AquaLang: A Streaming Dataflow Programming Language

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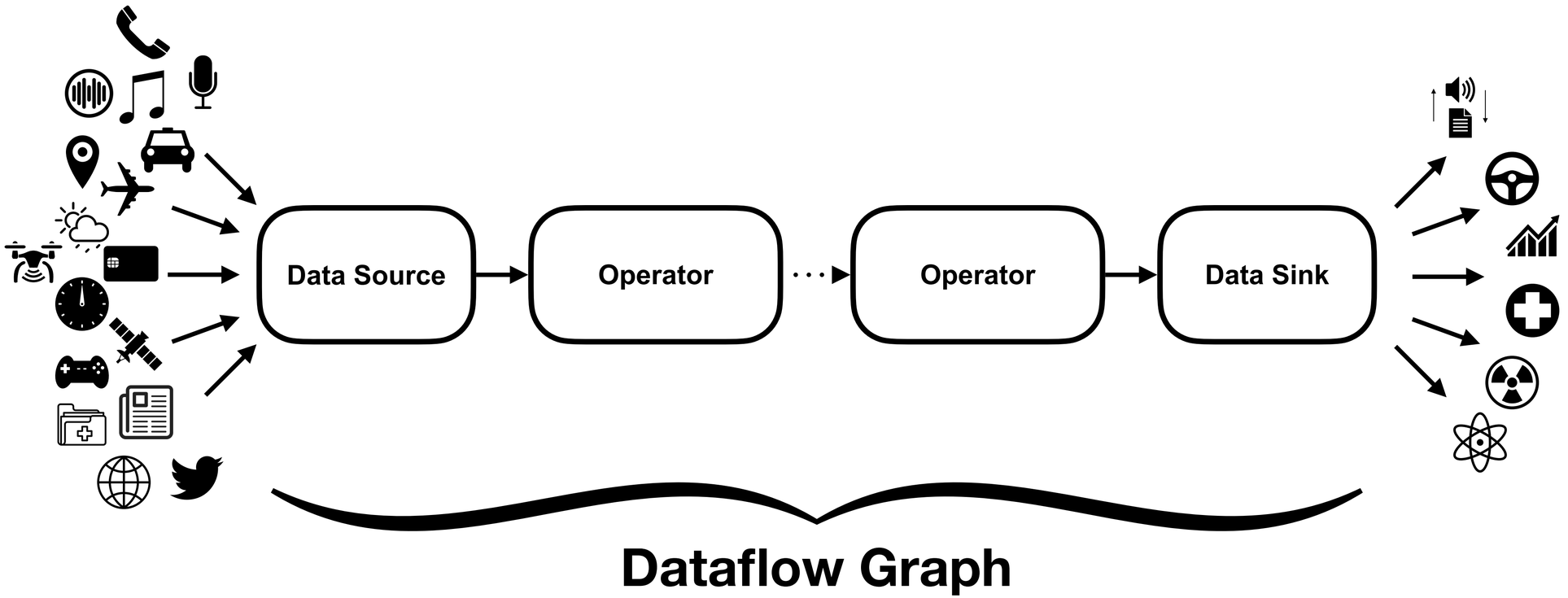
What is Dataflow Programming?



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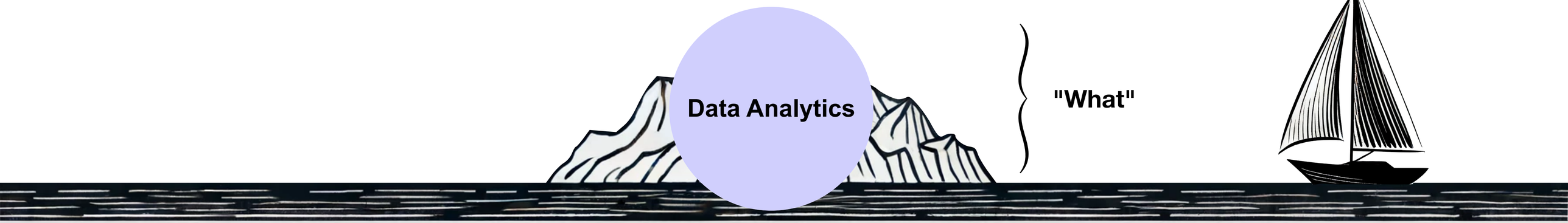

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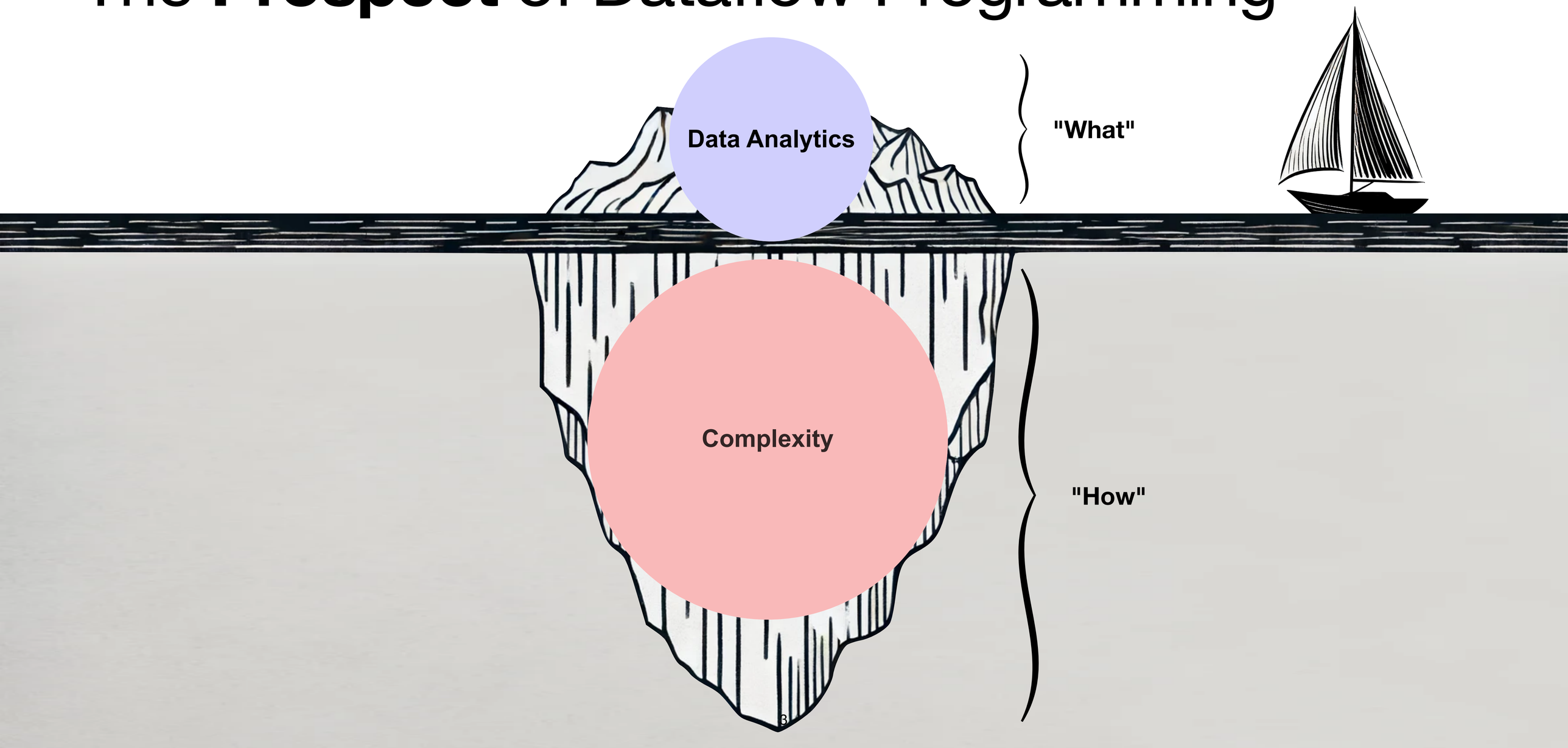

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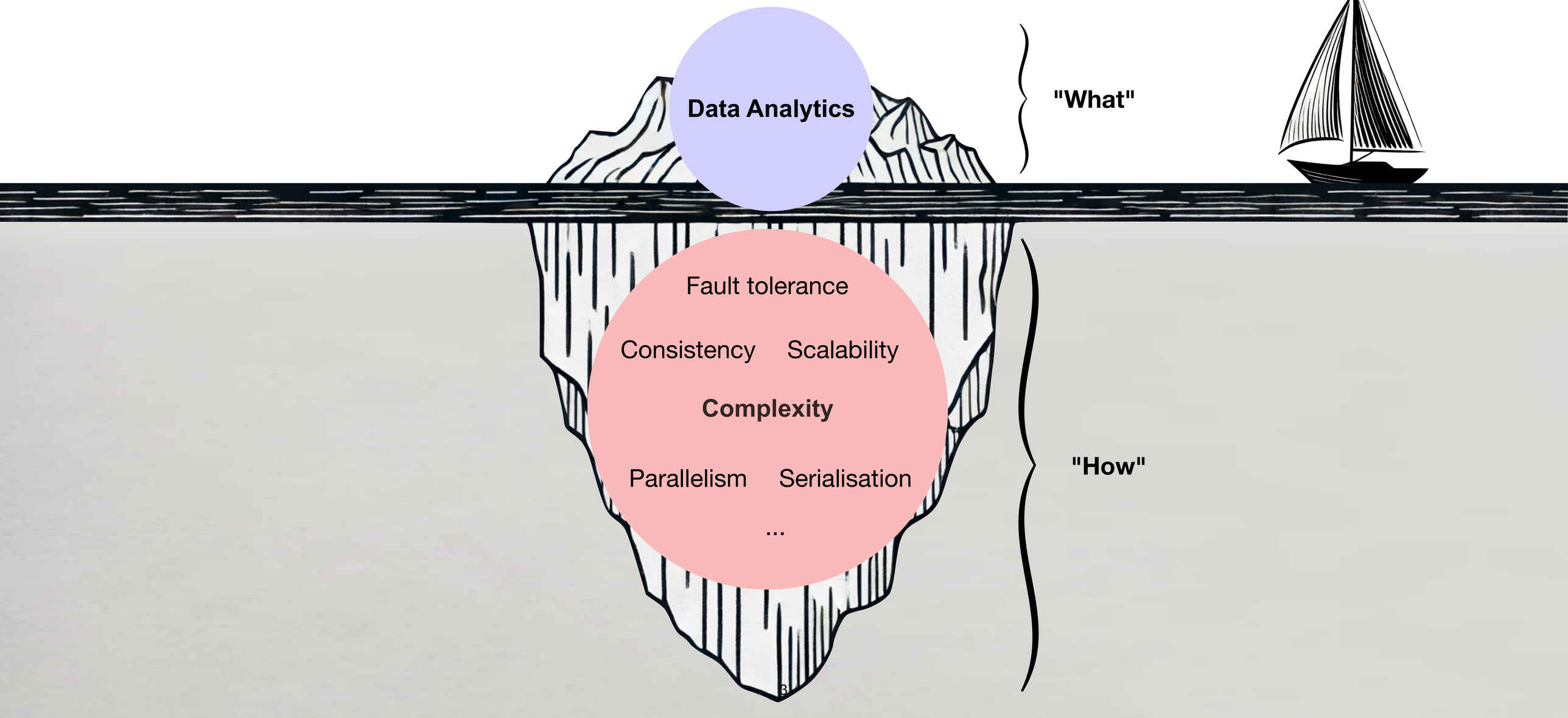
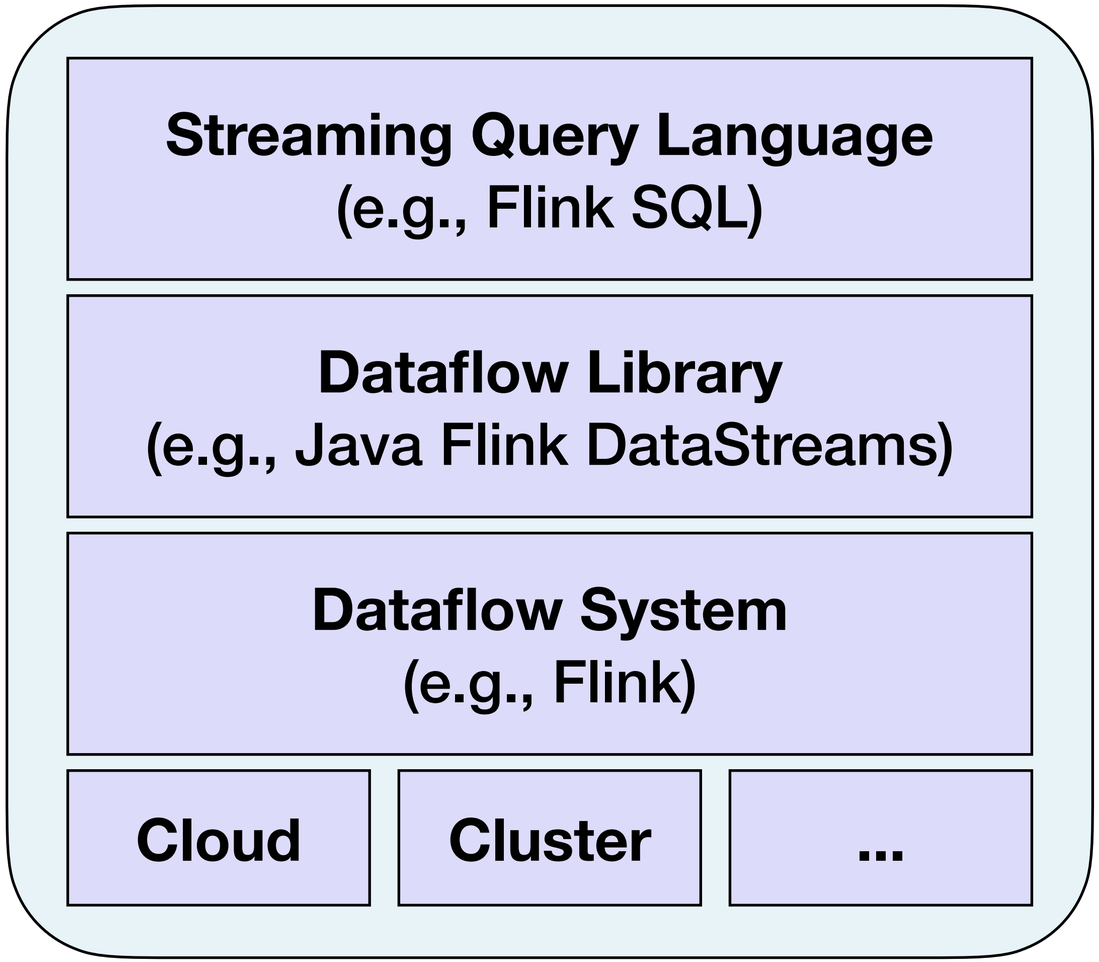


What exists today



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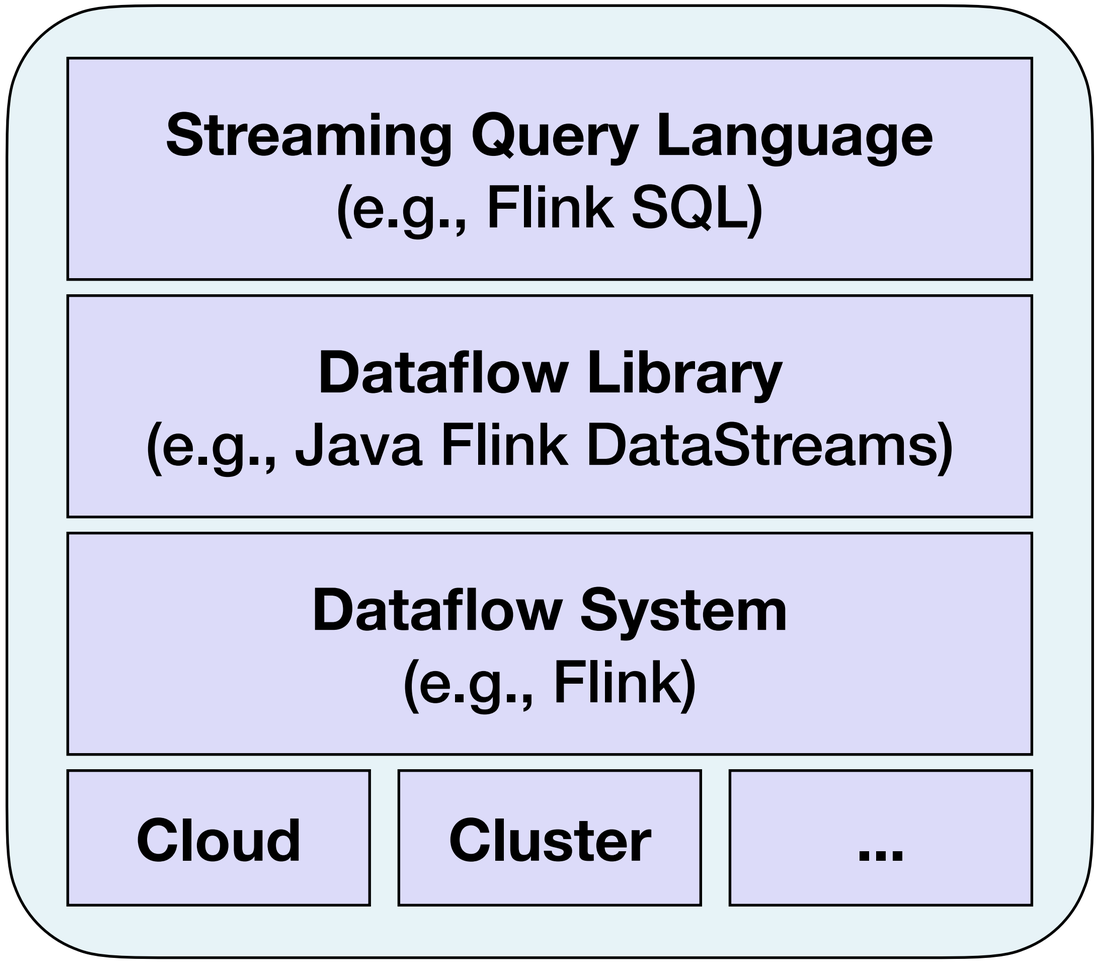

Why AquaLang?

Example Application

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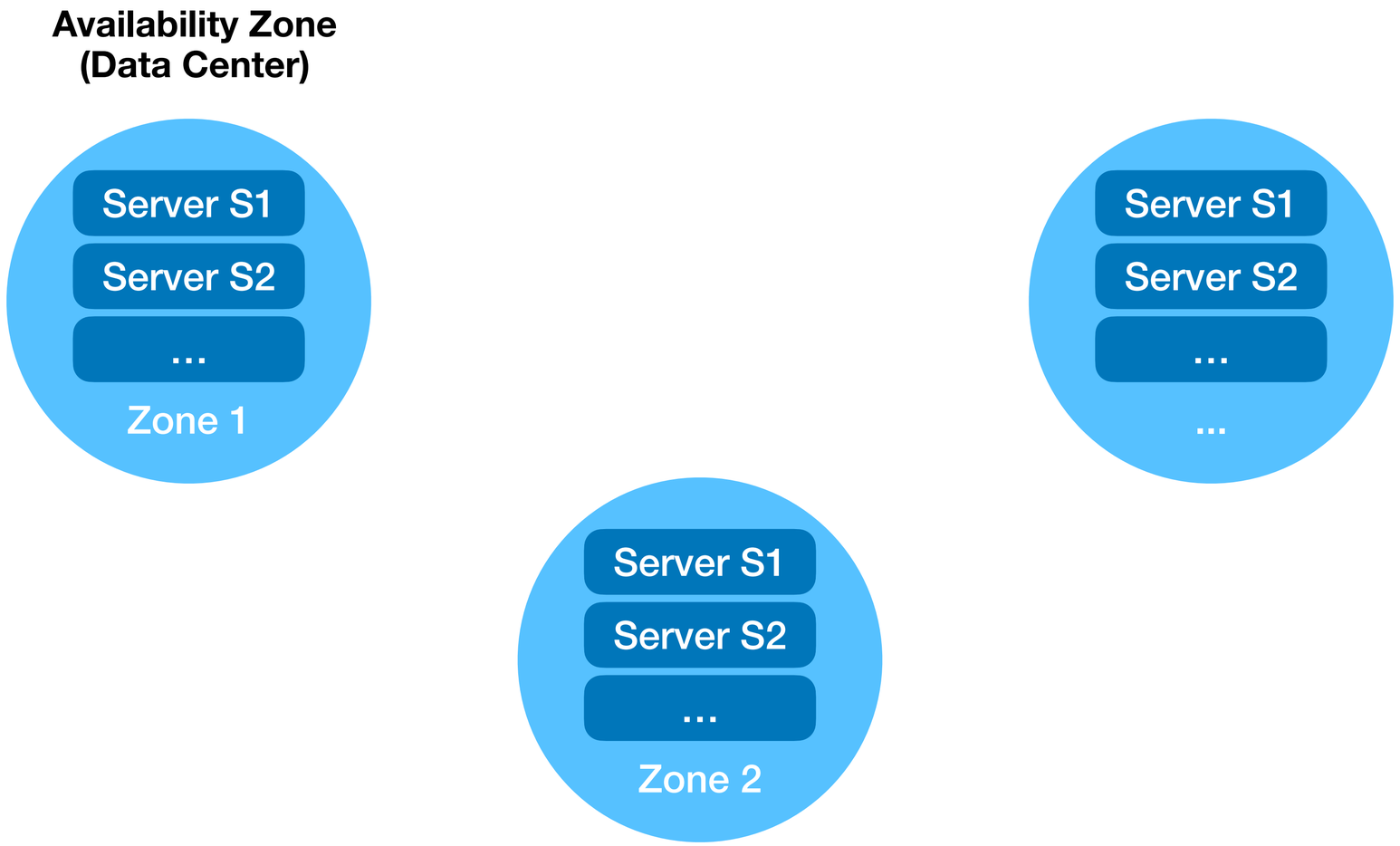

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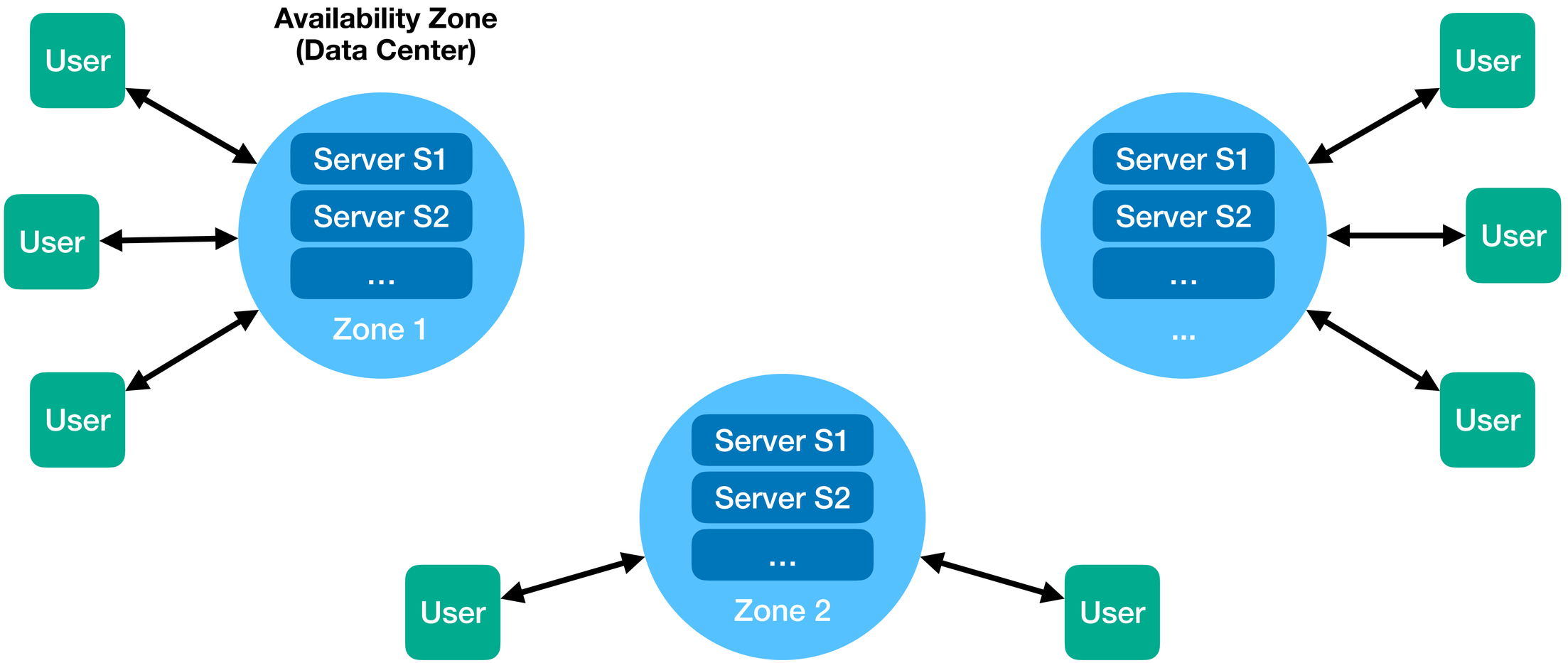

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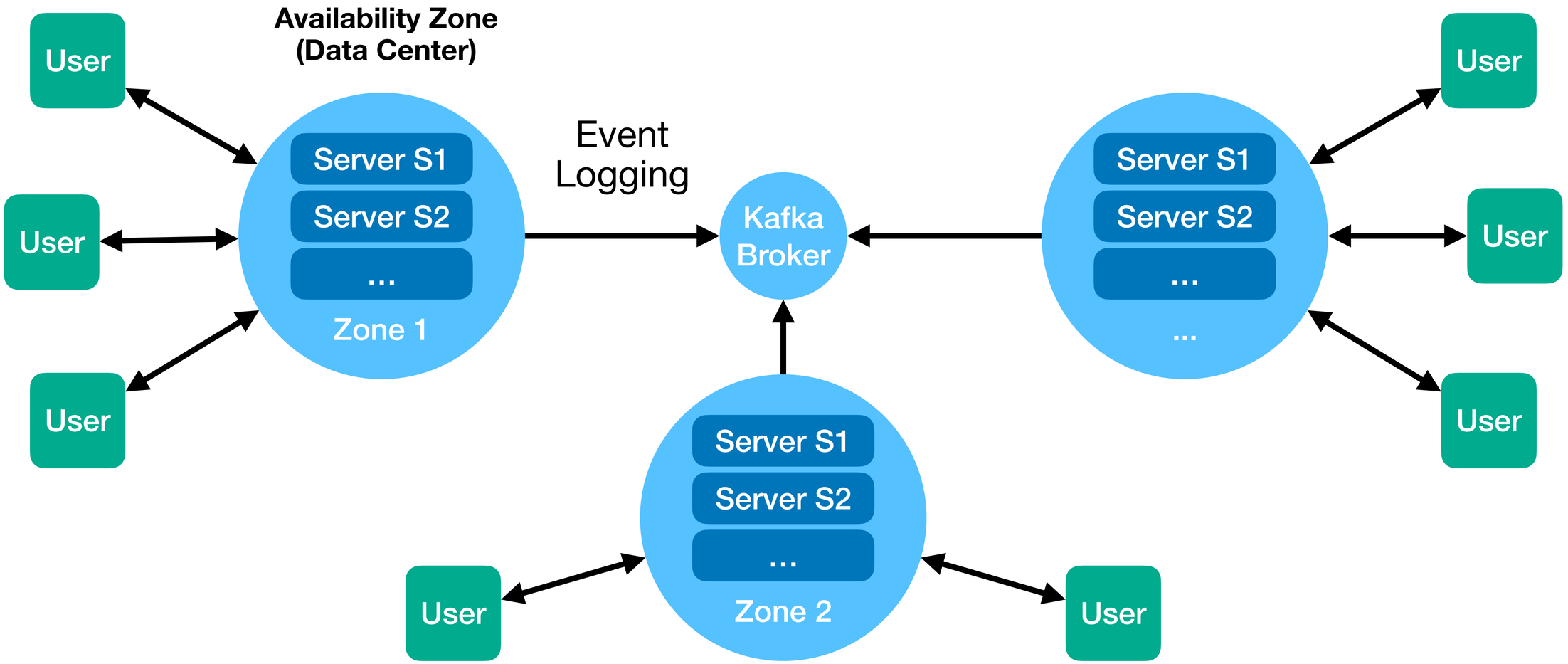

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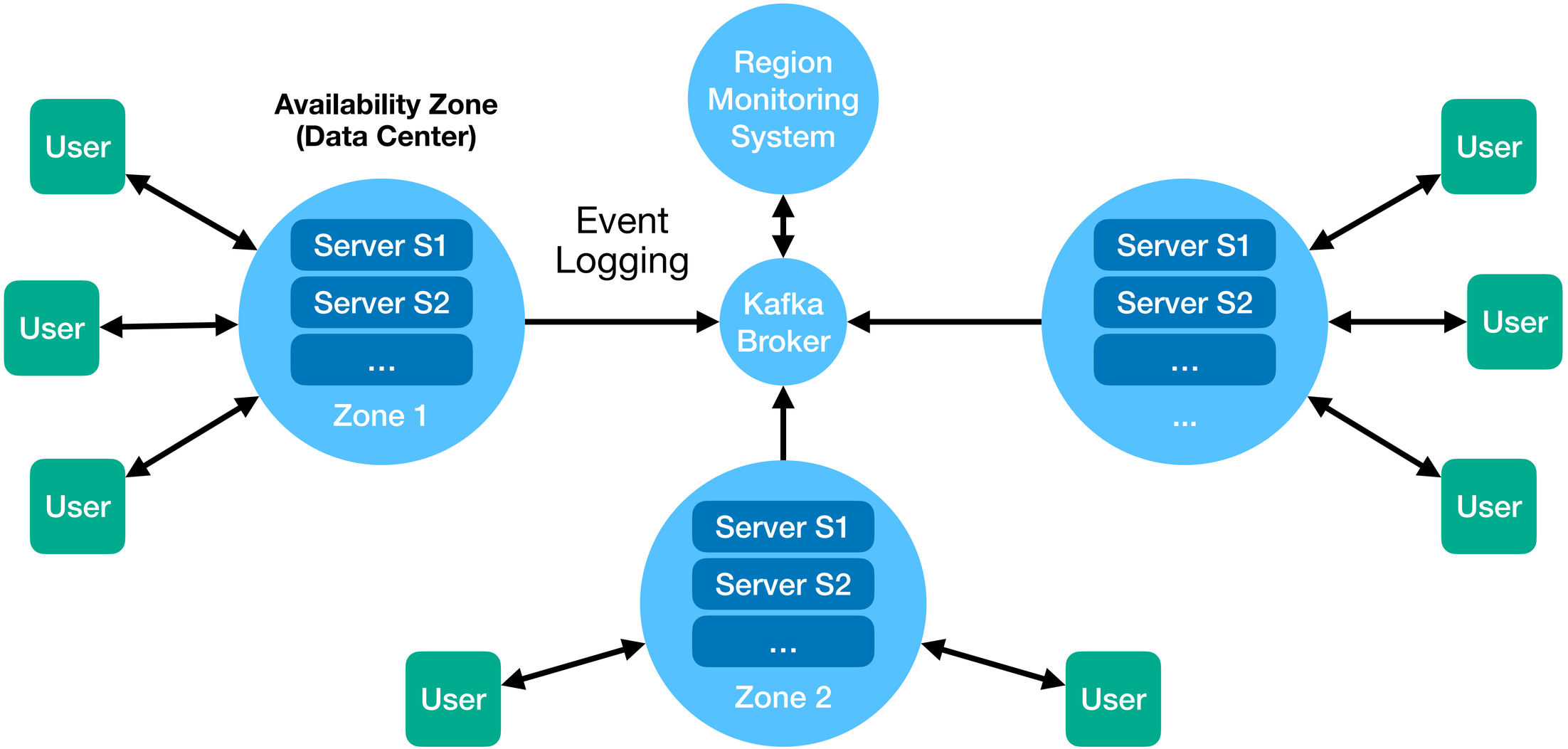

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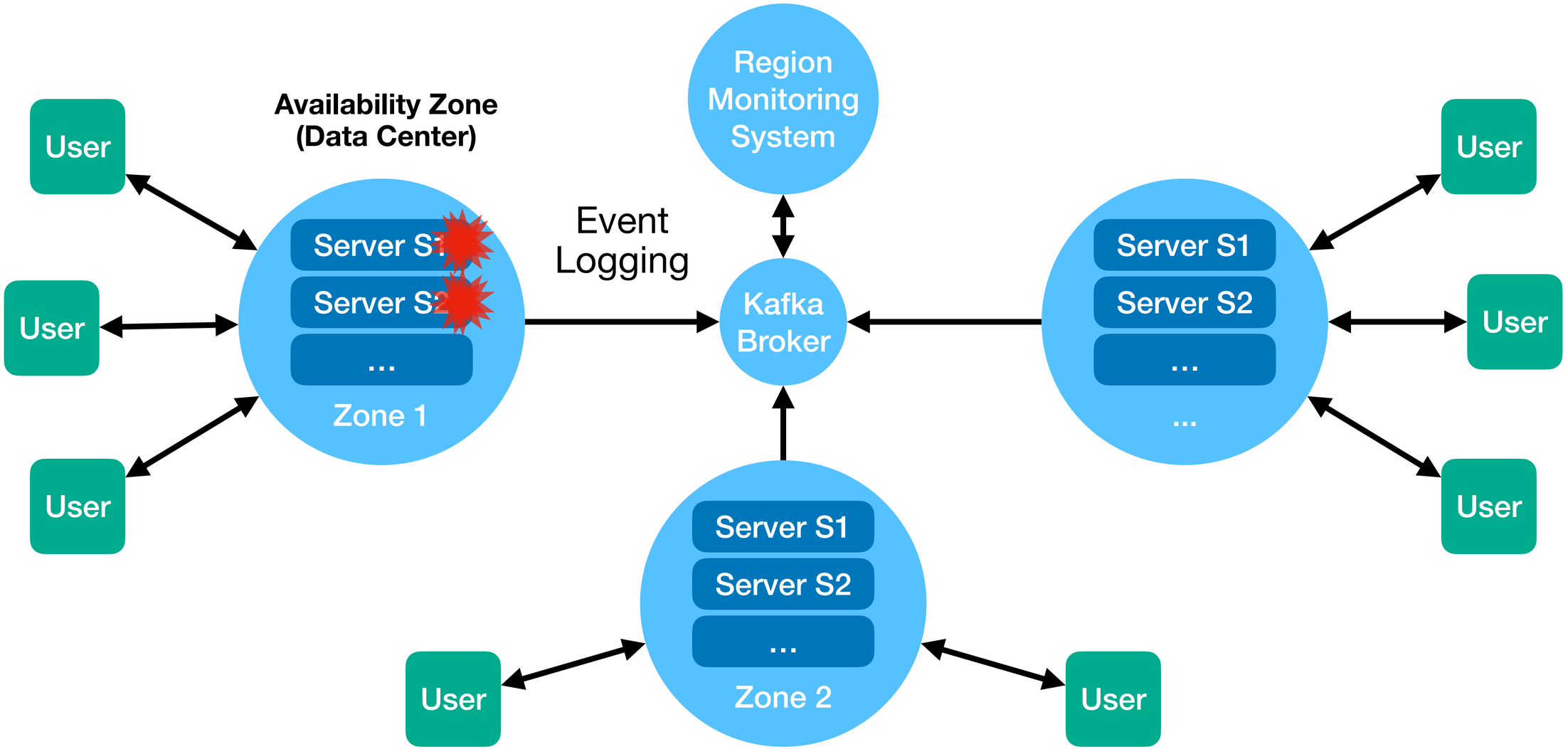

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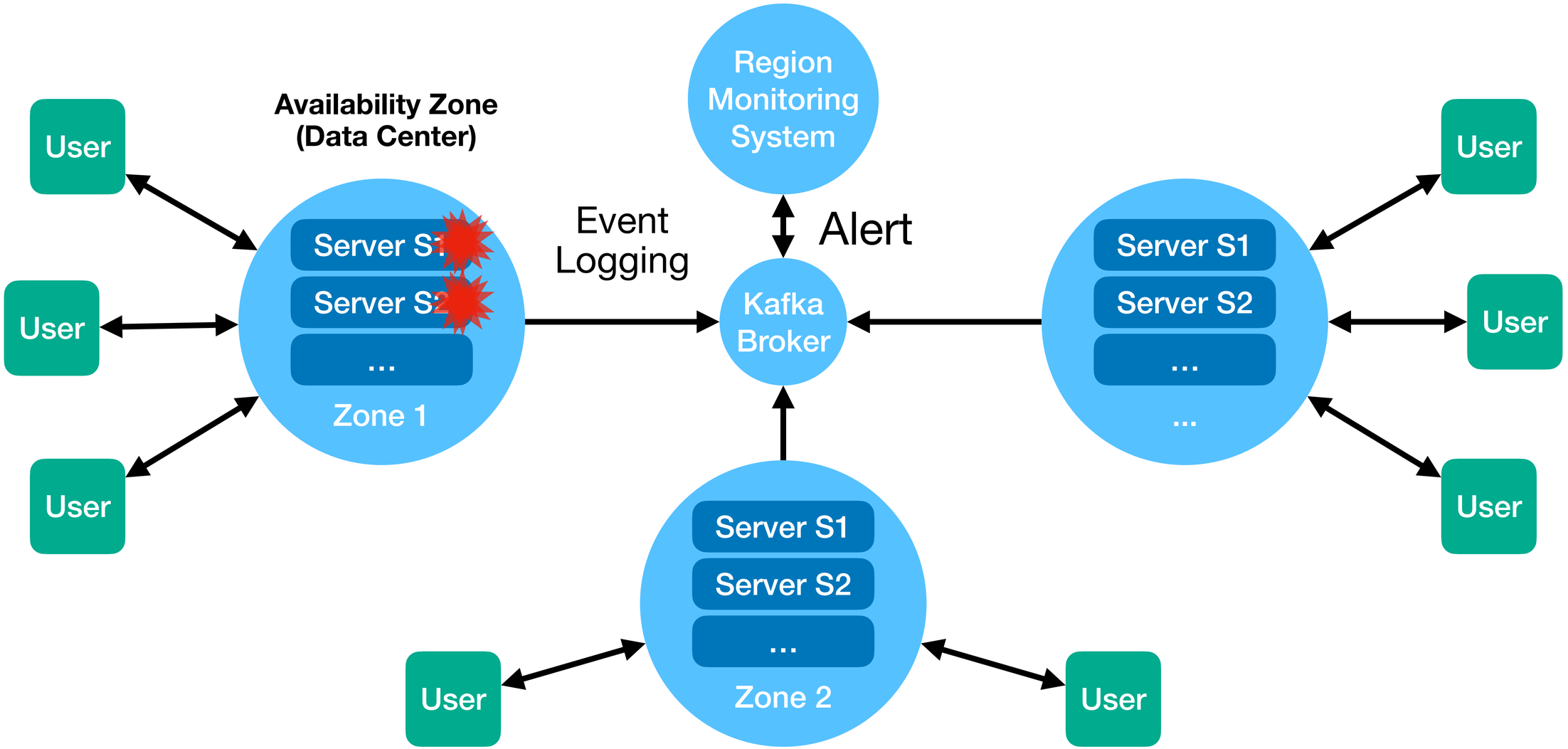

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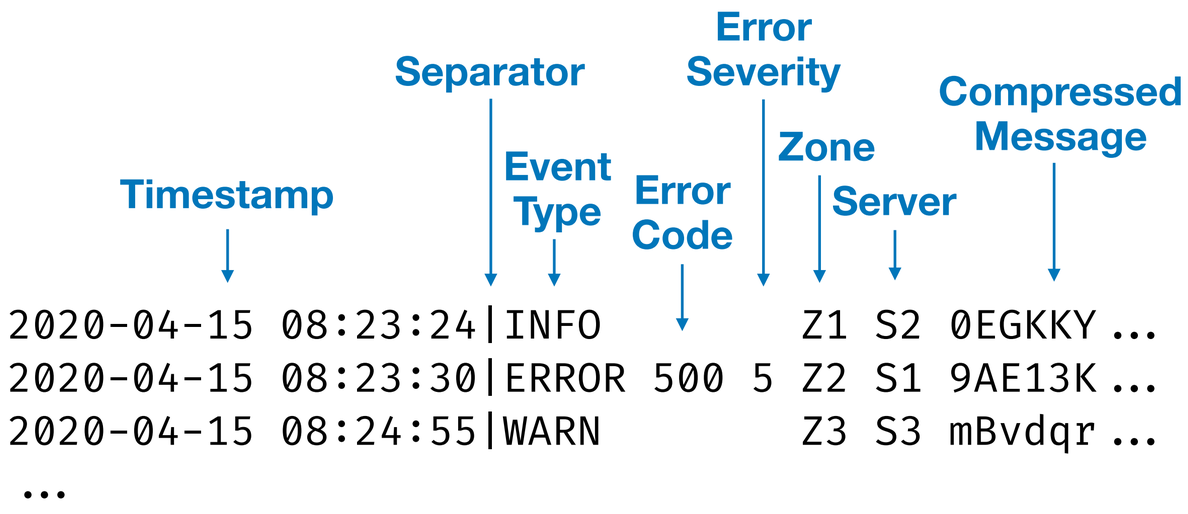

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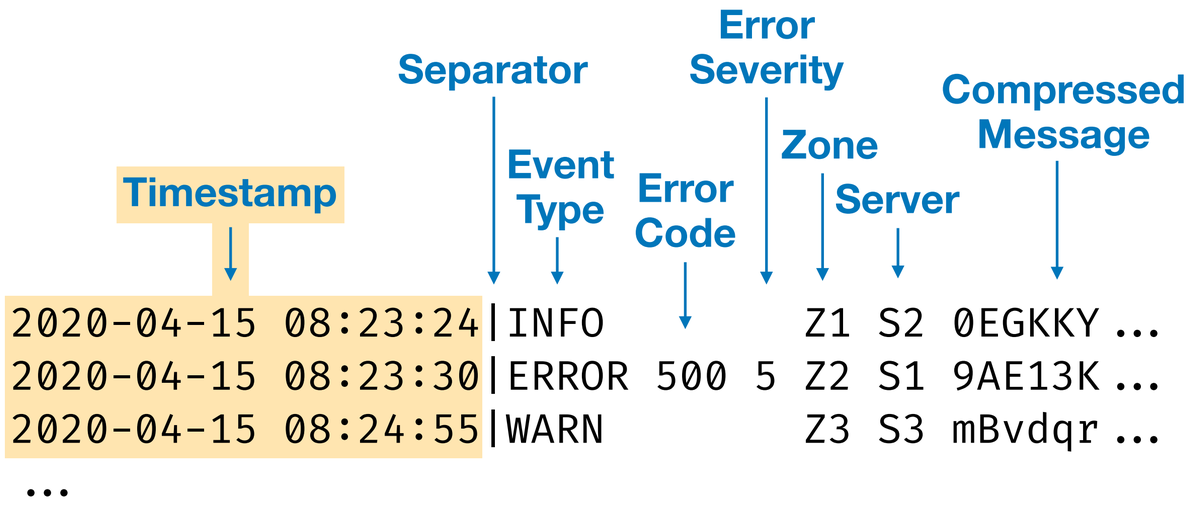

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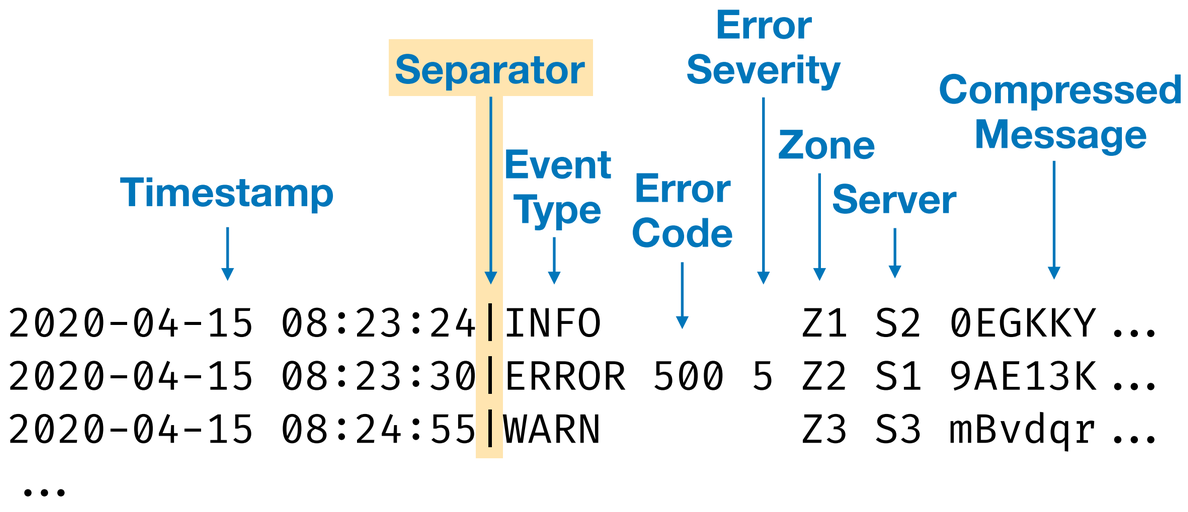

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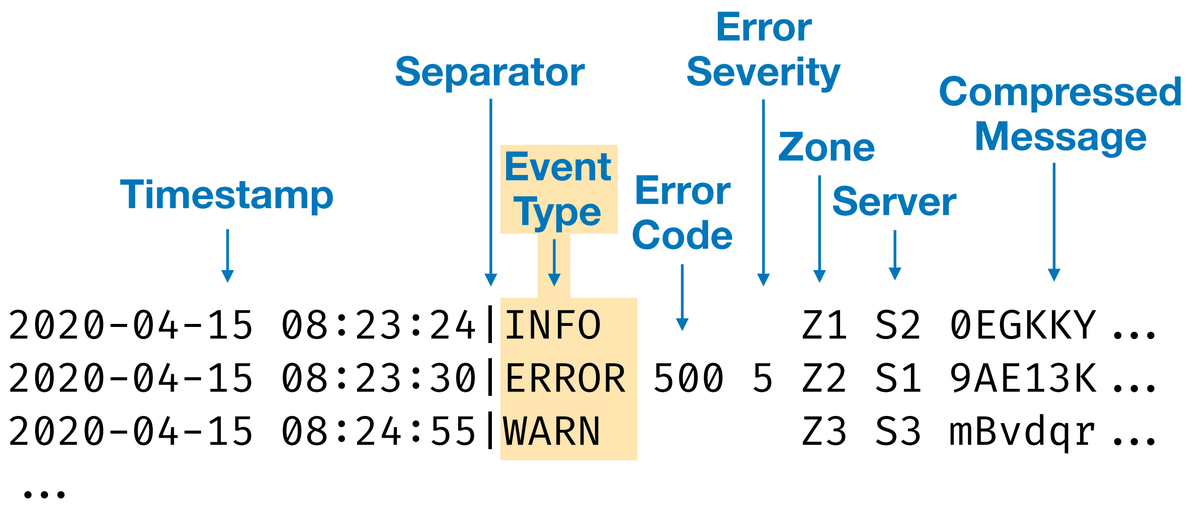

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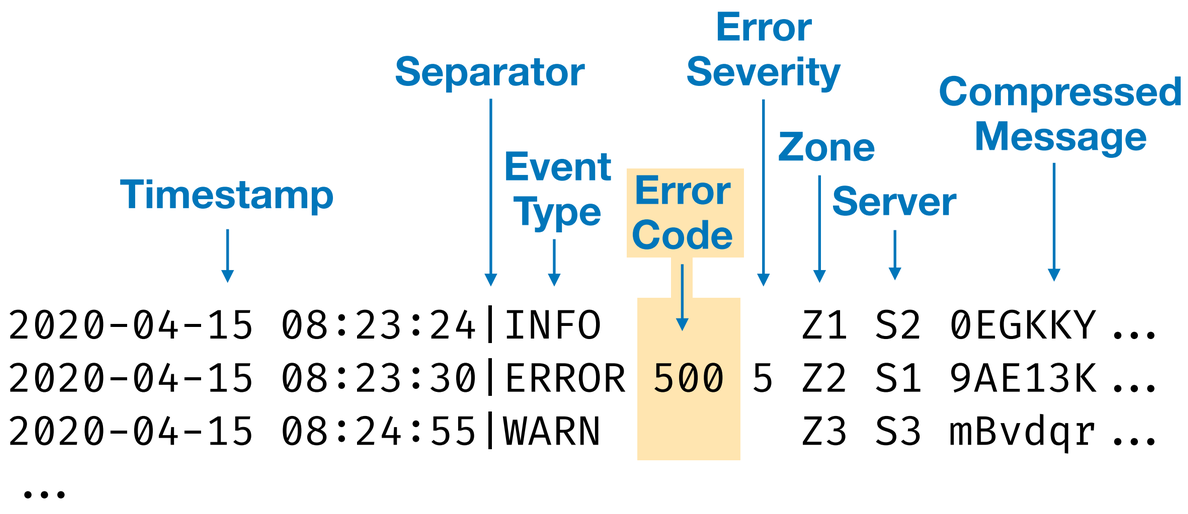

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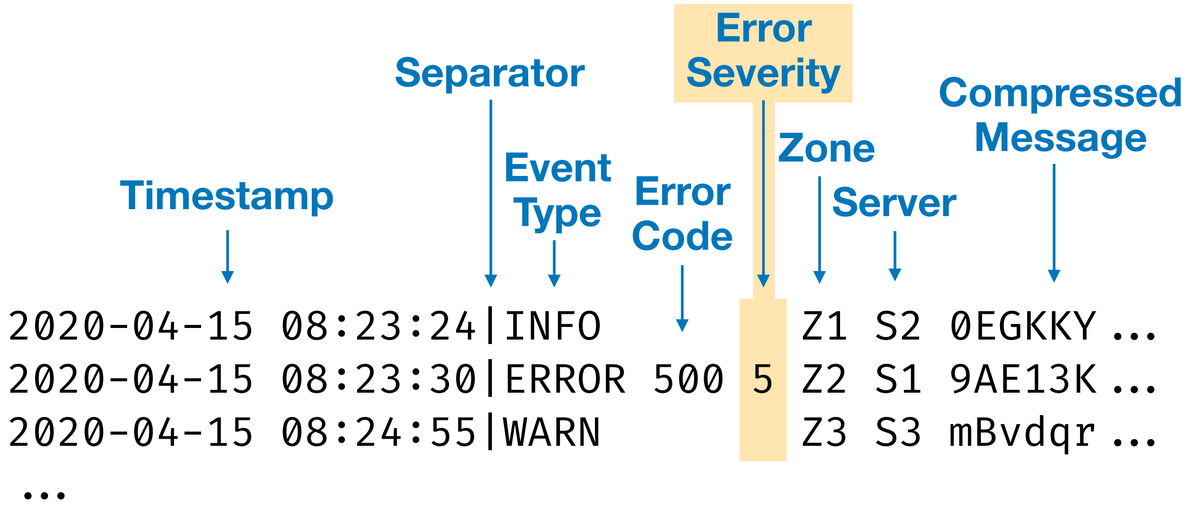

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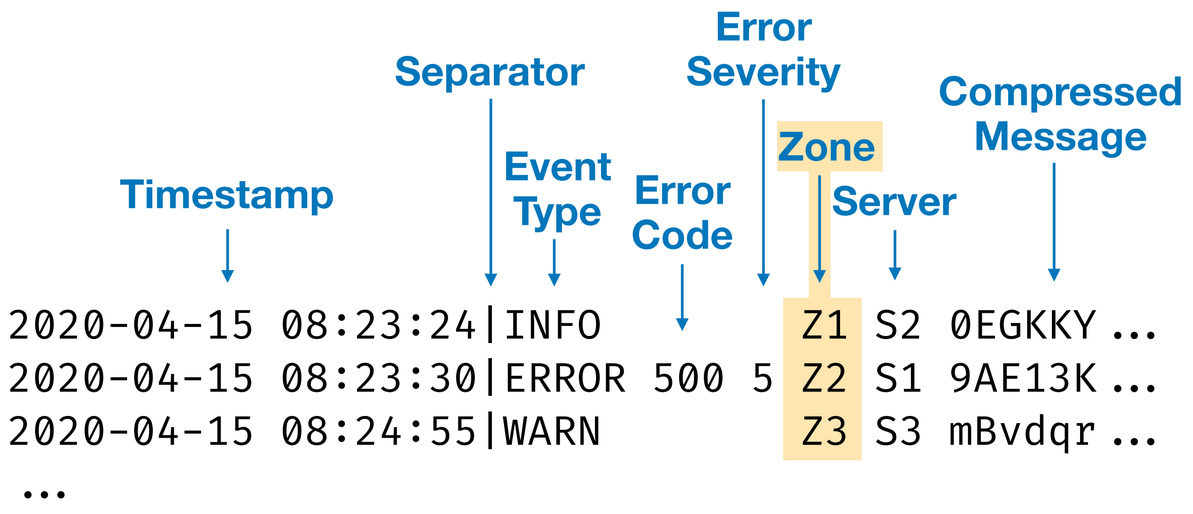

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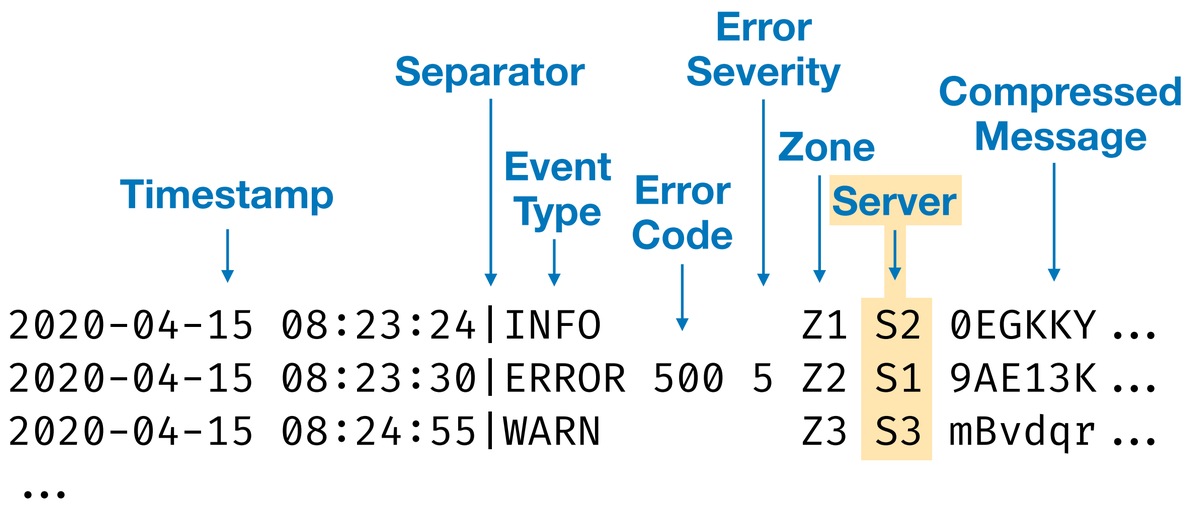

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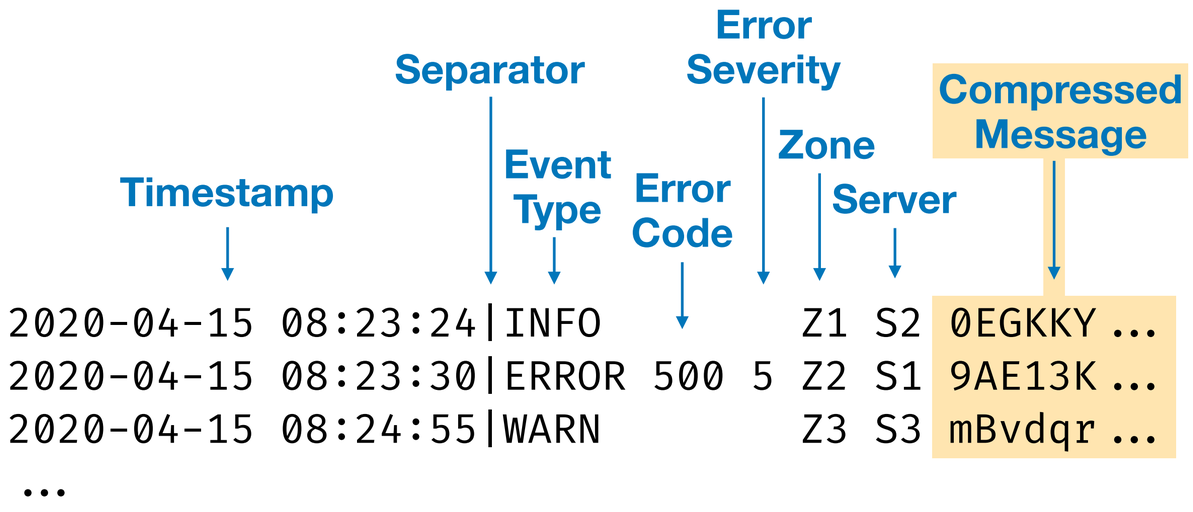

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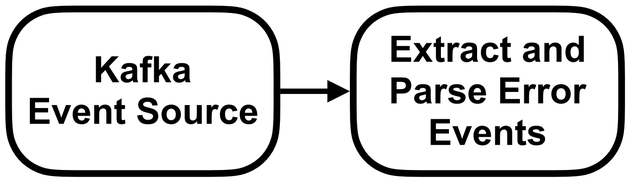

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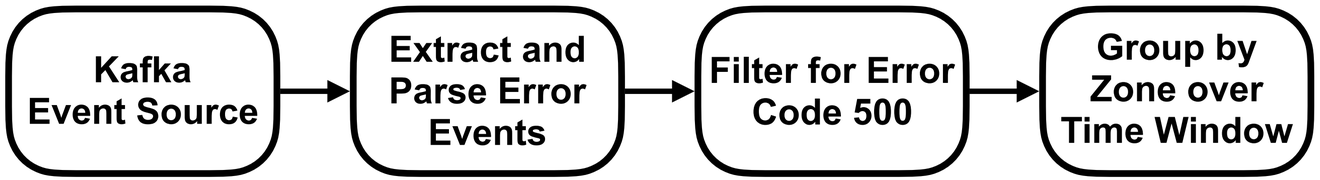

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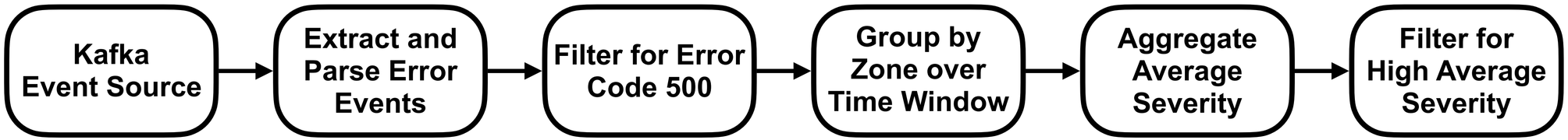

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How to isolate the parsing code for reuse and testing?

Example Application - UDFs

Flink SQL

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  WITH ( ... );

> CREATE TABLE Alerts(zone STRING, avg_severity INT, ... )
  WITH ( ... );

```

Flink Java API (Maven project)

```java
package com.example;
import org.apache.flink.*;

@FunctionHint(
    input = @DataTypeHint("STRING"),
    output = @DataTypeHint("ROW<code INT, severity INT,
                                zone STRING, server STRING,
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public class Parse extends TableFunction<Row> {
    public void eval(String line) {
        String[] parts = line.split(" ");
        String eventType = parts[0];
        if (eventType.equals("ERROR")) {
            int code = Integer.parseInt(parts[1]);
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            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            collect(Row.of(code,severity,zone,server,message));
        }
    }
}
```

Example Application - UDFs

Flink SQL

```
> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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Example Application - UDFs

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> INSERT INTO Alerts
SELECT zone, AVG(severity) AS avg_severity,
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FROM TABLE(HOP(TABLE ErrorEvents, DESCRIPTOR(ts),
               INTERVAL '2' MINUTES, INTERVAL '10' MINUTES))
WHERE code = 500
GROUP BY window_start, window_end, zone
HAVING AVG(severity) > 2;
```

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            collect(Row.of(code,severity,zone,server,message));
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```

Example Application - Problems?

Flink SQL

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> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            collect(Row.of(code,severity,zone,server,message));
        }
    }
}
```

Example Application - Problems?

Flink SQL

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> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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SELECT ts, parsed.*
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               INTERVAL '2' MINUTES, INTERVAL '10' MINUTES))
WHERE code = 500
GROUP BY window_start, window_end, zone
HAVING AVG(severity) > 2;
```

Problem:
Separate compilation

Flink Java API (Maven project)

```
package com.example;
import org.apache.flink.*;

@FunctionHint(
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    output = @DataTypeHint("ROW<code INT, severity INT,
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public class Parse extends TableFunction<Row> {
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            int severity = Integer.parseInt(parts[2]);
            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            collect(Row.of(code,severity,zone,server,message));
        }
    }
}
```

Example Application - Problems?

Flink SQL

```
> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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> ADD JAR 'file:///UDFs/target/UDFs-1.0.jar';
> CREATE FUNCTION Parse AS 'com.example.Parse' LANGUAGE JAVA;

> CREATE VIEW ErrorEvents AS
SELECT ts, parsed.*
FROM RawEvents, LATERAL TABLE(Parse(line)) AS parsed;

> I
SEL                                S avg_severity,
                                   end
FROM TABLE(HOP(TABLE ErrorEvents, DESCRIPTOR(ts),
               INTERVAL '2' MINUTES, INTERVAL '10' MINUTES))
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GROUP BY window_start, window_end, zone
HAVING AVG(severity) > 2;
```

Problem:
Cannot pushdown predicate into UDF

Flink Java API (Maven project)

```
package com.example;
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@FunctionHint(
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            int severity = Integer.parseInt(parts[2]);
            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            collect(Row.of(code,severity,zone,server,message));
        }
    }
}
```

Example Application - Problems?

Flink SQL

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> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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  WITH ( ... );

> ADD JAR 'file:///UDFs/target/UDFs-1.0.jar';
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SELECT ts, parsed.*
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SELECT zone, AVG(severity) AS avg_severity,
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```

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public class Parse extends TableFunction<Row> {
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        String[] parts = line.split(" ");
        String eventType = parts[0];
        if (eventType.equals("ERROR")) {
            int code = Integer.parseInt(parts[1]);
            int severity = Integer.parseInt(parts[2]);
            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            collect(Row.of(code,severity,zone,server,message));
        }
    }
}
```

Problem:
Cannot pushdown projection into UDF

Example Application - Problems?

Flink SQL

```
> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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            collect(Row.of(code,severity,zone,server,message));
        }
    }
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```

Problem:
Impedance mismatch

Example Application - Problems?

Flink SQL

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Problem:
Undefined behaviour

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        String[] parts = line.split(" ");
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            int code = Integer.parseInt(parts[1]);
            int severity = Integer.parseInt(parts[2]);
            String zone = parts[3];
            String server = parts[4];
            String message = parts[5];
            System.out.println("Parsed line: " + line);
            collect(Row.of(code,severity,zone,server,message));
        }
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```

Example Application - Problems?

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> CREATE TABLE RawEvents(ts TIMESTAMP(3), line STRING, ... )
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        }
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```

Problem:
Close coupling

Other options?

Other options?

Flink DataStream API

```
1  StreamExecutionEnvironment env = StreamExecutionEnvironment.getExecutionEnvironment();
2
3  env.addSource(new FlinkKafkaConsumer<>("eventlog", ...))
4    .assignTimestampAndWatermarks( ... )
5    .flatMap(new Parse())
6    .filter(event -> event.getCode() == 500)
7    .map(event -> Tuple2.of(event.getZone(), event.getSeverity()))
8    .keyBy(tuple -> tuple.f0)
9    .window(SlidingEventTimeWindows.of(Time.minutes(10), Time.minutes(1)))
10   .apply((zone, window, errors, out) -> {
11       double avgSeverity = errors.map(error -> error.severity).average();
12       out.collect(Tuple4.of(window.getStart(), window.getEnd(), zone, avgSeverity));
13   })
14   .map(tuple -> tuple.f0 + "," + tuple.f1 + "," + tuple.f2 + "," + tuple.f3)
15   .addSink(new FlinkKafkaProducer<>("alerts", ...));
16
17 env.execute();
```

Other options?

Flink DataStream API

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16
17 env.execute();
```

Runtime Error: The return type of function 'org.example.Main$$Lambda$263/0x00000008002e3040@36074e47' could not be determined automatically, due to **type erasure.** You can give type information hints by using the **returns(...) method** on the result of the transformation call.

Other options?

Flink DataStream API

```
1  StreamExecutionEnvironment env = StreamExecutionEnvironment.getExecutionEnvironment();
2
3  env.addSource(new FlinkKafkaConsumer<>("eventlog", ...))
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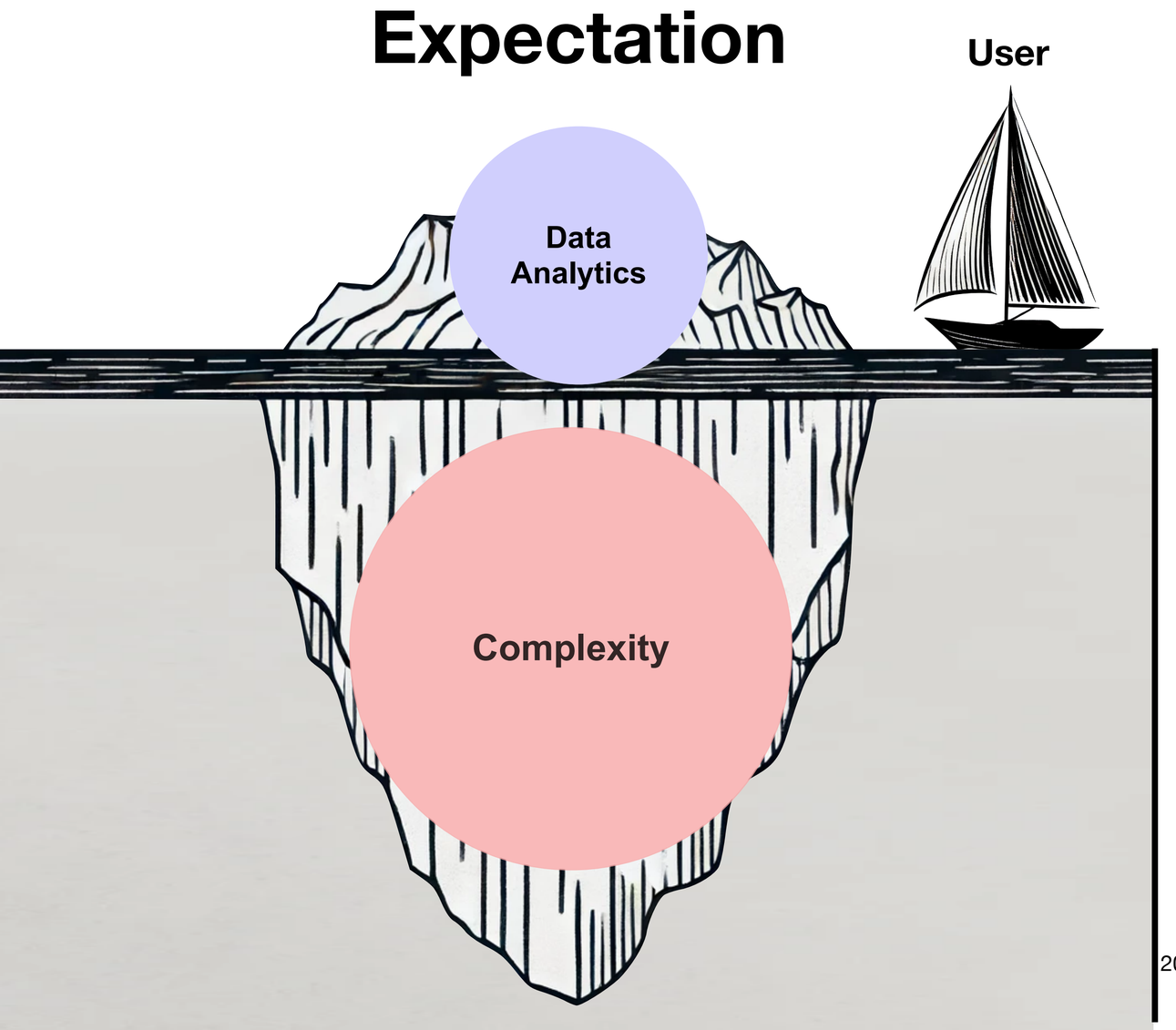
6    .filter(event -> event.getCode() == 500)
7    .map(event -> Tuple2.of(event.getZone(), event.getSeverity()))
8    .returns(TypeInformation.of(new TypeHint<Tuple2<String, Integer>>() {}))
9    .keyBy(tuple -> tuple.f0)
10   .window(SlidingEventTimeWindows.of(Time.minutes(10), Time.minutes(1)))
11   .apply((zone, window, events, out) -> {
12       double avgSeverity = events.map(event -> event.severity).average();
13       out.collect(Tuple4.of(window.getStart(), window.getEnd(), zone, avgSeverity));
14   })
15   .map(tuple -> tuple.f0 + "," + tuple.f1 + "," + tuple.f2 + "," + tuple.f3)
16   .addSink(new FlinkKafkaProducer<>("alerts", ...));
17
18 env.execute();
```

The **Reality** of Dataflow Systems



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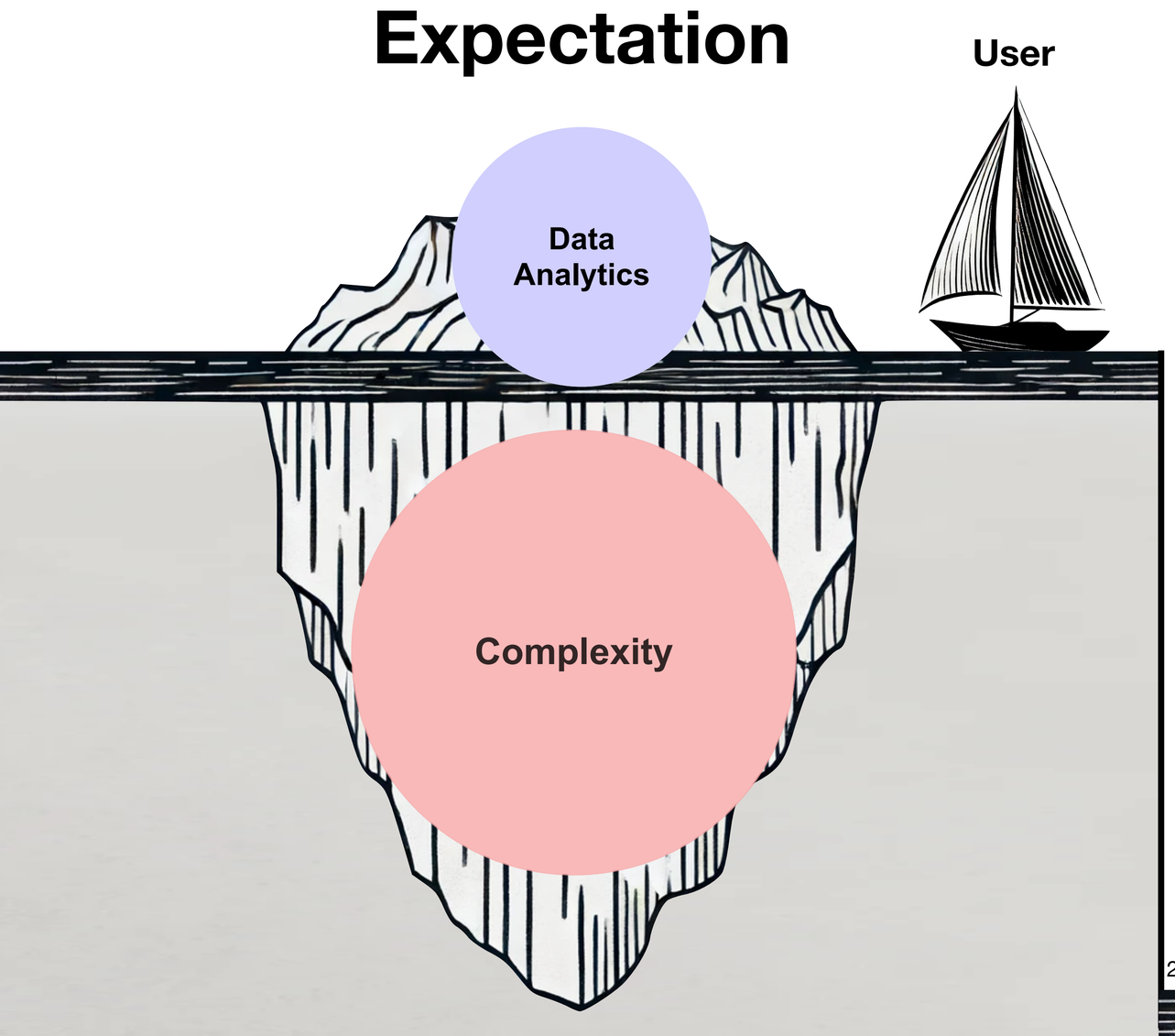

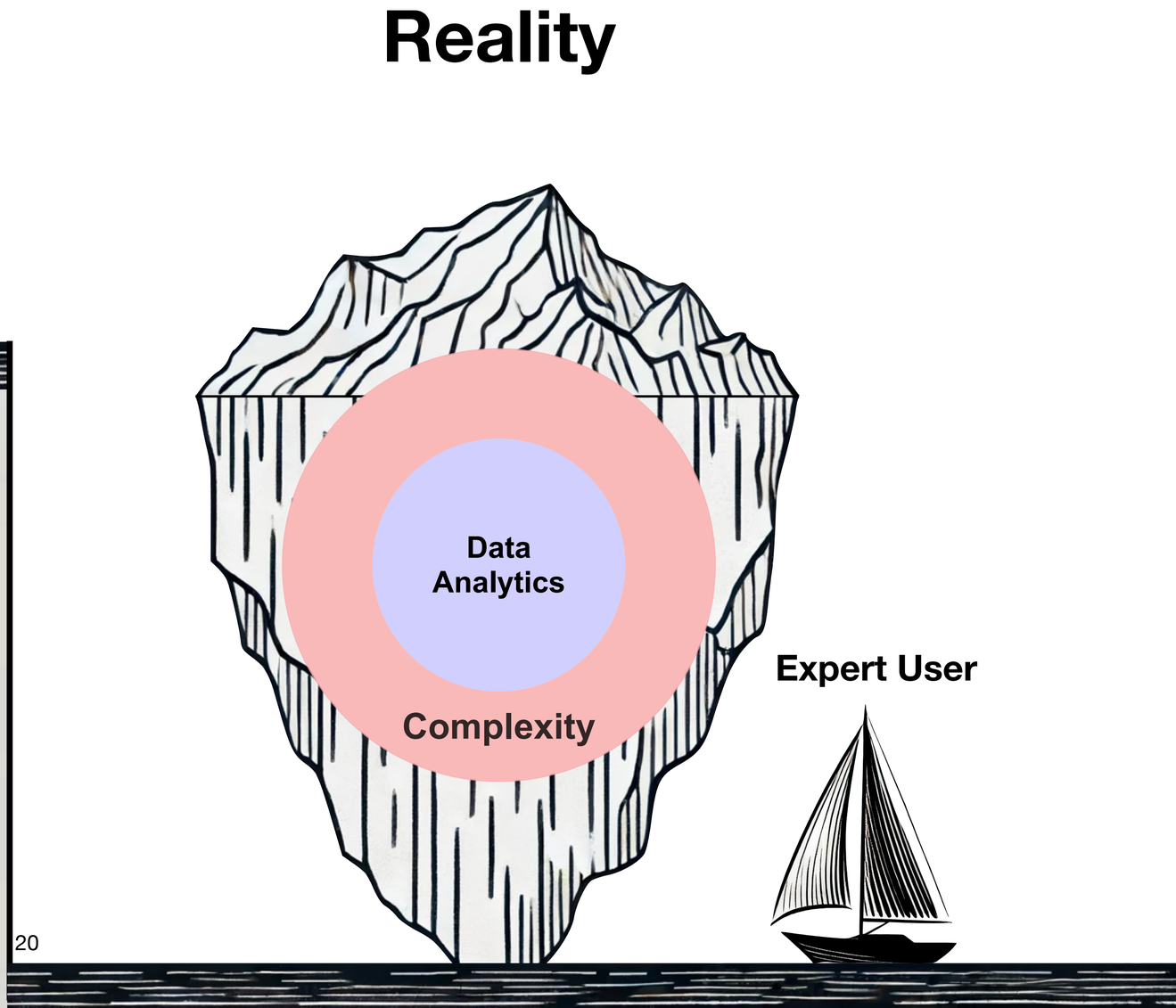

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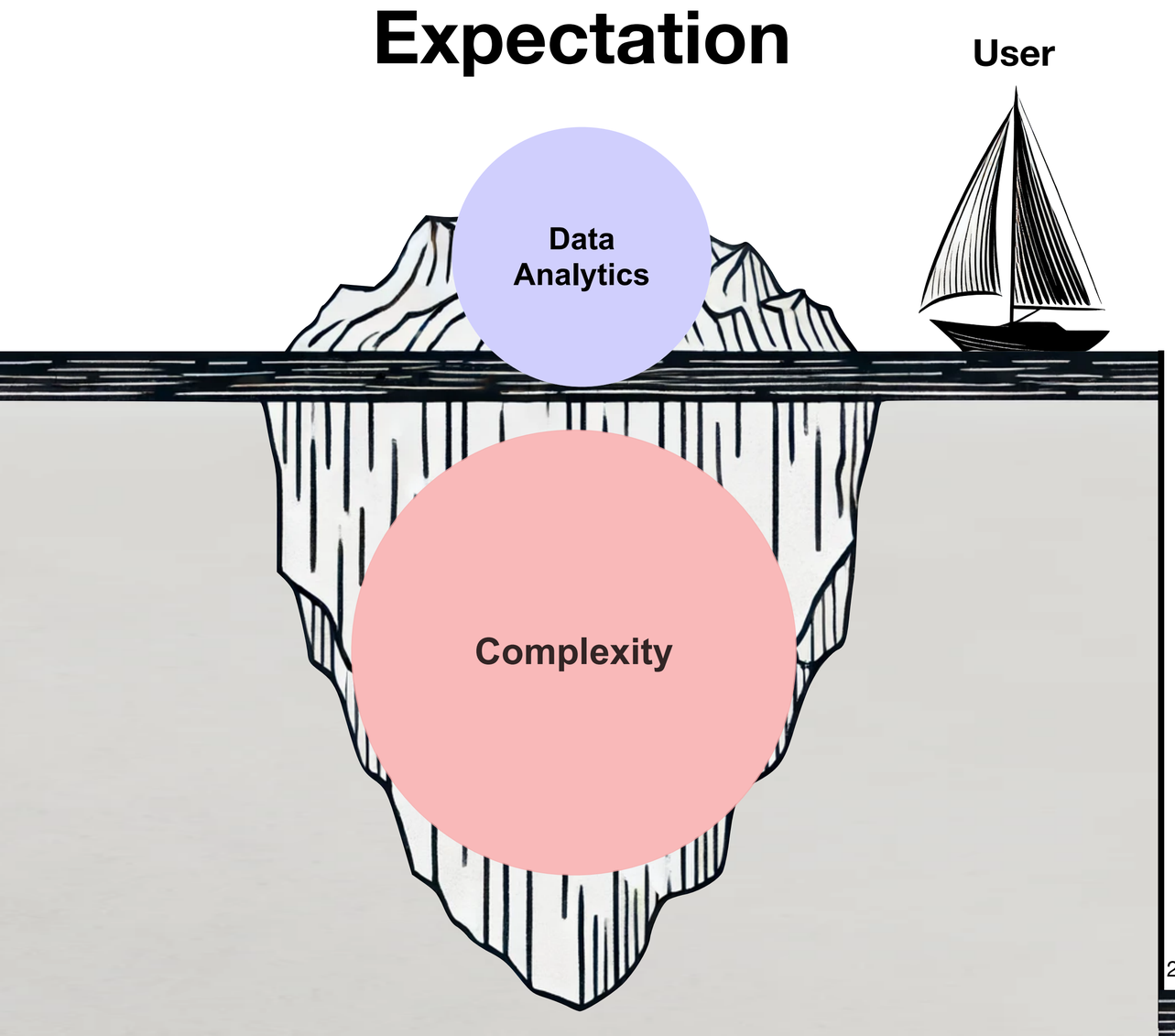

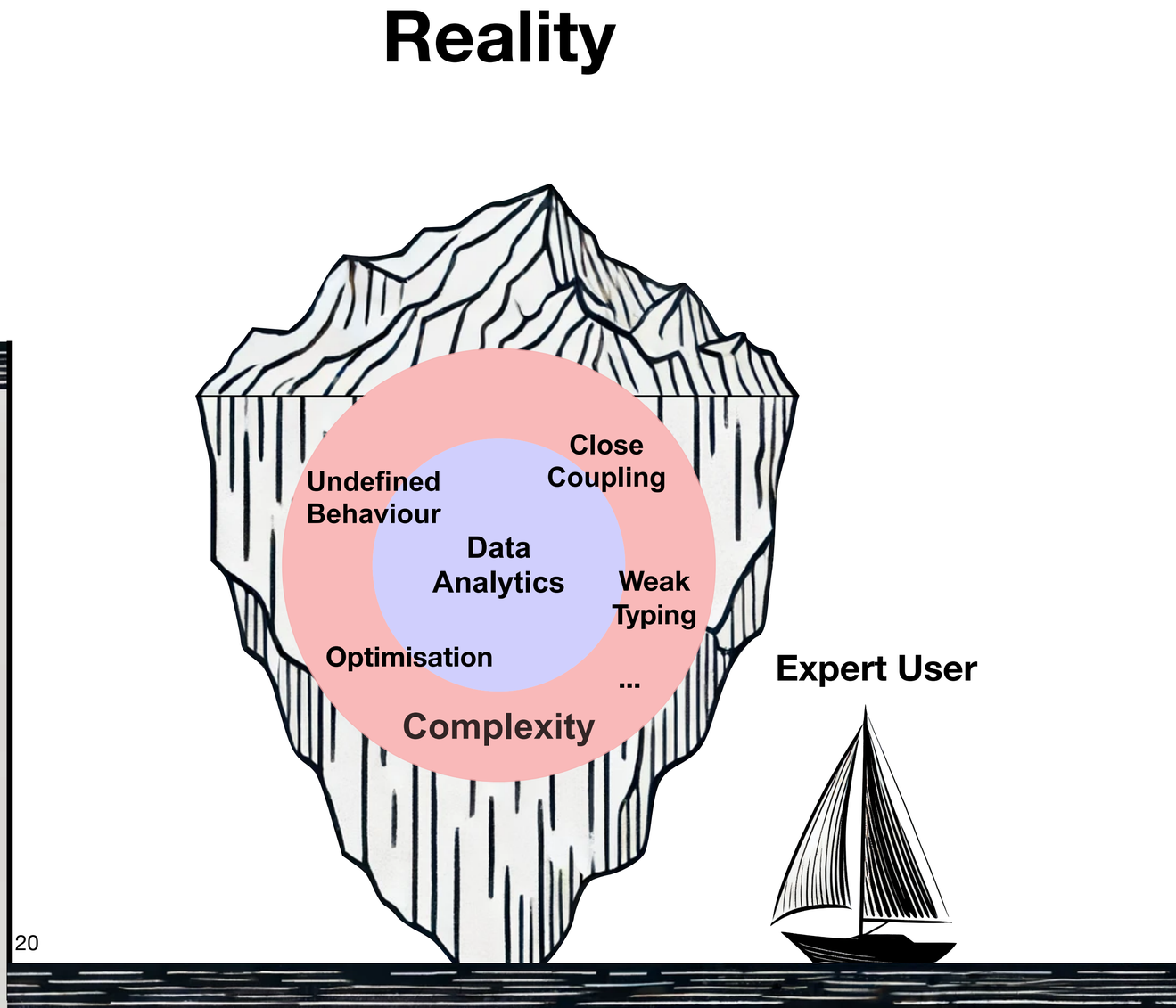

Solutions?

Solutions?

Extend Flink SQL with support for User Defined Functions

Solutions?

Extend Flink SQL with support for User Defined Functions

Create a new language


Streaming
Query Languages
AquaLang
General Purpose
Programming Languages
+ Safety, Conciseness, Optimisability
+ and more?
+ UDFs

AquaLang: Dataflow Programming

AquaLang: Dataflow Programming

```
1  struct RawEvent(ts:Time, line:String);
2  struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);
```

AquaLang: Dataflow Programming

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struct RawEvent(ts:Time, line:String);
struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);

def parse(line: String): Option[ErrorEvent] = {
    val parts = line.split(" ");
    val eventType = parts[0];
    if eventType == "ERROR" {
        val code = parts[1].parse();
        val severity = parts[2].parse();
        val zone = parts[3];
        val server = parts[4];
        val message = parts[5];
        Some(ErrorEvent(code, severity, zone, server, message))
    } else {
        None
    }
}
```

AquaLang: Dataflow Programming

```
struct RawEvent(ts:Time, line:String);
struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);

def parse(line: String): Option[ErrorEvent] = { … }

Stream[RawEvent]::source(Reader::kafka("eventlog", …), Format::csv('|'), _.time)
    .flatMap(event ⇒ parse(event.line))
    .filter(error ⇒ error.code == 500)
    .keyBy(error ⇒ error.zone)
    .window(Window::sliding(1m, 10m), (errors, zone, win) ⇒ {
        val avg_severity = errors.map(error ⇒ error.severity).average();
        record(zone, avg_severity, win.start, win.end)
    })
    .filter(data ⇒ data.avg_severity > 2)
    .sink(Writer::kafka("alerts", …), Format::json())
    .run(Backend::flink(…));
```

AquaLang: Dataflow Programming

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```

No undefined behaviour:
UDFs are verified to be side-effect free.

AquaLang: Dataflow Programming

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    .sink(Writer::kafka("alerts", …), Format::json())
    .run(Backend::flink(…));
```

No close coupling:
Dataflow graphs can be run on different dataflow systems

AquaLang: Dataflow Programming

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Functional Syntax

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Functional Syntax

Relational Syntax

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Functional Syntax

Semantically Equivalent

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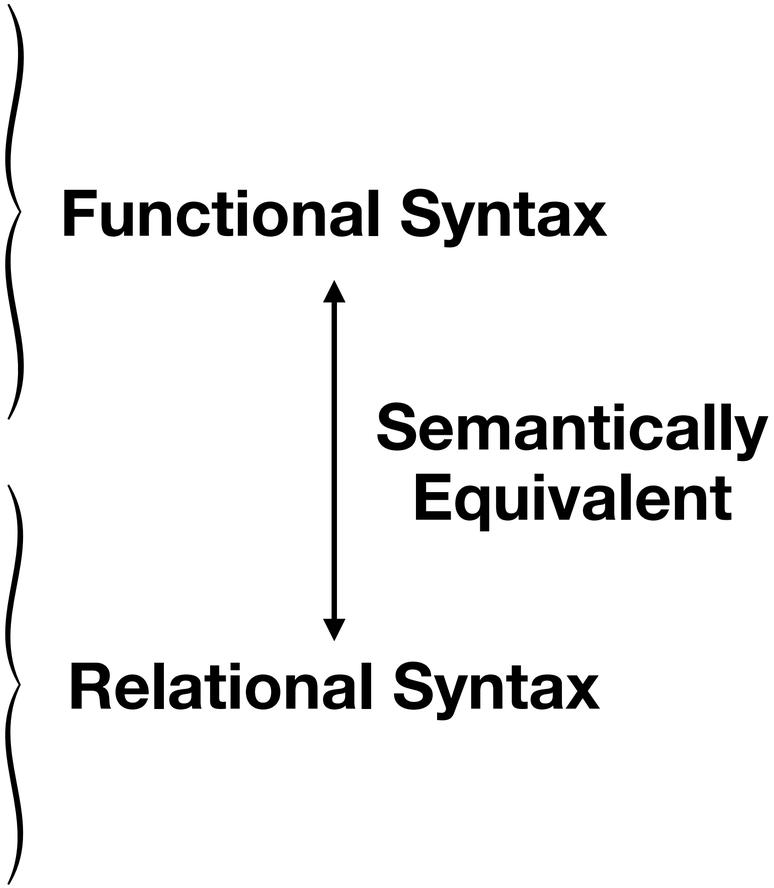

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Functional Syntax

Semantically Equivalent

Relational Syntax

Optimisations

AquaLang: Optimisation via Equality Saturation

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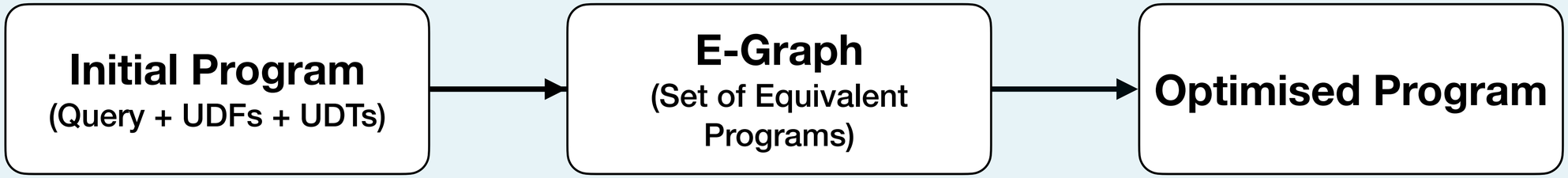
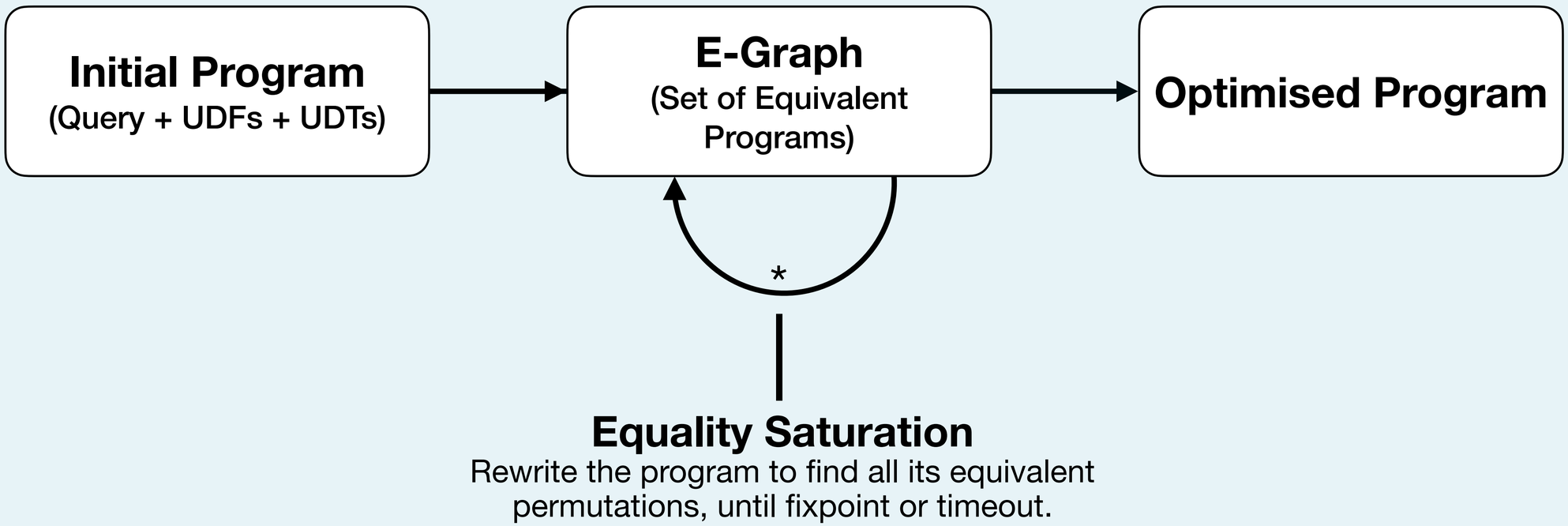
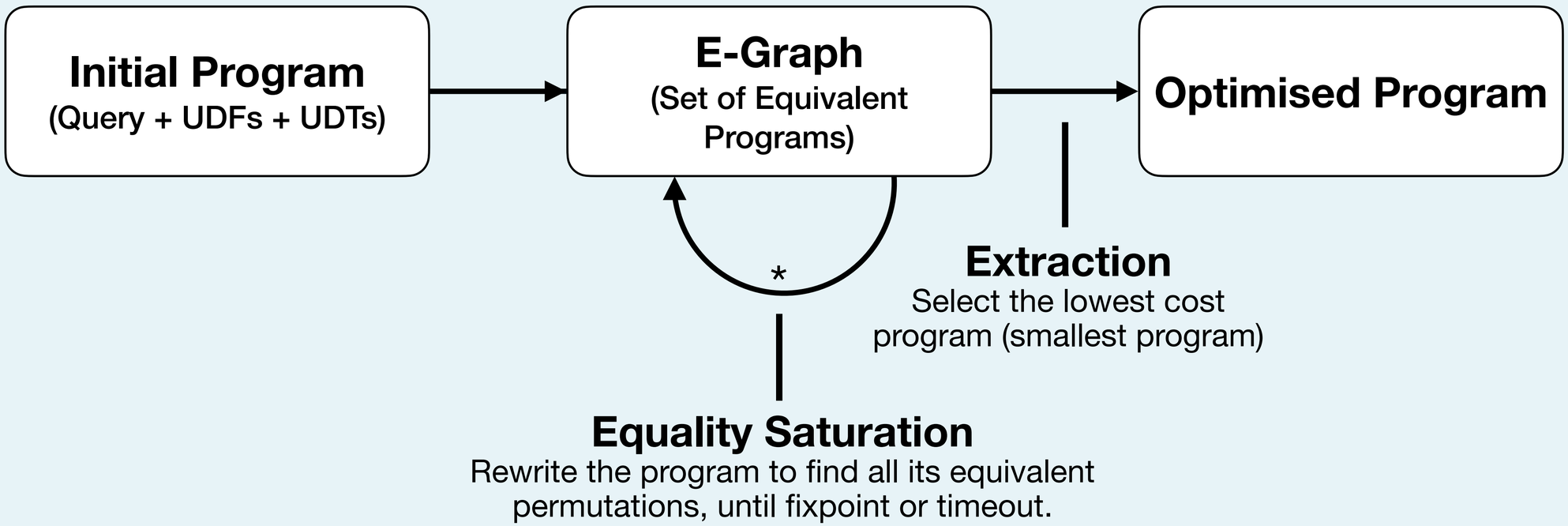


AquaLang: Optimisation via Equality Saturation



AquaLang: Optimisation via Equality Saturation



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    compute avg_severity = avg of error.severity
where avg_severity > 2
select zone, avg_severity, win.start, win.end
into sink( ... );
```

AquaLang: Optimisation

```
1  struct RawEvent(ts:Time, line:String);
2  struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);
3
4  def parse(line: String): Option[RawError] = { … }
5
6  from event in Stream[RawEvent]::source(…)
7  from error in {
8      val parts = event.line.split(" ");
9      val eventType = parts[0];
10     if eventType == "ERROR" {
11         val code = parts[1].parse();
12         val severity = parts[2].parse();
13         val zone = parts[3];
14         val server = parts[4];
15         val message = parts[5];
16         Some(ErrorEvent(code, severity, zone, server, message))
17     } else { None }
18 }
19 where error.code == 500
20 group zone = error.zone
21     over win = Window::sliding(1min, 10min)
22     compute avg_severity = avg of error.severity
23 where avg_severity > 2
24 select zone, avg_severity, win.start, win.end
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```

More features

AquaLang: Dataflow Programming

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11     compute avg_severity = avg of severity
12 where avg_severity > 2
13 select zone, avg_severity, win.start, win.end
14 into sink( ... );
```

AquaLang: Dataflow Programming

```
1  struct RawEvent(ts:Time, line:String);
2  struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);
3
4  from event in Stream[RawEvent]::source(…)
5  val parts = event.line.split(" ")
6  where parts[0] == "ERROR"
7    and parts[1].parse() == 500
8  select severity = parts[2].parse(), zone = parts[3]
9  group zone
10     over win = Window::sliding(1min, 10min)
11     compute avg_severity = avg of severity
12 where avg_severity > 2
13 select zone, avg_severity, win.start, win.end
14 into sink( ... );
```

AquaLang: Dataflow Programming

```
struct RawEvent(ts:Time, line:String);
struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);

def queryAlerts(input: Stream[RawEvent], errorCode: u8): Stream[_] =
    from event in input
    val parts = event.line.split(" ")
    where parts[0] == "ERROR"
      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
    into sink( ... );
```

AquaLang: Dataflow Programming

```
struct RawEvent(ts:Time, line:String);
struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);

def queryAlerts(input: Stream[RawEvent], errorCode: u8): Stream[_] =
    from event in input
    val parts = event.line.split(" ")
    where parts[0] == "ERROR"
      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
    into sink( ... );
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AquaLang: Dataflow Programming

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    where parts[0] == "ERROR"
      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
    into sink( ... );
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AquaLang: Dataflow Programming

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      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
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AquaLang: Dataflow Programming

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    from event in input
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      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
    into sink( ... );

from alert in queryAlerts(Stream::source(…), 401)
where alert.zone == "Z2"
into sink(…).run(…);
```

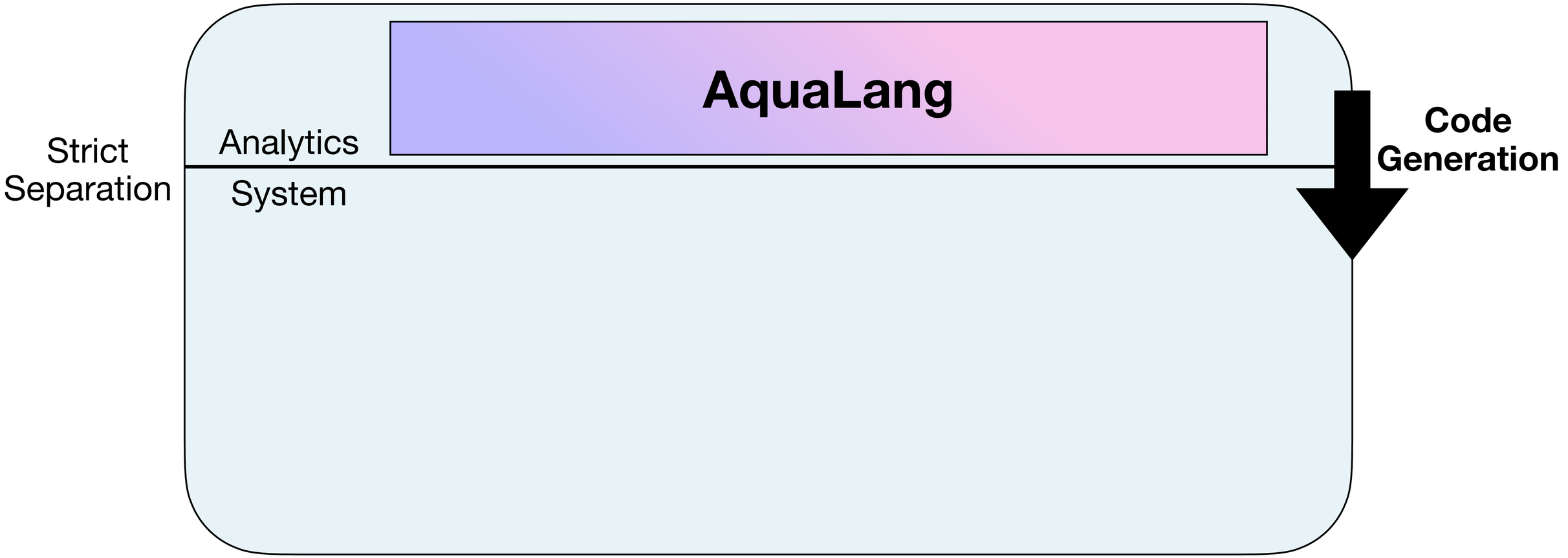
AquaLang: Dataflow Programming

```
struct RawEvent(ts:Time, line:String);
struct ErrorEvent(code:u8, severity:u8, zone:String, server:String, message:String);

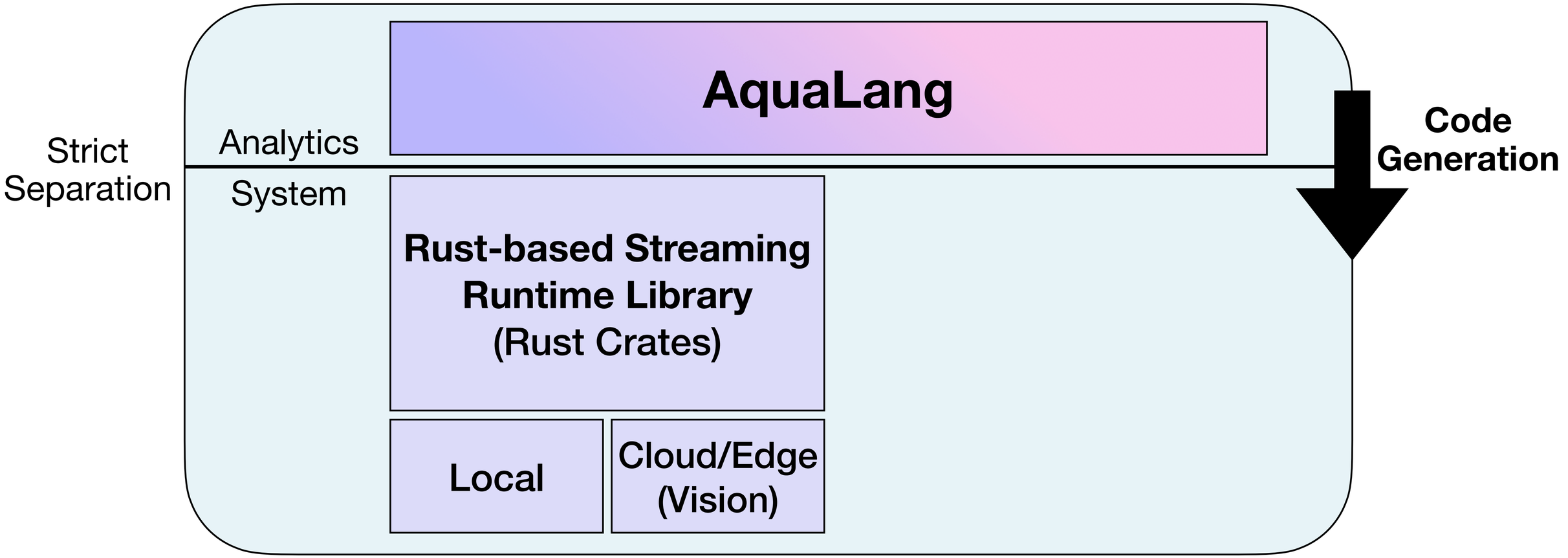
def queryAlerts(input: Stream[RawEvent], errorCode: u8): Stream[_] =
    from event in input
    val parts = event.line.split(" ")
    where parts[0] == "ERROR"
      and parts[1].parse() == errorCode
    select severity = parts[2].parse(), zone = parts[3]
    group zone
      over win = Window::sliding(1min, 10min)
      compute avg_severity = avg of severity
    where avg_severity > 2
    select zone, avg_severity, win.start, win.end
    into sink( ... );

from alert in queryAlerts(Stream::source(…), 401)
where alert.zone == "Z2"
into sink(…).run(…);
```

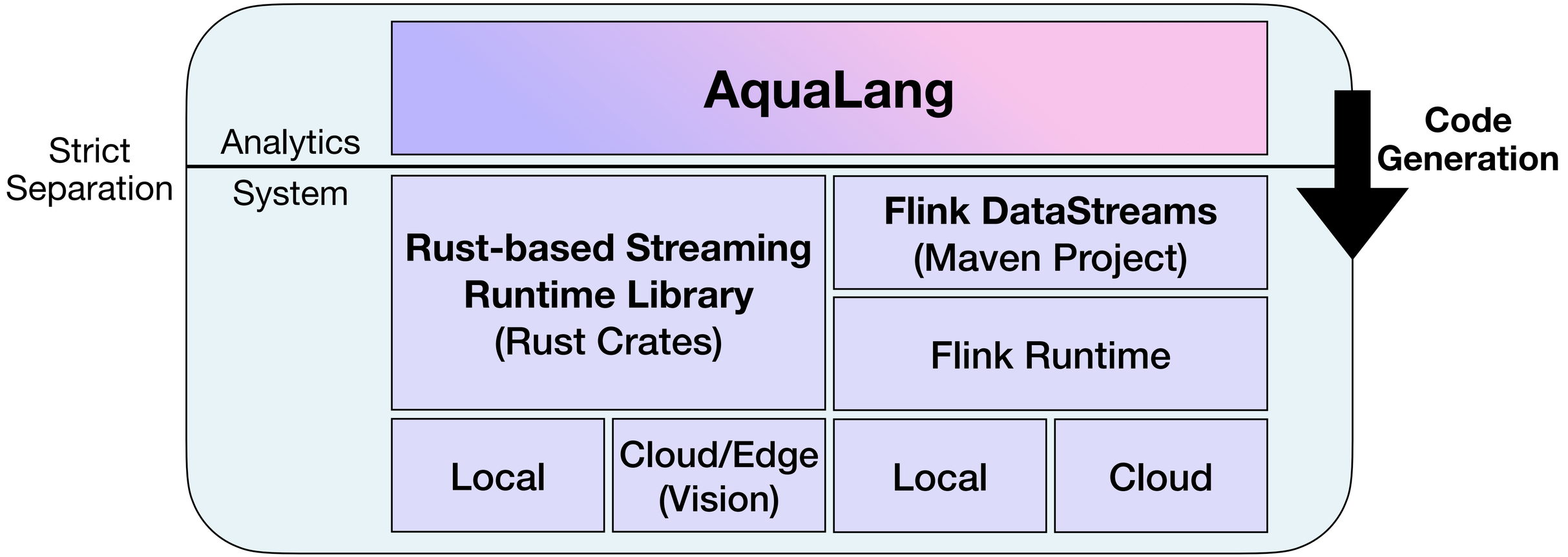
AquaLang: Code Generation



AquaLang: Code Generation



AquaLang: Code Generation



Conclusion

- **AquaLang** is a programming language that targets streaming dataflow systems
- **AquaLang** is designed to be compositional, safe, fast, and easy to use
- We are aiming to release a beta version later this year
- If you find **AquaLang** interesting, please get in touch! :)
  - **Website**: https://aqua-language.github.io/
  - **GitHub**: https://github.com/aqua-language/aqua
  - **Paper**: AquaLang - A Dataflow Programming Language (DEBS'24)