Providing Cloud Resiliency:

Fault Localization using Message Flow Reconstruction and Targeted Fault Injection

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Outline

- Motivation
- Approximate Fault Localization (AFL)
  - Concept
  - Approach
- Framework overview
- Targeted fault injection to generate failure profiles
- Evaluation
- Conclusions

Motivation

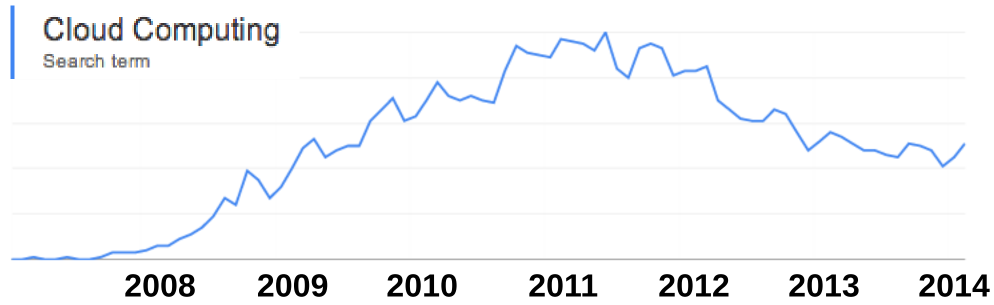
Cloud Computing is becoming mainstream

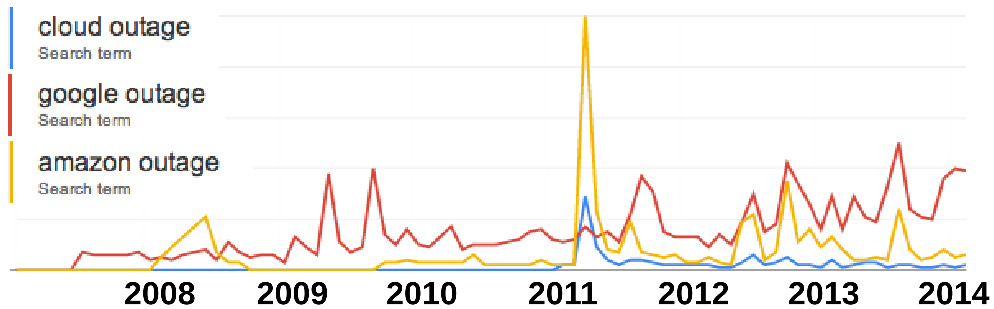
but its **Reliability**

and **Security**

... remain **an increasing concerns**

How often people "google"...





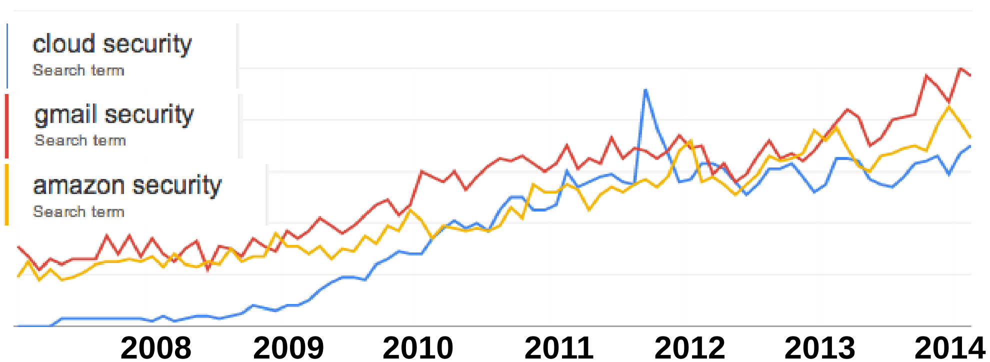


Image source: Google Trends for Searches

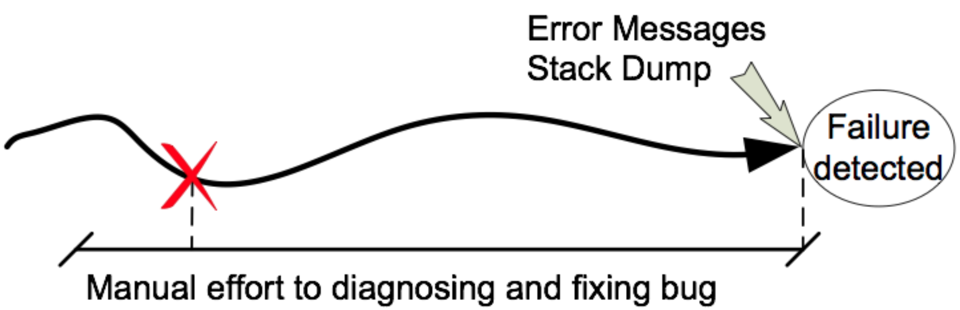
** Gartner, Hype Cycle for Cloud Computing, 2011 David Mitchell Smith Publication , 27 July 2011*

Achieving Resilient Cloud Computing

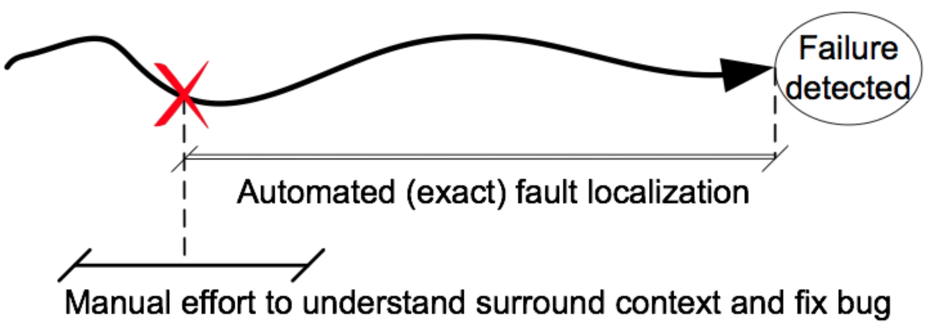
- Runtime failures inevitable
  - accidental errors
  - software bugs
  - malicious attacks
- Need efficient monitoring, detection, and recovery from runtime failures
- Need accurate failure diagnosis to enable system and application fixes
- *This talk* introduces a low-cost approach for approximate fault localization (and hence, failure diagnosis) in a distributed computing infrastructure such as cloud

Fault Localization/Failure Diagnosis

Manual inspection



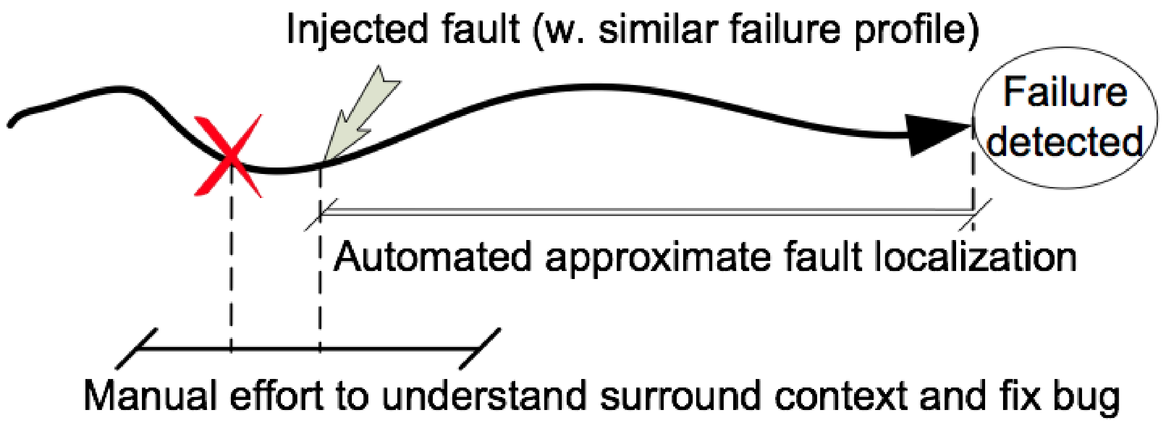
Automated (exact) fault localization



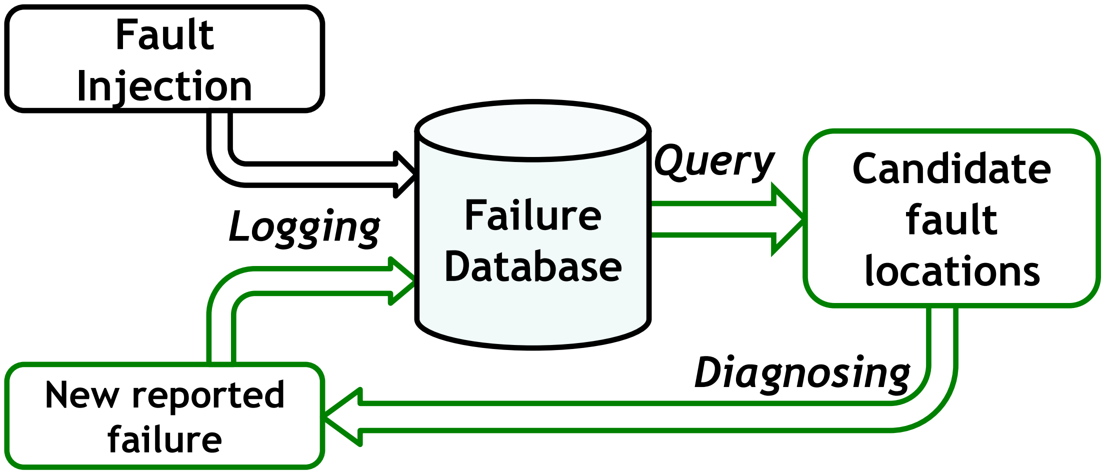
- Diagnosing a problem starts from certain locations indicated by failure profiles (e.g., error messages, a call stack)
- Trace backward through the execution flows to identify the origin of the problem
- Attempt to identify exact fine-grained locations (e.g., at program statement level) of failure's root causes
- Prohibitively expensive, particularly in large distributed systems, such as cloud infrastructure

X – root cause location

Approximate Fault Localization: Concept

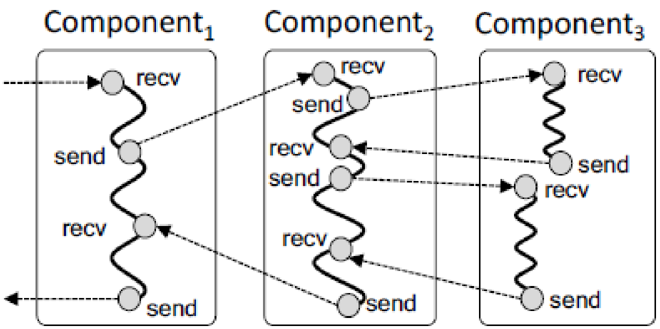


Assumption: Similar failure profiles imply similar faults



Approximate Fault Localization: Approach

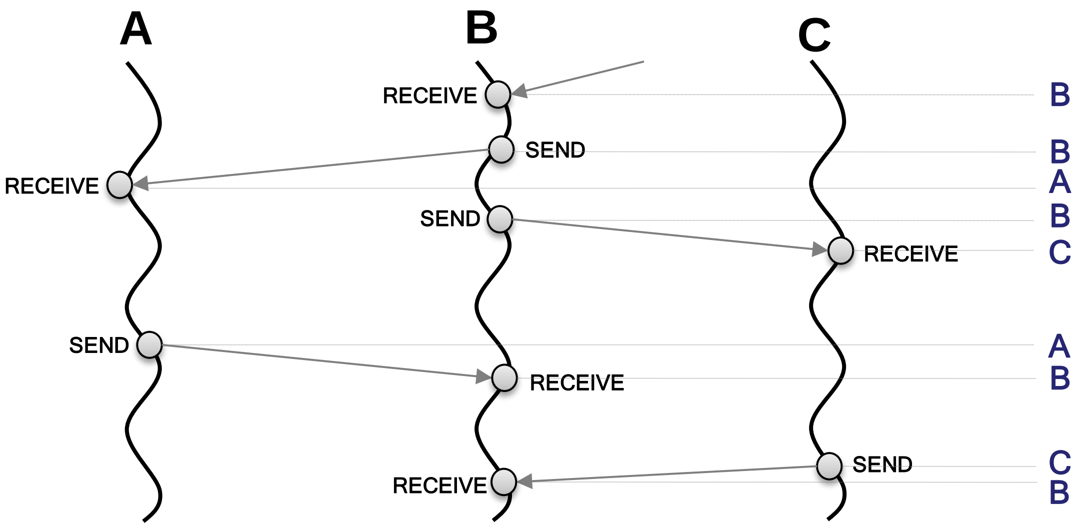
- Upon a failure in a system collect a failure profile
  - e.g. in terms of *sent* and *received* messages
- Process failure profile to reconstruct an end-to-end processing flow corresponding to the failure



  - a sequence of system events across distributed components invoked to process a user/application request
- Use the reconstructed processing flow to query against a pre-constructed failure profiles stored in Failure Profiles Database
  - Use "string edit distance" metric to identify similar flows and "pinpoint" the fault location

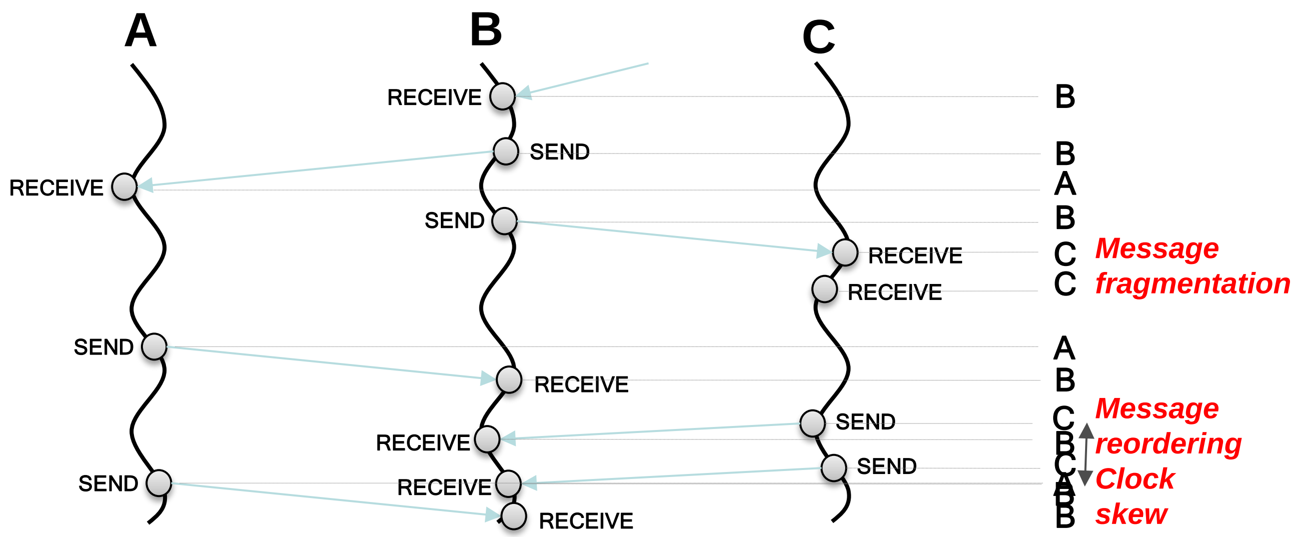
Message Flow Reconstruction and Comparison

- Need to represent event flows so to enable fast identification of similar flows
- Event flows translated into event strings



  - an event in a string represented as a letter that corresponds to the source component of this event, e.g., ***BBABCABCB***
  - event order based on timestamps
- Compare flows using *String Edit Distance*
  - the minimum number of insertion, deletion, or replacement of a letter required for changing one string into the other

Example: Edit Distance



Run 1 → ***BBABCABCB***

Run 2 → ***BBABCCCBAB***

→ ***Edit Distance = 5***

Enabling Techniques

- Distributed Events Tracing

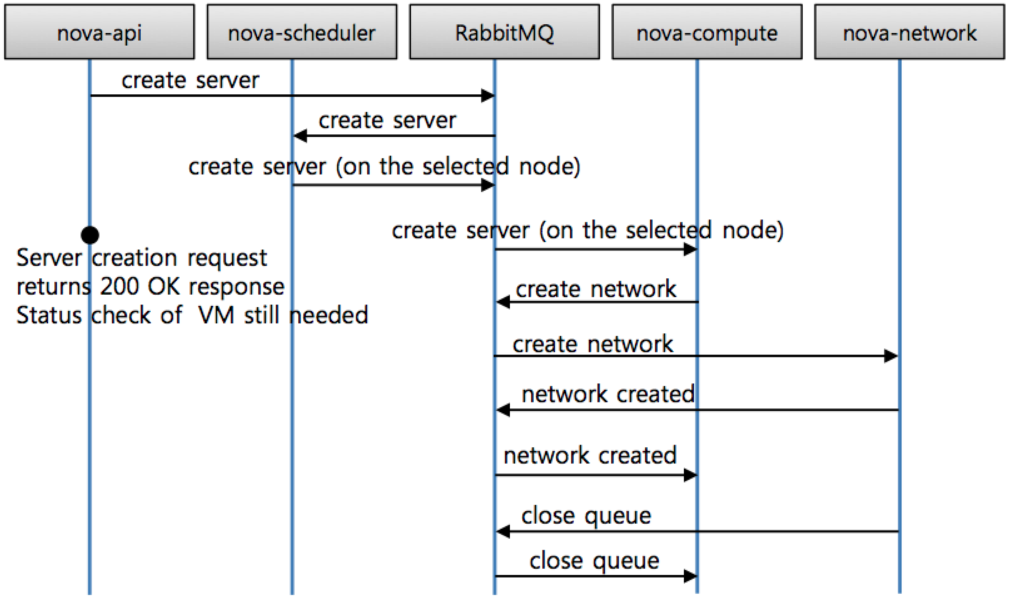
  record system events (e.g., syscall, library call) in distributed systems

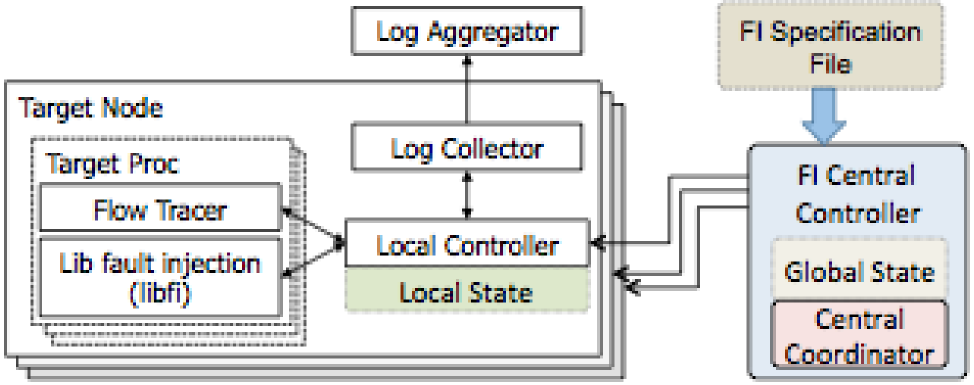
- Message Flow Reconstruction and Comparison

  quantify the dissimilarity between failure profiles

- Targeted Fault Injection

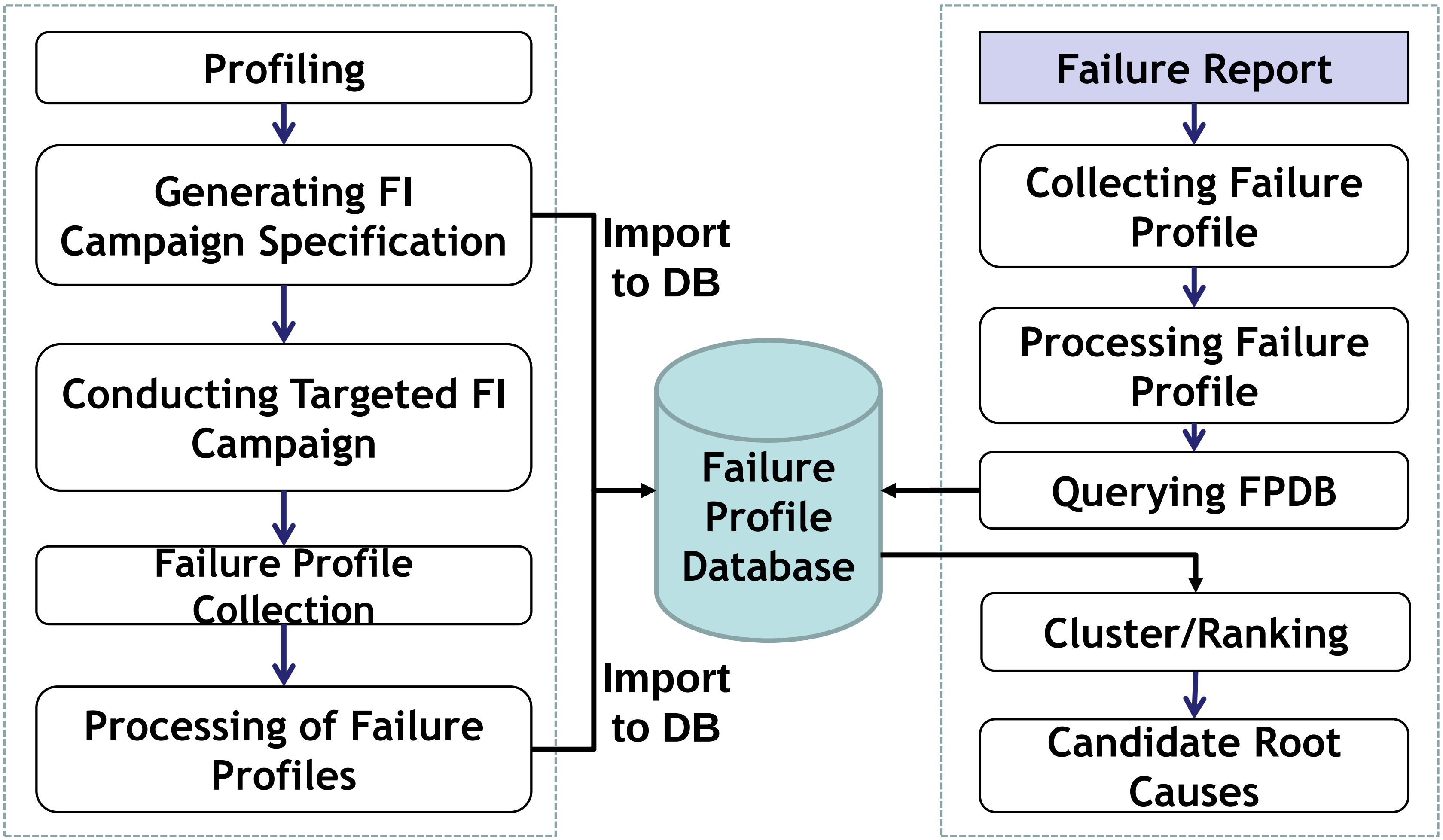
  deterministically inject faults at exact locations in the execution flow of a distributed system





Framework Overview

Failure Database Construction **Fault Localization Process**



Data Cleanup

- Collected end-to-end flows must be cleaned up to remove non-deterministic events
  - system noise, i.e., periodic messages such as heartbeats
  - message fragmentation,
  - out-of-order messages
- Non-determinisms in the processing flows make trace comparison non-trivial
- In order to automate the diagnosis we assume that
  - processing of a request is deterministic

Targeted Fault Injection

- Allows inserting faults precisely at the intended location
  - Based on the processing flow of each request as the request traverses multiple components
- Minimize side effects to target systems
  - Non-intrusive - no source code modification required
  - Fast and light weigh communication between FI components
- Precise tracking and synchronization of event sequences
  - Catch system level events (e.g., libc function calls)
  - Global synchronization when an event is captured
- Easy to use
  - Compact, reusable specification to define FI experiments

Targeted Fault Injection Approach

Pre-Injection Analysis → **FI Specification** → **Fault Injection Campaign** → **Results**

Pre-Injection Analysis: Profile the system under workloads to identify injection points and causal event sequences

FI Specification: A specification for defining precise fault injection scenarios

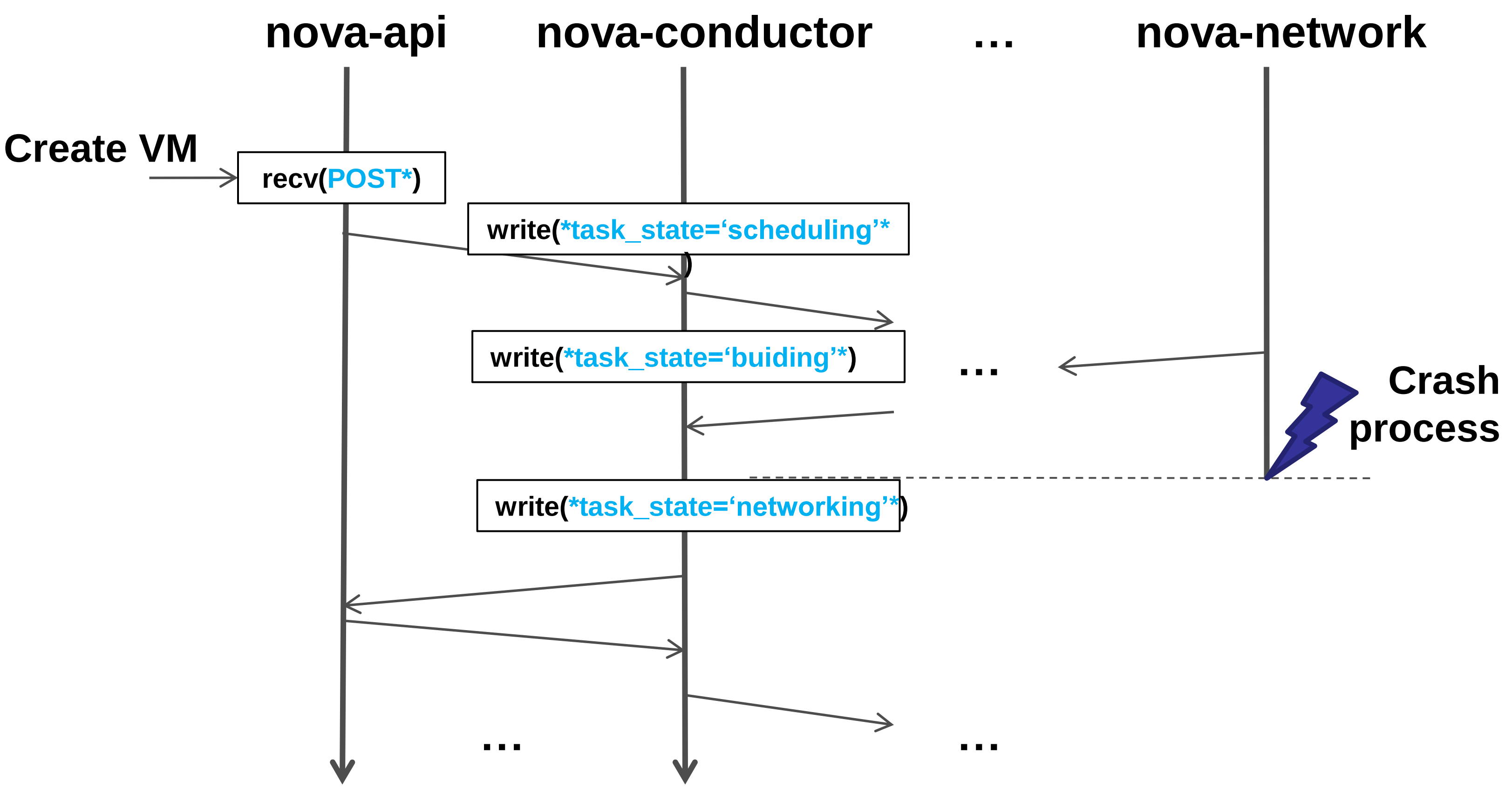
Fault Injection Campaign: Execution of automated FI experiments

Results: Failure profile database, Reliability assessment

Inserting faults at precisely specified execution points

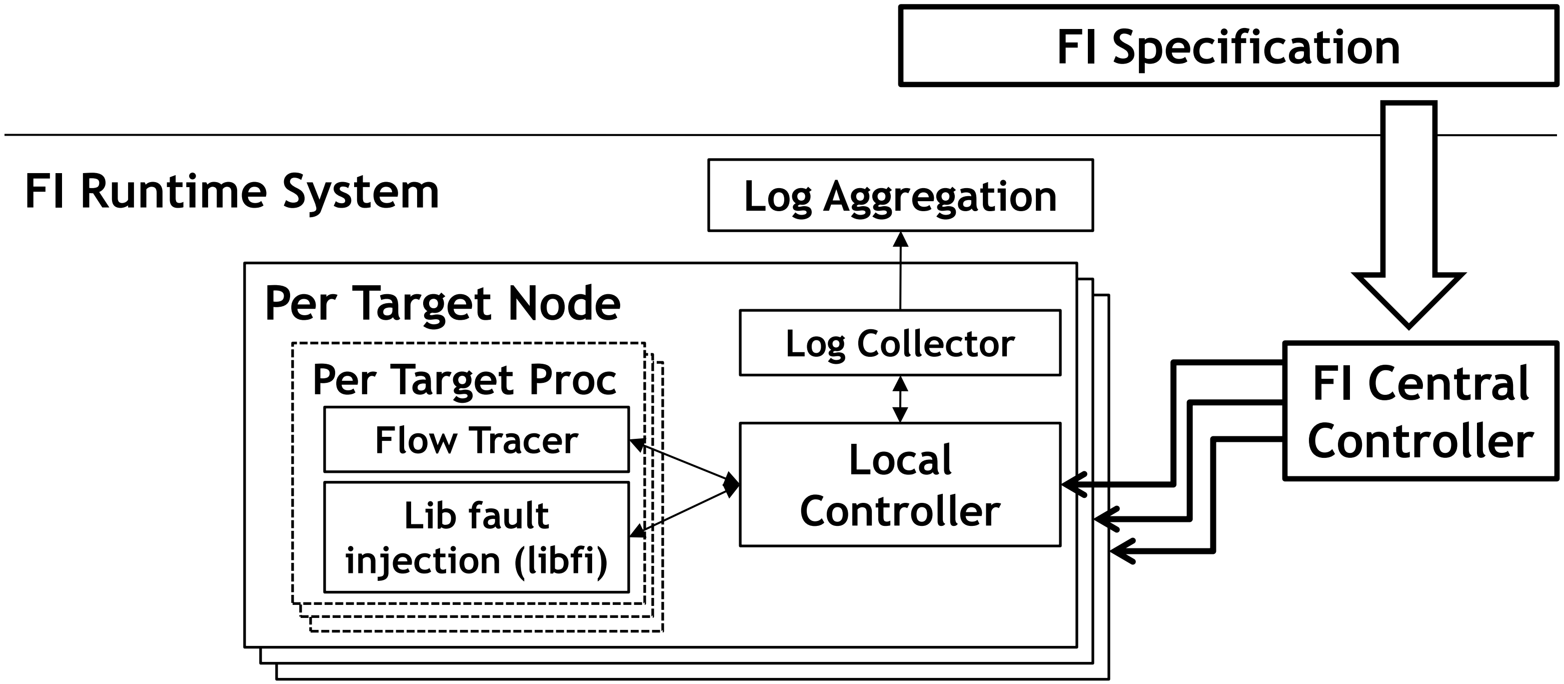
Example Processing Flow and Fault Injection

On **creating VM** request, before the request state changes to "**networking**", **inject a crash** to the **nova-network** process



System Architecture

- *Target Applications:* multiple processes across multiple nodes
- Each node: One *Local Controller*
- Each process: One *Injector (libfi)*, one *Flow Tracer*
- *FI Central Controller* operates in an event-driven fashion to drive the injection



Evaluation

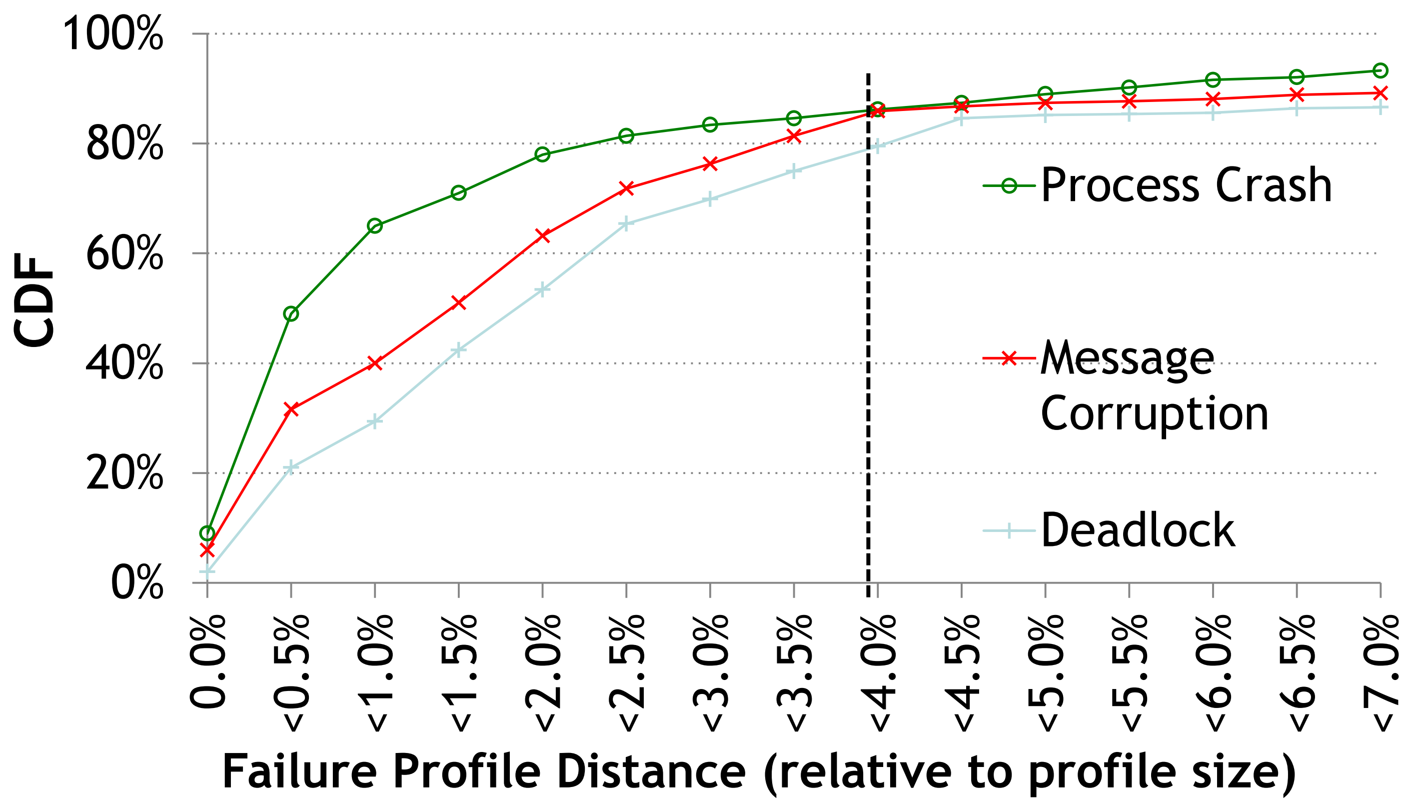
- *Target:* OpenStack, an open source distributed cloud management system
- *Validation*
  - Do similar failure profiles imply similar faults?
- *Evaluation of AFL Accuracy*
  - Identification of fault type and affected component(s)
  - *Fault distance* between the determined fault location and the actual injected fault (Top-K nearest faults)
    - fault distance measured as the number of *libc* calls between the determined approximate fault location and the actual fault location in the end-to-end flow of fault-free execution

Construction of Failure Profile Database (FPDB)

Fault Type	Location Type	$\|\mathbb{F}\|$	$\|\mathbb{FP}\|$
Process Crash	All monitored libc calls	23323	116589
Message Corruption	All *read*, *write*, *send*, and *recv* libc calls	18221	91092
Deadlock	All thread and lock related libc calls	2143	10702

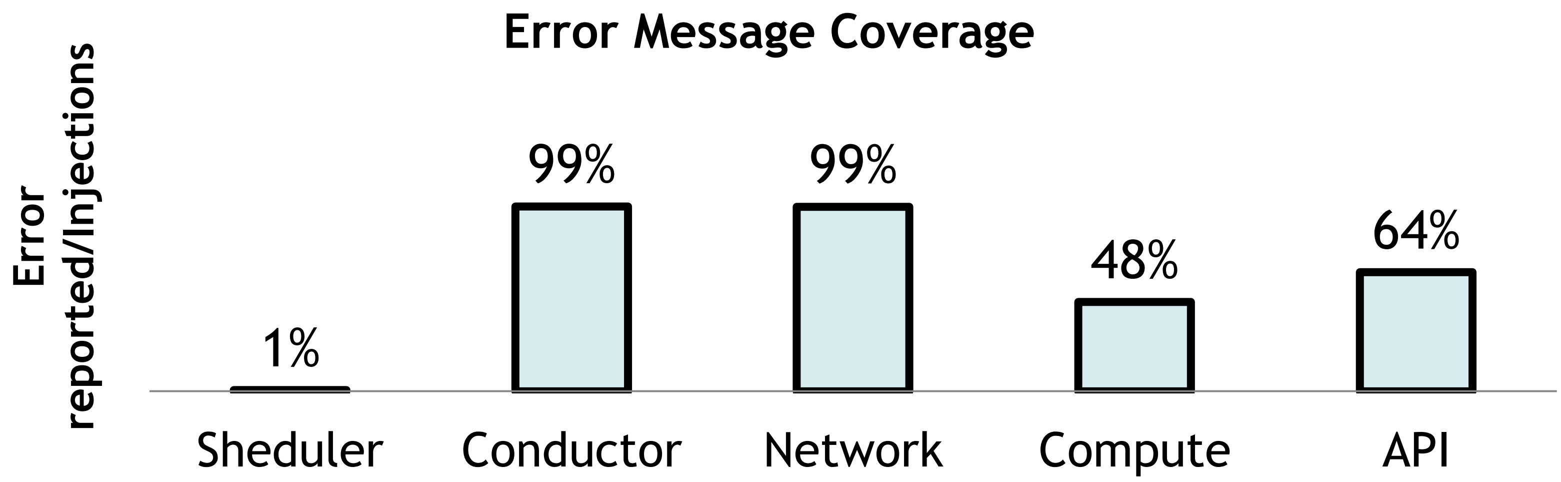
- The FPDB is constructed for VM Provision (nova boot) requests
- Five failure profiles collected for each fault
- Fault models:
  - Contained faults: *Process crash*, *deadlock* (within a process)
  - Propagated faults: *Message corruption*

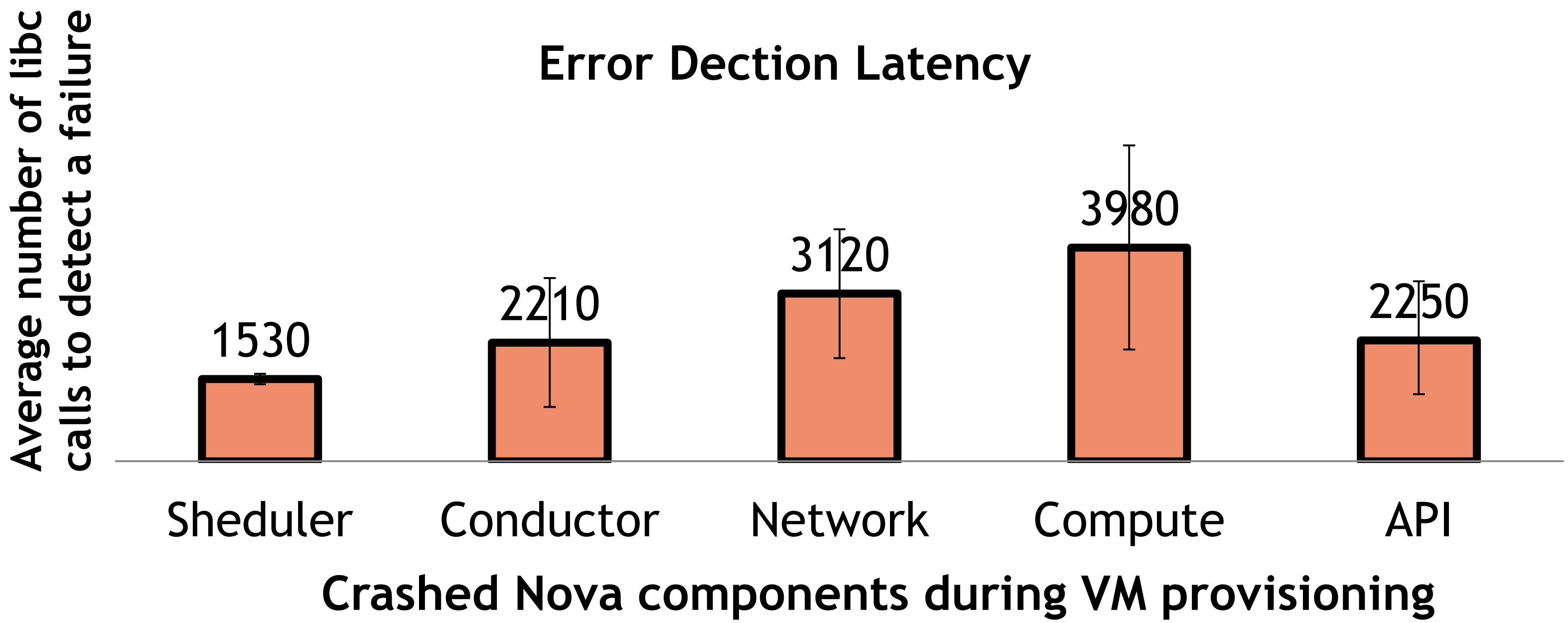
Do Similar Failure Profiles Imply Same faults?



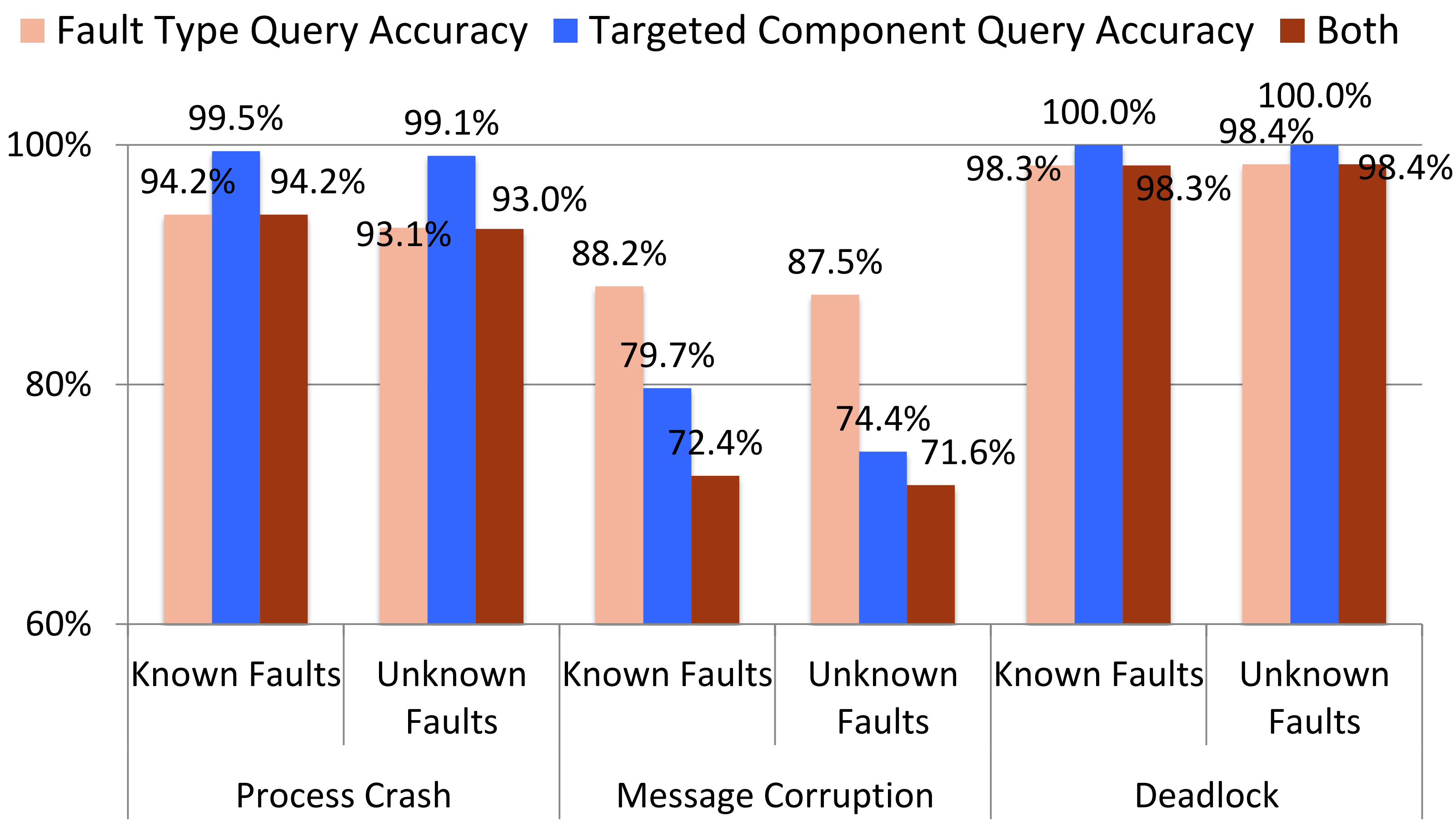
More than 80% of all the injected faults, across all three fault models, result in less than 4% of the failure profile variation

OpenStack Error Reporting





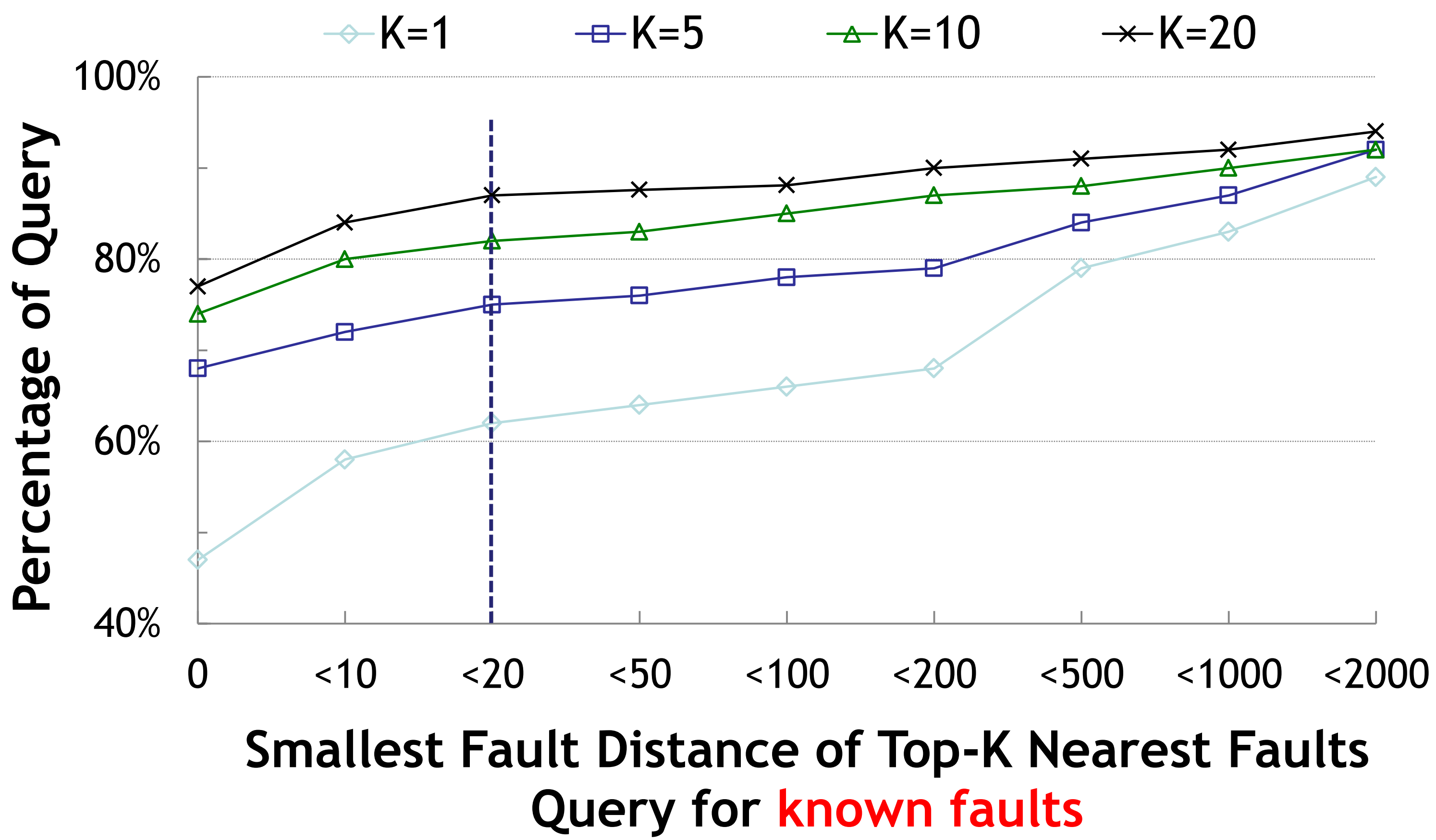
Accuracy of AFL: Determining Fault Type and Affected Component(s)



Known fault: a fault that has at least one failure profile in failure database

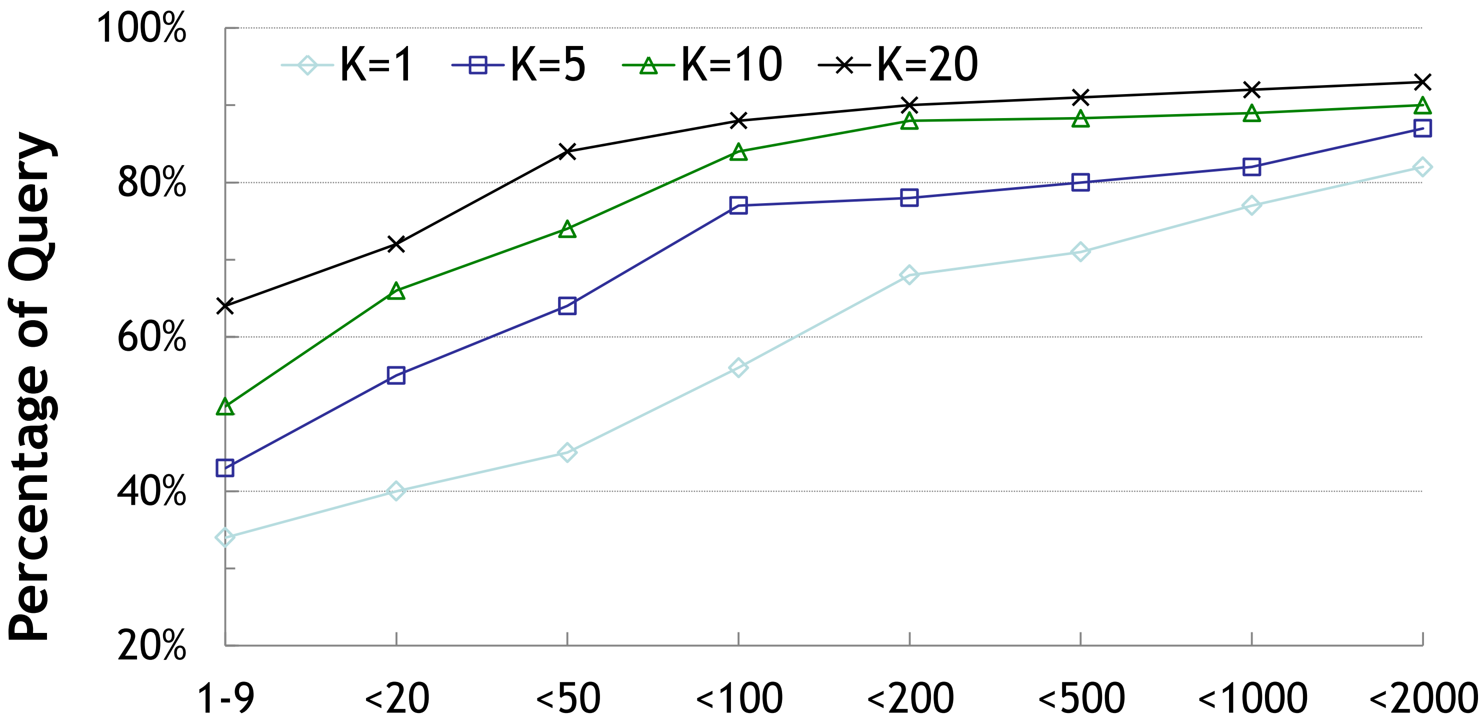
Unknown fault: a fault that does not have any failure profile in failure database

Accuracy of AFL: Top-K Nearest Faults for Known Faults



50% of the Top-1 query results contain the exact fault locations, i.e., **fault distance is zero**

Accuracy of AFL: Top-K Nearest Faults for **Unknown Faults**



Smallest Fault Distance of Top-K Nearest Faults Query for unknown faults

Two orders of magnitude better than OpenStack's error reporting mechanism

Conclusions

- Develop low-cost method for the approximate fault localization
  - reduce the cost of fault diagnostic while providing precision close to the methods used for the exact fault localization
  - support large complex distributed environments such as the cloud computing
- Demonstrate effectiveness of the prototype implementation on the OpenStack
  - effective in determining (approximate) fault/error locations
  - highly accurate in identifying the failure types and the affected components

Sponsors and Other Collaborators

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