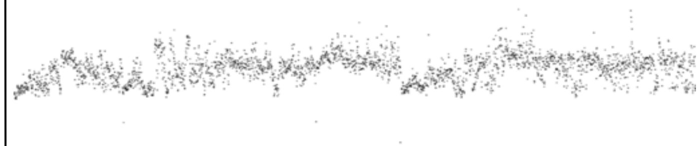
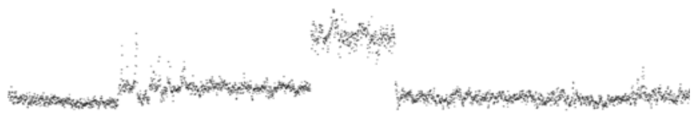
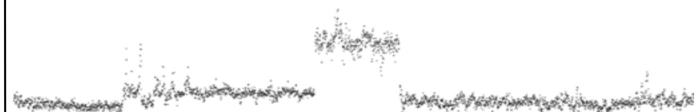
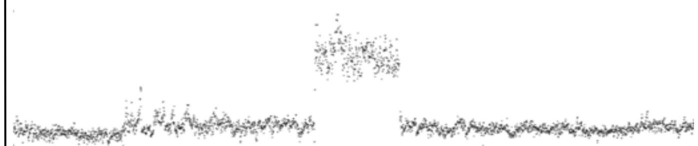
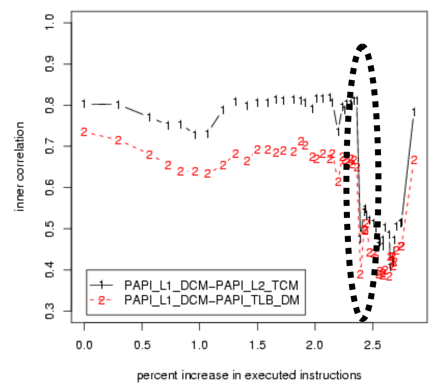
- How does perturbation impact our ability to reason about system behavior?

Inner Perturbation Details

	Good	Perturbed
L1_DCM		
L2_TCM		
S	*not measured*	

- Each row different metric
- “Good” is trace before perturbation
- “Perturbed” is trace after perturbation
- “S” is the software metric collected in “Perturbed” but not in “Good”



How to Evaluate Perturbation?

- Any instrumentation perturbs system behavior
- Count number of times a metric occurs
  - Hardware: no charge
  - Software: cost to increment
- Baseline trace
  - Only collect hardware metrics
    - Cost is to periodically collect metrics
  - Expect minimal perturbation, but no guarantee
  - Expect relationship between metrics are preserved

IPC over time for SPECjvm98