XStream

Declarative authoring of distributed stream processing pipelines
(Or, embedded DSLs make for great stream processing APIs)

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Demo
Real-time car fleet tracking

- GPS receiver (position data, 1 update/s)
- OBD via CAN bus (engine data, 1 update/s)
- Dashcam (HD video, H.264 encoded, 500kbps, on-demand)
- On-board Unit (Quad-core ARM Cortex-A9 1Ghz, 1GB RAM + 4G USB Modem)

2 real cars, 10 hours footage
400 virtual cars
Applications in World-wide Streams

- Applications = continuous queries (a.k.a. “flows”) + dashboards (UI widgets)
- Queries are created using a **flow-based programming** approach
- **Library** for JavaScript & TypeScript: XStream/JS
- Script generates a dataflow that is optimized by WWS **dataflow compiler**
Related Work

- Microsoft Dryad, **DryadLINQ**, Nectar, Naiad
- IBM **JAQL**, System S
- MIT WaveScript
- Google Cloud Dataflow, MapReduce, **FlumeJava**, Sawzall, Millwheel
- Distributed stream processing: Borealis, Stanford STREAM
- Streaming SQL dialects: Esper EQL, StreamSQL, Oracle CQL
- Data-parallel stream processing: Apache Storm, Spark Streaming, Flink, Samza
- Apache Hive
- Apache Quarks
Example flow
Alert me of congested areas near me
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```javascript
let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>(()))
  .transform(([e]) => [Object.assign({}, e, { id: e.car_id, lng: e.lon })])
  .pipe(resample({ "sample_period": 1 }));

let car = stream({'filter': {stream: 'location', id: "$MYCAR"}})
  .pipe(union_streams<Array<CarStream>>(()));

car.transform(([e]) => [Object.assign({}, e, { lng: e.lon })])
  .expand()
  .sink("fenceCenter");

let fence = geofence<Array<CarStream>>({ perimeter: 100 });

all.pipe(fence);
car.pipe(fence.center);

let detector = jerkDetector();
fence.set.pipe(detector);

let clusters = detector.rapid_decel.pipe(geocluster());
clusters.transform((c) =>
  ({ set: c.top_clusters.map(({{centroid: {lon, lat}, cluster_id}}) => ({lon, lat, cluster_id})) })
).sink("congestedAreas");
```
Example flow
Alert me of congested areas near me

let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>())
  .transform(([e]) => [Object.assign({}, e, { id: e.car_id, lng: e.lon })])
  .pipe(resample({ "sample_period": 1 }));

let car = stream({'filter': {stream: 'location', id: $MYCAR }})
  .pipe(union_streams<Array<CarStream>>());

  car.transform(([e]) => [Object.assign({}, e, { lng: e.lon })]
    .expand()
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let clusters = detector.rapid_decel.pipe(geocluster());
clusters.transform((c) =>
  ({{ set: c.top_clusters.map(({{centroid: {lon, lat}, cluster_id}}) => ({{lon, lat, cluster_id}})) }})
  .sink("congestedAreas");
Example flow
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let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>()
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  .sink("congestedAreas");
```

Built-in operators on streams
Example flow
Alert me of congested areas near me

```javascript
let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>()
  .transform(([e]) => [Object.assign({}, e, { id: e.car_id, lng: e.lon })])
  .pipe(resample({ "sample_period": 1 }));

let car = stream({'filter': {stream: 'location', id: $MYCAR }})
  .pipe(union_streams<Array<CarStream>>());

car.transform(([e]) => [Object.assign({}, e, { lng: e.lon })])
  .expand()
  .sink("fenceCenter");

let fence = geofence<Array<CarStream>>({ perimeter: 100 });

all.pipe(fence);
car.pipe(fence.center);

let detector = jerkDetector();

fence.set.pipe(detector);

let clusters = detector.rapid_decel.pipe(geocluster());

clusters.transform((c) =>
  ({ set: c.top_clusters.map(({centroid: {lon, lat}, cluster_id}) => ({lon, lat, cluster_id}))) })
  .sink("congestedAreas");
```

"External" (user-defined) operators
Example flow
Alert me of congested areas near me

```javascript
let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>())
  .transform(([e]) => [Object.assign({}, e, { id: e.car_id, lng: e.lon })])
  .pipe(resample({ "sample_period": 1 }));

let car = stream({'filter': {stream: 'location', id: $MYCAR }})
  .pipe(unionStreams<Array<CarStream>>());

car.transform(([e]) => [Object.assign({}, e, { lng: e.lon }])
  .expand()
  .sink("fenceCenter");

let fence = geofence<Array<CarStream>>({ perimeter: 100 });

all.pipe(fence);
car.pipe(fence.center);

let detector = jerkDetector();
fence.set.pipe(detector);

let clusters = detector.rapid_decel.pipe(geocluster());
clusters.transform((c) =>
  ({ set: c.top_clusters.map(((centroid: {lon, lat}, cluster_id)) => ({lon, lat, cluster_id})) })
  .sink("congestedAreas");
```

External operator “wiring”
Example flow
Alert me of congested areas near me

```javascript
let all = stream<Array<CarStream>>({"filter": {stream: 'engine'}})
  .pipe(union_streams<Array<CarStream>>()
  .transform(([e]) => [Object.assign({}, e, { id: e.car_id, lng: e.lon })])
  .pipe(resample({ "sample_period": 1 }));

let car = stream({'filter': {stream: 'location', id: $MYCAR }})
  .pipe(union_streams<Array<CarStream>>()
  .transform(([e]) => [Object.assign({}, e, { lng: e.lon })])
  .expand()
  .sink("fenceCenter");

let fence = geofence<Array<CarStream>>({ perimeter: 100 });
all.pipe(fence);
car.pipe(fence.center);

let detector = jerkDetector();
fence.set.pipe(detector);

let clusters = detector.rapid_decel.pipe(geocluster());
clusters.transform((c) =>
  ({ set: c.top_clusters.map(((centroid: {lon, lat}, cluster_id}) => ({lon, lat, cluster_id})) })
).sink("congestedAreas");
```

Delayed/remote code execution
Launching XStream Flows

The “Flow”

Functional dataflow specification

let fence =
resolve_streams({type: "Car", port: "engine"})
-> resample({ period: 1, primary_key: "id" })
-> geofence({ perimeter: 100 });

let car = resolve_stream(
  id: "$MYCAR",
  type: 'Car',
  port: 'location' );
car -> fence.center;

let detector = fence.set -> detectSpeedDrop({
  threshold: 10, // 10 mph drop
  time_window: 2 // within 2 seconds
});
detector
  -> geocluster(
    proximity_radius: 100, // meters
    min_cluster_size: 2, // at least 2 cars
    time_window: 5 // within 5 seconds
  )
  -> sink("brakeAlert");

Functional “How”

Logical Query Plan

Physical Query Plan

(optimized plan, e.g. operators are fused)

Deployment “How”

Placed Query Plan
XStream: external or embedded DSL?

```javascript
function relay({events: ev, switches: s}) {
  let left = ev.transform([$, null]);
  let right = s.filter($) == true
           .transform([null, $]);

  union(left, right)
  .reduce([null, false], [[pe, pb], [e, b]]:
          [e ?? pe, b ?? false]
  .filter([e, b]: b
  .transform([e, b]: e
);
}
```

XStream DSL

```javascript
function relay({ events: ev, switches: s }) {
  let left = ev.transform($ => [$, null]);
  let right = s.filter($) === true
                .transform($ => [null, $]);

  return union(left, right)
    .reduce([null, false], ([[pe, pb], [e, b]]) =>
               [e || pe, b !== null])
    .filter([[e, b]) => b)
    .transform(([e, b]) => e);
}
```

XStream/JS
Embedded DSLs make for great stream processing APIs

“fluent APIs” in Java/Scala: Apache Storm, Apache Spark (incl. Spark Streaming), Apache Flink

Craig Chambers et al. on FlumeJava’s predecessor called “Lumberjack” (PLDI 2010):

• “The implicitly parallel, mostly functional programming model was not natural for many of its intended users. FlumeJava’s explicitly parallel model [...] coupled with its “mostly imperative” model [...], is much more natural for most of these programmers.”

• LumberJack: **static analysis** (hard and imprecise) vs FlumeJava: just run the program to generate the graph and then reason from that. Simpler and more precise.

• **Tooling.** “Building an efficient, complete, usable Lumberjack-based system is much more difficult [...] than building an equivalently efficient, complete, and usable FlumeJava system.”

• **“Novelty is an obstacle to adoption.** By being embedded in a well-known programming language, FlumeJava focuses the potential adopter’s attention on a few new features, namely the Flume abstractions and the handful of Java classes and methods implementing them.”
Summary: XStream

- A high-level query interface to compose end-to-end dataflows
- Embeddable as a library in existing programming languages
- Compiler optimizes generated query plan prior to deployment
- Deployer deploys operators across (wide-area) distributed execution environment
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