How I Learned to Stop Worrying and Love Raw Events

Event Sourcing & CQRS with FastAPI and Celery

PyCon Athens 2025

Who Am I?

- **Staff Engineer** with 10+ years in Python
- Studied **Physics** → **Computational Physics** → **Software Engineering**
- **Passionate about building systems** with quality

My journey: From "Events are too complex!" to "Events are the solution to complexity!"

What We'll Discuss

Core Principles

- **Event Sourcing**: Store every change as an immutable event
- **CQRS**: Separate read and write concerns

Python Ecosystem Examples

- **FastAPI**: API surface for commands and queries
- **Celery**: Async event processing
- **Pydantic**: Data validation and modeling

The Aftermath

- **Real-world patterns** and gotchas
- **Performance considerations**
- **Debugging and testing** in an immutable world

The Nightmare: "Who Deleted My User?"

A real debugging story:

```python
def delete_user(user_id: int):
    db.delete_user(user_id)
```

The problem:

Monday 3:47 PM: "Sarah's account is missing!"
Tuesday 9:15 AM: "When was it deleted? Who did it? Why?"

What we can't answer:

- ❌ **When** was the user deleted?
- ❌ **Who** deleted the user?
- ❌ **Why** was it deleted?

The system has no memory of what happened

Enter Event Sourcing: The System That Remembers

We store every change as an immutable event:

```
UserDeleted(
    event_id=uuid4(),
    aggregate_id="user_123",
    version=5,
    timestamp=datetime.now(),
    event_type="USER_DELETED",
    data={ "deleted_by": "admin_456", "reason": "Account closure request" }
)
```

Now we can answer everything:

- ✅ **When**: March 15, 3:47 PM
- ✅ **Who**: Admin ID 456
- ✅ **Why**: Account closure request

Every action becomes a permanent record

Core Concepts: Events

Immutable Facts

Events are immutable facts that represent state changes in the system.

Example:

User Created Event - John Doe, john@example.com, March 15

Key characteristics:

- **Immutable**: Once created, events never change
- **Facts**: They represent what actually happened
- **Complete**: Each event contains all necessary data
- **Versioned**: Events have sequence numbers for ordering

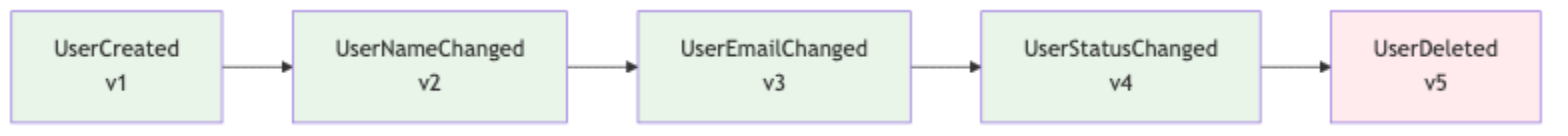
Key principle: **Events are immutable facts** - they never change

Core Concepts: Event Streams

Ordered Sequences

Event streams are ordered sequences of events for a specific aggregate.

Example:



Key characteristics:

- **Ordered**: Events have strict chronological ordering
- **Complete**: Contains the full history of an aggregate
- **Replayable**: Can rebuild any point in time
- **Source of truth**: The definitive record of what happened

The stream is the source of truth - rebuild any point in time

Core Concepts: Commands

Intent to Change

Commands represent the intent to change the system state.

Example:

"Create a new user account"

Key characteristics:

- **Intent**: They express what we want to happen
- **Validation**: Can be validated before execution
- **Idempotent**: Safe to retry if needed
- **Entry point**: The starting point for all changes

Commands are the entry point - they represent what we want to do

Core Concepts: Queries

Intent to Read (CQRS Separation)

Queries represent the intent to read data from the system.

Example:

"Show me user John Doe's profile"

Key characteristics:

- **Read-only**: They never change system state
- **Optimized**: Designed for specific read patterns
- **Separate models**: Different from command models (CQRS)
- **Fast**: Optimized for quick data retrieval

Queries are separate from commands - different models for different purposes

Core Concepts: Aggregates

Domain Logic

Aggregates contain domain logic and apply business rules to create events.

Example:

- User email must be unique
- Cannot delete already deleted user

Key characteristics:

- **Business rules**: Enforce domain-specific validation
- **State management**: Maintain current state from events
- **Event creation**: Generate new events based on commands
- **Consistency**: Ensure business invariants are maintained

Aggregates apply business logic and create events

Core Concepts: Event Store

Source of Truth

Event Store is the append-only storage for all events in the system.

Example:

User John Doe's Event Stream

- **Event 1**: User Created (March 15, 2:30 PM)
- **Event 2**: Email Changed (March 16, 10:15 AM)

Key characteristics:

- **Append-only**: Events are never modified or deleted
- **Immutable**: Once written, events are permanent
- **Stream management**: Organizes events by aggregate
- **Optimistic concurrency**: Prevents conflicting writes

Event Store is append-only - events never change or delete

Core Concepts: Projections

Building Read Models

Projections build optimized read models from events for fast querying.

Example:

- Event: User Created → Action: Create user record
- Event: Email Changed → Action: Update email field

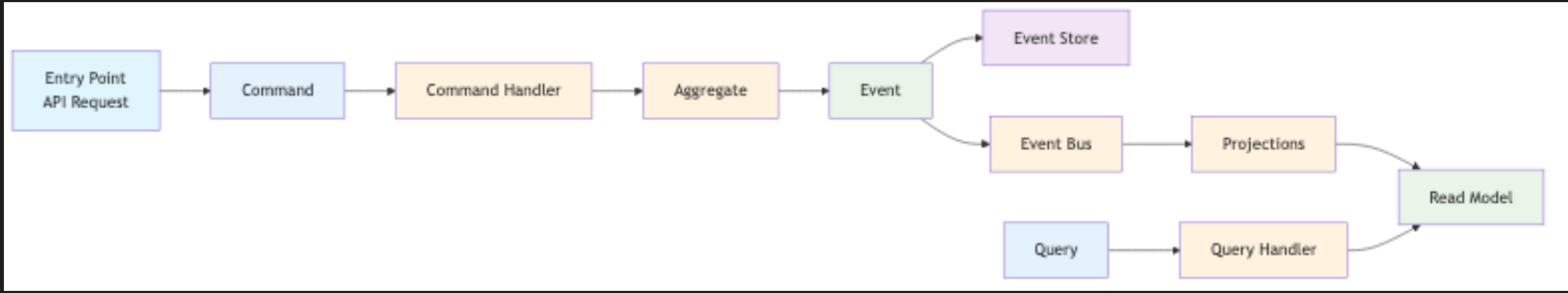
Key characteristics:

- **Event-driven**: Triggered by new events
- **Read-optimized**: Designed for specific query patterns
- **Denormalized**: Optimized for performance, not normalization
- **Eventually consistent**: Updated asynchronously

Projections transform events into optimized read models for fast querying

How Everything Works Together

The complete flow:



Each interaction follows this pattern - from command to projection

FastAPI: The Command Interface

Real implementation with Pydantic:

```python
@router.post("/users")
async def create_user(
    user_data: dict,
    handler: CreateUserCommandHandler = Depends(InfraFactory.create_user_command_handler)
):
    try:
        # Create command with validation
        command = CreateUserCommand(
            name=user_data["name"],
            email=user_data["email"]
        )

        # Process command
        await handler.handle(command)

        # Return immediately (event stored successfully)
        return {"user_id": command.user_id}
    except ValidationError as e:
        raise HTTPException(status_code=400, detail=str(e))
    except BusinessRuleViolation as e:
        raise HTTPException(status_code=409, detail=str(e))
```

Command Handlers: Business Logic

How we structure command processing:

```python
class CreateUserCommandHandler:
    async def handle(self, command: CreateUserCommand) -> None:
        # Retrieve all events for this aggregate
        events = await self.event_store.get_stream(command.user_id)

        # Create empty aggregate and replay events
        user = UserAggregate(command.user_id)
        for event in events:
            user.apply(event)

        # Call domain method and get new events
        new_events = user.create_user(command.name, command.email)

        # Persist and dispatch events using unit of work
        async with self.uow:
            await self.event_store.append_to_stream(command.user_id, new_events)
            await self.event_handler.dispatch(new_events)
```

Command Handler orchestrates: Event Store + Event Handler with Unit of Work

Event Handler: Celery Integration

How events are dispatched to Celery tasks:

```python
class CeleryEventHandler:
    def __init__(self):
        # Map event types to Celery tasks
        self.event_handlers = {
            "USER_CREATED": [
                "process_user_created_task",
                "send_welcome_email_task"
            ],
            # ... other event types
        }

    async def dispatch(self, events: List[Event]) -> None:
        for event in events:
            if event.event_type in self.event_handlers:
                for task_name in self.event_handlers[event.event_type]:
                    # All tasks receive the same event payload structure
                    celery_app.send_task(task_name, kwargs={"event": event.model_dump()})
```

Event Handler dispatches to message queues, Celery tasks handle messages and call projections

Celery Tasks: Event Processing

How Celery tasks process events and call projections:

```python
@app.task(name="process_user_created_task")
def process_user_created_task(event: Dict[str, Any]) -> None:
    # Convert async function to sync for Celery
    process_user_created_async_sync = async_to_sync(process_user_created_async)

    # Execute the async projection
    process_user_created_async_sync(event=event)

async def process_user_created_async(event: EventDTO) -> None:
    # Get projection and call it
    projection = UserProjection(read_model, event_publisher)
    await projection.handle_user_created(event)
```

Celery tasks are wrappers that call the appropriate projection handlers

Projections: Event-Driven Read Models

How projections build read models:

```python
class UserProjection:
    async def handle_user_created(self, event: Event) -> None:
        # Build read model from event
        user_data = {
            "aggregate_id": event.aggregate_id,
            "name": event.data.get("name"),
            "email": event.data.get("email"),
            "status": event.data.get("status"),
            "created_at": event.timestamp,
        }

        # Save to read model
        await self.read_model.save_user(user_data)
```

FastAPI: Query Interface

How we expose read models:

```python
@users_router.get("/{user_id}")
async def get_user(
    user_id: str,
    query_handler: GetUserQueryHandler = Depends(InfraFactory.create_get_user_query_handler)
) -> Dict[str, Any]:
    return {"user": (await query_handler.handle(GetUserQuery(user_id=user_id))).dict()}

@users_router.get("/{user_id}/history")
async def get_user_history(
    user_id: str,
    query_handler: GetUserHistoryQueryHandler = Depends(InfraFactory.create_get_user_history_query_handler)
):
    return {"events": [event.dict() for event in await query_handler.handle(GetUserHistoryQuery(user_id=user_id))]}
```

FastAPI queries expose read models with dependency injection

The Aftermath: Real-World Patterns & Gotchas

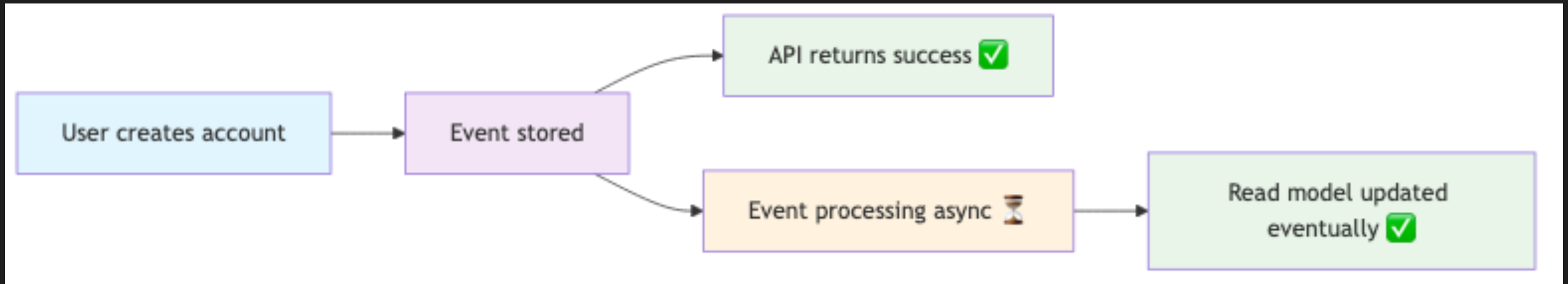
What happens when you actually build this?

- **Eventual consistency**: Why it's a feature, not a bug
- **Performance challenges**: When replaying becomes slow
- **Debugging superpowers**: What debugging looks like in an immutable world
- **The dark side**: When NOT to use event sourcing

Let's talk about the real challenges

Eventual Consistency: The Feature Nobody Talks About

The story: "Why isn't my data updated?"



The reality:

- **User sees success immediately** - great UX
- **Data appears in UI within seconds** - acceptable
- **Processing can retry on failure** - resilient

Eventual consistency is a feature, not a bug

When Event Sourcing Goes Wrong

The performance nightmare:

```python
# The problem: Replaying 10,000 events
def get_user_state(user_id: str):
    events = event_store.get_stream(user_id)  # 10,000 events!
    return replay_events(events)  # Takes 5 seconds 😱
```

The solution: Snapshots

```python
# The fix: Start from a snapshot
def get_user_state(user_id: str):
    snapshot = get_latest_snapshot(user_id)  # Current state
    recent_events = get_events_since_snapshot(user_id, snapshot.version)
    return replay_from_snapshot(snapshot, recent_events)  # 50ms ✅
```

Performance is a feature you have to design for

Retries: The Resilience Pattern

The story: "What happens when things fail?"

The challenge:

- **Network failures** - temporary connectivity issues
- **Database timeouts** - high load situations
- **Third-party service failures** - external dependencies
- **Processing errors** - bugs in projections

The solution: Retry with backoff

- **Immediate retry** - for transient failures
- **Exponential backoff** - for persistent issues
- **Dead letter queues** - for permanent failures
- **Circuit breakers** - to prevent cascade failures

Retries make your system resilient to real-world failures

The Dark Side: When NOT to Use Event Sourcing

Event sourcing is NOT for:

- **Simple CRUD applications** - overkill
- **Teams new to distributed systems** - steep learning curve
- **Systems with simple audit requirements** - traditional logging suffices
- **Performance-critical reads** - eventual consistency overhead

Event sourcing is for systems that need to explain themselves

Real-World Trade-offs

What you gain:

- ✅ **Complete audit trail** - every change recorded
- ✅ **Time travel** - see any point in history
- ✅ **Debugging superpowers** - trace every decision
- ✅ **Scalability** - separate read/write concerns

What you lose:

- ❌ **Simplicity** - more complex than CRUD
- ❌ **Immediate consistency** - eventual consistency
- ❌ **Storage overhead** - events take more space
- ❌ **Learning curve** - new patterns to master

Event sourcing is a trade-off, not a silver bullet

Key Takeaways

What we learned:

1. Event sourcing is about building systems that can explain themselves
2. Python + FastAPI + Celery are more than capable for serious architecture
3. Eventual consistency is a feature, not a bug
4. Performance requires design - snapshots, indexing, caching
5. Event sourcing is not for every system - know when to use it

The goal: Build systems that can explain themselves 6 months from now

Thank You!

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Questions? Let's discuss!