Online Structure Learning for Traffic Management

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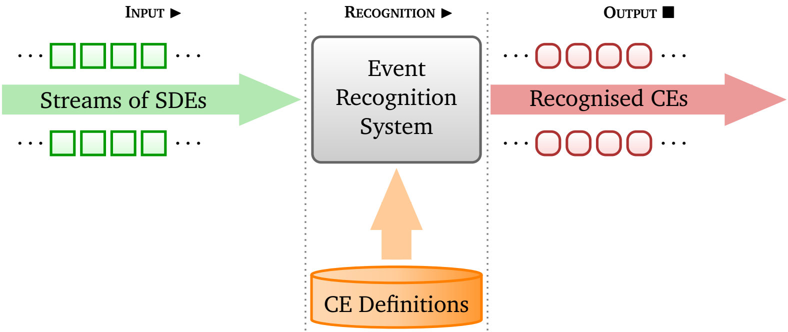
Introduction

- Event recognition applications in sensor environments:
  - Mostly based on manually constructed patterns
  - Patterns may be very hard to identify manually
  - Learning relational structures in the presence of uncertainty is desirable

- We applied $\texttt{OSL}\alpha$ to learning definitions for traffic congestions
  - Real sensor data provided in the context of the SPEEDD project[1]
  - Learned definitions are used for event detection

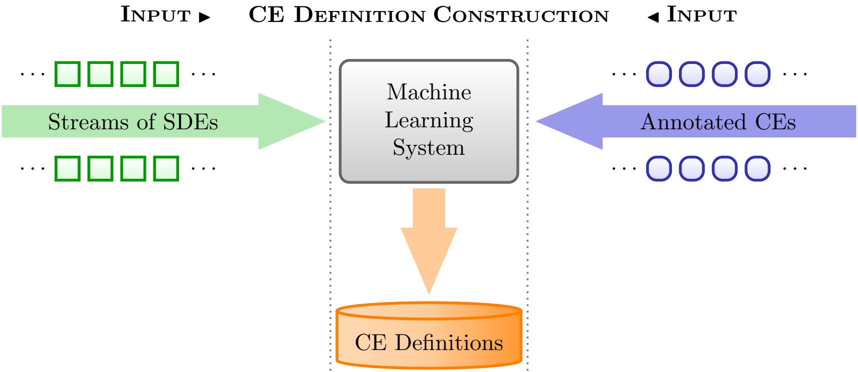
[1] www.speedd-project.eu

Event Recognition



- Event Calculus & Axiomatization
  - Logic formalism to represent and reason about events and their effects
  - CE initiations and terminations define whether a fluent holds or not
  - *Law of inertia*: Fluents persist over time, unless affected by an event

Learning CE Definitions



Procedure of OSLα

Learnt Hypothesis $\mathbf{H_t}$:

0.4 `HoldsAt`(`congestion`(lid), t+1) $\Leftarrow$
  `HappensAt`(`fast_Slt20`(lid), t)$\wedge$
  `HappensAt`(`fast_Ogt45`(lid), t)

`MLN–EC` **Axioms**:

`HoldsAt`(f, t+1) $\Leftarrow$
  `InitiatedAt`(f, t)

`HoldsAt`(f, t+1) $\Leftarrow$
  `HoldsAt`(f, t) $\wedge$
  $\neg$`TerminatedAt`(f, t)

$\neg$`HoldsAt`(f, t+1) $\Leftarrow$
  `TerminatedAt`(f, t)

$\neg$`HoldsAt`(f, t+1) $\Leftarrow$
  $\neg$`HoldsAt`(f, t) $\wedge$
  $\neg$`InitiatedAt`(f, t)

OSLα

Data Stream/Training Examples

Micro-Batch $\mathcal{D}_t$

`HappensAt`(`fast_Slt25`(53708), 99)
`HappensAt`(`fast_Ogt55`(53708), 99)
`HappensAt`(`slow_Slt15`(53708), 99)
`HappensAt`(`slow_Ogt65`(53708), 99)
`Next`(99, 100)
`HoldsAt`(`congestion`(53708), 100)
...

Procedure of $\texttt{OSL}\alpha$

Learnt Hypothesis $\mathbf{H_t}$:

$0.4\ \texttt{HoldsAt}(\texttt{congestion}(lid),\ t{+}1) \Leftarrow$
$\texttt{HappensAt}(\texttt{fast\_Slt20}(lid),\ t) \wedge$
$\texttt{HappensAt}(\texttt{fast\_Ogt45}(lid),\ t)$

MLN–EC Axioms:

$\texttt{HoldsAt}(f,\ t{+}1) \Leftarrow$
$\quad \texttt{InitiatedAt}(f,\ t)$

$\texttt{HoldsAt}(f,\ t{+}1) \Leftarrow$
$\quad \texttt{HoldsAt}(f,\ t) \wedge$
$\quad \neg\texttt{TerminatedAt}(f,\ t)$

$\neg\texttt{HoldsAt}(f,\ t{+}1) \Leftarrow$
$\quad \texttt{TerminatedAt}(f,\ t)$

$\neg\texttt{HoldsAt}(f,\ t{+}1) \Leftarrow$
$\quad \neg\texttt{HoldsAt}(f,\ t) \wedge$
$\quad \neg\texttt{InitiatedAt}(f,\ t)$

$\texttt{OSL}\alpha$

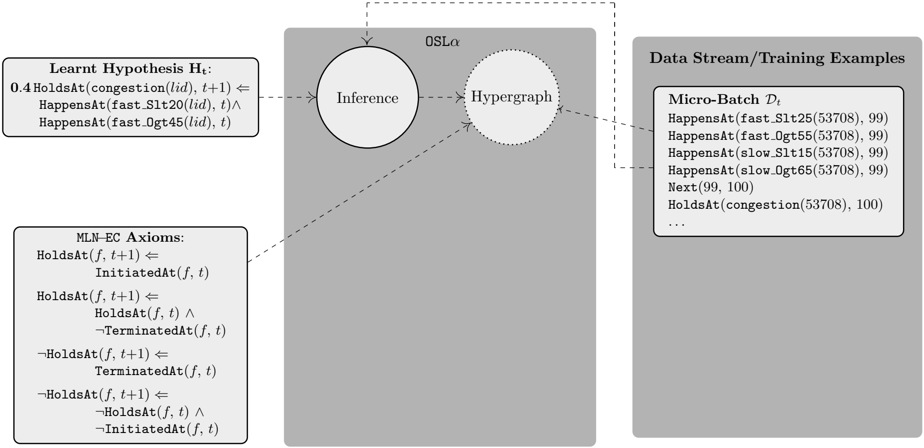
Inference

Data Stream/Training Examples

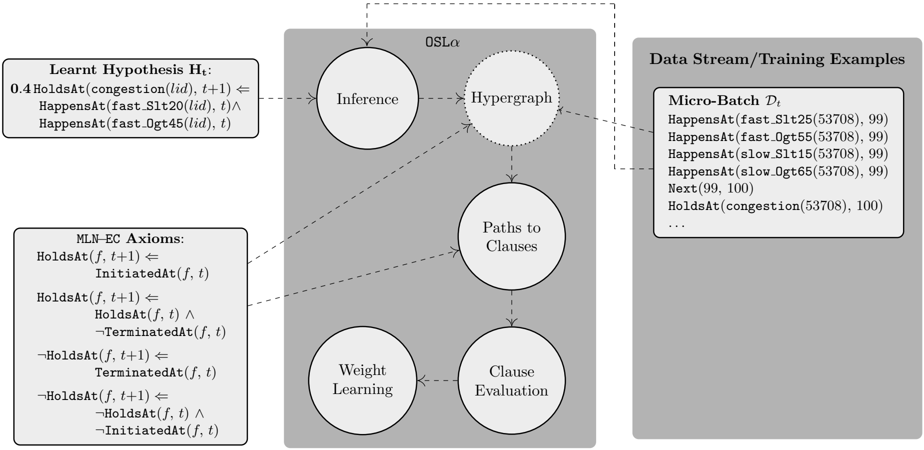
Micro-Batch $\mathcal{D}_t$

$\texttt{HappensAt}(\texttt{fast\_Slt25}(53708),\ 99)$
$\texttt{HappensAt}(\texttt{fast\_Ogt55}(53708),\ 99)$
$\texttt{HappensAt}(\texttt{slow\_Slt15}(53708),\ 99)$
$\texttt{HappensAt}(\texttt{slow\_Ogt65}(53708),\ 99)$
$\texttt{Next}(99,\ 100)$
$\texttt{HoldsAt}(\texttt{congestion}(53708),\ 100)$
...

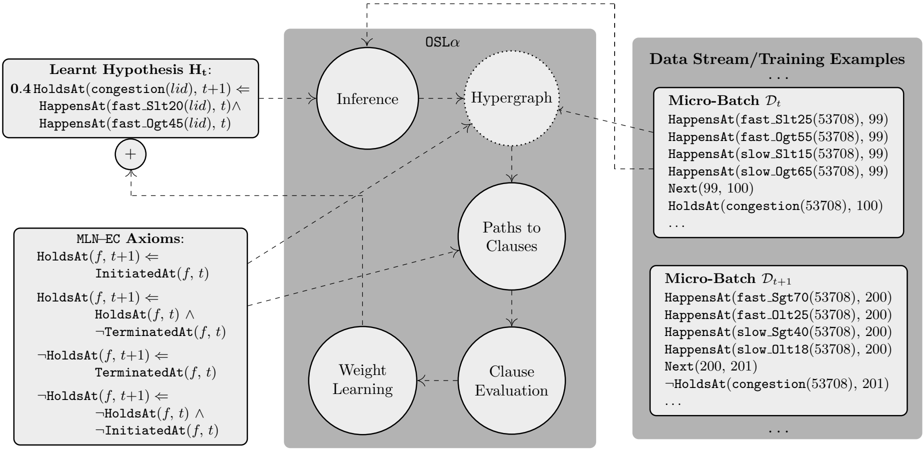
Procedure of OSLα



Procedure of OSLα



Procedure of OSLα

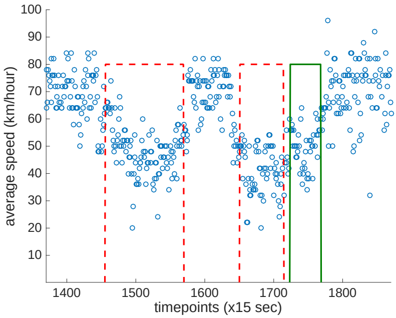


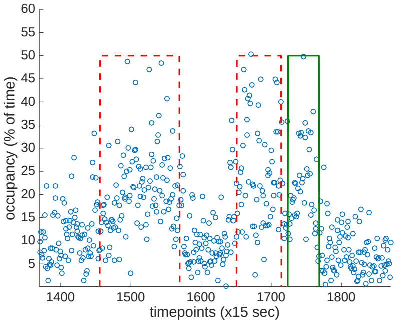
Dataset

- Real data collected from sensors
  - Mounted on the southern part of the Grenoble ring road
  - 19 collection points along 12km stretch on the highway
  - Each collection point has a sensor per lane
- Consists of one month of data (≈ 3.3GiB)
- Annotated by human traffic controllers for traffic congestion
- Sensor data are collected every 15 seconds and contain:
  - Total number of vehicles passing through a lane
  - Average speed and sensor occupancy

Learning Challenges (1/3)

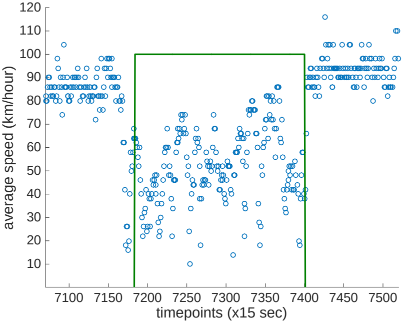
- Traffic congestion annotation is largely incomplete
  - Leading to the incorrect penalization of good rules



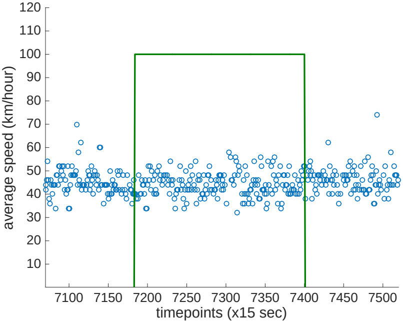


Learning Challenges (2/3)

- Quality of information of each sensor differs



(a) Fast



(b) Queue

Learning Challenges (3/3)

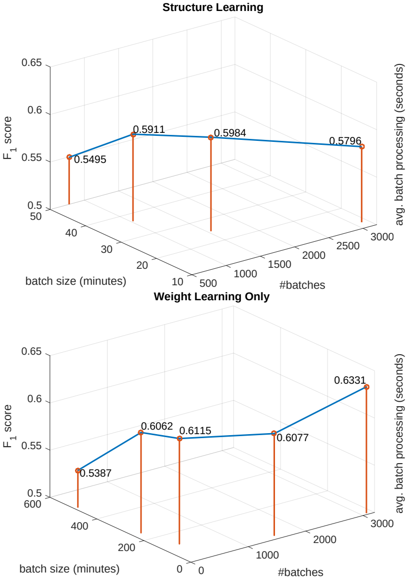
- Generic location- and lane-agnostic rules are not sufficient
  - They capture the concept of traffic congestion in a few locations, and completely fail in others.

$$
\begin{aligned}
&\texttt{InitiatedAt}(\texttt{congestion}(lid),\, t) \Leftarrow \\
&\qquad \texttt{HappensAt}(\texttt{aggr}(lid, occupancy, avgspd),\, t) \wedge \\
&\qquad avgspd < 50 \wedge occupancy > 25
\end{aligned}
$$

Experimental Setup

- Data are stored in a database
  - Micro-batches were constructed dynamically by querying the database
- Input events were produced by discretizing the numerical data
- The total length of the training sequence consists of 172799 timepoints
  - We consider only SDEs in fast lanes
- 10-fold cross-validation
- Compare $\texttt{OSL}\alpha$ vs AdaGrad online weight learner
  - $\texttt{OSL}\alpha$ starting from an empty hypothesis
  - AdaGrad operating on manually constructed definitions

Experimental Results



Summary & Future Work

- `OSL`α achieves comparable predictive accuracy to manually curated rules
- `OSL`α can process data batches efficiently
  - Faster search procedure may match AdaGrad processing time
- Low predictive accuracy of the learned model
  - Extend `OSL`α to handle missing supervision

Acknowledgements

Any Questions?