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ErrorPrism: Reconstructing Error Propagation Paths in Cloud Service Systems

Junsong Pu[1], Yichen Li[3], Zhuangbin Chen✉[1], Jinyang Liu[3],

Zhihan Jiang[2], Jianjun Chen[3], Rui Shi[3], Zibin Zheng[1], Tieying Zhang[3]

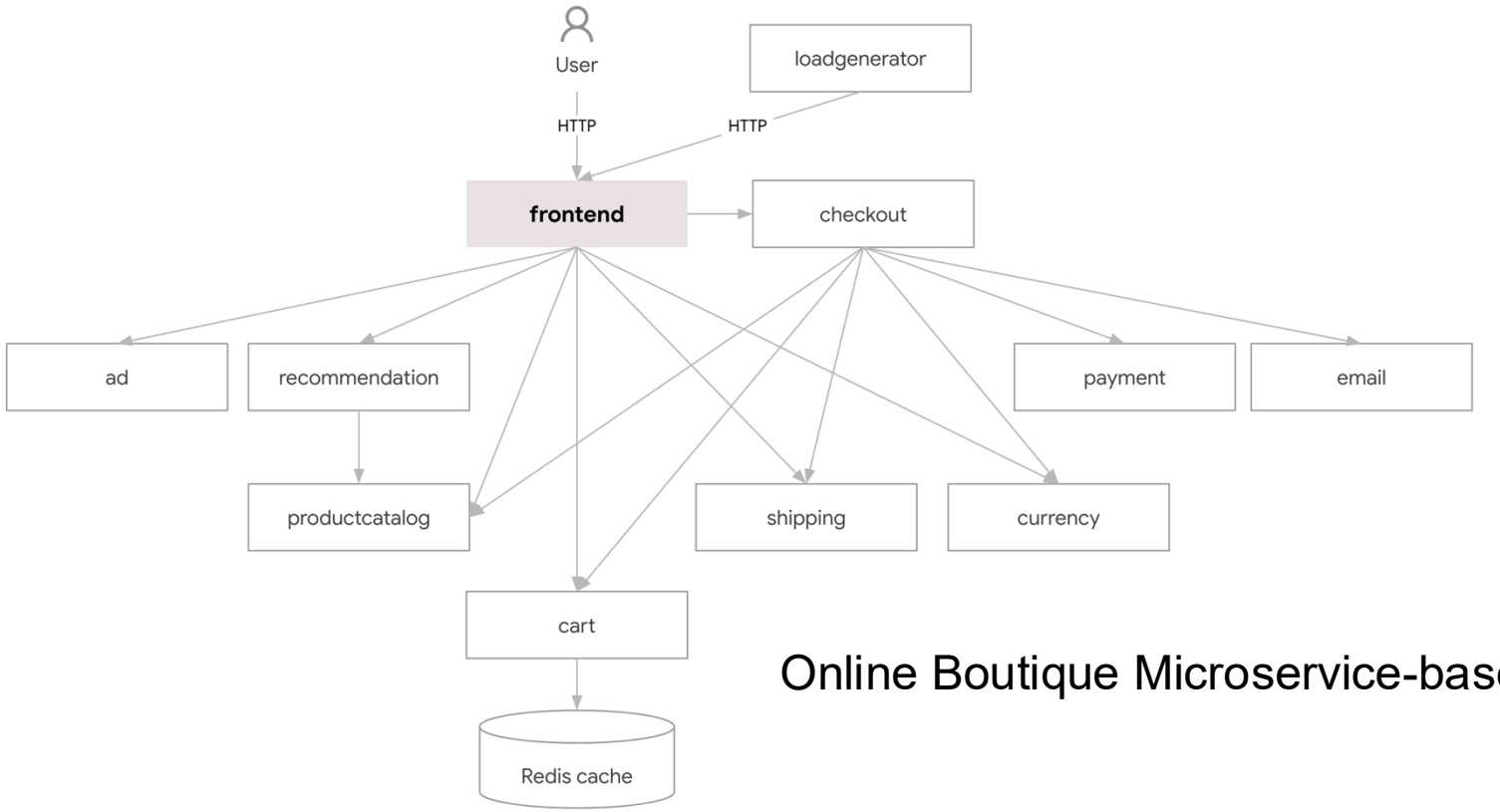
[1]Sun Yat-sen University

[2]The Chinese University of Hong Kong

[3]ByteDance

Cascading Failures in Cloud Systems

- Modern cloud systems are built on **Microservices**
- This architecture is scalable, but failures are complex and interconnected
- How are these cascading errors handled and reported at the code level?



Online Boutique Microservice-based Application

Figure source: https://github.com/GoogleCloudPlatform/microservices-demo

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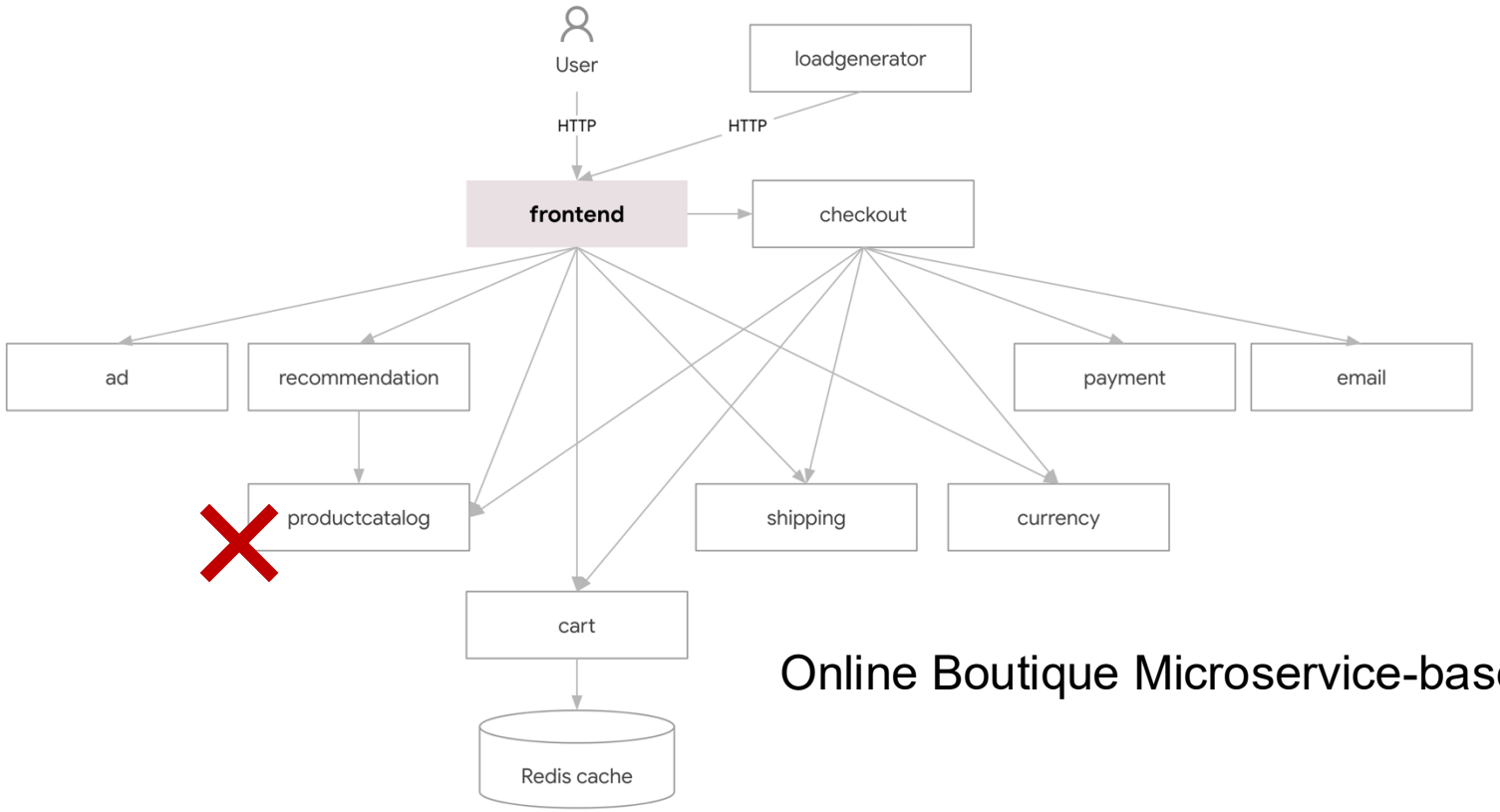

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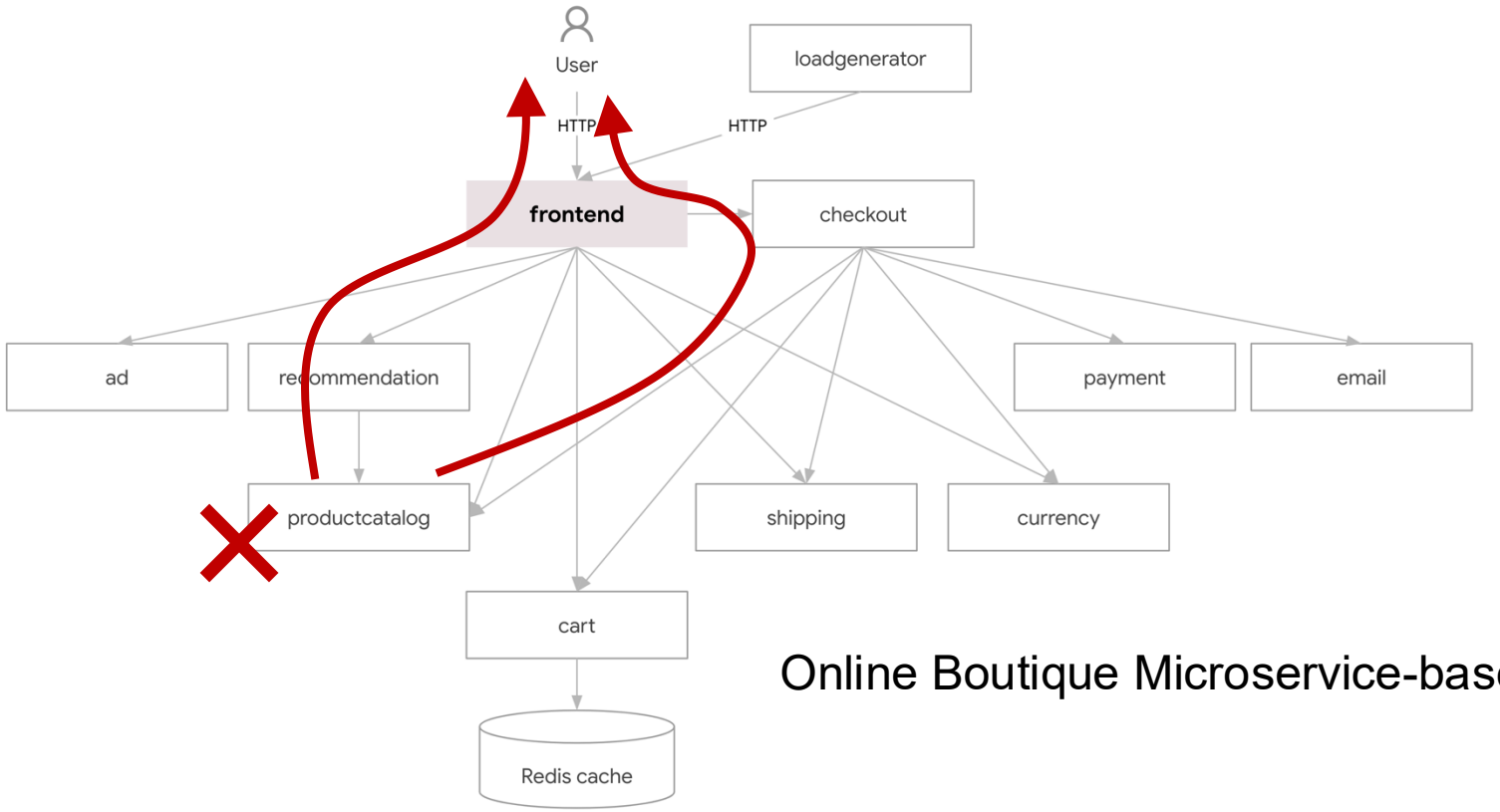

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Error Wrapping Mechanism

- Modern languages (*e.g.* **Go** and **Rust**) treat errors as **explicit return values**, instead of exceptions as in Java and Python
- **Error Wrapping** mechanism allows functions to add context to *any* error

```
func ReadRemoteFile() (string, error) {
    data, err := remote.ReadFile("config.txt")
    if err != nil {
        return Err: "file read error: %w", err
    }
    if len(data) == 0 {
        return Err: "parsing: empty file"
    }
    return string(data), nil
}
```

```
func runApp() error {
    content, err := ReadFile()

    if err != nil {
        return Err: "failed to load config : %w", err
    }
}
```

```
func main() {
    // ...
    if err := runApp(); err != nil {
        Log "immigration failed: %w", err
    }
}
```

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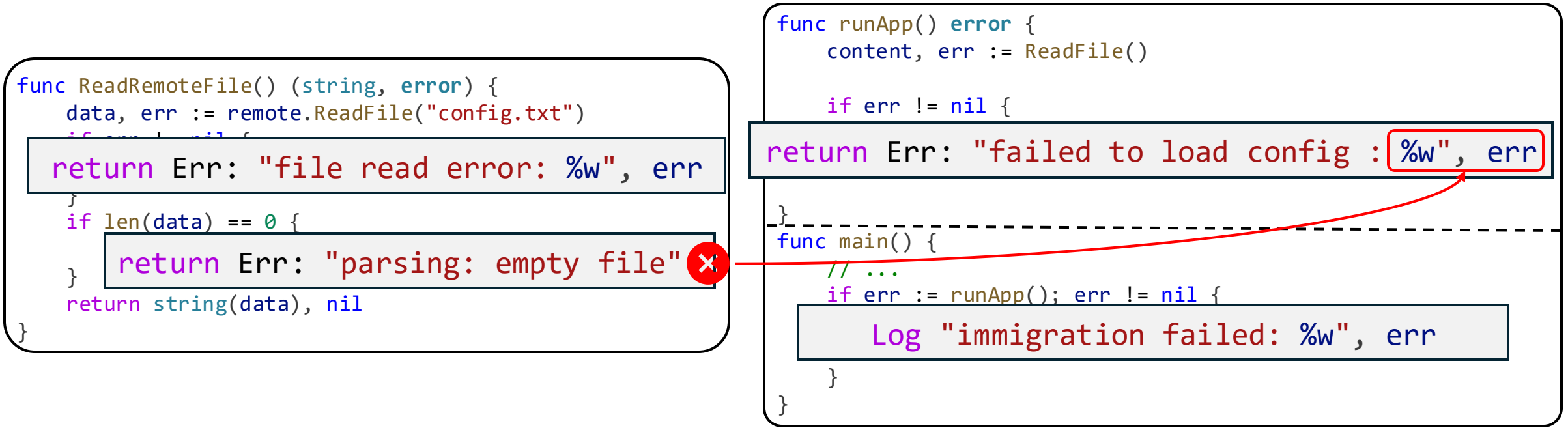

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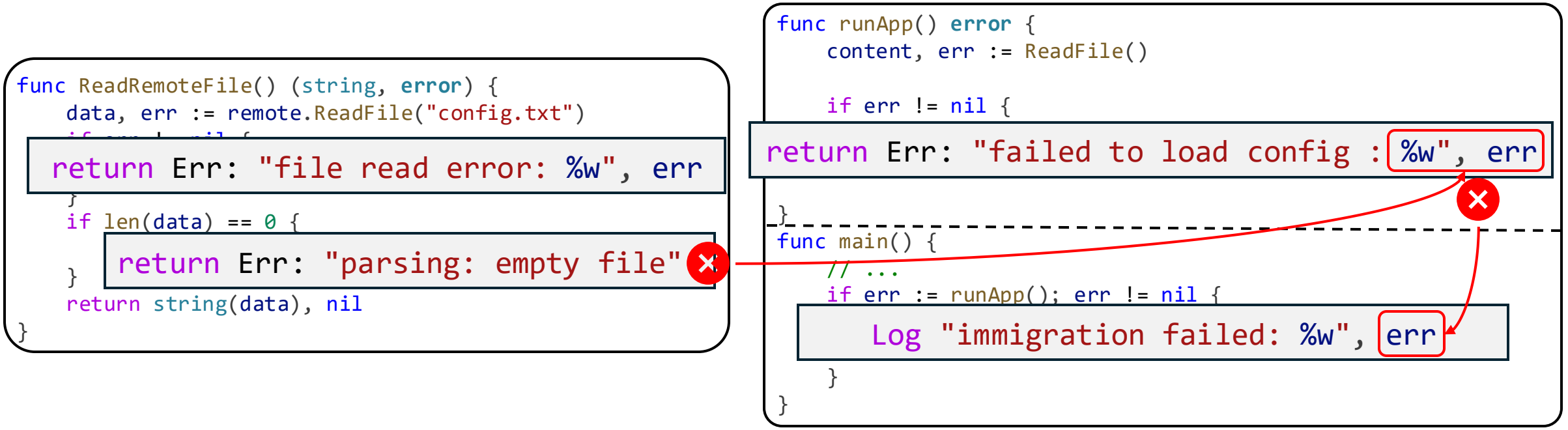

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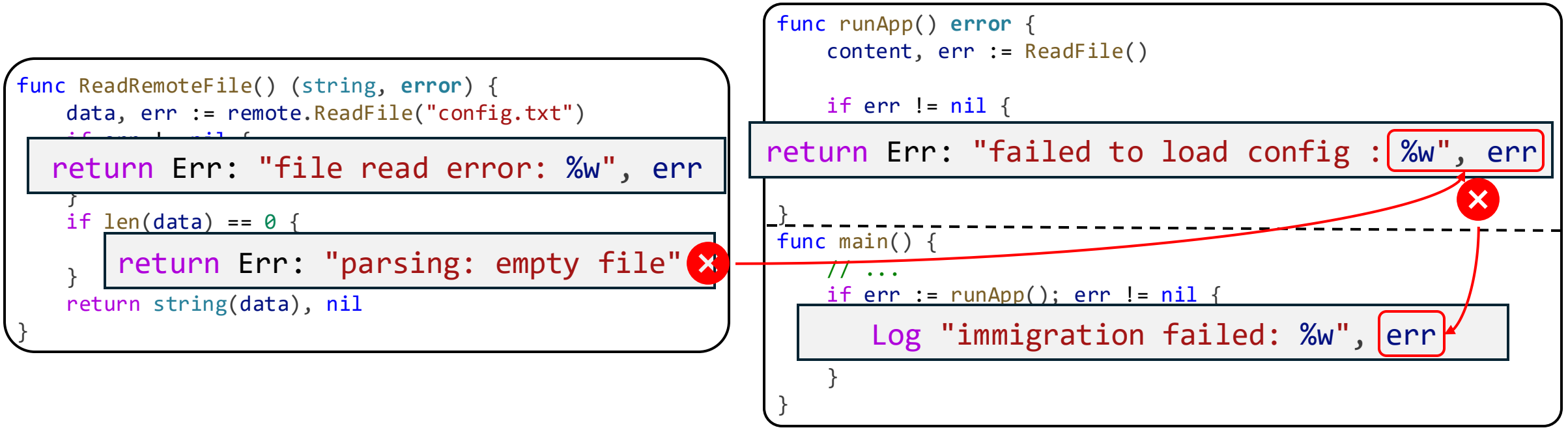
- The error propagation chain precisely describes a failure with structured context from its technical origin to its business impact



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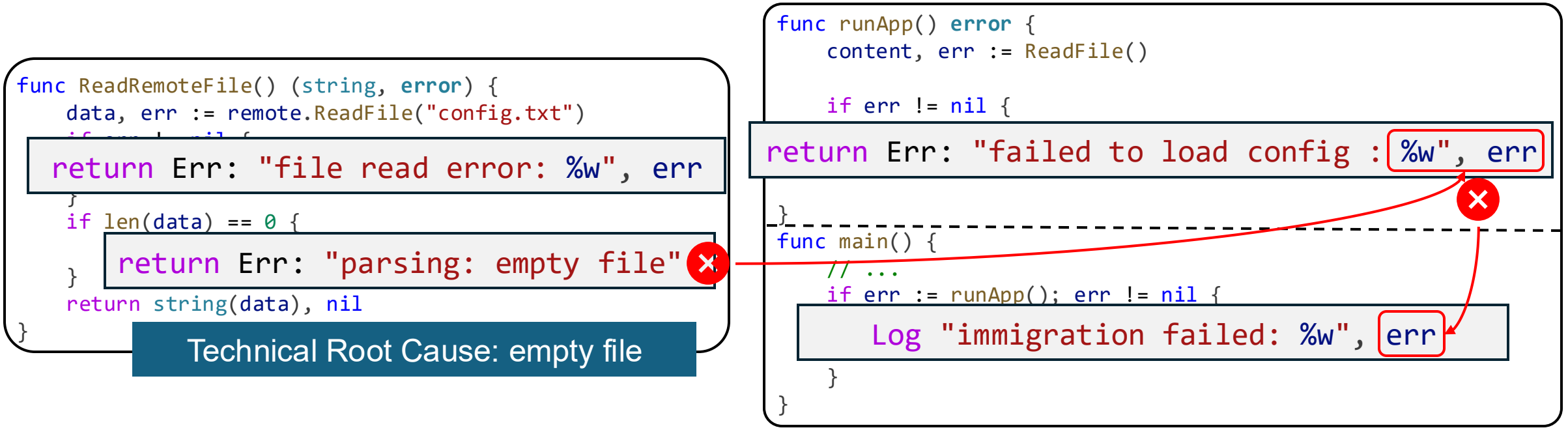

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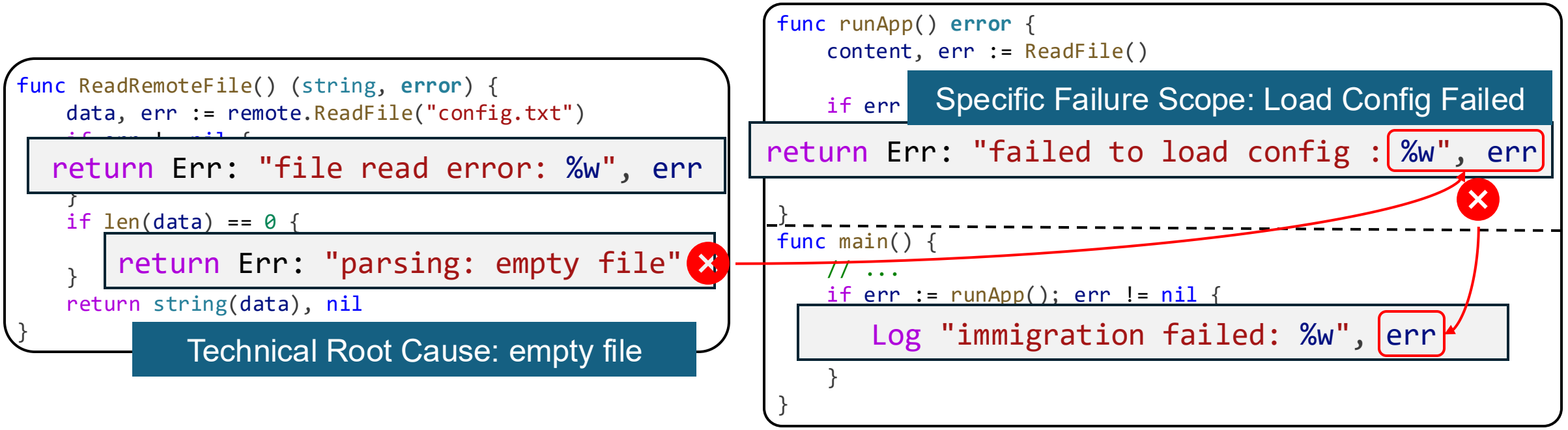

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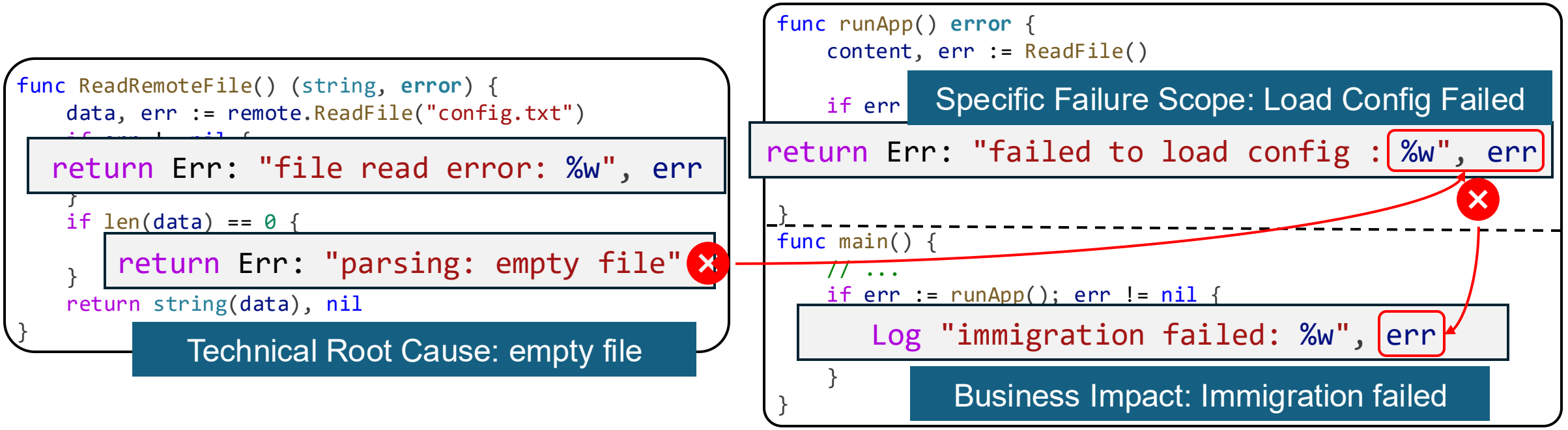
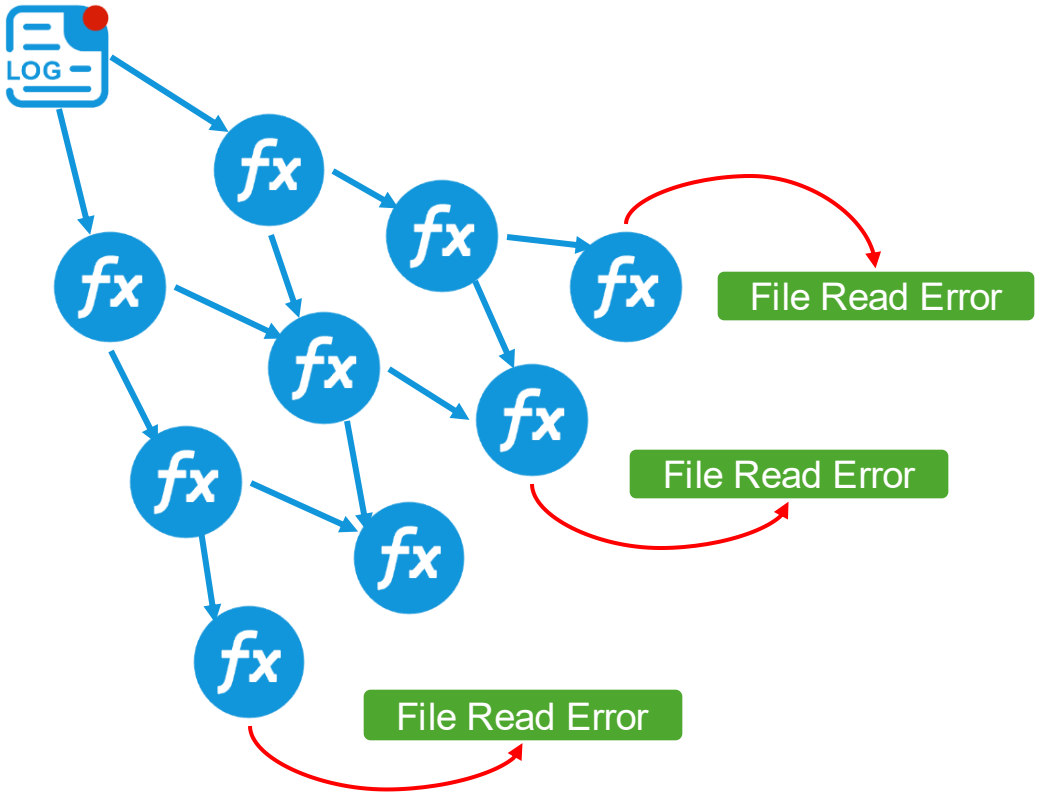


New Problem: **Error Obfuscation**

- **Definition**: The final error chain which includes context from *multiple functions*, is flattened into a single log string that **hides the runtime path*** in the final service.



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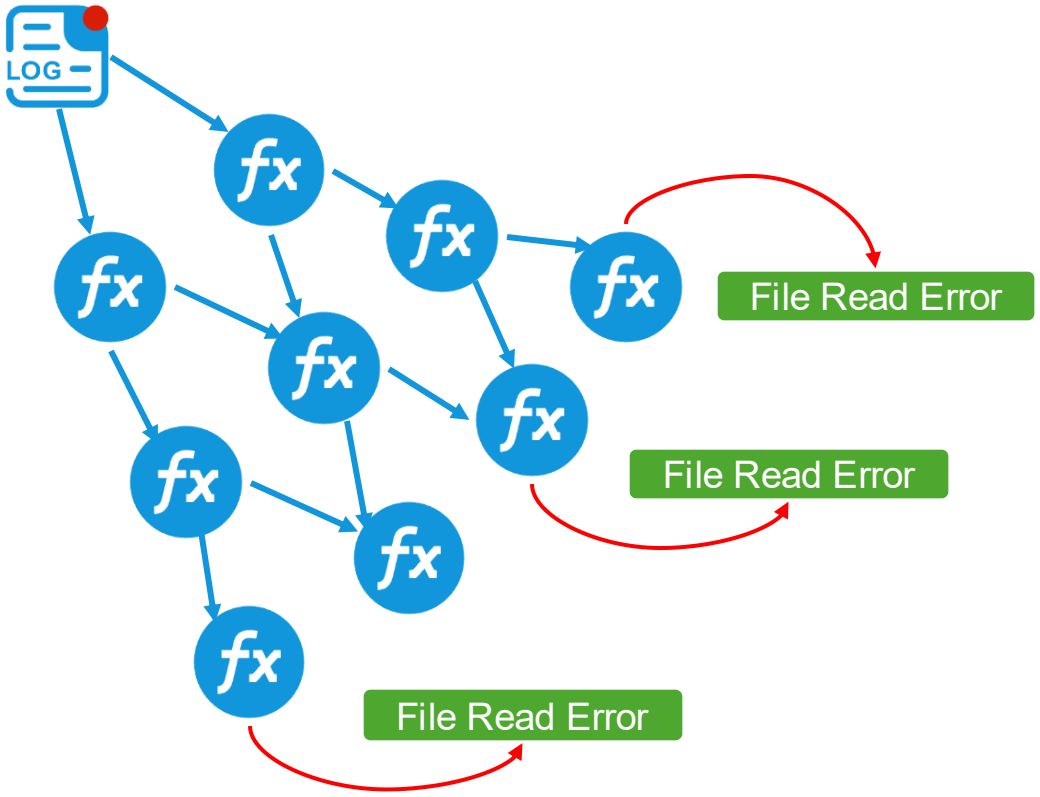

Example Error Message:

Immigration failed: failed to load config:
file read error: <*>

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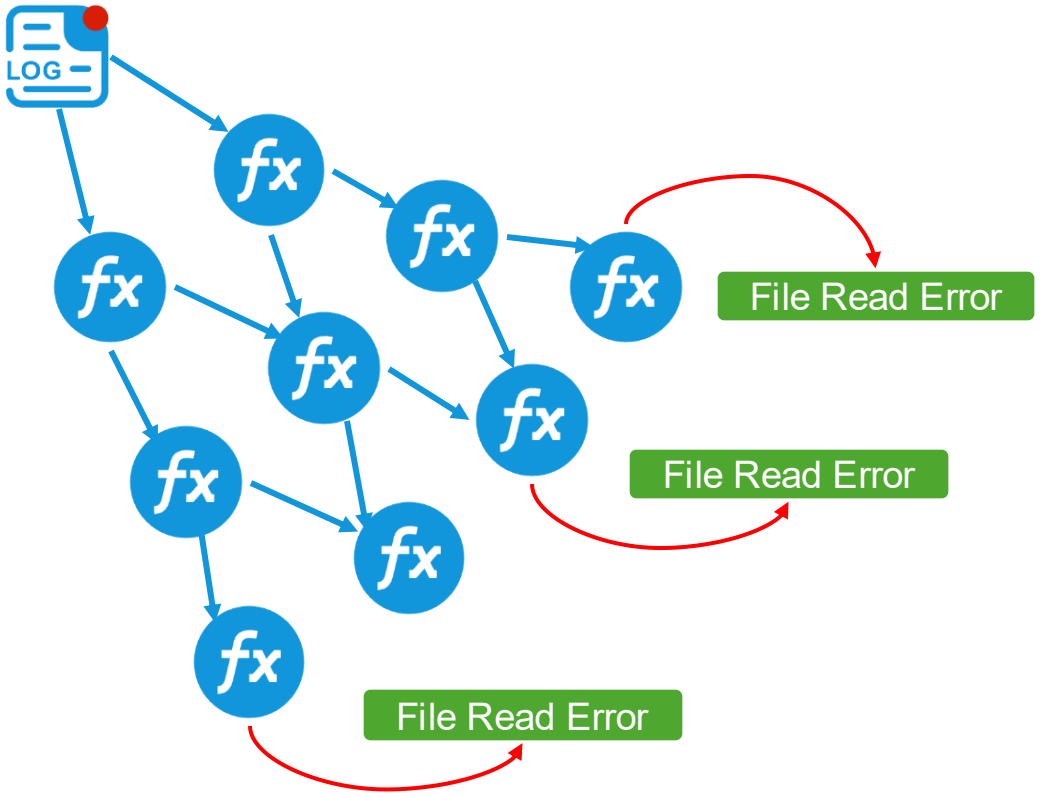

Example Error Message:

Immigration failed: failed to load config: **file read error**: <*>

There is too many paths that could lead to a file read error !

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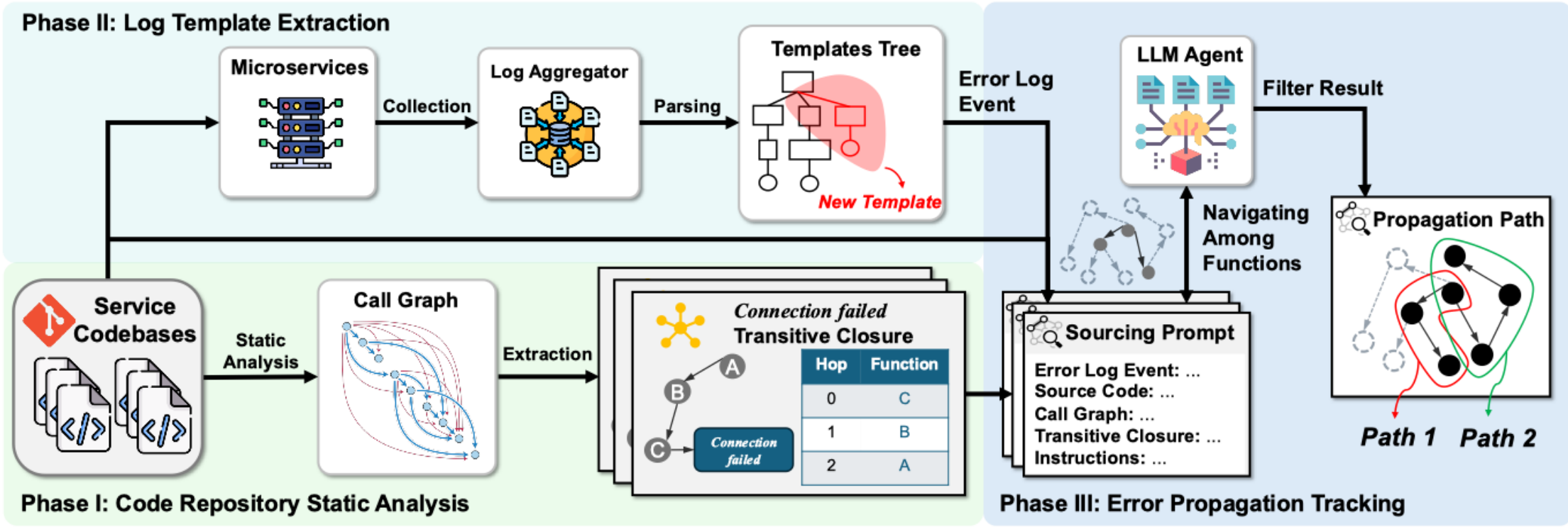
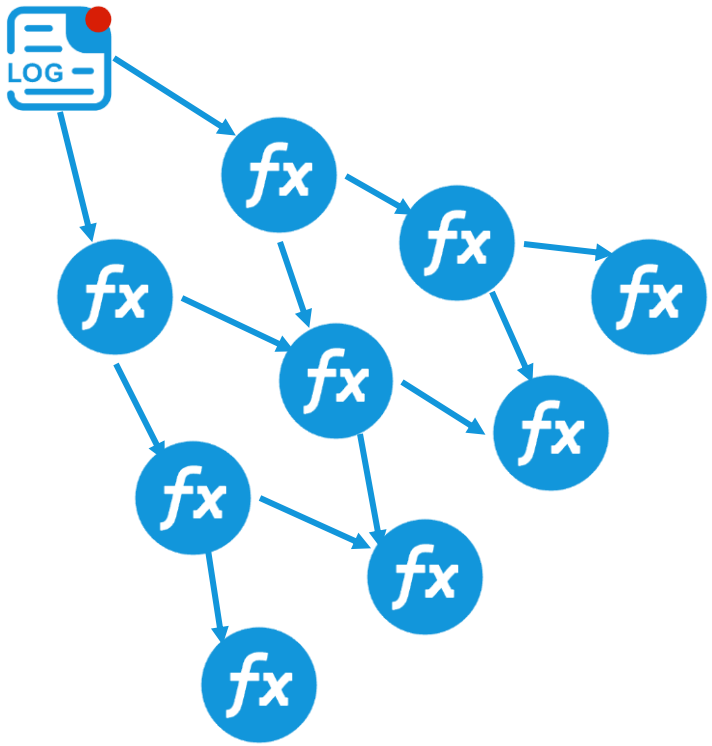
ErrorPrism: Overview



Offline (Phase I): Perform a one-time static analysis on selected functions to build a call graph and an error-string index

Online (Phase II & III): When a new log event is extracted, LLM agent uses pre-computed error-string index and call graph to perform a semantic, backward search and reconstruct the final error path

Static Analysis



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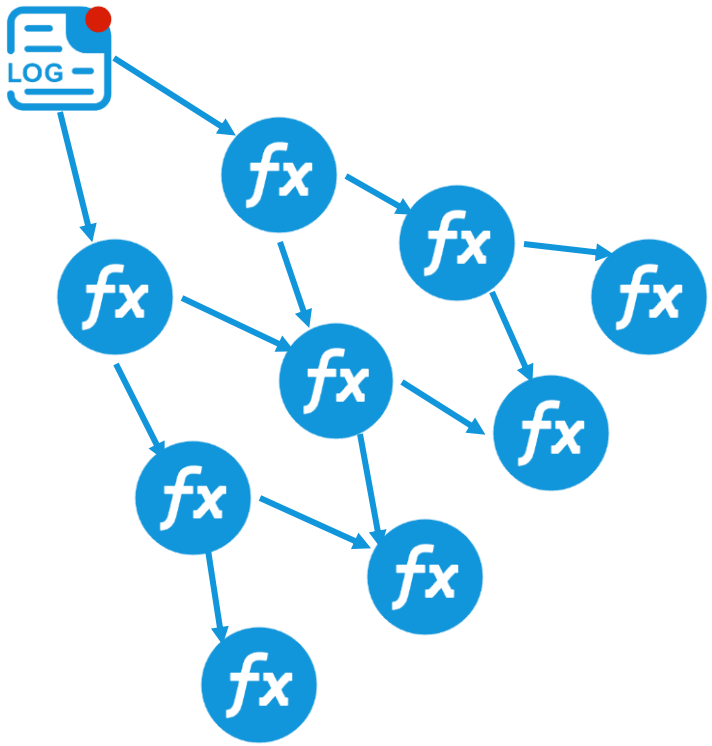

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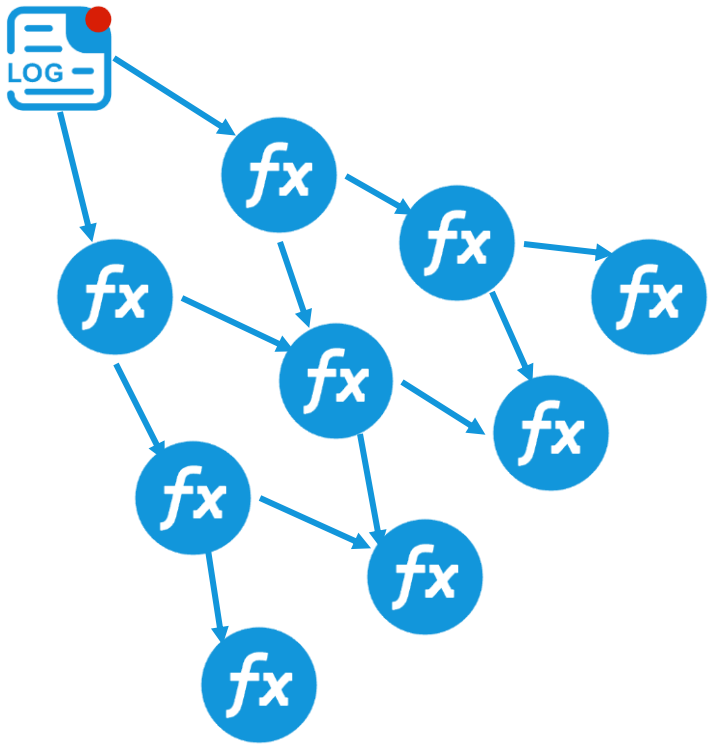

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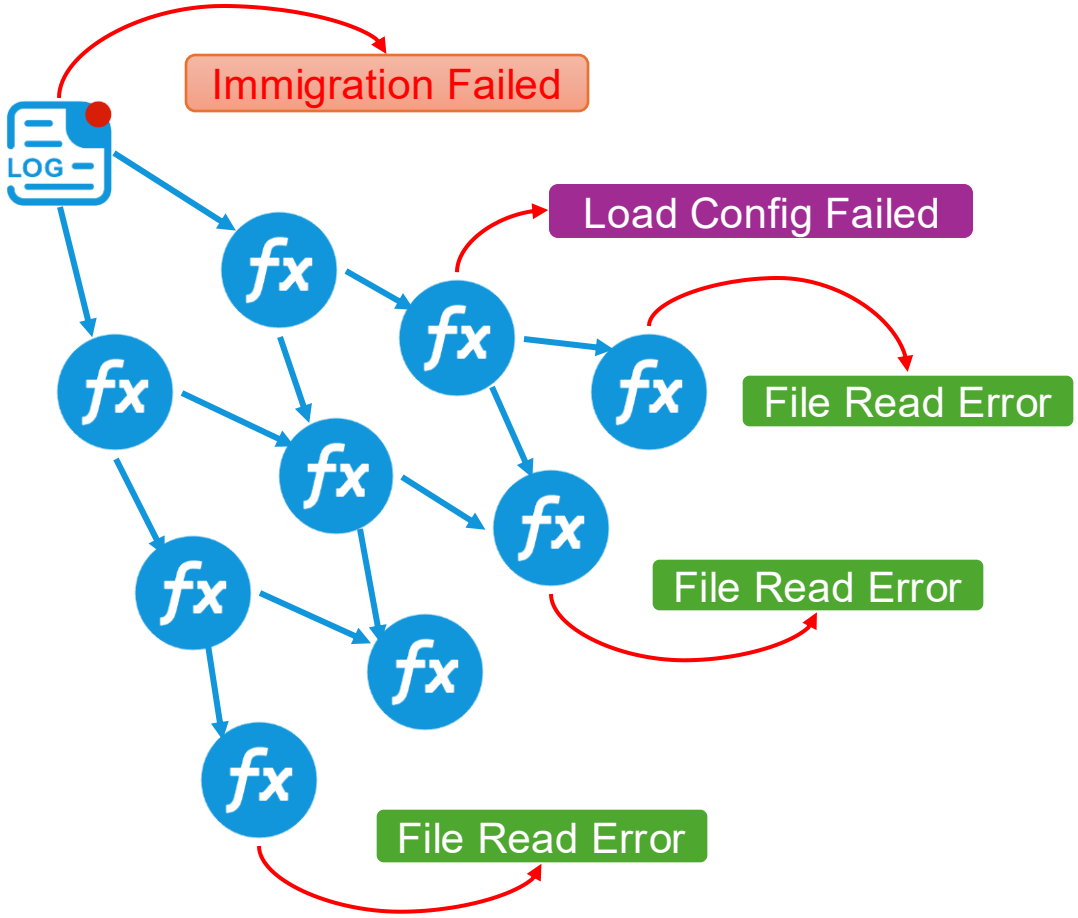

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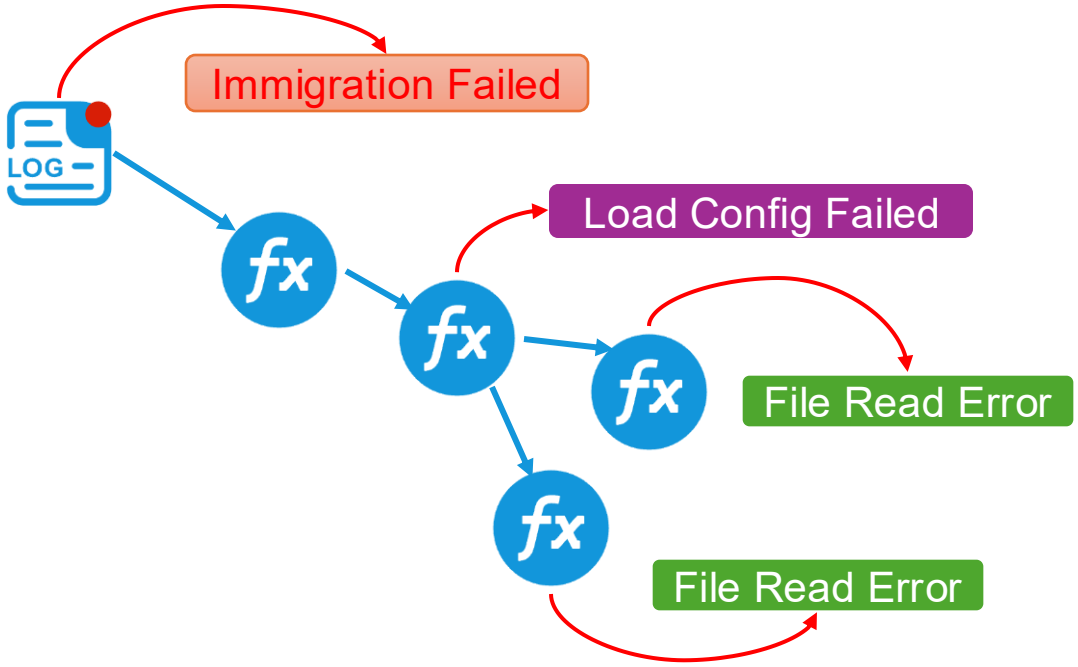

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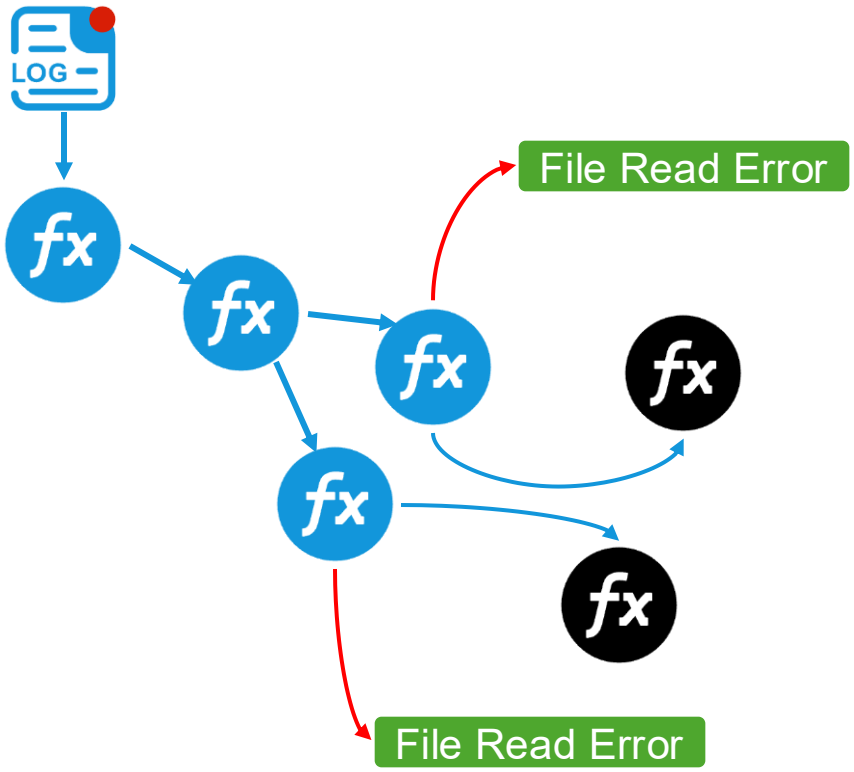

However, there can be multiple paths are structurally possible

Static analysis can't understand the intent of the code, so it gets stuck.

Error Templates:
Immigration failed: failed to load config: file read error: Failed to fetch cluster configuration…(**NOT IN INDEX**)

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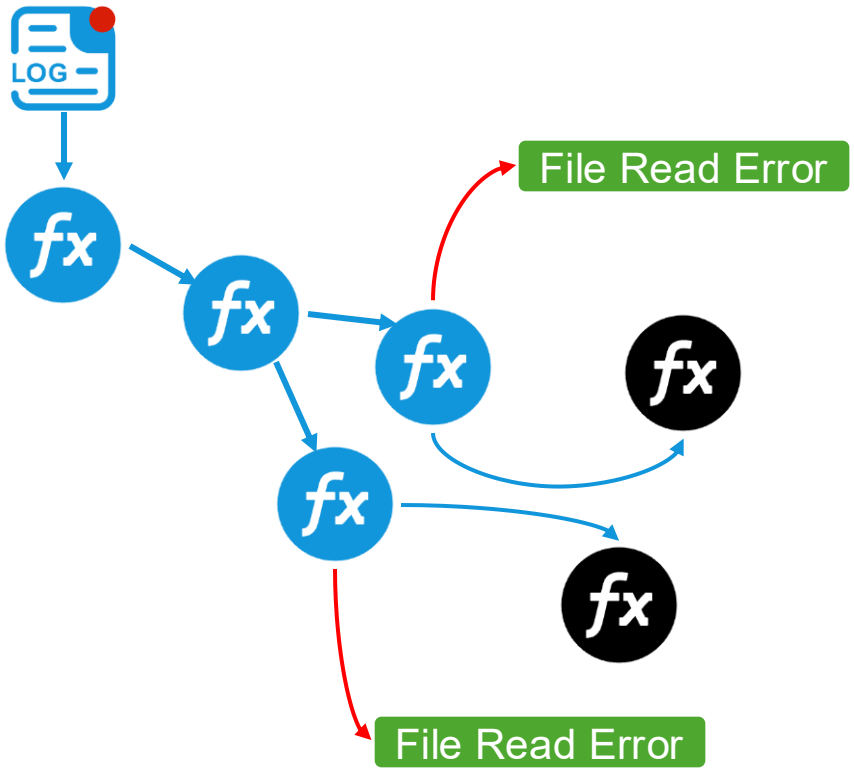

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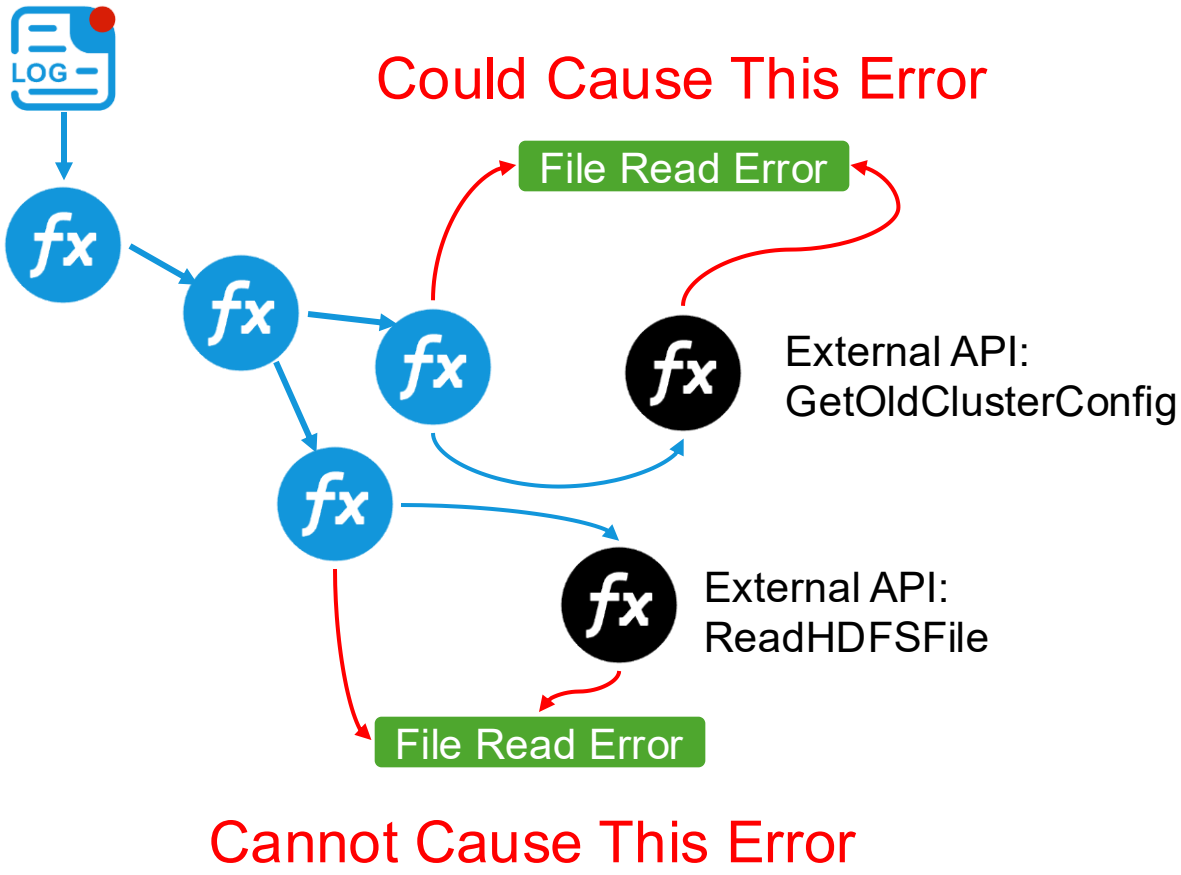

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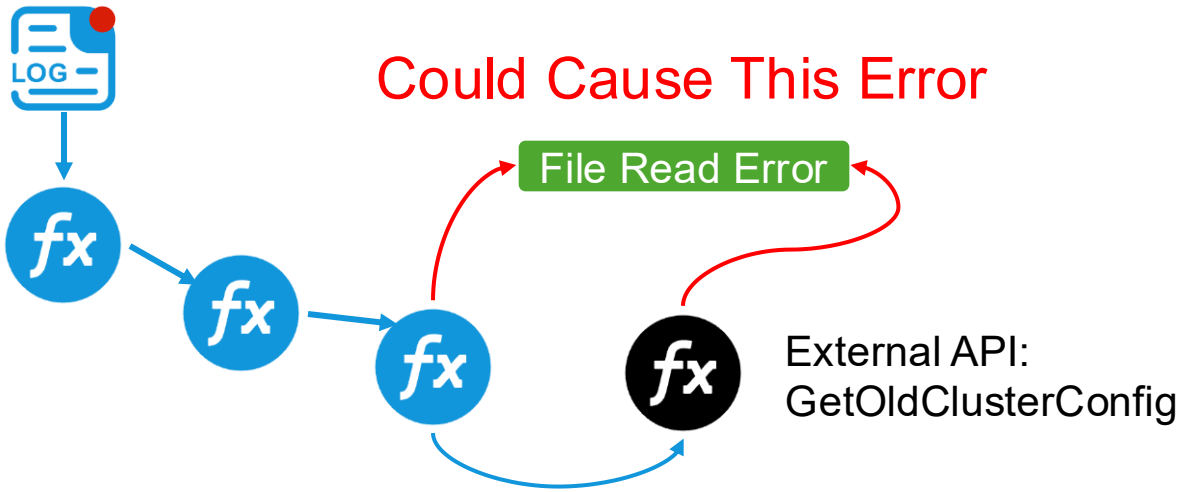

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Evaluation: Dataset Construction

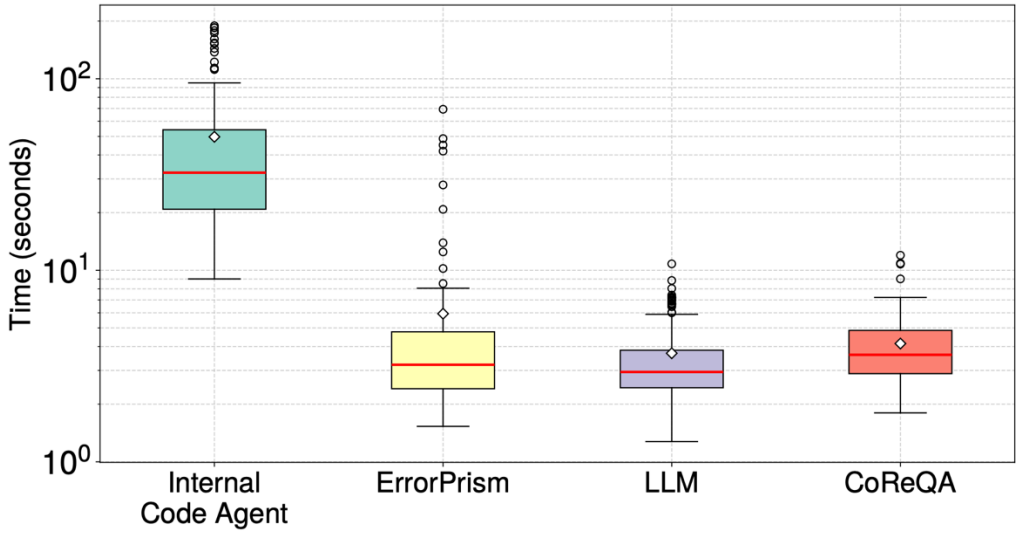
- **Environment:** Tested on a large-scale production platform at ByteDance.
- **Scope:** Analyzed **67** microservices, **~1 millon LOC** of Go code.
- **Ground Truth:** Manually collected and verified **102 real-world error events**.
- **Verification:** For each of the 102 events, engineers meticulously traced and recorded the complete, correct propagation path by hand.

Evaluation: Results

- **RQ1 (Accuracy*): ErrorPrism achieved 97.0% accuracy** in perfectly reconstructing the complete error paths. Accuracy remains high on long paths (>=3 hops) where other methods fail.
- **RQ2 (Efficiency): ErrorPrism** found the correct path **~8x faster** than the general-purpose code agent.

Method	Hop					Total
	0	1	2	3	≥4	
ErrorPrism	**100**	**100**	95.2	**100**	**85.7**	**97.0**
Static Analysis	100	90.4	**98.8**	72.9	66.1	90.7
Internal Agent	100	87.1	90.5	84.6	57.1	87.1
CoReQA	75	67.7	54.8	53.8	14.3	57.4
Pure LLM	100	64.5	45.2	30.8	0	50.5

The Performance of Error Propagation Tracking (%)



The Inference Time of Error Propagation Tracking

*_Accuracy_ means the predicted path **exactly matched** the ground truth, while _Precision_ (for static analysis) measures **the proportion of correct functions** in the candidate set (see paper for full formula).

Discussion: Why **ErrorPrism** Works

- **Static Pruning (Enables Efficiency):**
  - The offline static analysis (Phase I) *massively* reduces the search space.
  - This is the key to our high performance (5.9s) and high accuracy.
- **LLM Reasoning (Enables Accuracy):**
  - The LLM agent only needs to reason about a *few* candidate functions.
  - This allows it to perform deep semantic analysis to solve semantic blind spots that static analysis alone can't.

Conclusion & Contributions

- We Identified **Error Obfuscation** as a critical challenge for microservice reliability.
- We Proposed **ErrorPrism**, a novel hybrid framework, which use static analysis to prune the search space and an LLM agent to reason within that space.
- **ErrorPrism** proved to be highly effective (97% accuracy) and efficient (5.9s per request) in a large-scale industrial setting. This is a practical tool for automating Root Cause Analysis (RCA).

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SUN YAT-SEN UNIVERSITY

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Thank you!

Junsong Pu, 蒲俊宋

School of Software Engineering, Sun Yat-sen University

E-mail: pujs@mail2.sysu.edu.cn / angrychow@qq.com