Distributed Transactions on Serverless Stateful Functions

Distributed Transactions on Serverless Stateful Functions
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To appear in the proceedings of the 15th ACM International Conference on Distributed and Event-based Systems (DEBS) 2021.

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- Transactions
- Microservices & Cloud computing
- Stateful Functions & Coordinator Functions
- Evaluation
- Conclusion & discussion

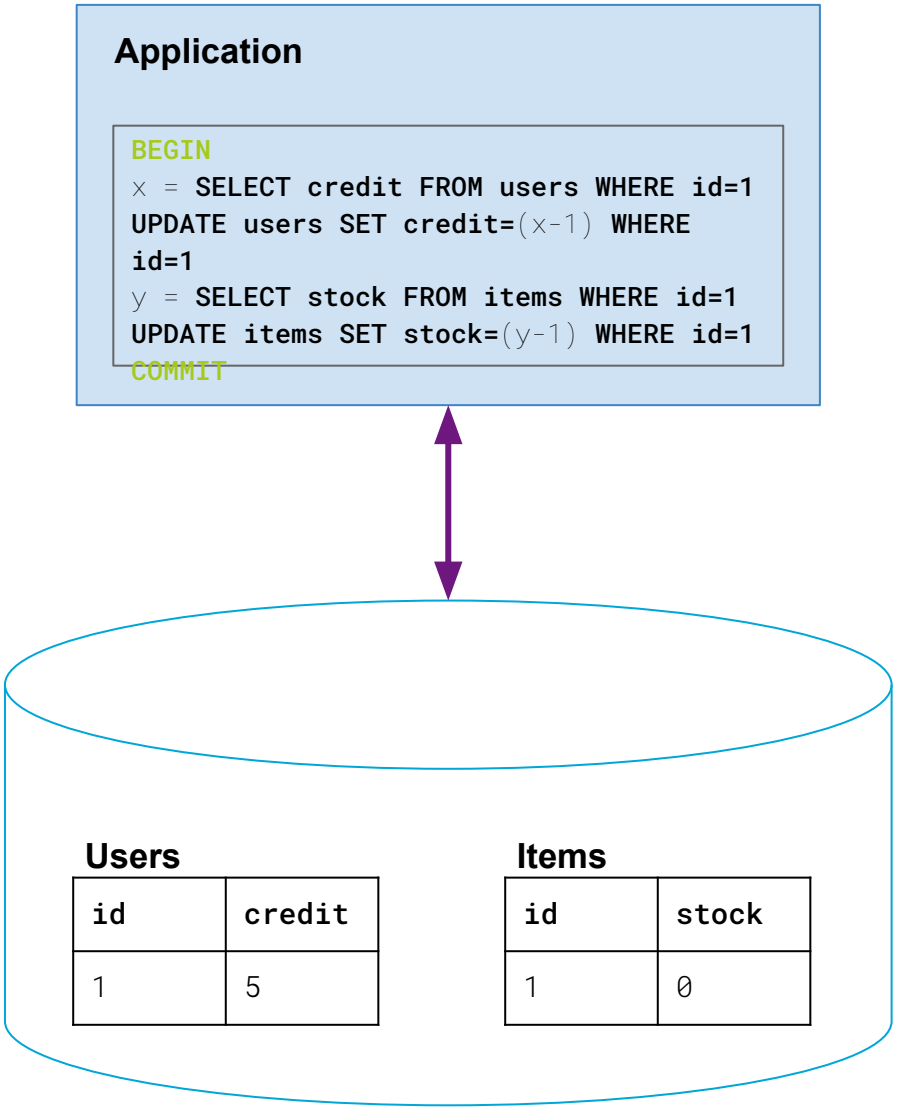
Transactions

Transactions

A transactions are a set of operations on data with 4 (**ACID**) guarantees:

- **A**tomicity
- **C**onsistency
- **I**solation
  - (*serializability*)
- **D**urability

Traditional Architecture



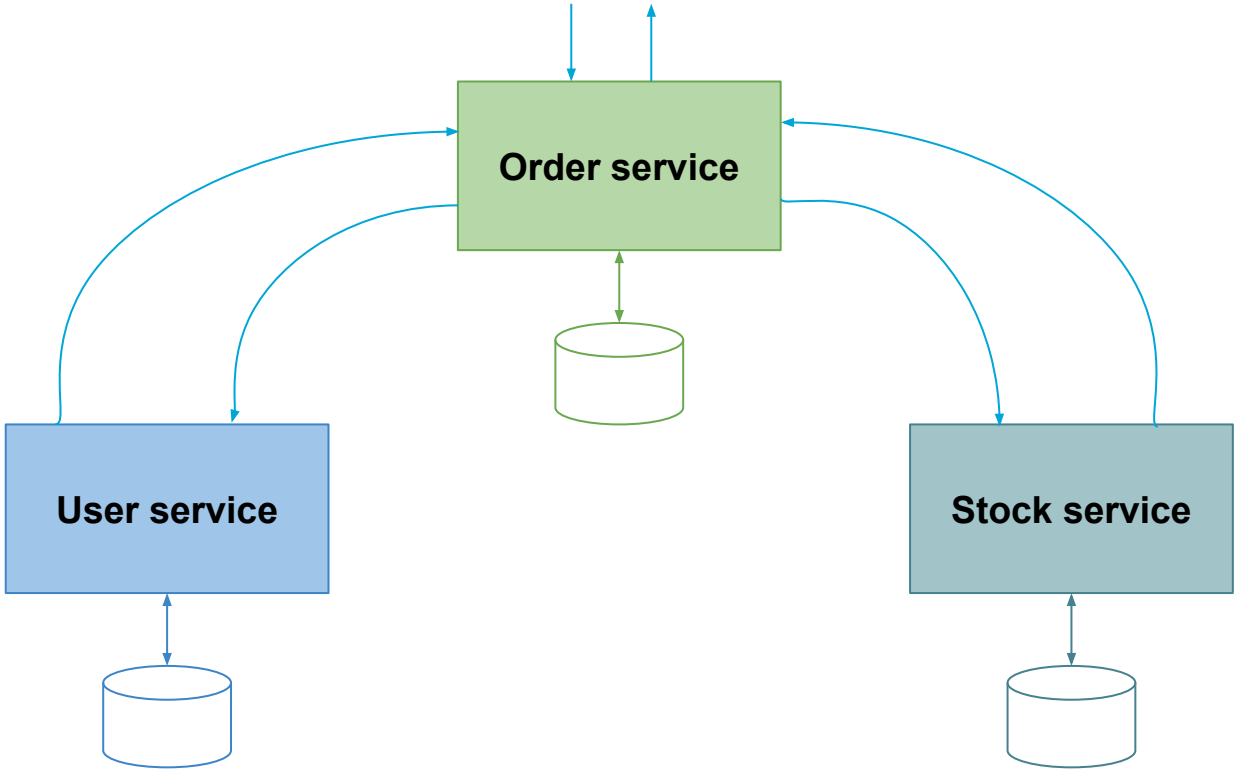
Distributed transactions

- **Two-Phase Commit** ensures **atomicity**
- **Two-Phase Locking** ensures **serializability**

Combining Two-Phase Locking and Two-Phase Commit can be used to implement **distributed** transactions

Microservice systems

Microservices

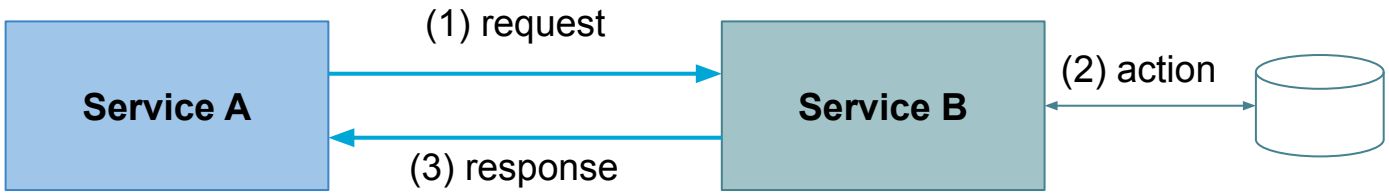


Microservices

Benefits

- Scaling components separately
- Deploying / updating components separately
- Deploying components on specific hardware
- Scaling development in organisations

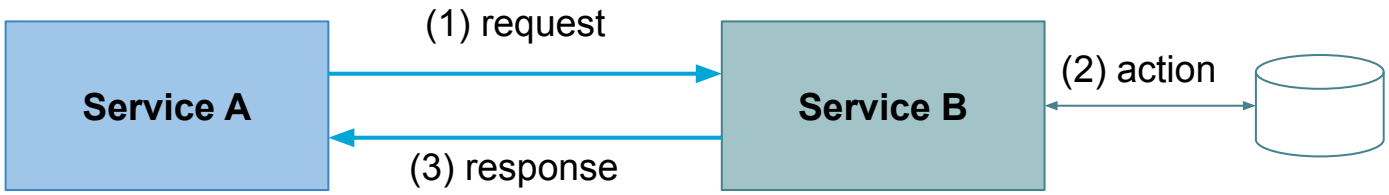
Two Generals' Problem



The network is **unreliable**, it is never certain whether a message will arrive

If **Service A** never receives message at 3, it does not know whether **Service B** has performed action at 2.

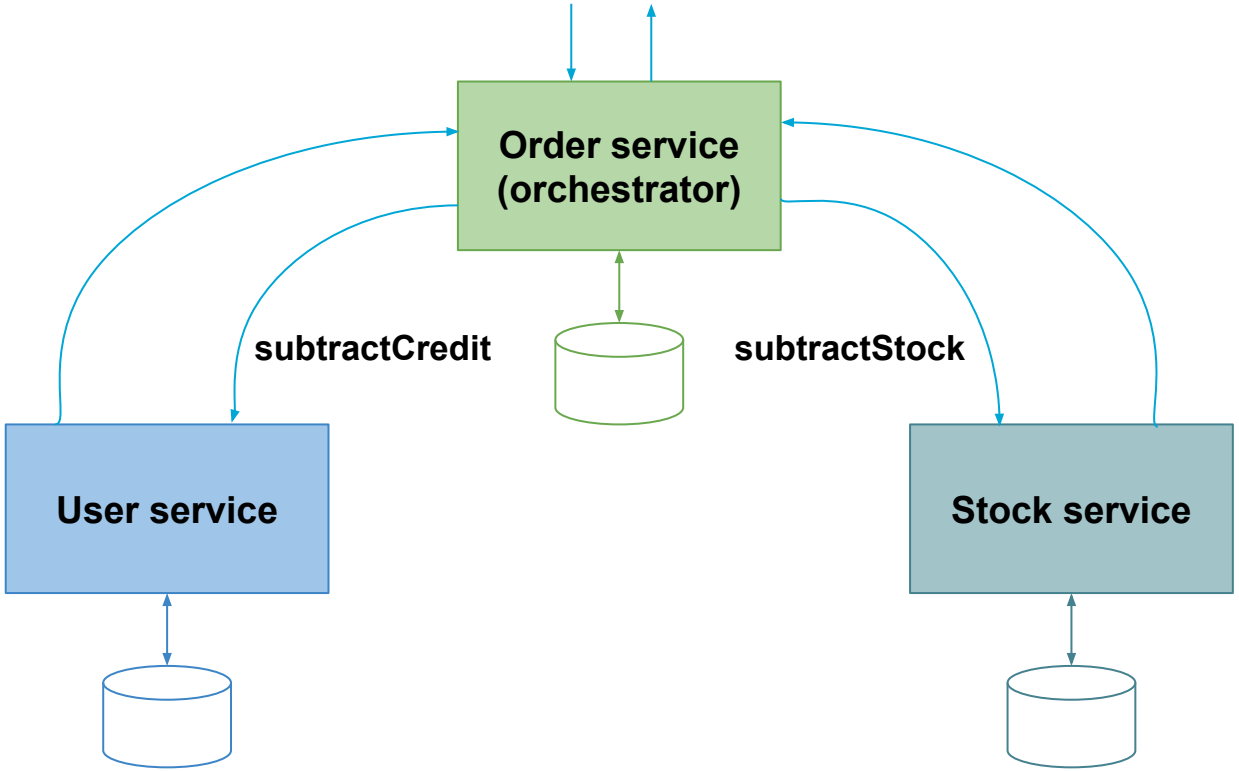
Processing guarantees



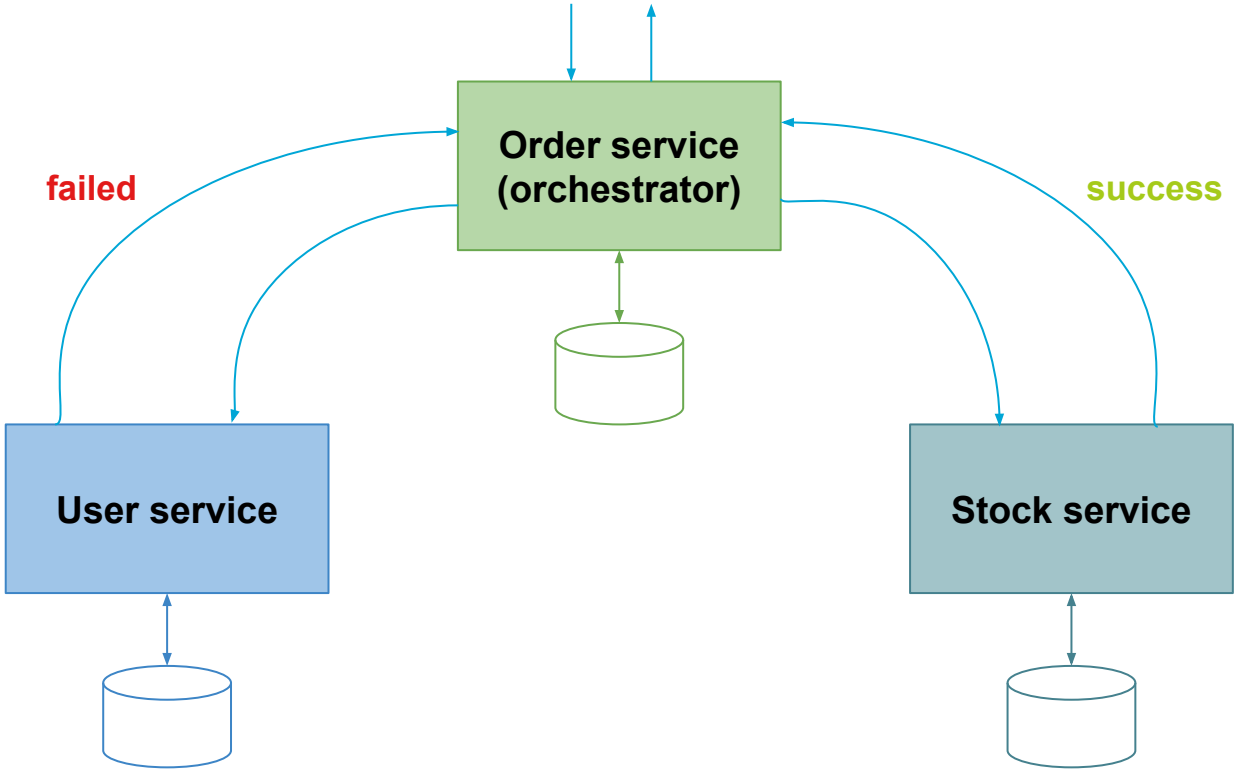
AT_MOST_ONCE: only try to send once and do not care about the results, action 2 may not be performed

AT_LEAST_ONCE: keep retrying until a response is received, action 2 may be performed multiple times

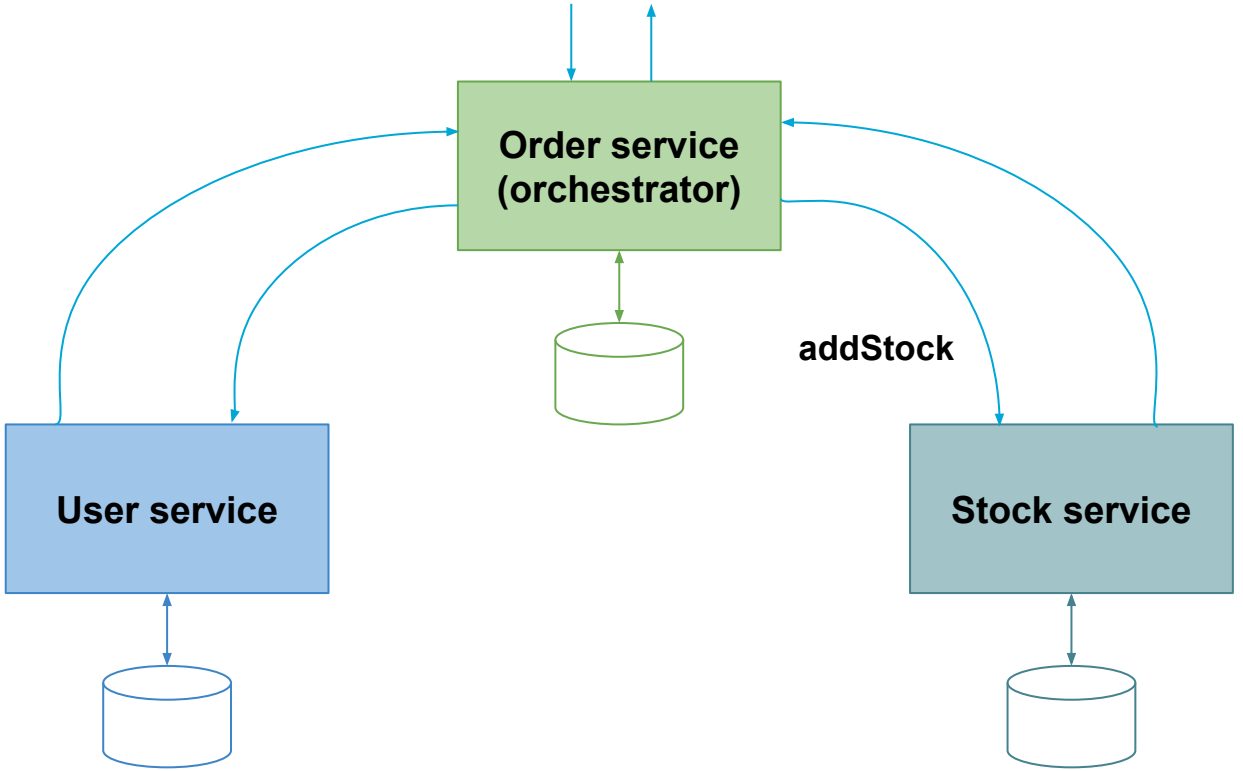
Saga orchestration



Saga orchestration



Saga orchestration



Transactions but with completely no <u>isolation</u>
<u>Atomicity</u> with of fault-tolerance is also hard to achieve

Cloud computing

Cloud computing

Make computing **accessible** for everyone

Goals:

- Eliminate up-front investment requirements and offer compute resources on demand
- Simplify distributed computing
  - Deployment and scalability
  - State management
    - Processing guarantees (exactly-once)
    - Distributed transactions

Cloud computing

Make computing **accessible** for everyone

Goals:

- ✓ Eliminate up-front investment requirements and offer compute resources on demand
- ~ Simplify distributed computing
  - Deployment and scalability
  - State management
    - Processing guarantees (exactly-once)
    - Distributed transactions

How can we improve on this?

Make computing **accessible** for everyone

Goals:

✓ Eliminate up-front investment requirements and offer compute resources on demand

~ Simplify distributed computing
- Deployment and scalability
- State management
  - Processing guarantees (exactly-once)
  - Distributed transactions

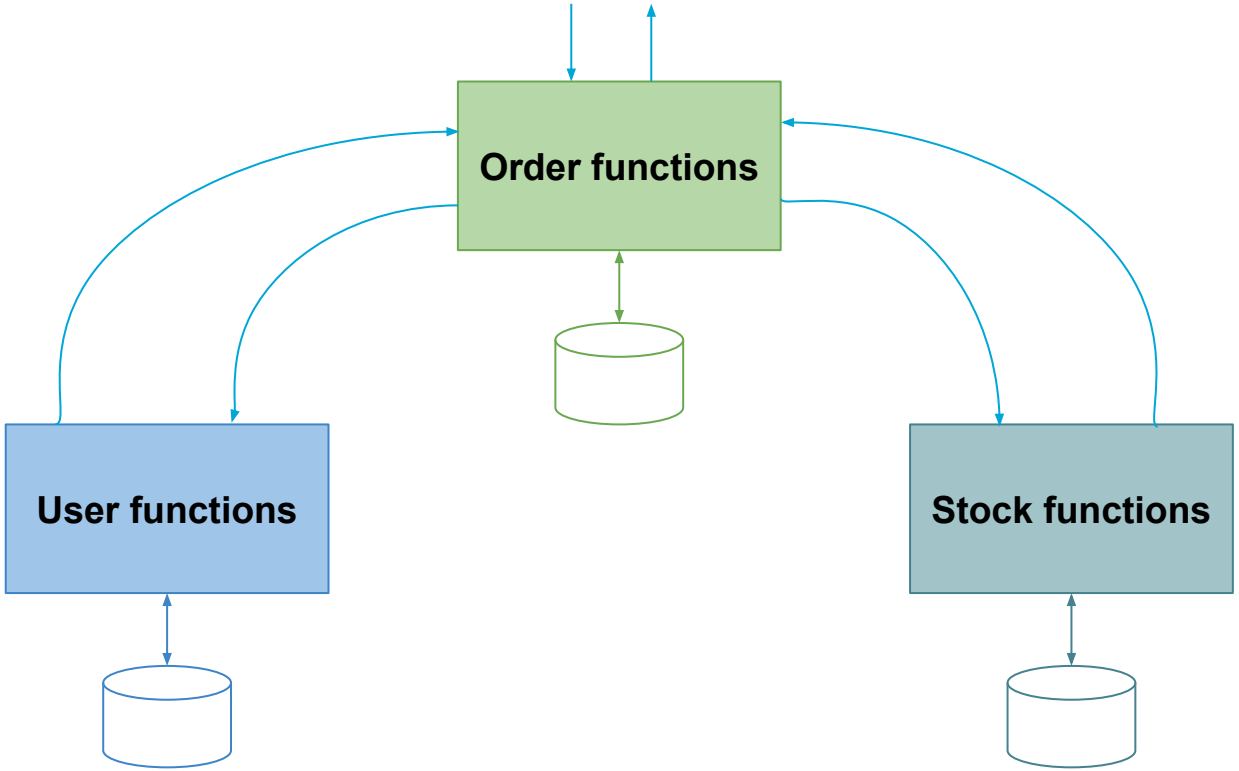
Serverless computing

Function-as-a-Service (FaaS) models as the first iteration of serverless

Goals:

- ✓ Eliminate up-front investment requirements and offer compute resources on demand
- ~ Simplify distributed computing
  - ✓ Deployment and scalability
  - State management
    - Processing guarantees (exactly-once)
    - Distributed transactions

Function-as-a-Service



Serverless computing

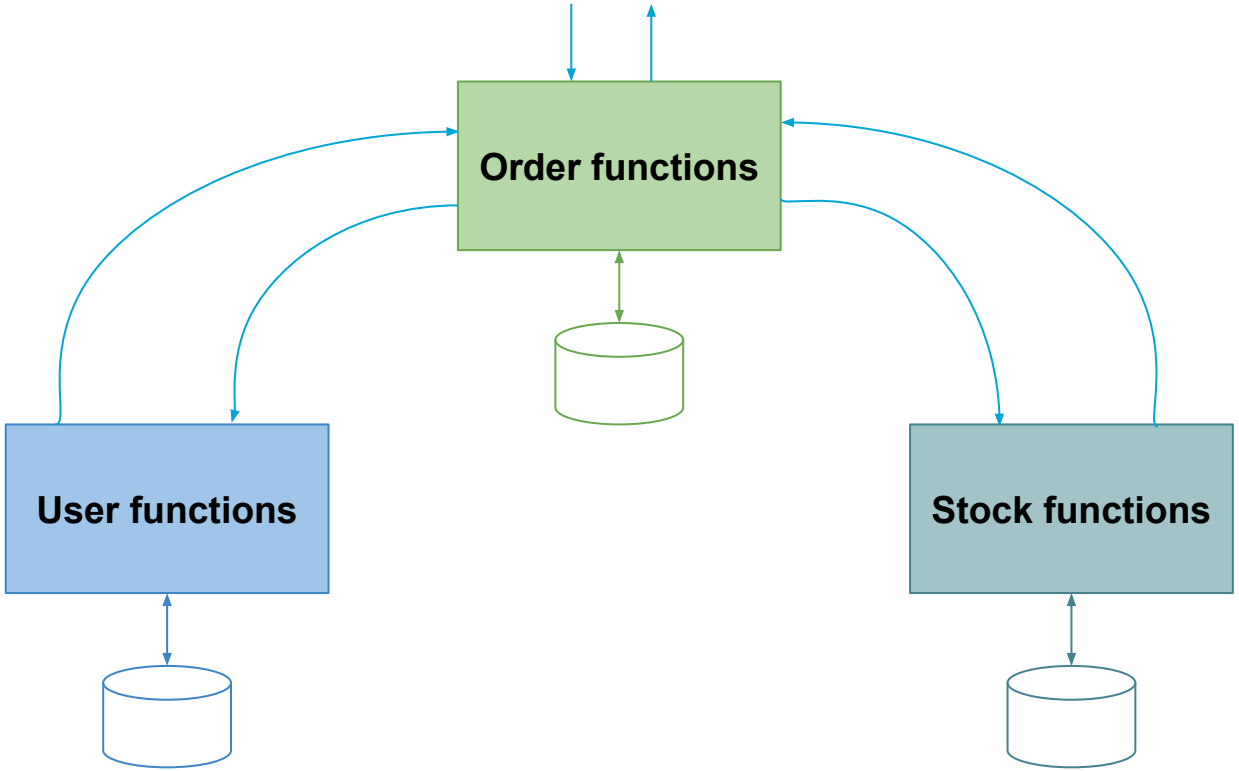
Stateful-Function-as-a-Service (SFaaS)
models as the second iteration of serverless

Goals:

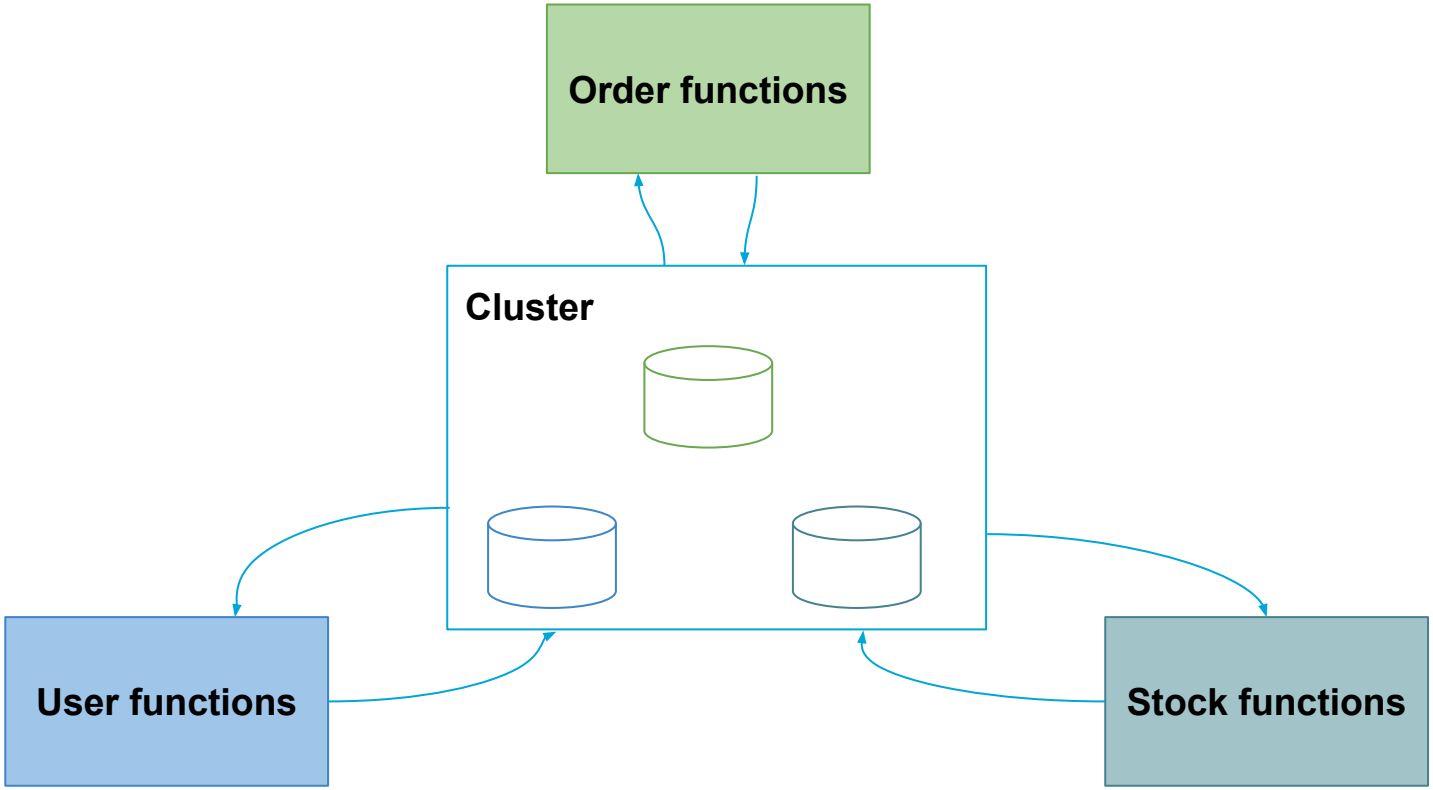
- ✓ Eliminate up-front investment requirements and offer compute resources on demand
- ~ Simplify distributed computing
  - ✓ Deployment and scalability
  - ~ State management
    - ✓ Processing guarantees (exactly-once)
    - • Distributed transactions

Flink Statefun

Functions-as-a-Service

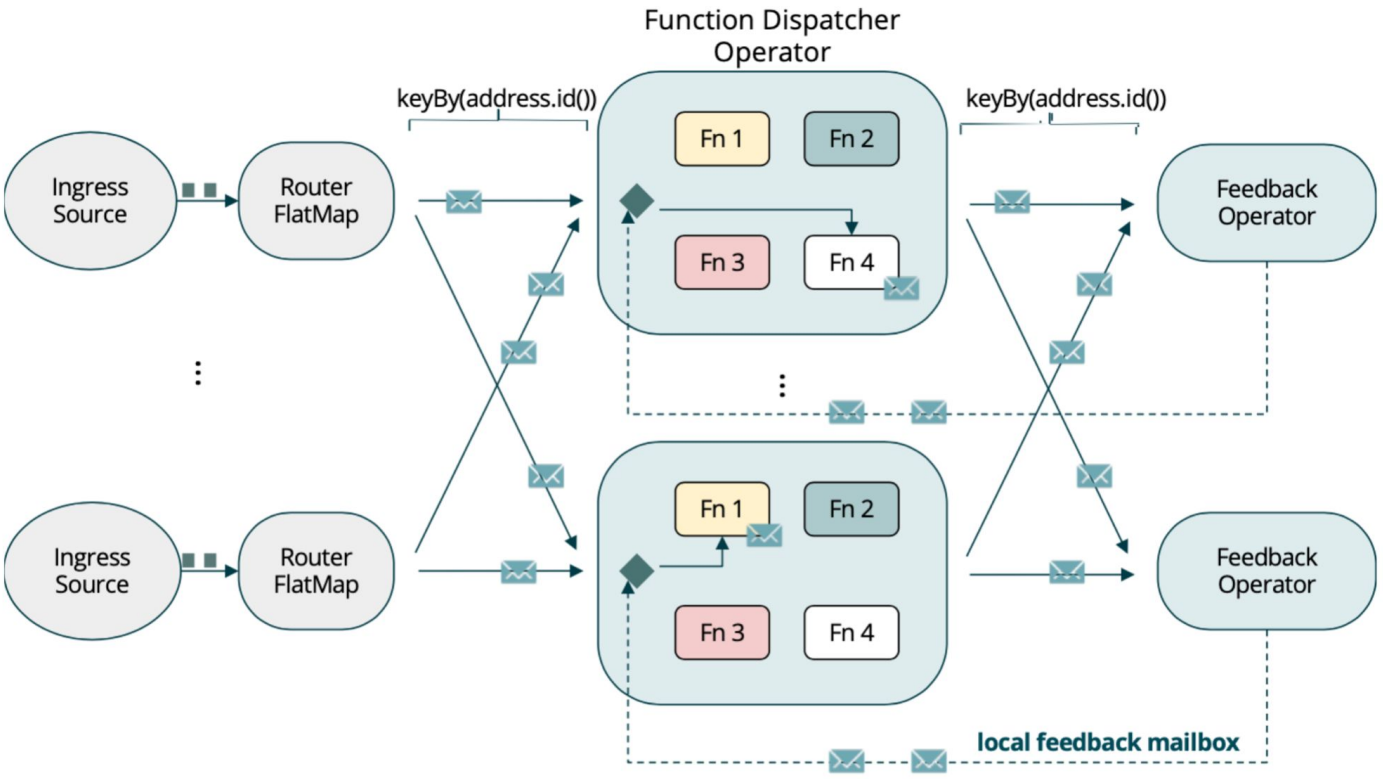


Stateful Function-as-a-Service



Couples *messaging* and *state management* to ensure exactly-once guarantees across both

Flink Statefun



Flink Statefun

Function instances encapsulate specific state based on their **address** (combination of *type* and *id*)

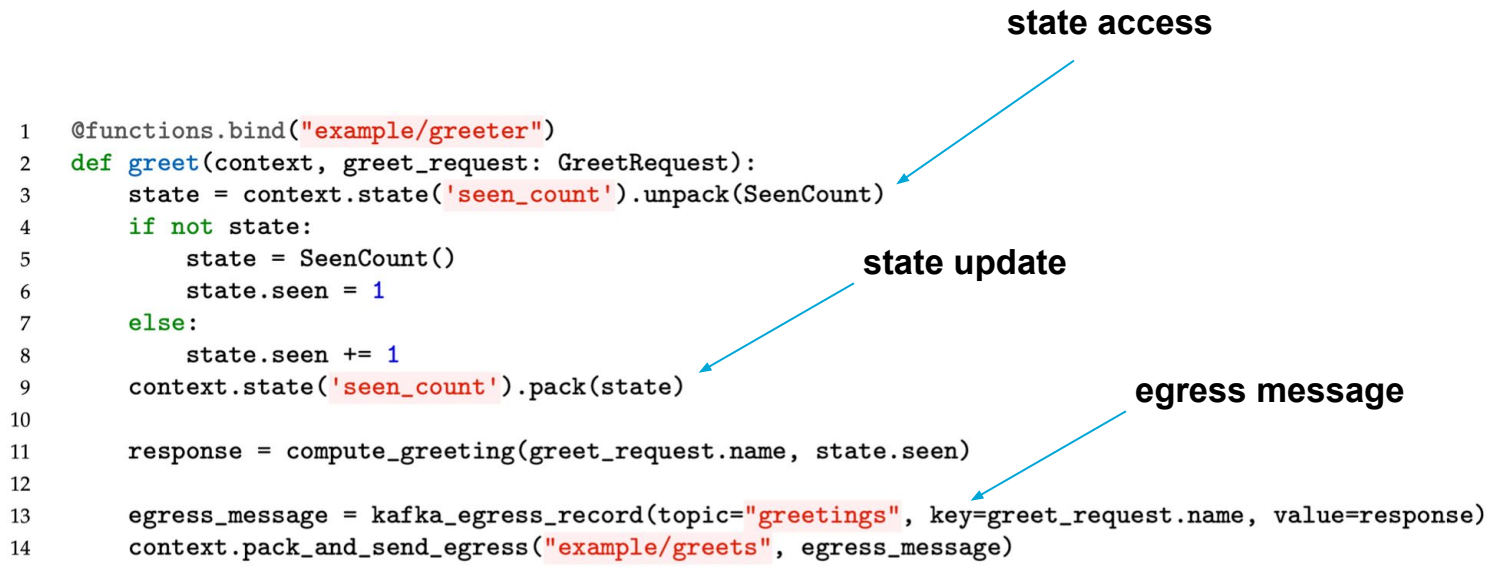
Function instances can perform **four side effects**:

- Updates to their encapsulated state
- Messages to other function instances
- Delayed messages to other function instances
- Messages to egresses

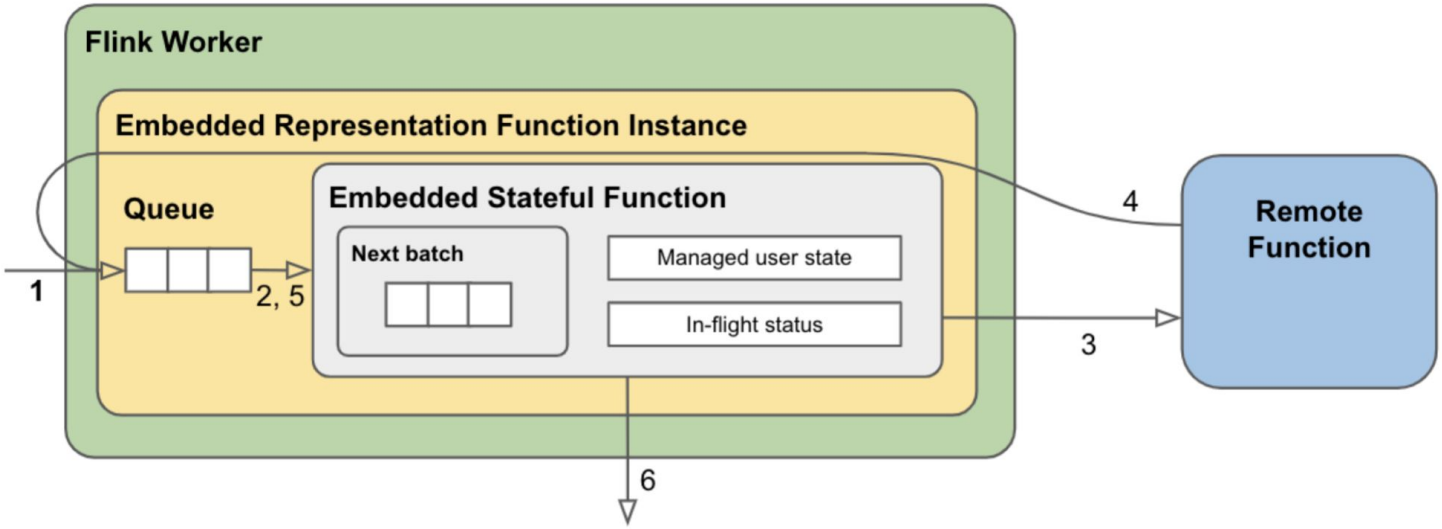
Function instances can be **invoked** by:

- Messages from other function instances
- Messages from ingresses

Flink Statefun



Flink Statefun




```
1   message InvocationBatchRequest {
2       Address target = 1;
3       repeated PersistedValue state = 2;
4       repeated Invocation invocations = 3;
5   }
6
7   message InvocationResponse {
8       repeated PersistedValueMutation state_mutations = 1;
9       repeated Invocation outgoing_messages = 2;
10      repeated DelayedInvocation delayed_invocations = 3;
11      repeated EgressMessage outgoing_egresses = 4;
12  }
```

State is sent to the remote function

The resulting side effects

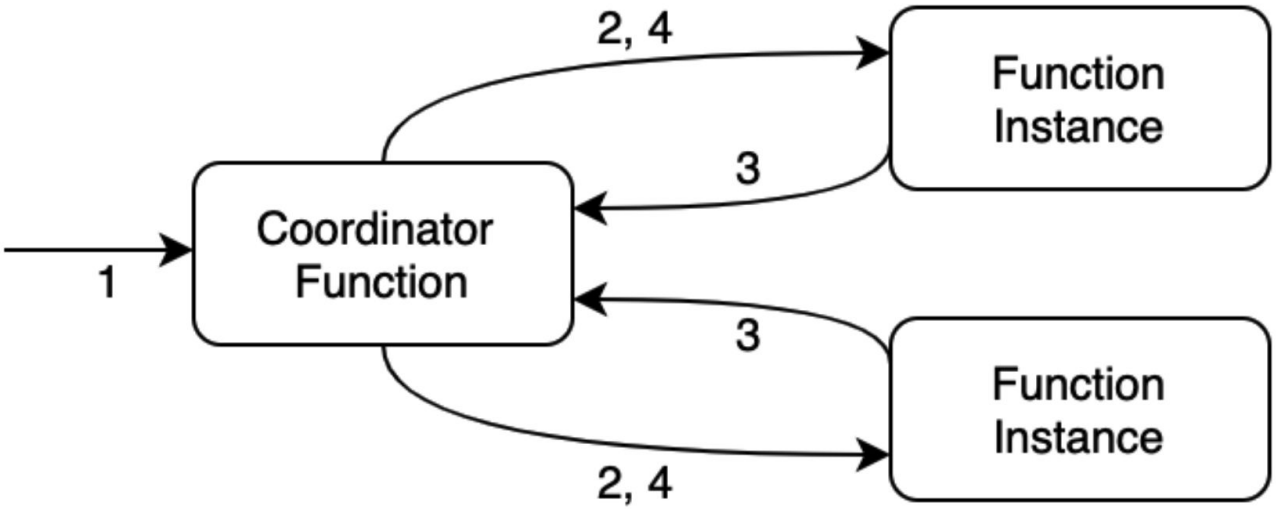
Coordinator functions for distributed transactions

Serverless computing

Goals:

- ✓ Eliminate up-front investment requirements and offer compute resources on demand
- ✓ Simplify distributed computing
  - ✓ Deployment and scalability
  - ✓ State management
    - ✓ Processing guarantees (exactly-once)
    - ✓ Distributed transactions

Coordinator functions



This relies on Statefun's exactly_once guarantees and linearizable operations on single function instances

Coordinator functions

Coordinator functions are simply *specialized function instances* to coordinate a serializable transaction or sagas

Coordinator function instances can perform **side effects**:

- Add messages to other function instances to the saga or transactions
- Add side effects to perform based on the completion of the saga

Coordinator function instances can be **invoked** by:

- Messages from other function instances
- Messages from ingresses

Coordinator functions

invocations part of the transaction

```
def handle_transfer(context, message: Transfer):
    # Send messages
    subtract_credit = SubtractCredit(amount = message.amount)
    context.pack_and_send_atomic_invocation("ycsb/account_function",
                                            message.outgoing_id,
                                            subtract_credit)
    add_credit = AddCredit(amount = message.amount)
    context.pack_and_send_atomic_invocation("ycsb/account_function",
                                            message.incoming_id,
                                            add_credit)
```

Coordinator functions

invocations part of the saga

require explicit compensating invocations

```
1   def handle_transfer(context, message: Transfer):
2       # Send messages
3       subtract_credit = SubtractCredit(amount=message.amount)
4       add_credit = AddCredit(amount=message.amount)
5       context.pack_and_send_invocation_pair("ycsb-example/account_function",
6                                             message.outgoing_id,
7                                             subtract_credit,
8                                             add_credit)
9       context.pack_and_send_invocation_pair("ycsb-example/account_function",
10                                            message.incoming_id,
11                                            add_credit,
12                                            subtract_credit)
```

Regular functions

- Functions should be able to **fail** explicitly
- **Batching** should be **adjusted** to respect **isolation** of invocations part of a **serializable transaction**
- **Locking** should be introduced
- It should participate in the protocols for sagas and serializable transactions

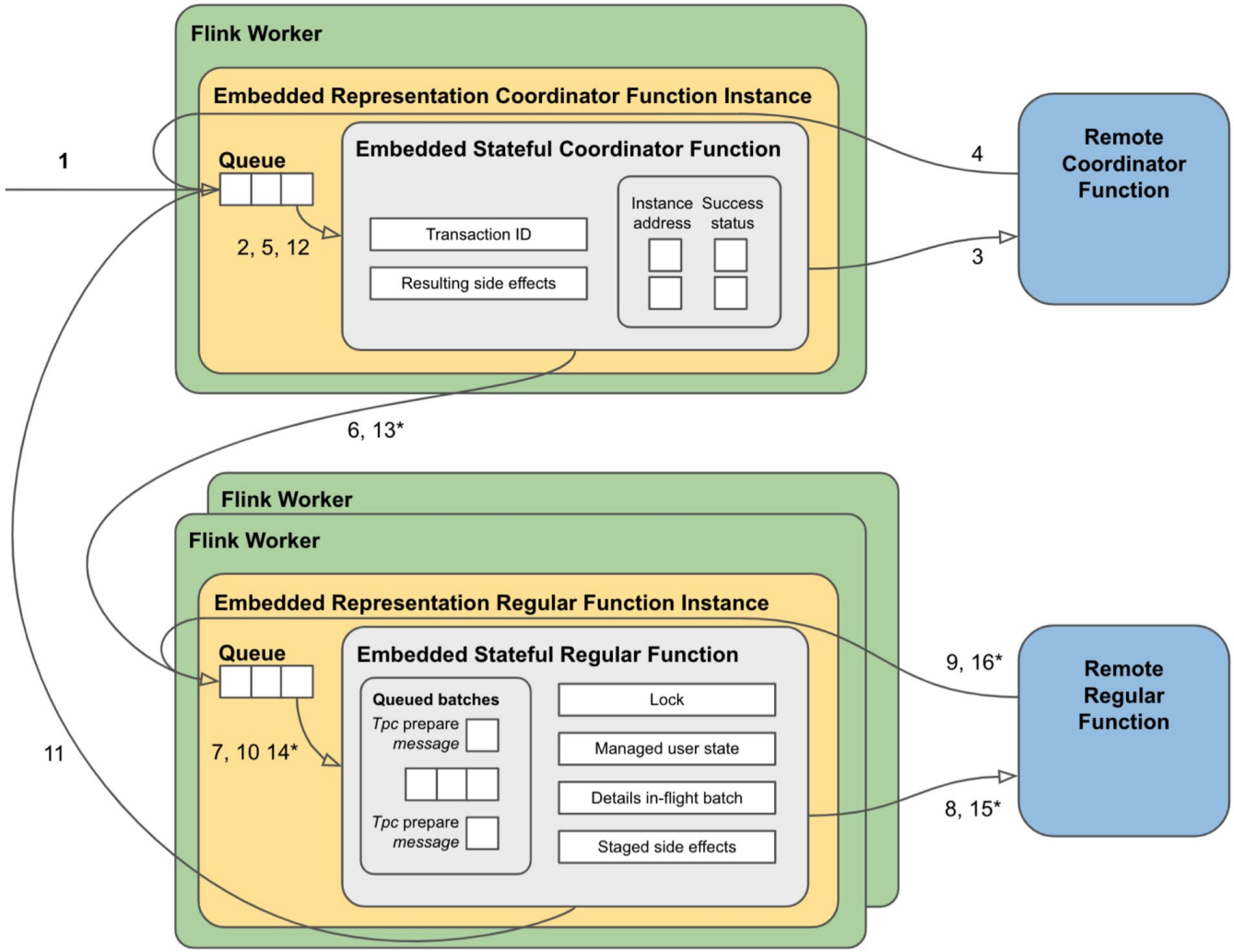
Explicit failure

```python
class NotFoundException(FunctionInvocationException):
    def __init__(self, request_id):
        super().__init__(request_id)

@functions.bind("example/user_function")
async def account_function(context, message: Read):
    # Get state
    user = context.state('user').unpack(User)

    if not user:
        raise NotFoundException(message.request_id)
    else:
        response = Response(request_id=request_id, status_code=200, state=user)
        egress_message = kafka_egress_record(topic="responses", key=request_id, value=response)
        context.pack_and_send_egress("ycsb-example/kafka-egress", egress_message)

@functions.bind_exception_handler(NotFoundException)
async def handle_not_found(context, request_id):
    response = Response(request_id=request_id, status_code=404)
    egress_message = kafka_egress_record(topic="responses", key=request_id, value=response)
    context.pack_and_send_egress("ycsb-example/kafka-egress", egress_message)
```

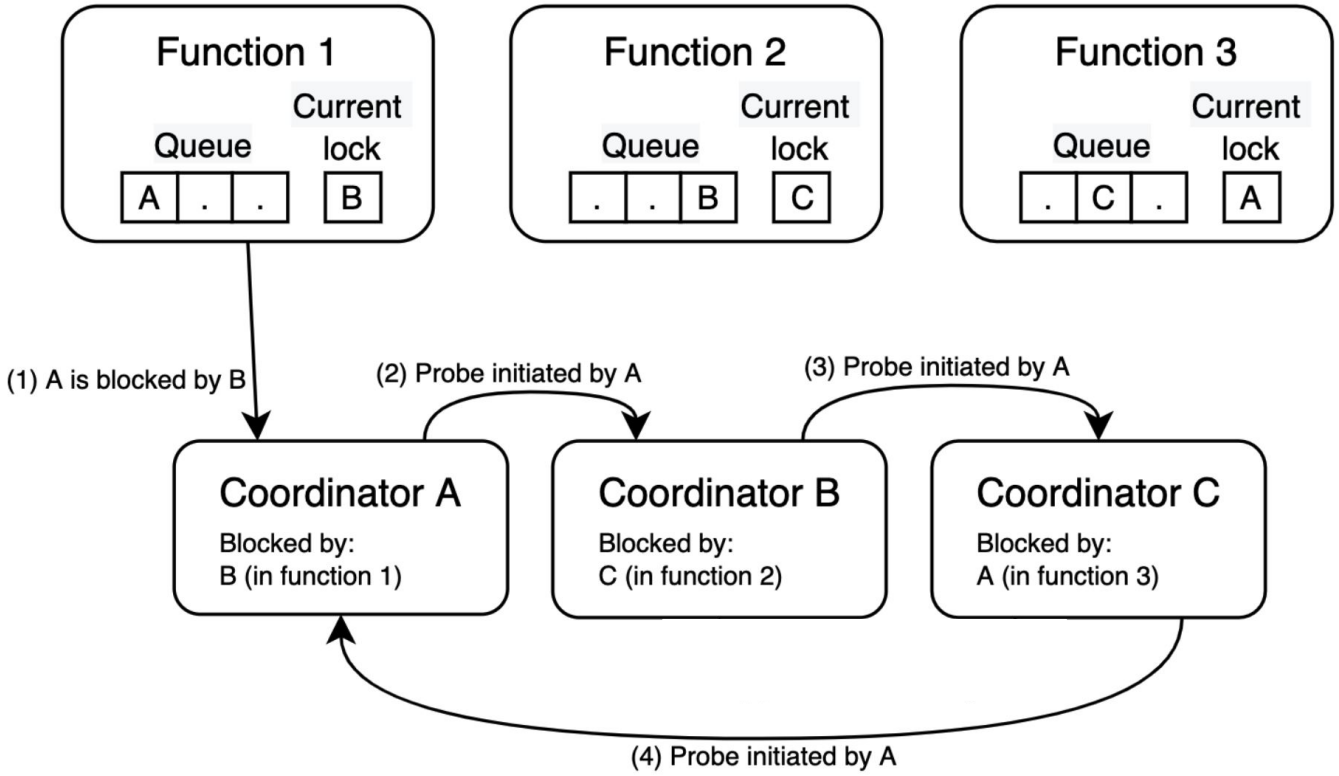
Raise an exception

Exception handler for non-transactional invocations

Coordinator functions



Deadlock detection



K. Mani Chandy, Jayadev Misra, and Laura M. Haas. 1983. Distributed Deadlock Detection. *ACM Trans. Comput. Syst.* 1, 2 (May 1983), 144–156.

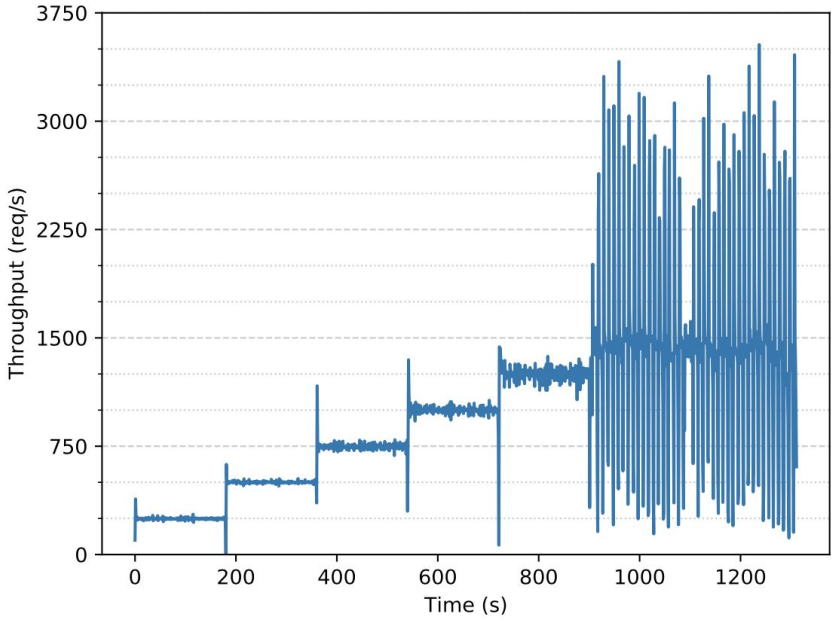
Evaluation

Evaluation

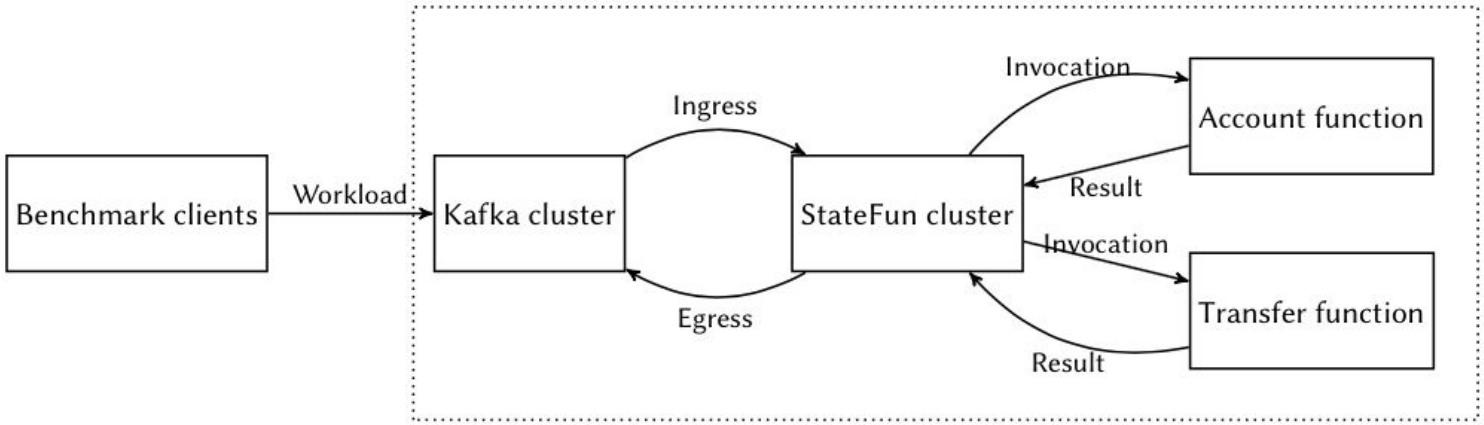
Based on an extension of **YCSB**

- Stage 1: insert *x* keys in the system
- Stage 2: perform of workload of read and write operations
  - Extended with transfer operations
  - Uniform distribution

Measured **maximum throughput** and **latency**

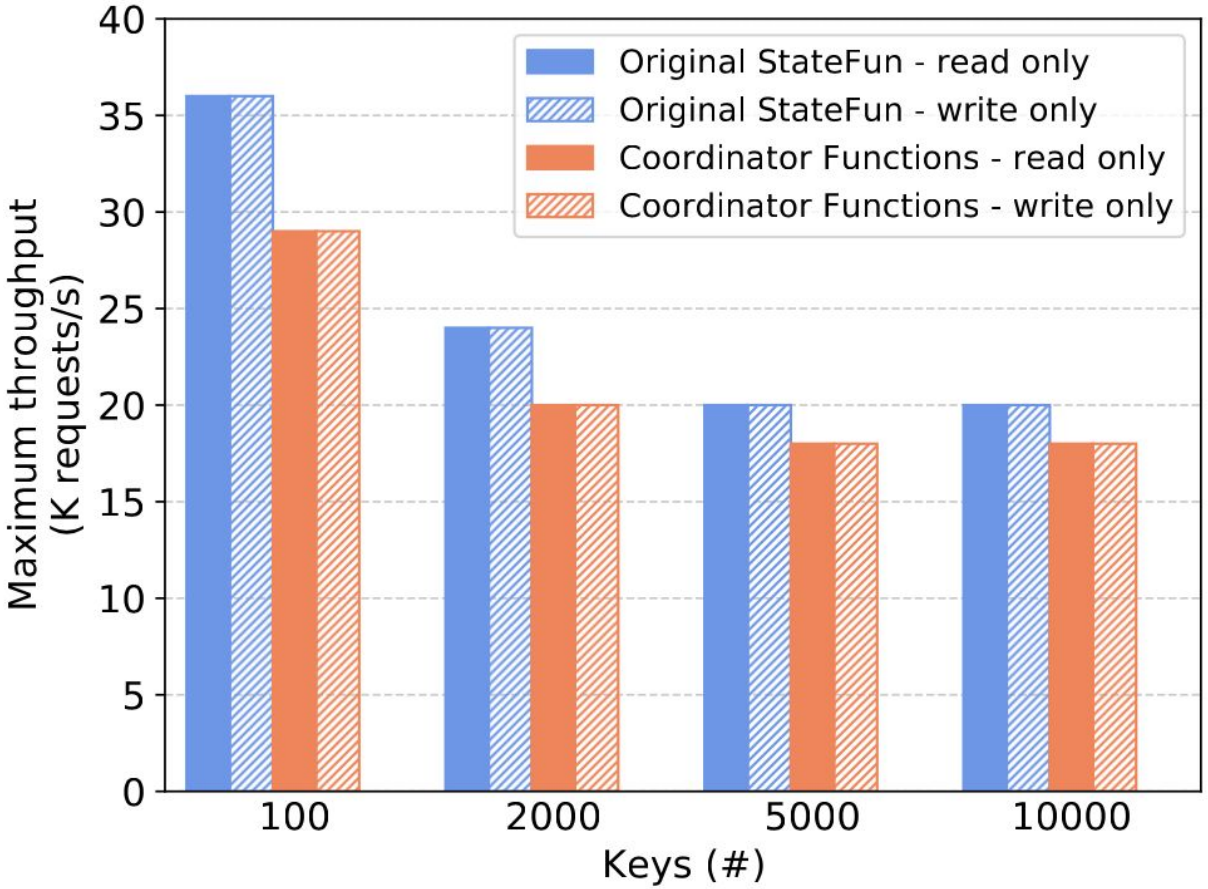


Evaluation



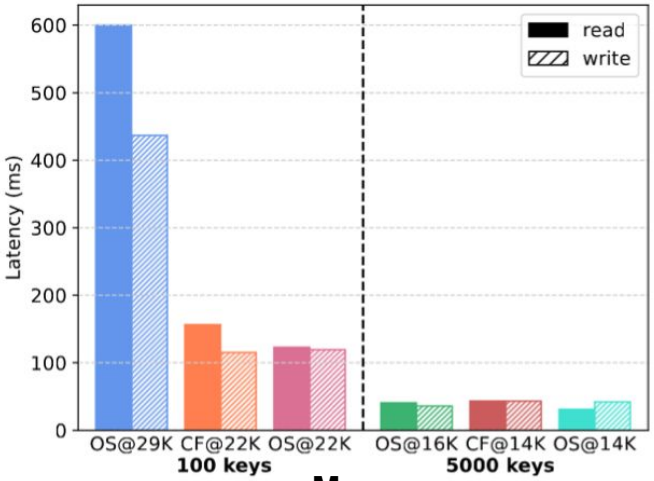
Statefun is restricted to a number of instances and CPUs other components are scaled so they are not the bottleneck

Evaluation

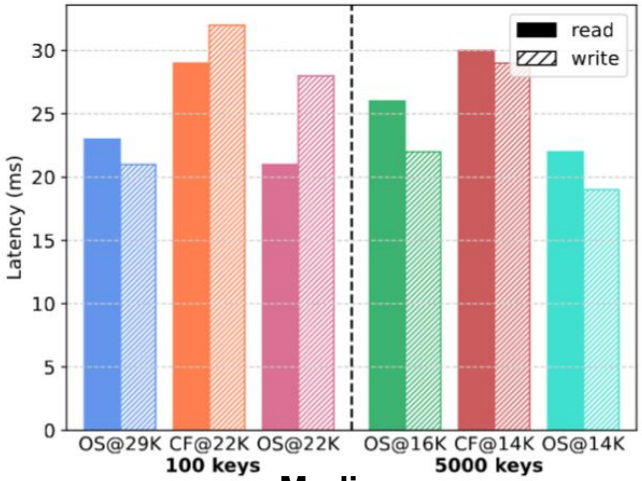


~20% drop in performance for 100 keys
~10% drop in performance for 5000+ keys

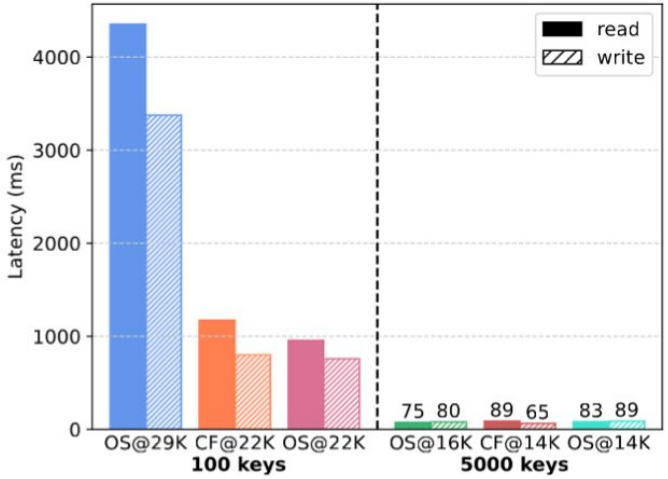
Evaluation



Mean

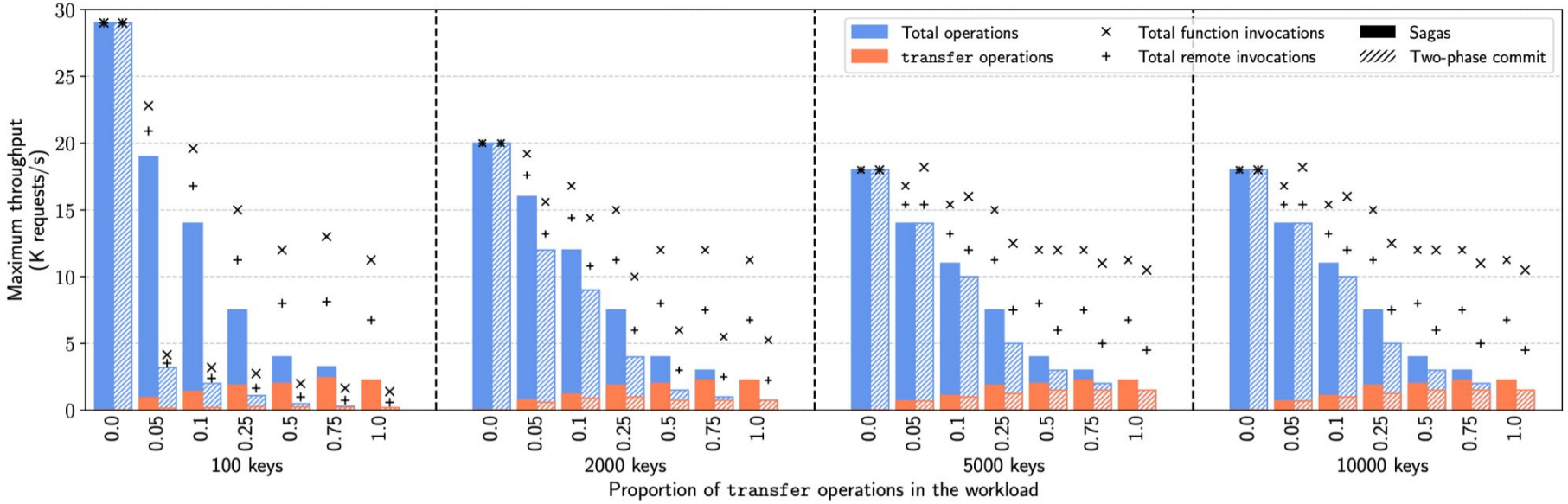


Median



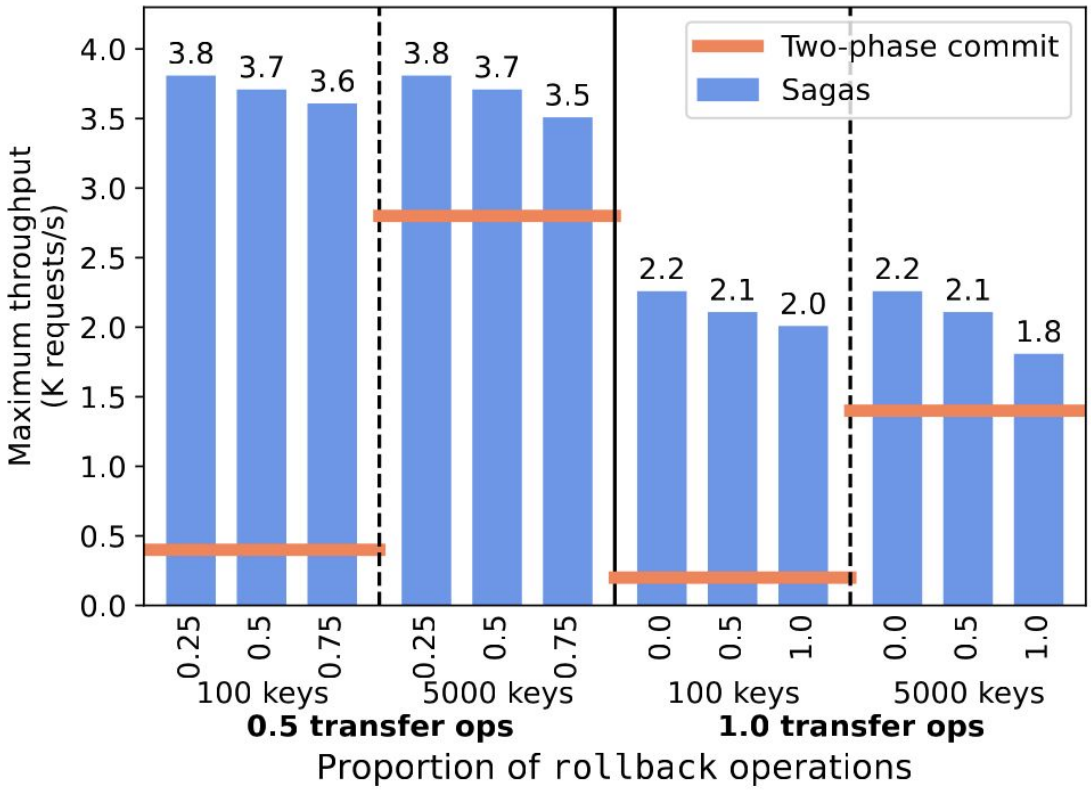
95th percentile

Evaluation



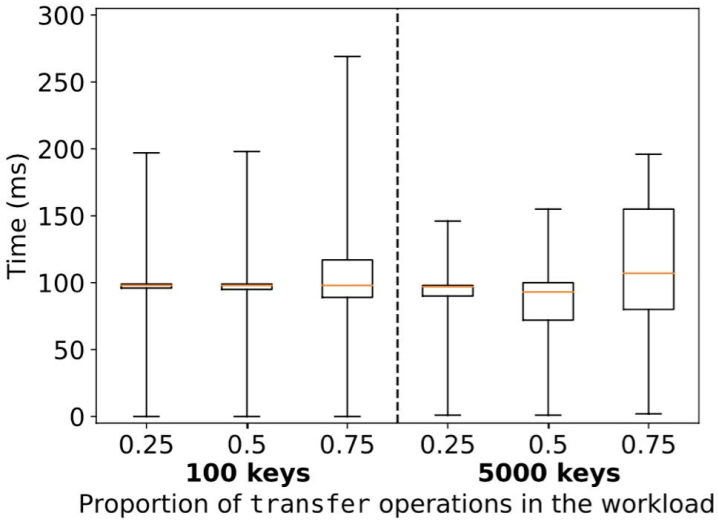
Very poor performance for serializable transaction across 100 keys
More comparable performance for 5000+ keys

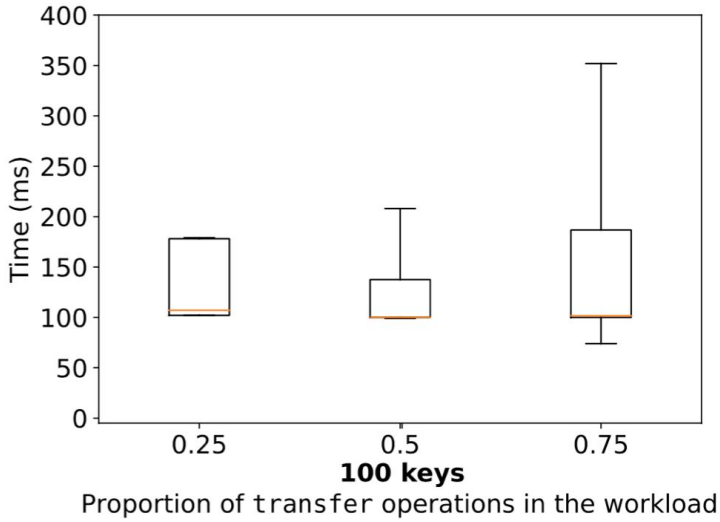
Evaluation



Rollbacks have some overhead for sagas
Sagas still perform better than serializable transactions even at 100% rollbacks

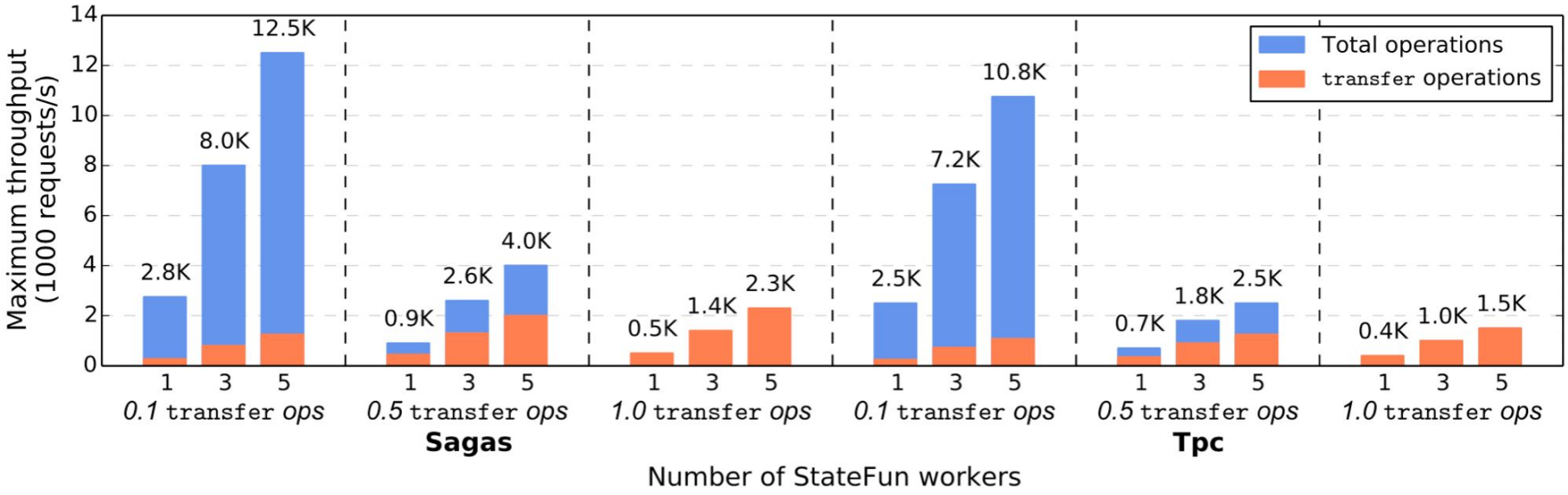
Evaluation





Keys	Transfer proportion	Deadlocks / `transfer` ops
100	0.25	9/12014 (0.07%)
	0.5	27/24107 (0.11%)
	0.75	82/35875 (0.22%)
5000	0.25	0/60121
	0.5	0/120089
	0.75	0/179794

Evaluation



Consistent **90%** scalability efficiency for **sagas**

87% scalability efficiency for **serializable transactions** at **10% transfers**
75% scalability efficiency for **serializable transactions** at **100% transfers**

Conclusion

- Simple programming model abstracting away all distributed systems concerns from the application developer
- Acceptable performance overhead on non-transactional workloads
- Good scalability for saga-based transactions and acceptable scalability for serializable transactions

Future work

Make Stateful Functions complete

- State access without specific function ID
  - Secondary indices
  - WHERE clause
- Aggregates over state across function instances
- Versioning of state / updating functions
- Research based on use cases developing improved benchmarks

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