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

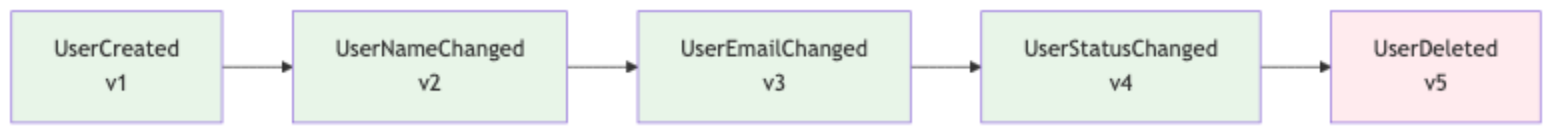
Key principle: Events are immutable facts - they never change

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

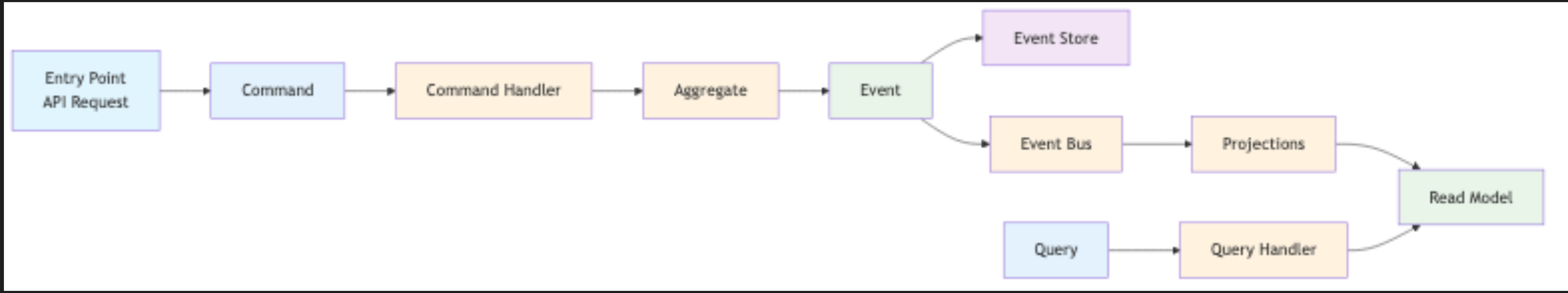
Key characteristics:

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

Projections handle business logic and update read models from events

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)
):
    # 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) or catch exceptions via middleware
    return {"user_id": command.user_id}
```

FastAPI commands accept requests and return immediately after event storage

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:

```
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)
```

Projections build optimized read models from events for fast querying

FastAPI: Query Interface

How we expose read models:

```
@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}/{timestamp}/")
async def get_user_at_timestamp(
    user_id: str,
    timestamp: datetime = Query(..., description="ISO 8601 format: YYYY-MM-DDTHH:MM:SSZ"),
    query_handler: GetUserAtTimestampQueryHandler = Depends(InfraFactory.create_get_user_at_timestamp_query_handler)
):
    return {"user": (await query_handler.handle(GetUserAtTimestampQuery(user_id=user_id, timestamp=timestamp))).dict()}
```

FastAPI queries expose read models with dependency injection

The Aftermath: Real-World Patterns & Gotchas

What happens when you actually build this?

- **Eventual consistency**: How to handle the delay between write and read
- **Error handling & retries**: Different strategies for commands vs projections
- **Performance with snapshots**: When replaying becomes slow
- **Debugging superpowers**: What debugging looks like in an immutable world

Let's talk about the real challenges

Eventual Consistency: The Real Challenge

The story: "Update user's first name"

```
# User updates first name
POST /users/123/ {"first_name": "John"}
# API returns success immediately
# But read model might not be updated yet
```

Two approaches to handle this:

1. Optimistic Updates (Naive)

- Frontend updates UI immediately
- Refresh might show old data
- Depends on read model update time

2. Outbox Pattern (Advanced)

- Store events in outbox table with job status
- Track processing status (pending, processing, completed, failed)
- Create views of unprocessed events

Performance with Snapshots

The performance challenge:

```python
async def handle(self, command: CreateUserCommand) -> None:
    events = await self.event_store.get_stream(command.user_id)  # 10,000 events!
    user = UserAggregate(command.user_id)
    for event in events:
        user.apply(event)  # Takes 5 seconds 😱
    # ... rest of command handler logic
```

The solution: Snapshots in Command Handler

```python
async def handle(self, command: CreateUserCommand) -> None:
    try:
        snapshot = await self.snapshot_store.get_latest_snapshot(command.user_id)
        recent_events = await self.event_store.get_events_since_snapshot(command.user_id, snapshot.version)
        # Rebuild aggregate from snapshot
        user = UserAggregate.from_snapshot(snapshot)
        for event in recent_events:
            user.apply(event)
    except SnapshotNotFound:
        # Fallback to previous code
```


Snapshots require aggregate changes - rebuild state efficiently

Error Handling & Retries: Two Different Worlds

Commands (Synchronous) - API Failures:

```python
# Unit of Work ensures atomicity
async with self.uow:
    await self.event_store.append_to_stream(user_id, new_events)
    await self.event_handler.dispatch(new_events)
# Either succeeds or fails - API gets 500
```

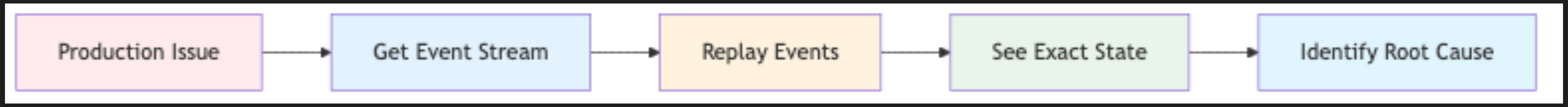
Projections (Asynchronous) - Celery Retries:

```python
# Celery handles retries with late acknowledgment
@app.task(bind=True, max_retries=3)
def process_user_created_task(self, event: Dict[str, Any]) -> None:
    try:
        # Process event
        projection.handle_user_created(event)
    except Exception as exc:
        # Celery retries automatically
        raise self.retry(countdown=60, exc=exc)

# Idempotence is critical - same message can arrive multiple times
```

Debugging Superpowers: The Immutable World

The story: "Something broke at 3:47 PM"




```python
# Traditional debugging: "I don't know what happened"
def debug_issue():
    # Check logs... maybe?
    # Check database... current state only
    # Ask users... unreliable
    pass

# Event sourcing debugging: "I can see exactly what happened"
def debug_issue(user_id: str, timestamp: datetime):
    events = event_store.get_events(user_id, around=timestamp)

    print(f"User {user_id} at {timestamp}:")
    for event in events:
        print(f"  {event.timestamp}: {event.type} - {event.data}")

    # Replay to see exact state
    state = replay_events(events)
    print(f"State: {state}")
```

Real-World Trade-offs & Key Takeaways

When NOT to use Event Sourcing:

- **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

What you gain vs what you lose:

✅ Gain	❌ Lose
Complete audit trail	Simplicity
Time travel capabilities	Immediate consistency
Debugging superpowers	Storage overhead
Scalability	Learning curve

Key Takeaways:

Thank You!

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Questions? Let's discuss!