EDFI: A Dependable Fault Injection Tool for Dependability Benchmarking Experiments

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Fault Injection

- Well-established dependability benchmarking technique.
- Inexpensively emulates realistic faults in a synthetic setting.
- Previously applied to several different categories of systems.
- Common application scenarios:
  - Characterize system behavior under errors.
  - Evaluate effectiveness of fault-tolerance mechanisms.
  - High-coverage testing of error-handling code.

Existing Fault Injection Techniques

Preruntime, location-based

- Weak faultload coverage guarantees (poor *precision*).
- Cannot prevent spurious fault activation (poor *controllability*).

Run-time, location-based

- Similar to preruntime, but injections are triggered by HW/SW traps.
- Seeks to address the controllability issues of preruntime strategies.

Run-time, time-based

- Periodically interrupts execution to perform fault injection.
- Significantly constraints the nature of the injected faults.
- Poor reproducibility and comparability of the results.

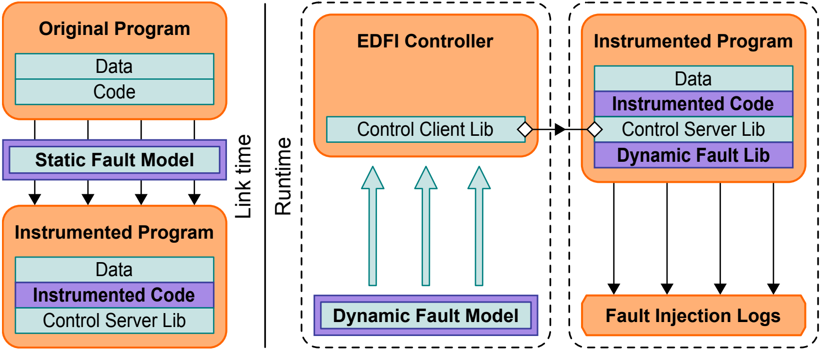
WWW: What We Want

- A "*dependable*" fault injection tool.
- Provides strong faultload coverage guarantees.
- Structurally prevents spurious fault activation.
- Guarantees full observability of the experiments.
- Delivers reproducible and comparable fault injection experiments.
- Adapts to different systems and (nondeterministic) workloads.

EDFI Overview

- Statically injects multiple simultaneous faults over the entire code.
- Relies on instrumentation to dynamically activate faults on demand.
- Guarantees a controlled and predetermined faultload at runtime.
- Delivers *precise*, *controllable*, and *observable* experiments.
- Supports several possible realistic software fault types.
- Allows users to specify complex static and dynamic fault models.

EDFI Architecture



Execution-driven Fault Injection

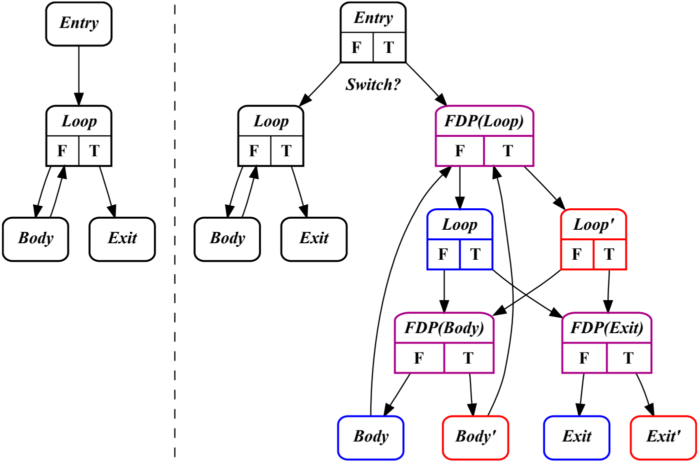
Overview

- Compiles the code into multiple (faulty and nonfaulty) versions.
- Interleaves them in a user-controlled way during the experiment.
- Implemented using an efficient *basic block cloning* strategy.

Basic block cloning

- **Pristine BB**: original unmodified BB, used during normal execution.
- **Fault-free BB**: original unmodified BB, used during the experiment.
- **Faulty BB**: transformed BB with faults, used during the experiment.
- **FDP BB**: fault decision point, used during the experiment.

Basic Block Cloning Example



(a) Original CFG *(b) CFG after function entry instrumentation*

Static Fault Model

- Shapes the faultload distribution at preruntime.
- Specifies fault types, locations, conditions, and intensity.
- User inputs fault types and their probability of occurrence.
- Static fault handlers (*SFHs*) specify conditions of occurrence.
- Static fault impact factors (*SFIFs*) amplify fault probabilities.
- *SFHs* and *SFIFs* are evaluated on a per-fault location basis.

Static Fault Model API

```
class StaticFaultHandler {
    virtual void init(Module &M, string &params) {}
    virtual bool canInject(Value *faultLocation,
                           double faultProb) = 0;
    virtual void inject(Value *faultLocation) = 0;
};

class StaticFaultAnalyzer {
    static double getMaxSFIF(void);
    virtual void init(Module &M, string &params) {}
    virtual double getSFIF(Value *faultLocation) = 0;
};
```

Dynamic Fault Model

- Controls and alters the faultload distribution at runtime.
- Dynamic fault triggers (*DFTs*):
  - Determine when to switch to faulty execution.
  - Invoked by instrumentation at fault decision points.
  - Support for transitent, intermittent, and temporal faults.
- Dynamic fault loggers (*DFLs*):
  - Determine what to do when faults are activated.
  - Invoked by instrumentation at fault activation points.
  - Support for event logging and fault injection statistics.

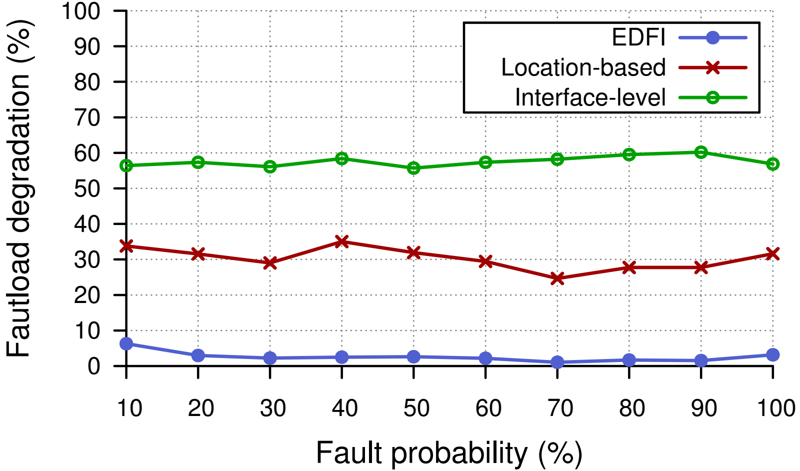
Dynamic Fault Model API

```
void edfi_onstart(edfi_context_t *context);

int  edfi_onfdp(edfi_context_t *context,
                const char *file, int line);

void edfi_onfault(edfi_context_t *context,
                  const char *file, int line,
                  int num_fault_types, ...);

void edfi_onstop(edfi_context_t *context);
```

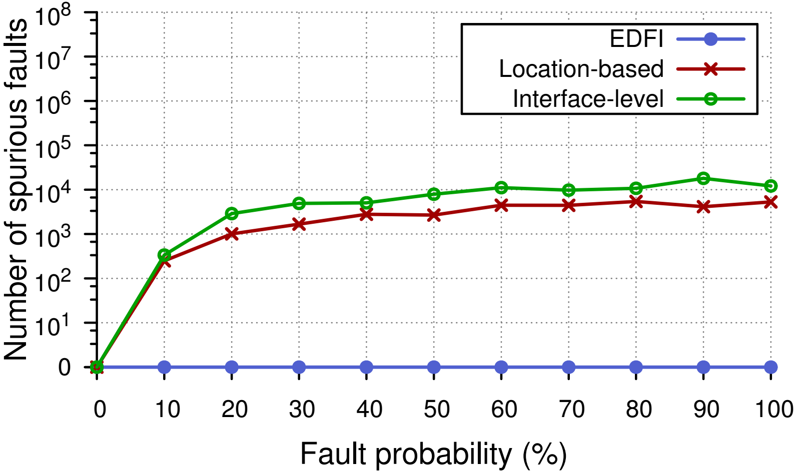
Experience

- Implemented EDFI with support for generic UNIX programs.
- Evaluated on 2 popular server programs (Apache httpd and MySQL).
- Modest virtual memory overhead observed at runtime (1.5-44.5%).
- Low performance overhead during normal execution (0.7-5.4%).
- *DFTs* and *DFLs* impact during the experiment: 1.8-644.8%.

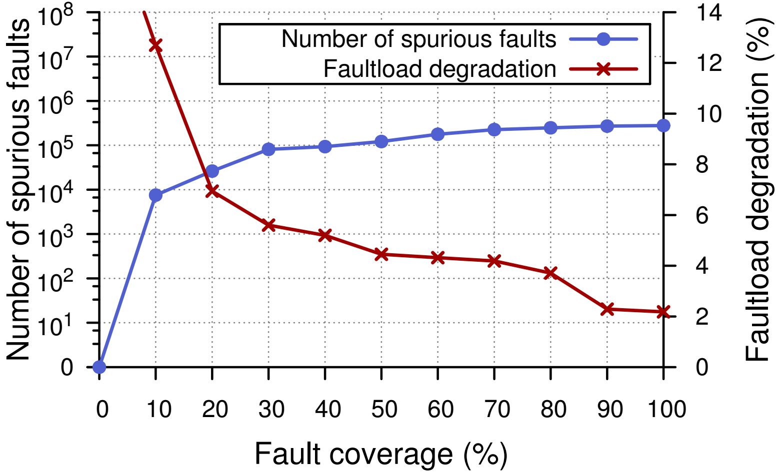
Precision


EDFI
Location-based
Interface-level
Fautload degradation (%)
Fault probability (%)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100

Controllability



Precision-controllability Tradeoff



Summary

- EDFI: a new "*dependable*" fault injection tool.
- Guarantees a predetermined and controlled faultload at runtime.
- Delivers *precise*, *controllable*, and *observable* experiments.
- Supports sophisticated static and dynamic fault models.
- Provides fine-grained control over the fault injection experiment.
- Minimizes perturbations to the system during normal execution.

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Thank you!
Any questions?

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