Developing event-driven microservices with event sourcing and CQRS

Chris Richardson

Author of POJOs in Action

Founder of the original CloudFoundry.com

@crichardson

chris@chrisrichardson.net

http://plainoldobjects.com

http://microservices.io

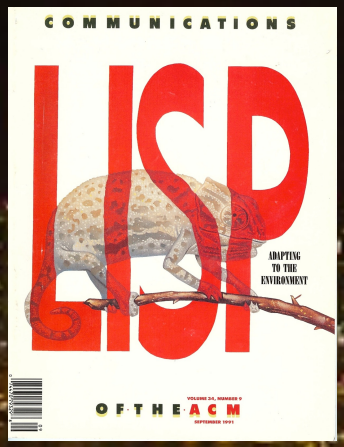
Presentation goal

Show how Event Sourcing and

Command Query Responsibility Segregation (CQRS)

are a great way to implement microservices

About Chris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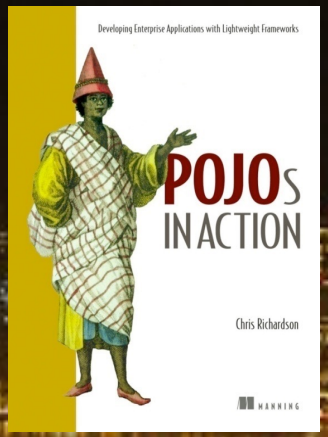
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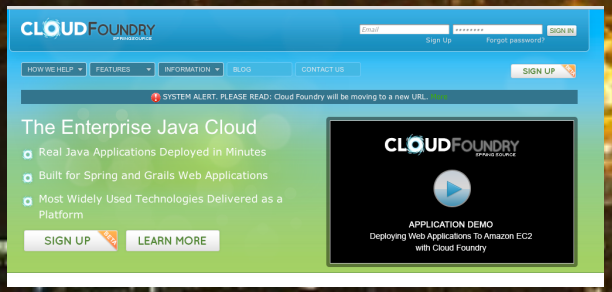
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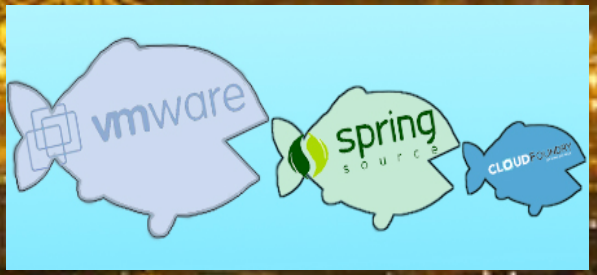
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About Chris

Consultant and trainer focusing on microservices

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

About Chris

Founder of a startup that is creating a platform that makes it easy for application developers write microservices

(http://bit.ly/trialeventuate)

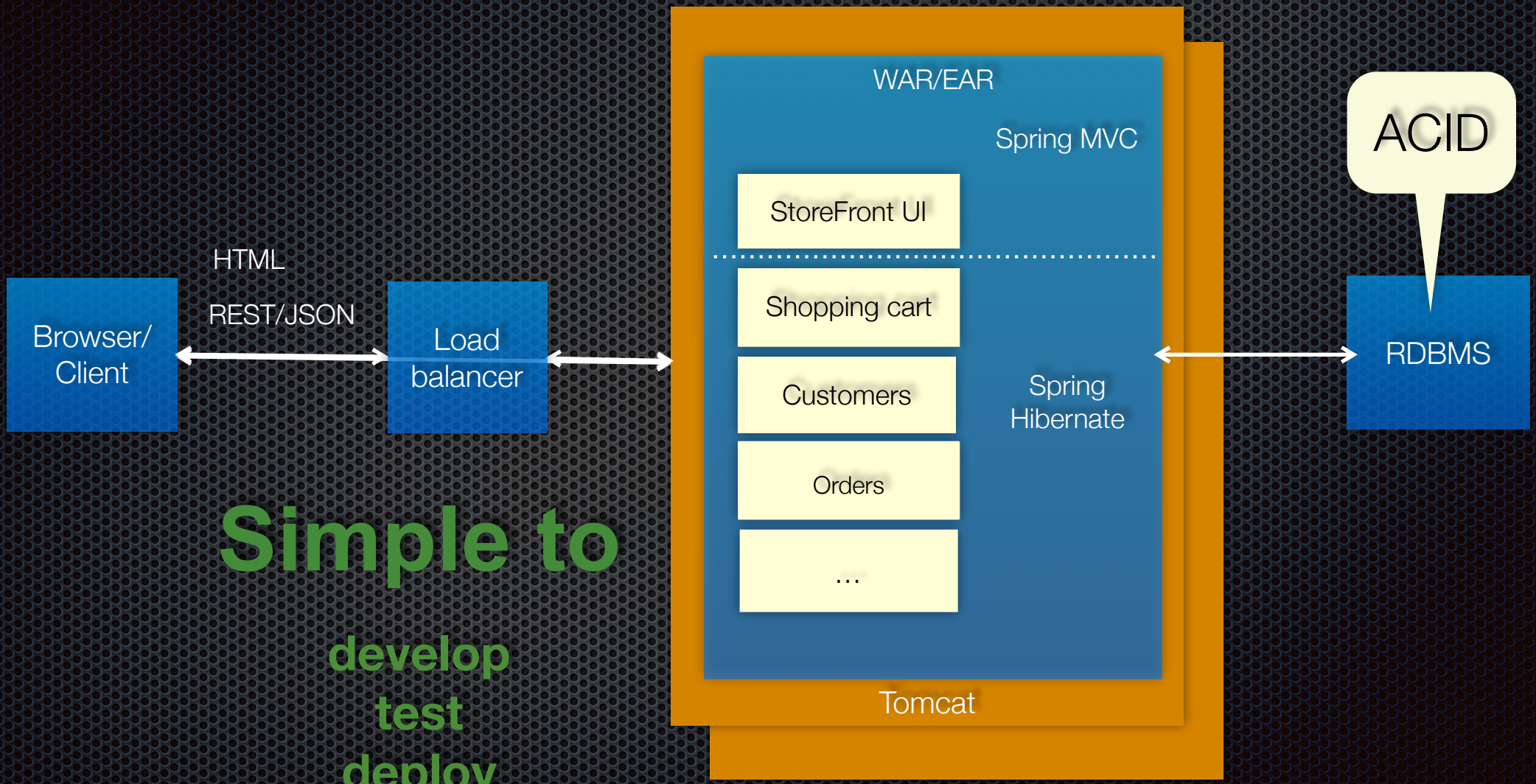
For more information

- https://github.com/cer/event-sourcing-examples
- http://microservices.io
- http://plainoldobjects.com/
- https://twitter.com/crichardson
- http://eventuate.io/

Agenda

- Why event sourcing?
- Overview of event sourcing
- ACID-free design
- Designing a domain model based on event sourcing
- Implementing queries in an event sourced application
- Event sourcing and microservices

Traditional monolithic architecture

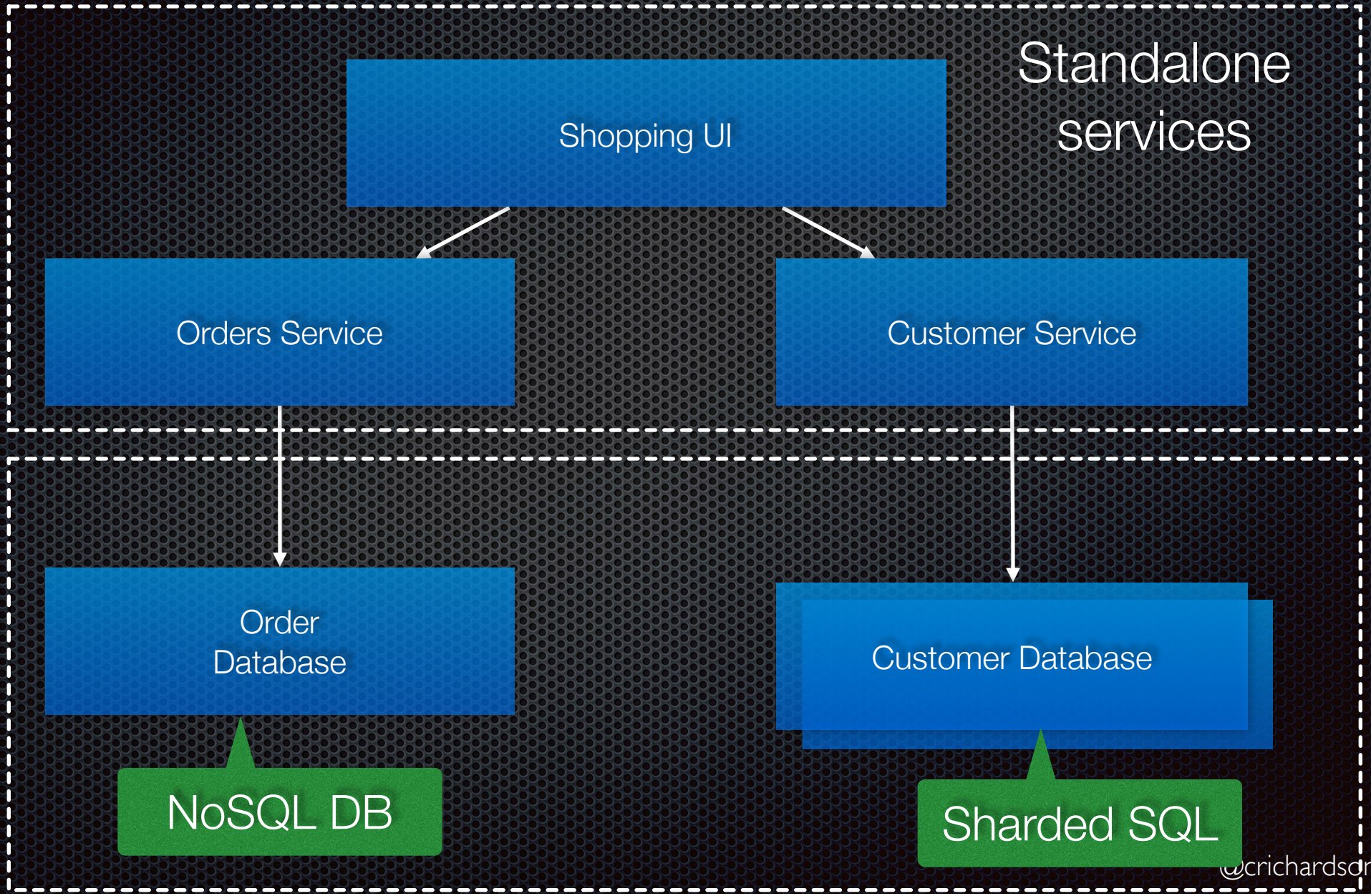


Simple to

develop
test
deploy
scale

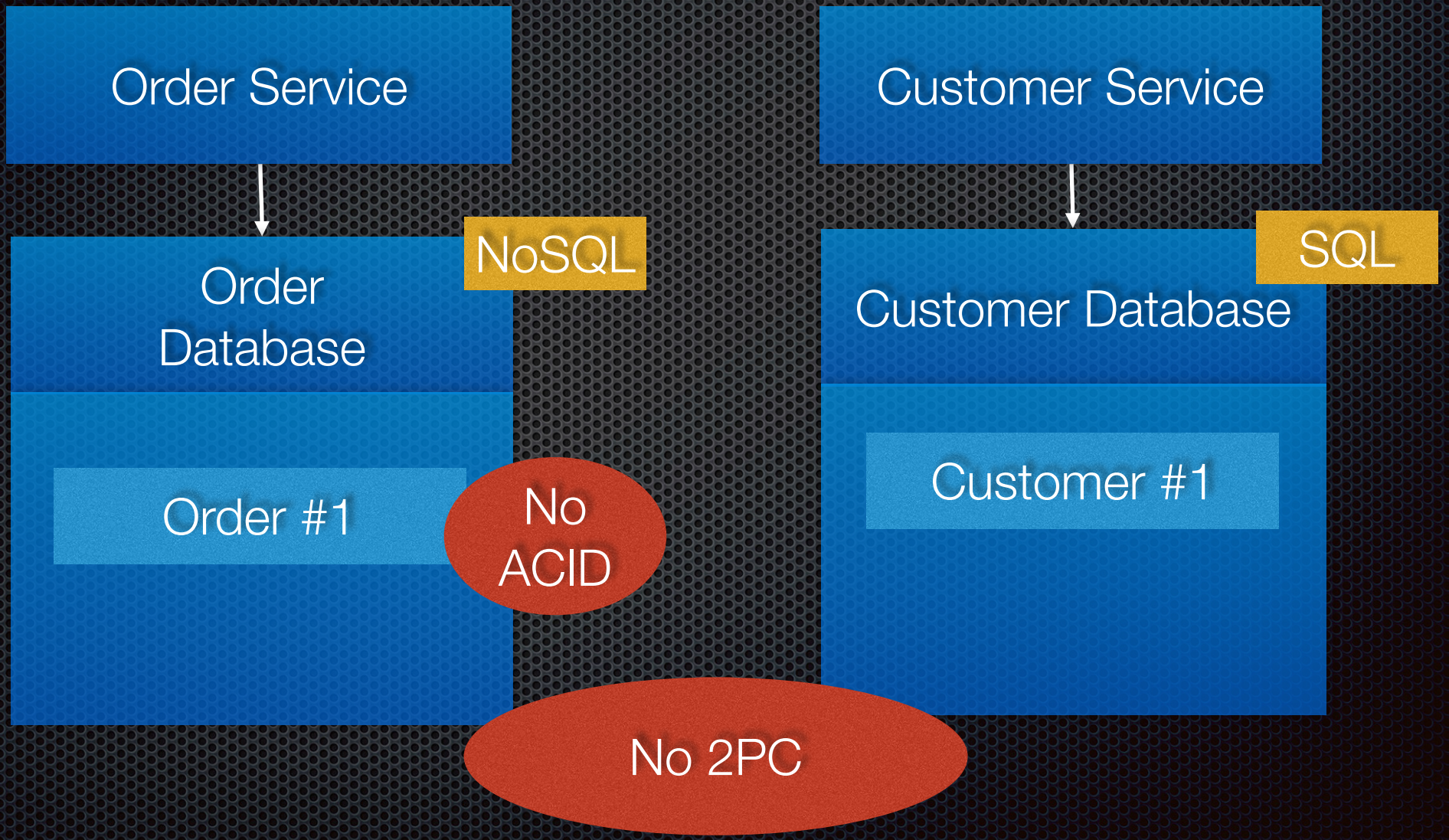

But that leads* to
monolithic hell
For large and/or complex applications...

Today: use a microservice, polyglot architecture

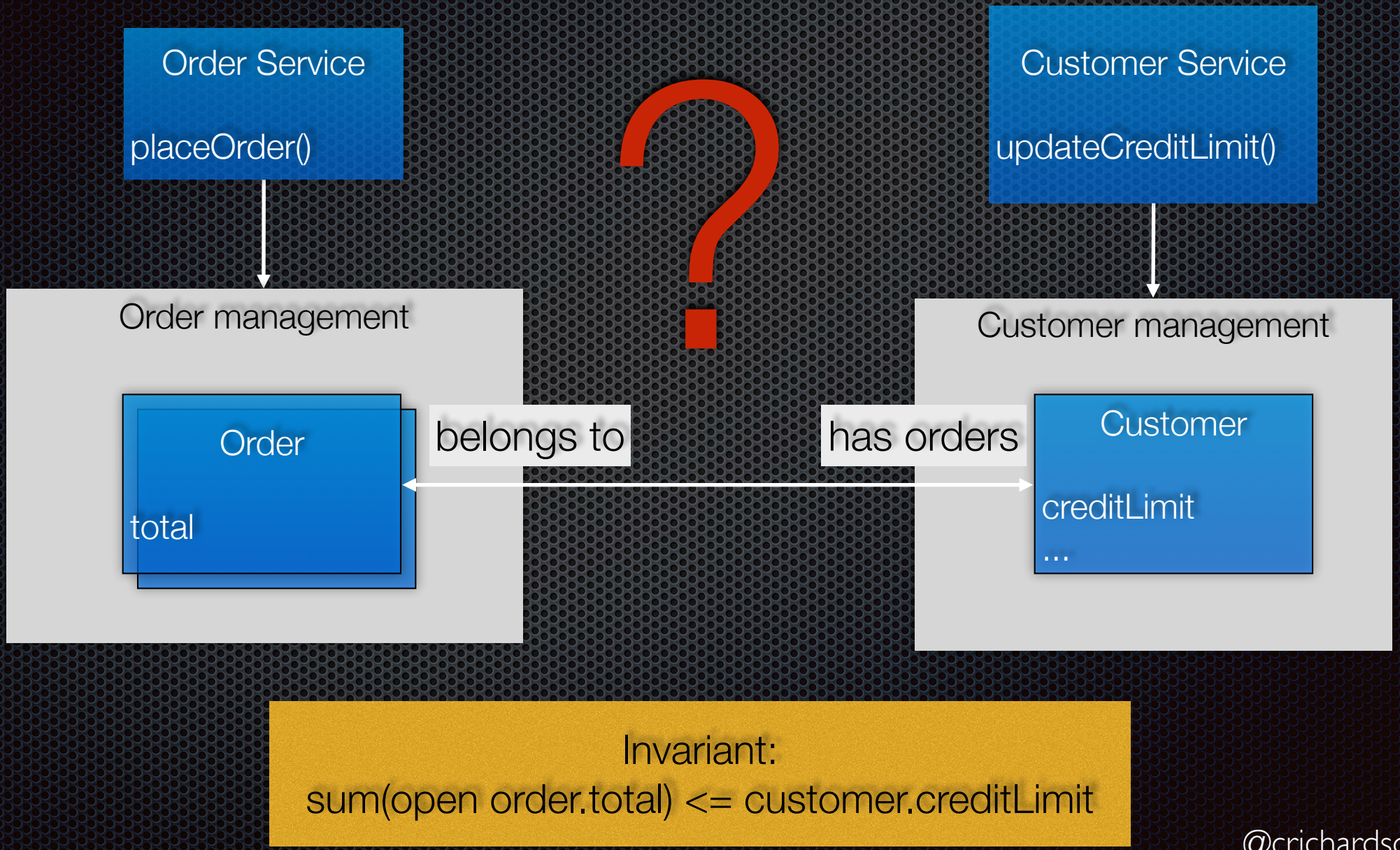


But now we have distributed data management problems

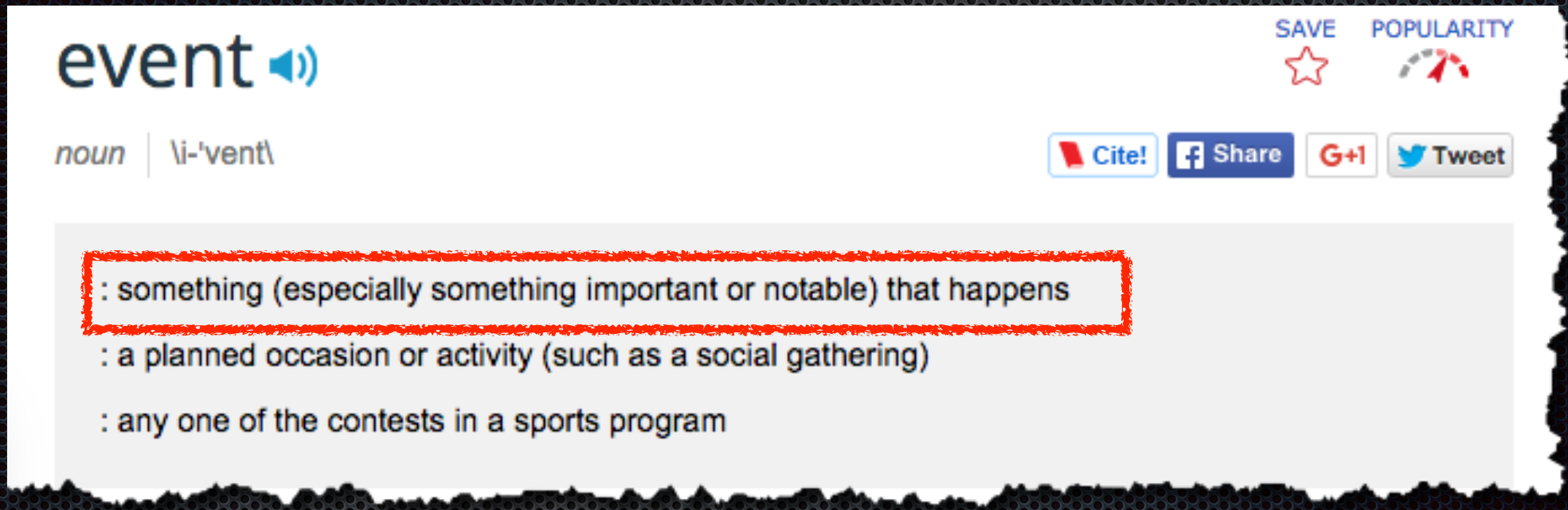
Example: placing an order



How to maintain invariants?



Use an event-driven architecture.....

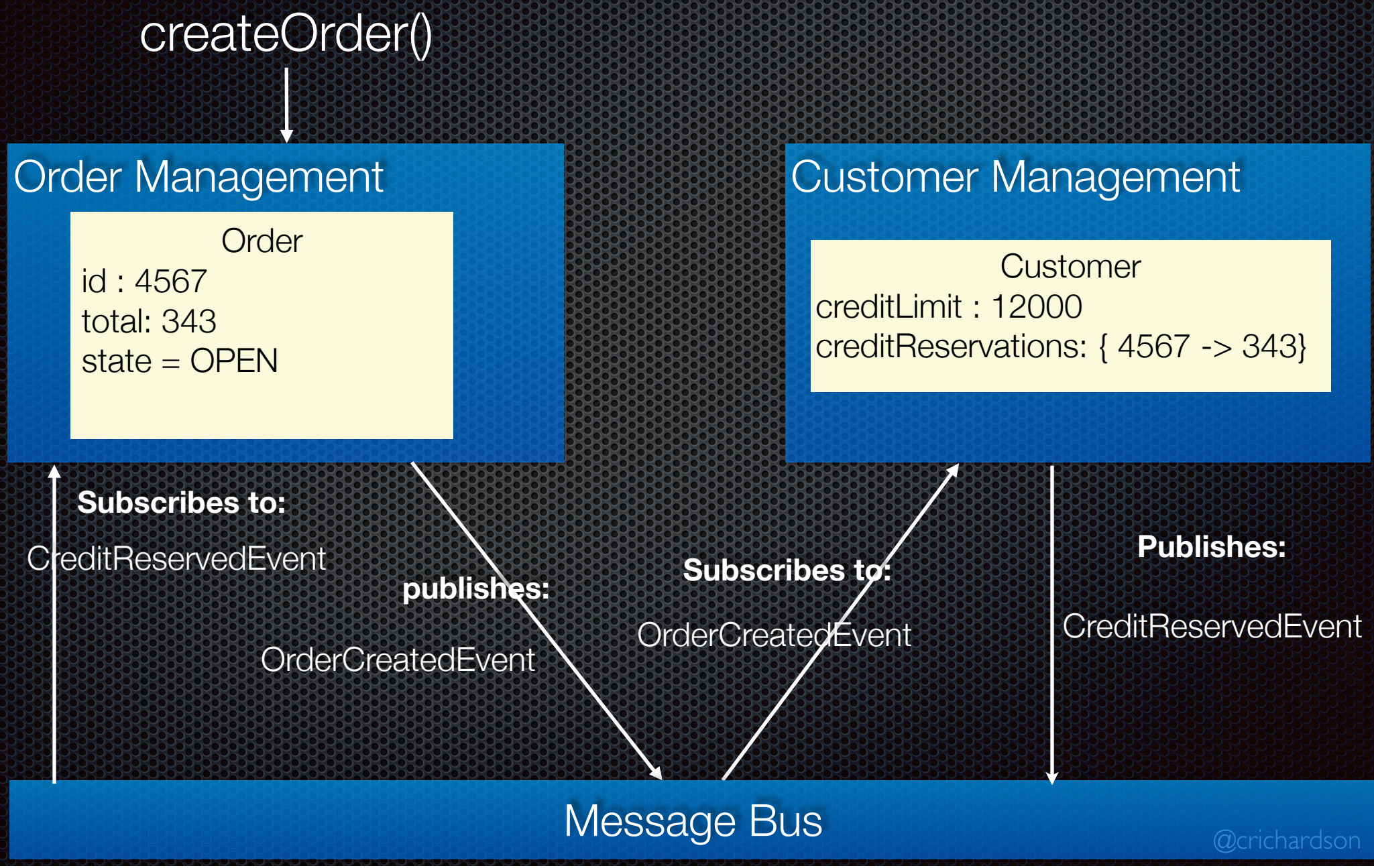


http://www.merriam-webster.com/dictionary/event

....Use an event-driven architecture

- Services **publish** events when something important happens, e.g. state changes
- Services **subscribe** to events and update their state
  - Maintain **eventual consistency** across multiple aggregates (in multiple datastores)
  - Synchronize replicated data

Eventually consistent credit checking

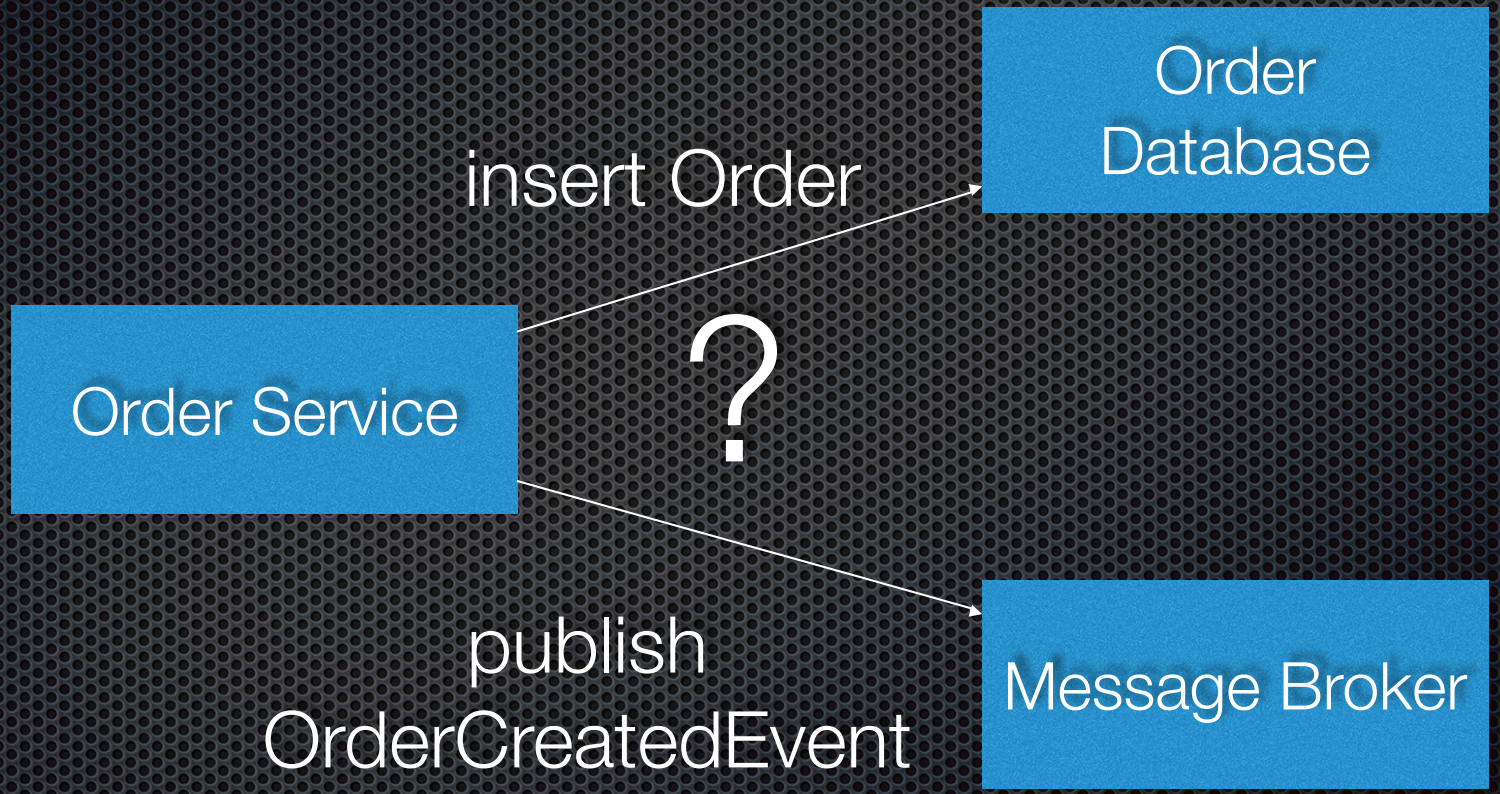


Now there are two problems to solve....

Problem #1: How to design eventually consistent business logic?

More on that later....

Problem #2: How atomicity update database and publish an event



dual write problem

Update and publish using 2PC

- Guaranteed atomicity **BUT**
- Need a distributed transaction manager
- Database and message broker must support 2PC
- Impacts reliability
- Not fashionable
- 2PC is best avoided

Transaction log tailing

- How:
  - Read the database "transaction log" = single source of truth
  - Publish events to message broker
- LinkedIn databus https://github.com/linkedin/databus
  - Supports Oracle and MySQL
  - Publish as events
- AWS DynamoDB streams
  - Ordered sequence of creates, updates, deletes made to a DynamoDB table
  - Last 24 hours
  - Subscribe to get changes
- MongoDB
  - Read the oplog

Transaction log tailing: benefits and drawbacks

- **Benefits**
  - No 2PC
  - No application changes required
  - Guaranteed to be accurate
- **Drawbacks**
  - Immature
  - Database specific solutions
  - Low-level DB changes rather business level events = need to reverse engineer domain events

Use database triggers

- Track changes to tables
- Insert events into an event table
  - Use datastore as a message queue
- Pull events from event table and write to message broker

Database triggers: benefits and drawbacks

- **Benefits**
  - No 2PC
  - No application changes required
- **Drawbacks**
  - Requires the database to support them
  - Database specific solutions
  - Low-level DB changes rather business level events = need to reverse engineer domain events
  - Error-prone, e.g. missing trigger

Application created events

- Use datastore as a message queue
  - Txn #1: Update database: new entity state & event
  - Txn #2: Consume event
  - Txn #3: Mark event as consumed
- Eventually consistent mechanism (used by eBay)
- See BASE: An Acid Alternative, http://bit.ly/ebaybase

Application created events

- **Benefits**
  - High-level domain events
  - No 2PC
- **Drawbacks**
  - Requires changes to the application
  - Only works for SQL and **some** NoSQL databases
  - Error-prone

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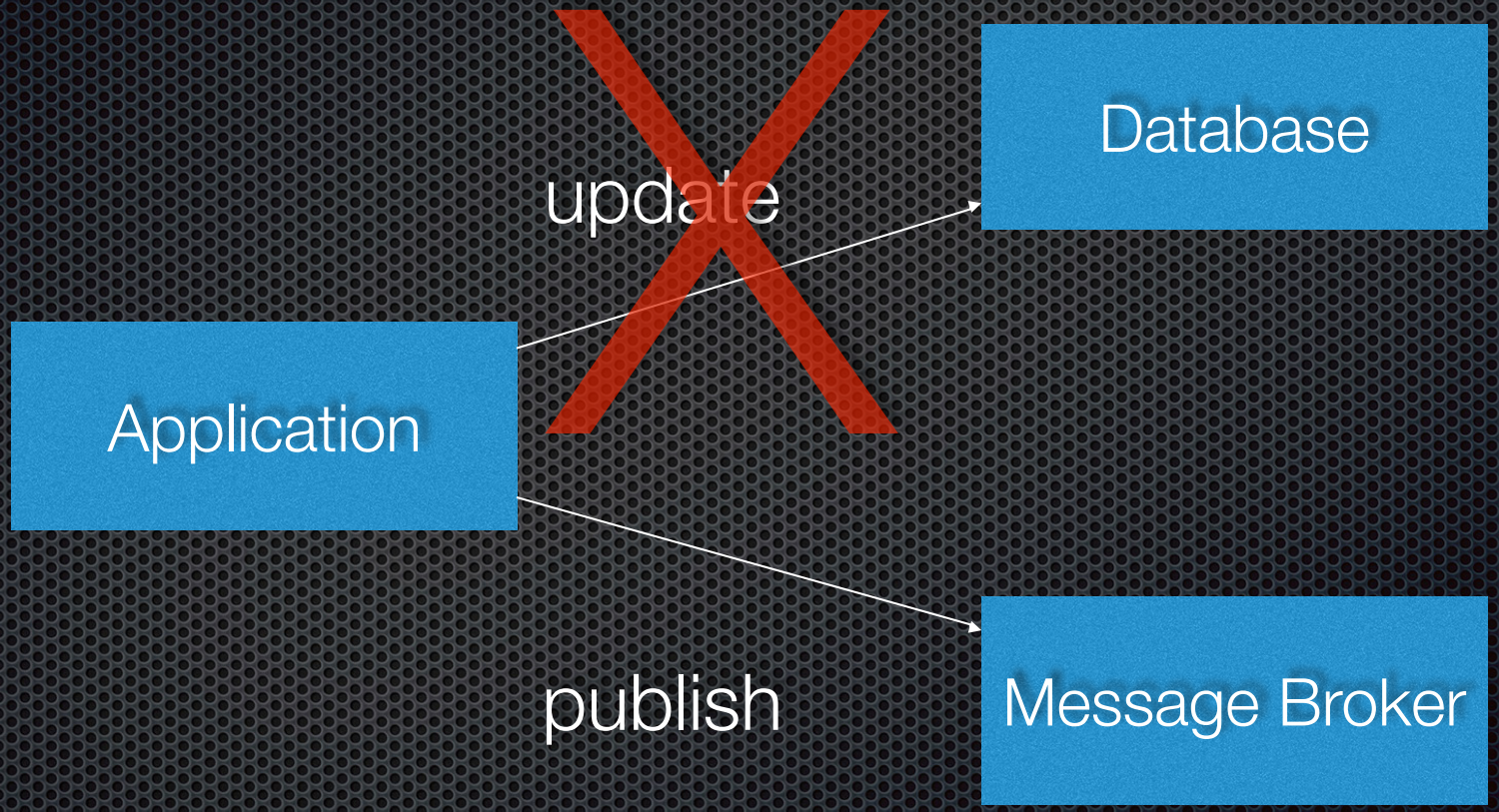
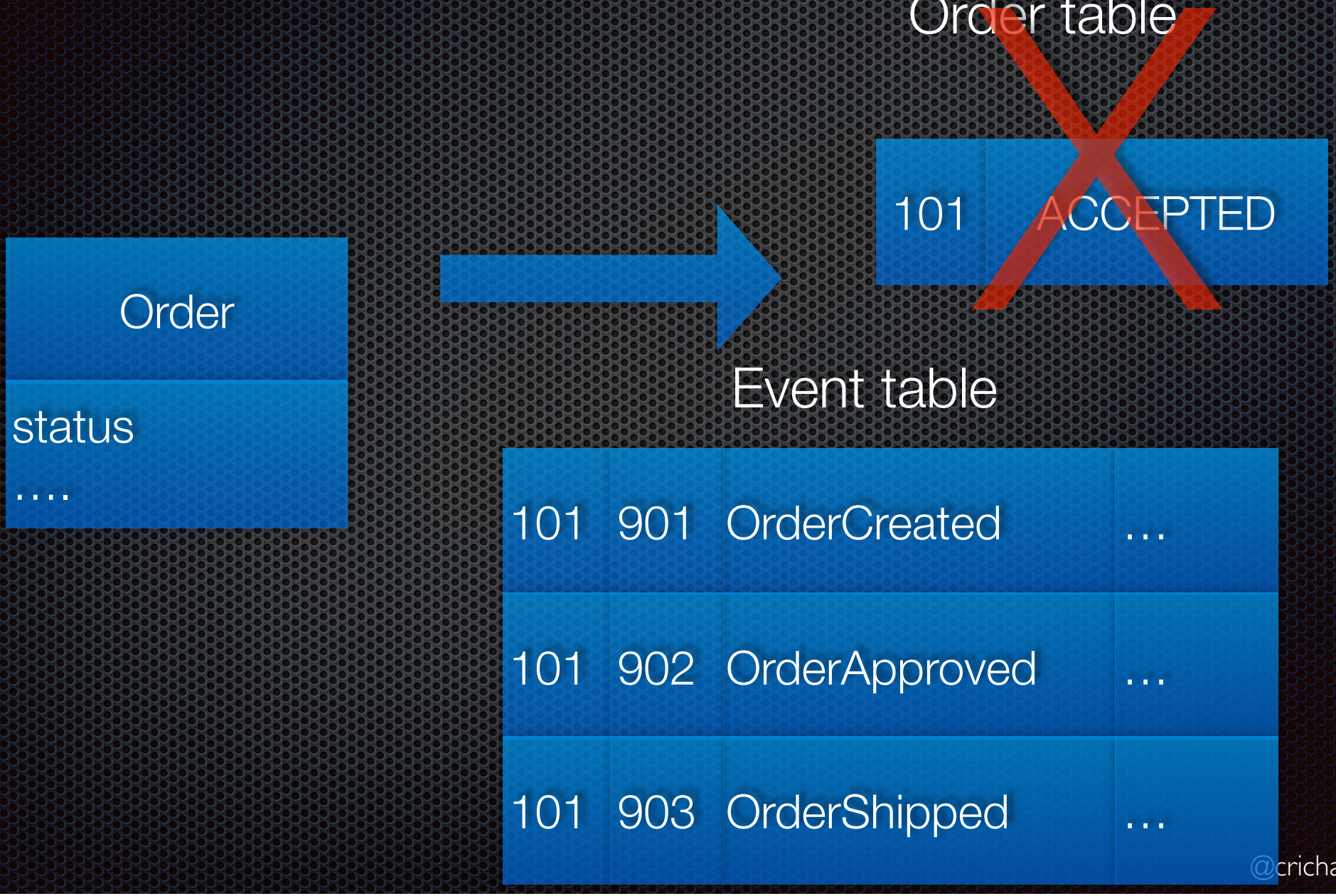
Just publish events



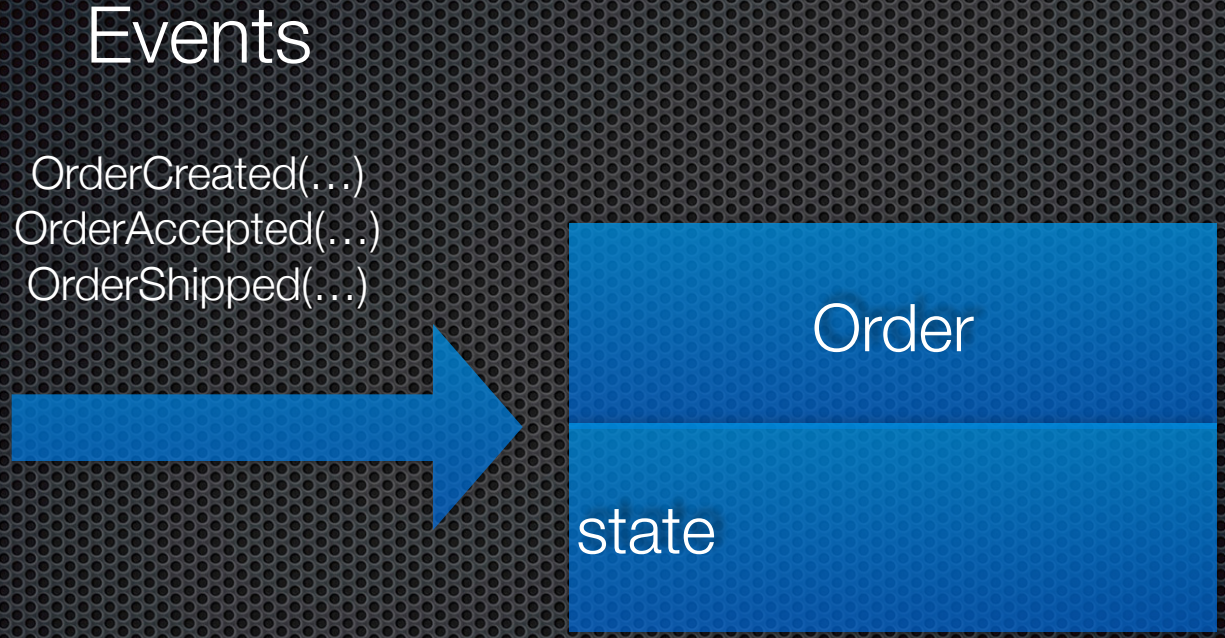
Event sourcing

- For each aggregate (business entity):
  - Identify (state-changing) domain events
  - Define Event classes
- For example,
  - ShoppingCart: ItemAddedEvent, ItemRemovedEvent, OrderPlacedEvent
  - Order: OrderCreated, OrderCancelled, OrderApproved, OrderRejected, OrderShipped

Persists events NOT current state



Replay events to recreate state

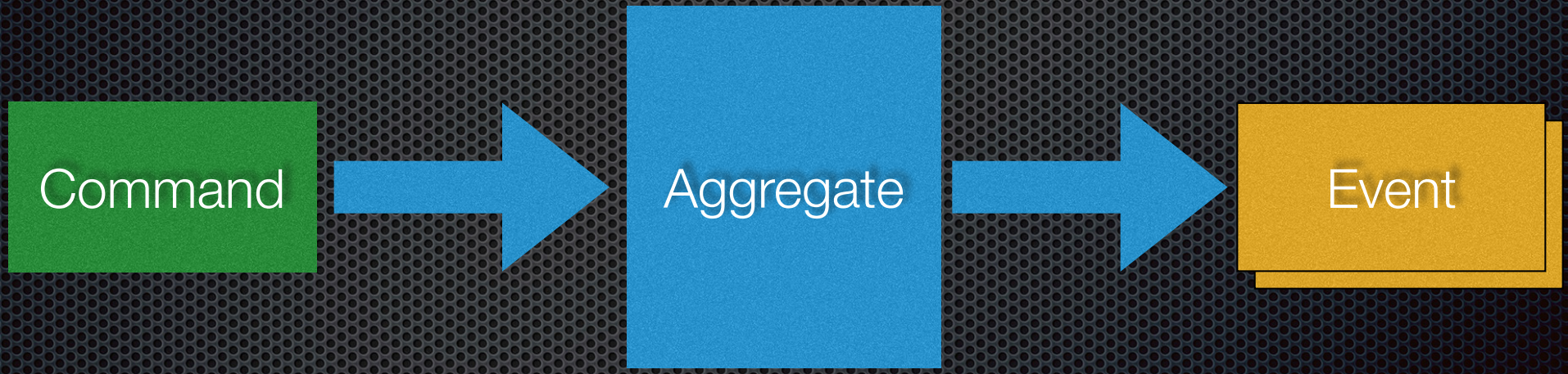


Periodically snapshot to avoid loading all events

The present is a fold over history

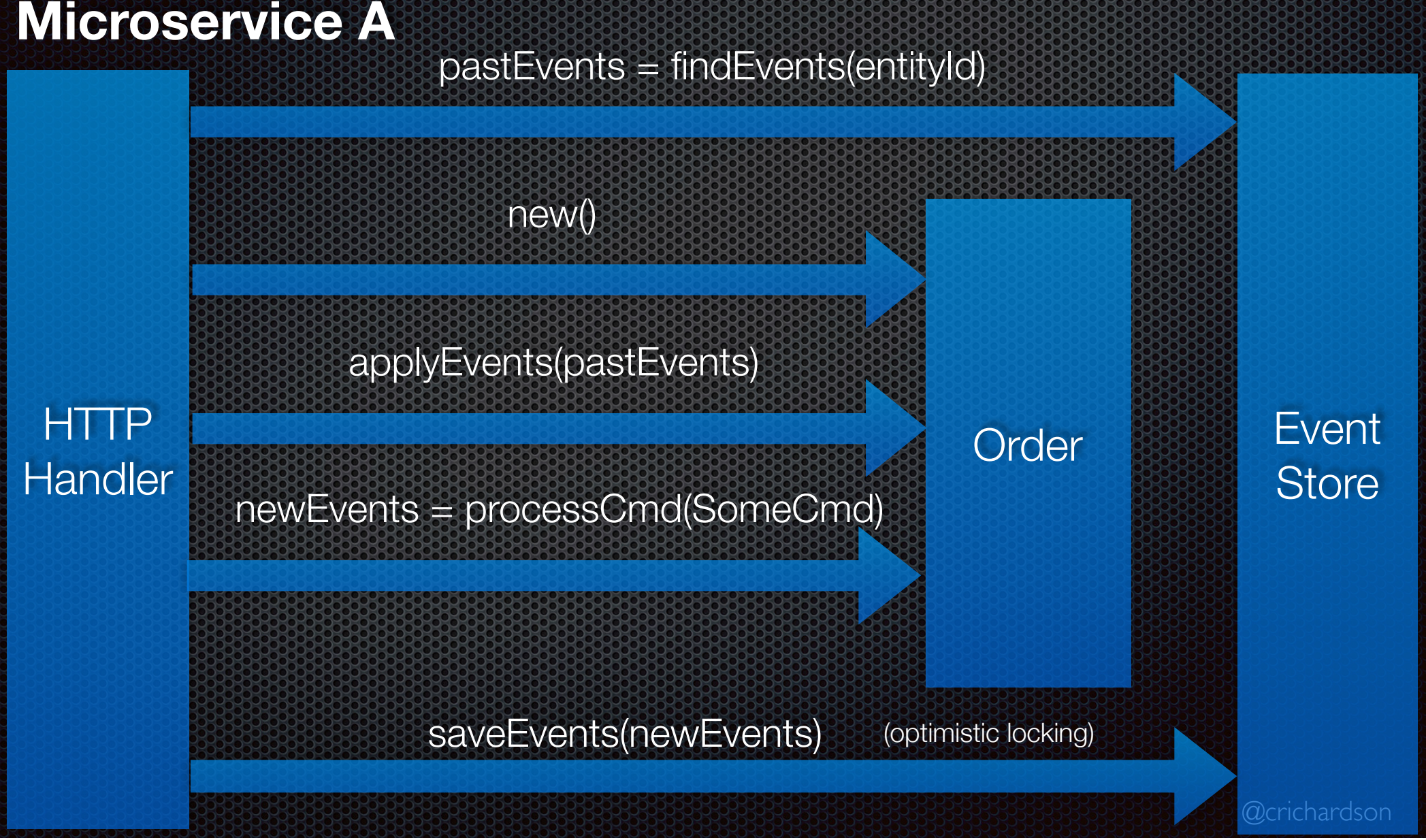
currentState = foldl(applyEvent, initialState, events)

Aggregates: Command ⇒ Events

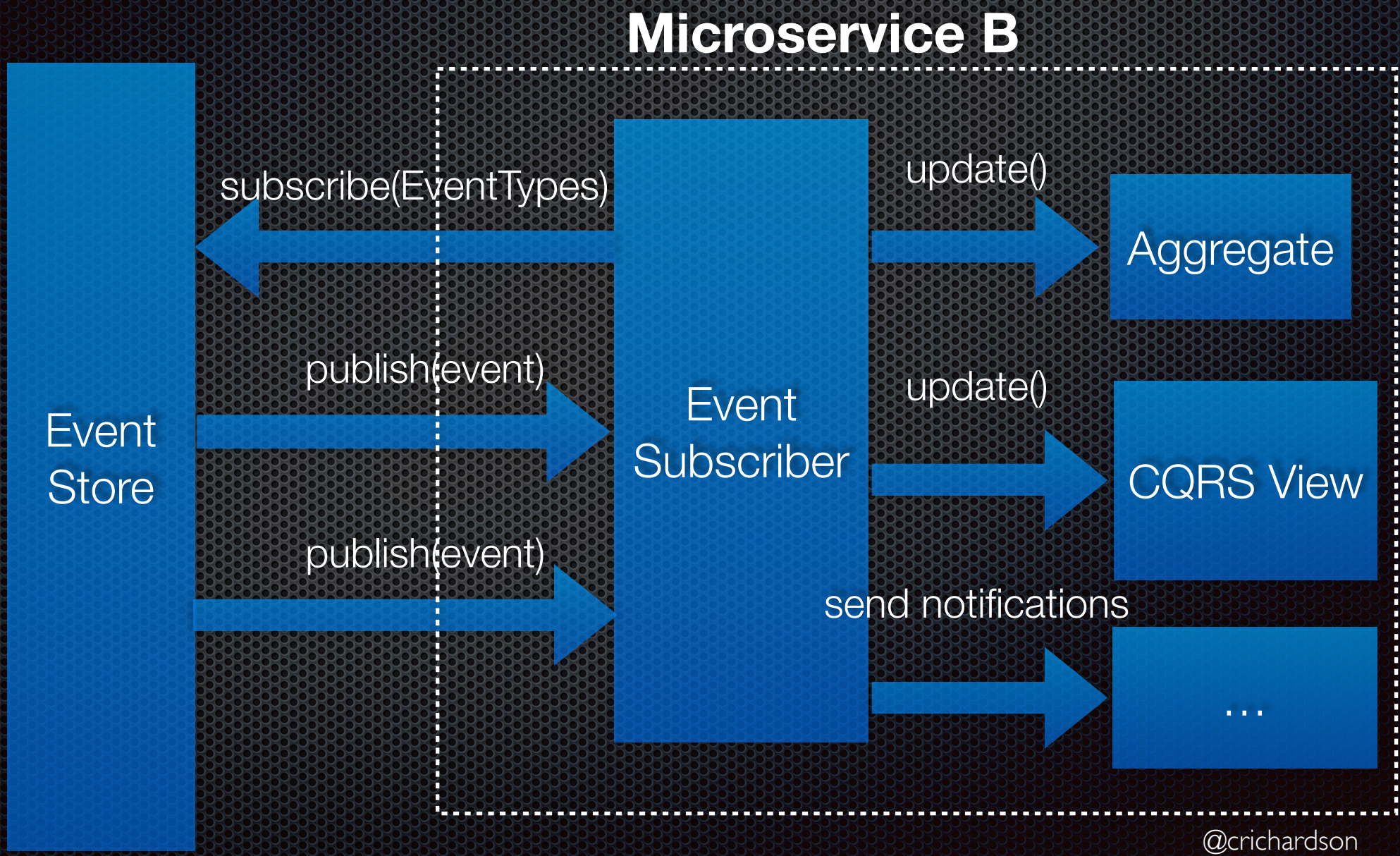


Aggregates: Event ⇒ Updated aggregate

Request handling in an event-sourced application



Event Store publishes events - consumed by other services



Event store = database + message broker

- Hybrid database and message broker
- Implementations:
  - Home-grown/DIY
  - geteventstore.com by Greg Young
  - http://eventuate.io (mine)

Benefits of event sourcing

- Solves data consistency issues in a Microservice/NoSQL-based architecture
- Reliable event publishing: publishes events needed by predictive analytics etc, user notifications,…
- Eliminates O/R mapping problem (mostly)
- Reifies state changes:
  - Built-in, reliable audit log,
  - temporal queries
- Preserved history ⇒ More easily implement future requirements

Drawbacks of event sourcing

- Weird and unfamiliar
- Events = a historical record of your bad design decisions
- Handling duplicate events can be tricky
- Application must handle eventually consistent data
- Event store only directly supports PK-based lookup => use Command Query Responsibility Segregation (CQRS) to handle queries

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Implementing createOrder()

POST /orders


```
class OrderServiceImpl {

 public Order createOrder() {
    … Creates Order …
 }

}
```

Implement requirements and preserve invariants

Story

As a customer
I want to place an order
So that I get the needed products

Invariant:
sum(open order.total) <= customer.creditLimit

Scenario

Given that my available credit is $1500
When I place a $250 order
Then the order is created
Then my available credit is $1250

Pre conditions

Post conditions

Scenario

Given that my available credit is $1500
When I place a $2500 order
Then the order is rejected
Then my available credit is $1500

createOrder() updates multiple aggregates

- Updates **Customer** aggregate's available credit
- **Creates** Order aggregate
- Associates **Order** with **Customer**

Old-style ACID…

BEGIN TRANSACTION

… VERIFY CREDIT …

… CREATE ORDER…

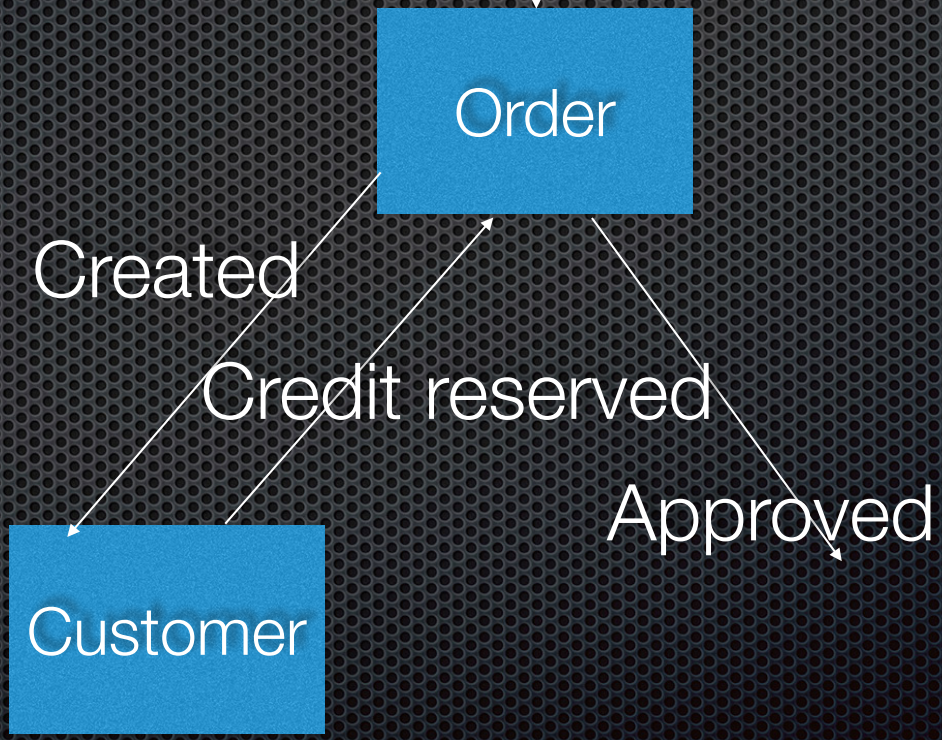
COMMIT TRANSACTION

… becomes eventually consistent (BASE)

- Updating multiple aggregates
  - multi-step, event-driven flow
  - each step updates one Aggregate
- Service creates saga to coordinate workflow
  - A state machine
  - Part of the domain, e.g. Order aggregate OR Synthetic aggregate
- Post-conditions and invariants eventually become true

Creating an order

```
public Order createOrder() {
    … Creates Order …
}
```



Need compensating transactions

- Pre-conditions might be false when attempting to update an aggregate
- Credit check fails ⇒ cancel order
- Credit check succeeded but customer cancels order ⇒ undo credit reservation
- …

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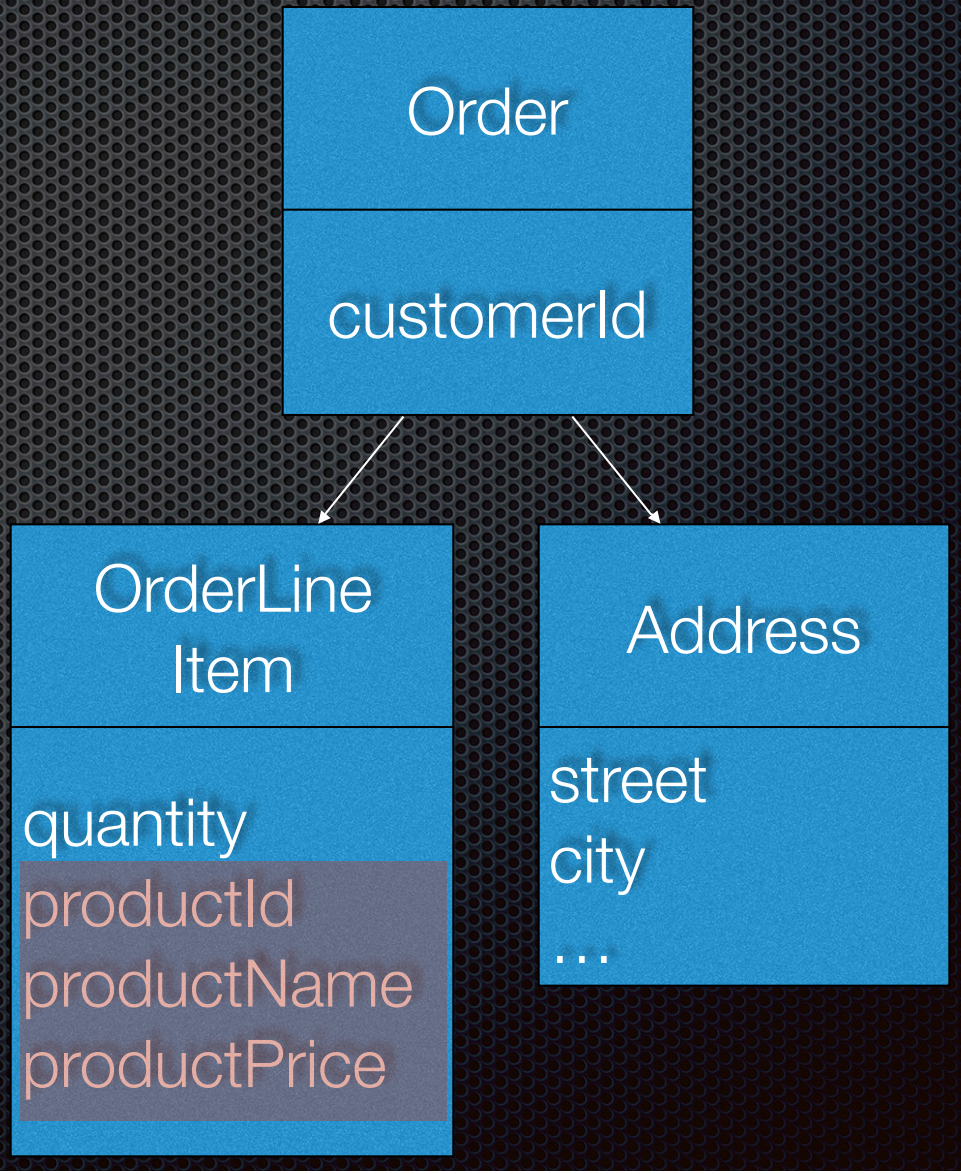
Use the familiar building blocks of DDD

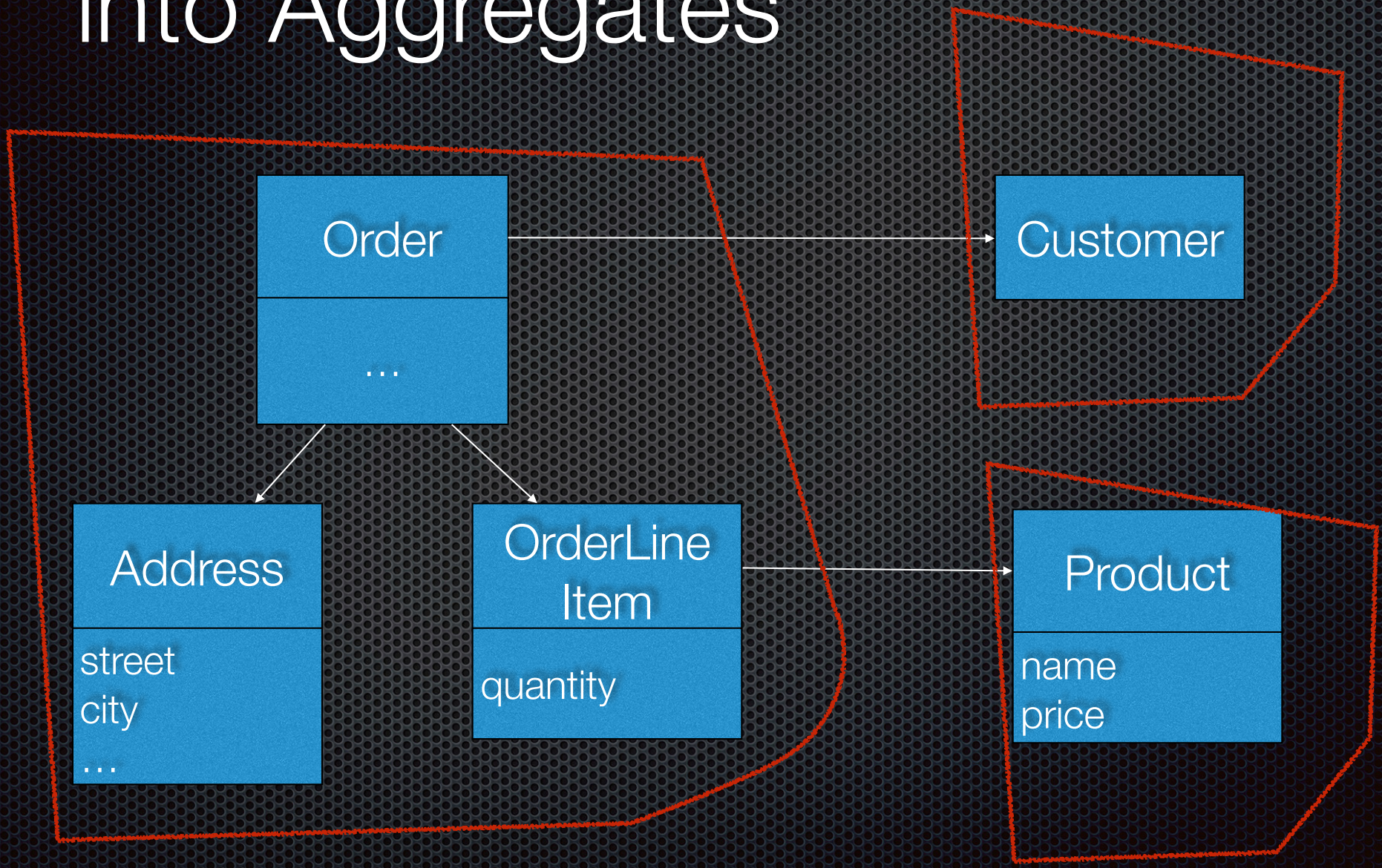
- Entity
- Value object
- Services
- Repositories
- Aggregates ⟸ **essential**

Aggregate design

- Graph consisting of a root entity and one or more other entities and value objects
- Each core business entity = Aggregate: e.g. customer, Account, Order, Product, ….
- Reference other aggregate roots via primary key
- Often contains partial copy of other aggregates' data



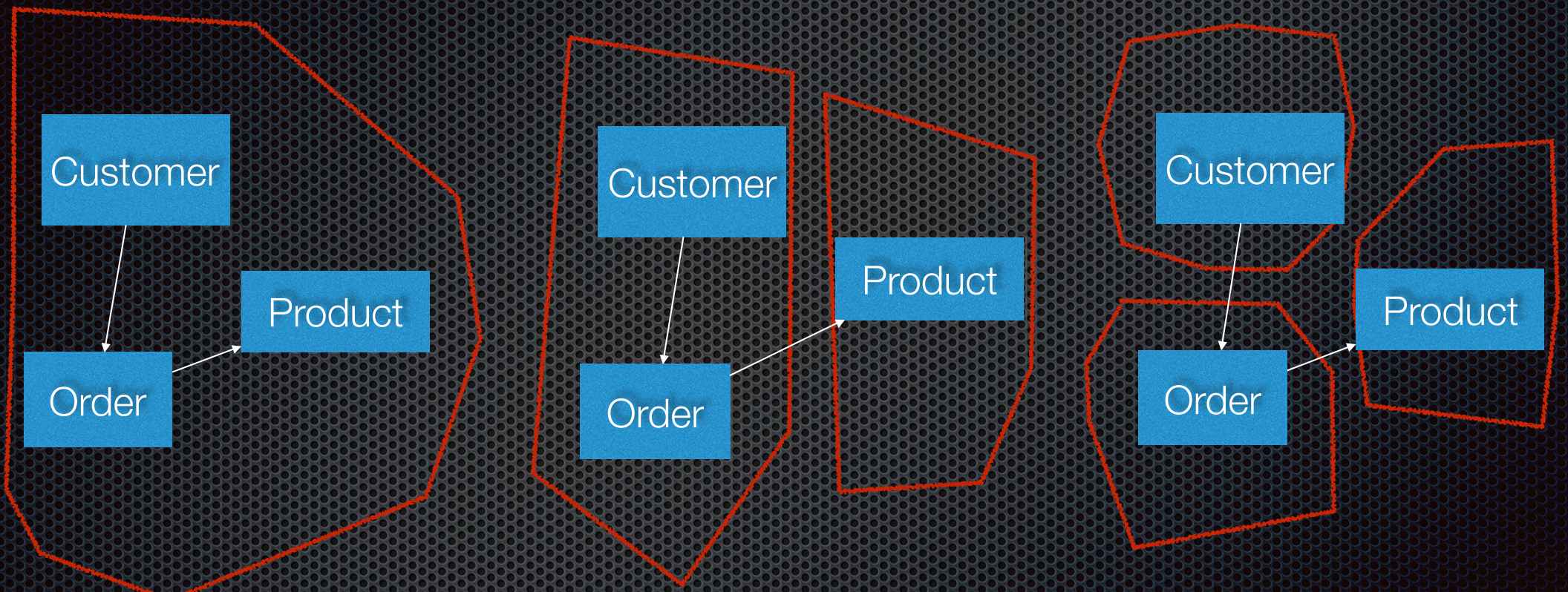
Partition the domain model into Aggregates



Transaction = processing one command by one aggregate

- No opportunity to update multiple aggregates within a transaction
- Aggregate granularity is important
- If an update must be atomic (i.e. no compensating transaction) then it must be handled by a single aggregate
  - e.g. scanning boarding pass at security checkpoint or when entering jetway

Aggregate granularity

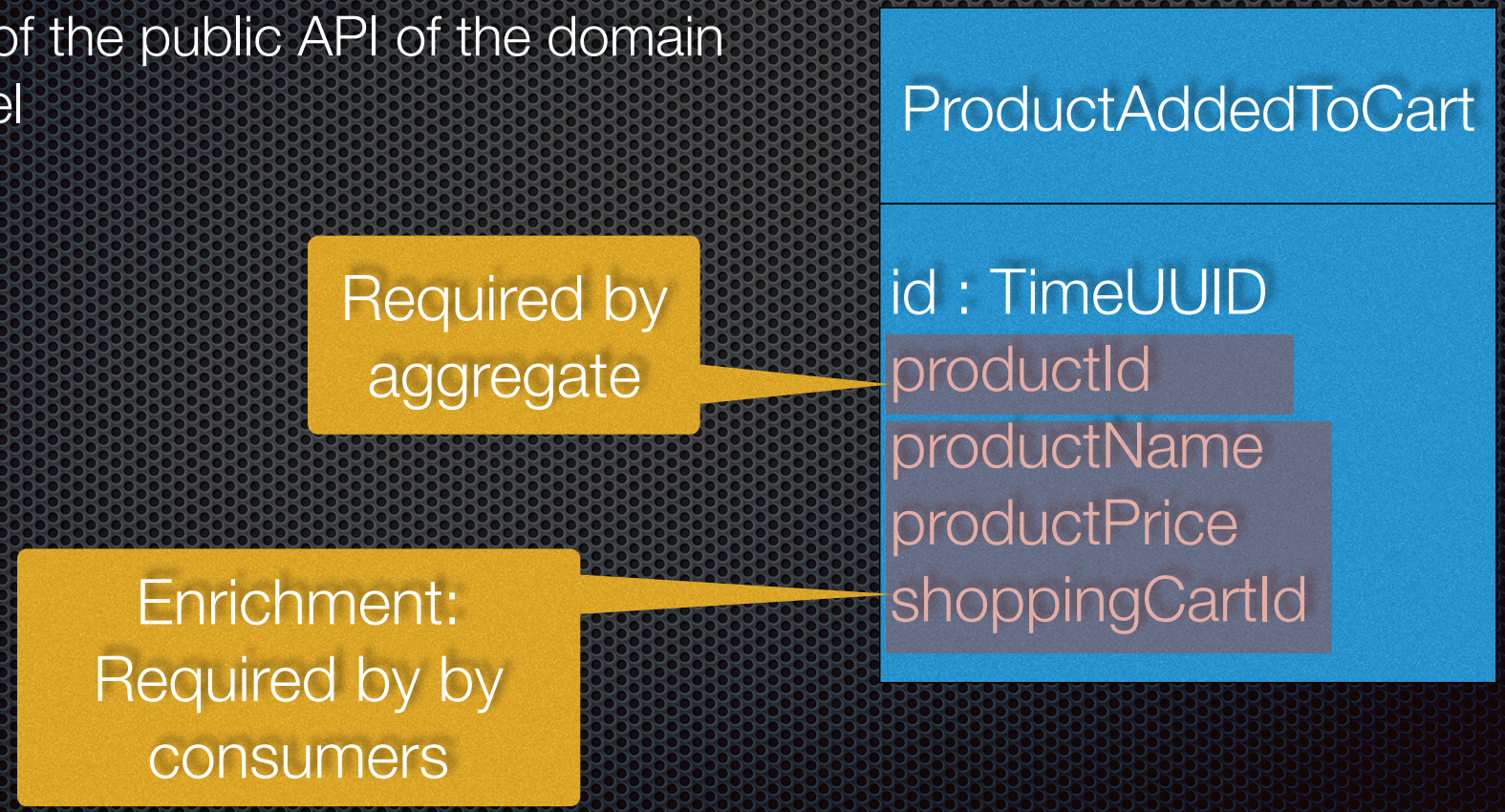


Consistency

Scalability/
User experience

Designing domain events

- Record state changes for an aggregate
- Part of the public API of the domain model



Example event

```
public class OrderCreatedEvent implements OrderEvent {
  private Money orderTotal;
  private EntityIdentifier customerId;

  @Override
  public boolean equals(Object obj) { return EqualsBuilder.reflectionEquals(this, obj); }

  @Override
  public int hashCode() { return HashCodeBuilder.reflectionHashCode(this); }

  public OrderCreatedEvent(EntityIdentifier customerId, Money orderTotal) {...}

  public Money getOrderTotal() { return orderTotal; }

  public EntityIdentifier getCustomerId() { return customerId; }
}
```

Designing commands

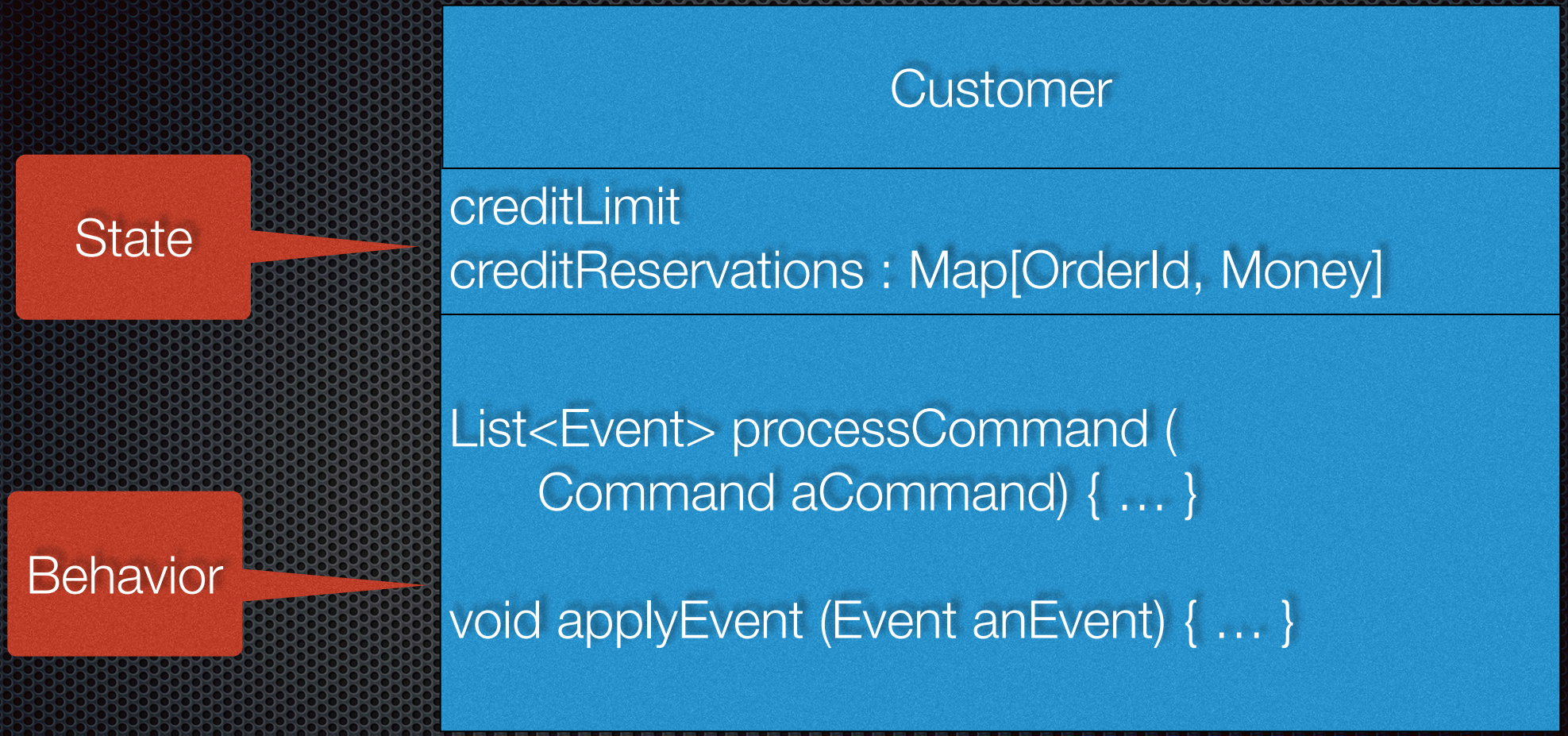
- Created by a service from incoming request
- Processed by an aggregate
- Immutable
- Contains value objects for
  - Validating request
  - Creating event
  - Auditing user activity

Example command

```
public class CreateCustomerCommand implements CustomerCommand {
  private final String name;
  private final Money creditLimit;

  public CreateCustomerCommand(String name, Money creditLimit) {...}

  public Money getCreditLimit() { return creditLimit; }

  public String getName() { return name; }
}
```

Hybrid OO/FP domain objects

OO = State + Behavior



Aggregate traits

Used by Event Store to reconstitute aggregate

Apply event returning updated Aggregate

```
trait Aggregate[T] { self : T =>
  def applyEvent(event : Event) : T
}

trait CommandProcessingAggregate[T, -CT] extends Aggregate[T] { self : T =>
  def processCommand(command : CT) : Seq[Event]
}
```

Map Command to Events

ReflectiveMutableCommand ProcessingAggregate

```
abstract class ReflectiveMutableCommandProcessingAggregate[T, -CT <: Command]
  extends CommandProcessingAggregate[T, CT] { self : T =>

  def applyEvent(event : Event) : T = {
    getClass.getMethod("apply", event.getClass).invoke(this, event)
    this
  }

  def processCommand(command : CT) : Seq[Event] =
    getClass.getMethod("process", command.getClass).invoke(this, command).asInstanceOf[java.util.List[Event]]

}
```

Customer - command processing

```
public class Customer extends ReflectiveMutableCommandProcessingAggregate<Customer, CustomerCommand> {

  private Money creditLimit;
  private Map<EntityIdentifier, Money> creditReservations;

  Money availableCredit() {
    return creditLimit.subtract(creditReservations.values().stream().reduce(Money.ZERO, Money::add));
  }

  Money getCreditLimit() { return creditLimit; }

  public List<Event> process(CreateCustomerCommand cmd) {
    return EventUtil.events(new CustomerCreatedEvent(cmd.getName(), cmd.getCreditLimit()));
  }

  public List<Event> process(ReserveCreditCommand cmd) {
    if (availableCredit().isGreaterThanOrEqual(cmd.getOrderTotal()))
      return EventUtil.events(new CustomerCreditReservedEvent(cmd.getOrderId(), cmd.getOrderTotal()));
    else
      return EventUtil.events(new CustomerCreditLimitedExceededEvent(cmd.getOrderId()));
  }

  public void apply(CustomerCreatedEvent event) {...}

  public void apply(CustomerCreditReservedEvent event) {...}

  public void apply(CustomerCreditLimitedExceededEvent event) {...}

}
```

Customer - applying events

```
public class Customer extends ReflectiveMutableCommandProcessingAggregate<Customer, CustomerCommand> {

  private Money creditLimit;
  private Map<EntityIdentifier, Money> creditReservations;

  Money availableCredit() {...}

  Money getCreditLimit() { return creditLimit; }

  public List<Event> process(CreateCustomerCommand cmd) {...}

  public List<Event> process(ReserveCreditCommand cmd) {...}


  public void apply(CustomerCreatedEvent event) {
    this.creditLimit = event.getCreditLimit();
    this.creditReservations = new HashMap<>();
  }

  public void apply(CustomerCreditReservedEvent event) {
    this.creditReservations.put(event.getOrderId(), event.getOrderTotal());
  }

  public void apply(CustomerCreditLimitedExceededEvent event) {
    // Do nothing
  }

}
```

Event Store API

T is a subclass of Aggregate[T]

```
trait EventStore {

  def save[T <: Aggregate[T]](entityClass: Class[T], events: java.util.List[Event]) :
    Observable[EntityIdAndVersion]

  def update[T <: Aggregate[T]](entityClass: Class[T], entityIdAndVersion : EntityIdAndVersion, events: java.util.List[Event])
    Observable[EntityIdAndVersion]

  def find[T <: Aggregate[T]](entityClass: Class[T], entityId: EntityIdentifier):
    Observable[EntityWithMetadata[T]]

  def find[T <: Aggregate[T]](entityClass: Class[T], entityId: EntityIdentifier, triggeringEvent : PublishedEvent):
    Observable[EntityWithMetadata[T]]
```

Rx Observable = Future++

Creating an order

```
public class OrderServiceImpl implements OrderService {

  private final AggregateRepository<Order, OrderCommand> orderRepository;

  public OrderServiceImpl(AggregateRepository<Order, OrderCommand> orderRepository) {
    this.orderRepository = orderRepository;
  }

  @Override
  public Observable<EntityWithIdAndVersion<Order>>
        createOrder(EntityIdentifier customerId, Money orderTotal) {
    return orderRepository.save(new CreateOrderCommand(customerId, orderTotal));
  }
}
```

save() concisely specifies:
1.Creates Customer aggregate
2.Processes command
3.Applies events
4.Persists events

Event handling in Customers

Triggers BeanPostProcessor

Durable subscription name

```
@EventSubscriber(id="customerWorkflow")
public class CustomerWorkflow {

  @EventHandlerMethod
  public Observable<?> reserveCredit(EventHandlerContext<OrderCreatedEvent> ctx) {
    OrderCreatedEvent event = ctx.getEvent();
    Money orderTotal = event.getOrderTotal();
    EntityIdentifier customerId = event.getCustomerId();
    EntityIdentifier orderId = ctx.getEntityIdentifier();

    return ctx.update(Customer.class, customerId, new ReserveCreditCommand(orderTotal, orderId));
  }

}
```

1.Load Customer aggregate
2.Processes command
3.Applies events
4.Persists events

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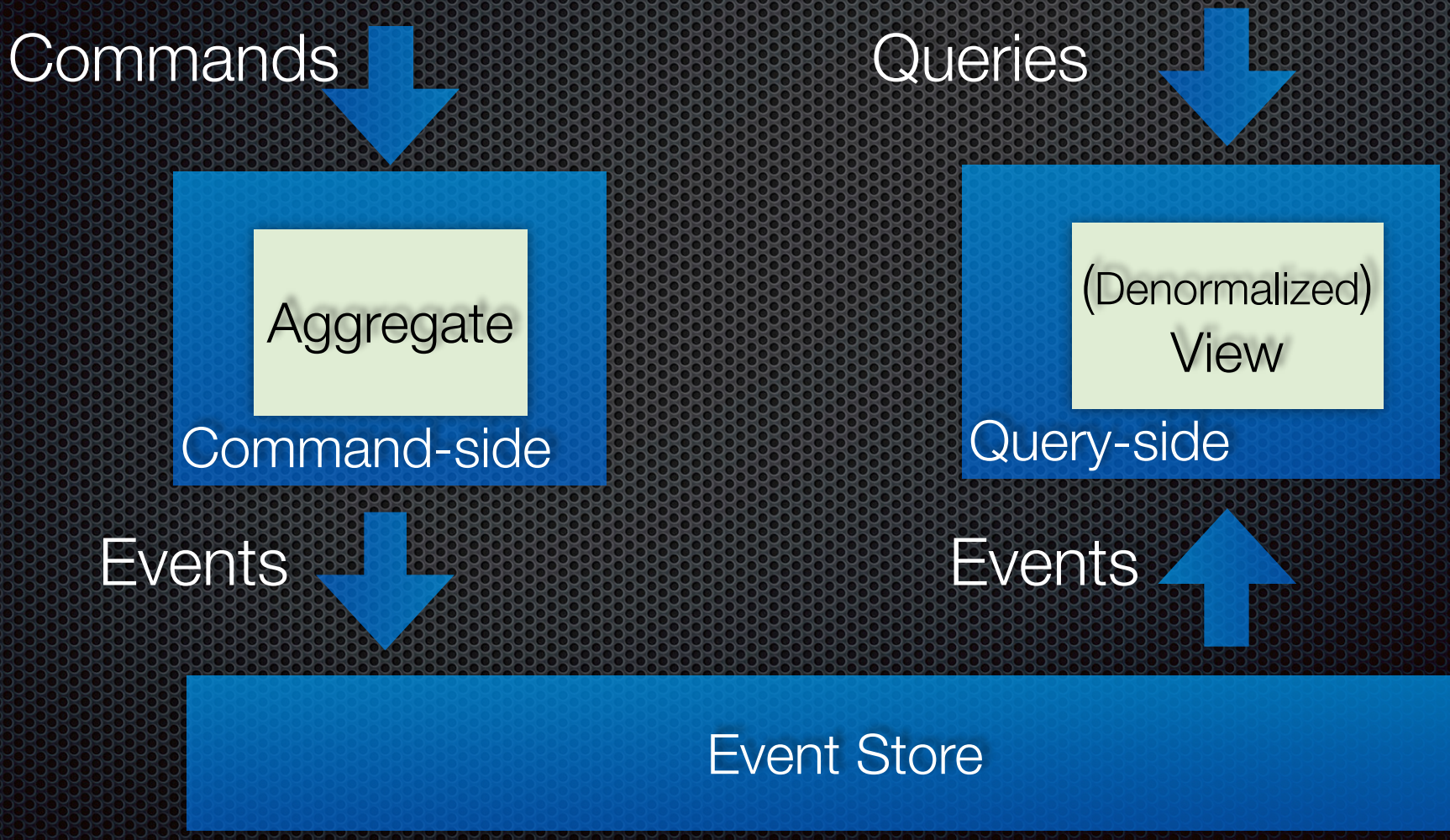
Let’s imagine you want to display a customer and their recent orders

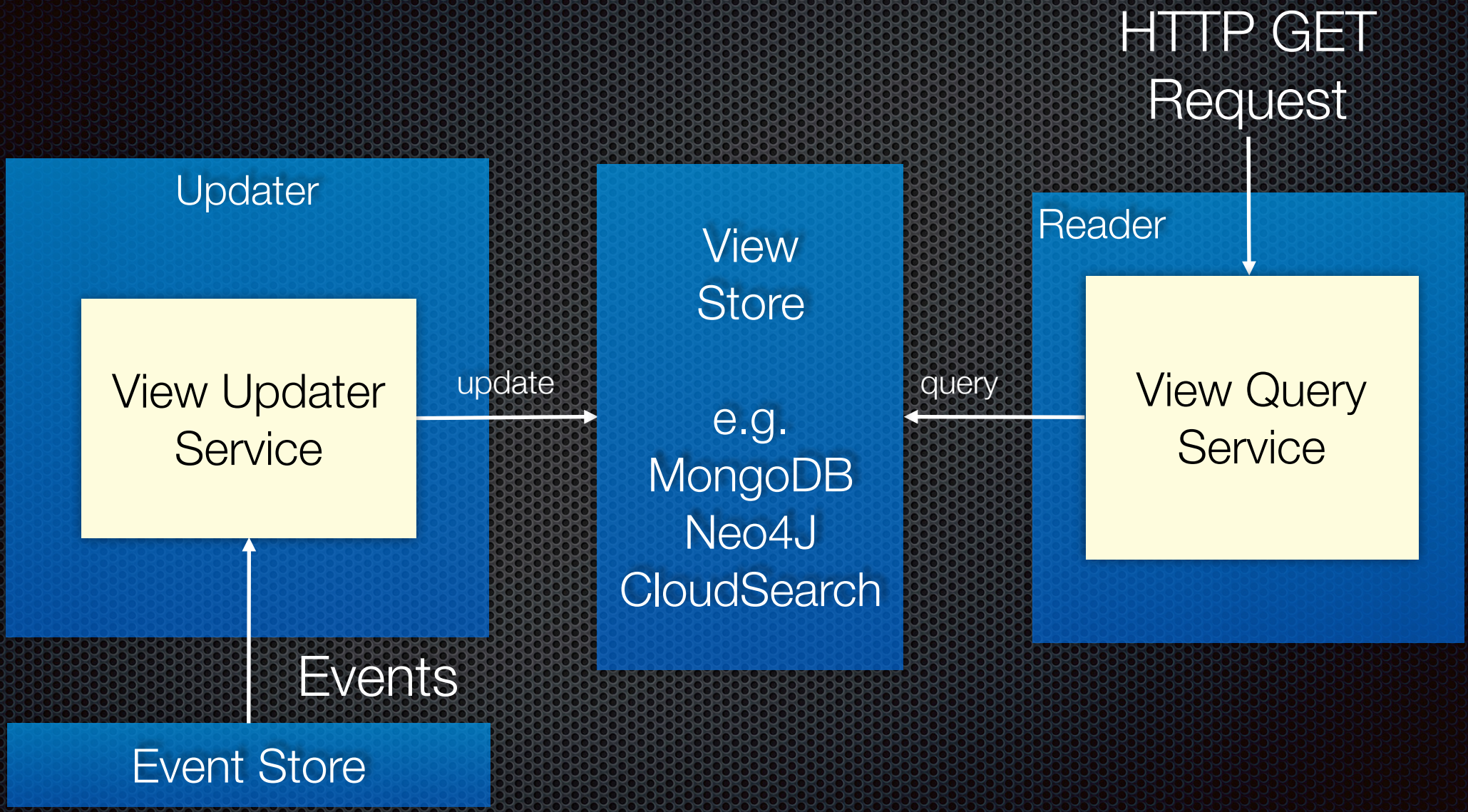
Need to ‘join’ customers and orders
BUT
Event store only supports primary key lookup

Use Command Query Responsibility Segregation (CQRS)

Command Query Responsibility Segregation (CQRS)



Query-side design



Persisting a customer and order history in MongoDB

```
{
    "_id" : "0000014f9a45004b-0a00270000000000",
    "_class" : "net.chrisrichardson…..views.orderhistory.CustomerView",
    "version" : NumberLong(5),
    "orders" : {
        "0000014f9a450063-0a00270000000000" : {
            "state" : "APPROVED",
            "orderId" : "0000014f9a450063-0a00270000000000",
            "orderTotal" : {
                "amount" : "1234"
            }
        },
        "0000014f9a450063-0a00270000000001" : {
            "state" : "REJECTED",
            "orderId" : "0000014f9a450063-0a00270000000001",
            "orderTotal" : {
                "amount" : "3000"
            }
        }
    },
    "name" : "Fred",
    "creditLimit" : {
        "amount" : "2000"
    }
}
```

Denormalized = efficient lookup

Persisting customers and order info using Spring Data for MongoDB...

```
@EventSubscriber(id="orderHistoryWorkflow")
public class OrderHistoryViewWorkflow {

  private OrderHistoryViewService orderHistoryViewService;


  @Autowired
  public OrderHistoryViewWorkflow(OrderHistoryViewService orderHistoryViewService) {
    this.orderHistoryViewService = orderHistoryViewService;
  }

  @EventHandler
  public Observable<Object> createCustomer(DispatchedEvent<CustomerCreatedEvent> de) {
    String customerId = de.getEntityIdentifier().getId();
    orderHistoryViewService.createCustomer(customerId, de.event().getName(), de.event().getCreditLimit());
    return Observable.just(null);
  }

  @EventHandler
  public Observable<Object> createOrder(DispatchedEvent<OrderCreatedEvent> de) {...}

  @EventHandler
  public Observable<Object> orderApproved(DispatchedEvent<OrderApprovedEvent> de) {...}

  @EventHandler
  public Observable<Object> orderRejected(DispatchedEvent<OrderRejectedEvent> de) {...}

}
```

Persisting customers and order using Spring Data for MongoDB...

```
public class OrderHistoryViewService {

  private CustomerViewRepository customerViewRepository;

  @Autowired
  public OrderHistoryViewService(CustomerViewRepository customerViewRepository) {
    this.customerViewRepository = customerViewRepository;
  }

  void createCustomer(String customerId, String customerName, Money creditLimit) {
    CustomerView customerView = findOrCreateCustomerView(customerId);
    customerView.setName(customerName);
    customerView.setCreditLimit(creditLimit);
    customerViewRepository.save(customerView);
  }

  private CustomerView findOrCreateCustomerView(String customerId) {
    CustomerView customerView = customerViewRepository.findOne(customerId);
    if (customerView == null) {
      customerView = new CustomerView();
      customerView.setId(customerId);
      customerView = customerViewRepository.insert(customerView);
    }
    return customerView;
  }
```

```
public interface CustomerViewRepository extends MongoRepository<CustomerView, String> {
}
```

Other kinds of views

- AWS Cloud Search
  - Text search as-a-Service
  - View updater batches aggregates to index
  - View query service does text search
- AWS DynamoDB
  - NoSQL as-a-Service
  - On-demand scalable - specify desired read/write capacity
  - Document and key-value data models
  - Useful for denormalized, UI oriented views

Benefits and drawbacks of CQRS

Benefits

- Necessary in an event-sourced architecture
- Separation of concerns = simpler command and query models
- Supports multiple denormalized views
- Improved scalability and performance

Drawbacks

- Complexity
- Potential code duplication
- Replication lag/eventually consistent views

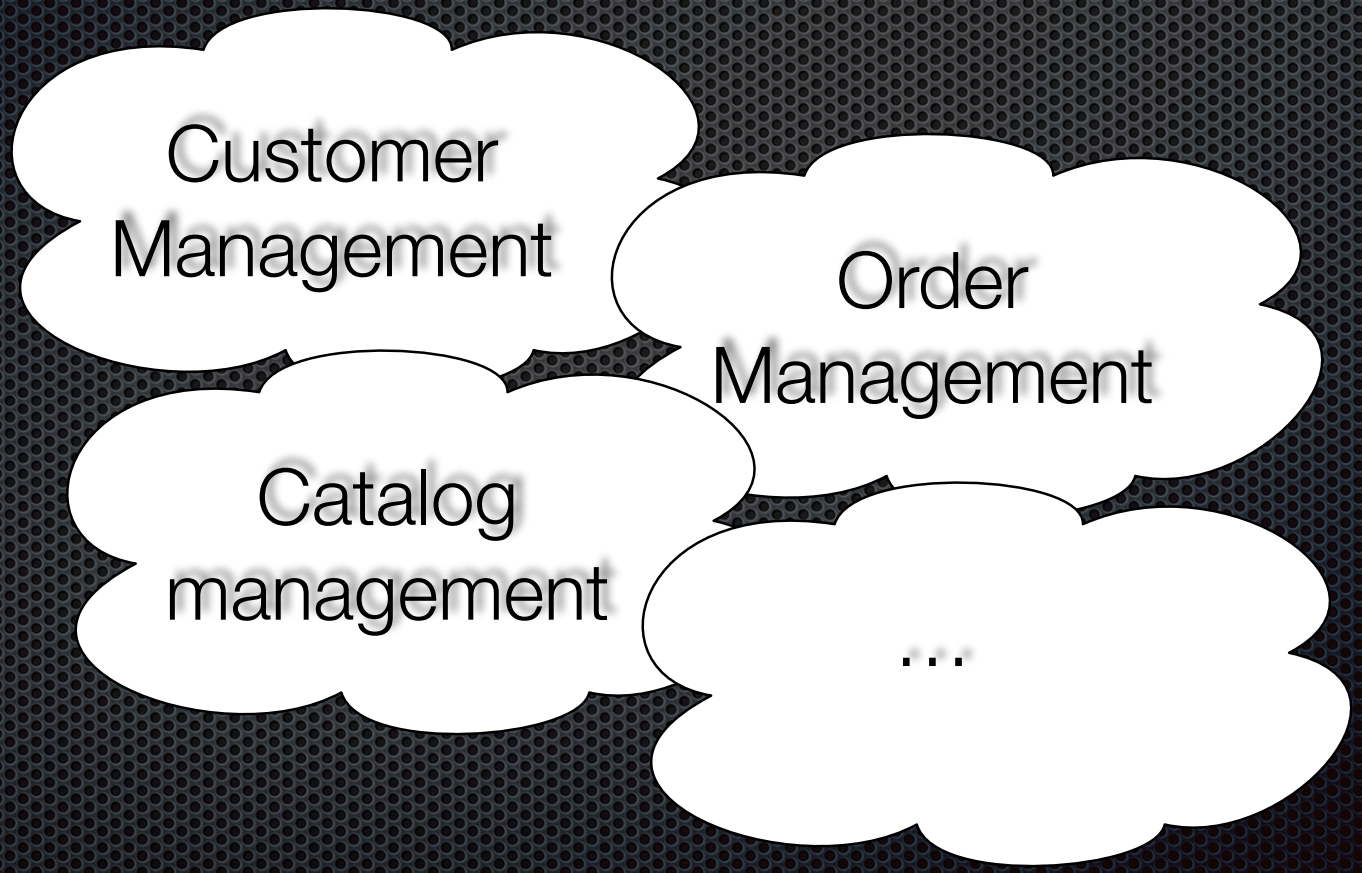
Agenda

- Why event sourcing?
- Overview of event sourcing
- ACID-free design
- Designing a domain model based on event sourcing
- Implementing queries in an event sourced application
- Event sourcing and microservices

Partitioning into microservices: Use Strategic DDD

Strategic design: identify sub-domains and bounded contexts

Strategic design: identify sub-domains and bounded contexts



Bounded context = microservices

Command side

Query side

Customer management

domain model

Order management

domain model

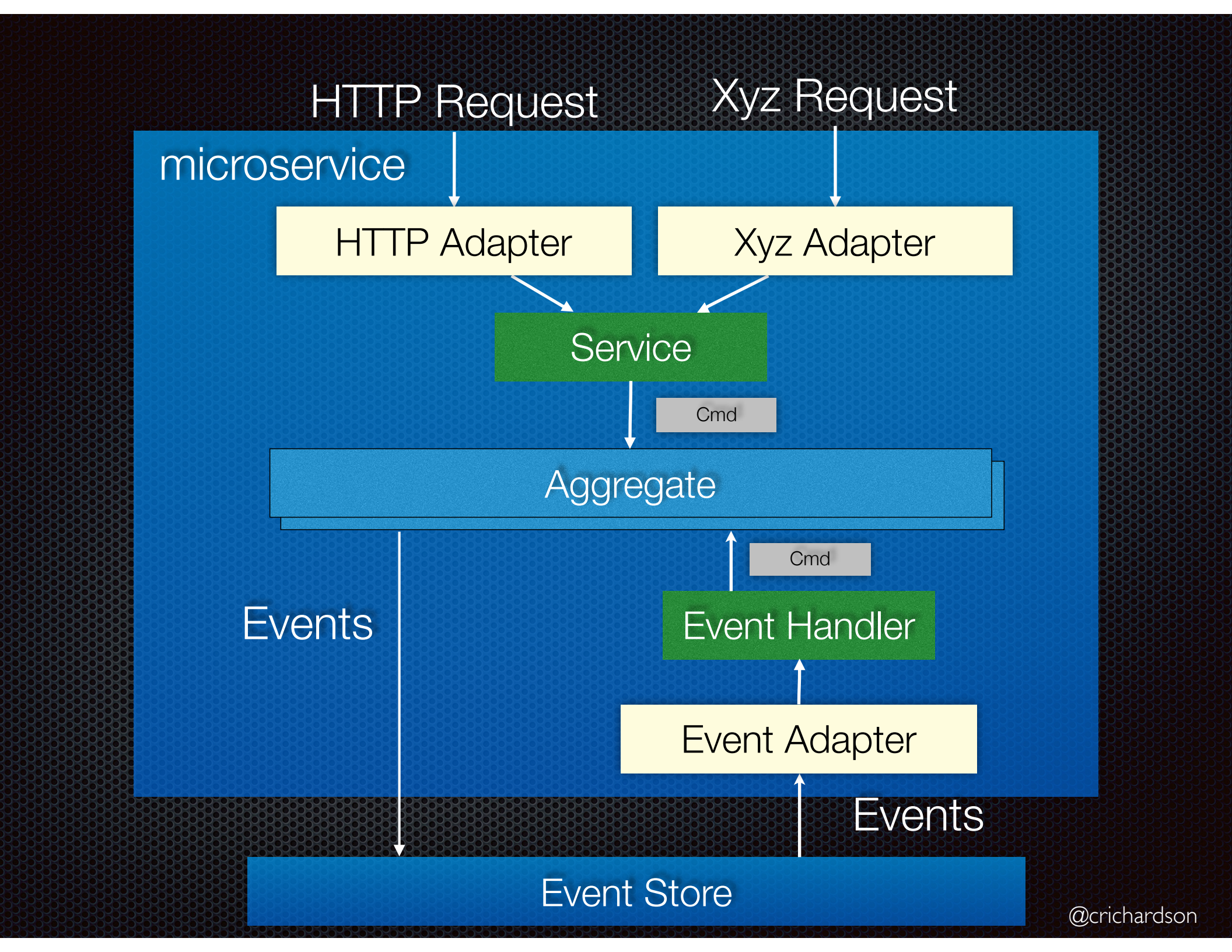
Customer view

Catalog management

domain model

…

domain model


HTTP Request
Xyz Request
microservice
HTTP Adapter
Xyz Adapter
Service
Cmd
Aggregate
Cmd
Events
Event Handler
Event Adapter
Events
Event Store
@crichardson

Order Controller

```
@RestController
public class OrderController {

  private OrderService orderService;

  @Autowired
  public OrderController(OrderService orderService) { this.orderService = orderService; }

  @RequestMapping(value="/orders", method= RequestMethod.POST)
  public Observable<CreateOrderResponse> createOrder(@RequestBody CreateOrderRequest createOrderRequest) {

    Observable<EntityWithIdAndVersion<Order>> order =
            orderService.createOrder(new EntityIdentifier(createOrderRequest.getCustomerId()),
                    createOrderRequest.getOrderTotal());

    return order.map(ewidv -> new CreateOrderResponse(ewidv.getEntityIdentifier()));
  }


}
```

When to use microservices?

In the beginning:

- You don't need it
- It will slow you down

Later on:

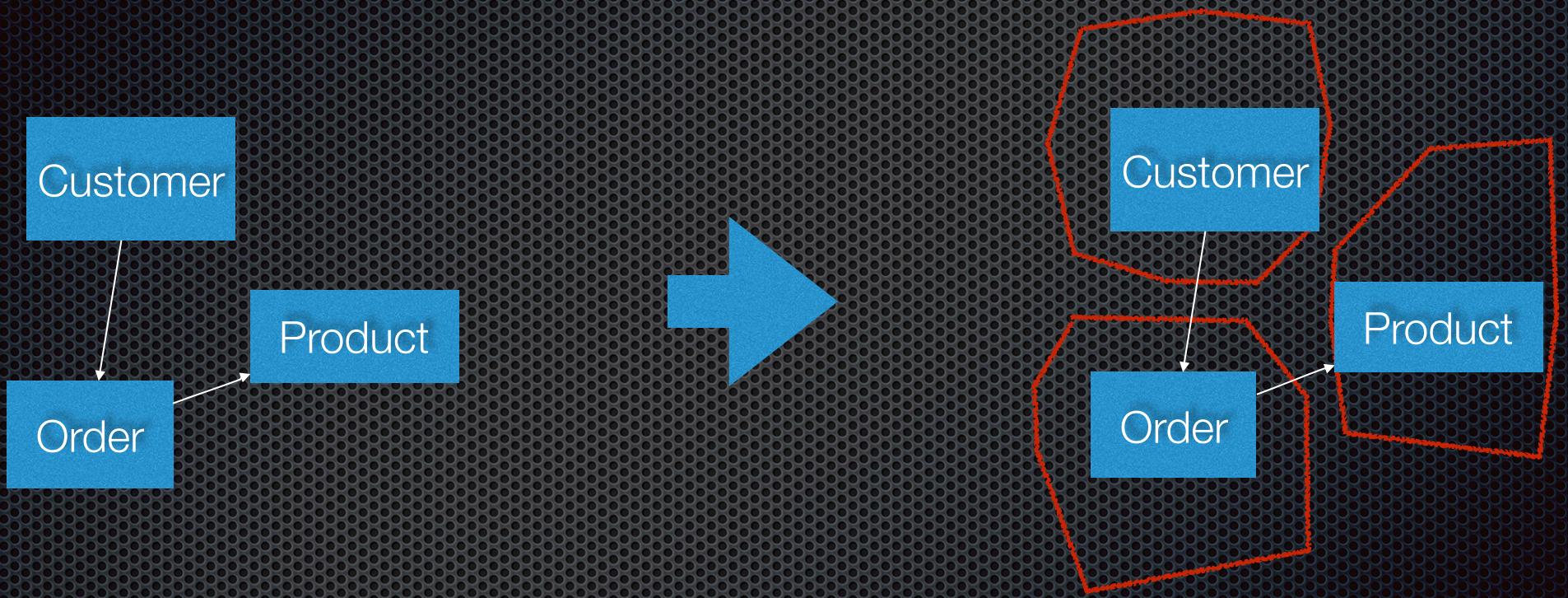
- You need it
- Refactoring dependencies is painful

Aggregates + Event Sourcing

=

Modular domain model

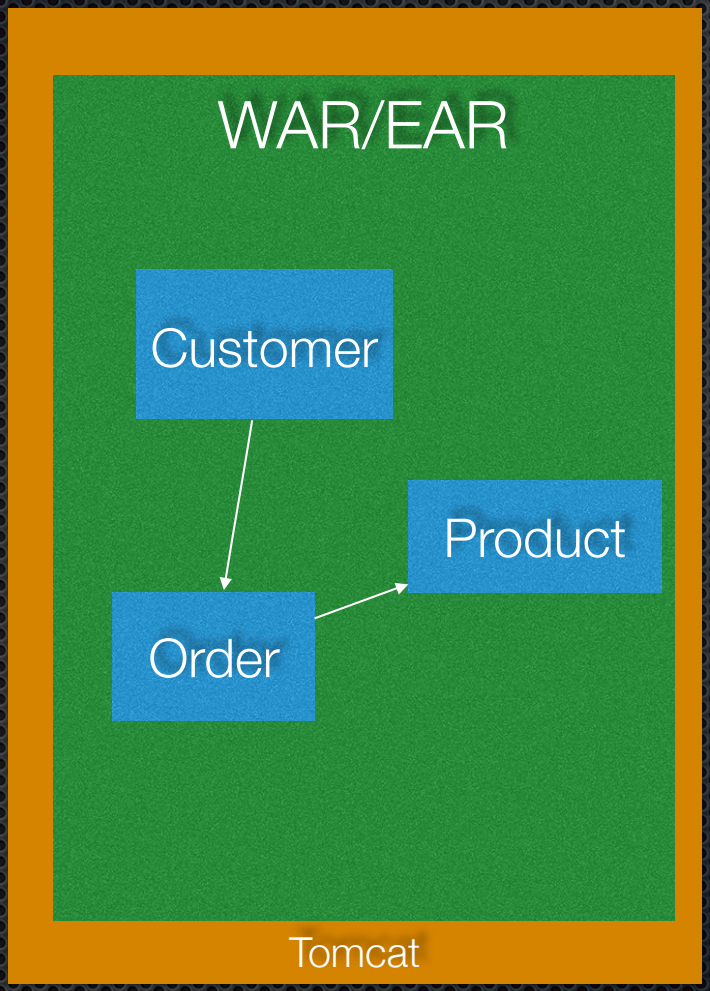
Modular domain model



Tightly coupled
ACID

Loosely coupled aggregates
Eventually consistent

MonolithicFirst approach



Not entirely free though -
Event Sourcing premium

But no Big Ball of Mud to untangle

Microservices deployment

Much higher - microservices premium

Summary

- Event sourcing solves key data consistency issues with:
  - Microservices
  - Partitioned SQL/NoSQL databases
- Apply strategic DDD to identify microservices
- Apply tactical DDD to design individual services
- Use CQRS to implement materialized views for queries

@crichardson chris@chrisrichardson.net

http://plainoldobjects.com http://microservices.io