# OSL$\alpha$: Online Structure Learning using Background Knowledge Axiomatization


Evangelos Michelioudakis[1], Anastasios Skarlatidis[1], Georgios Paliouras[1] and Alexander Artikis[2,1]

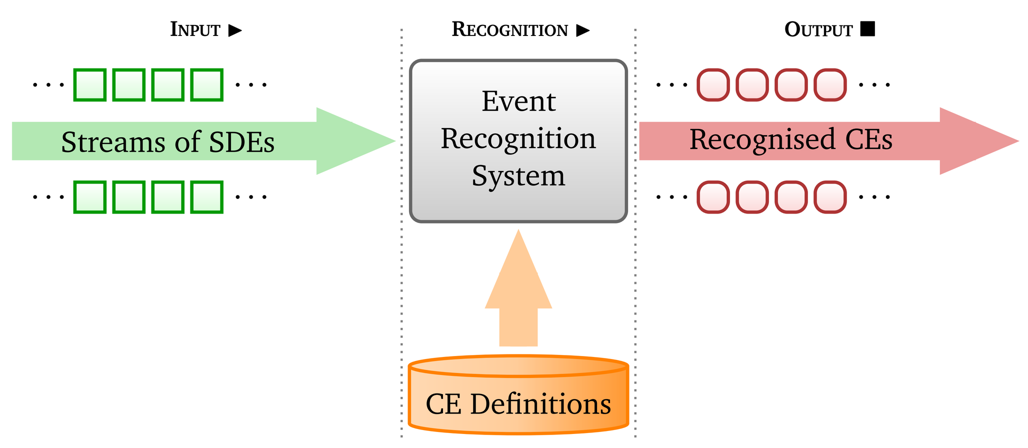
Institute of Informatics and Telecommunications, NCSR "Demokritos"[1]
Department of Maritime Studies, University of Piraeus[2]

{vagmcs,anskarl,paliourg,a.artikis}@iit.demokritos.gr


## Introduction

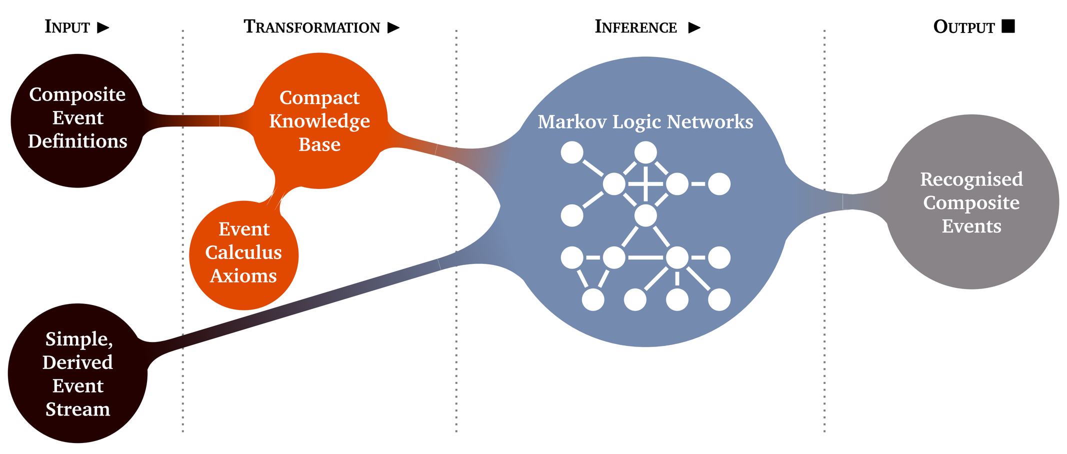
- Targets:
  - Learning in temporal domains
  - Handle uncertainty and complex relational structure
  - Handle large (streaming) training data
- Approach:
  - Markov Logic Networks, Event Calculus (MLN–EC)
  - Online structure learning (OSL$\alpha$)
- Starting point: Online Structure Learning (OSL) algorithm
  - ✓ Online strategy for updating the model
  - ✗ Cannot handle a search space having large domain of constants
  - ✗ Does not exploit background knowledge
  - ✗ Does not support first-order logic functions

## Event Recognition




## Probabilistic Event Calculus

- Event Calculus
  - Logic formalism to represent and reason about events
  - Defines whether a fluent holds or not at a specific time-point
  - *Law of inertia*: Fluents persist over time
- MLN–EC

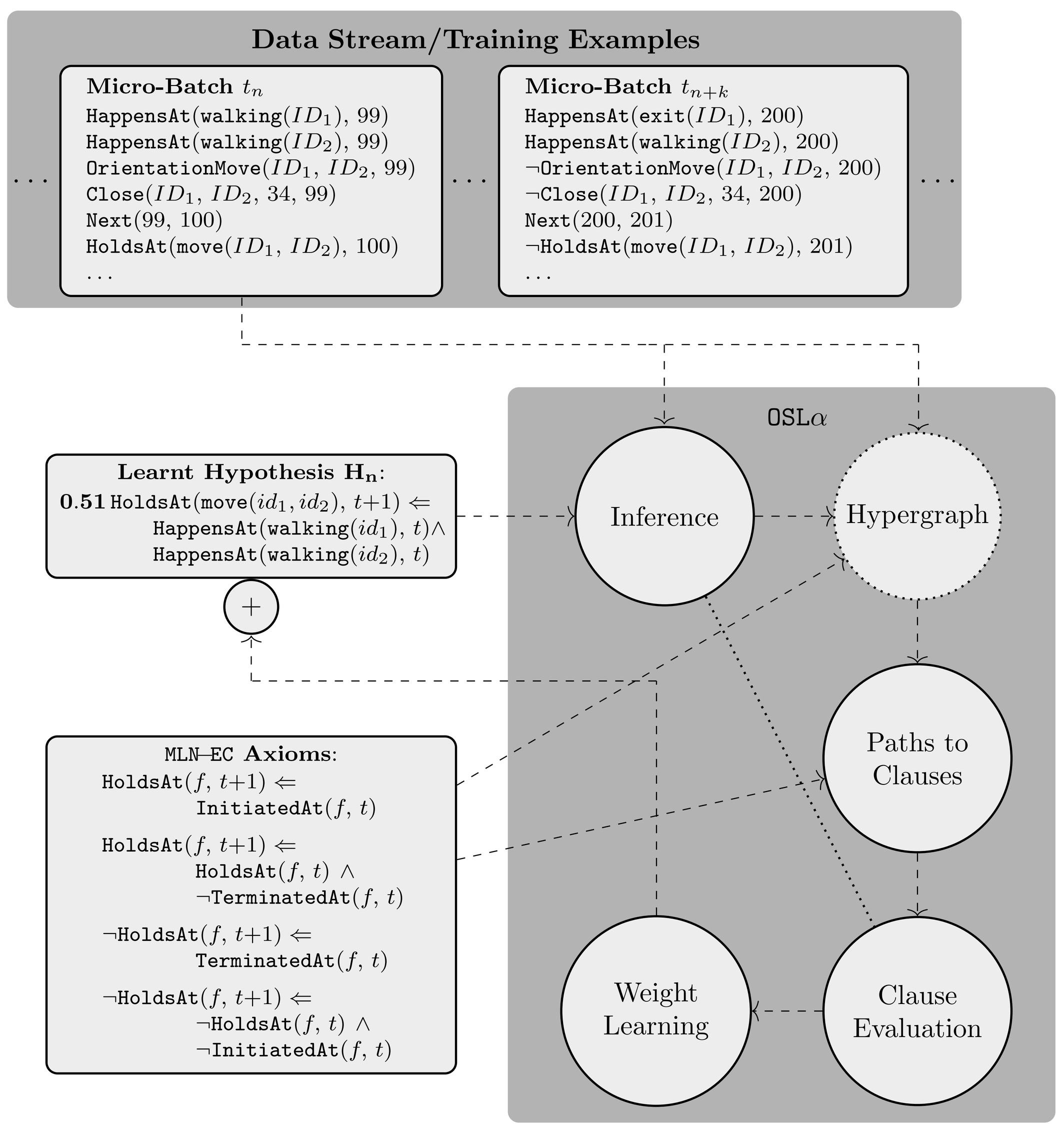



## Activity Recognition

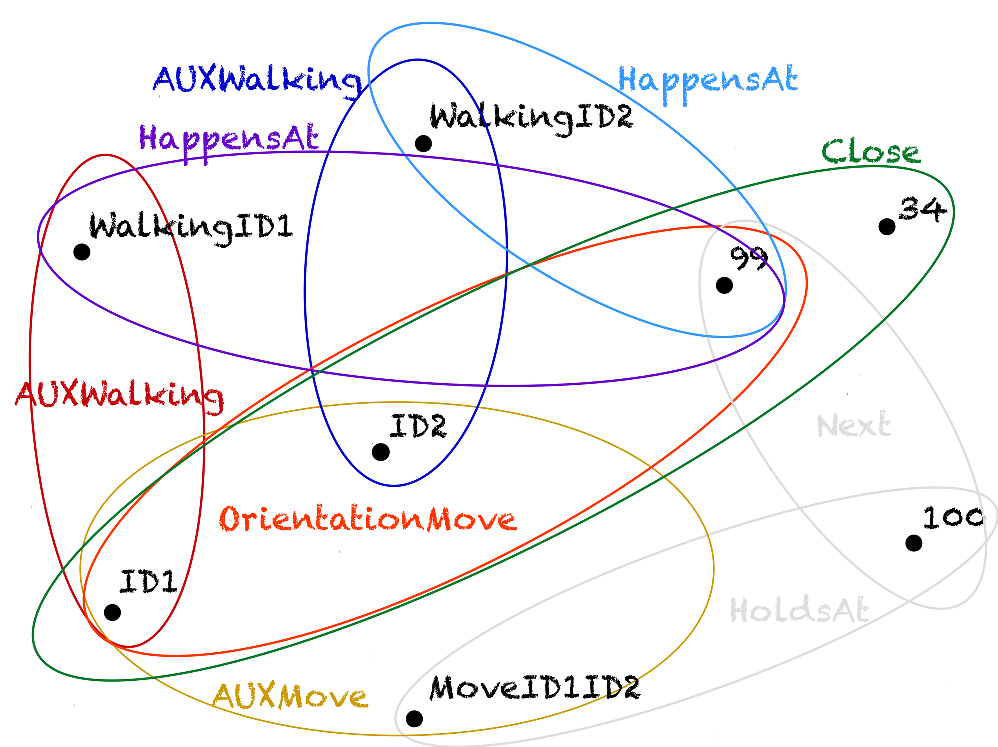
- Recognize complex activities between multiple persons
  - Data from surveillance video footage
- Video frames are annotated by human experts
  - Observed individual activities (walking, active, enter, etc)
  - Activities among persons (meeting or moving together)

| Simple Derived Events | Supervision of Composite Events |
|---|---|
| ... | ... |
| HappensAt(walking(ID$_1$), 99) | |
| HappensAt(walking(ID$_2$), 99) | |
| OrientationMove(ID$_1$, ID$_2$, 99) | HoldsAt(move(ID$_1$, ID$_2$), 100) |
| Close(ID$_1$, ID$_2$, 34, 99) | |
| Next(99, 100) | |
| ... | ... |

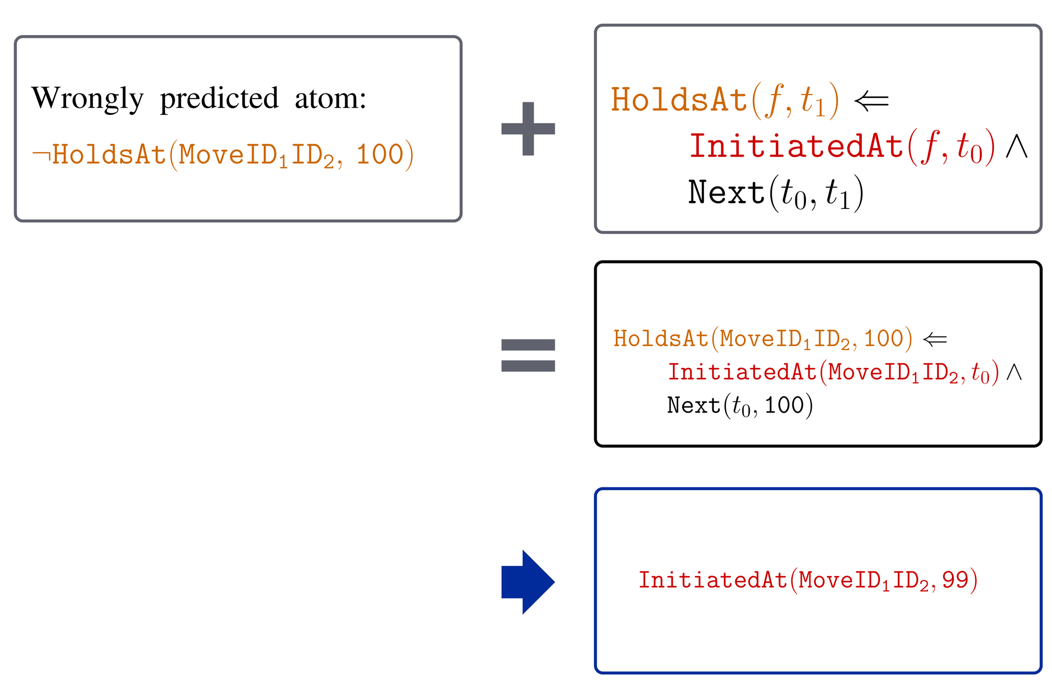
## OSL$\alpha$ Procedure




## Hypergraph and Relational Pathfinding




## Template Guided Search




## Clause Creation, Clause Evaluation and Weight Learning

1. Generalize each path into a definite clause:

$$\texttt{InitiatedAt}(\texttt{move}(id_1, id_2), t) \Leftarrow \texttt{HappensAt}(\texttt{walking}(id_1), t) \wedge \texttt{HappensAt}(\texttt{walking}(id_2), t)$$

   Predicate completion and template predicate elimination
   - Produce clauses independent of the template predicates

2. Clause Evaluation:

   Keep clauses whose coverage of the annotation is significantly greater than that of the clauses already learnt.

3. Weight Learning using AdaGrad:
   - Extended clauses initially inherit their ancestors weights
   - Optimize the weights of all clauses

## Experimental Evaluation

- Activity recognition using the CAVIAR dataset
  - 28 surveillance videos
- Learn target concepts for meet and move CEs
- 19 sequences of SDEs and CE annotations
- 10-fold cross-validation
- Implemented on LoMRF (http://github.com/anskarl/LoMRF)

| Method | meet | | | move | | |
|---|---|---|---|---|---|---|
| | Precision | Recall | $F_1$–score | Precision | Recall | $F_1$–score |
| EC$_{crisp}$ | 0.6868 | 0.8556 | 0.7620 | 0.9093 | 0.6390 | 0.7506 |
| AdaGrad | 0.7228 | 0.8547 | 0.7833 | 0.9172 | 0.6674 | 0.7726 |
| MaxMargin | 0.9189 | 0.8133 | **0.8629** | 0.8443 | 0.9410 | **0.8901** |
| OSL$\alpha$ | 0.8192 | 0.8509 | 0.8347 | 0.8056 | 0.7522 | 0.7780 |

| Method | meet | | move | |
|---|---|---|---|---|
| | training | testing | training | testing |
| OSL$\alpha$ | **22m 49s** | 54s | **1h 56m 2s** | 1m 6s |
| OSL | > 25h | - | - | - |

## Conclusions

Probabilistic online structure learning (OSL$\alpha$) based on MLNs
- Exploits background knowledge axiomatization (MLN–EC)
- Considers both types of wrongly predicted atoms
- Supports a subset of first-order logic functions

## Future Research

1. Faster hypergraph search
2. Learn hierarchical definitions and support negated literals
3. Structure learning in the presence of unobserved data