Managing data consistency in a microservice architecture using Sagas

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http://eventuate.io http://learn.microservices.io

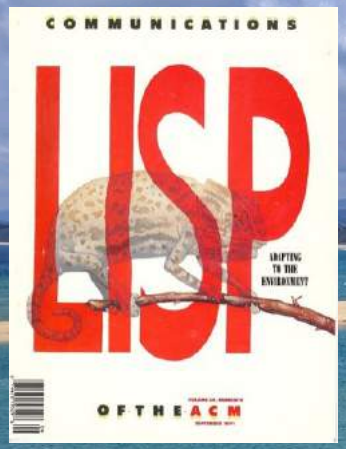
SATURN 2018

Presentation goal

Distributed data management challenges in a microservice architecture

Sagas as the transaction model

About Chris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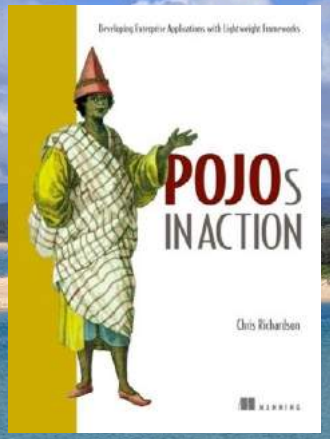
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About Chris

Consultant and trainer focusing on modern application architectures including microservices

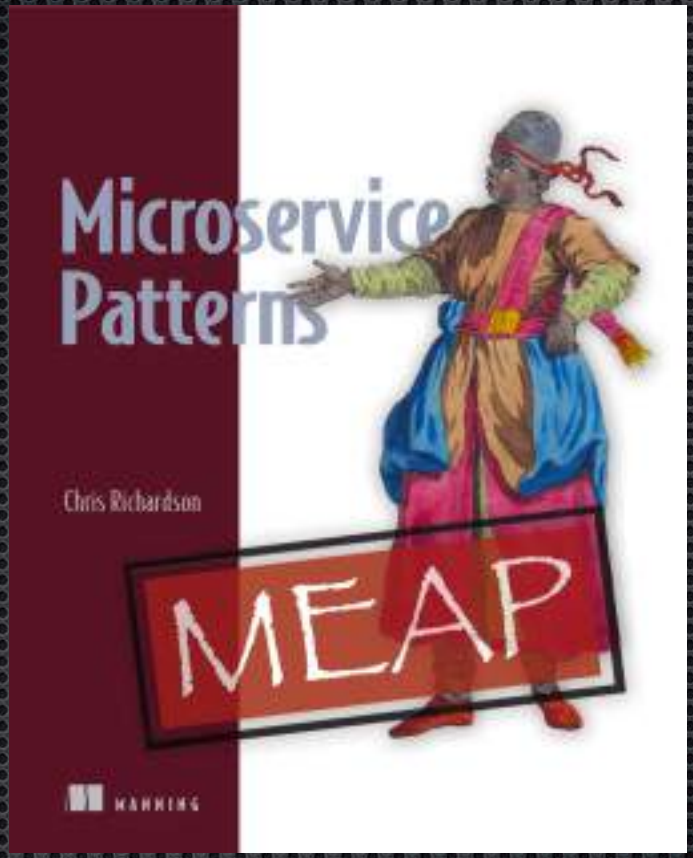
(http://www.chrisrichardson.net/)

About Chris

Founder of a startup that is creating an open-source/SaaS platform that simplifies the development of transactional microservices

(http://eventuate.io)

For more information



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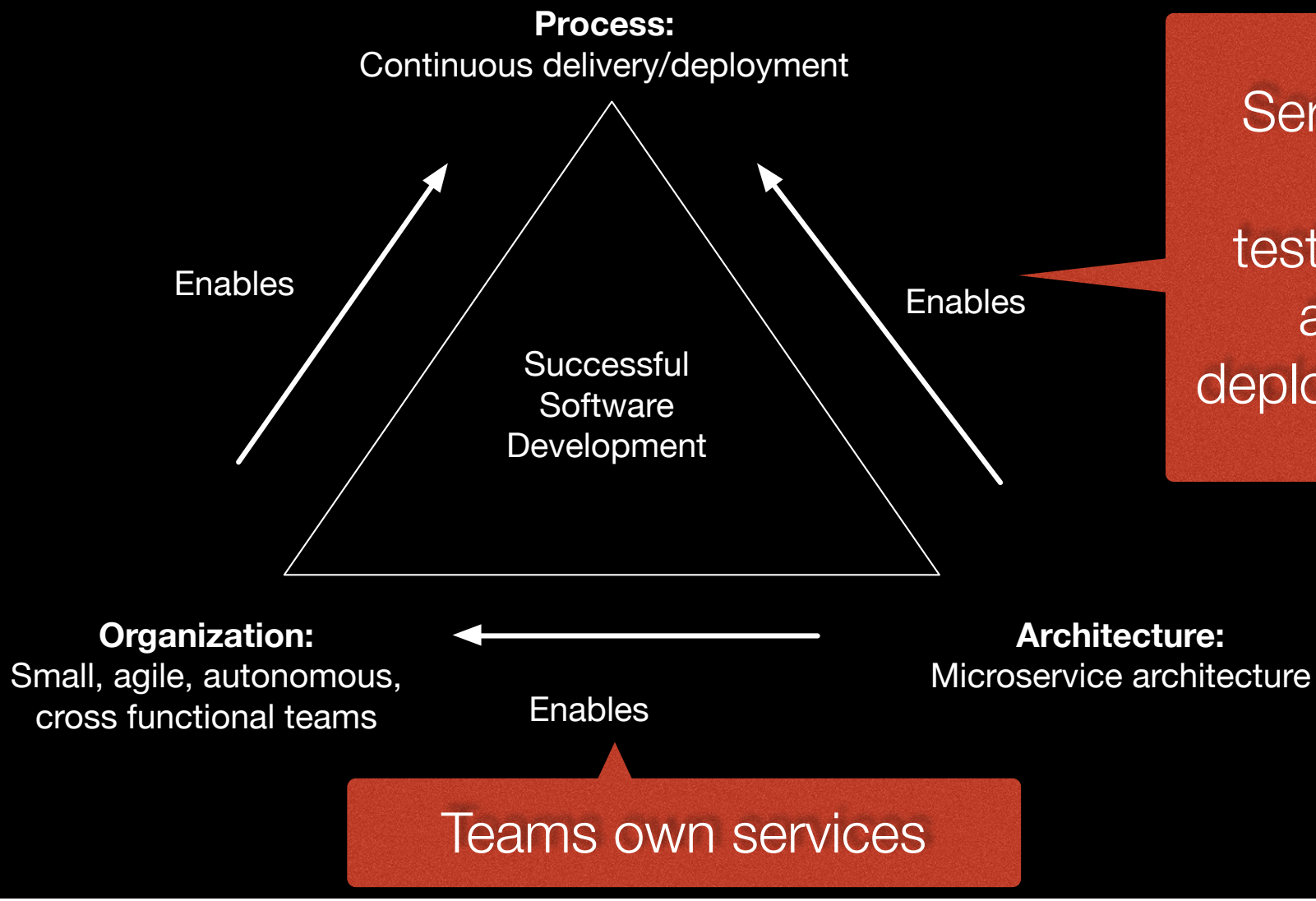
http://learn.microservices.io

Agenda

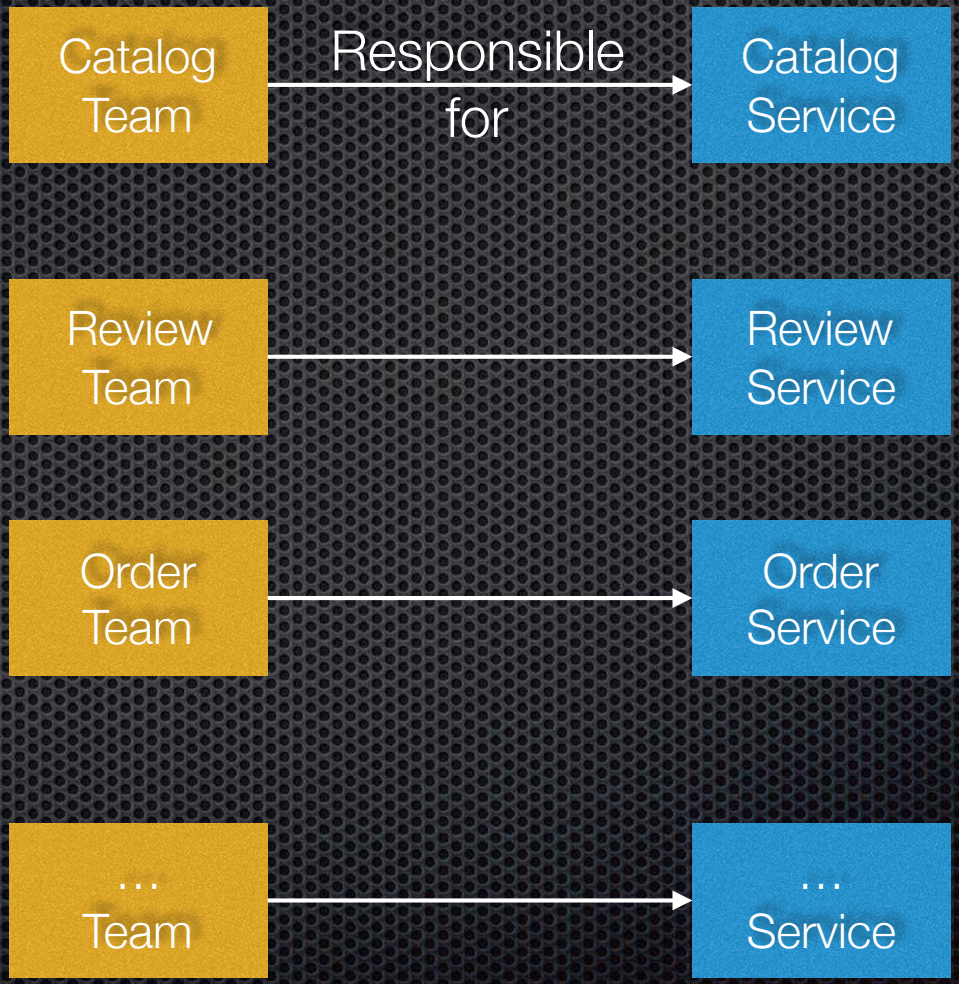
- ACID is not an option
- Overview of sagas
- Coordinating sagas
- Countermeasures for data anomalies
- Using reliable and transactional messaging

The microservice architecture
structures
an application as a
set of loosely coupled services

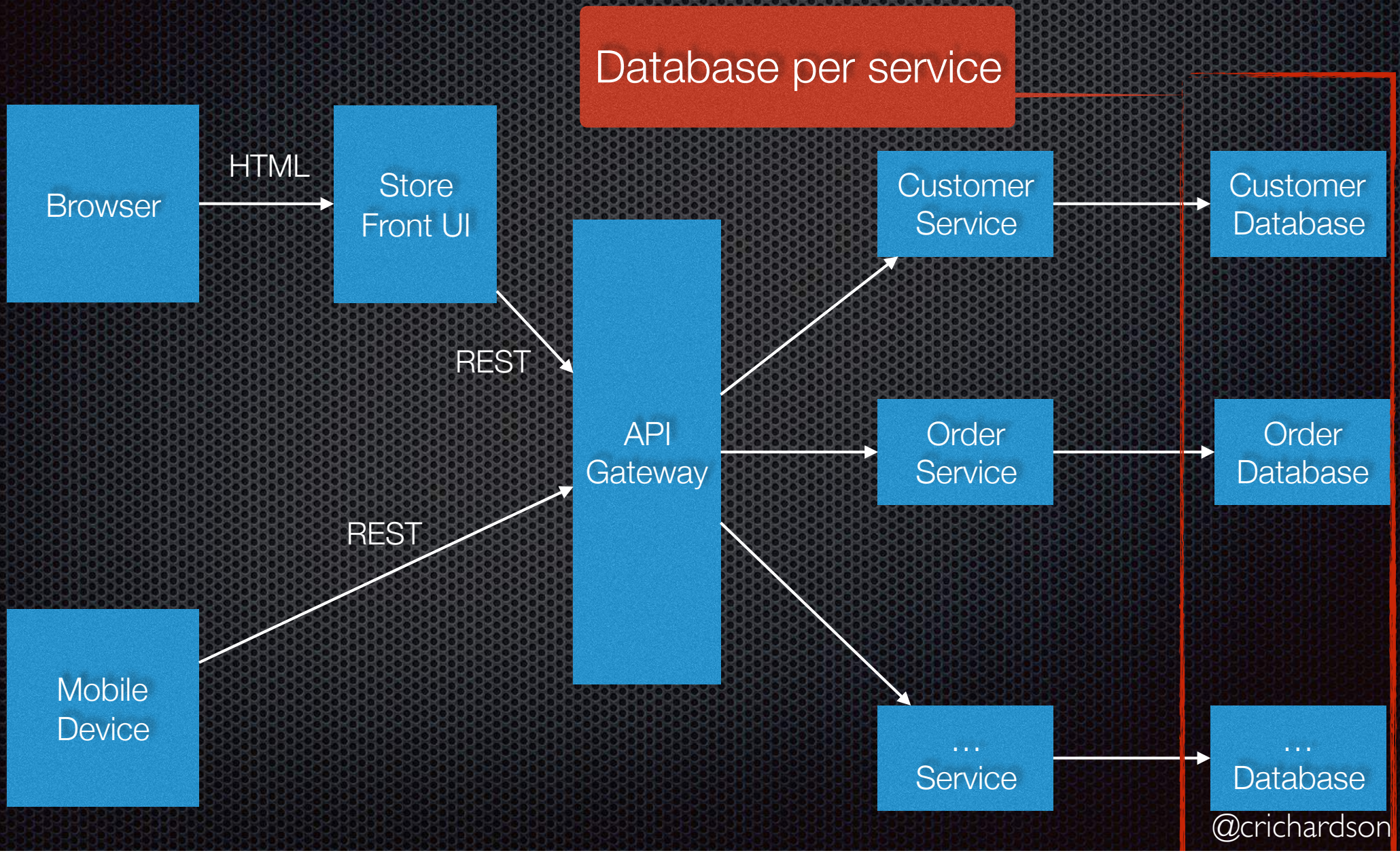
Microservices enable continuous delivery/deployment



Each team owns one or more services



Microservice architecture

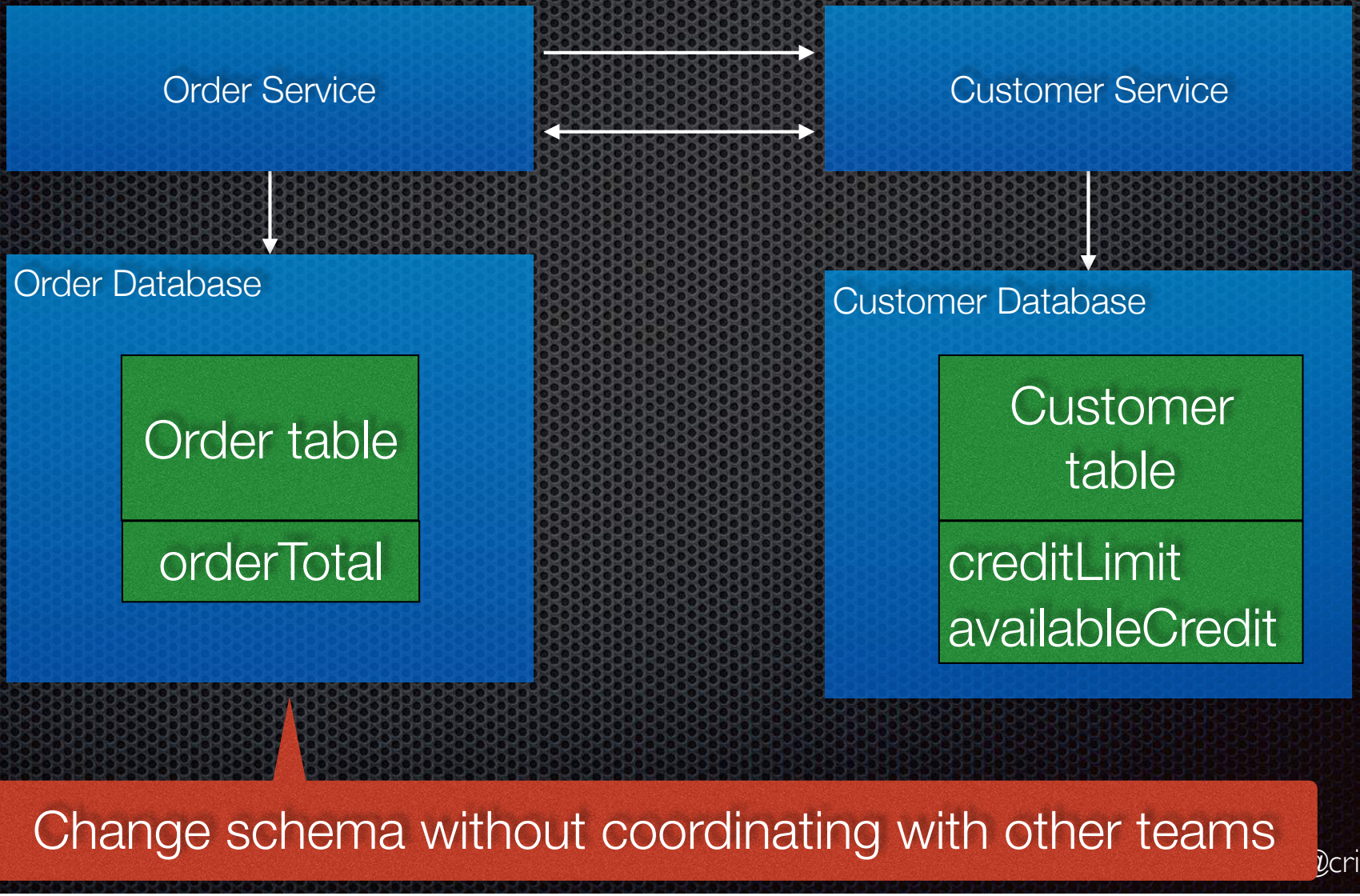


Private database

!=

private database **server**

Loose coupling = encapsulated data



But…

How to maintain data consistency?

How to implement queries?

How to maintain data consistency?

createOrder(customerId, orderTotal)

Pre-conditions:

- customerId is valid

Post-conditions

- Order was created
- Customer.availableCredit -= orderTotal

Spans services

Customer class

Invariant:

availableCredit >= 0
availableCredit <= creditLimit

Cannot use ACID transactions that span services

Distributed transactions

```
BEGIN TRANSACTION
...
SELECT ORDER_TOTAL
 FROM ORDERS WHERE CUSTOMER_ID = ?
...
SELECT CREDIT_LIMIT
FROM CUSTOMERS WHERE CUSTOMER_ID = ?
...
INSERT INTO ORDERS ...
...
COMMIT TRANSACTION
```

Private to the Order Service

Private to the Customer Service

2PC is not an option

- Guarantees consistency

BUT

- 2PC coordinator is a single point of failure
- Chatty: at least O(4n) messages, with retries O(n^2)
- Reduced throughput due to locks
- Not supported by many NoSQL databases (or message brokers)
- CAP theorem ⇒ 2PC impacts availability
- ….

ACID ⇒

Basically
Available
Soft state
Eventually consistent

http://queue.acm.org/detail.cfm?id=1394128

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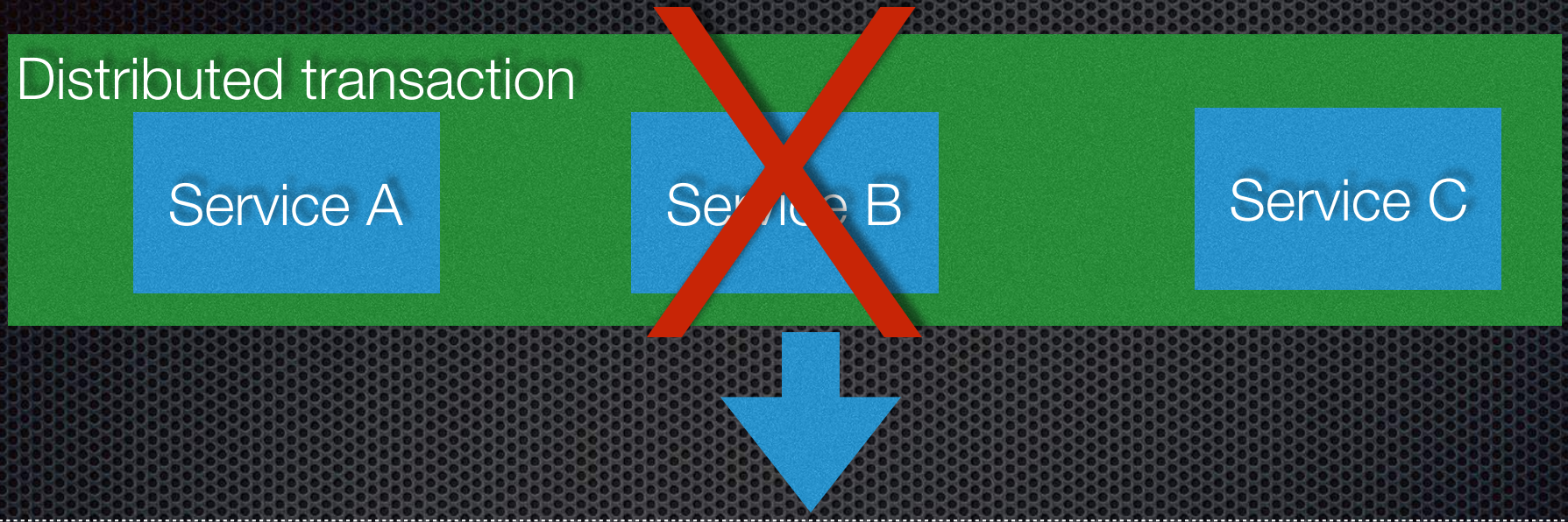
From a 1987 paper

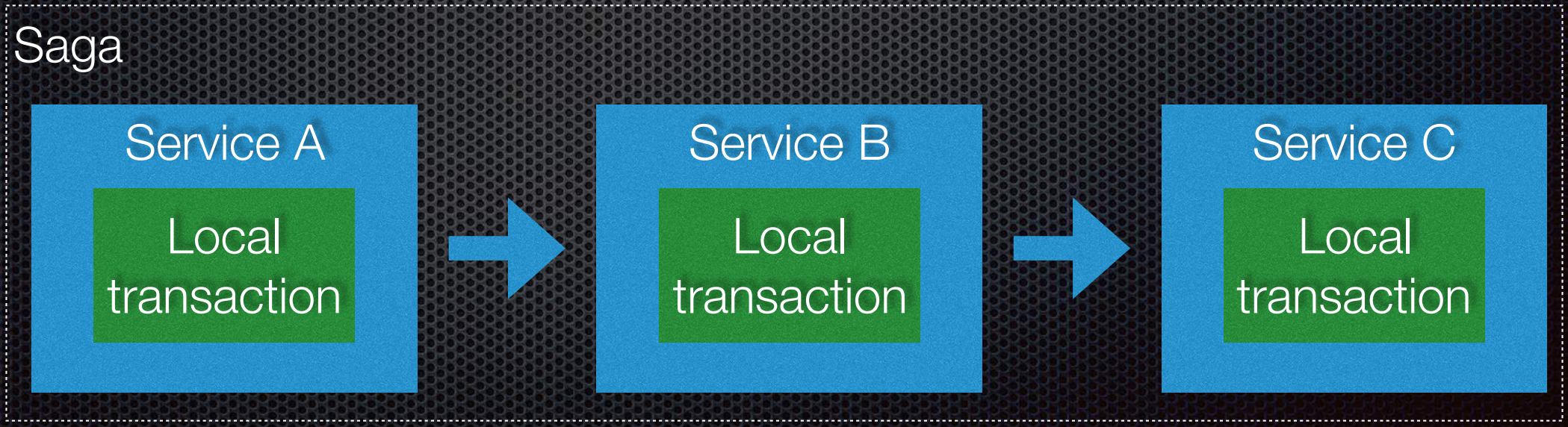
SAGAS

Hector Garcia-Molina
Kenneth Salem

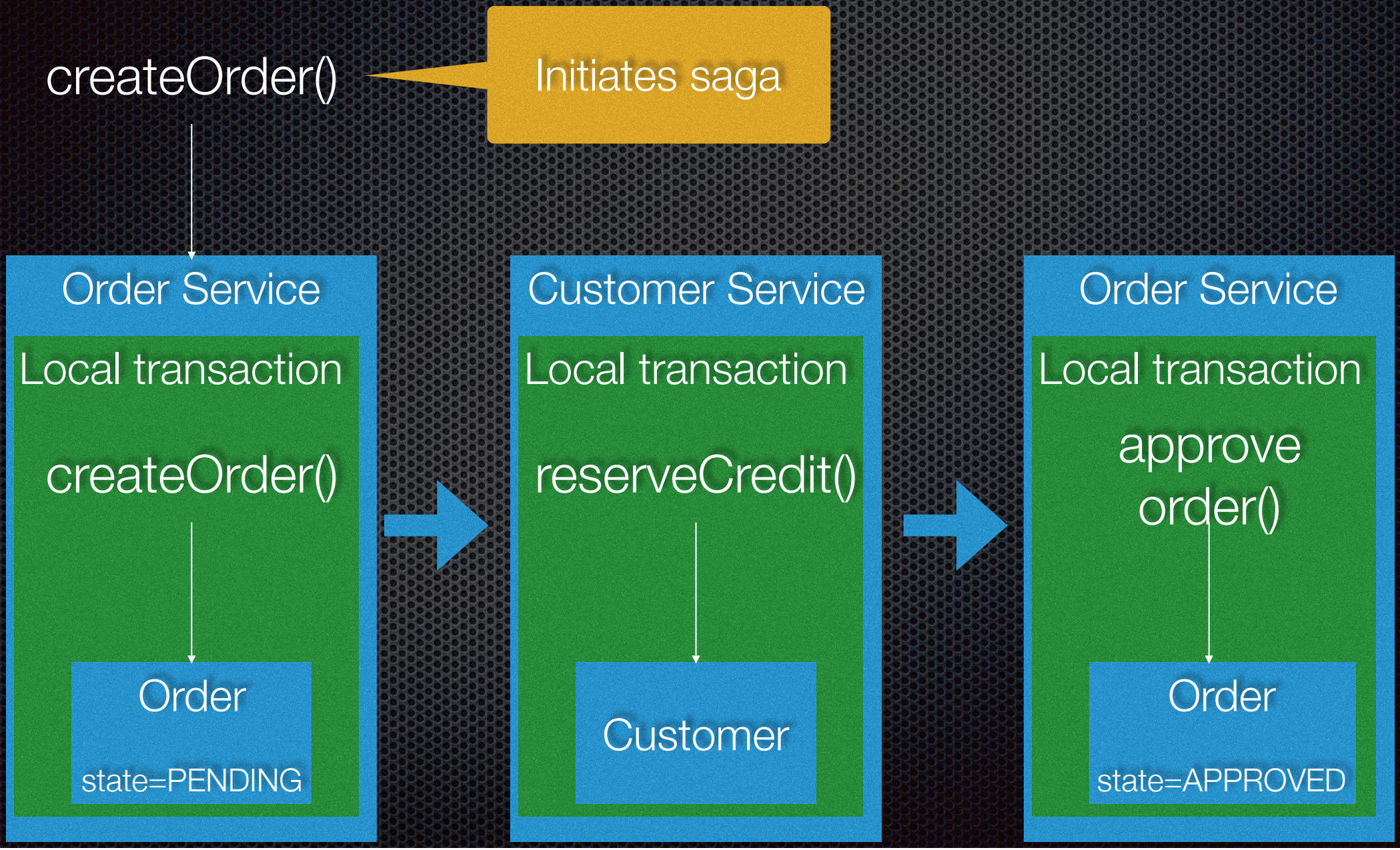
Department of Computer Science
Princeton University
Princeton, N J 08544

Use Sagas instead of 2PC





Create Order Saga



But what about rollback?

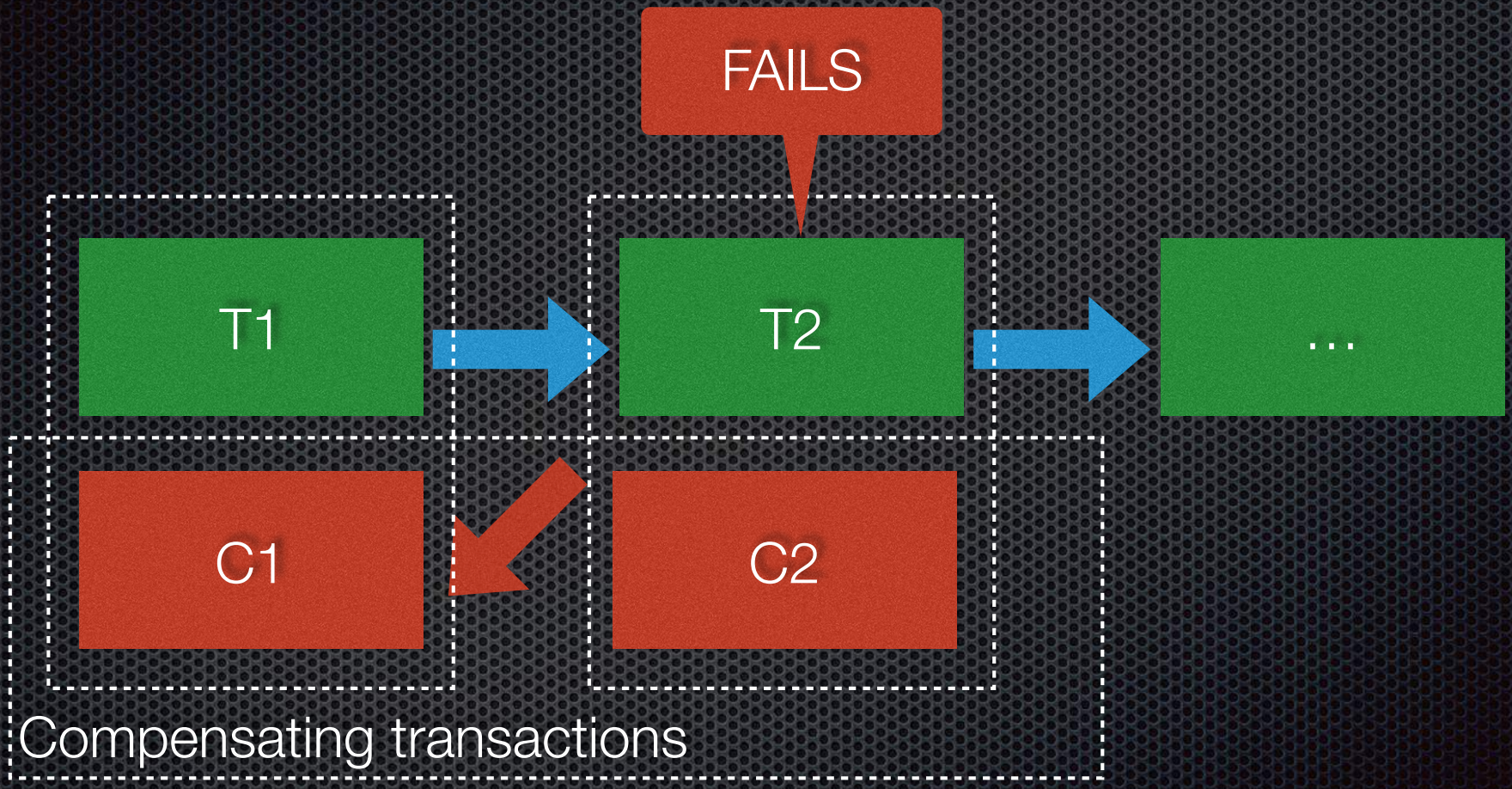
```
BEGIN TRANSACTION
...
UPDATE ...
...
INSERT ....
...
.... BUSINESS RULE VIOLATED!!!!
...
ROLLBACK TRANSACTION
```

Really simple!

Rolling back sagas

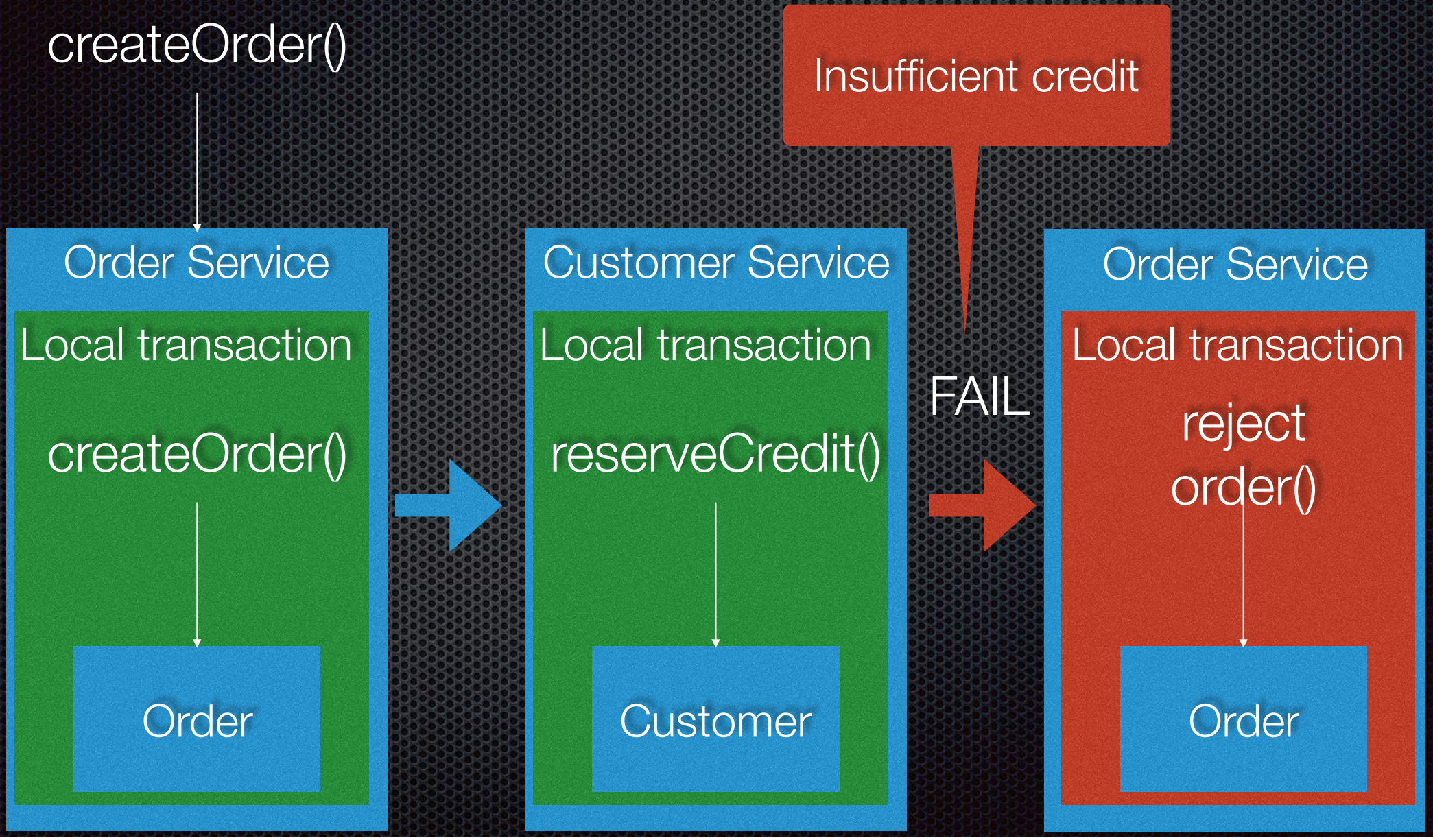
- Use compensating transactions
- Developer must write application logic to “rollback” eventually consistent transactions
- Careful design required!

Saga: Every Ti has a Ci



T1 ⇒ T2 ⇒ C1

Create Order Saga - rollback



Writing compensating transactions isn't always easy

- Write them so they will always succeed
  - If a compensating transaction fails => no clear way to recover
- Challenge: Undoing changes when data has already been changed by a different transaction/saga
  - More on this later

Non-compensatable actions

- For example, sending an email can’t be unsent.
- Move actions that can’t be undone to the end of the saga
- More on this later.

Sagas complicate API design

- Synchronous API vs Asynchronous Saga
- Request initiates the saga. When to send back the response?
- Option #1: Send response when saga completes:

  + Response specifies the outcome

  - Reduced availability

- Option #2: Send response immediately after creating the saga **(recommended)**:

  + Improved availability

  - Response does not specify the outcome. Client must poll or be notified

Revised Create Order API

- createOrder()
  - returns id of newly created order
  - **NOT** fully validated
- getOrder(id)
  - Called periodically by client to get outcome of validation

Minimal impact on UI

- UI hides asynchronous API from the user
- Saga will usually appear instantaneous (<= 100ms)
- If it takes longer ⇒ UI displays “processing” popup
- Server can push notification to UI

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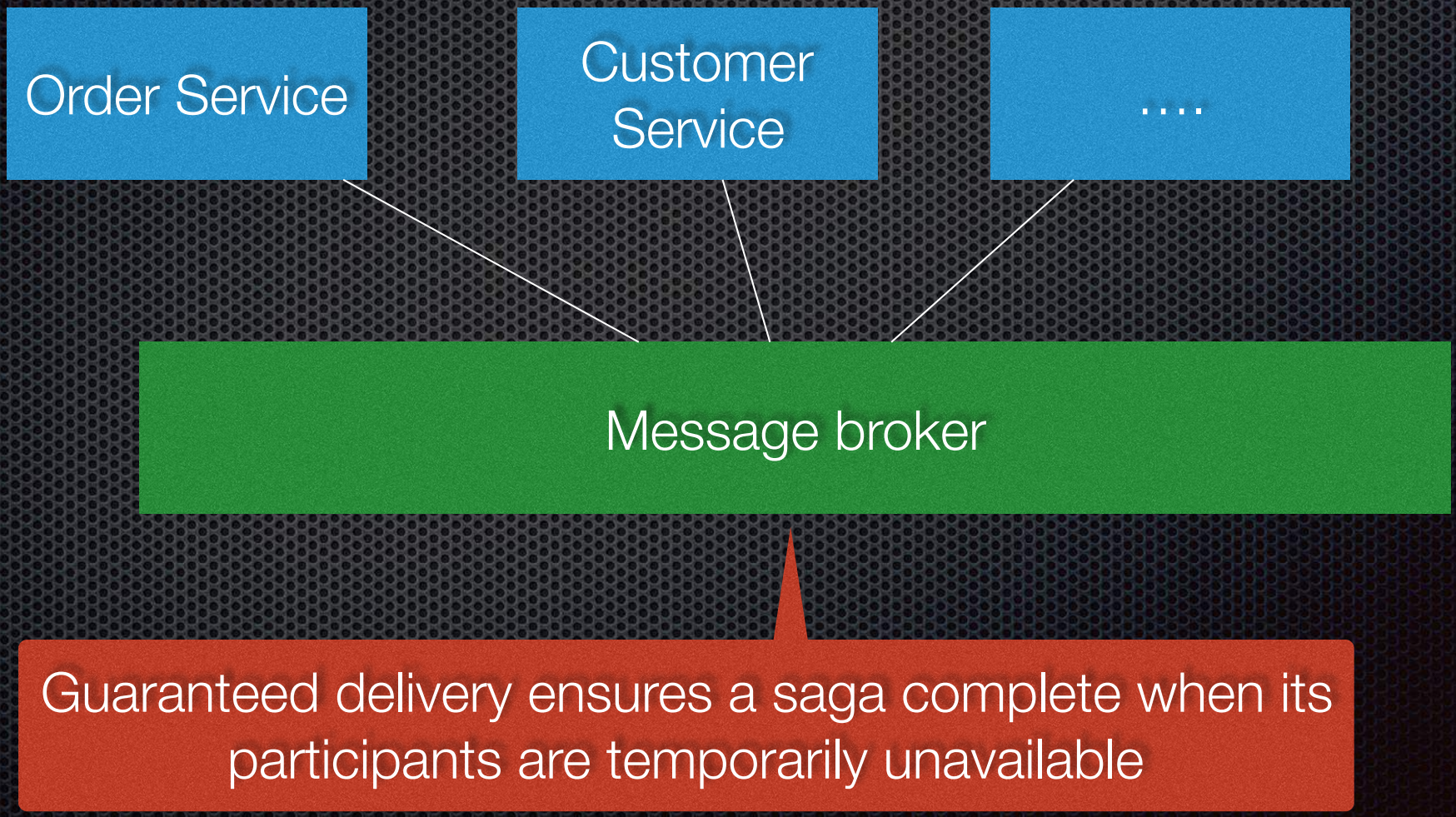
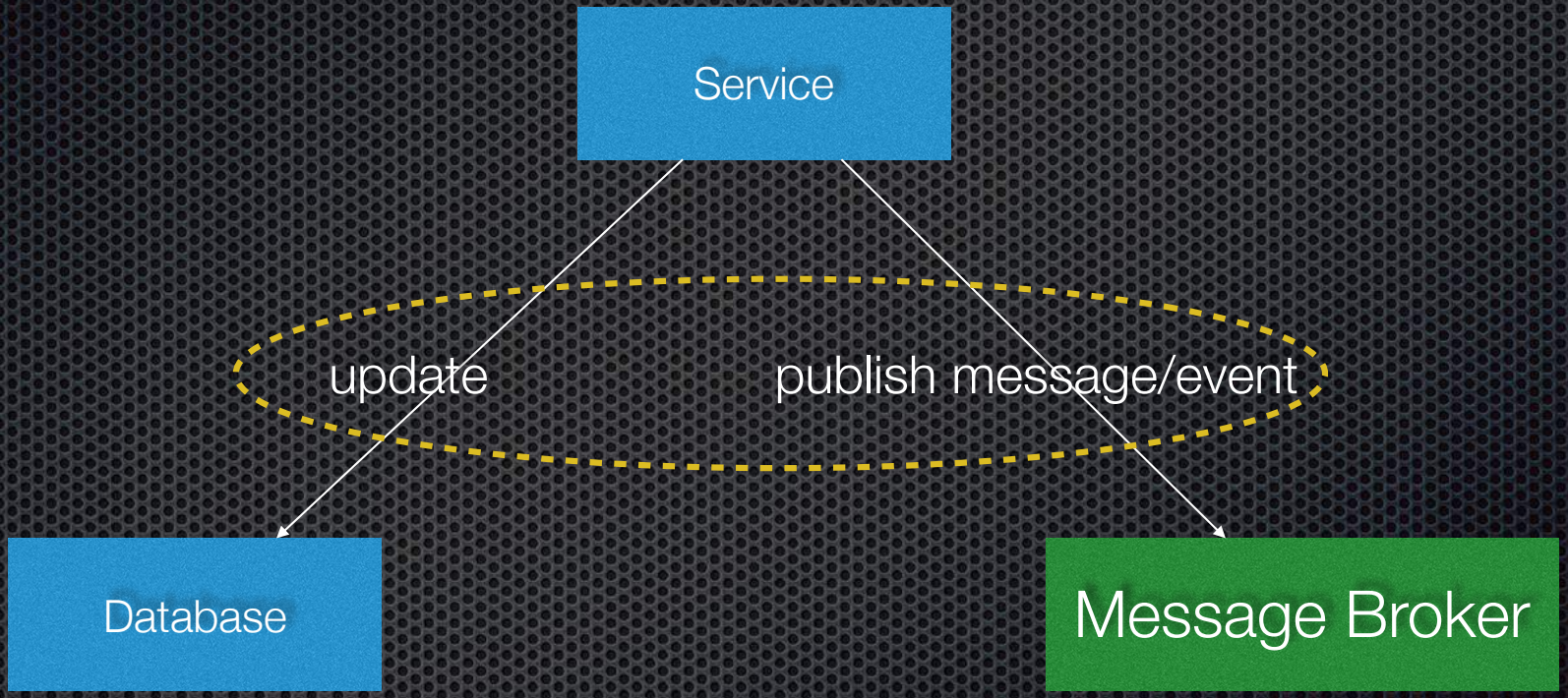
How to sequence the saga transactions?

- After the completion of transaction Ti “something” must decide what step to execute next
- Success: which T(i+1) - branching
- Failure: C(i - 1)

Use asynchronous, broker-based messaging



Saga step = a transaction local to a service



Transactional DB: BEGIN … COMMIT

DDD: Aggregate

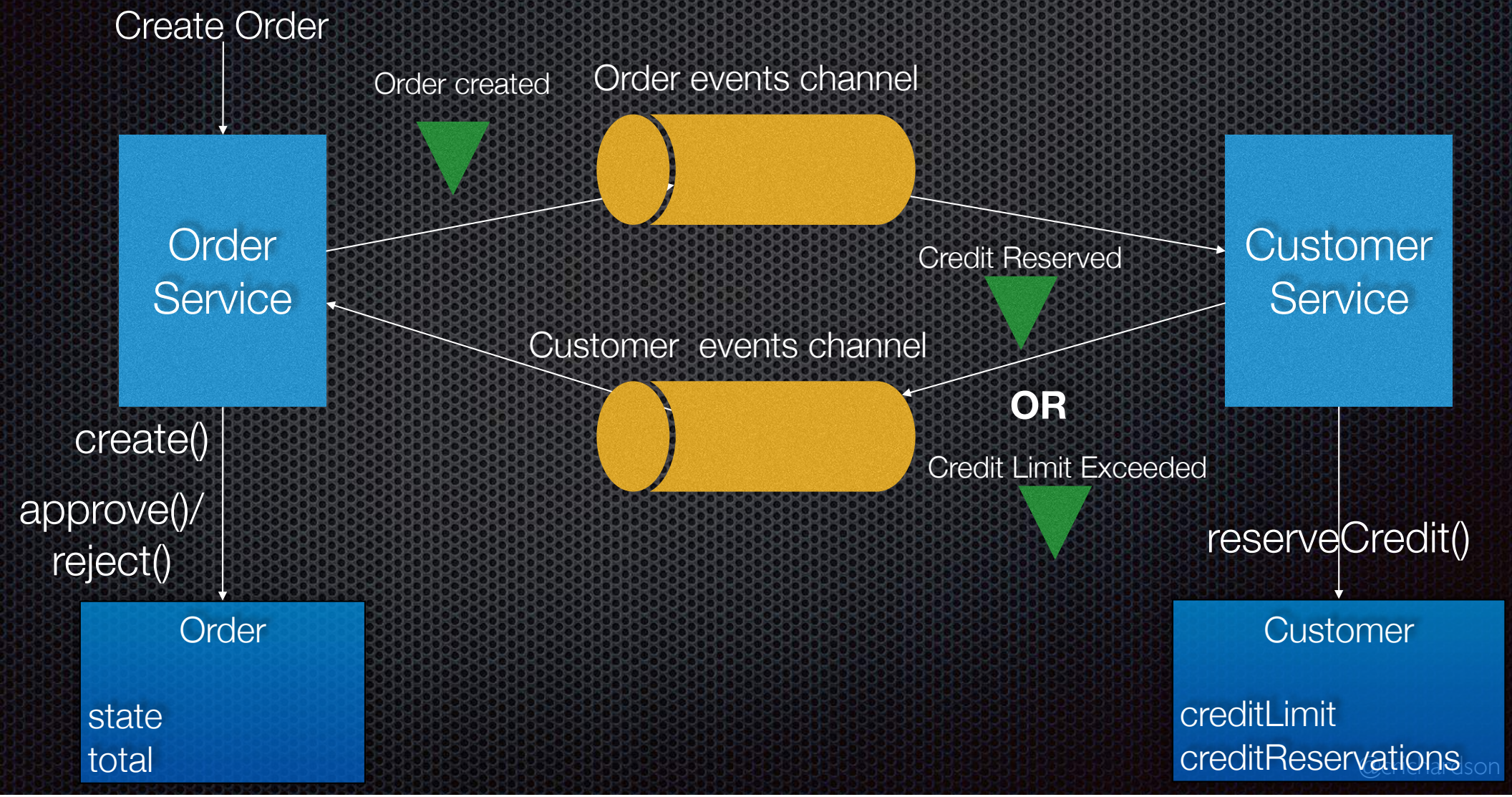
NoSQL: single ‘record’

Choreography: **distributed** decision making

vs.

Orchestration: **centralized** decision making

Option #1: Choreography-based coordination using events



Order Service: publishing domain events

```
public class OrderService {

  @Autowired
  private DomainEventPublisher domainEventPublisher;

  @Autowired
  private OrderRepository orderRepository;

  @Transactional
  public Order createOrder(OrderDetails orderDetails) {
    Order order = Order.createOrder(orderDetails);
    orderRepository.save(order);
    domainEventPublisher.publish(Order.class,
            order.getId(),
            singletonList(new OrderCreatedEvent(order.getId(), orderDetails)));
    return order;
  }
}
```

Create order

Publish event

Customer Service: consuming domain events…

```
public class OrderEventConsumer {

  @Autowired
  private CustomerRepository customerRepository;

  @Autowired
  private DomainEventPublisher domainEventPublisher;

  public DomainEventHandlers domainEventHandlers() {
    return DomainEventHandlersBuilder
            .forAggregateType("io.eventuate.examples.tram.ordersandcustomers.orders.domain.Order")
            .onEvent(OrderCreatedEvent.class, this::orderCreatedEventHandler)
            .build();
  }

  private void orderCreatedEventHandler(DomainEventEnvelope<OrderCreatedEvent> domainEventEnvelope) {...}
}
```

Subscribe to event

https://github.com/eventuate-tram/eventuate-tram-examples-customers-and-orders

Customer Service: consuming domain events

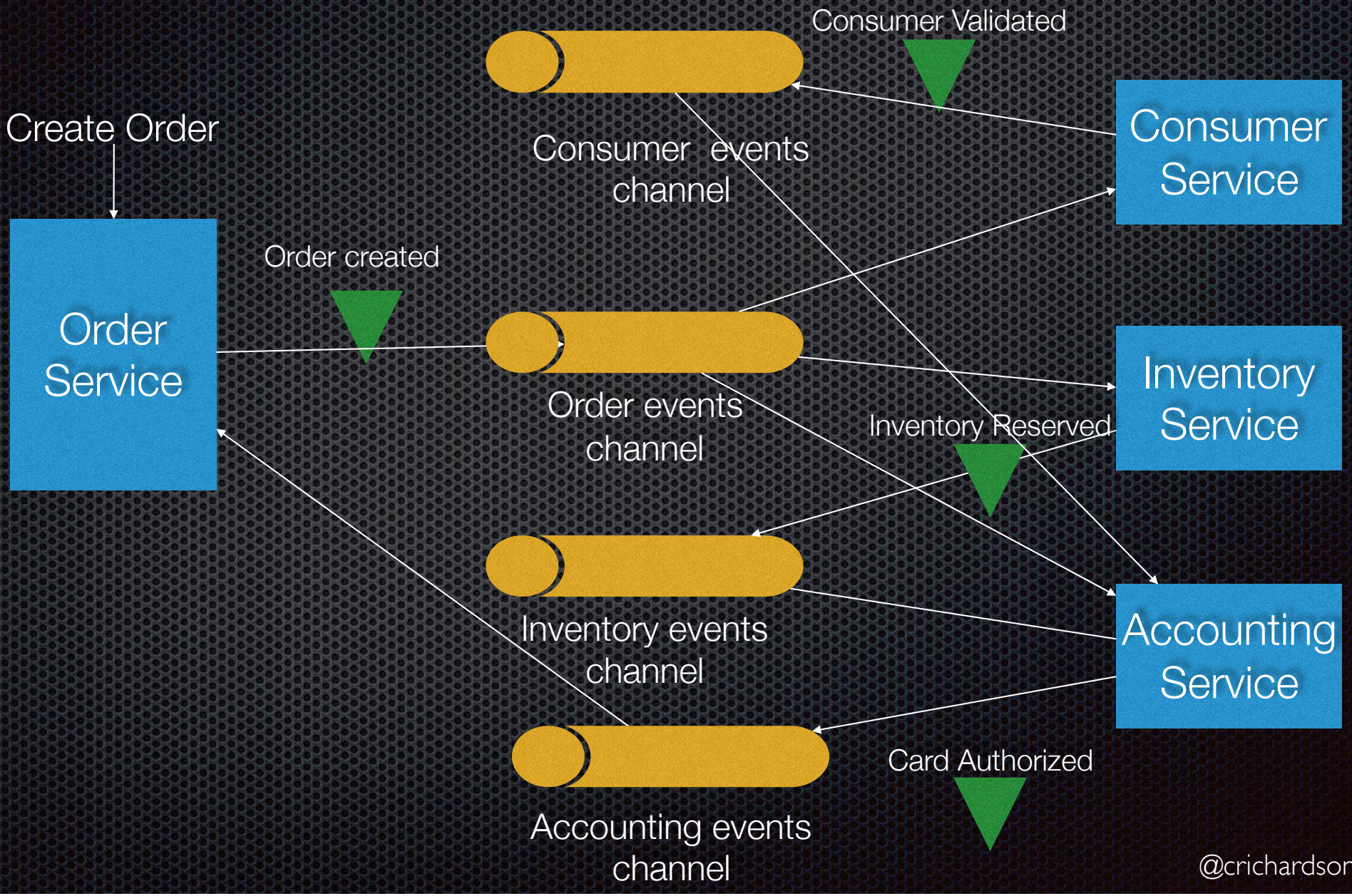
```
private void orderCreatedEventHandler(DomainEventEnvelope<OrderCreatedEvent> domainEventEnvelope) {

  OrderCreatedEvent orderCreatedEvent = domainEventEnvelope.getEvent();

  Customer customer = customerRepository
          .findOne(orderCreatedEvent.getOrderDetails().getCustomerId());

  try {
    customer.reserveCredit(orderCreatedEvent.getOrderId(),
            orderCreatedEvent.getOrderDetails().getOrderTotal());

    CustomerCreditReservedEvent customerCreditReservedEvent =
            new CustomerCreditReservedEvent(orderCreatedEvent.getOrderId());

    domainEventPublisher.publish(Customer.class,
            customer.getId(),
            Collections.singletonList(customerCreditReservedEvent));

  } catch (CustomerCreditLimitExceededException e) {

    CustomerCreditReservationFailedEvent customerCreditReservationFailedEvent =
            new CustomerCreditReservationFailedEvent(orderCreatedEvent.getOrderId());

    domainEventPublisher.publish(Customer.class,
            customer.getId(),
            Collections.singletonList(customerCreditReservationFailedEvent));
  }
}
```

Attempt to Reserve credit

Publish event on success

Publish event on failure

More complex choreography example



Benefits and drawbacks of choreography

Benefits

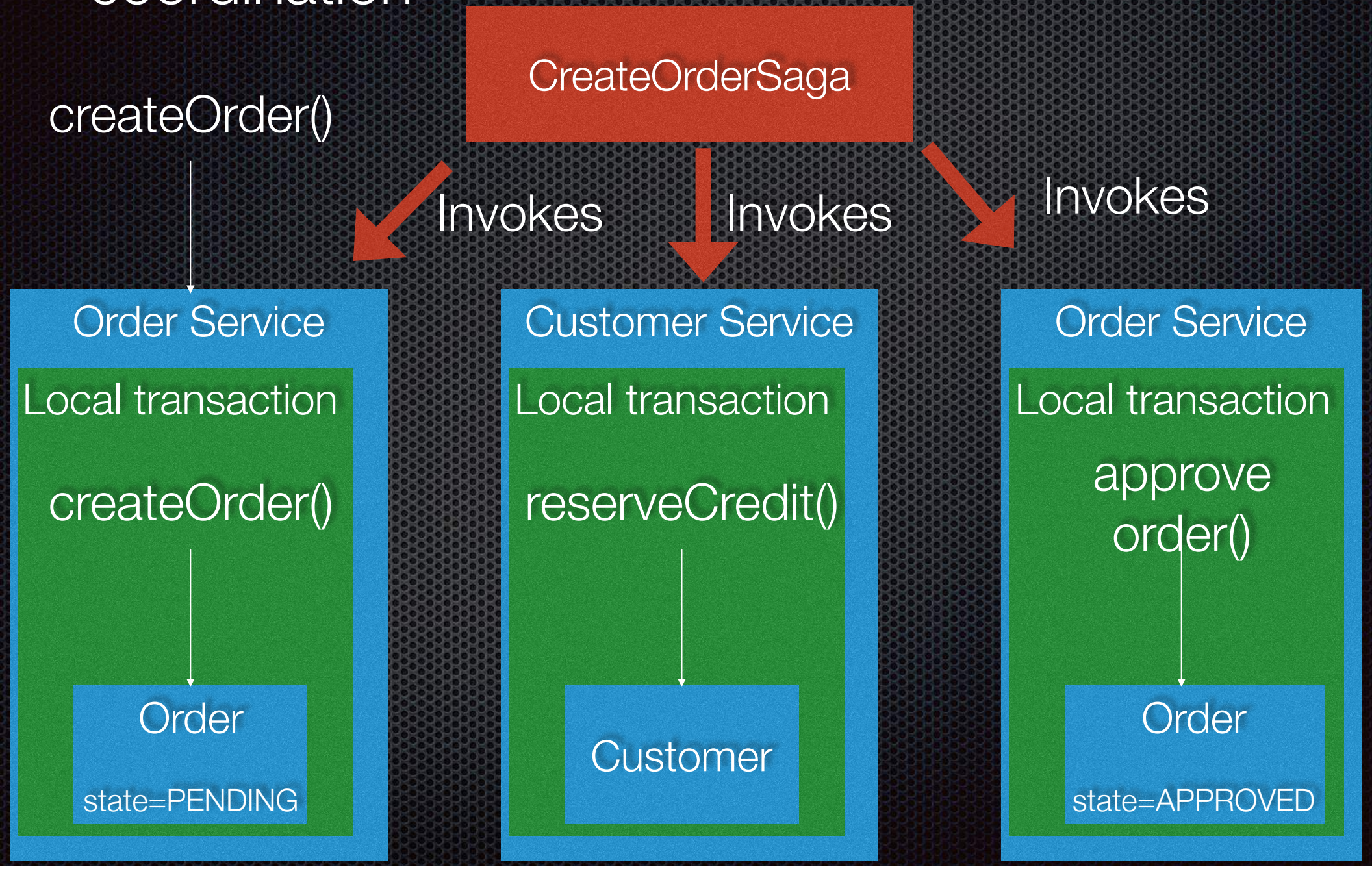
- Simple, especially when using event sourcing
- Participants are loosely coupled

Drawbacks

- Cyclic dependencies - services listen to each other's events
- Overloads domain objects, e.g. Order and Customer **know** too much
- Events = indirect way to make something happen

https://github.com/eventuate-examples/eventuate-examples-java-customers-and-orders

Option #2: Orchestration-based saga coordination

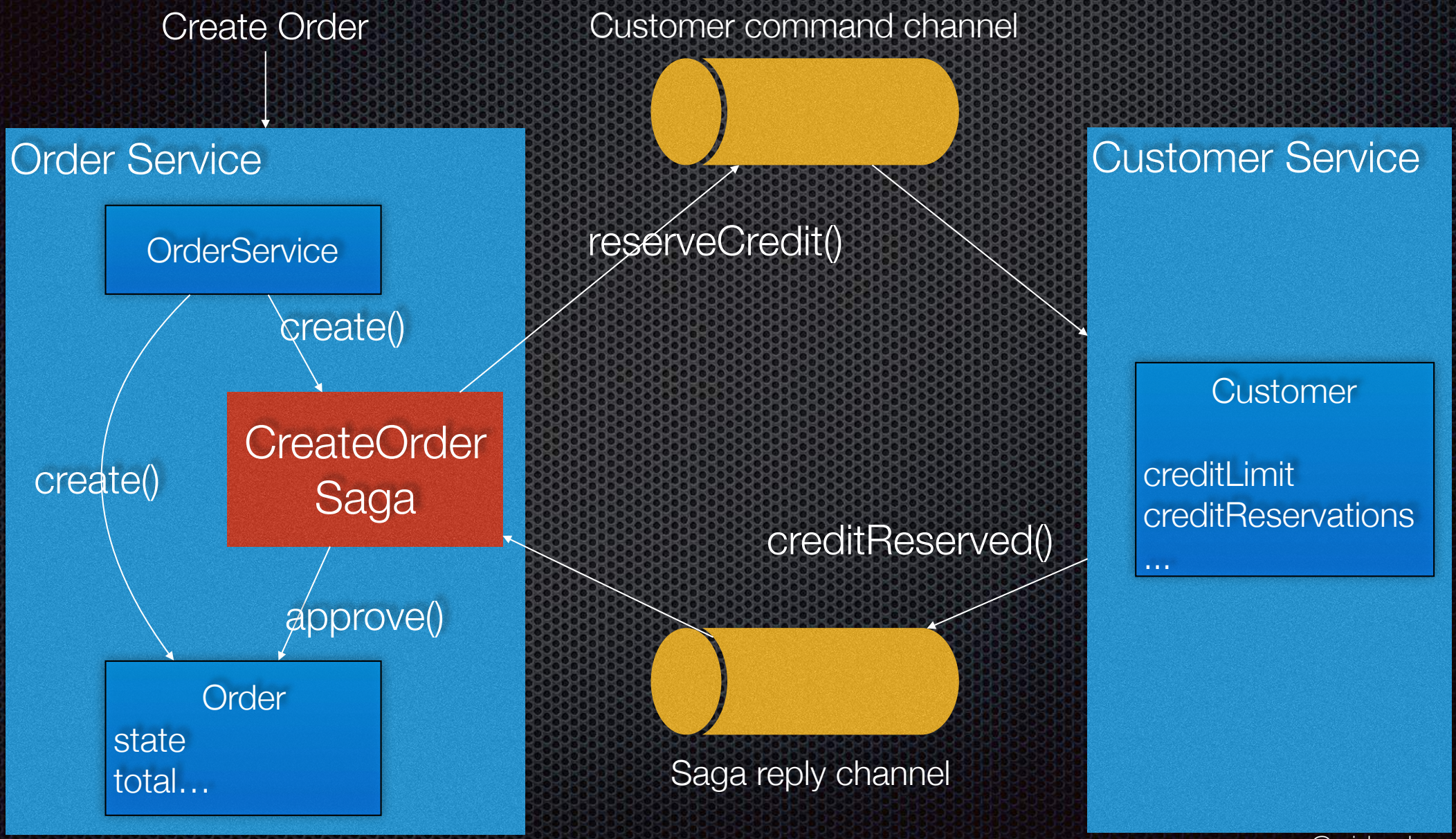


A saga (orchestrator)
is a **persistent object**
that
tracks the state of the saga
and
invokes the participants

Saga orchestrator behavior

- On create:
  - Invokes a saga participant
  - Persists state in database
  - Wait for a reply
- On reply:
  - Load state from database
  - Determine which saga participant to invoke next
  - Invokes saga participant
  - Updates its state
  - Persists updated state
  - Wait for a reply
  - …

CreateOrderSaga orchestrator



CreateOrderSaga definition

```
public class CreateOrderSaga implements SimpleSaga<CreateOrderSagaData> {

  private SagaDefinition<CreateOrderSagaData> sagaDefinition =
          step()
            .withCompensation(this::reject)
          .step()
            .invokeParticipant(this::reserveCredit)
          .step()
            .invokeParticipant(this::approve)
          .build();


  @Override
  public SagaDefinition<CreateOrderSagaData> getSagaDefinition() { return this.sagaDefinition; }


  private CommandWithDestination reserveCredit(CreateOrderSagaData data) {
    long orderId = data.getOrderId();
    Long customerId = data.getOrderDetails().getCustomerId();
    Money orderTotal = data.getOrderDetails().getOrderTotal();
    return send(new ReserveCreditCommand(customerId, orderId, orderTotal))
            .to("customerService")
            .build();
  }
```

Saga's Data

Sequence of steps

step = (T_i, C_i)

Build command to send

Customer Service command handler

```
public class CustomerCommandHandler {

  @Autowired
  private CustomerRepository customerRepository;

  public CommandHandlers commandHandlerDefinitions() {
    return SagaCommandHandlersBuilder
            .fromChannel("customerService")
            .onMessage(ReserveCreditCommand.class, this::reserveCredit)
            .build();
  }

  public Message reserveCredit(CommandMessage<ReserveCreditCommand> cm) {
    ReserveCreditCommand cmd = cm.getCommand();
    long customerId = cmd.getCustomerId();
    Customer customer = customerRepository.findOne(customerId);
    try {
      customer.reserveCredit(cmd.getOrderId(), cmd.getOrderTotal());
      return withSuccess(new CustomerCreditReserved());
    } catch (CustomerCreditLimitExceededException e) {
      return withFailure(new CustomerCreditReservationFailed());
    }
  }
```

Route command to handler

Reserve credit

Make reply message

Eventuate Tram Sagas

- Open-source Saga orchestration framework
- Currently for Java
- https://github.com/eventuate-tram/eventuate-tram-sagas
- https://github.com/eventuate-tram/eventuate-tram-sagas-examples-customers-and-orders

Benefits and drawbacks of orchestration

Benefits

- Centralized coordination logic is easier to understand
- Reduced coupling, e.g. Customer knows less. Simply has API
- Reduces cyclic dependencies

Drawbacks

- Risk of smart sagas directing dumb services

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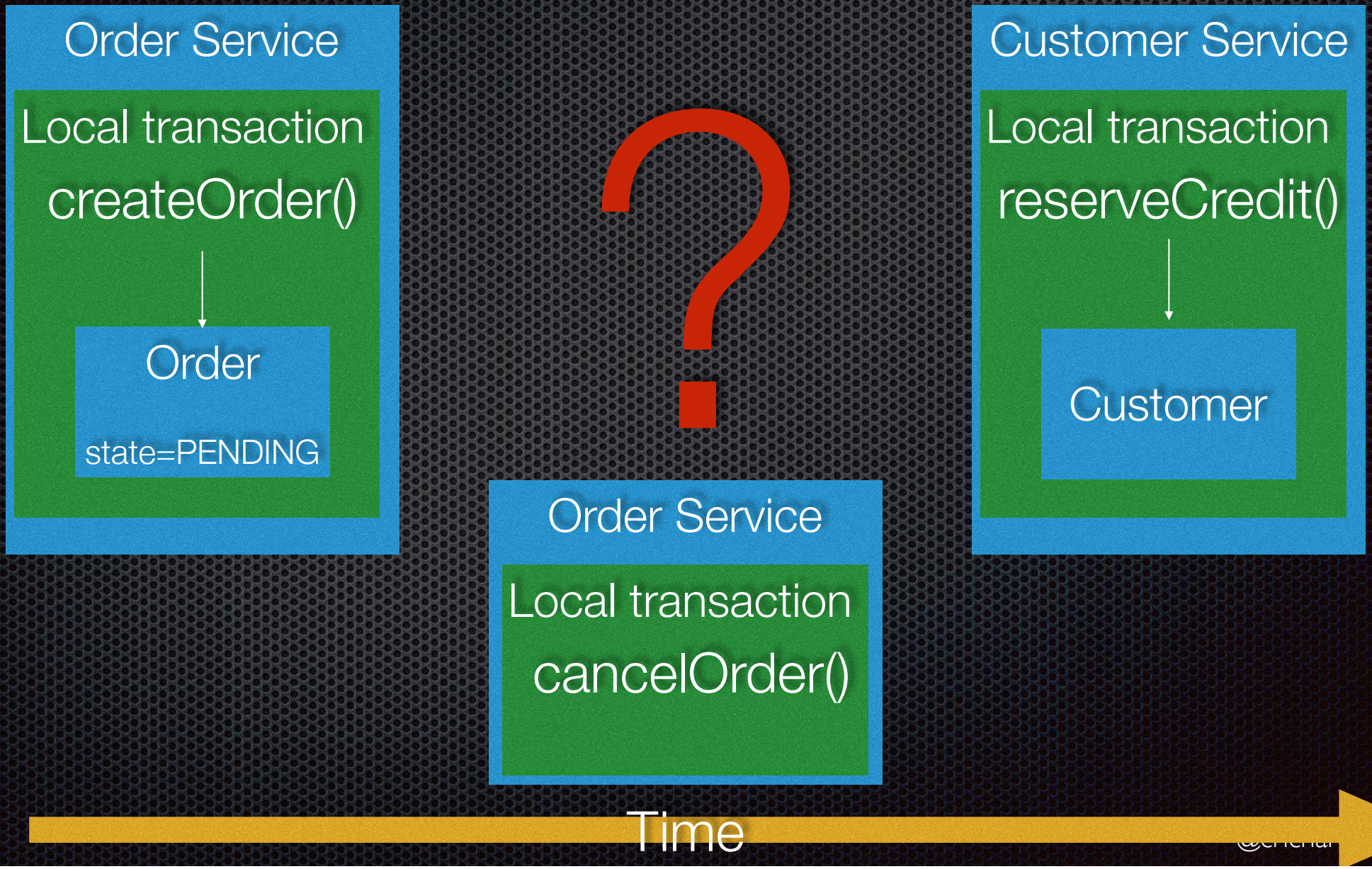
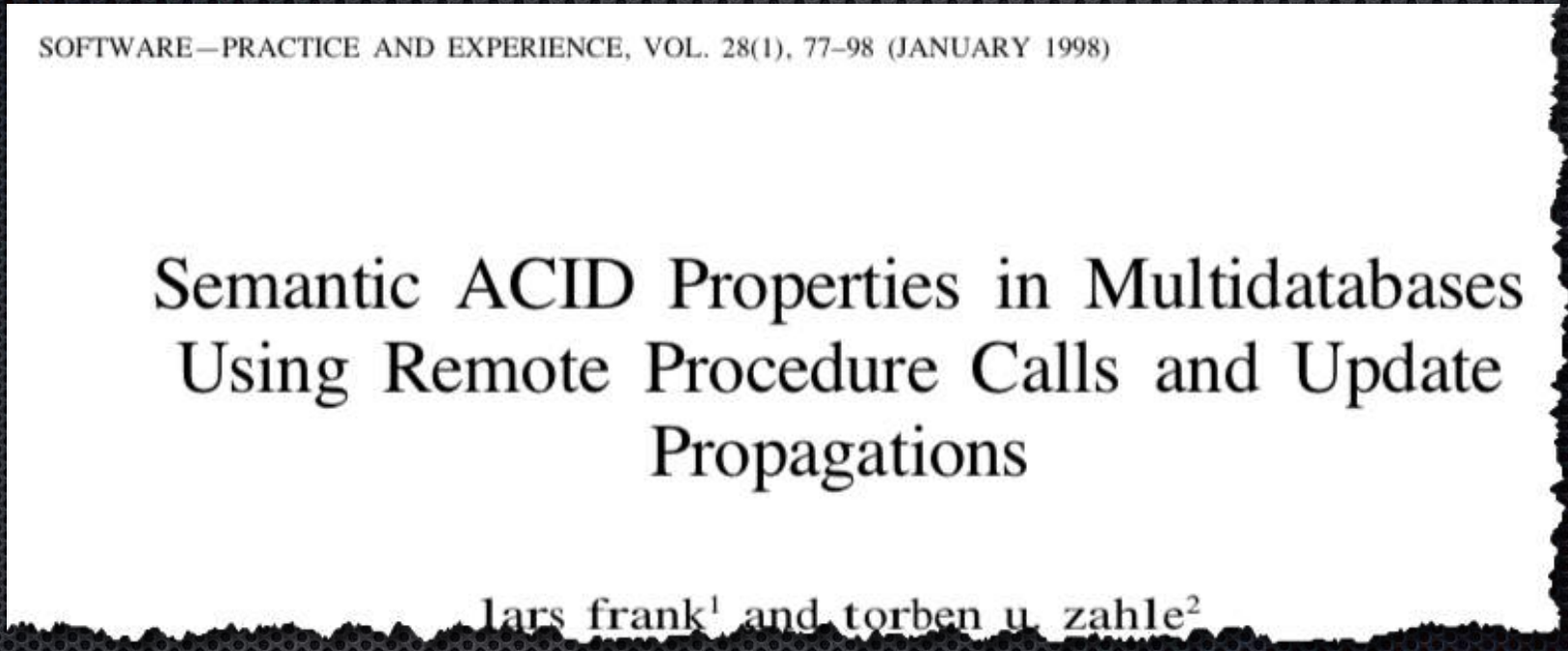
Lack of isolation ⇒ complicates business logic



How to cancel a PENDING Order?

- Don't ⇒ throw an OrderNotCancellableException
  - Questionable user experience
- "Interrupt" the Create Order saga?
  - Cancel Order Saga: set order.state = CANCELLED
  - Causes Create Order Saga to rollback
  - But is that enough to cancel the order?
- Cancel Order saga waits for the Create Order saga to complete?
  - Suspiciously like a distributed lock
  - But perhaps that is ok

Countermeasure Transaction Model



SOFTWARE—PRACTICE AND EXPERIENCE, VOL. 28(1), 77–98 (JANUARY 1998)

Semantic ACID Properties in Multidatabases Using Remote Procedure Calls and Update Propagations

lars frank[1] and torben u. zahle[2]

http://bit.ly/semantic-acid-ctm - paywall 😢

Sagas are ACD

- **Atomicity**
  - Saga implementation ensures that all transactions are executed **OR** all are compensated
- **Consistency**
  - Referential integrity within a service handled by local databases
  - Referential integrity across services handled by application
- **Durability**
  - Durability handled by local databases

Lack of I ⇒ anomalies

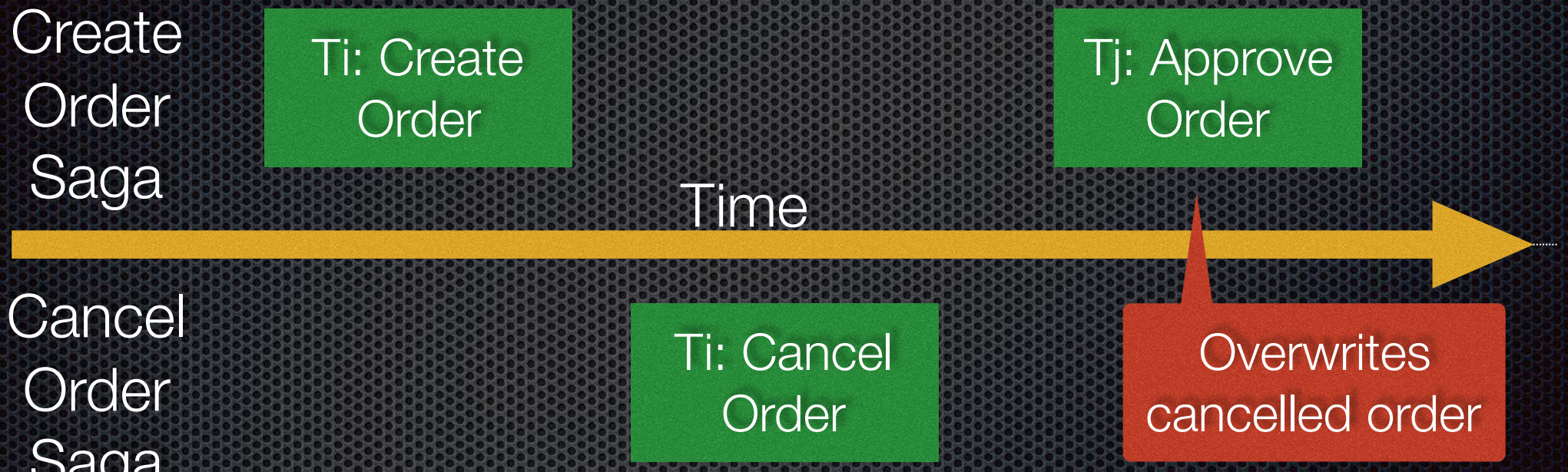
Outcome of
concurrent execution
!=
a sequential execution

Sounds scary

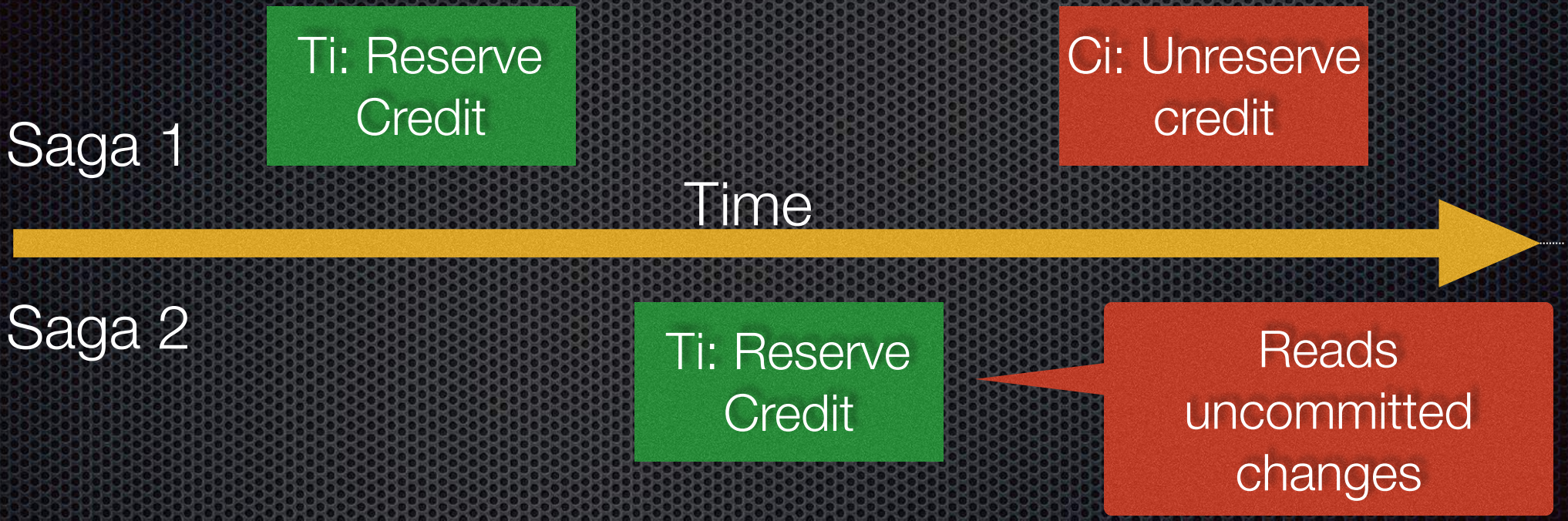
BUT

It's common to relax isolation to improve performance

Anomaly: Lost update

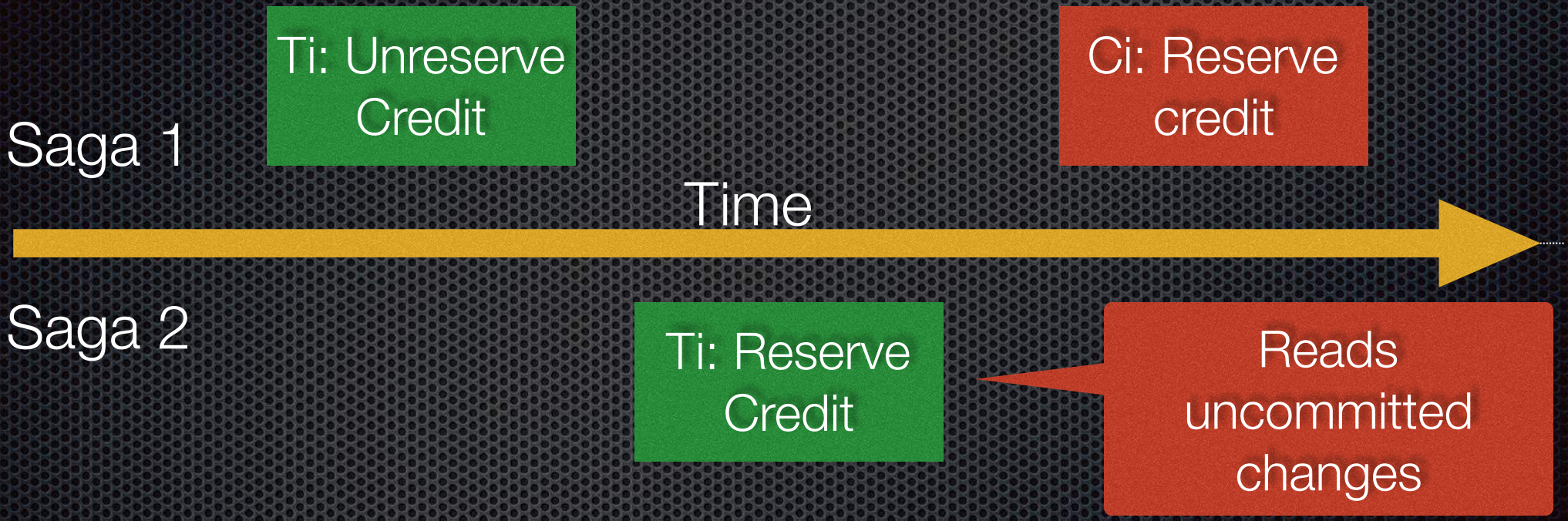


Anomaly: Dirty reads …



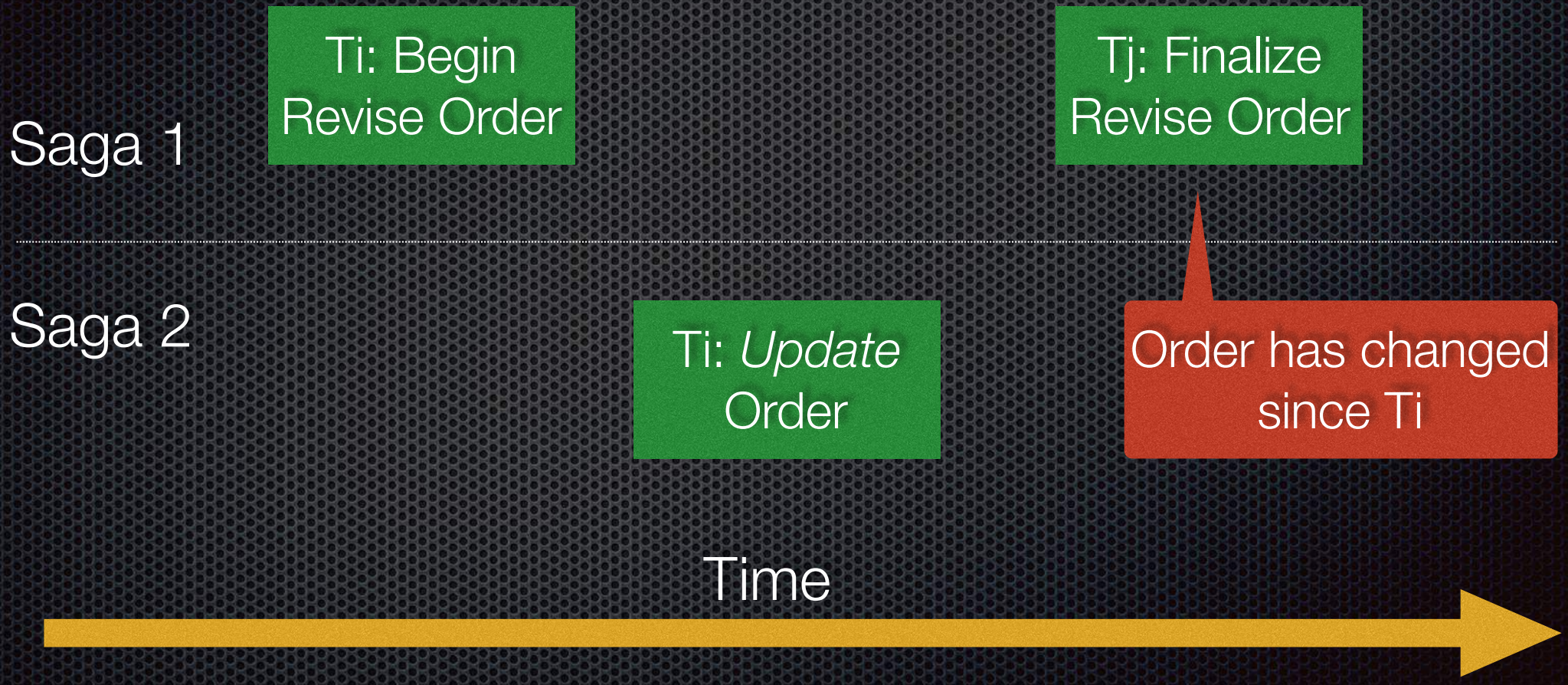
Order rejected unnecessarily

… Anomaly: Dirty reads



Credit limit exceeded!

Anomaly: non-repeatable/ fuzzy read

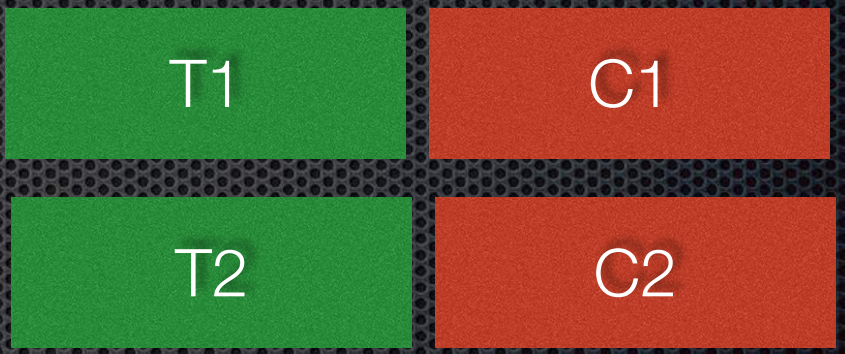


Countermeasures for **reducing*** impact of isolation anomalies…

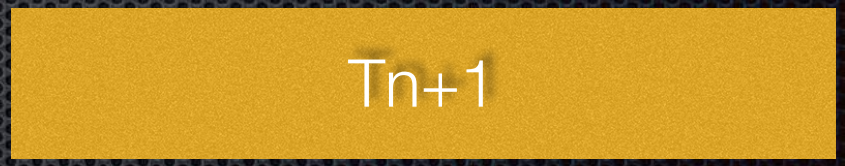
i.e. good enough, eventually consistent application

Saga structure

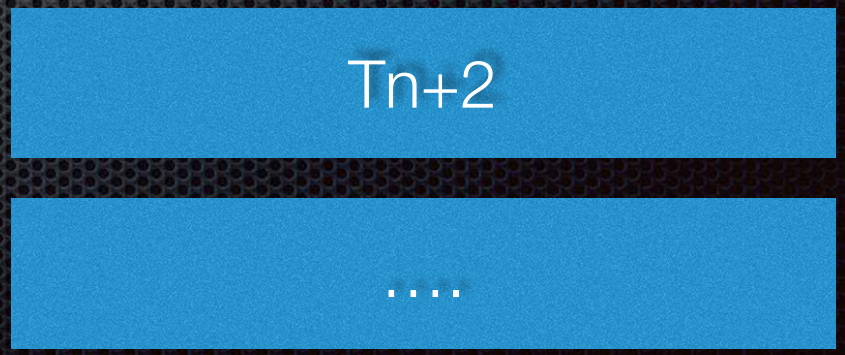
Compensatable transactions



Pivot transaction = GO/NO GO

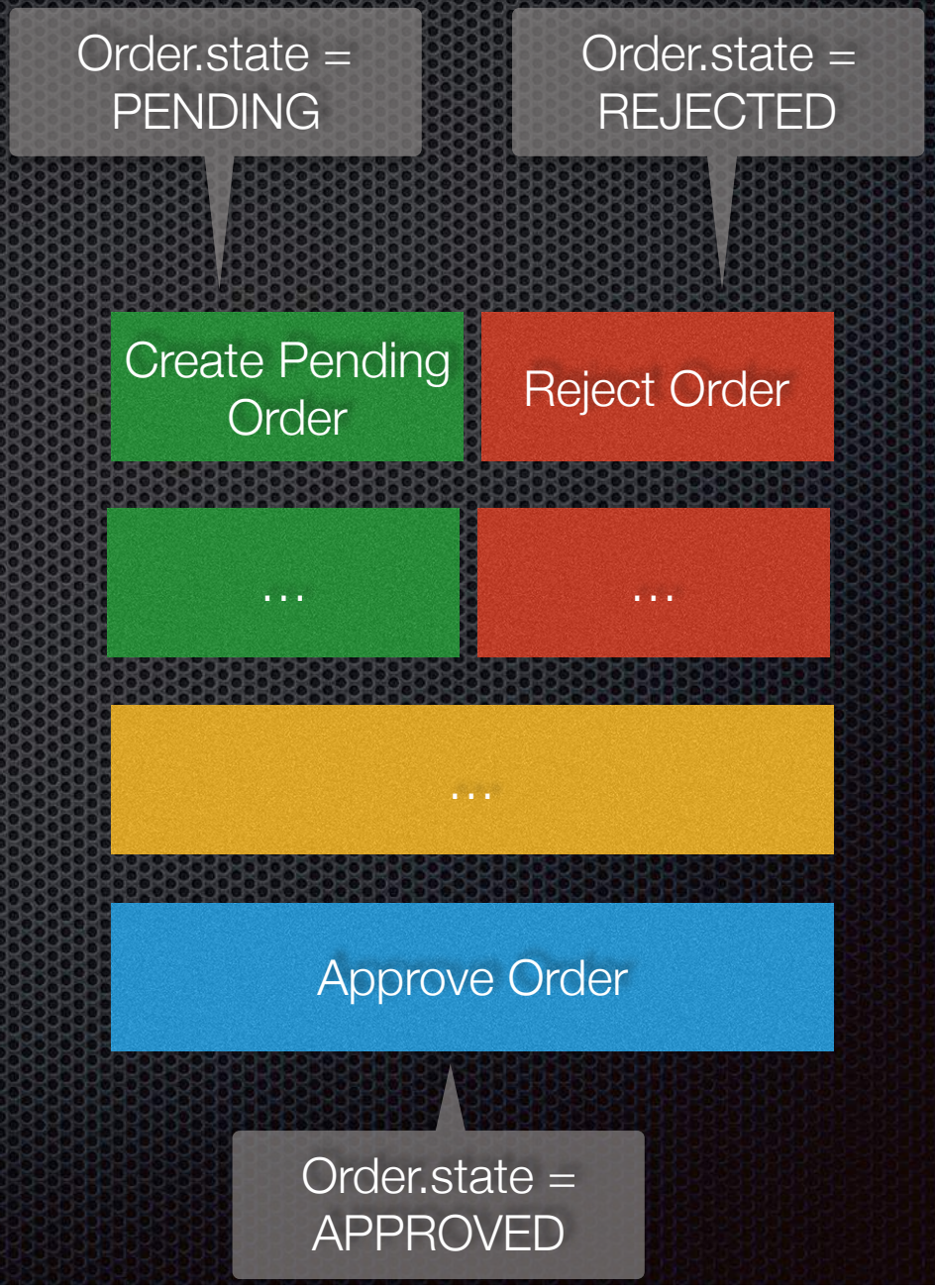


Retriable transactions that can’t fail



Countermeasure: Semantic lock

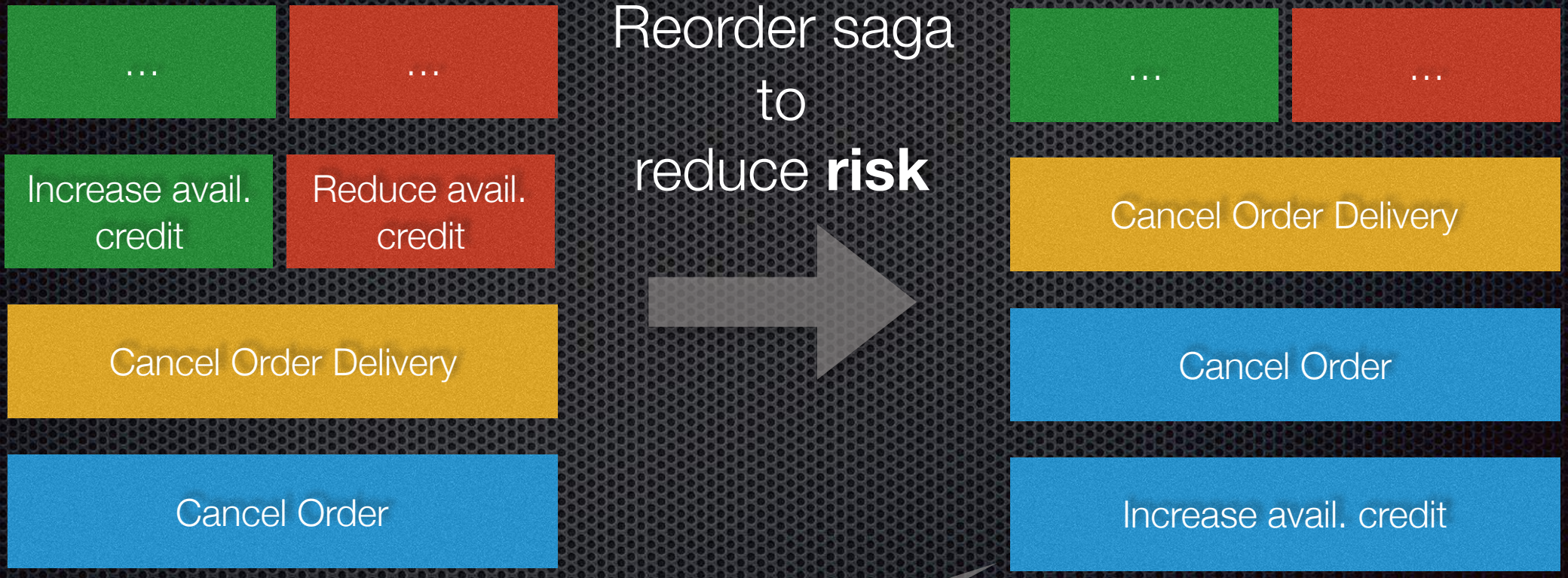
- Compensatable transaction sets flag, retriable transaction releases it
- Indicates a possible dirty read
- Flag = lock:
  - prevents other transactions from accessing it
  - Require deadlock detection, e.g. timeout
- Flag = warning - treat the data differently, e.g.
  - Order.state = PENDING
  - a pending deposit



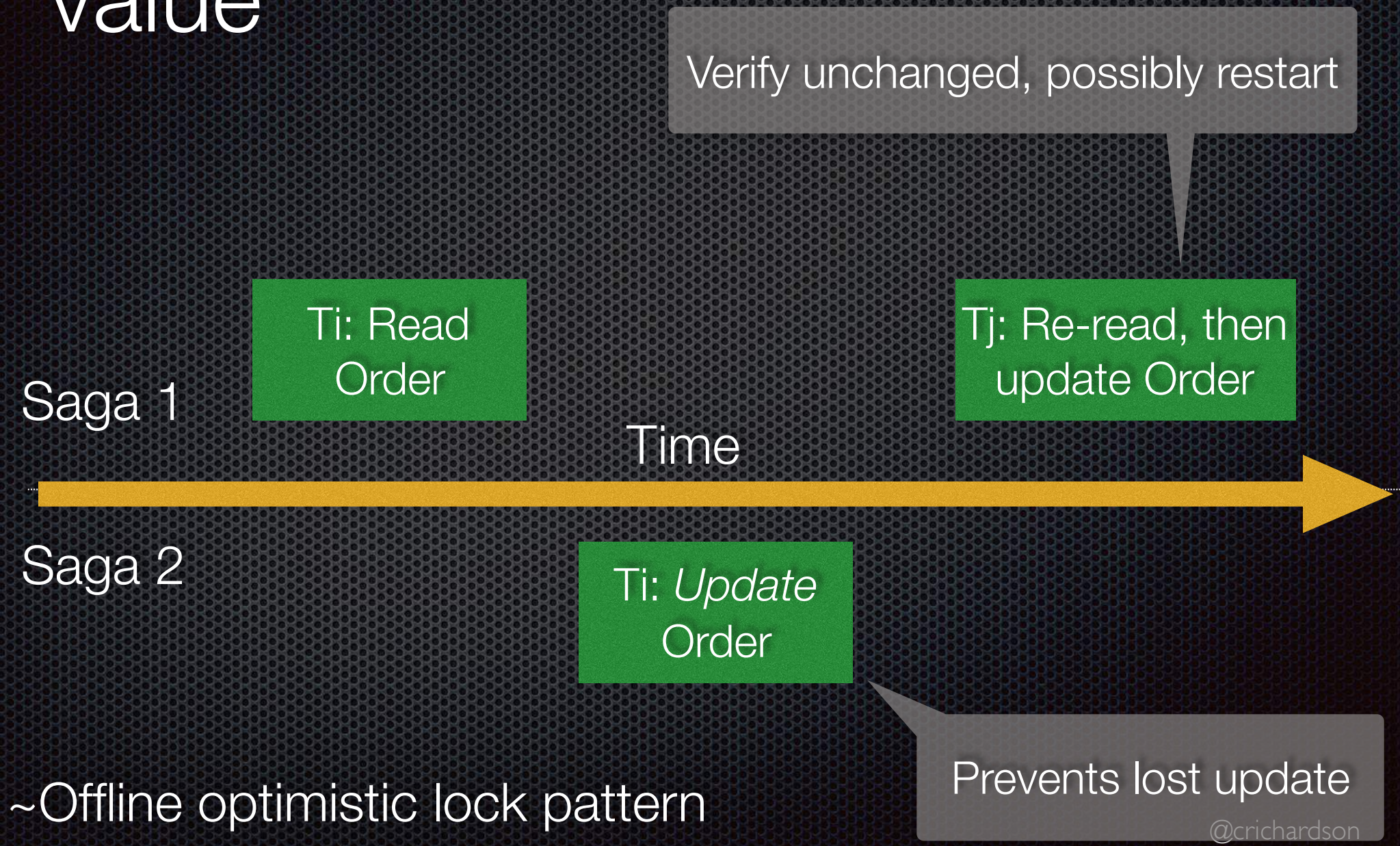
Countermeasure: Commutative updates

- Commutative: g(f(x)) = f(g(x))
- For example:
  - Account.debit() compensates for Account.credit()
  - Account.credit() compensates for Account.debit()
- Avoids lost updates

Countermeasure: Pessimistic view

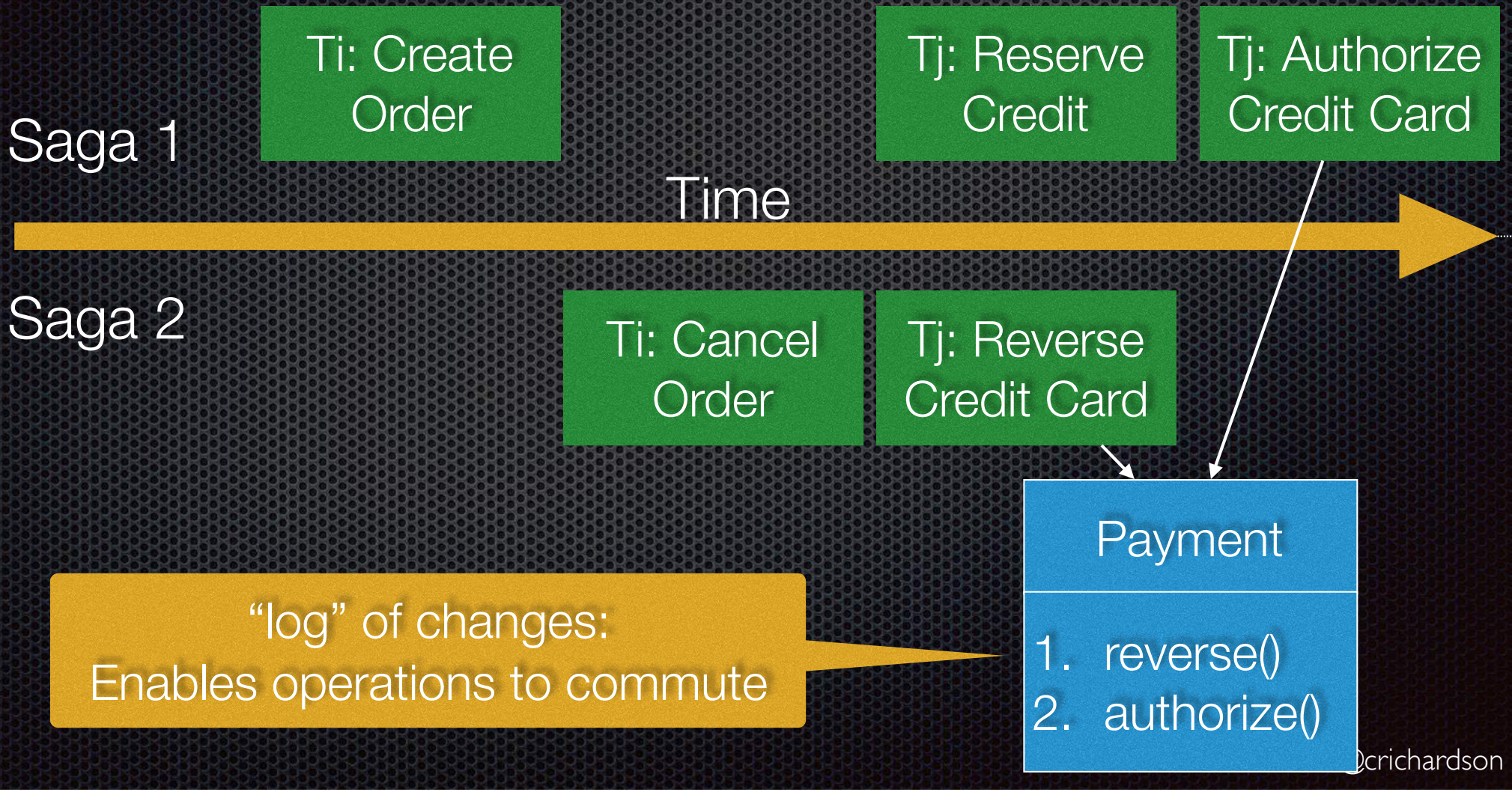


Countermeasure: Re-read value



~Offline optimistic lock pattern

Countermeasure: version file



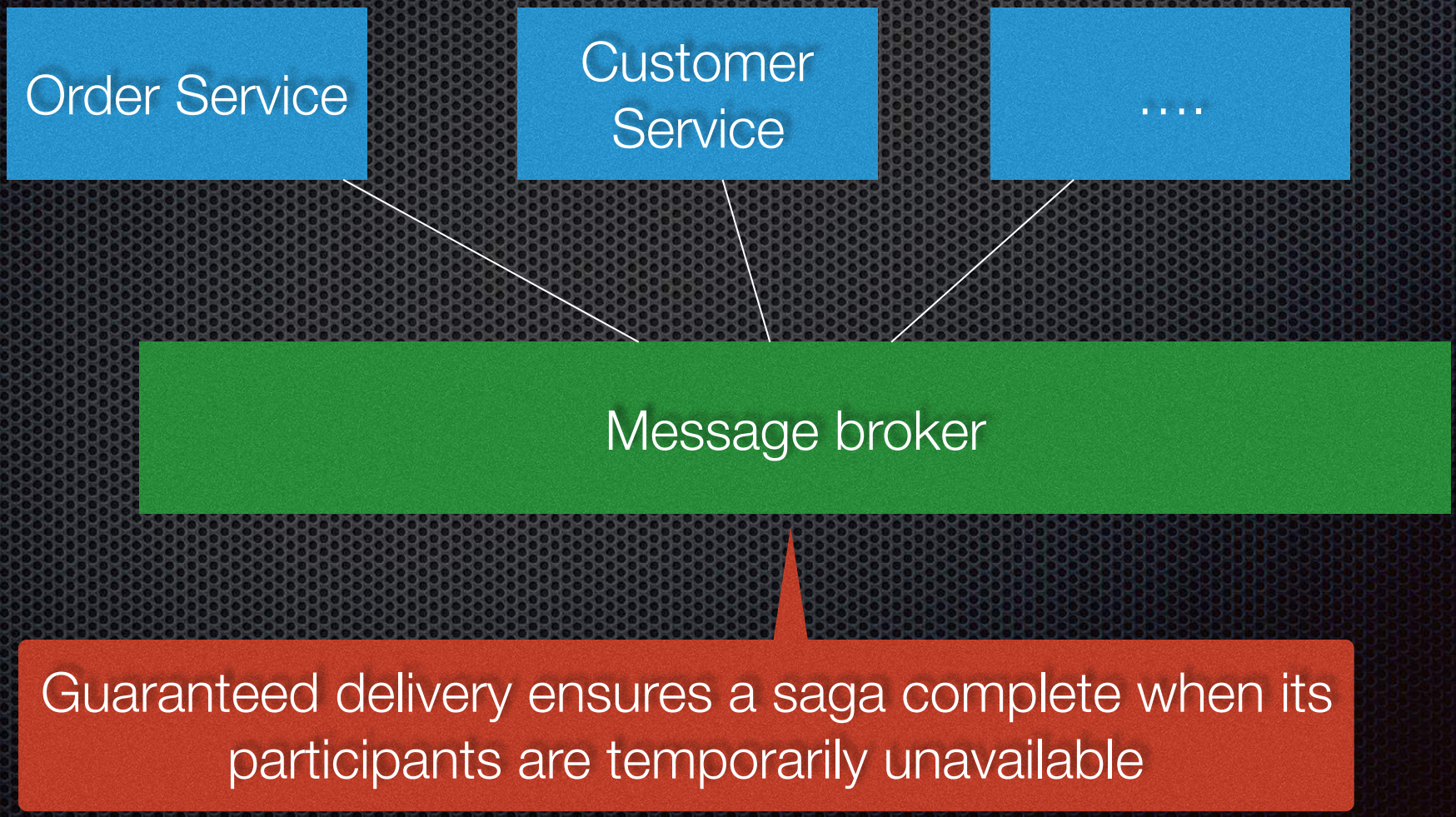
Countermeasure: By value

- Business risk determines strategy
- Low risk => semantic ACID
- High risk => use 2PC/distributed transaction

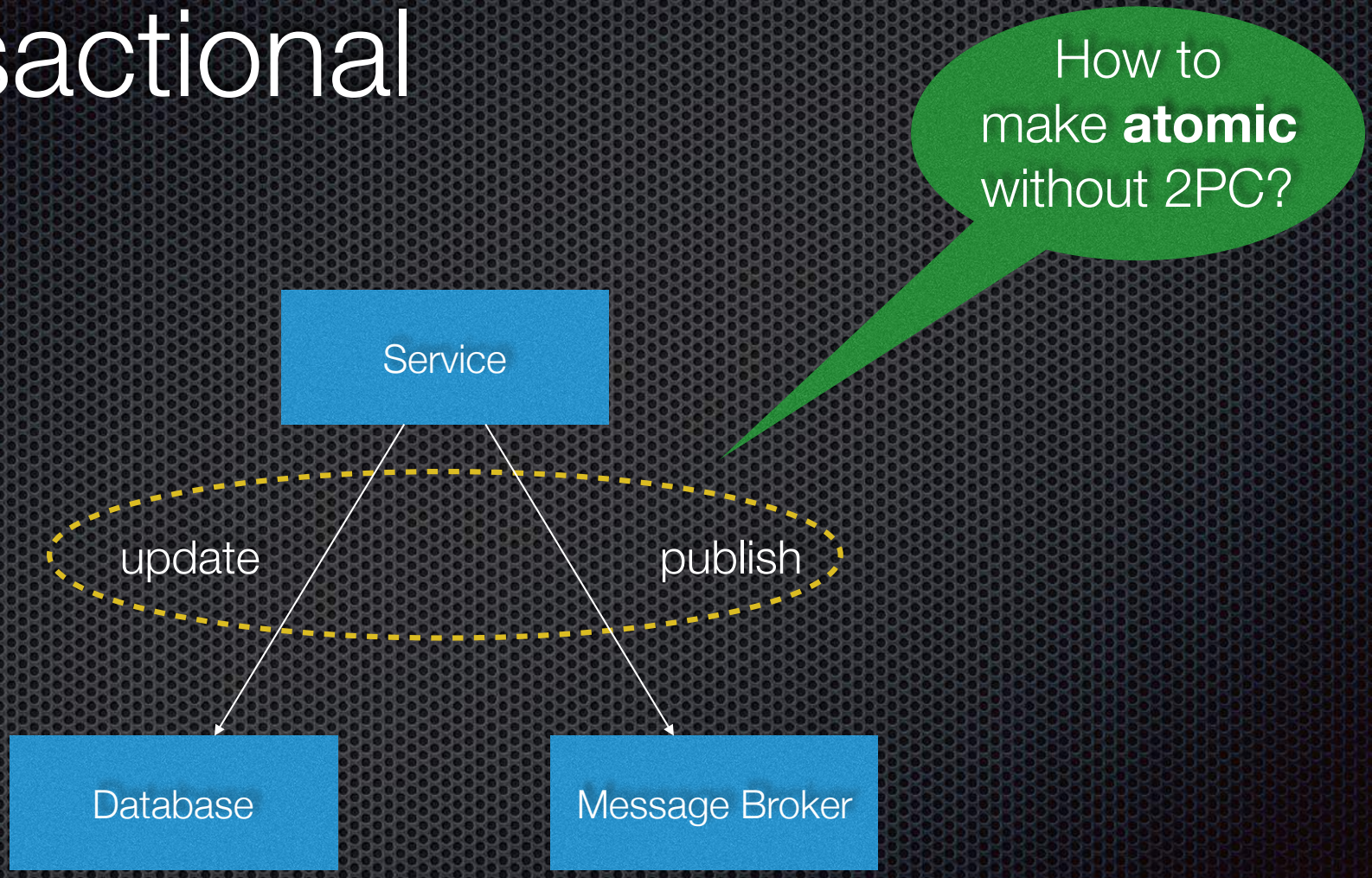
Agenda

- ACID is not an option
- Overview of sagas
- Coordinating sagas
- Countermeasures for data anomalies
- Using reliable and transactional messaging

Use asynchronous, broker-based messaging



Messaging must be transactional



Option #1: Use database table as a message queue

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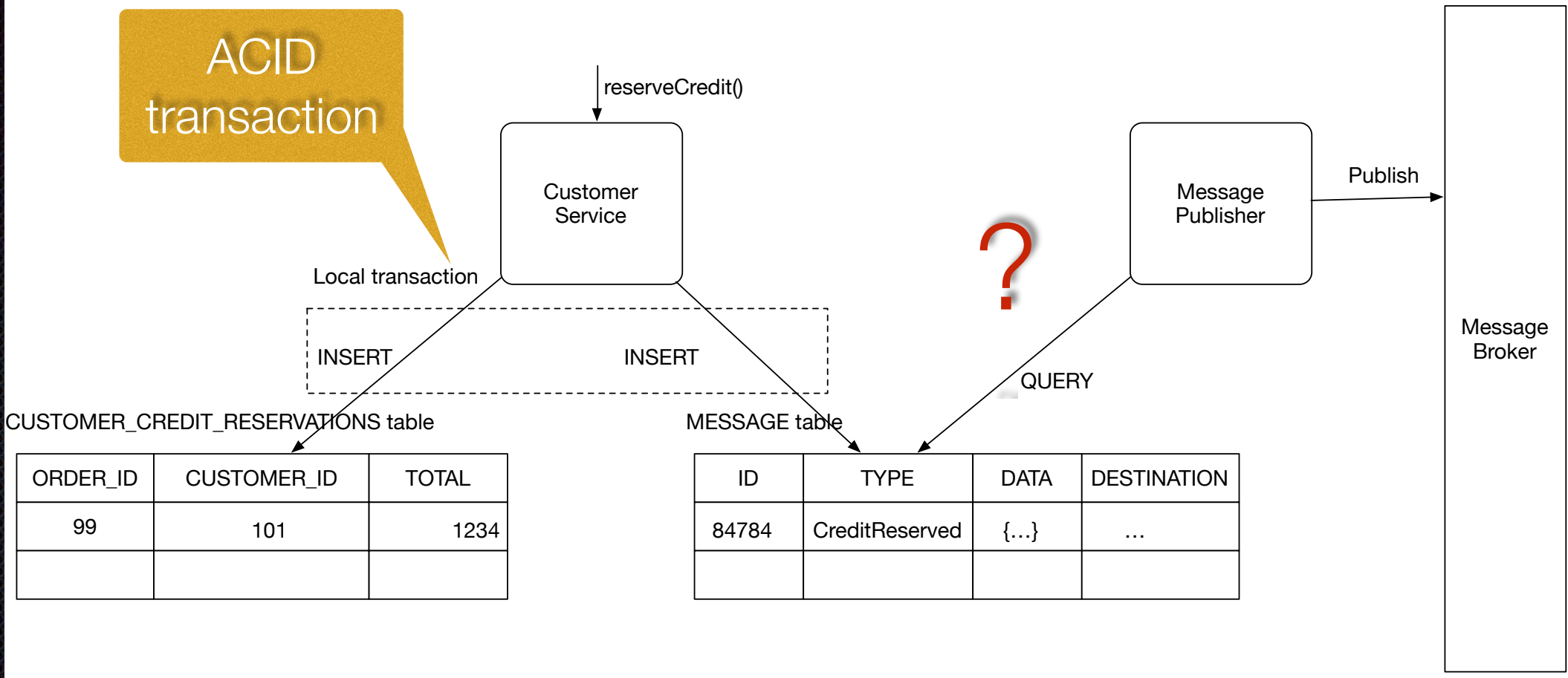
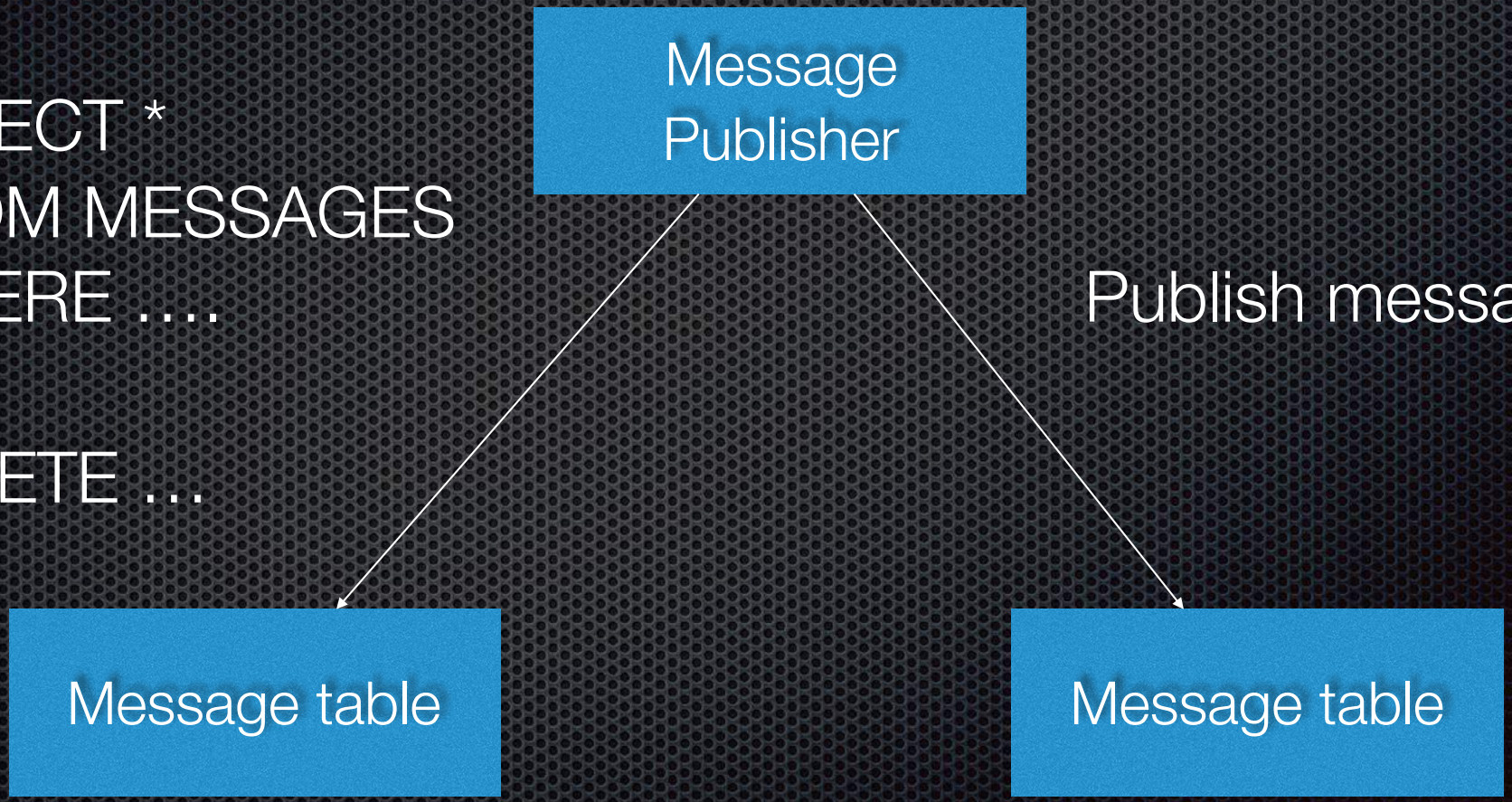


- See BASE: An Acid Alternative, http://bit.ly/ebaybase

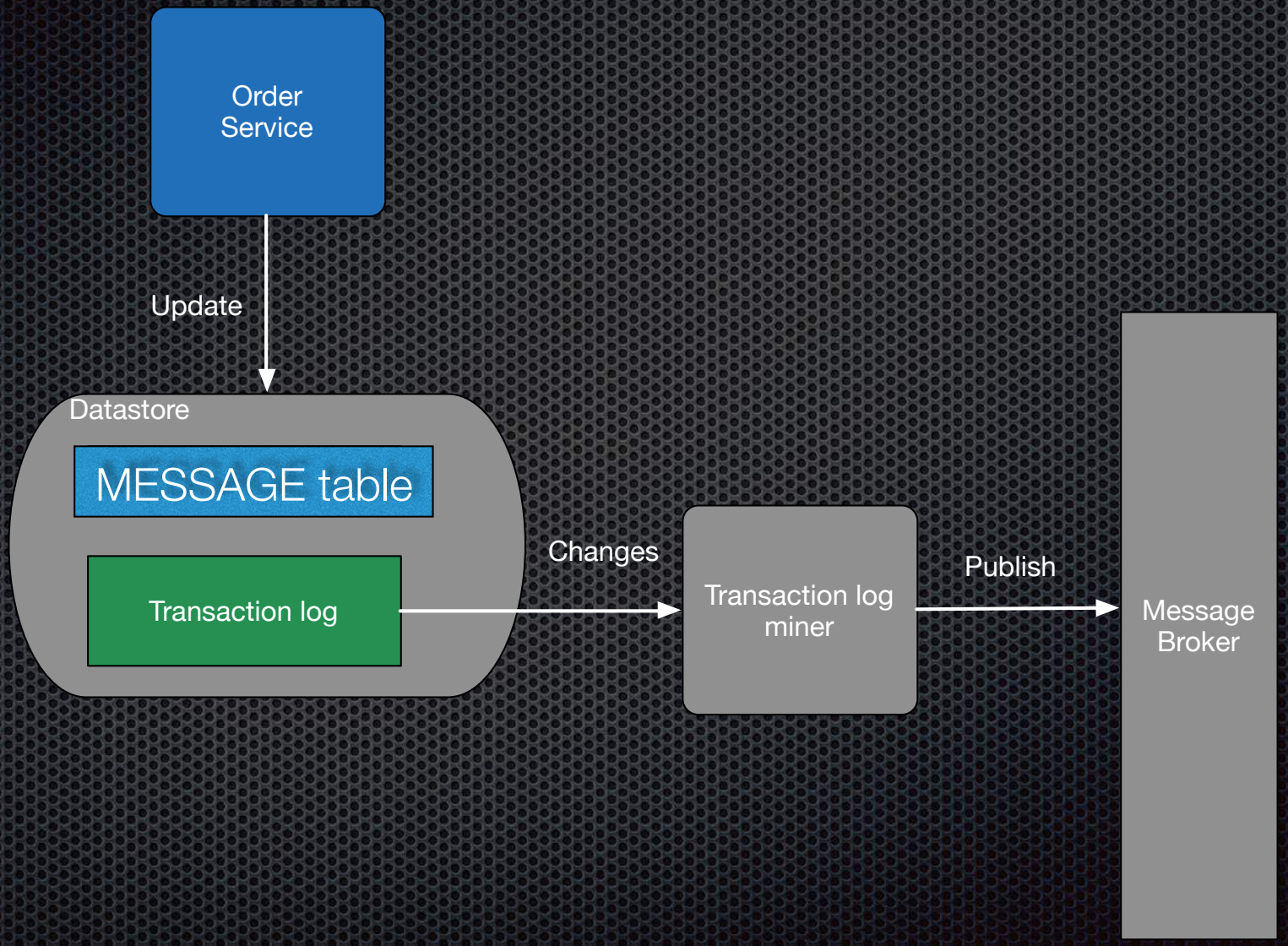
Publishing messages by polling the MESSAGE table

SELECT *
FROM MESSAGES
WHERE ….

DELETE …



Transaction log tailing



Transaction log tailing

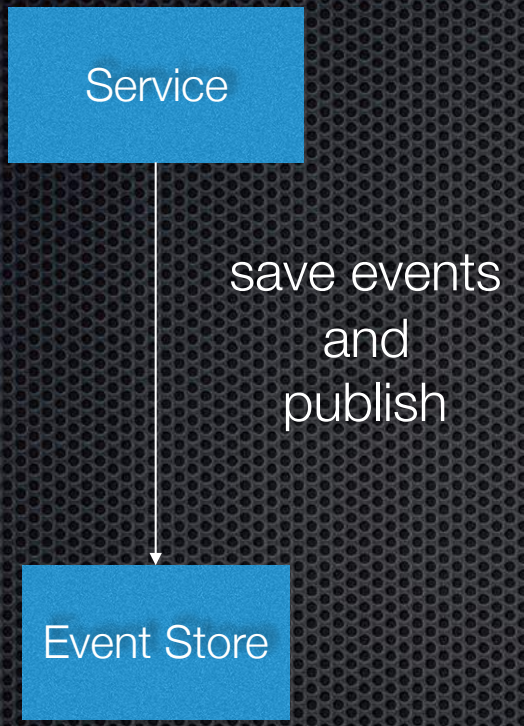
- Eventuate Local - reads MySQL binlog
- Oracle Golden Gate
- AWS DynamoDB streams
- MongoDB - Read the oplog

Transaction log tailing: benefits and drawbacks

- **Benefits**
  - No 2PC
  - No application changes required
  - Guaranteed to be accurate
- **Drawbacks**
  - Obscure
  - Database specific solutions
  - Tricky to avoid duplicate publishing

Option #2: Event sourcing: event-centric persistence

Event sourcing: persists an object as a sequence of events



Event table

Entity id	Entity type	Event id	Event type	Event data
101	Order	901	OrderCreated	…
101	Order	902	OrderApproved	…
101	Order	903	OrderShipped	…

Every state change ⇒ event

Guarantees:

state change

->

event is published

Implementing choreography-based sagas is straightforward

Preserves history of domain objects

Supports temporal queries

Built-in auditing

Summary

- Microservices tackle complexity and accelerate development
- Database per service is essential for loose coupling
- Use ACID transactions **within** services
- Use orchestration-based or choreography-based sagas to maintain data consistency **across** services
- Use countermeasures to reduce impact of anomalies caused by lack of isolation

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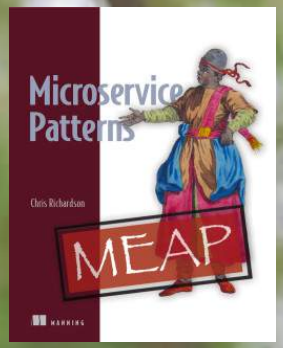

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Questions?

http://learn.microservices.io