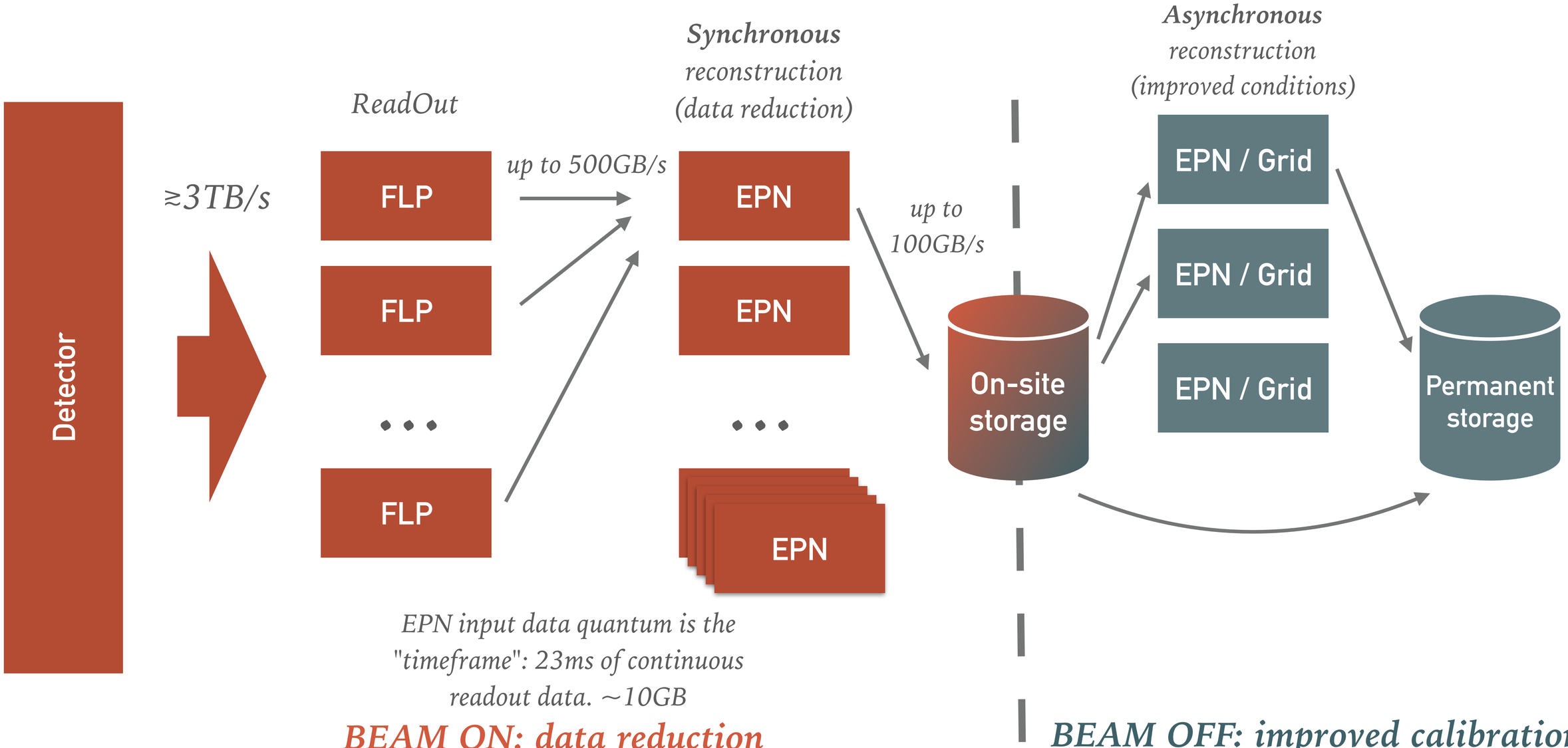
Evolution of the ALICE Software Framework for LHC Run 3

Giulio Eulisse (CERN), for the ALICE Collaboration

ALICE

ALICE IN RUN 3: POINT2



EPN input data quantum is the "timeframe": 23ms of continuous readout data. ~10GB

BEAM ON: data reduction

BEAM OFF: improved calibration

ALICE O2 SOFTWARE FRAMEWORK IN ONE SLIDE

Transport Layer: ALFA / FairMQ[1]

- **Standalone processes** *for deployment flexibility.*
- **Message passing** *as a parallelism paradigm.*
- **Shared memory** *backend for reduced memory usage and improved performance.*

[1] *See "ALFA: ALICE-FAIR new message queuing based framework" by Mohammad Al Turani*

ALICE O2 SOFTWARE FRAMEWORK IN ONE SLIDE

Data Layer: O2 Data Model

Message passing aware data model. Support for multiple backends:

- **Simplified, zero-copy** *format optimised for performance and direct GPU usage. Useful e.g. for TPC reconstruction on the GPU.*
- **ROOT based serialisation.** *Useful for QA and final results.*
- **Apache Arrow based.** *Useful as backend of the analysis ntuples and for integration with other tools.*

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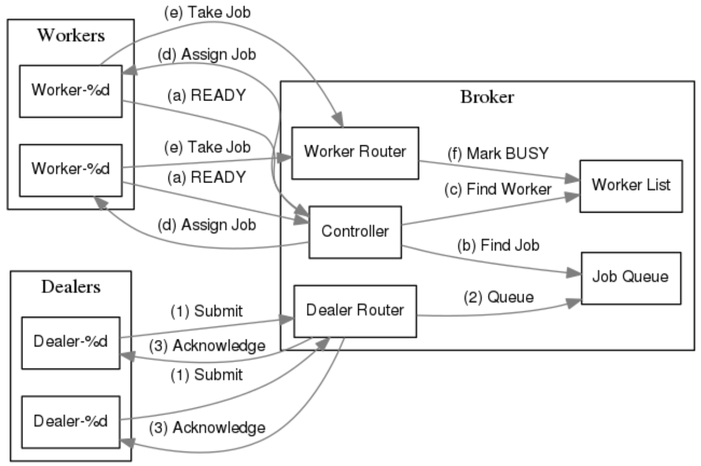
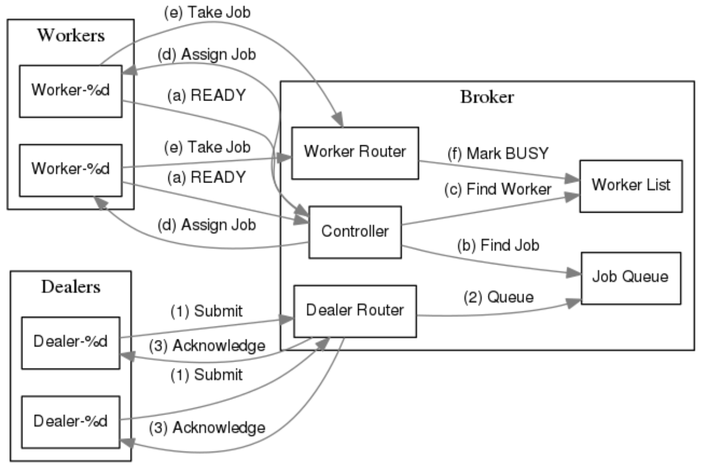
DISTRIBUTED SYSTEMS ARE HARD

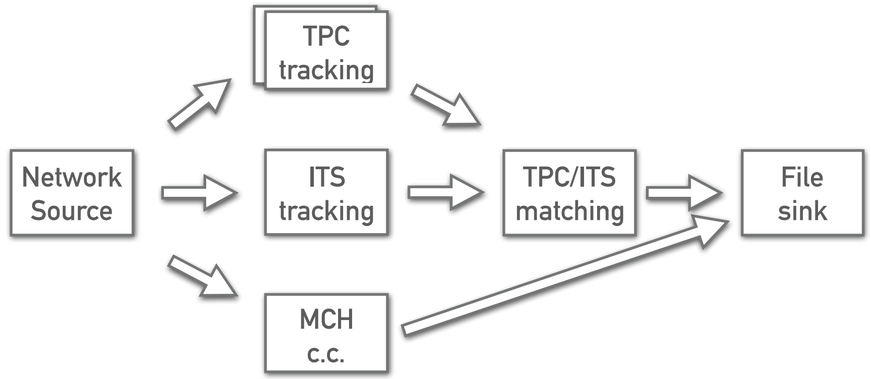


There are only **two hard problems** in distributed systems:

2. Exactly-once delivery
1. Guaranteed order of messages
2. Exactly-once delivery

DISTRIBUTED SYSTEMS ARE HARD





There are only **two hard problems** in distributed systems:

2. Exactly-once delivery
1. Guaranteed order of messages
2. Exactly-once delivery

Since too many people did not get the joke, we started thinking how to simplify this for the user, as a result we decided to build a **data flow engine (pipelines!)** on top of our distributed system backend.

ALICE O2 SOFTWARE FRAMEWORK IN ONE SLIDE

Data Processing Layer (DPL)

Abstracts away the hiccups of a distributed system, presenting the user a familiar "Data Flow" system.

- ***Reactive-like design*** *(push data, don't pull)*
- ***Declarative Domain Specific Language*** *for topology configuration (C++17 based).*
- ***Integration*** *with the rest of the production system, e.g. Monitoring, Logging, Control.*
- ***Laptop mode****, including graphical debugging tools.*

Data Layer: O2 Data Model

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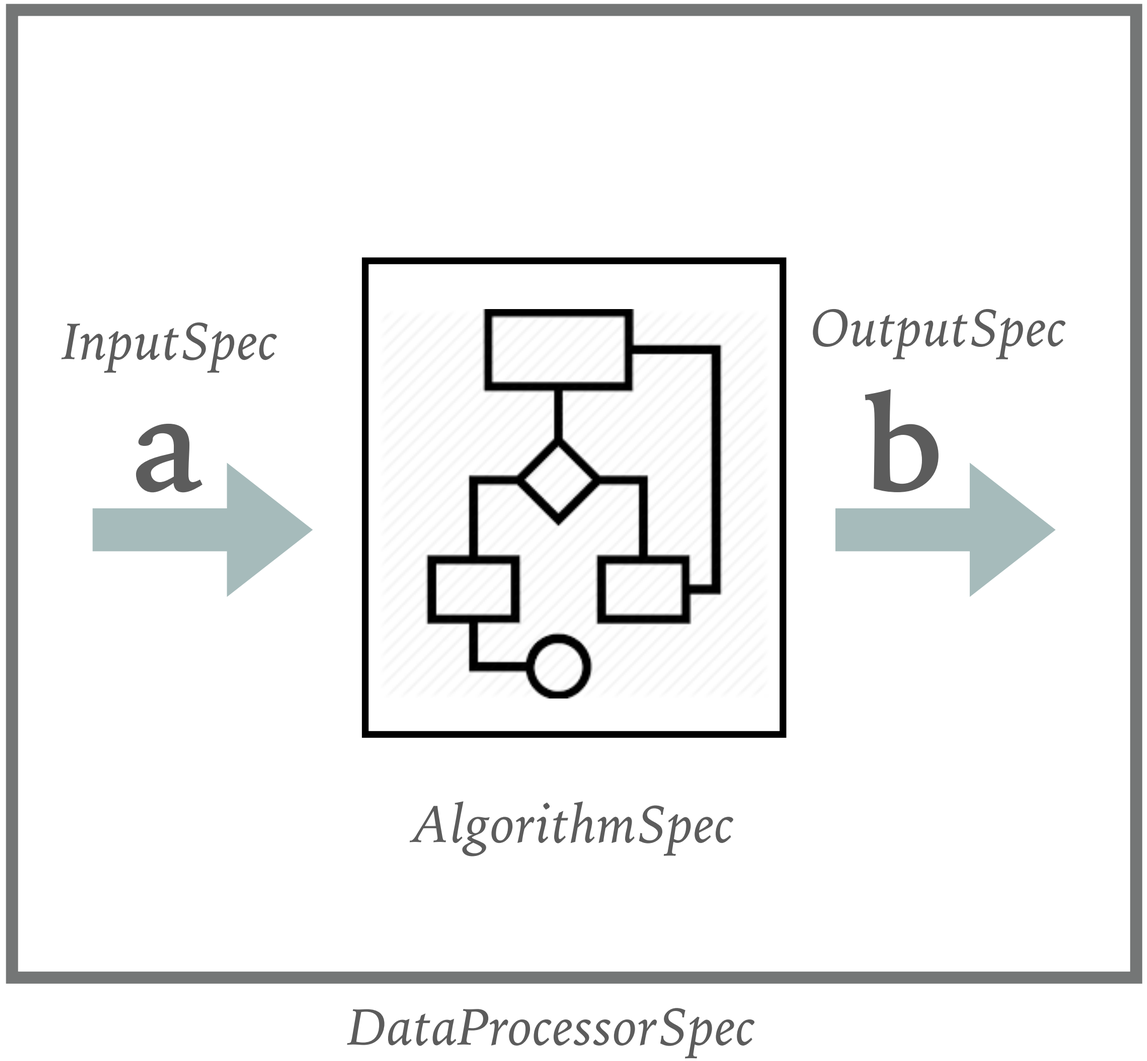
Transport Layer: ALFA / FairMQ[1]

- **Standalone processes** *for deployment flexibility.*
- **Message passing** *as a parallelism paradigm.*
- **Shared memory** *backend for reduced memory usage and improved performance.*

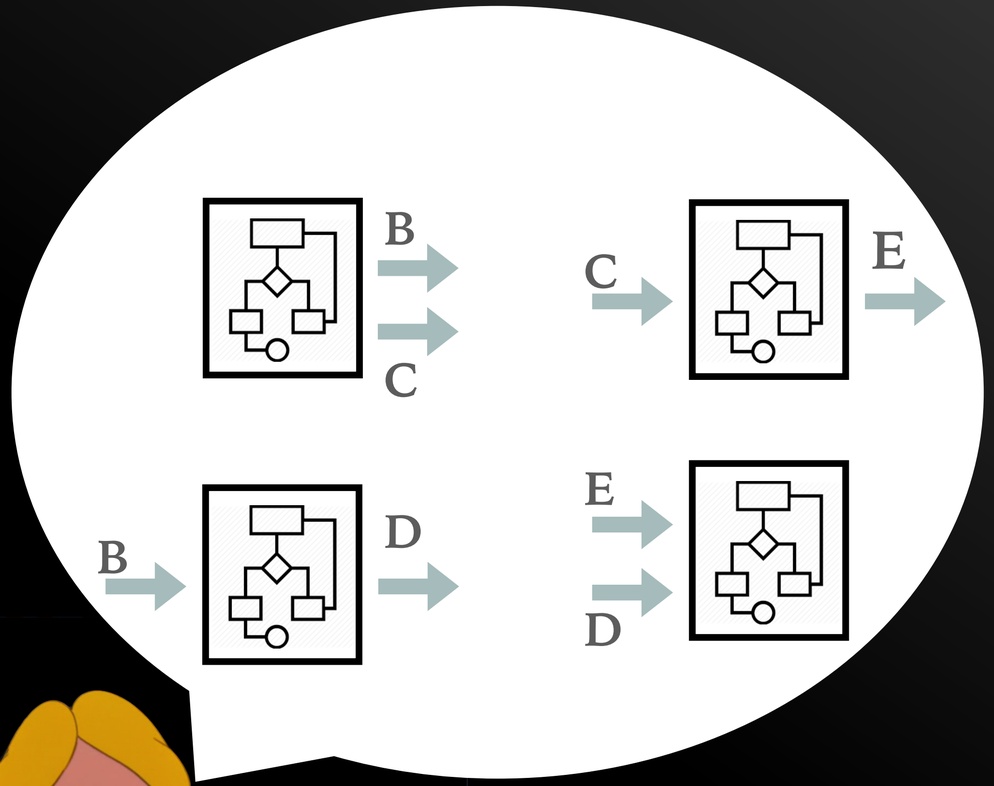
DATA PROCESSING LAYER: BUILDING BLOCK

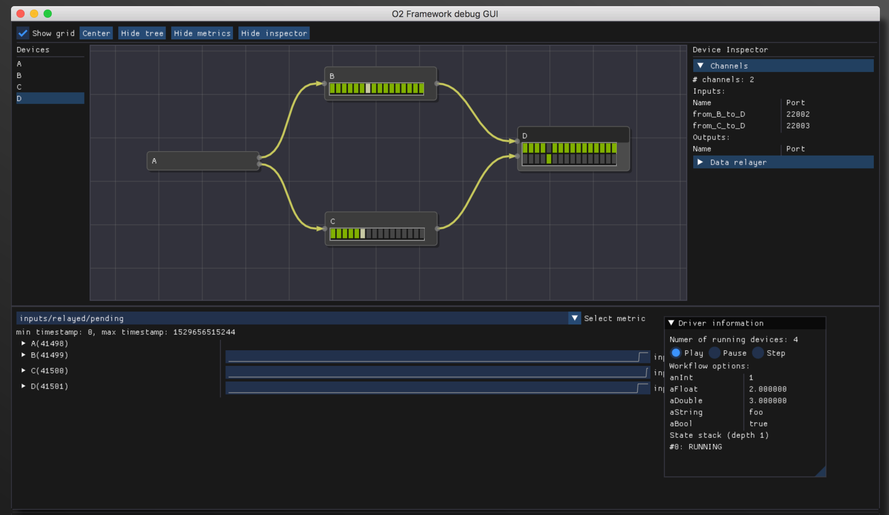
A DataProcessorSpec *defines a pipeline stage as a building block.*

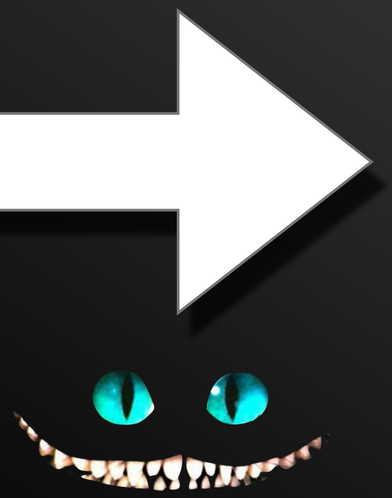
- *Specifies **inputs and outputs** in terms of the O2 Data Model descriptors.*
- *Provide an implementation of how to act on the inputs to produce the output.*
- *Advanced user can express possible data or time parallelism opportunities.*



DATA PROCESSING LAYER: IMPLICIT TOPOLOGY

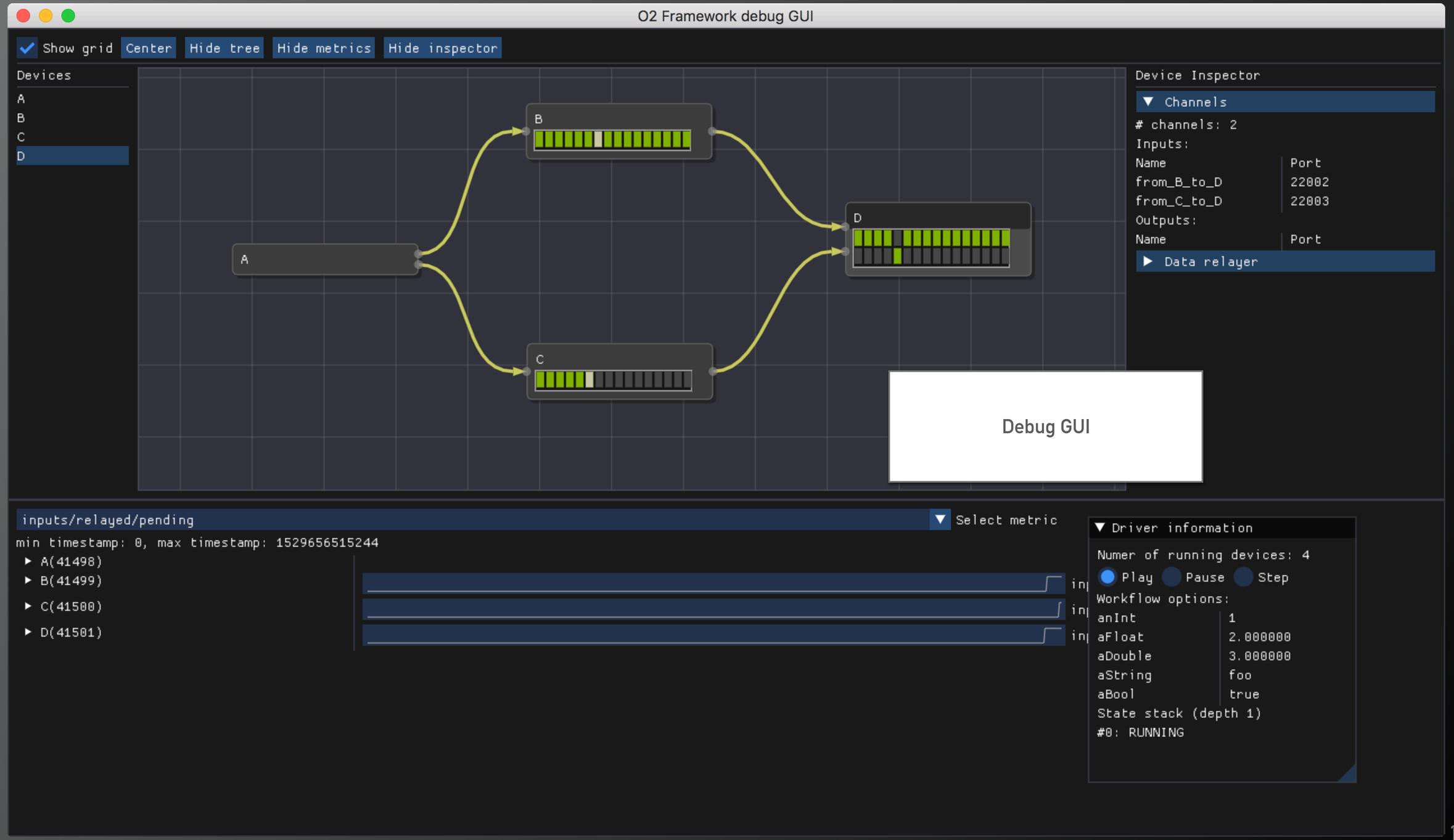


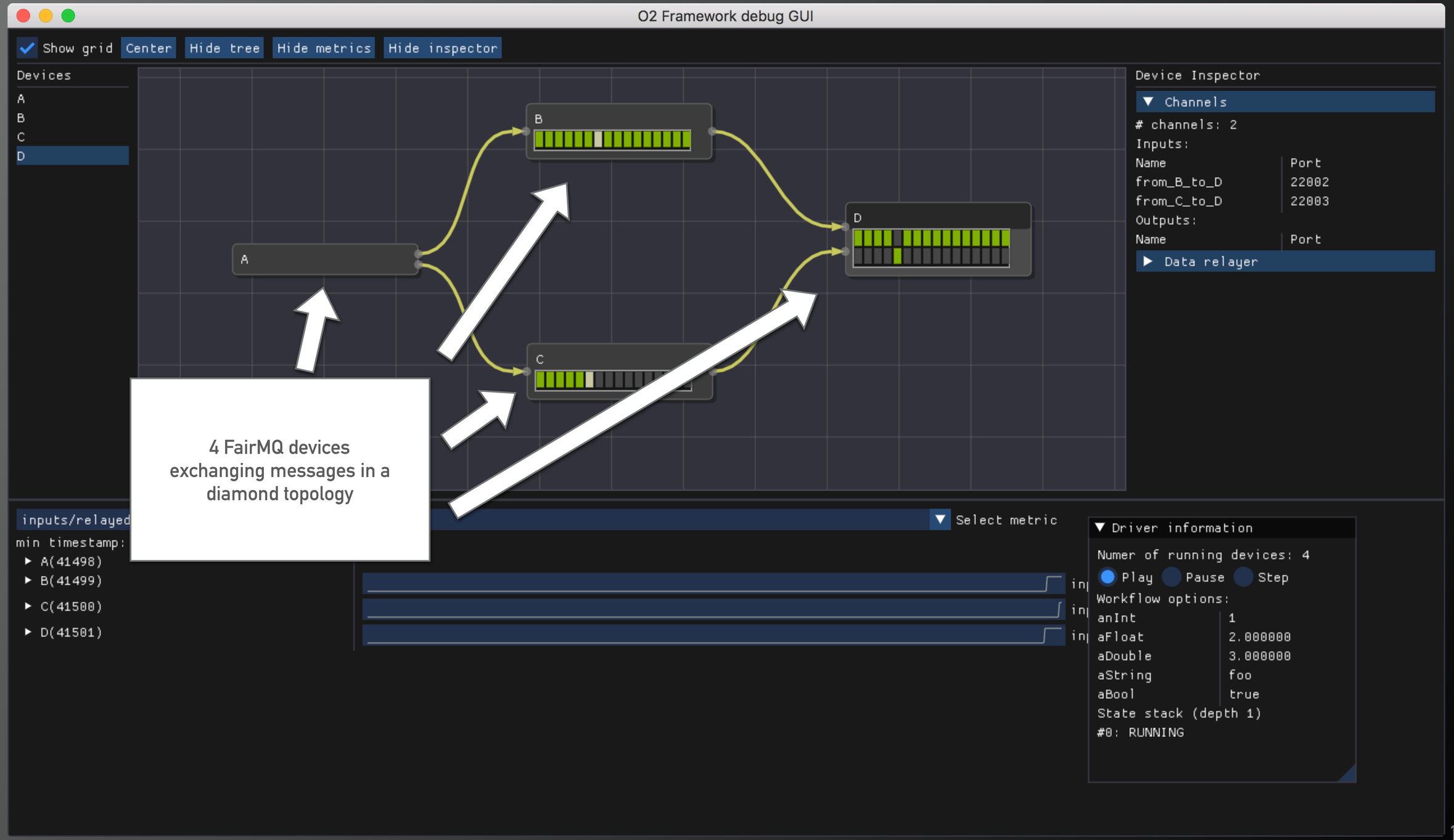




Data Processing Layer

Topology is defined implicitly.
Topological sort ensures a viable dataflow is constructed (no cycles!).
Laptop users gets immediate feedback through the debug GUI.
Service API allows integration with non data flow components (e.g. Control)


O2 Framework debug GUI
Show grid
Center
Hide tree
Hide metrics
Hide inspector
Devices
A
B
C
D
A
B
C
D
Device Inspector
Channels
channels: 2
Inputs:
Name
Port
from_B_to_D
22002
from_C_to_D
22003
Outputs:
Name
Port
Data relayer
Debug GUI
inputs/relayed/pending
Select metric
min timestamp: 0, max timestamp: 1529656515244
A(41498)
B(41499)
C(41500)
D(41501)
Driver information
Numer of running devices: 4
Play
Pause
Step
Workflow options:
anInt
1
aFloat
2.000000
aDouble
3.000000
aString
foo
aBool
true
State stack (depth 1)
#0: RUNNING


O2 Framework debug GUI
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Device Inspector
Channels
channels: 2
Inputs:
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Port
from_B_to_D
22002
from_C_to_D
22003
Outputs:
Name
Port
Data relayer
4 FairMQ devices exchanging messages in a diamond topology
inputs/relayed
Select metric
min timestamp:
A(41498)
B(41499)
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D(41501)
Driver information
Numer of running devices: 4
Play
Pause
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Workflow options:
anInt
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aString
foo
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true
State stack (depth 1)
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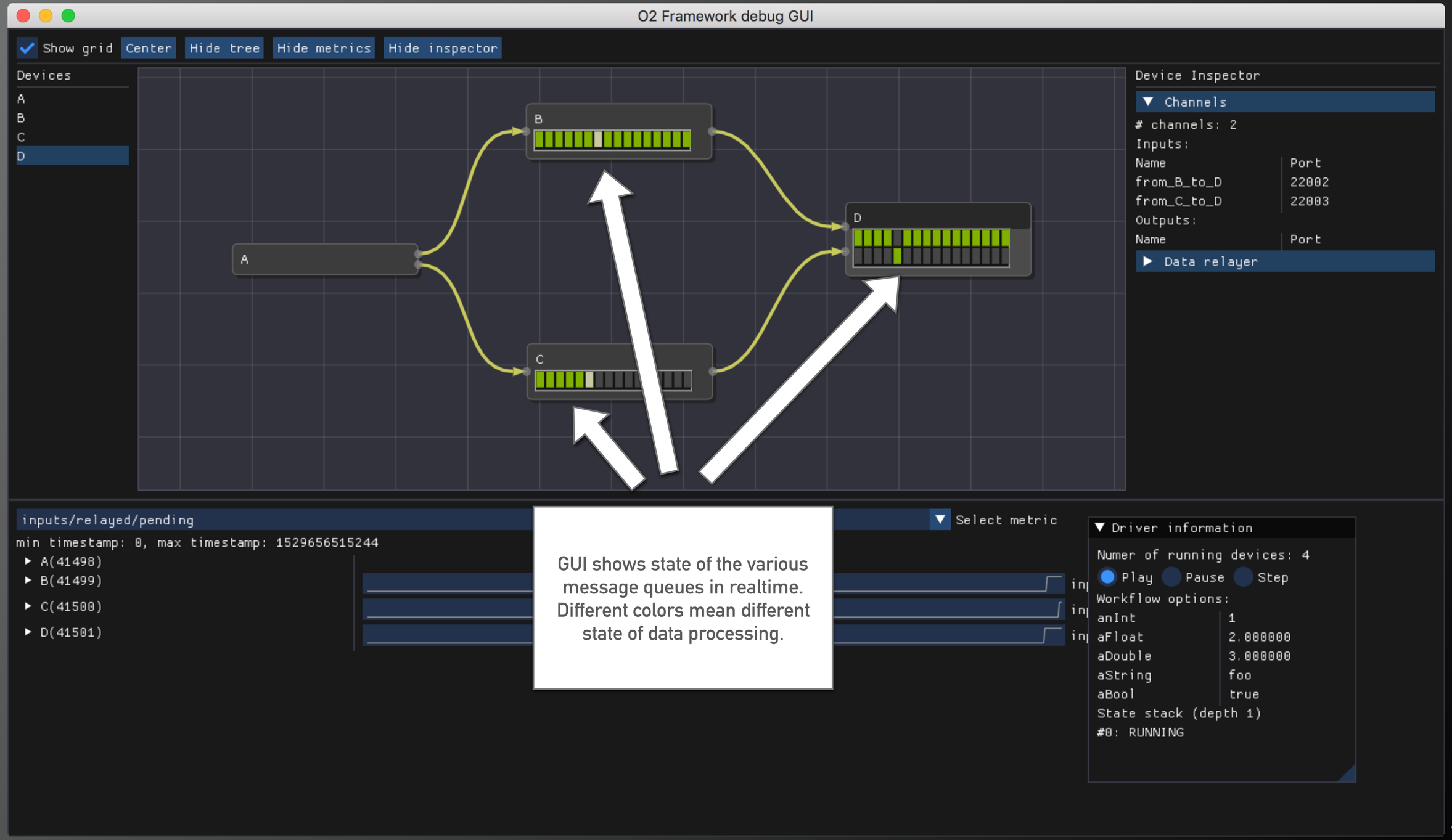
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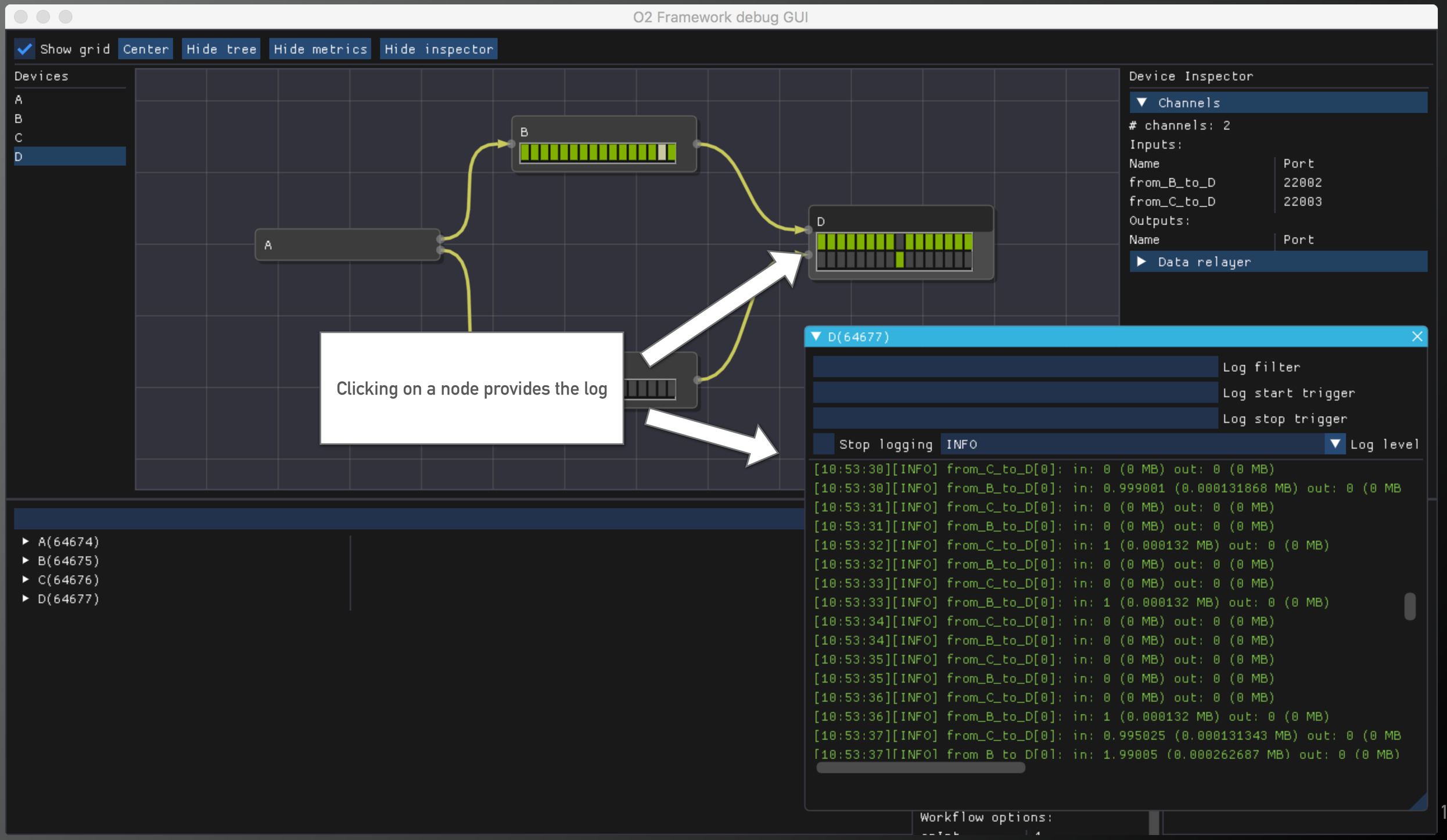
Data relayer
inputs/relayed/pending
Select metric
min timestamp: 0, max timestamp: 1529656515244
A(41498)
B(41499)
C(41500)
D(41501)
GUI shows state of the various message queues in realtime. Different colors mean different state of data processing.
Driver information
Numer of running devices: 4
Play
Pause
Step
Workflow options:
anInt
1
aFloat
2.000000
aDouble
3.000000
aString
foo
aBool
true
State stack (depth 1)
#0: RUNNING


O2 Framework debug GUI
Show grid
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Hide tree
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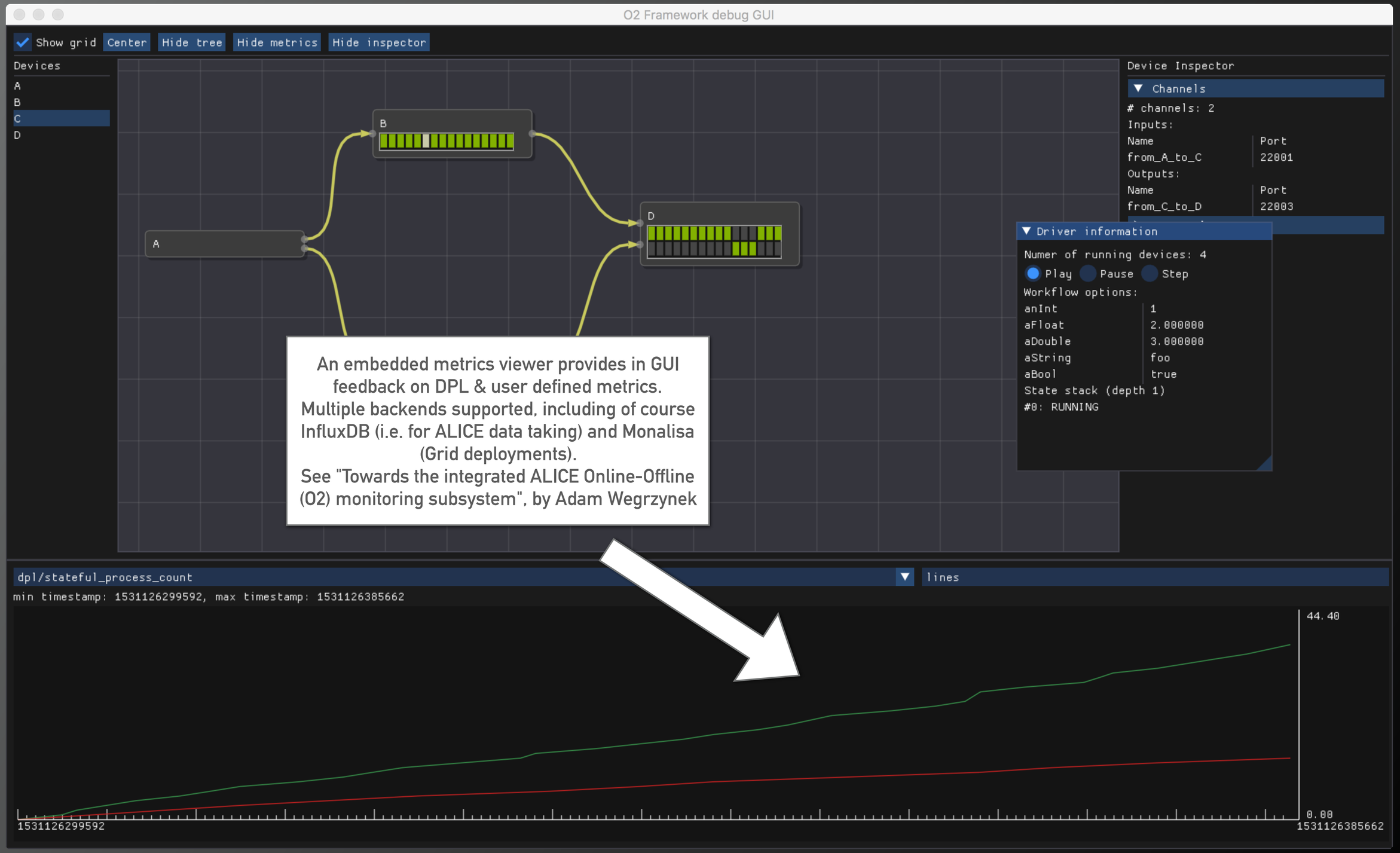
Hide inspector
Devices
A
B
C
D
B
A
D
Clicking on a node provides the log
Device Inspector
Channels
channels: 2
Inputs:
Name
Port
from_B_to_D
22002
from_C_to_D
22003
Outputs:
Name
Port
Data relayer
D(64677)
Log filter
Log start trigger
Log stop trigger
Stop logging
INFO
Log level
[10:53:30][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:30][INFO] from_B_to_D[0]: in: 0.999001 (0.000131868 MB) out: 0 (0 MB
[10:53:31][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:31][INFO] from_B_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:32][INFO] from_C_to_D[0]: in: 1 (0.000132 MB) out: 0 (0 MB)
[10:53:32][INFO] from_B_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:33][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:33][INFO] from_B_to_D[0]: in: 1 (0.000132 MB) out: 0 (0 MB)
[10:53:34][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:34][INFO] from_B_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:35][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:35][INFO] from_B_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:36][INFO] from_C_to_D[0]: in: 0 (0 MB) out: 0 (0 MB)
[10:53:36][INFO] from_B_to_D[0]: in: 1 (0.000132 MB) out: 0 (0 MB)
[10:53:37][INFO] from_C_to_D[0]: in: 0.995025 (0.000131343 MB) out: 0 (0 MB
[10:53:37][INFO] from_B_to_D[0]: in: 1.99005 (0.000262687 MB) out: 0 (0 MB)
A(64674)
B(64675)
C(64676)
D(64677)
Workflow options: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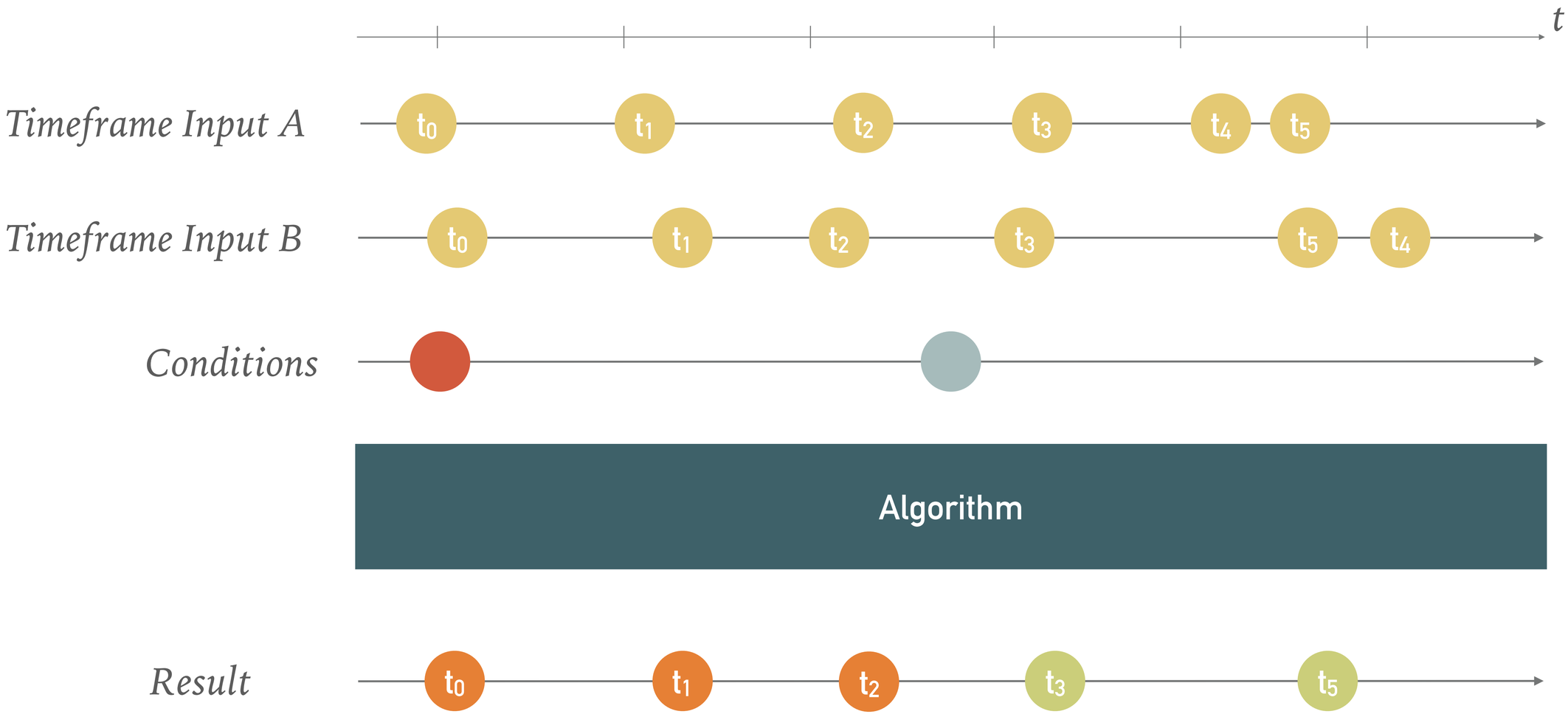
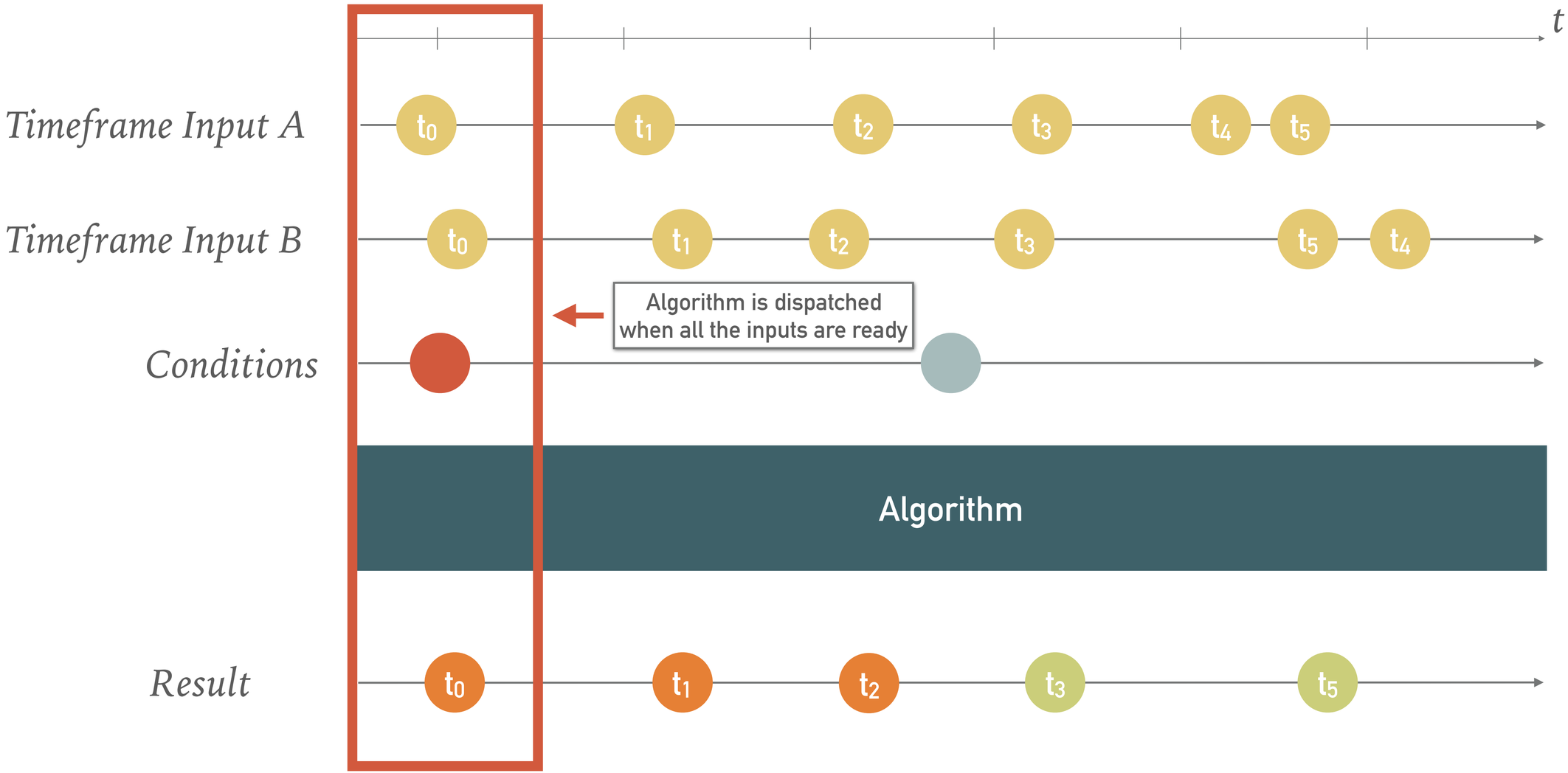
true
State stack (depth 1)
#0: RUNNING
An embedded metrics viewer provides in GUI feedback on DPL & user defined metrics.
Multiple backends supported, including of course InfluxDB (i.e. for ALICE data taking) and Monalisa (Grid deployments).
See "Towards the integrated ALICE Online-Offline (O2) monitoring subsystem", by Adam Wegrzynek
dpl/stateful_process_count
lines
min timestamp: 1531126299592, max timestamp: 1531126385662
44.40
0.00
1531126299592
1531126385662

REACTIVE DESIGN

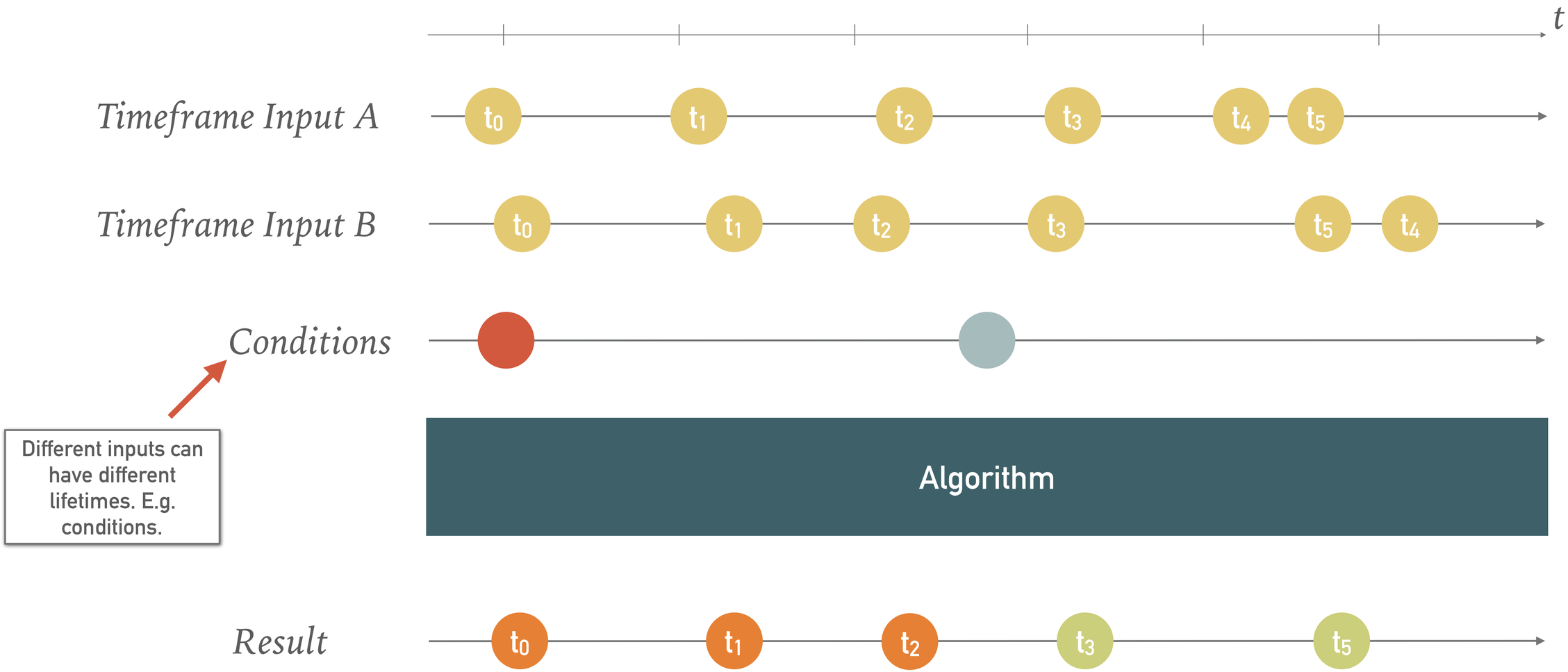
Data is described as pushed through the pipeline.



REACTIVE DESIGN



REACTIVE DESIGN



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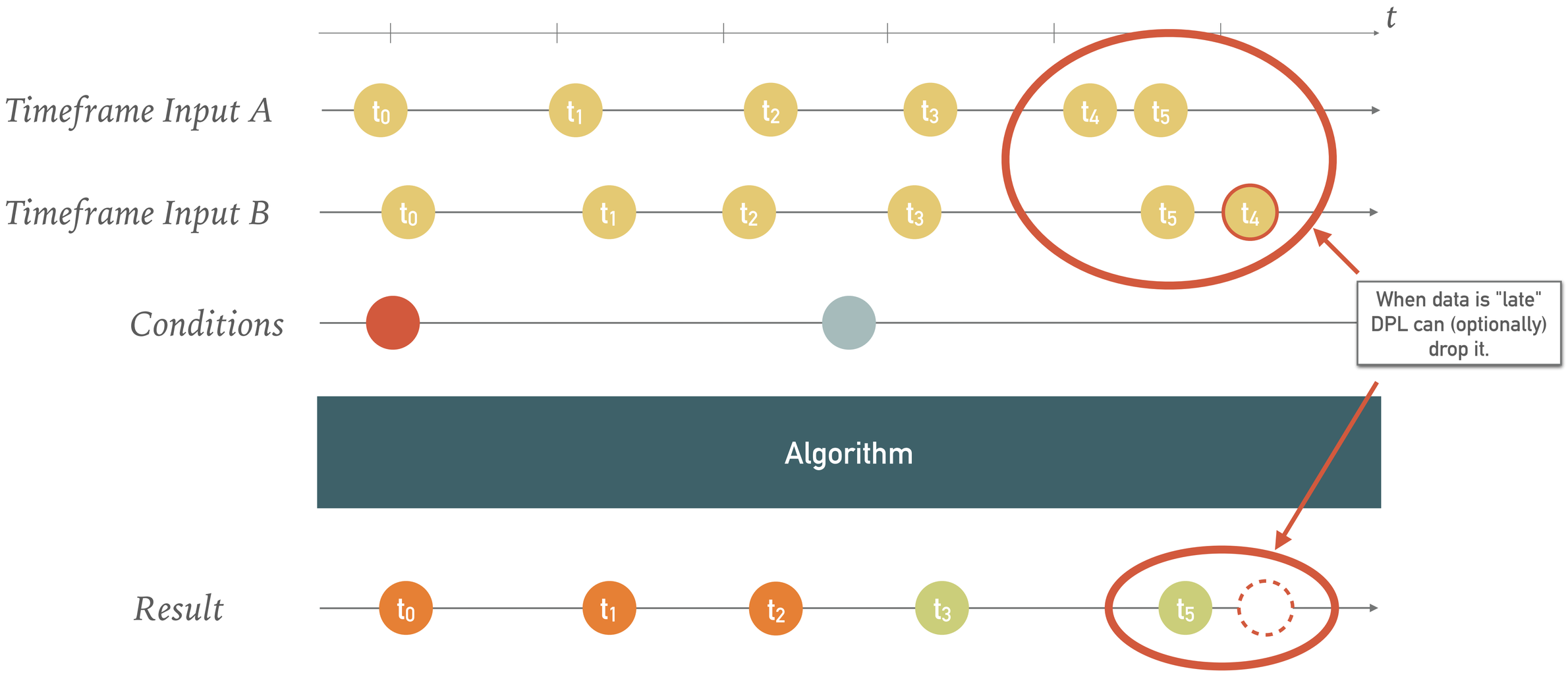
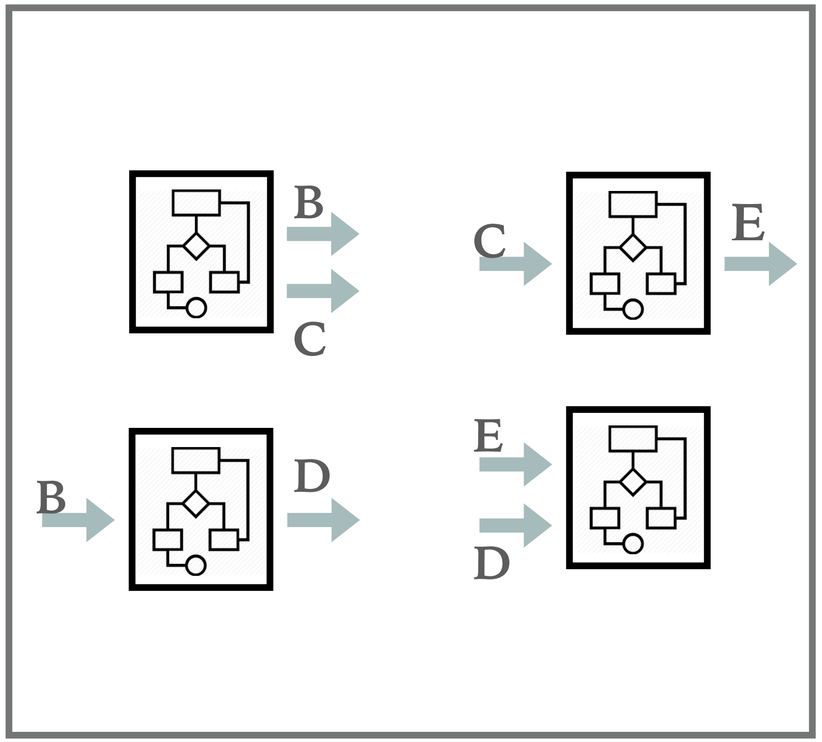


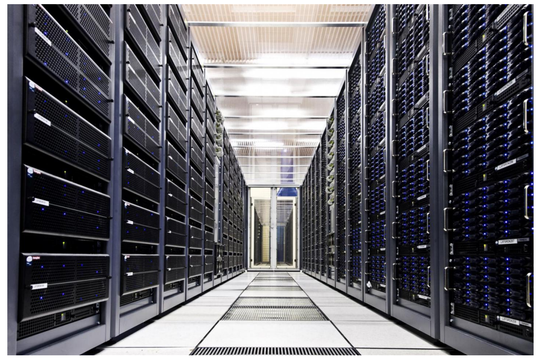
Support for multiple deployment strategies.



Compiles into a single executable for the laptop user.

Generates DDS[1] configuration for deployment on a farm.

```
<topology id="o2-dataflow">
 <decltask id="A">
  <exe reachable="true">../bin/o2DiamondWorkflow --id A ...</exe>
 </decltask>
 <decltask id="B">
  <exe reachable="true">../bin/o2DiamondWorkflow --id B ...</exe>
 </decltask>
 <decltask id="C">
  <exe reachable="true">../bin/o2DiamondWorkflow --id C ...</exe>
 </decltask>
 <decltask id="D">
   <exe reachable="true">../bin/o2DiamondWorkflow --id D ...</exe>
 </decltask>
</topology>
```



Integration with O2 Control system ongoing.[2]

[1] see "DDS – The Dynamic Deployment System" poster by Andrey Lebved

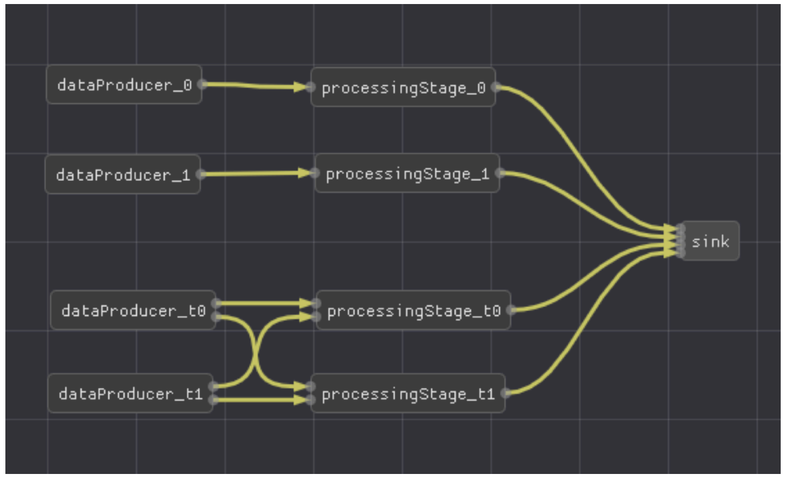
[2] see "Towards the ALICE Online-Offline (O2) control system" by Teo Mrnjavac

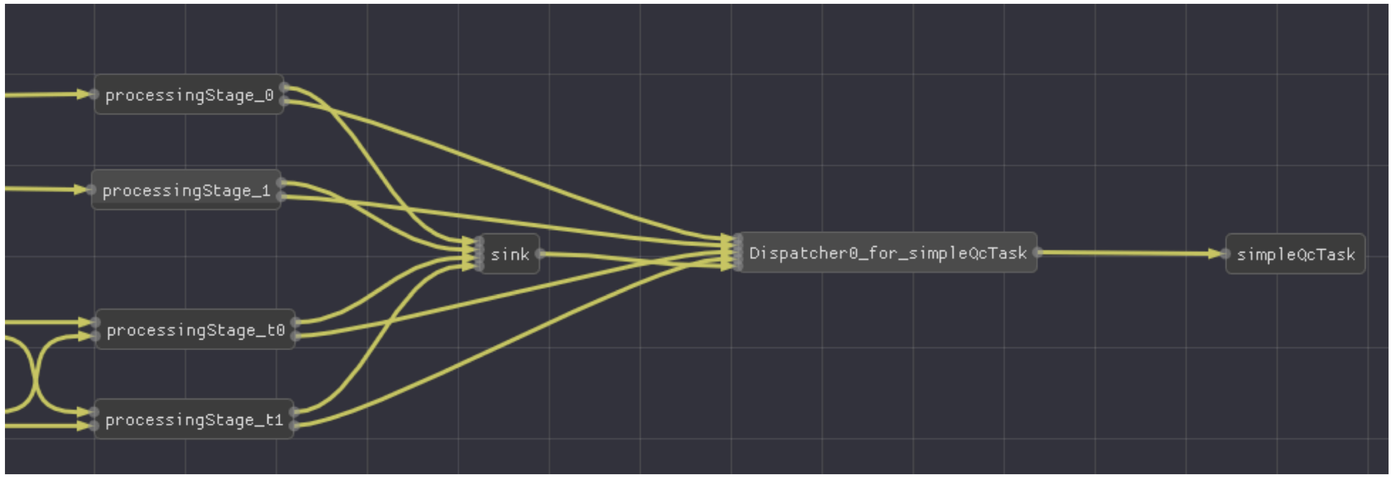
```cpp
#include "Framework/runDataProcessing.h"

using namespace o2::framework;

AlgorithmSpec simplePipe(std::string const &what) {
  return AlgorithmSpec{ [what](ProcessingContext& ctx) {
    auto bData = ctx.outputs().make<int>(OutputRef{what}, 1);
  } };
}

WorkflowSpec defineDataProcessing(ConfigContext const&specs) {
  return WorkflowSpec{
  { "A", Inputs{}, {OutputSpec{{"a1"}, "TST", "A1"}, OutputSpec{{"a2"}, "TST", "A2"}},
    AlgorithmSpec{
      [](ProcessingContext &ctx) {
       auto aData = ctx.outputs().make<int>(OutputRef{ "a1" }, 1);
       auto bData = ctx.outputs().make<int>(OutputRef{ "a2" }, 1);
      }
    }
  },
  { "B", {InputSpec{"x", "TST", "A1"}}, {OutputSpec{{"b1"}, "TST", "B1"}}, simplePipe("b1")},
  { "C", {InputSpec{"x", "TST", "A2"}}, {OutputSpec{{"c1"}, "TST", "C1"}}, simplePipe("c1")},
  { "D", {InputSpec{"b", "TST", "B1"}, InputSpec{"c", "TST", "C1"}}, Outputs{},
    AlgorithmSpec{[](ProcessingContext &ctx) {}}
  }
  };
}
```

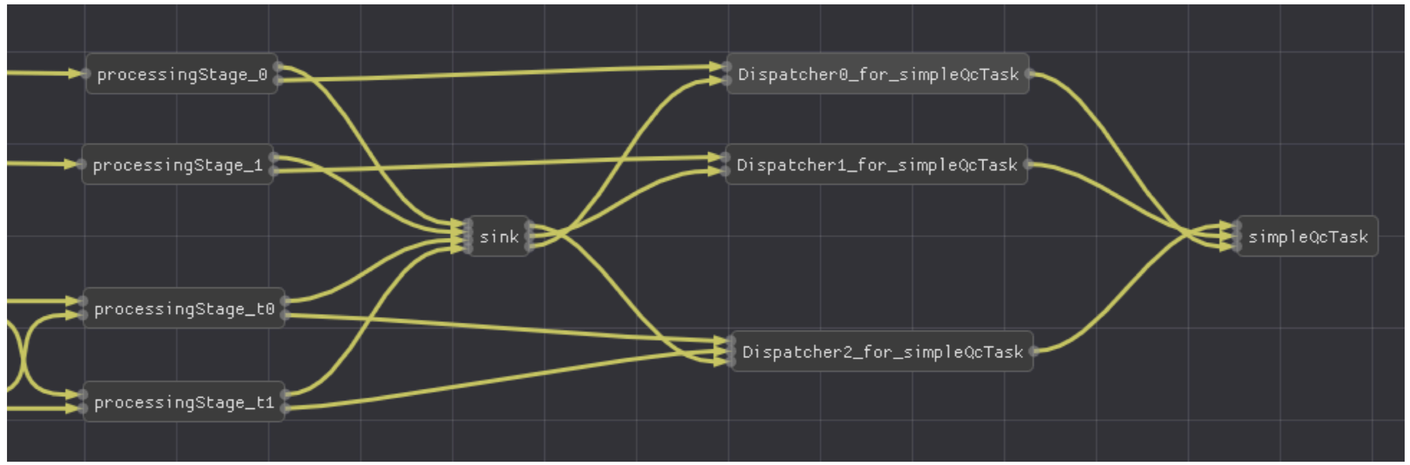
The previous example (GUI included) requires 27 user's SLOC.

A FEW EXAMPLES

COMPOSABLE WORKFLOWS

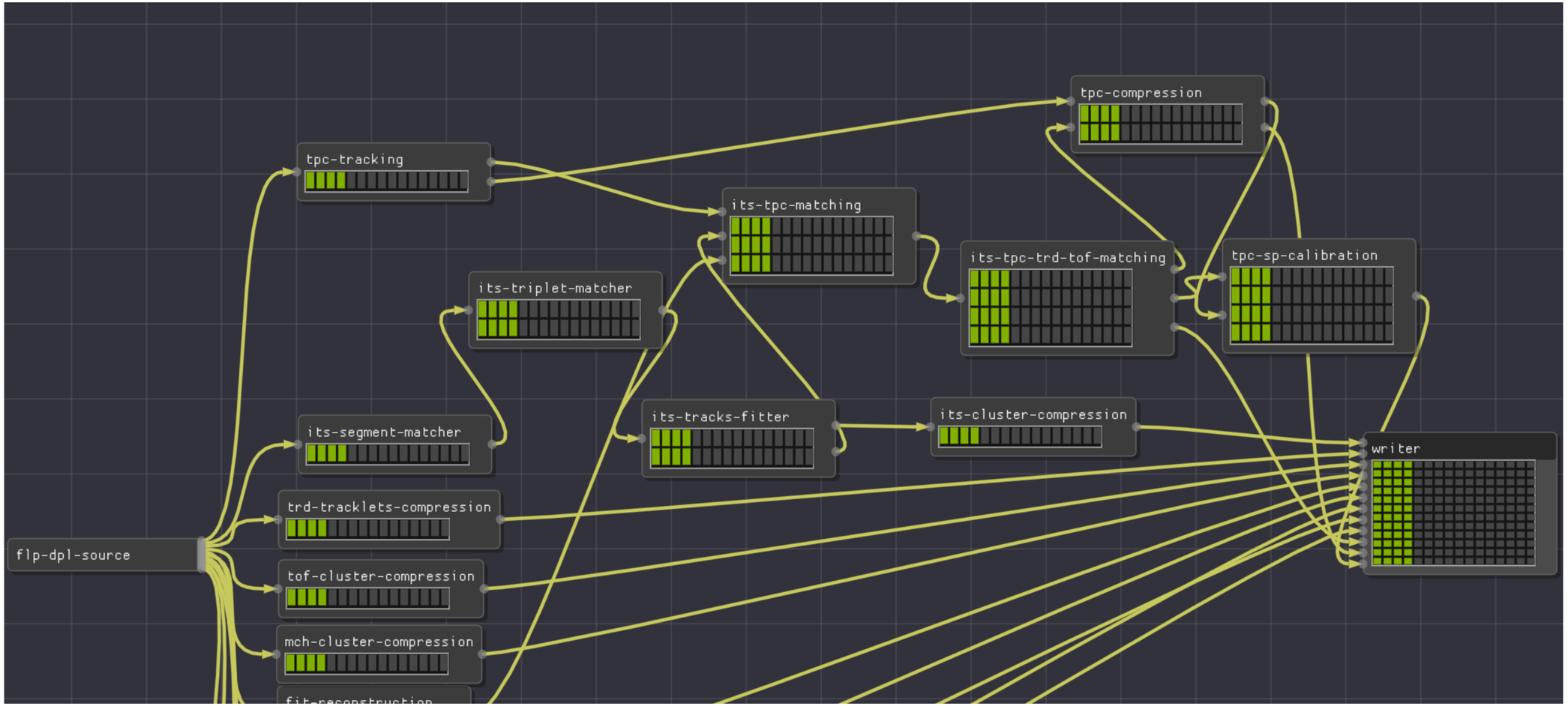






Declarative configuration allows for easy customisation: e.g. adding a (one or more) dispatchers for QA.

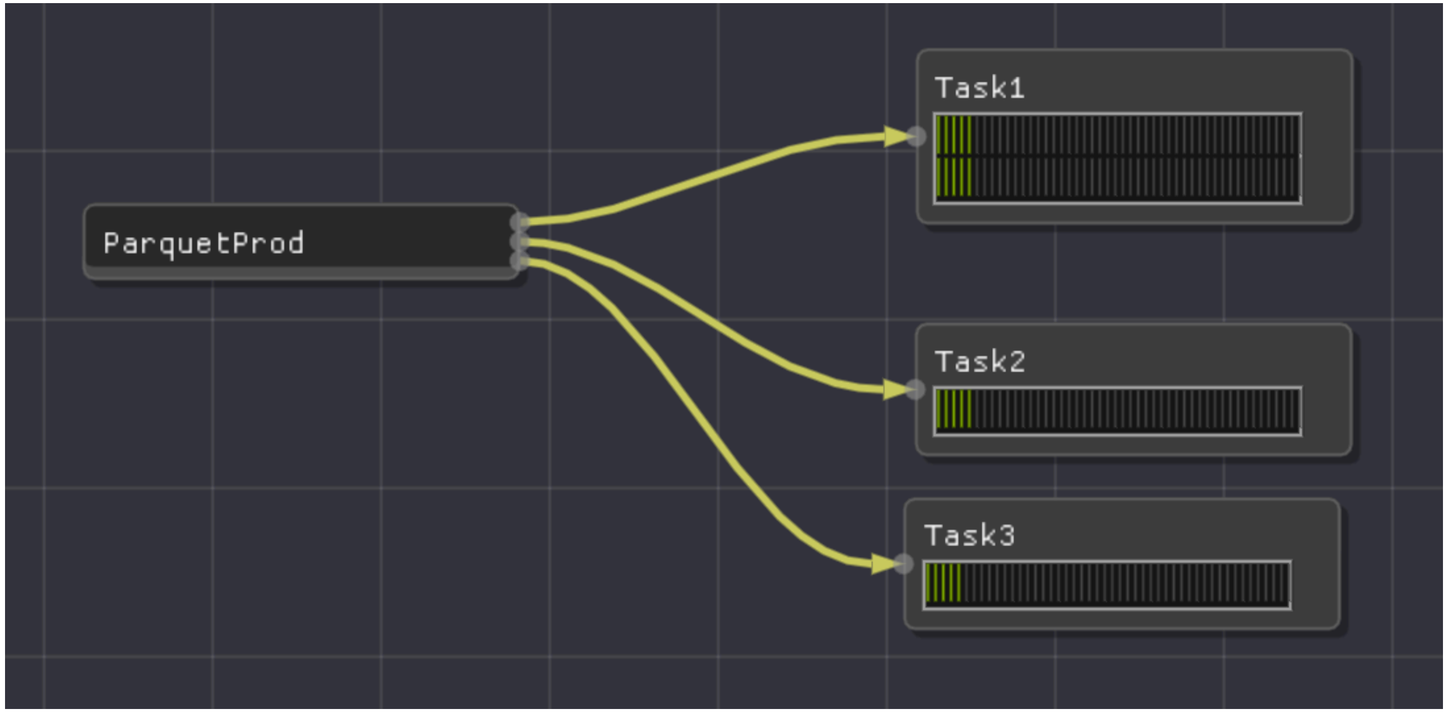
RECONSTRUCTION & GENERAL DATAFLOW



See "Data handling in the ALICE O2 event processing" by Matthias Richter

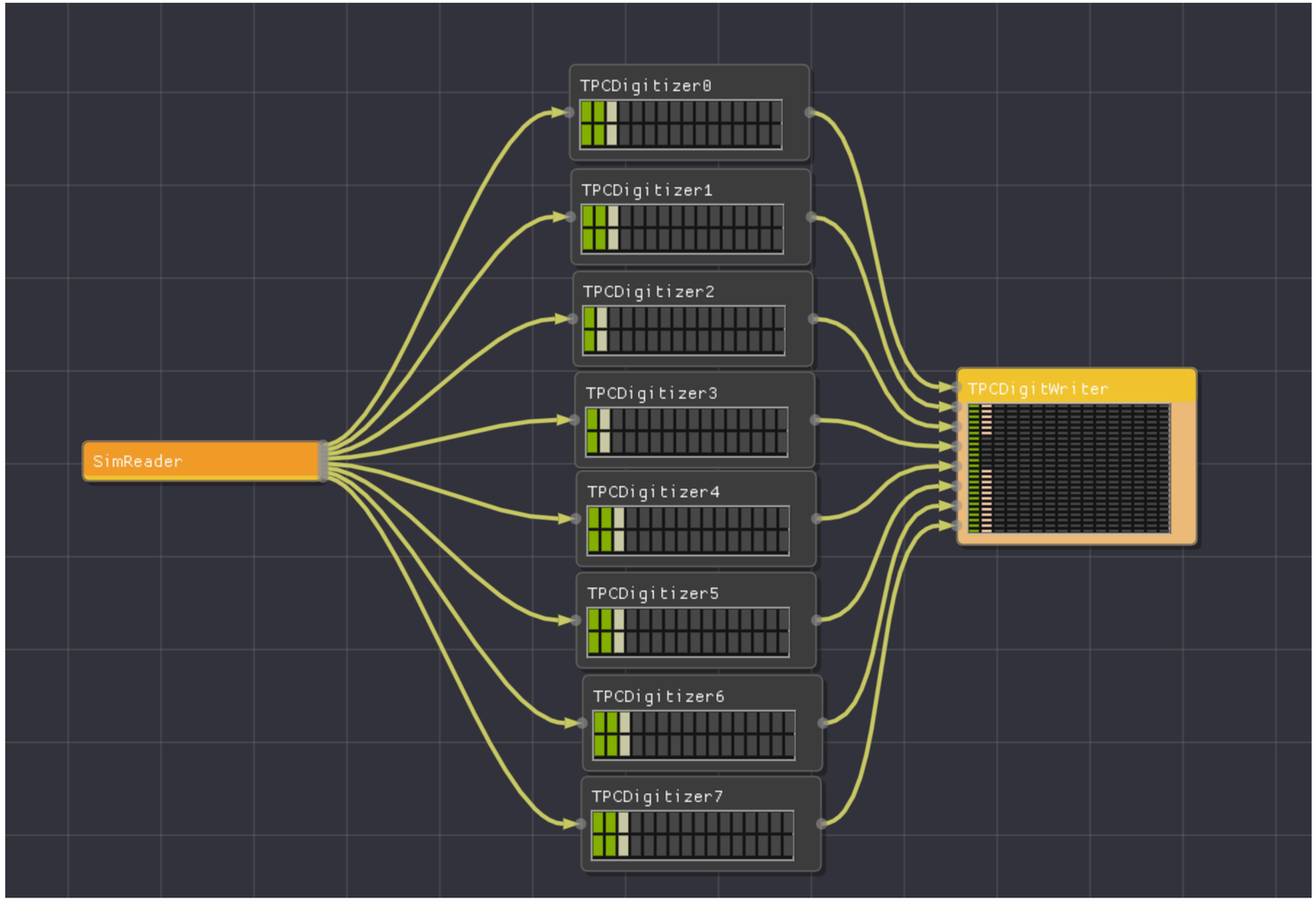
DPL AND ANALYSIS

We are investigating about using the Data Processing Layer also for Analysis.



See "The ALICE Analysis Framework for LHC Run 3 " by Dario Berzano

PARALLEL DIGITIZATION



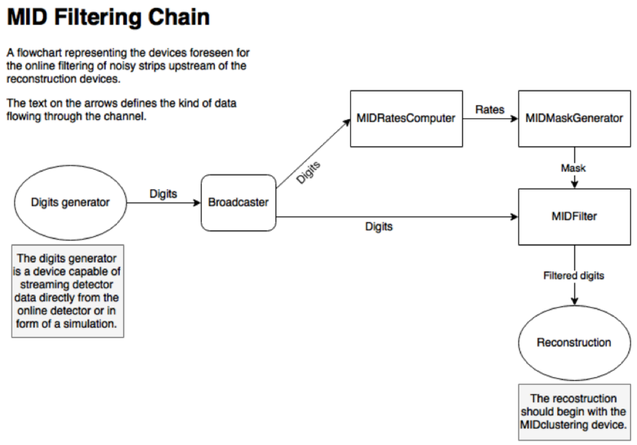
See "A scalable and asynchronous detector simulation system based on ALFA" by Sandro Wenzel

DPL USAGE: MUON IDENTIFIER FILTERING CHAIN

Nice demonstrator by Gabriele Fronzè for Muon Identifier (MID) filtering.

MID Filtering chain concept

github.com/gabrielefronze/AliceO2/tree/dev-DPL-Apr18-2/Detectors/MUON/MID/Filtering



MID Filtering in DPL (2)

github.com/gabrielefronze/AliceO2/blob/dev-DPL-Apr18-2/Detectors/MUON/MID/Filtering/src/FilteringChainDPL.cxx

And it works!

SUMMARY

- The challenges posed by Run 3 imposed to rethink ALICE Computing Architecture, **blending the traditional Online and Offline roles**.
- The **message passing ALFA Framework** is the foundation of ALICE O2 Software Framework.
- We built a message passing / shared memory friendly data model which minimises copy and (de-)serialisation.
- Taking advantage of the O2 Data Model we build a **data flow engine on top of ALFA** to reduce user code and abstract away common hiccups of distributed systems.

BACKUP

TIMEFRAME

Data quantum will not be the event, but the "Timeframe".

- *~23ms worth of data taking in continuous readout. Equivalent to 1000 collisions. Atomic unit.*
- *~10GB after timeframe building. Vast majority in TPC clusters.*
- *Compressed to ~2GB after asynchronous reconstruction, thanks to track-model-compression, storing clusters instead of ADC values, tailored fixed point integer format, logarithmic precision, entropy encoding.*
- *50x the number of collisions of RUN2.*
- *All MinBias. We need to (lossly) compress information, not filter it.*

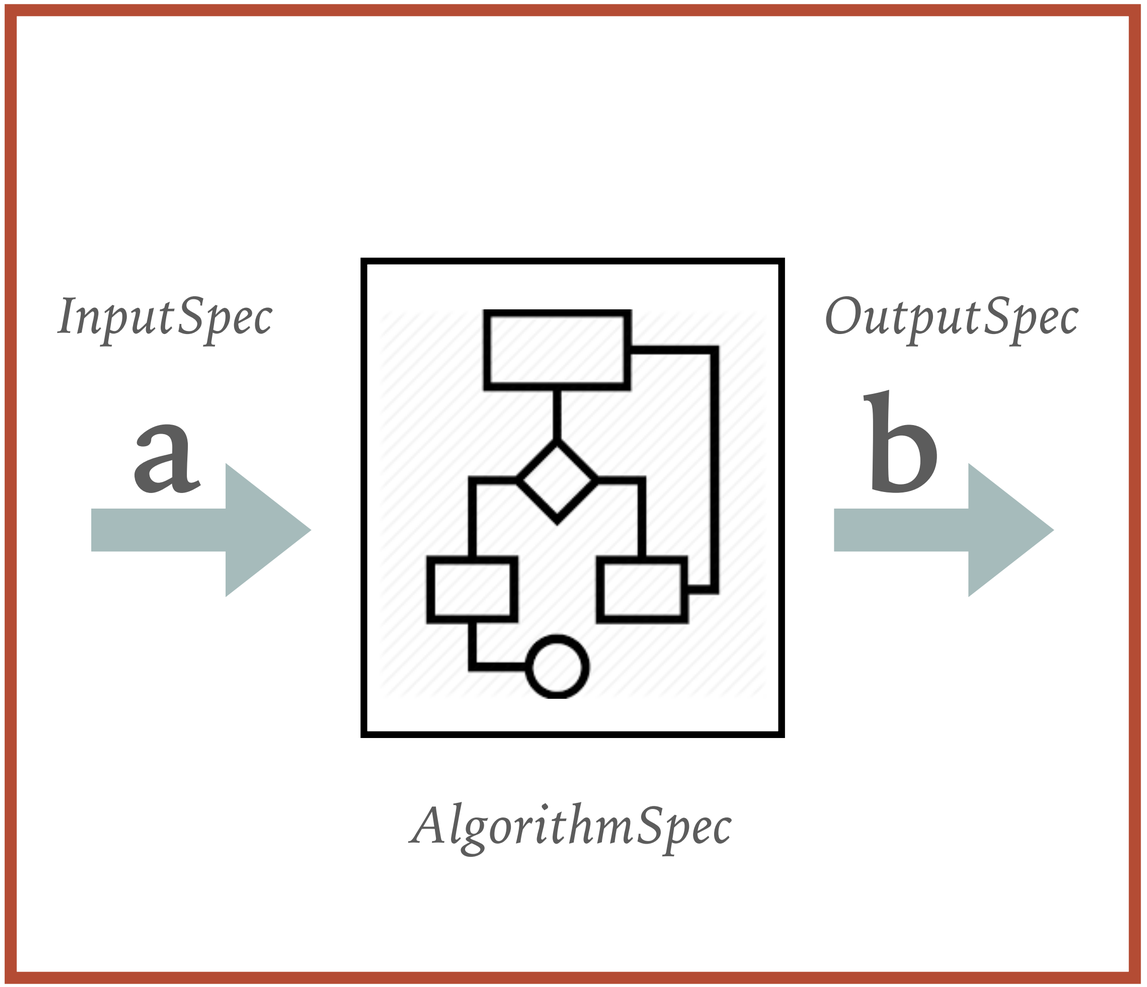
O2 DATA MODEL

A timeframe is a collection of `(header, payload)` *pairs. Headers defines the type of data. Different header types can be stacked to store extra metadata (mimicking a Type hierarchy structure). Both header and payloads should be usable in a* ***message passing*** *environment.*

Different payloads might have ***different serialisation strategies****. E.g.:*

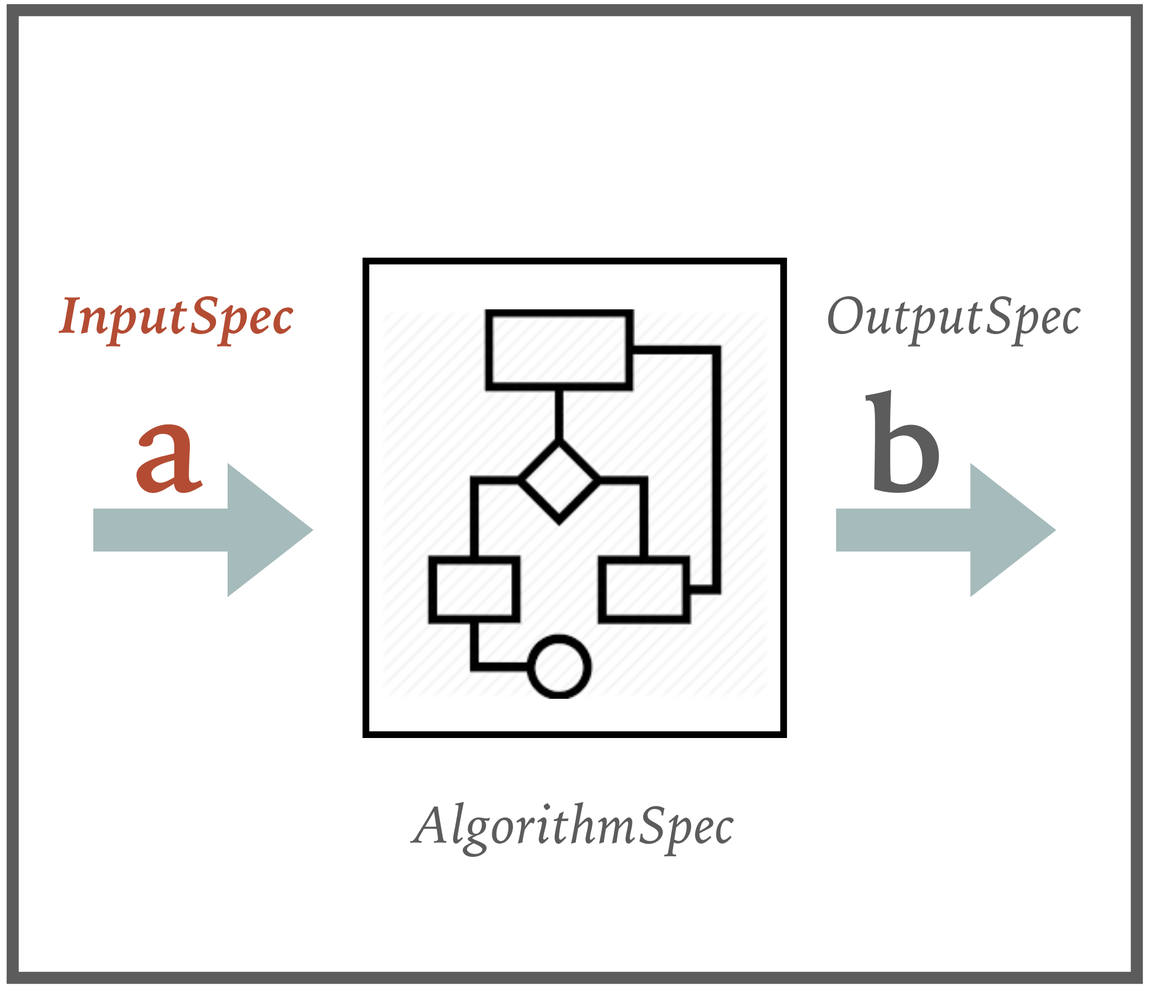
- *TPC clusters / tracks:* ***flat POD data with relative indexes****, well suitable for GPU processing.*
- *QA histograms:* ***serialised ROOT*** *histograms.*
- *AOD:* ***some columnar data format****. Multiple solutions being investigated.*

DATA PROCESSING LAYER: HOW



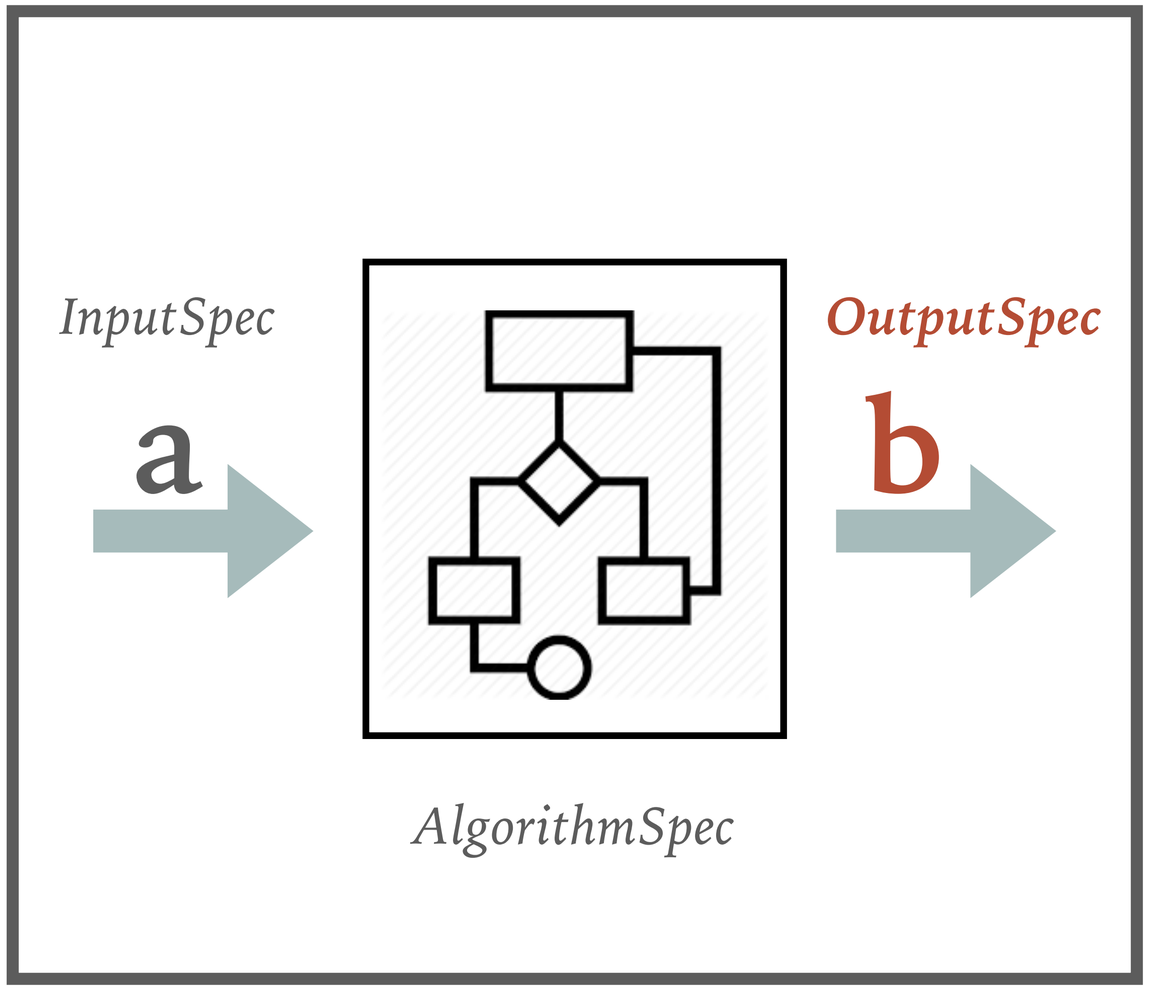

```
DataProcessorSpec{
  "A",
  Inputs{
   InputSpec{"a", "TPC", "CLUSTERS"}
  },
  Outputs{
   OutputSpec{{"b"}, "TPC", "TRACKS"}
  },
  AlgorithmSpec{
    [](ProcessingContext &ctx) {
       auto track = ctx.outputs().make<Track>(OutputRef{ "b" }, 1);
    }
  }
}
```

DATA PROCESSING LAYER: HOW




```
DataProcessorSpec{
  "A",
  Inputs{
   InputSpec{"a", "TPC", "CLUSTERS"}
  },
  Outputs{
   OutputSpec{{"b"}, "TPC", "TRACKS"}
  },
  AlgorithmSpec{
    [](ProcessingContext &ctx) {
       auto track = ctx.outputs().make<Track>(OutputRef{ "b" }, 1);
    }
  }
}
```

DATA PROCESSING LAYER: HOW




```
DataProcessorSpec{
  "A",
  Inputs{
   InputSpec{"a", "TPC", "CLUSTERS"}
  },
  Outputs{
   OutputSpec{{"b"}, "TPC", "TRACKS"}
  },
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    [](ProcessingContext &ctx) {
       auto track = ctx.outputs().make<Track>(OutputRef{ "b" }, 1);
    }
  }
}
```
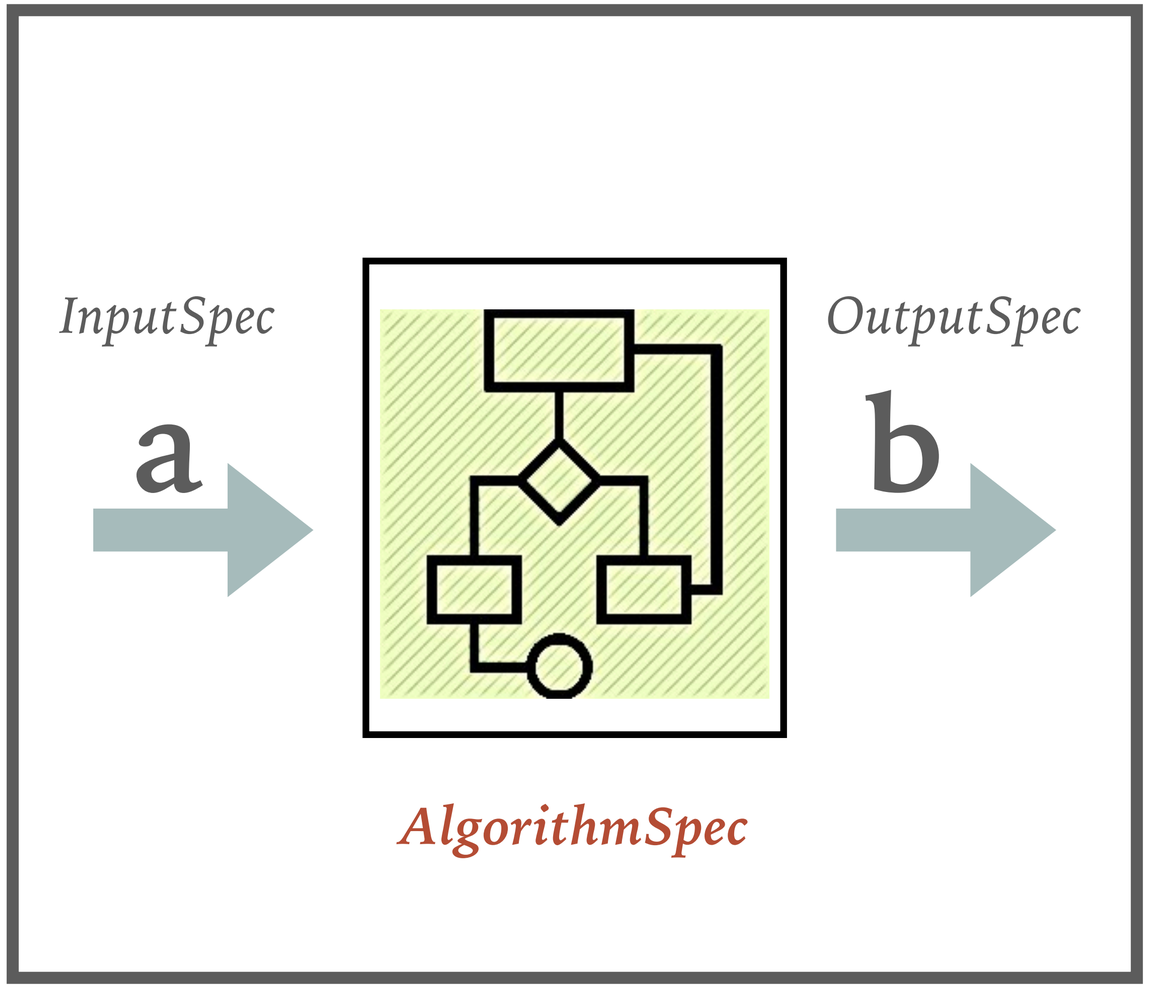

DATA PROCESSING LAYER: HOW




```
DataProcessorSpec{
  "A",
  Inputs{
   InputSpec{"a", "TPC", "CLUSTERS"}
  },
  Outputs{
   OutputSpec{{"b"}, "TPC", "TRACKS"}
  },
  AlgorithmSpec{
    [](ProcessingContext &ctx) {
       auto track = ctx.outputs().make<Track>(OutputRef{ "b" }, 1);
    }
  }
}
```

HOW DO YOU LIMIT CONTEXT SWITCH COSTS?

We will have a number of **running** processes which is ≲ the number of cores.

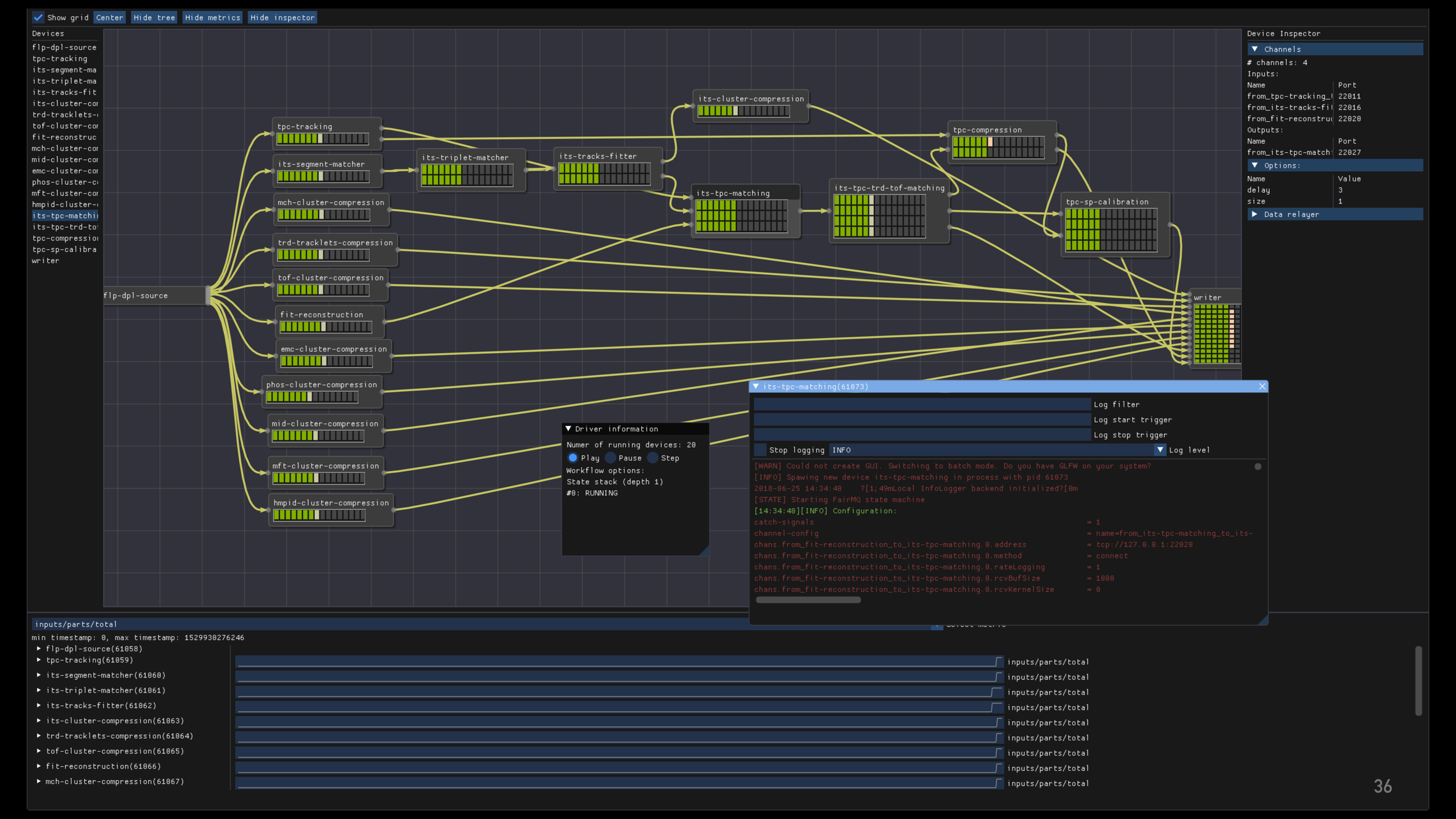
Our tasks **take long on a CPU scale** (seconds) thanks to the fact we treat one timeframe at the time (~1000 collisions). User code runs lock free.

By describing our computation in terms of **composable pipeline stages** we keep door open for (eventually dynamic) NxM mapping between data processors and actual processes.

We are **willing to pay an extra** price for the sake of:

- *Ease of deployment (microservices!)*
- *Crash resilience (data taking!)*
- *Ability to distribute over multiple nodes (HPC!)*
- *Flexibility (run GEANT3 + GEANT4 + FLUKA!)*

Limiting factor is in any case the GPU for TPC tracking (at least for the synchronous phase).


Show grid
Center
Hide tree
Hide metrics
Hide inspector
Devices
flp-dpl-source
tpc-tracking
its-segment-ma
its-triplet-ma
its-tracks-fit
its-cluster-cor
trd-tracklets-
tof-cluster-cor
fit-reconstruc
mch-cluster-cor
mid-cluster-cor
emc-cluster-cor
phos-cluster-c
mft-cluster-cor
hmpid-cluster-
its-tpc-matchi
its-tpc-trd-to
tpc-compressio
tpc-sp-calibra
writer
flp-dpl-source
tpc-tracking
its-segment-matcher
its-triplet-matcher
its-tracks-fitter
its-cluster-compression
its-tpc-matching
its-tpc-trd-tof-matching
tpc-compression
tpc-sp-calibration
writer
mch-cluster-compression
trd-tracklets-compression
tof-cluster-compression
fit-reconstruction
emc-cluster-compression
phos-cluster-compression
mid-cluster-compression
mft-cluster-compression
hmpid-cluster-compression
Driver information
Numer of running devices: 20
Play
Pause
Step
Workflow options:
State stack (depth 1)
#0: RUNNING
Device Inspector
Channels
channels: 4
Inputs:
Name
Port
from_tpc-tracking_
22011
from_its-tracks-fi
22016
from_fit-reconstru
22020
Outputs:
Name
Port
from_its-tpc-match
22027
Options:
Name
Value
delay
3
size
1
Data relayer
its-tpc-matching(61073)
Log filter
Log start trigger
Log stop trigger
Stop logging
INFO
Log level
[WARN] Could not create GUI. Switching to batch mode. Do you have GLFW on your system?
[INFO] Spawing new device its-tpc-matching in process with pid 61073
2018-06-25 14:34:40 ?[1;49mLocal InfoLogger backend initialized?[0m
[STATE] Starting FairMQ state machine
[14:34:40][INFO] Configuration:
catch-signals = 1
channel-config = name=from_its-tpc-matching_to_its-
chans.from_fit-reconstruction_to_its-tpc-matching.0.address = tcp://127.0.0.1:22020
chans.from_fit-reconstruction_to_its-tpc-matching.0.method = connect
chans.from_fit-reconstruction_to_its-tpc-matching.0.rateLogging = 1
chans.from_fit-reconstruction_to_its-tpc-matching.0.rcvBufSize = 1000
chans.from_fit-reconstruction_to_its-tpc-matching.0.rcvKernelSize = 0
inputs/parts/total
min timestamp: 0, max timestamp: 1529930276246
flp-dpl-source(61058)
tpc-tracking(61059)
its-segment-matcher(61060)
its-triplet-matcher(61061)
its-tracks-fitter(61062)
its-cluster-compression(61063)
trd-tracklets-compression(61064)
tof-cluster-compression(61065)
fit-reconstruction(61066)
mch-cluster-compression(61067)
inputs/parts/total