

Complex Event Processing for Mission Operation Systems

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Event correlation for the Ground Segment

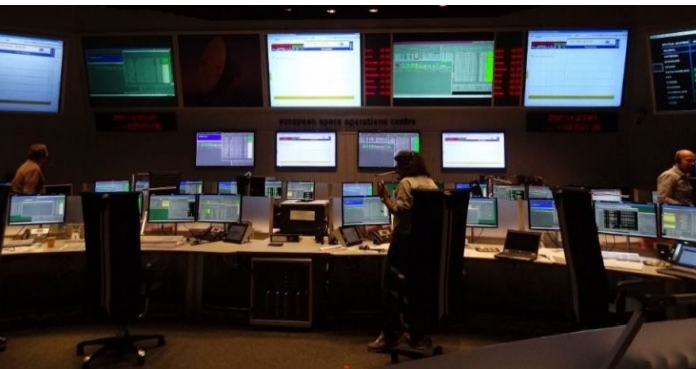
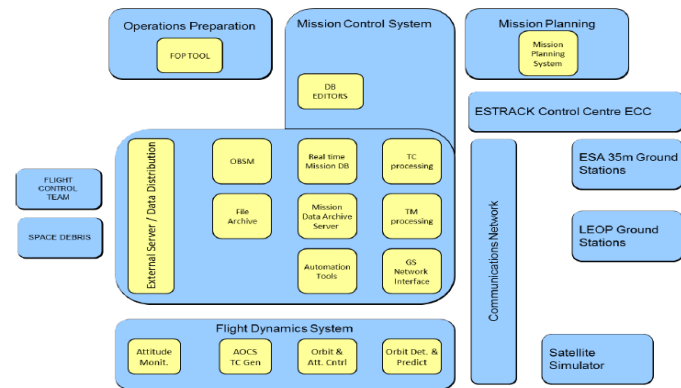


Operations Ground Segment a **complex system of systems**, high-throughput event sources

Spacecraft database consists of **tens of thousands of parameters**

Conditions change based on flight experience and mission evolution -> evolving **workaround databases** of **manual FCT instructions** based on system events

Need flexibility - adaptable, automated monitoring rules and source-agnostic capabilities



Event correlation for the Ground Segment



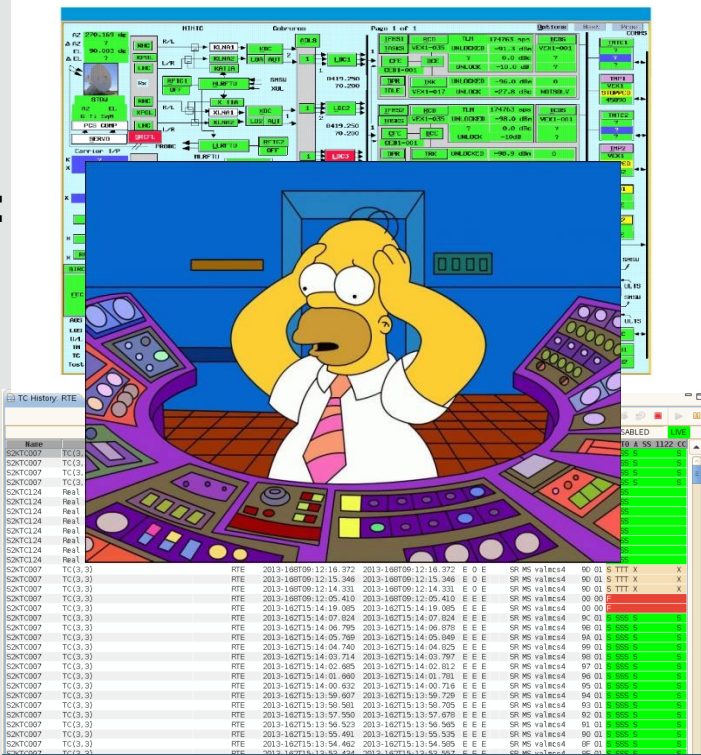
M&C typically limited to the subsystem under control, **no system-level monitoring**

Limited processing and analysis capabilities:
limit checking, synthetic (derived) parameters, filters – **static, stateless operations**

Advanced analysis tools only for **offline archive**

Exacerbating trends:

- Increasing data rates - test known bottlenecks
- Increasing mission complexity
- Fewer human operators per mission



Example from manual instruction database

frm_MAIN

EXM SY-CRP-000

Spacecraft Events Services 5 and 12

Ops FAQ

OOL Parameters

Search Events

exomars 2016

Negative Acknowledge Services 1 and 13

frm_Info

EXM Info

OPS Info

Event received TM[12,130]

Spaon Info

Condition: If parameter GFD69AAE (FD:PARAMID) is GPA5501Z or GPA5518Z and PMON 38 did not trigger
Assumed cause: STR blinding
Reaction: send email to on-call engineer (copy FCT) to notify the reception of the TM[12,130]

APID	PID	EVID	SPID	Mnemonic	DESCR	SpaonAction	SoeAction	CRP_Ri
758	47	2	709102001	GPS02003005	ENTER STBY NPU	Indicates unforeseen PDHU mode change to standby mode. Can be caused by any of the following events: 12, 15, 21, 22, 23, 24, 25 & 26	Check other PDHU events.	
758	47	3	709103001	GPS03003005	INIT TEST FAIL	Indicates failed health checks after PDHU power on or reboot. If event frequently repeated (every ~20 seconds) and alternated with event ID 2 ENTER STBY NPU this is a continuous reboot issue (similar to AR EXM_SC-21). In this case powercycle the PDHU with support from on-call SOE using FOP PD-FCP-102 & PD-FCP-101. Else, check if PDHU is in OPERATIONAL mode and stable (no frequent repetition of this event) and inform SOE.	Check EPDA0001 for failed health checks: Initialization section should hint at reset reason (which parameter out of GPS2501Z, GPS2502Z, GPS2503Z, GPS2504Z has value RESET?). Boot Status section should indicate any SW image loading errors (only parameter combinations allowed value NO_BOOT are (GPS2513Z & GPS2512Z & GPS2509Z & GPS2508Z & GPS2507Z) or (GPS2513Z & GPS2512Z & GPS2506Z)). Boot Self Test Status section should indicate which self tests were done and/or OK (only parameter allowed value NO_BOOT is GPS2518Z).	PD-FCP-102, P

What is Complex Event Processing? - Example

Simple example:

1. Credit card transaction (event)
2. Read and record card transaction time and geolocation (event processing)
3. Aggregation of multiple credit card transactions to derive an occurrence of a transaction within a short repeat interval and/or from geographically distributed locations (complex events)
4. Creation of a new complex event "Potential Fraud" based on inference rule (complex event processing)



What is Complex Event Processing?

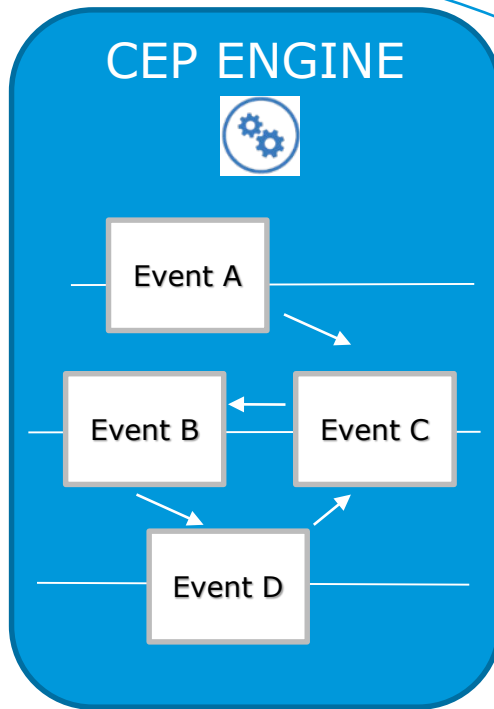
Multiple types, multiple sources



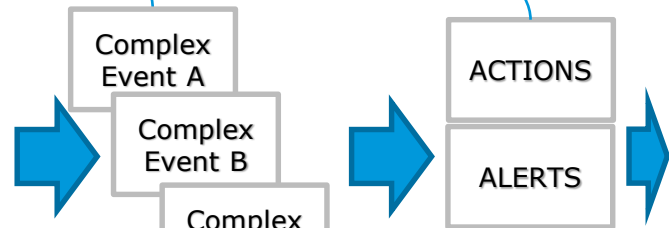
Partial or non-ordered



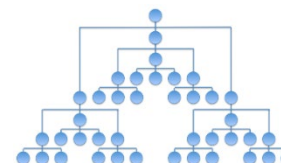
Linearly ordered



Automation



Event Classes and Hierarchies



What is Complex Event Processing? - Functions

Pre-processing of heterogeneous data

Event types

Data formats

Timestamps (e.g.
generation, reception)



What is Complex Event Processing? - Functions



**Abstraction from
real world events**

Representations for
human users

**e.g. change of
state, non-events**

Header & payload

Classes of events

What is Complex Event Processing? - Functions

Aggregate, encapsulate,
count, derive, filter,
suppress, merge/join,
query, limit rate, ...




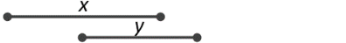
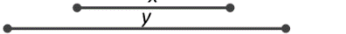
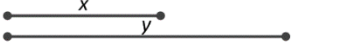

Traceability, **Causality**

Stateful

Low computation cost

Deterministic



Operator	Illustration
x before y y after x	
x equals y y equals x	
x meets y y metBy x	
x overlaps y y overlappedBy x	
x during y y contains x	
x starts y y startsBy x	
x finishes y y finishedBy x	

What is Complex Event Processing? - Functions



Expressive **Event Processing Language**

EPL statements to define and combine Operations

SQL-like, streams instead of tables

Simplicity for users important

What is Complex Event Processing? - Functions

Combine Operations to form
**processing rules and
pattern detection**

Windows (count or time
based, sliding) and
conditional, **stateful**
operations e.g. if within,
while, after, during, etc

**Transparency for users
important**





Customisable and interactive – **real time or offline**

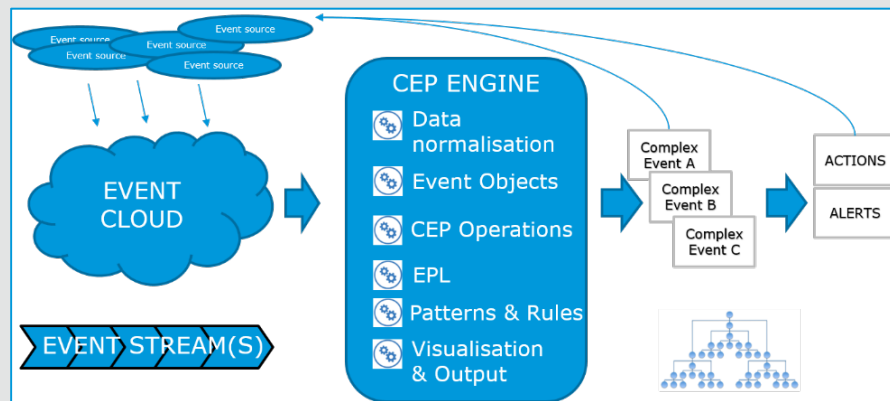
Output events to **alert** an operator **or trigger actions** for systems

Interfaces with consumers (e.g. source systems for automation, mobile devices)

What is Complex Event Processing? - Summary

- **Set of concepts and functions** for processing event streams with the goal to detect meaningful correlations and higher level events of interest

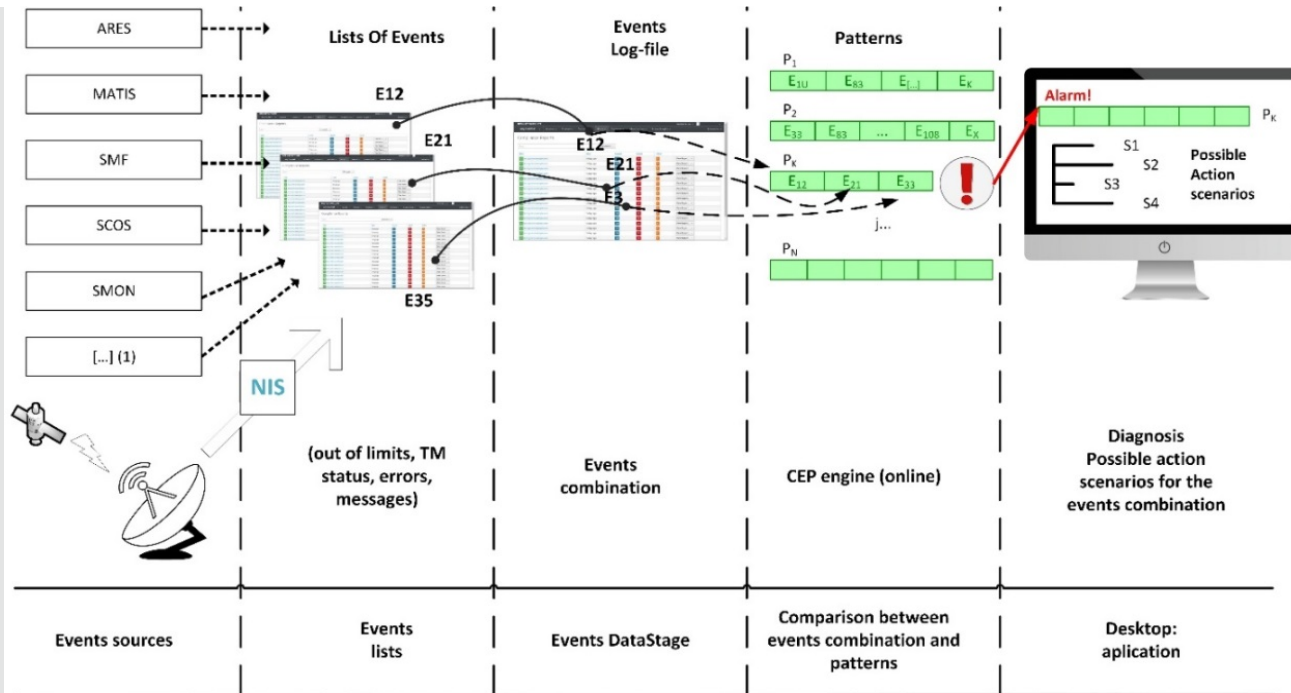
- **Enabling enhanced monitoring and reaction capabilities**



- **Historic or real-time**
- **Around since early 1990s!**

- Appears suitable for mission operations: **timeseries data, stateful, high throughput, low latency, multiple sources, automation**

CEP for the Ground Segment - Concept



(1) MPSF, GFST, MPSF, GFTS, REALS, ...

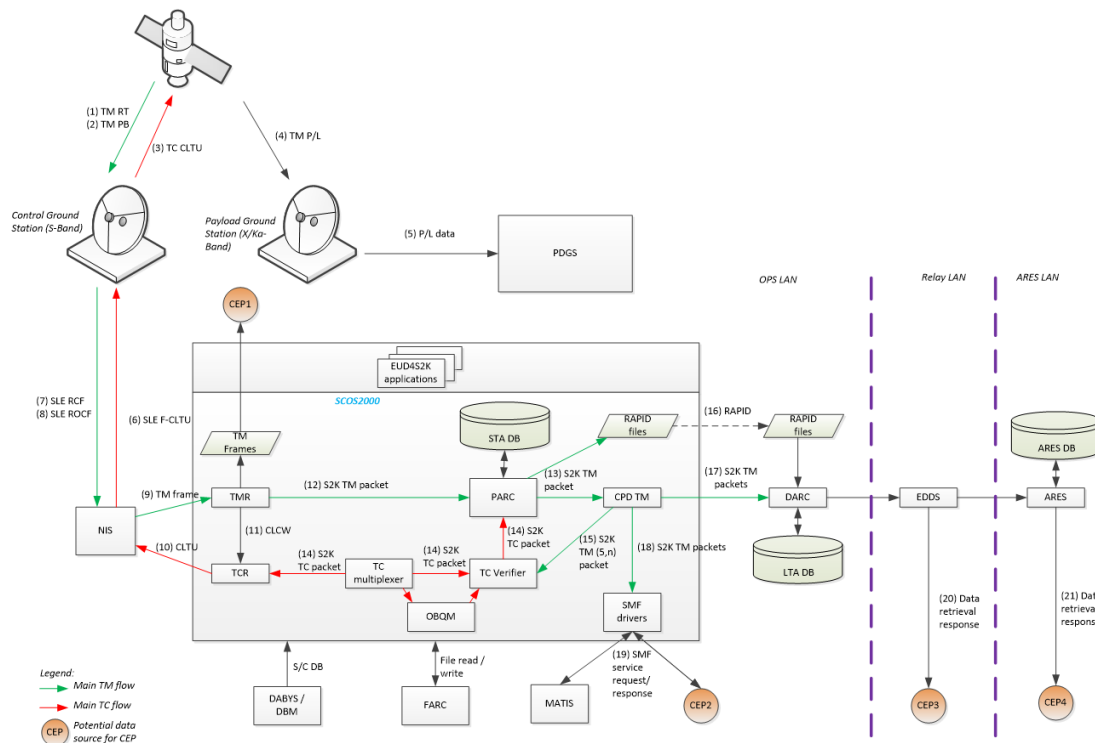
CEP for the Ground Segment – Use cases

ESOC operates a wide range of missions. **Potential use cases and scenarios strongly depend on the missions and their characteristics**



A significant response from FCT on use cases where existing **M&C capabilities were considered inefficient or limited**

CEP Deployment scenarios for TM/TC data



Mission Specific:

- UC-01: Star Tracker Blinding Events
- UC-02: Missing Large Data Units during Downlink
- UC-03: Avoid Requests for Re-transmission for Impaired Blocks
- UC-04: Rover Relay Use Case
- UC-11: AOCS Loss of Convergence
- Space Weather and Near-Earth Object notifications

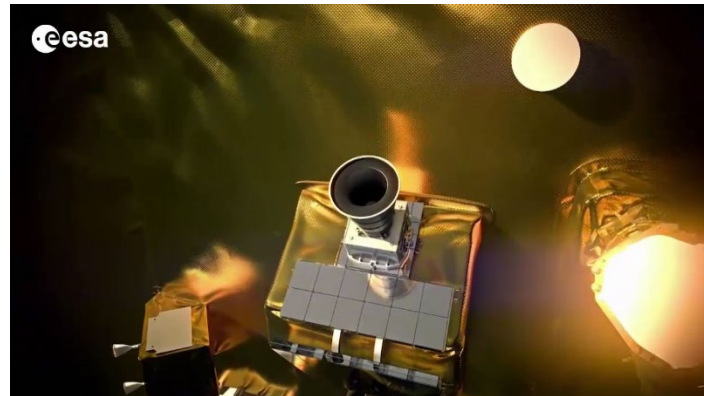
Generic:

- UC-05: Prevent Alarm Flooding
- UC-06: Multi-mission Critical Uplink Detection
- UC-07: Prediction of Required Manual Involvement – UC07
- UC-08: TC Stack/Schedule Verification
- UC-09: Detect “Missing” Events
- UC-10: “Super” Alarms / Out of Limits
- UC-12: E2E File transfer verification

UC-01: Star Tracker Blinding Events

Star tracker (STR) a common attitude determination device

Aim: Aid the operator in identifying if a reported STR blinding event is expected or not



Event sequence:

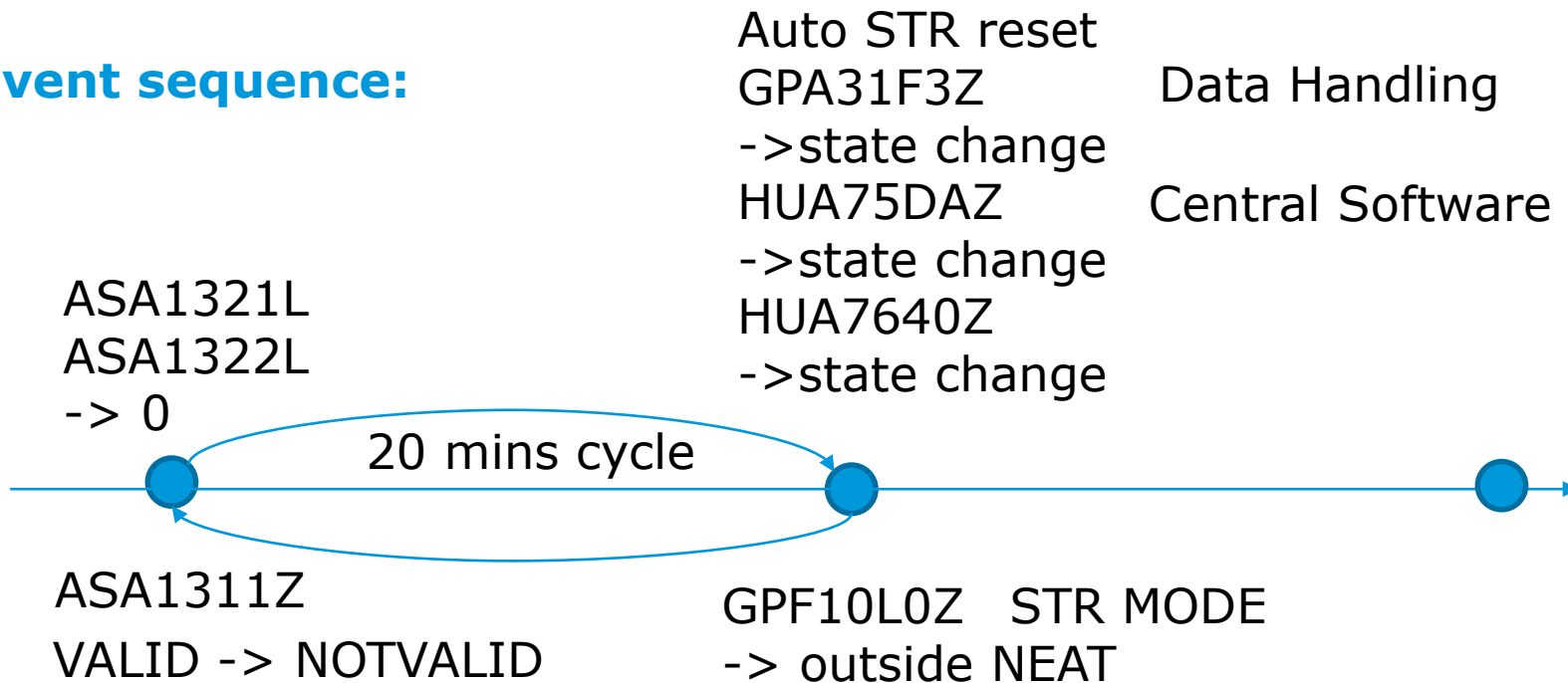
ASA1321L Valid stars
ASA1322L Detected stars
-> 0



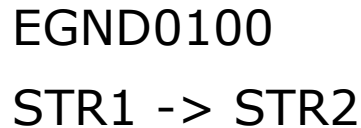
ASA1311Z Quaternion Flag
VALID -> NOTVALID

UC-01: Star Tracker Blinding Events

Event sequence:



Auto STR reset
GPA31F3Z
->state change
HUA75DAZ
->state change
HUA7640Z
->state change



UC-01: Star Tracker Blinding Events

Manual Operator Checks

Detected only if OOL set



ASA1321L
ASA1322L
-> 0

20 mins cycle

ASA1311Z
VALID -> NOTVALID

Auto STR reset
GPA31F3Z
->state change
HUA75DAZ
->state change
HUA7640Z
->state change



A number of OOL to correlate and check conditions

EGND0100
STR1 -> STR2

GPF10L0Z
-> outside NEAT



Check in MTP Viewer if blinding was expected

Check which STR in use

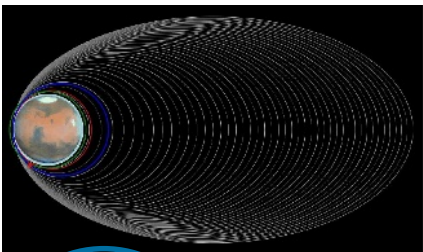
2.5 hours outside NEAT



UC-01: Star Tracker Blinding Events

Data (event) sources:

Flight Dynamics Event predictions



```
<vis id="AL00" time="2019-054T06:08:45.000Z" count="8150" duration="1058" lander="M20" criteria="fix_el_mask" elevation="00"/>
```

```
<occ id="MO2E" time="2019-054T05:51:40.000Z" count="4944" duration="0"/>
```

```
<sci id="S1BE" time="2019-054T06:41:17.000Z" count="2634" duration="0" object="Mars"/>
```

```
<sci id="S1BS" time="2019-054T05:42:47.000Z" count="2633" duration="3510" object="Mars"/>
```

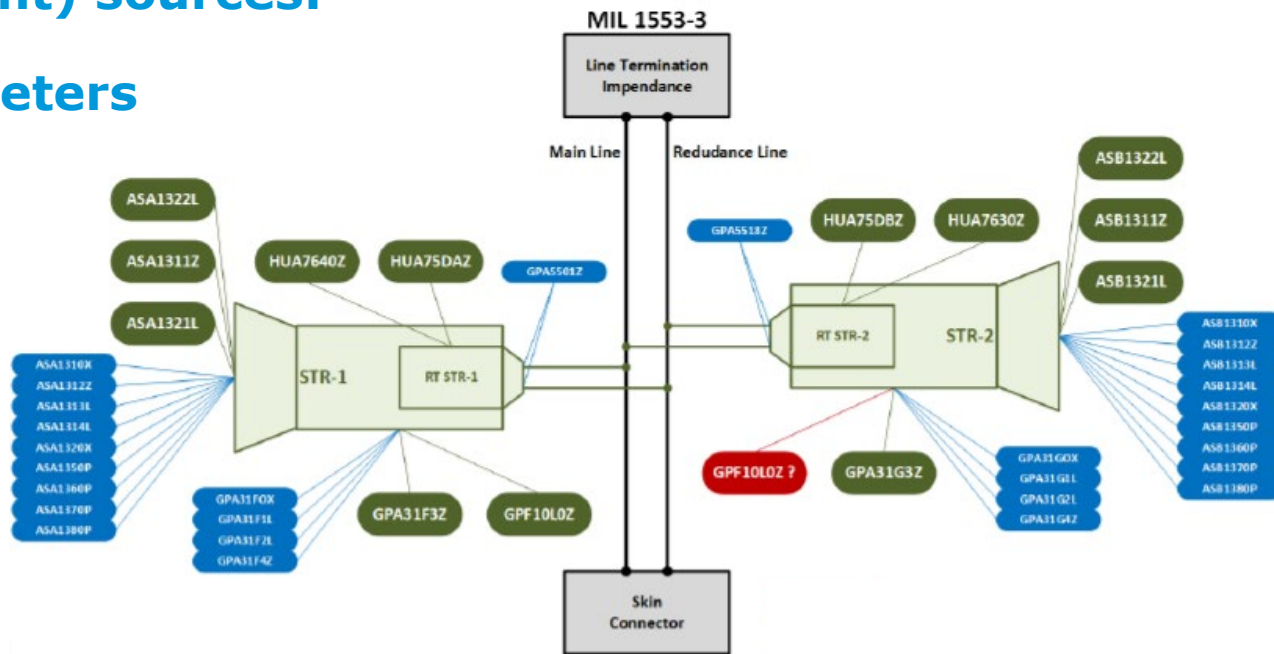
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Use case examples – Star Tracker blinding

Data (event) sources:

TM parameters



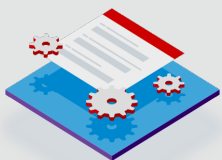
```
"metadata": [
  {
    "key": "id",
    "value": "4583"
  },
  {
    "key": "name",
    "value": "HUA7640Z"
  },
  {
    "key": "description",
    "value": "FMON 064 Curr Status"
  },
  {
    "key": "subsystem",
    "value": "TM"
  },
  {
    "key": "dataType",
    "value": "STRING"
  },
  {
    "key": "type",
    "value": "TM"
  },
  {
    "key": "complete",
    "value": "true"
  },
  {
    "key": "unit",
    "value": "none"
  }
],
"data": [
  {
    "date": "1539820877132",
    "value": 0,
    "calibratedValue": "N/A"
  }
]
```

European Space Agency

Technologies – Market Analysis (Examples)



IMPETUS



Flink



IBM Streams

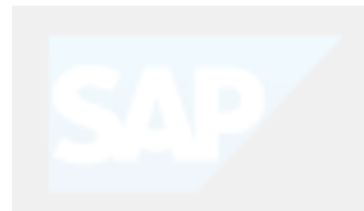


- **CEP Operations supported**
- **Accessibility** – APIs, SDKs, Documentation, community
- **Usability** – steep learning curves, EPL
- **Development maturity**
- **Licensing**
- **Computing resources** (CPU load, etc)
- **Machine learning plugins**
- **Scalability**
- **Processing throughput**

Technologies – Prototype trials



IMPETUS



Flink



IBM Streams



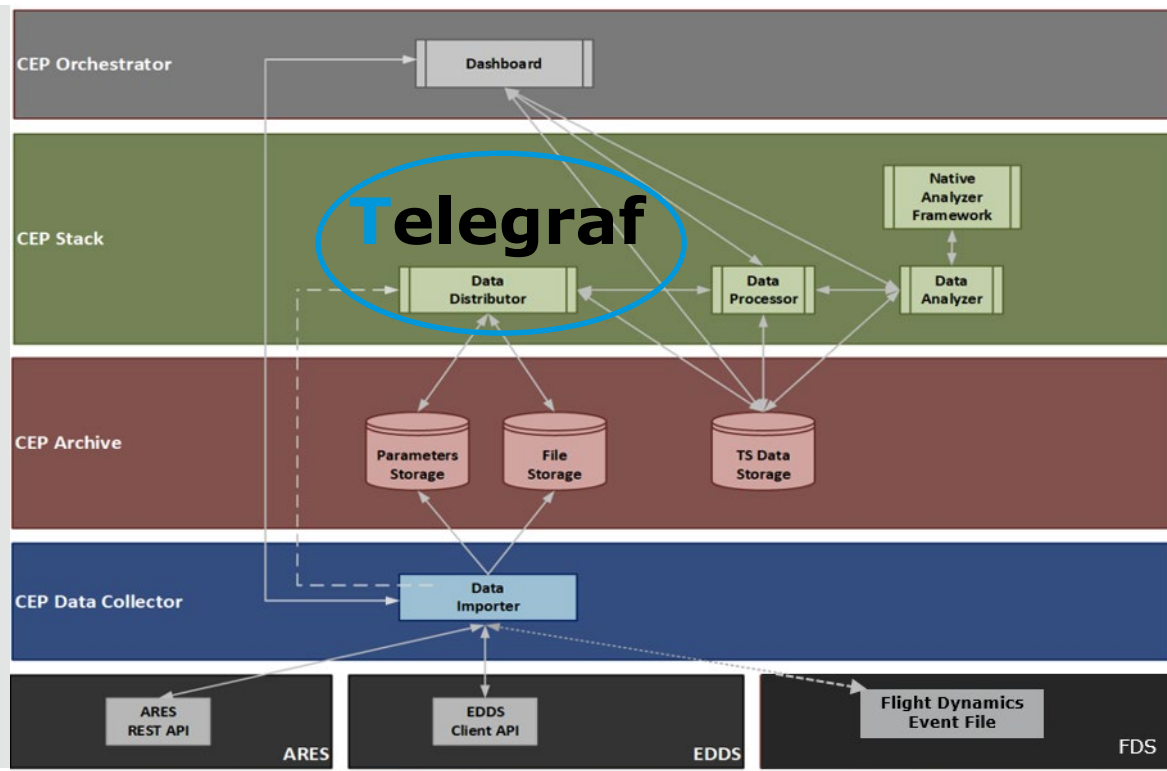
Technologies – Prototype trials – TICK Stack

T Telegraf: server agent for collecting and reporting

I

C

K



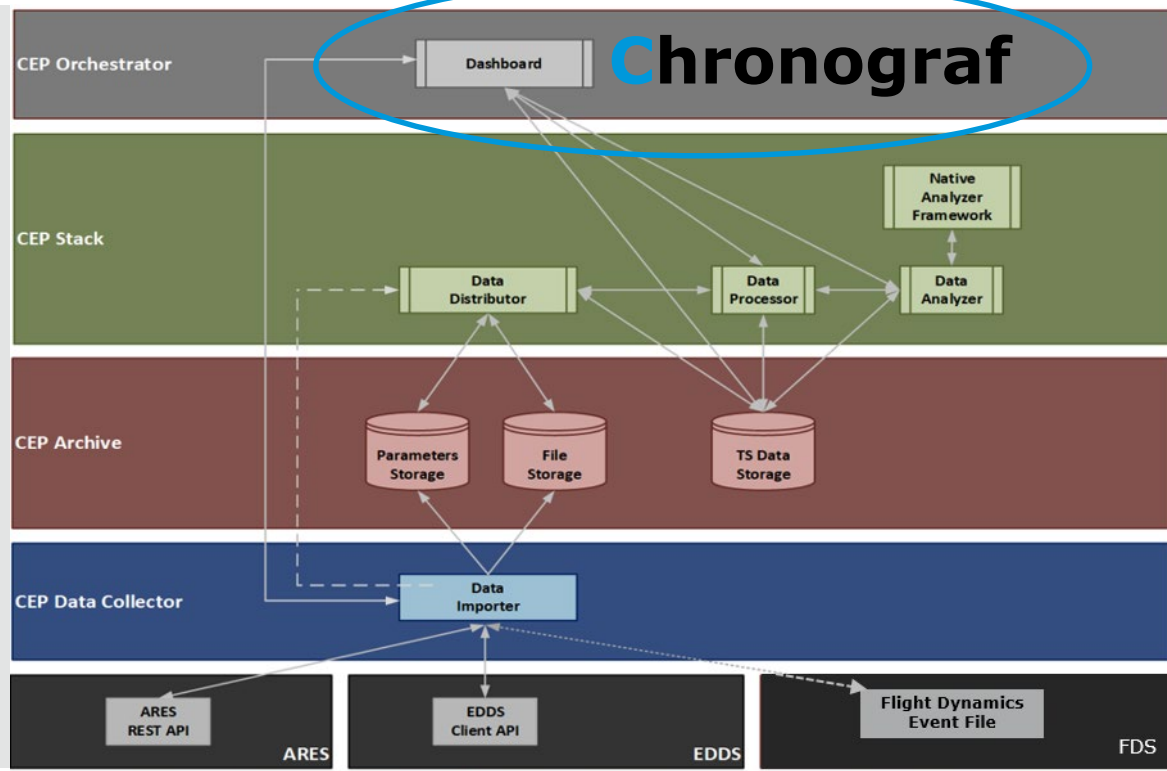


I InfluxDB storage and time series database

C

K

Technologies – Prototype trials – TICK Stack



T Telegraf: server agent for collecting and reporting

I InfluxDB storage and time series database

C Chronograf: user interface for the platform

K

Technologies – Prototype trials – TICK Stack



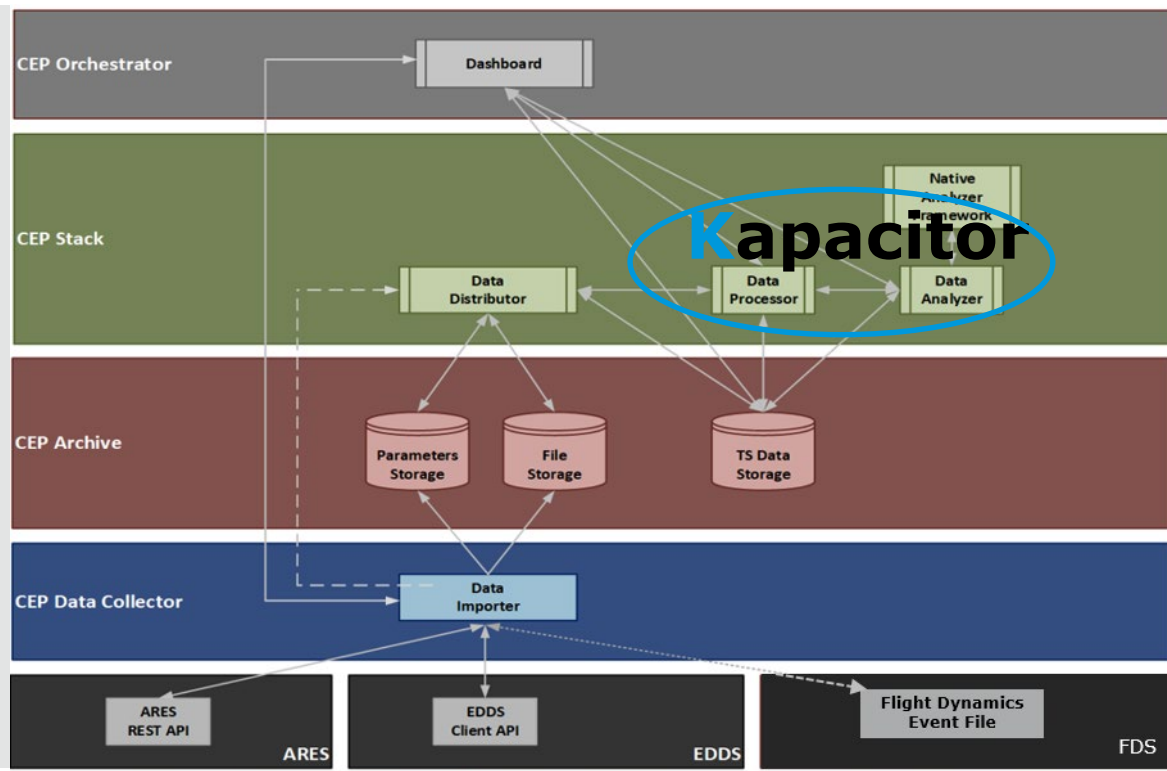
T Telegraf: server agent for collecting and reporting

I InfluxDB storage and time series database

C Chronograf: user interface for the platform

K Kapacitor: data processing engine

Kapacitor



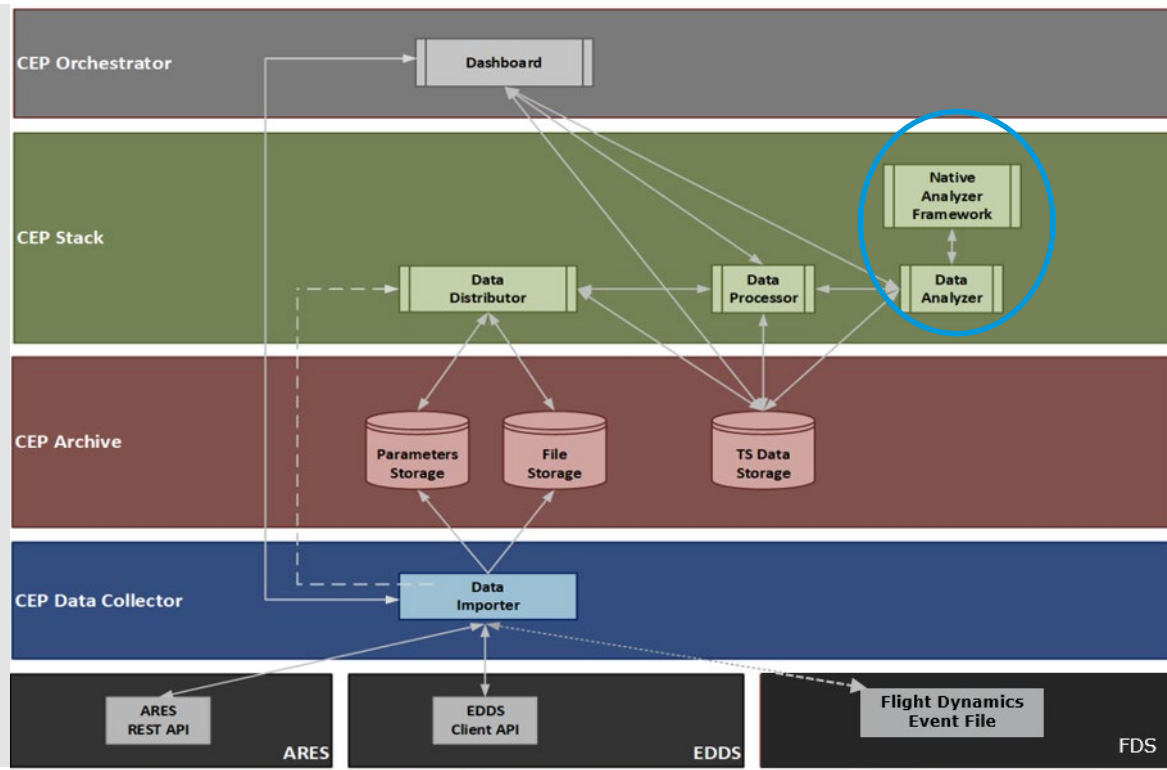
Technologies – Prototype trials – TICK Stack

**LoudML +
TensorFlow**

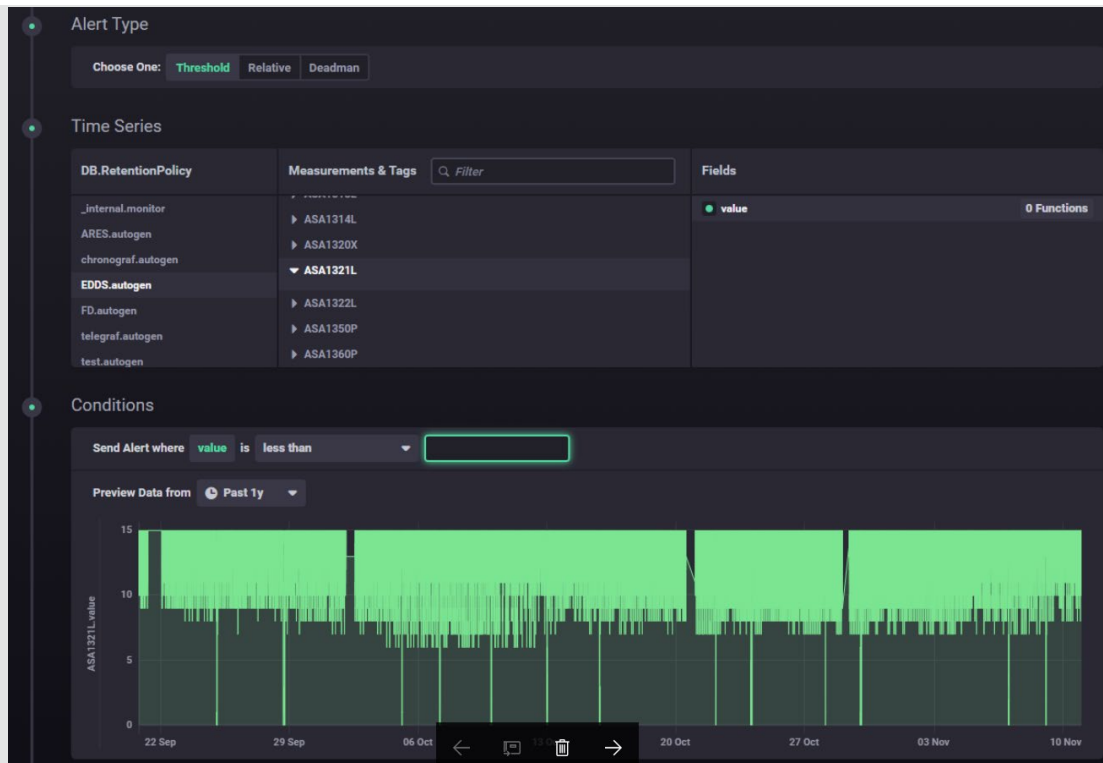


TensorFlow

Deep learning API to
prepare, train, and deploy
machine learning models
for predictive analytics of
InfluxDB data



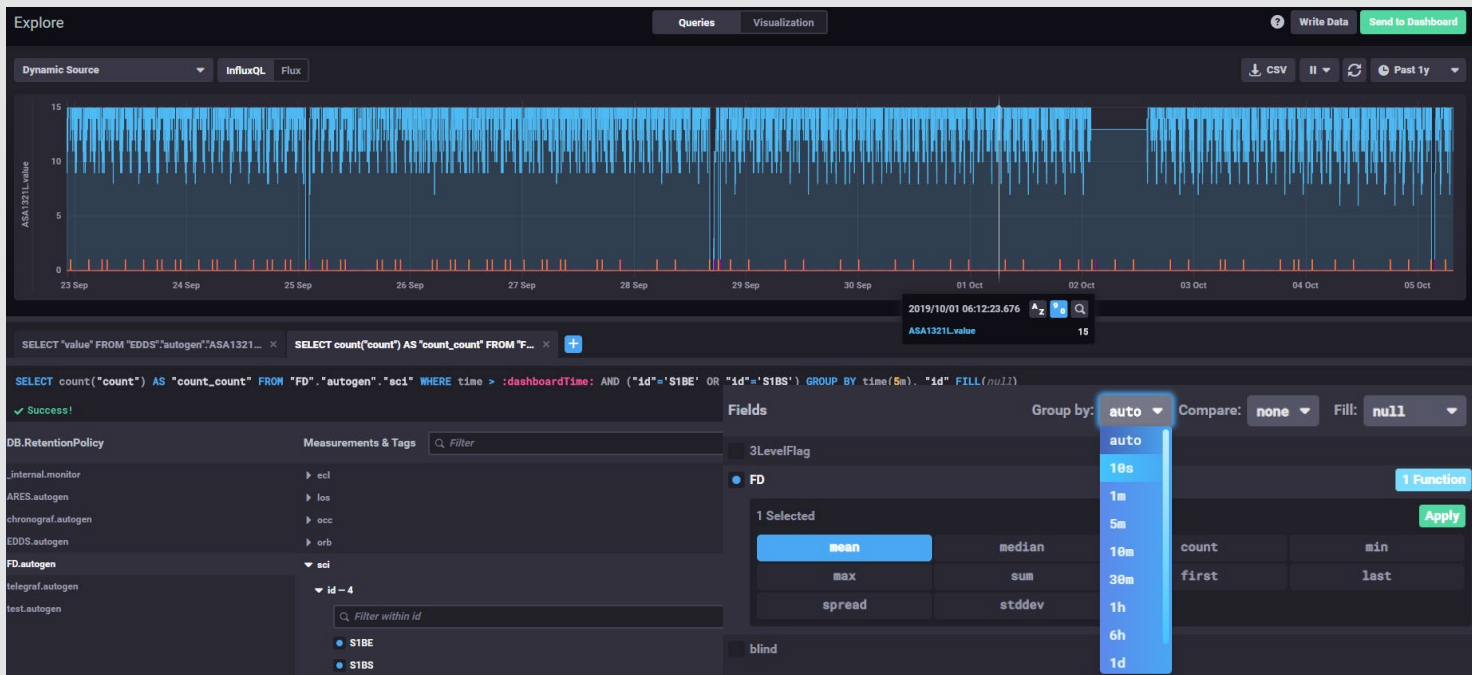
Technologies – Prototype trials – TICK Stack



Data normalisation ✓

Wizards for simple rules and statistics ✓

Technologies – Prototype trials – TICK Stack

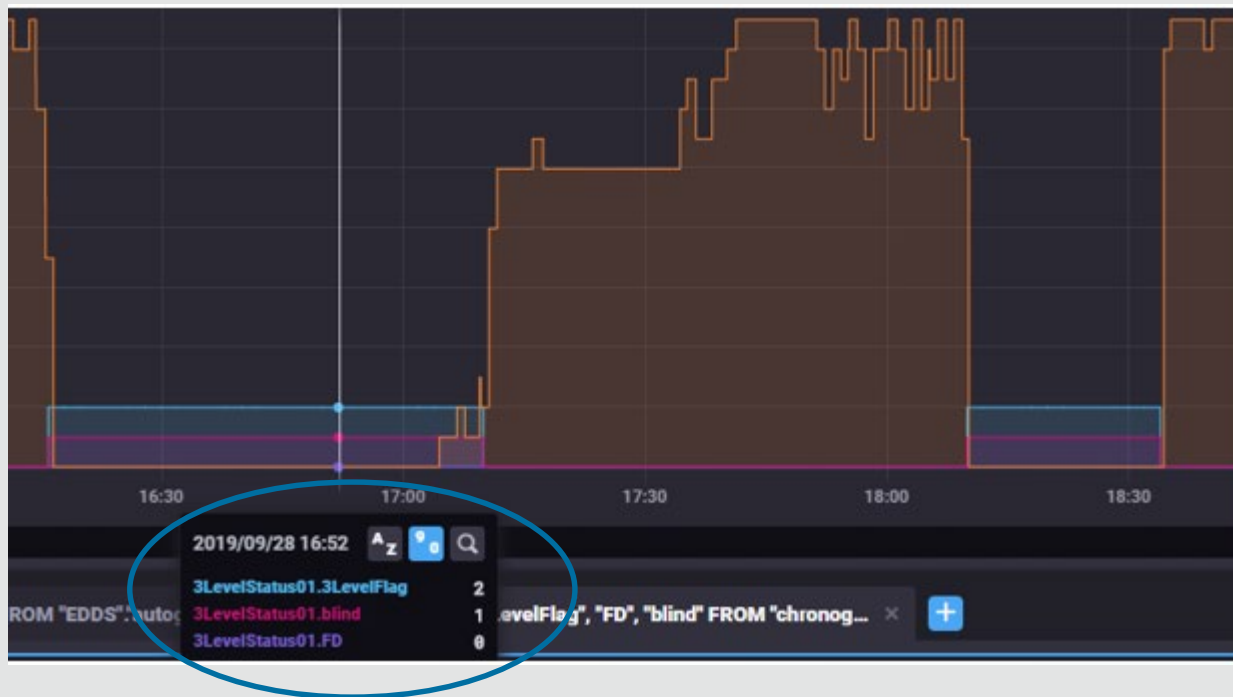


Simple
stream
window
analytics



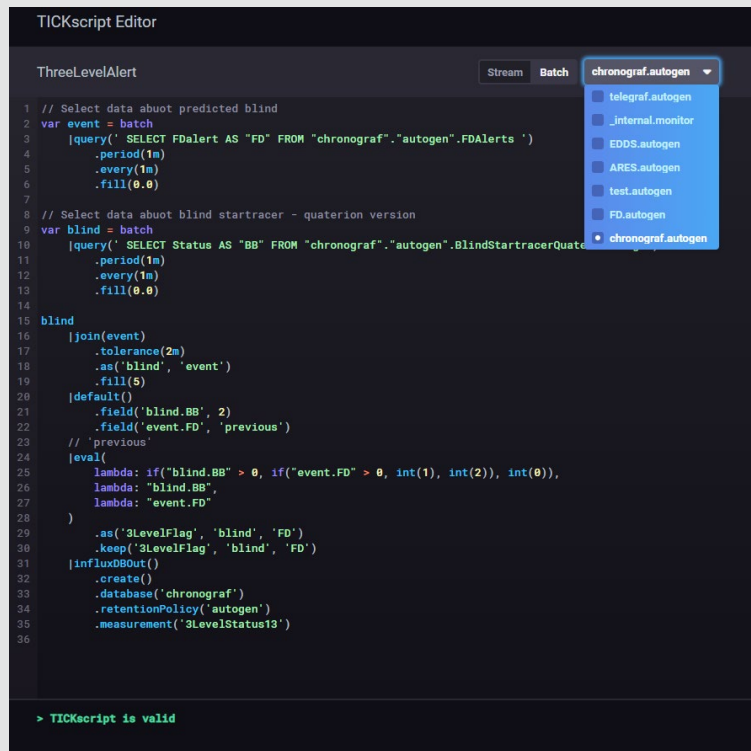
Queries





Conditional
alarm flags





```
TICKscript Editor

ThreeLevelAlert

Stream Batch chronograf.autogen

1 // Select data about predicted blind
2 var event = batch
3 |query(' SELECT FDAlert AS "FD" FROM "chronograf"."autogen".FDAlerts ')
4   .period(1m)
5   .every(1m)
6   .fill(0.0)
7
8 // Select data about blind startracer - quaternion version
9 var blind = batch
10 |query(' SELECT Status AS "BB" FROM "chronograf"."autogen".BlindStartracerQuat ')
11   .period(1m)
12   .every(1m)
13   .fill(0.0)
14
15 blind
16 |join(event)
17   .tolerance(2s)
18   .as('blind', 'event')
19   .fill(5)
20 |default()
21   .field('blind.BB', 2)
22   .field('event.FD', 'previous')
23 // 'previous'
24 |eval(
25   lambda: if("blind.BB" > 0, if("event.FD" > 0, int(1), int(2)), int(0)),
26   lambda: "blind.BB",
27   lambda: "event.FD"
28 )
29 .as('3LevelFlag', 'blind', 'FD')
30 .keep('3LevelFlag', 'blind', 'FD')
31 |influxDBOut()
32   .create()
33   .database('chronograf')
34   .retentionPolicy('autogen')
35   .measurement('3LevelStatus13')
36

> TICKscript is valid
```

Simple EPL ✗

Limited CEP capabilities – more focused on Extract, Transform, Load operations and not “true” CEP (first-order logic) operations ✗

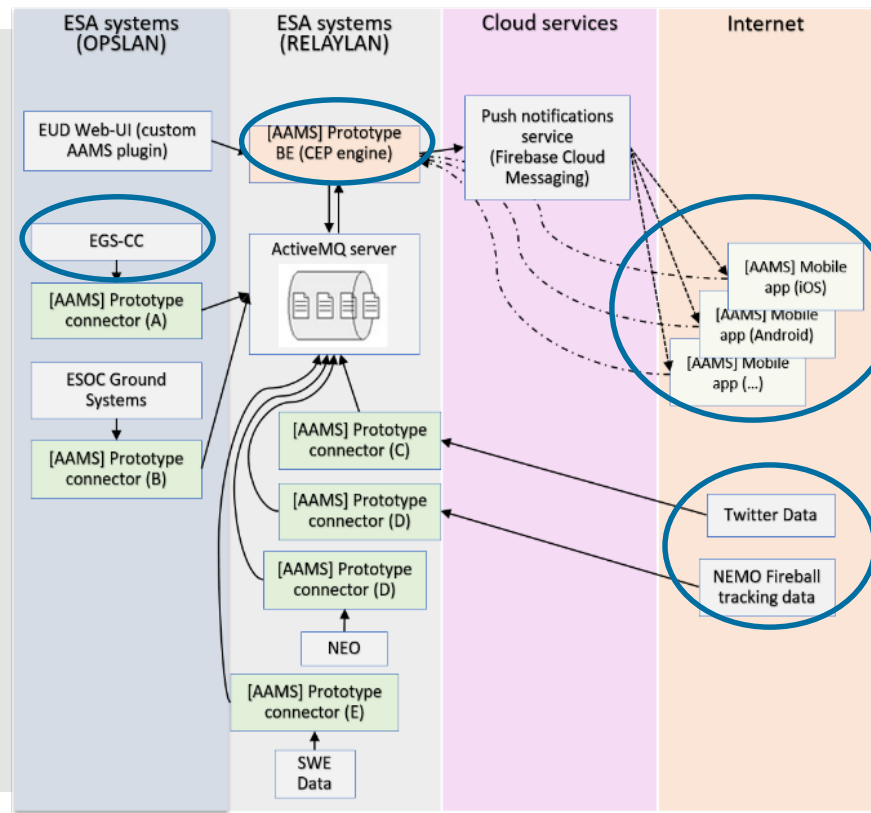
State machine-like constructs ✗

TICK2.0 may improve here

-> Replace Kapacitor in stack

Technologies – Prototype trials – Drools Fusion

Integrate directly
with **EGS-CC**



Mobile app UI

Ingest SWE, NEO
data and external
sources

Conclusions

Increasing need for automated, stateful event analysis in operations ground segments

Current M&C systems not equipped

A significant number of **use cases identified**

CEP a promising solution to aid operators, reduce alert fatigue, improve efficiency/automation

ESA **integrating and testing** a number of promising, **open source solution prototypes**

In future, **enhance integration with ML**



Thankyou for your attention!

Questions?