Guarding Serverless Applications with *Kalium*

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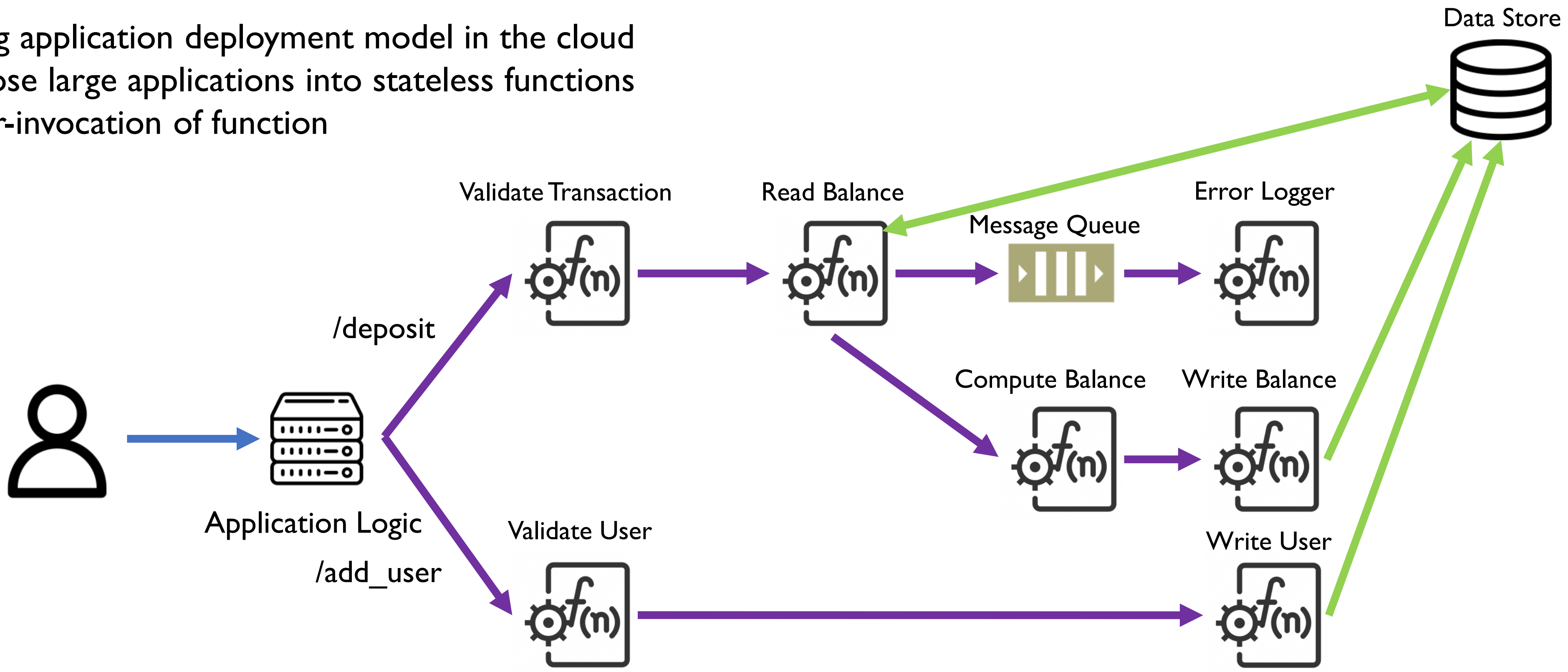
Outline

- Serverless Computing
- Security in Serverless Computing
- Our Approach: Kalium
- Evaluation
- Conclusion

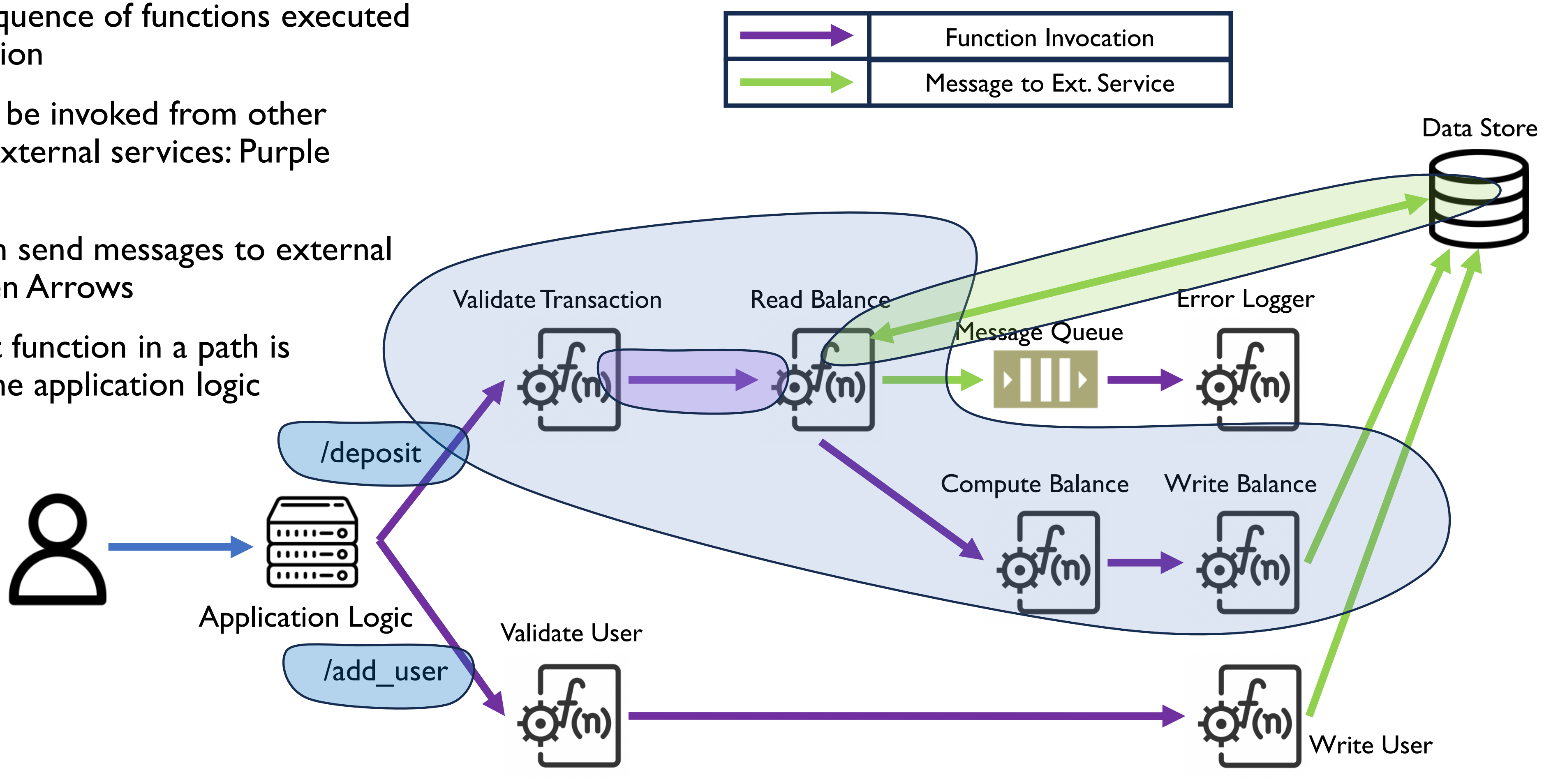
Serverless Computing

1. Upcoming application deployment model in the cloud
2. Decompose large applications into stateless functions
3. Billing per-invocation of function



Serverless Computing – Execution Paths

1. A path is a sequence of functions executed in the application
2. Functions can be invoked from other functions or external services: Purple Arrows
3. A function can send messages to external services: Green Arrows
4. Output of last function in a path is returned to the application logic



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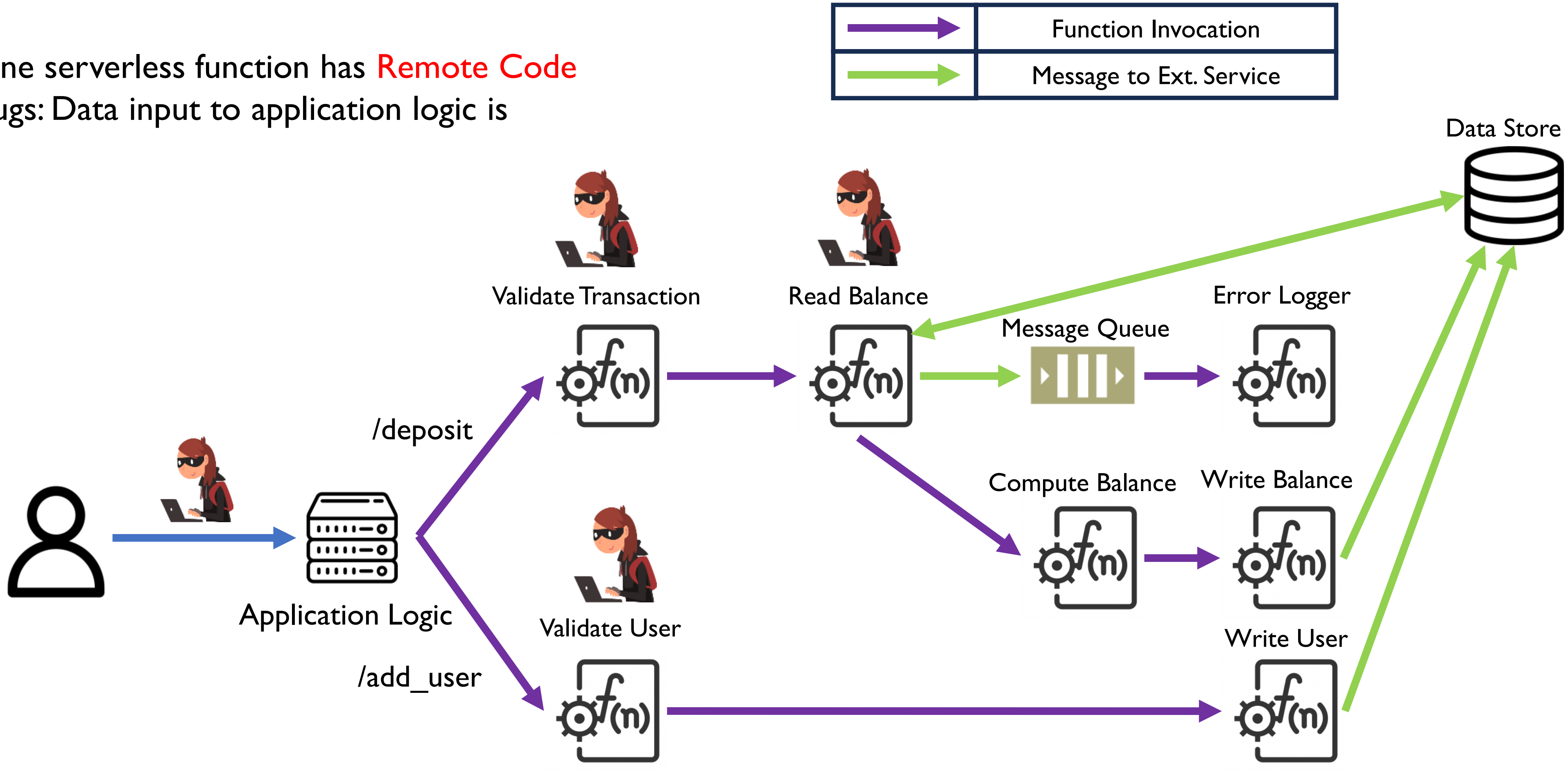
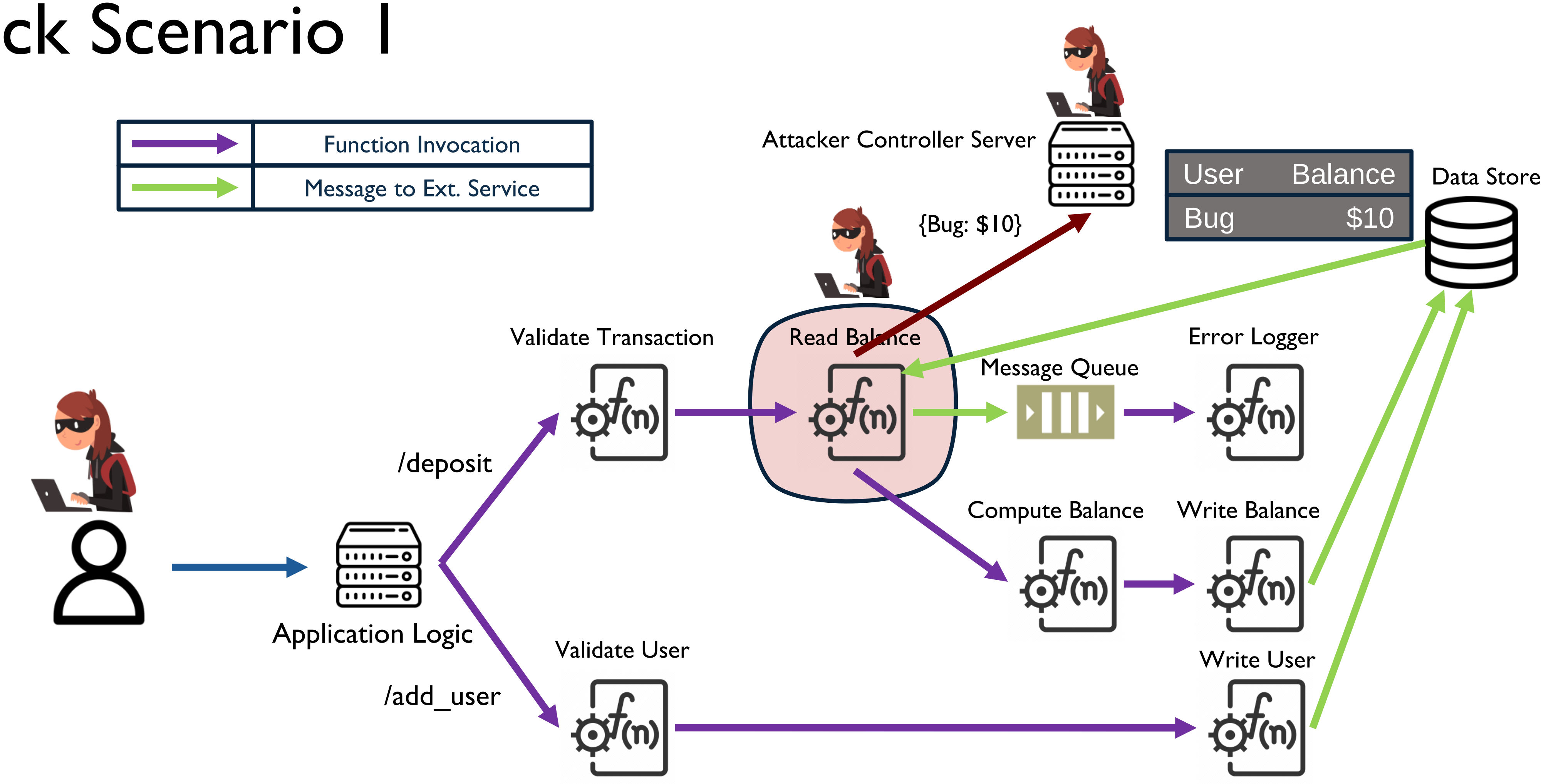
Threat Model

1. Serverless Infrastructure is secure

2. At least one serverless function has Remote Code Execution bugs: Data input to application logic is untrusted



Attack Scenario 1

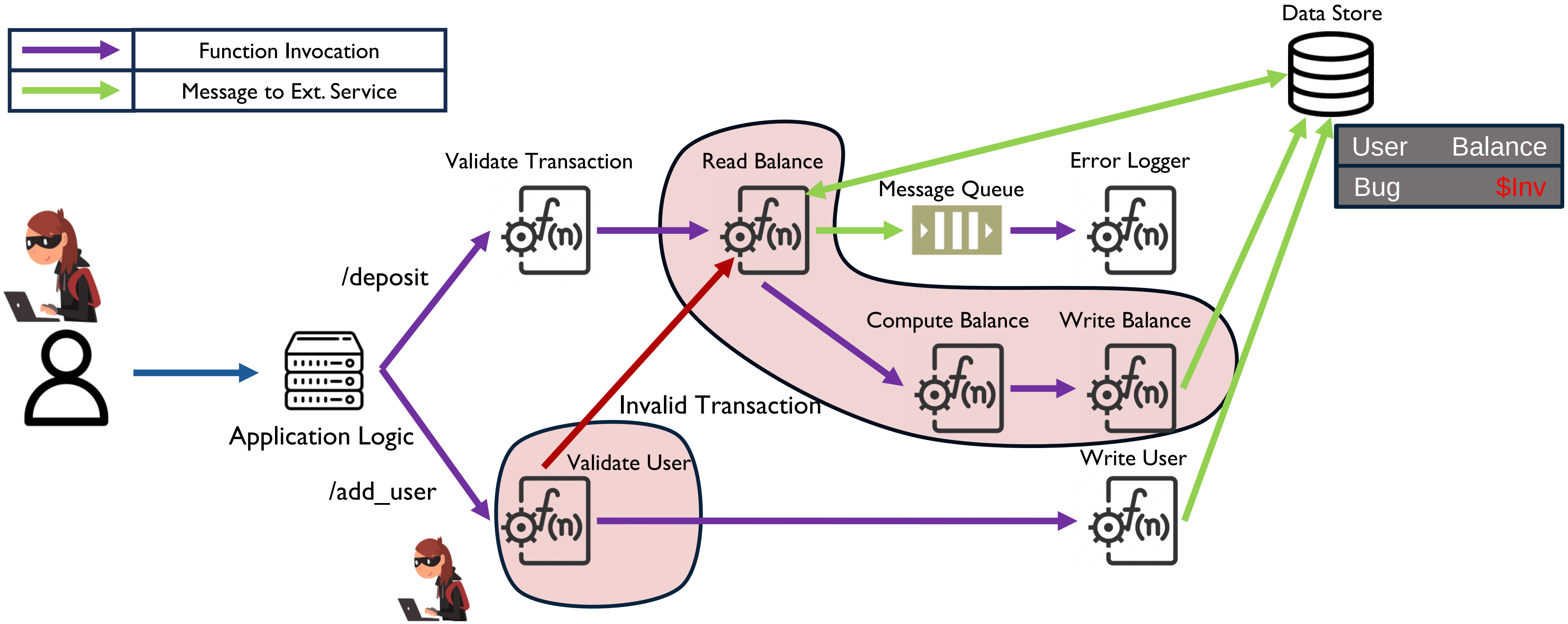


→	Function Invocation
→	Message to Ext. Service

User	Balance
Bug	$10

Confidential Information Should not Flow to Unintended External Locations

Attack Scenario 2

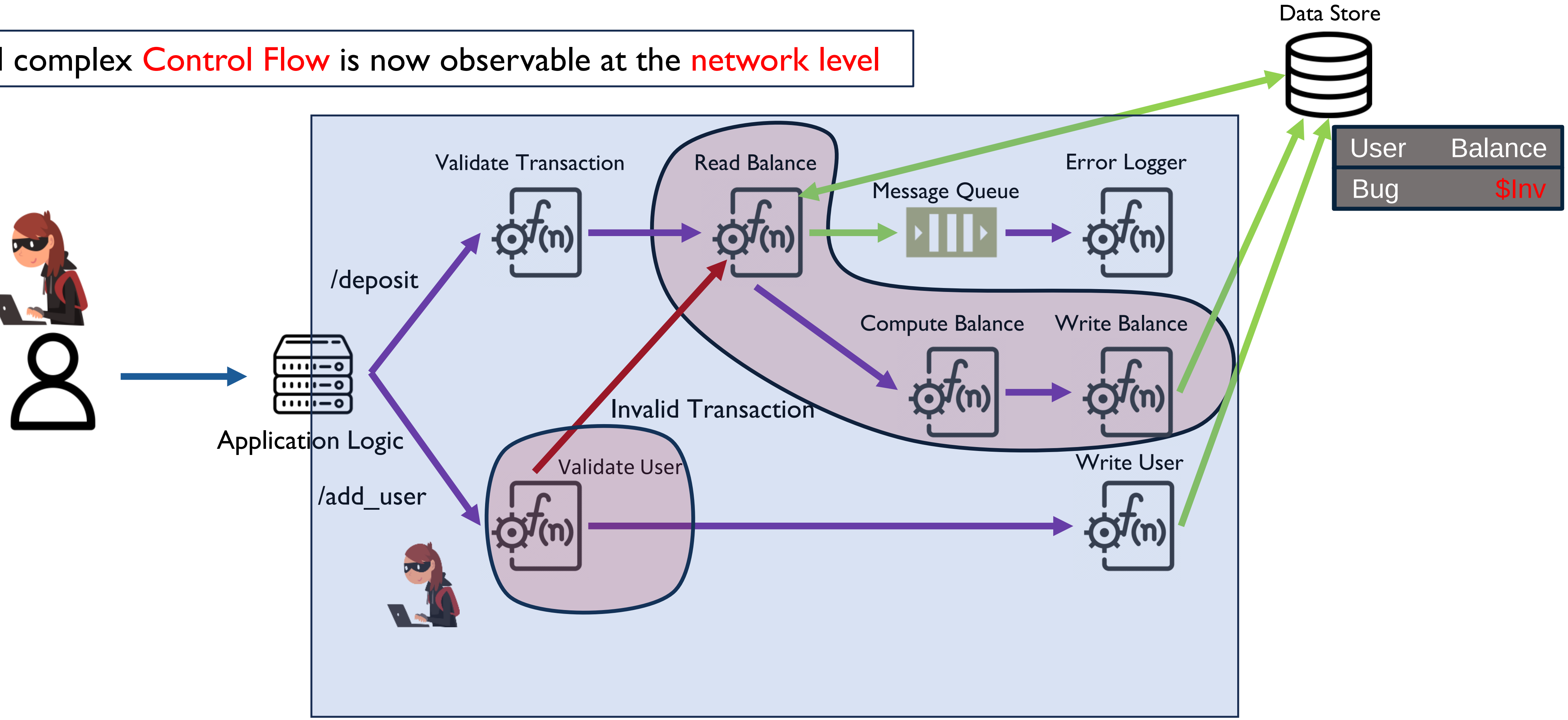


User	Balance
Bug	$Inv

Data Written to External Storage Should be the Result of a Valid Path

Insight for Attack Detection

Internal complex Control Flow is now observable at the network level



User	Balance
Bug	$Inv

Prior Work including information flow control and web application firewalls do not consider order of functions in a path

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Kalium - Overview

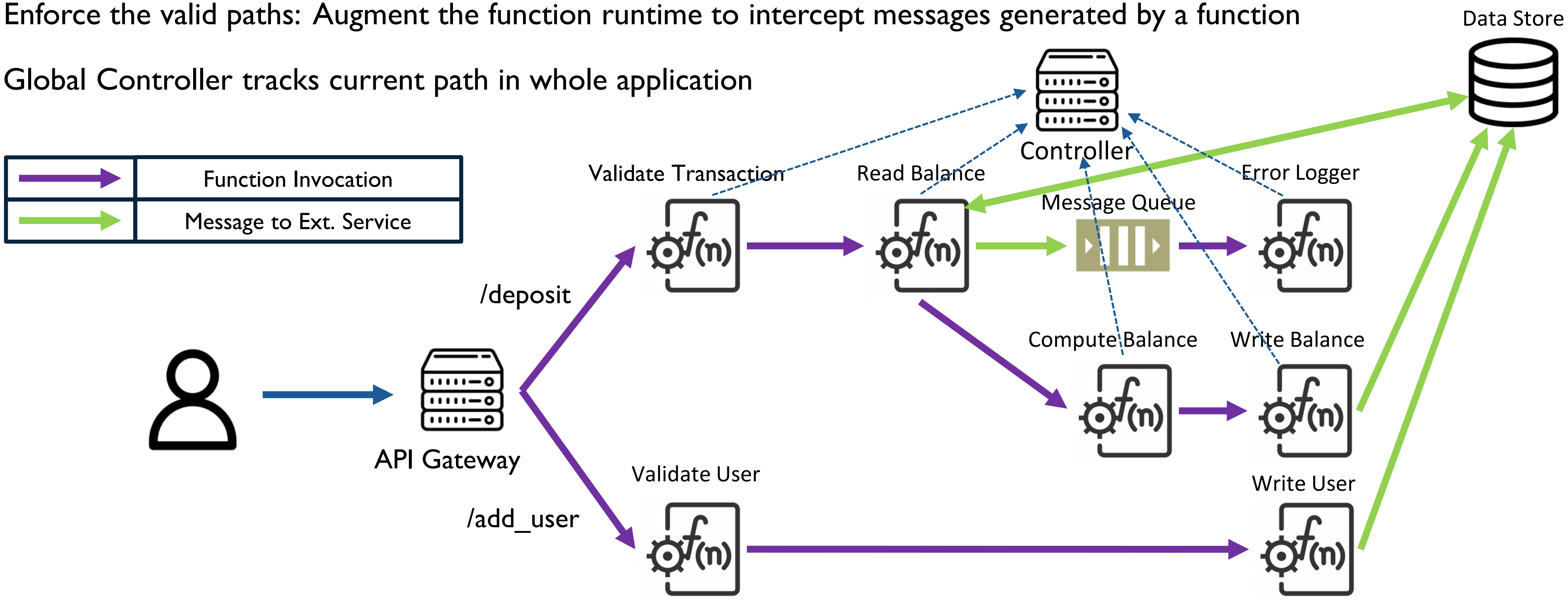
Idea: All executed paths in serverless application should be valid

Kalium: System to track paths and its validity in serverless applications

Application Profiling Stage: Build expected valid paths of each function and whole application

Enforce the valid paths: Augment the function runtime to intercept messages generated by a function

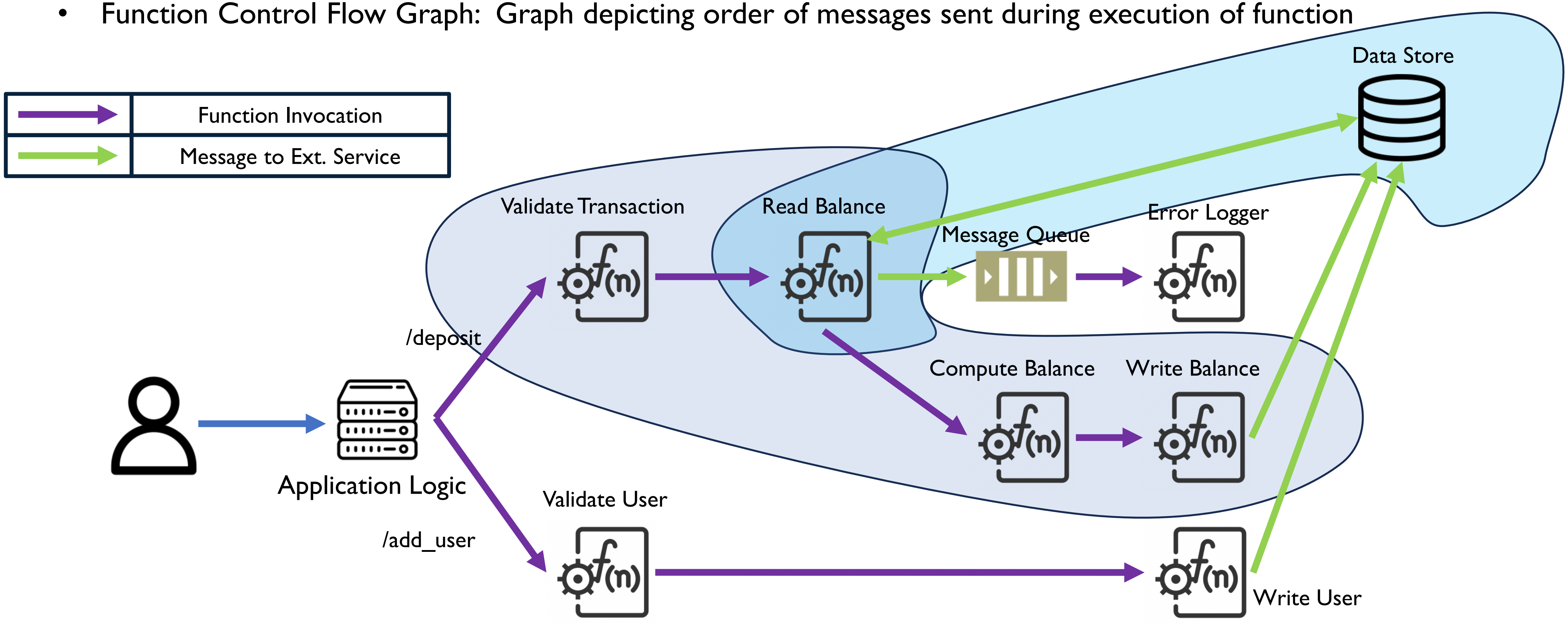
Global Controller tracks current path in whole application



Kalium – Serverless Control Flow

Define Application Control Flow Graph and Function Control Flow Graph

- Application Control Flow Graph: Graph depicting order of function invocations in application
- Function Control Flow Graph: Graph depicting order of messages sent during execution of function

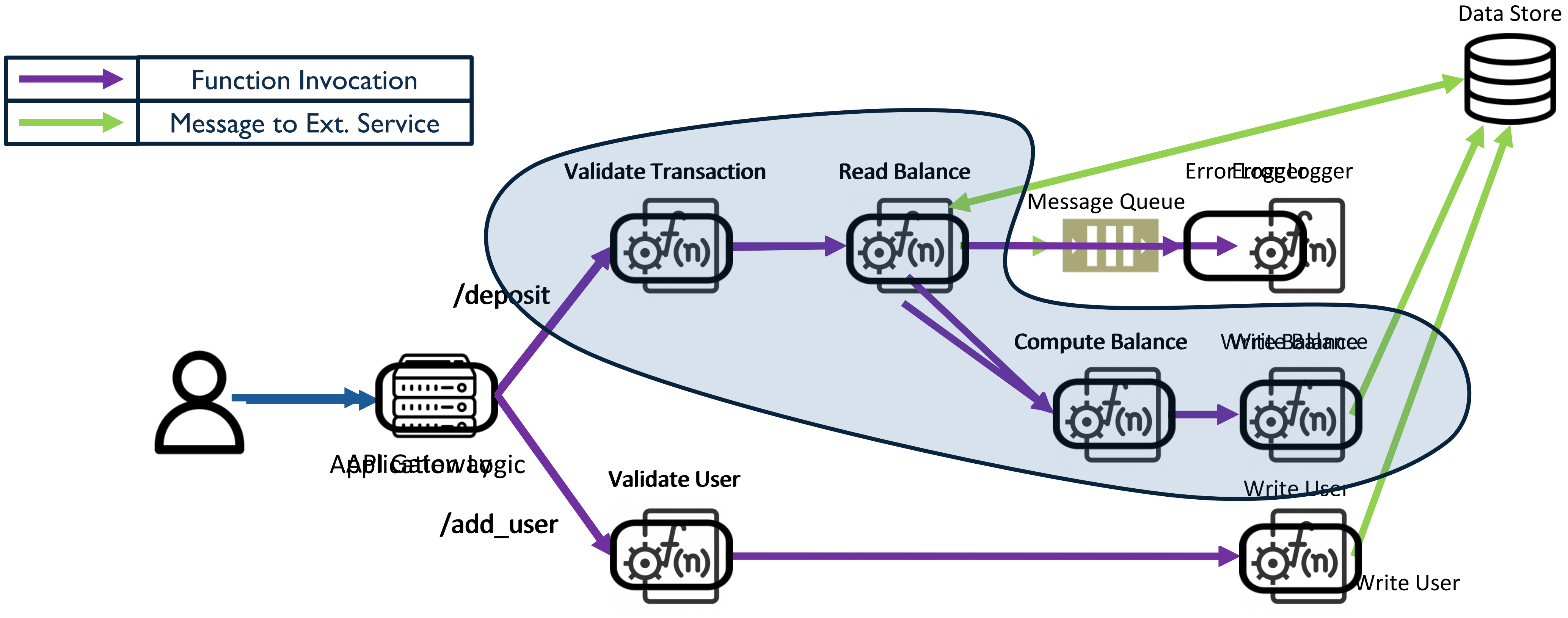


Application Control Flow

Application Control Flow Graph: Graph depicting order of function invocations in application

Nodes are the functions in the application

Edges between functions are labeled with URLs of destination function



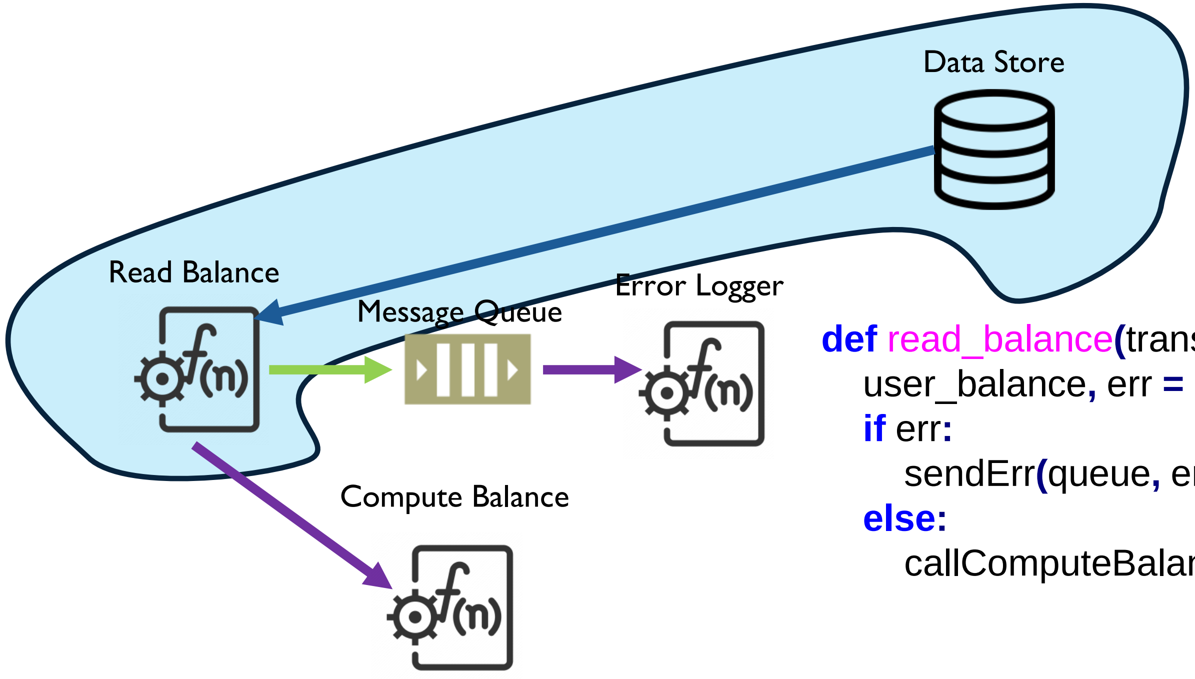
Function Control Flow

Function Control Flow Graph: Graph depicting order of messages sent during execution of function

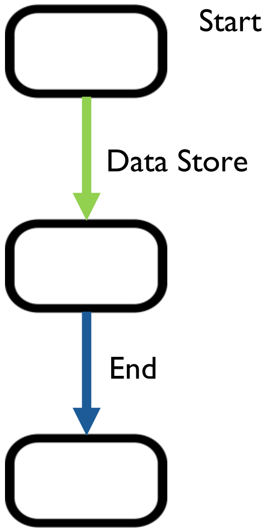
Nodes are internal function states before sending a message

Edges between nodes are labeled with URLs of destination external services

Each function is assumed to end in exactly one application sub-path



```
def read_balance(transaction):
    user_balance, err = getUserBalance(dataStore, transaction.user)
    if err:
        sendErr(queue, err)
    else:
        callComputeBalance(transaction, user_balance)
```

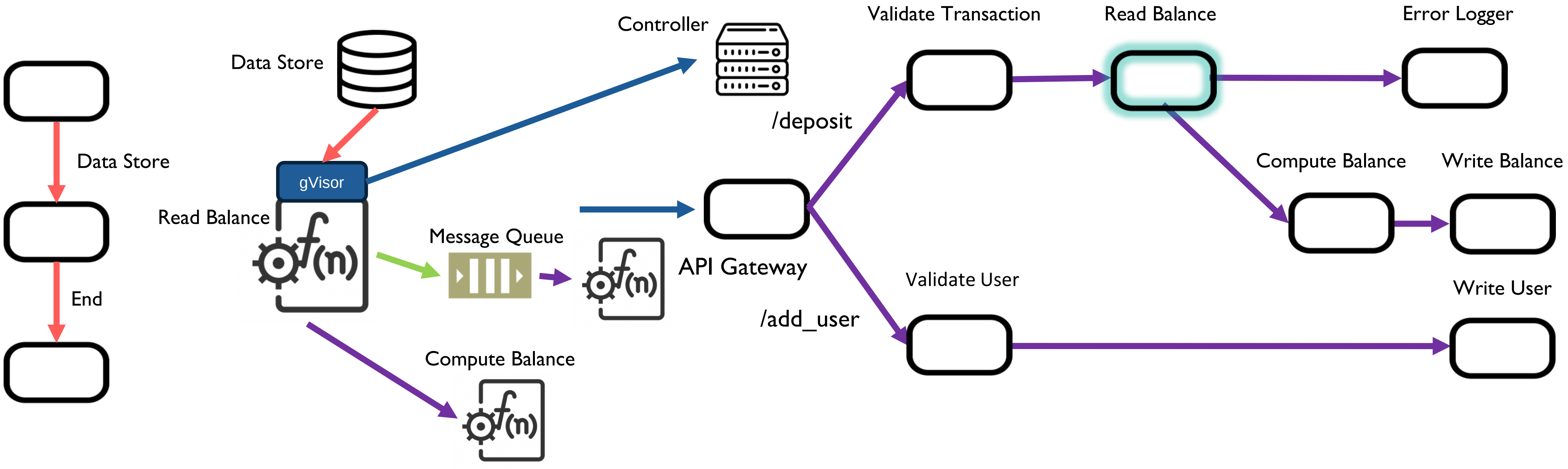


Kalium - Implementation

Intercept function messages at the network syscall level with augmented gVisor

Once a function finishes execution, it checks with the global controller whether to allow outgoing edge

A global controller maintains the position of the current function on application CFG



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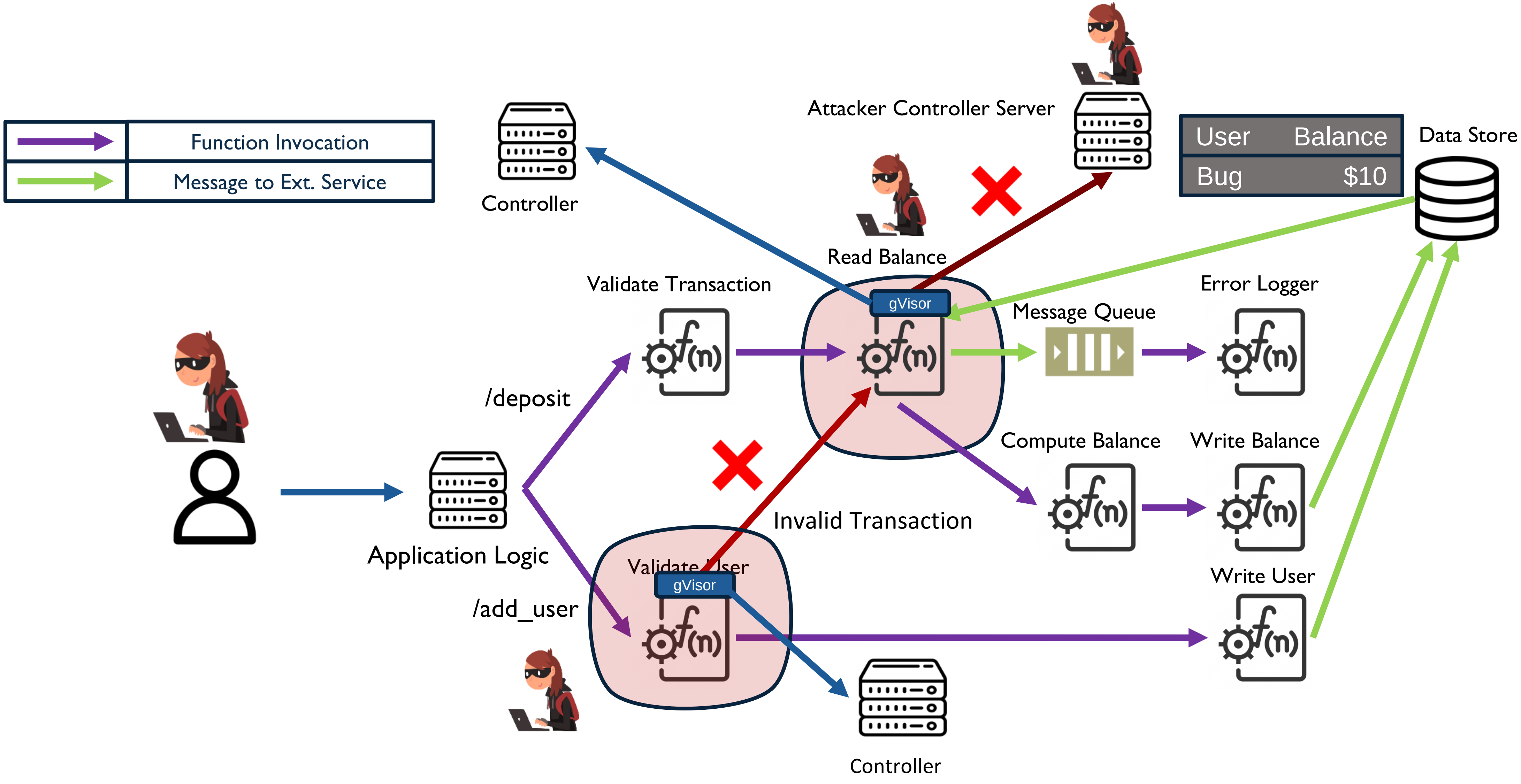
Evaluation – Attack Scenario 1 and 2



User	Balance
Bug	$10

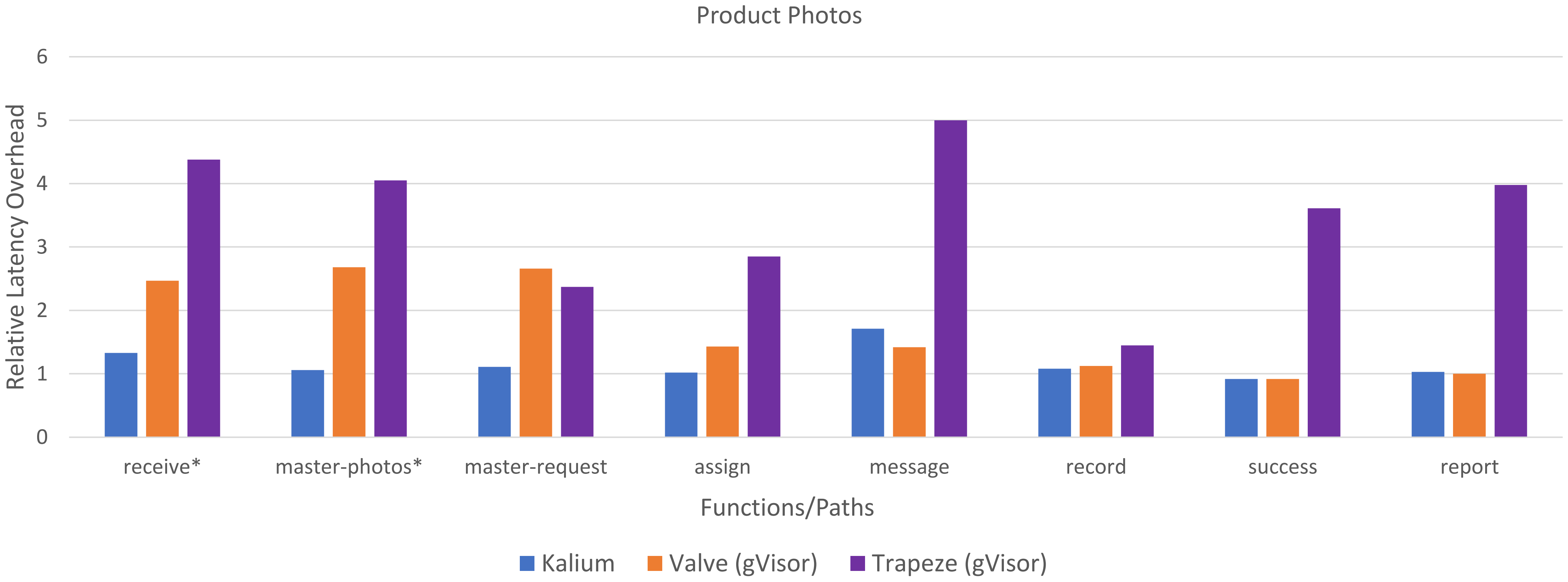
Kalium – Performance Evaluation

Benchmarks: Valve Benchmarks

Evaluation of graph generation: More details in the paper

Comparison: Valve (IFC) [WWW '20] on gVisor, Trapeze (IFC) [OOPSLA '18] on gVisor

Geomean: 1.25, 1.40 and 2.90 across all benchmark functions/paths for Kalium, Valve and Trapeze resp.



Conclusion

- Enforcing Control Flow is important for Serverless Application Security
- We present Kalium a Control Flow Integrity framework for Serverless Apps
- Kalium has reasonable performance overhead for enforcing Control Flow Integrity

https://github.com/multifacet/kalium_artifact

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Questions?