

NeuroSymbolic AI for Making Sense of Streaming Data: Probabilistic CER

Alexander Artikis^{1,2}
Periklis Mantenoglou³

¹NCSR Demokritos, Athens, Greece

²University of Piraeus, Greece

³Örebro University, Sweden



Slides, Papers, Code & Data

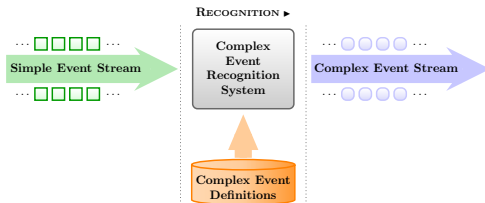


StreamingNeSy

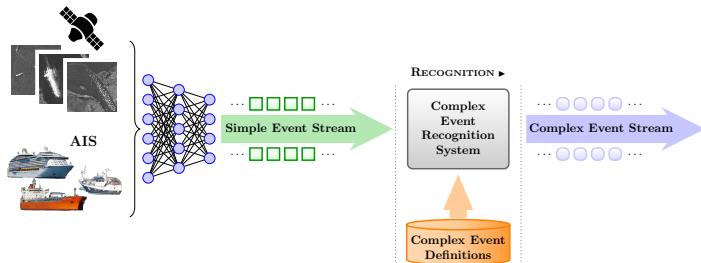


Complex Event Recognition lab

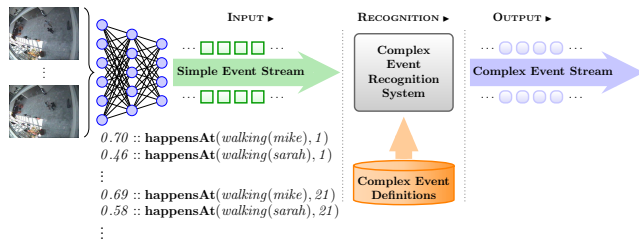
Complex Event Recognition (CER)



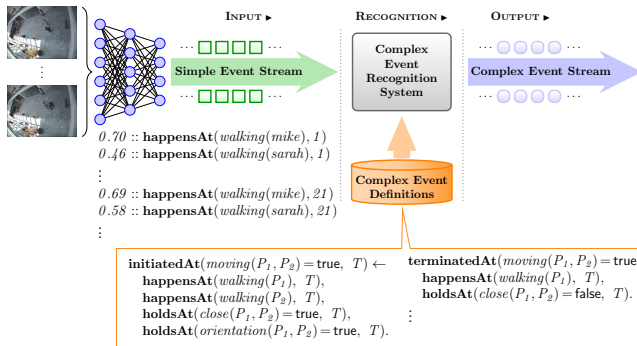
Complex Event Recognition (CER)



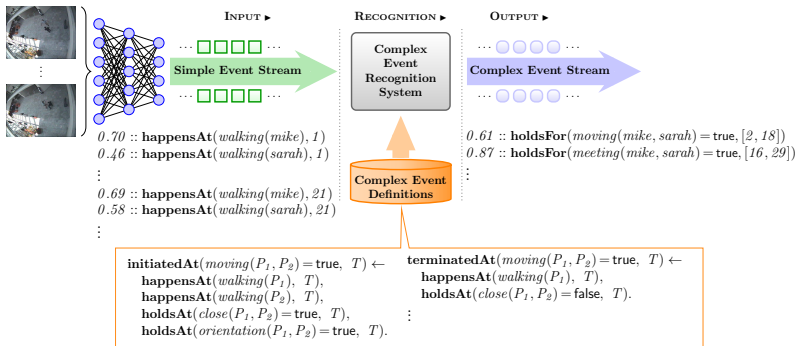
Complex Event Recognition under Uncertainty



Complex Event Recognition under Uncertainty



Complex Event Recognition under Uncertainty

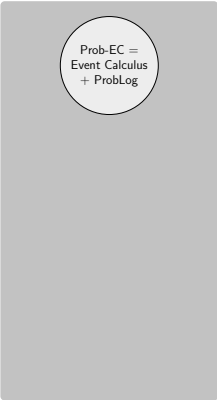


Activity Recognition



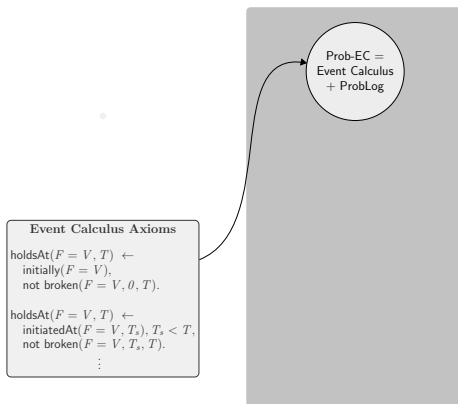
<https://cer.iit.demokritos.gr> (activity recognition)

Online Probabilistic Interval-Based Event Calculus

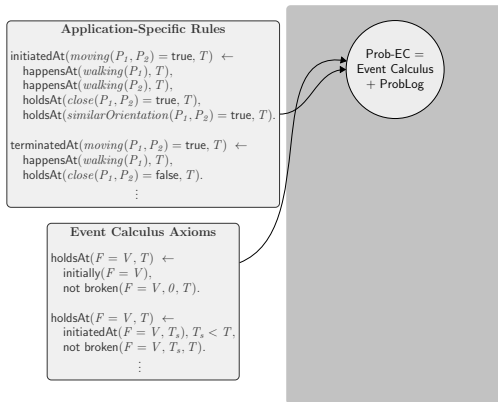


Prob-EC =
Event Calculus
+ ProbLog

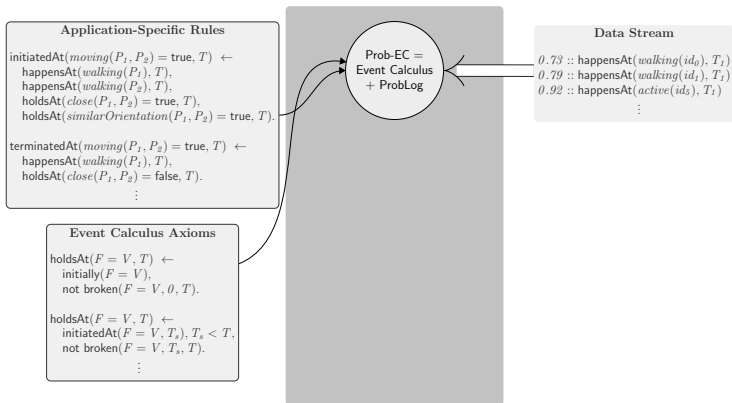
Online Probabilistic Interval-Based Event Calculus



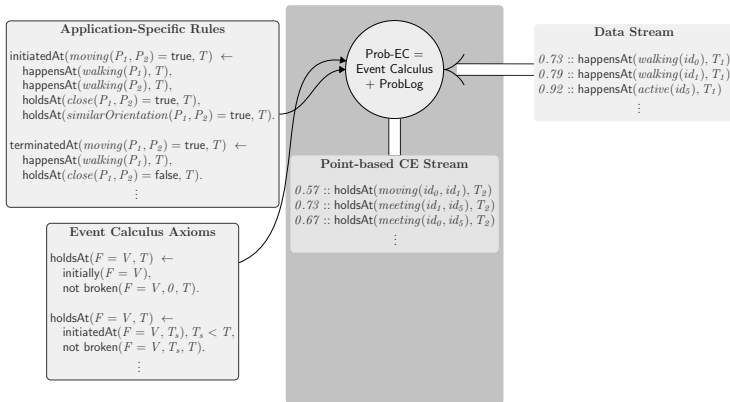
Online Probabilistic Interval-Based Event Calculus



Online Probabilistic Interval-Based Event Calculus



Online Probabilistic Interval-Based Event Calculus



Instantaneous Recognition

initiatedAt($moving(P_1, P_2) = \text{true}, T$) $\leftarrow$
 happensAt($walking(P_1), T$),
 happensAt($walking(P_2), T$),
 holdsAt($close(P_1, P_2) = \text{true}, T$),
 holdsAt($orientation(P_1, P_2) = \text{true}, T$).

terminatedAt($moving(P_1, P_2) = \text{true}, T$) $\leftarrow$
 happensAt($walking(P_1), T$),
 holdsAt($close(P_1, P_2) = \text{false}, T$).

0.70 :: **happensAt**($walking(mike), 1$).

0.46 :: **happensAt**($walking(sarah), 1$).

Instantaneous Recognition

initiatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 happensAt(*walking*(P_2), T),
 holdsAt(*close*(P_1, P_2) = true, T),
 holdsAt(*orientation*(P_1, P_2) = true, T).

terminatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 holdsAt(*close*(P_1, P_2) = false, T).

0.70 :: **happensAt**(*walking*(*mike*), 1).

0.46 :: **happensAt**(*walking*(*sarah*), 1).

$P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1)) =$
 $P(\text{happensAt}(\text{walking}(\text{mike}), 1)) \times$
 $P(\text{happensAt}(\text{walking}(\text{sarah}), 1)) \times$
 $P(\text{holdsAt}(\text{close}(\text{mike}, \text{sarah}) = \text{true}, 1)) \times$
 $P(\text{holdsAt}(\text{orientation}(\text{mike}, \text{sarah}) = \text{true}, 1))$
 $= 0.7 \times 0.46 \times 1 \times 1 = 0.322$

Instantaneous Recognition

initiatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 happensAt(*walking*(P_2), T),
 holdsAt(*close*(P_1, P_2) = true, T),
 holdsAt(*orientation*(P_1, P_2) = true, T).
terminatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 holdsAt(*close*(P_1, P_2) = false, T).

0.70 :: **happensAt**(*walking*(*mike*), 1).
0.46 :: **happensAt**(*walking*(*sarah*), 1).

$P(\text{holdsAt}(CE = \text{true}, t)) =$
 $P(\text{initiatedAt}(CE = \text{true}, t-1) \vee$
 $(\text{holdsAt}(CE = \text{true}, t-1) \wedge$
 $\neg \text{terminatedAt}(CE = \text{true}, t-1)))$

Instantaneous Recognition

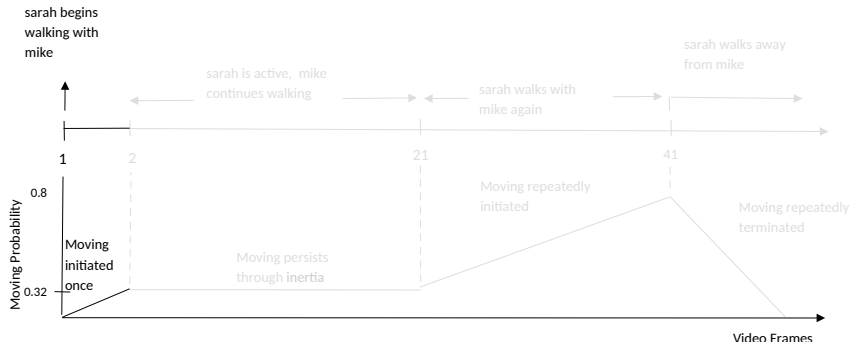
initiatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 happensAt(*walking*(P_2), T),
 holdsAt(*close*(P_1, P_2) = true, T),
 holdsAt(*orientation*(P_1, P_2) = true, T).
terminatedAt(*moving*(P_1, P_2) = true, T) $\leftarrow$
 happensAt(*walking*(P_1), T),
 holdsAt(*close*(P_1, P_2) = false, T).

0.70 :: **happensAt**(*walking*(*mike*), 1).

0.46 :: **happensAt**(*walking*(*sarah*), 1).

$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 2)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1) \vee$
 ($\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1)))$
 $= 0.322 + 0 \times 1 - 0.322 \times 0 \times 1 = 0.322$

Instantaneous Recognition

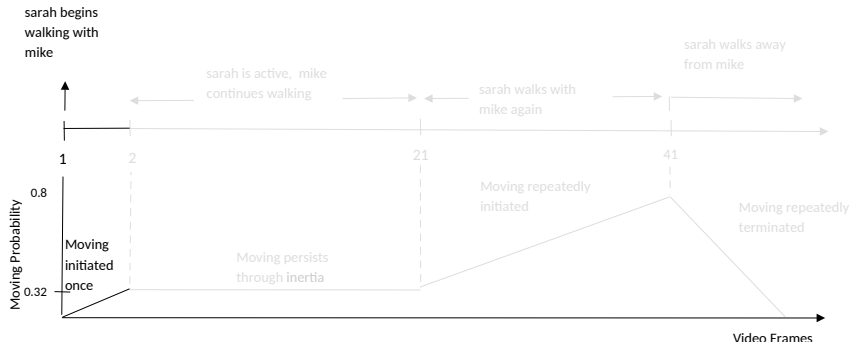


$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$
 $\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.70 :: \text{happensAt}(\text{walking}(\text{mike}), 1).$
 $0.46 :: \text{happensAt}(\text{walking}(\text{sarah}), 1).$

$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 2)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1) \vee$
 $(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 1)))$
 $= 0.322 + 0 \times 1 - 0.322 \times 0 \times 1 = 0.322$

Instantaneous Recognition

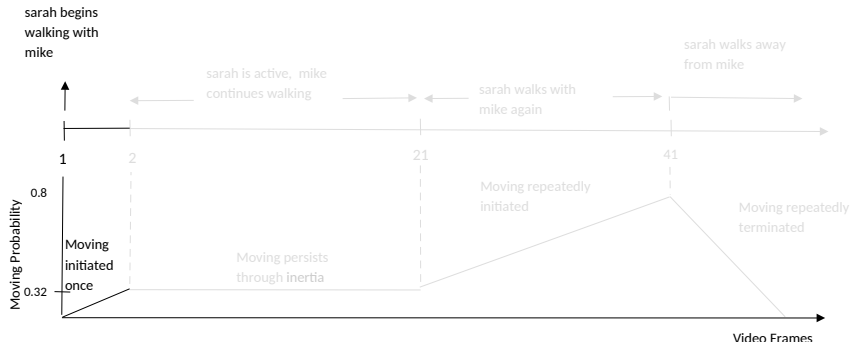


$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.73 :: \text{happensAt}(\text{walking}(\text{mike}), 2).$
 $0.55 :: \text{happensAt}(\text{active}(\text{sarah}), 2). \dots$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

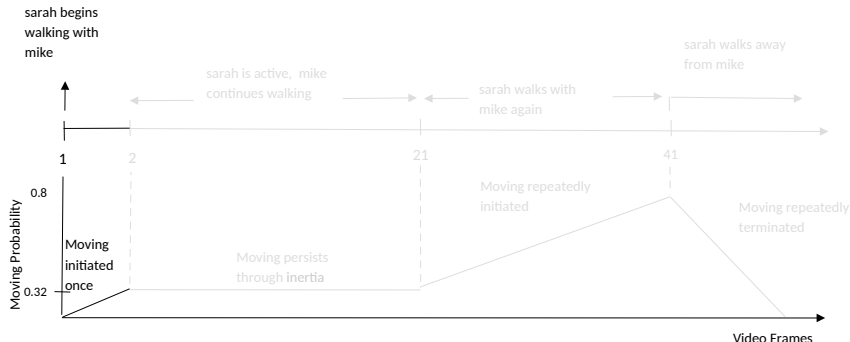
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.73 :: \text{happensAt}(\text{walking}(\text{mike}), 2).$

$0.55 :: \text{happensAt}(\text{active}(\text{sarah}), 2). \dots$

$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 3)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 2) \vee$
 $(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 2) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 2)))$
 $= 0 + 0.322 \times 1 - 0 \times 0.322 \times 1 = 0.322$

Instantaneous Recognition

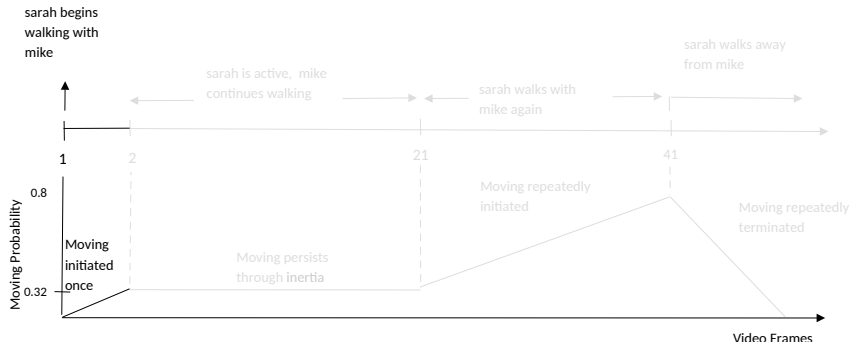


initiatedAt($moving(P_1, P_2) = \text{true}, T$) $\leftarrow$
happensAt($walking(P_1), T$),
happensAt($walking(P_2), T$),
holdsAt($close(P_1, P_2) = \text{true}, T$),
holdsAt($orientation(P_1, P_2) = \text{true}, T$).

terminatedAt($moving(P_1, P_2) = \text{true}, T$) $\leftarrow$
happensAt($walking(P_1), T$),
holdsAt($close(P_1, P_2) = \text{false}, T$).

$0.45 :: \text{happensAt}(walking(mike), 20).$
 $0.14 :: \text{happensAt}(active(sarah), 20).$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

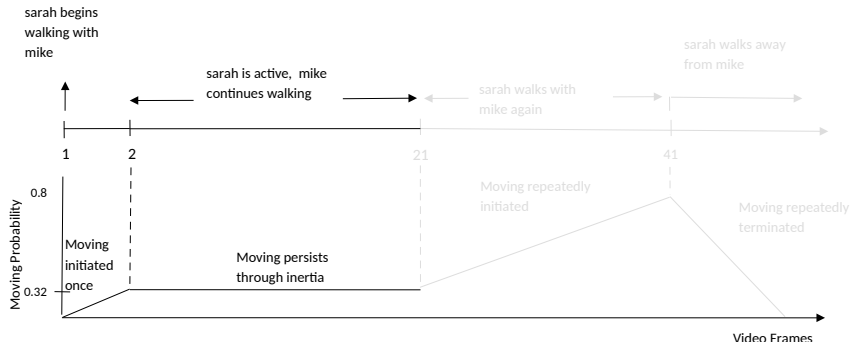
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.45 :: \text{happensAt}(\text{walking}(\text{mike}), 20).$

$0.14 :: \text{happensAt}(\text{active}(\text{sarah}), 20).$

$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20) \vee$
 $(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20)))$
 $= 0 + 0.322 \times 1 - 0 \times 0.322 \times 1 = 0.322$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

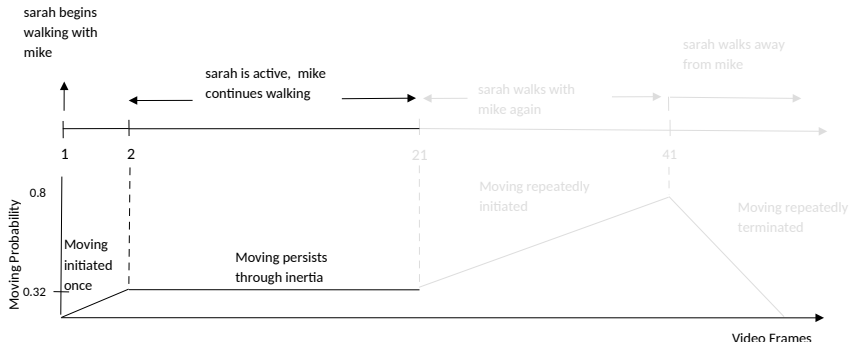
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.45 :: \text{happensAt}(\text{walking}(\text{mike}), 20).$

$0.14 :: \text{happensAt}(\text{active}(\text{sarah}), 20).$

$$\begin{aligned}
 &P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21)) = \\
 &P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20) \vee \\
 &\quad (\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20) \wedge \\
 &\quad \neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 20))) \\
 &= 0 + 0.322 \times 1 - 0 \times 0.322 \times 1 = 0.322
 \end{aligned}$$

Instantaneous Recognition

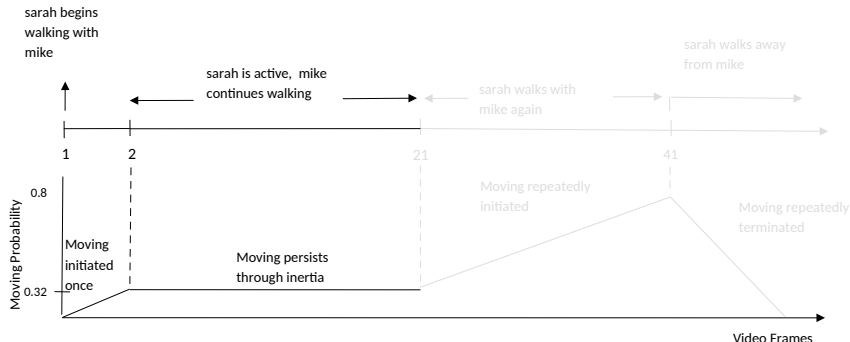


initiatedAt($moving(P_1, P_2) = true, T$) $\leftarrow$
happensAt($walking(P_1), T$),
happensAt($walking(P_2), T$),
holdsAt($close(P_1, P_2) = true, T$),
holdsAt($orientation(P_1, P_2) = true, T$).

terminatedAt($moving(P_1, P_2) = true, T$) $\leftarrow$
happensAt($walking(P_1), T$),
holdsAt($close(P_1, P_2) = false, T$).

0.39 :: **happensAt**($walking(mike), 21$).
0.28 :: **happensAt**($walking(sarah), 21$). ...

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

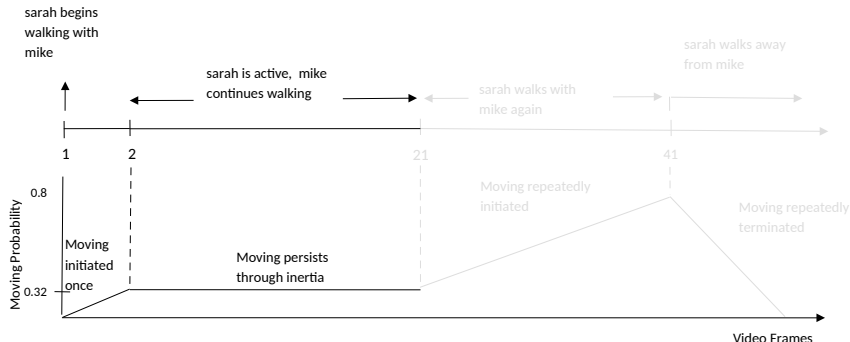
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.39 :: \text{happensAt}(\text{walking}(\text{mike}), 21).$

$0.28 :: \text{happensAt}(\text{walking}(\text{sarah}), 21). \dots$

$$\begin{aligned}
 P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21)) &= \\
 P(\text{happensAt}(\text{walking}(\text{mike}), 21)) &\times \\
 P(\text{happensAt}(\text{walking}(\text{sarah}), 21)) &\times \\
 P(\text{holdsAt}(\text{close}(\text{mike}, \text{sarah}) = \text{true}, 21)) &\times \\
 P(\text{holdsAt}(\text{orientation}(\text{mike}, \text{sarah}) = \text{true}, 21)) &= \\
 0.39 \times 0.28 \times 1 \times 1 &= 0.11
 \end{aligned}$$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

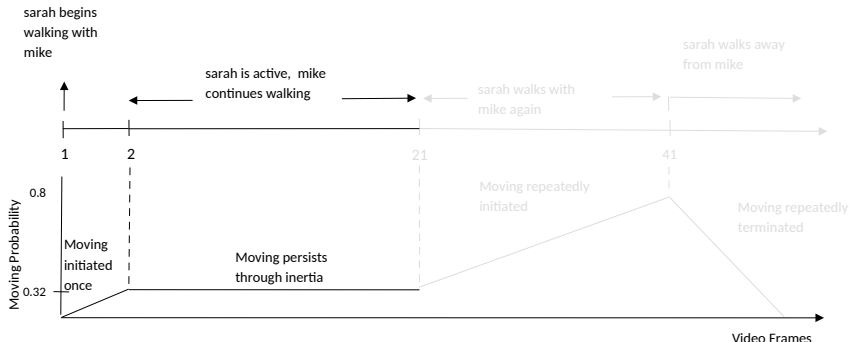
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.39 :: \text{happensAt}(\text{walking}(\text{mike}), 21).$

$0.28 :: \text{happensAt}(\text{walking}(\text{sarah}), 21). \dots$

$$\begin{aligned}
 &P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 22)) = \\
 &P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21) \vee \\
 &\quad (\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21) \wedge \\
 &\quad \neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21))) \\
 &= 0.11 + 0.322 \times 1 - 0.11 \times 0.322 \times 1 = 0.39
 \end{aligned}$$

Instantaneous Recognition



```

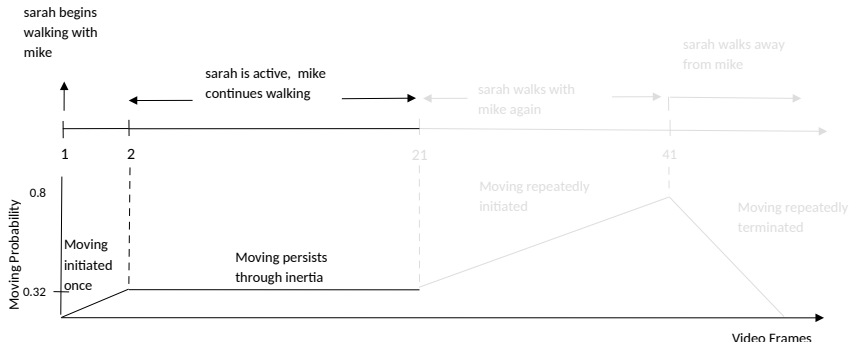
initiatedAt(moving( $P_1, P_2$ ) = true,  $T$ )  $\leftarrow$ 
  happensAt(walking( $P_1$ ),  $T$ ),
  happensAt(walking( $P_2$ ),  $T$ ),
  holdsAt(close( $P_1, P_2$ ) = true,  $T$ ),
  holdsAt(orientation( $P_1, P_2$ ) = true,  $T$ ).

terminatedAt(moving( $P_1, P_2$ ) = true,  $T$ )  $\leftarrow$ 
  happensAt(walking( $P_1$ ),  $T$ ),
  holdsAt(close( $P_1, P_2$ ) = false,  $T$ ).
  
```

```

0.28 :: happensAt(walking(mike), 40).
0.18 :: happensAt(walking(sarah), 40).
  
```

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

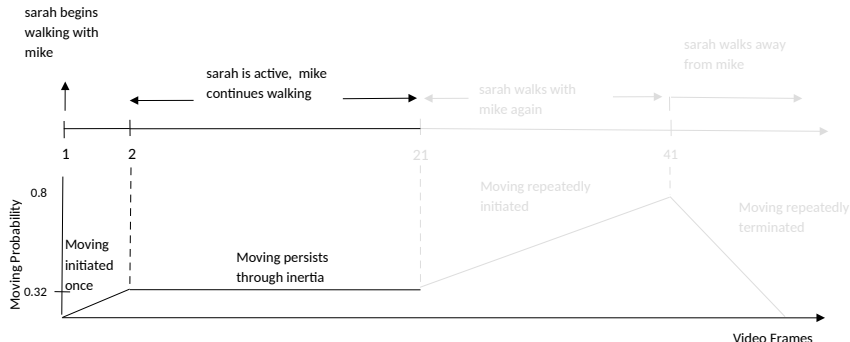
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.28 :: \text{happensAt}(\text{walking}(\text{mike}), 40).$

$0.18 :: \text{happensAt}(\text{walking}(\text{sarah}), 40).$

$P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40)) =$
 $P(\text{happensAt}(\text{walking}(\text{mike}), 40)) \times$
 $P(\text{happensAt}(\text{walking}(\text{sarah}), 40)) \times$
 $P(\text{holdsAt}(\text{close}(\text{mike}, \text{sarah}) = \text{true}, 40)) \times$
 $P(\text{holdsAt}(\text{orientation}(\text{mike}, \text{sarah}) = \text{true}, 40))$
 $= 0.28 \times 0.18 \times 1 \times 1 = 0.05$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

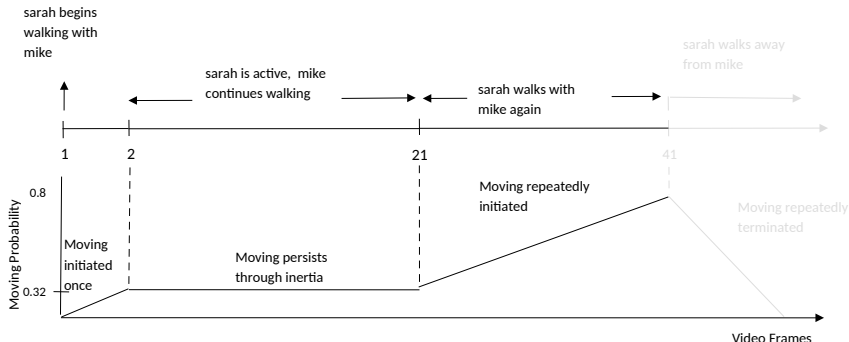
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.28 :: \text{happensAt}(\text{walking}(\text{mike}), 40).$

$0.18 :: \text{happensAt}(\text{walking}(\text{sarah}), 40).$

$$\begin{aligned}
 &P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41)) = \\
 &P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40) \vee \\
 &\quad (\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40) \wedge \\
 &\quad \neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40))) \\
 &= 0.05 + 0.79 \times 1 - 0.05 \times 0.79 \times 1 = 0.80
 \end{aligned}$$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

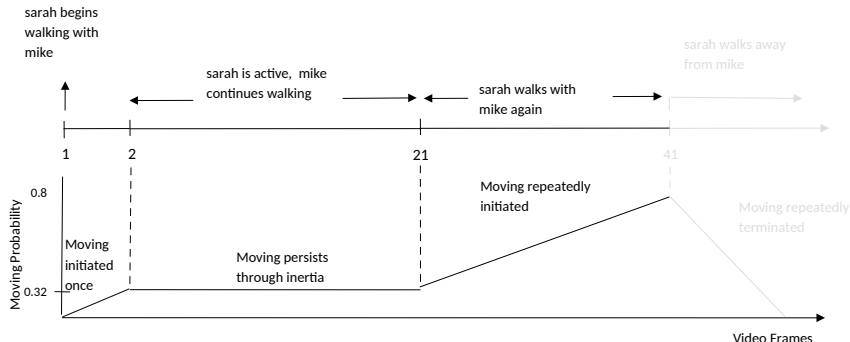
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.28 :: \text{happensAt}(\text{walking}(\text{mike}), 40).$

$0.18 :: \text{happensAt}(\text{walking}(\text{sarah}), 40).$

$$\begin{aligned}
 &P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41)) = \\
 &P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40) \vee \\
 &\quad (\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40) \wedge \\
 &\quad \neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 40))) \\
 &= 0.05 + 0.79 \times 1 - 0.05 \times 0.79 \times 1 = 0.80
 \end{aligned}$$

Instantaneous Recognition

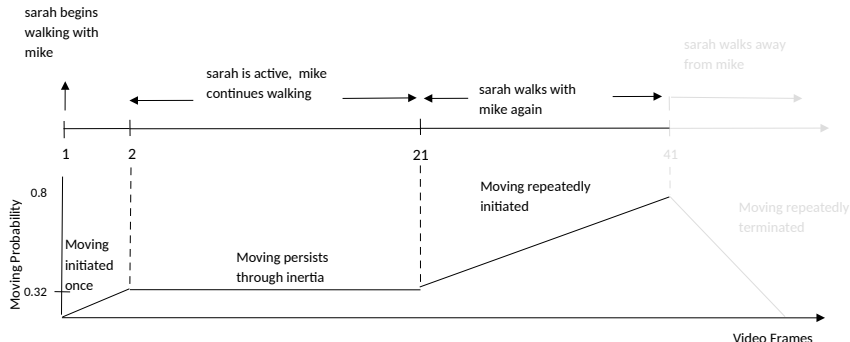


initiatedAt($moving(P_1, P_2) = true, T$) $\leftarrow$
happensAt($walking(P_1), T$),
happensAt($walking(P_2), T$),
holdsAt($close(P_1, P_2) = true, T$),
holdsAt($orientation(P_1, P_2) = true, T$).

terminatedAt($moving(P_1, P_2) = true, T$) $\leftarrow$
happensAt($walking(P_1), T$),
holdsAt($close(P_1, P_2) = false, T$).

0.18 :: **happensAt**($walking(mike), 41$).
0.79 :: **happensAt**($inactive(sarah), 41$). ...

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

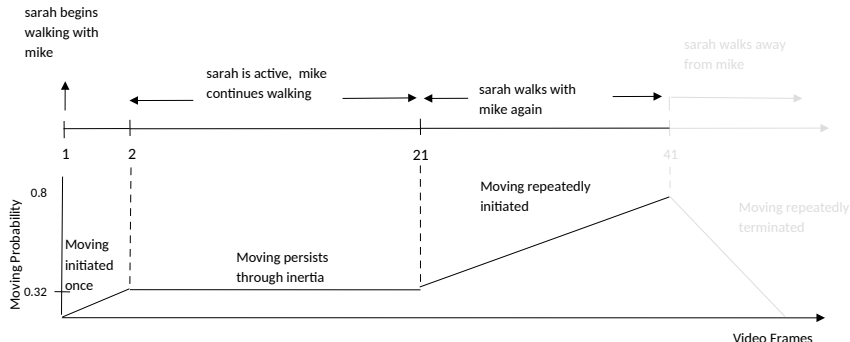
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.18 :: \text{happensAt}(\text{walking}(\text{mike}), 41).$

$0.79 :: \text{happensAt}(\text{inactive}(\text{sarah}), 41). \dots$

$$\begin{aligned}
 P(\text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41)) &= \\
 P(\text{happensAt}(\text{walking}(\text{mike}), 41)) \times \\
 P(\text{holdsAt}(\text{close}(\text{mike}, \text{sarah}) = \text{false}, 41)) \\
 &= 0.18 \times 1 = 0.18
 \end{aligned}$$

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

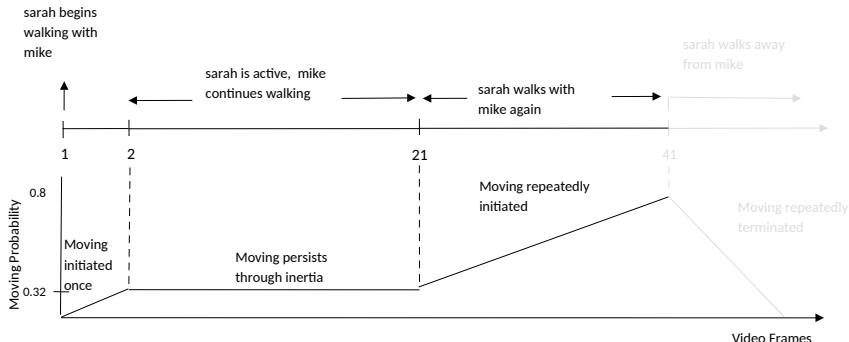
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$0.18 :: \text{happensAt}(\text{walking}(\text{mike}), 41).$

$0.79 :: \text{happensAt}(\text{inactive}(\text{sarah}), 41). \dots$

$$\begin{aligned}
 &P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 42)) = \\
 &P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41) \vee \\
 &\quad (\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41) \wedge \\
 &\quad \neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 41))) \\
 &= 0 + 0.8 \times (1 - 0.18) - 0 \times 0.8 \times (1 - 0.18) = 0.66
 \end{aligned}$$

Instantaneous Recognition



```

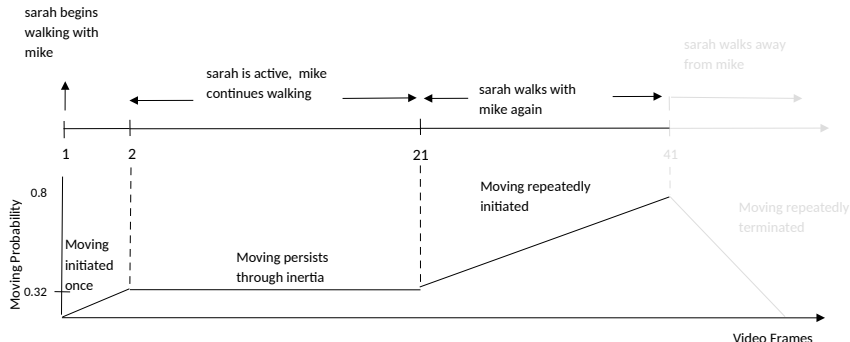
initiatedAt(moving( $P_1, P_2$ ) = true,  $T$ )  $\leftarrow$ 
  happensAt(walking( $P_1$ ),  $T$ ),
  happensAt(walking( $P_2$ ),  $T$ ),
  holdsAt(close( $P_1, P_2$ ) = true,  $T$ ),
  holdsAt(orientation( $P_1, P_2$ ) = true,  $T$ ).

terminatedAt(moving( $P_1, P_2$ ) = true,  $T$ )  $\leftarrow$ 
  happensAt(walking( $P_1$ ),  $T$ ),
  holdsAt(close( $P_1, P_2$ ) = false,  $T$ ).
  
```

```

1.00 :: happensAt(walking(mike), 49).
0.96 :: happensAt(inactive(sarah), 49).
  
```

Instantaneous Recognition



$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$

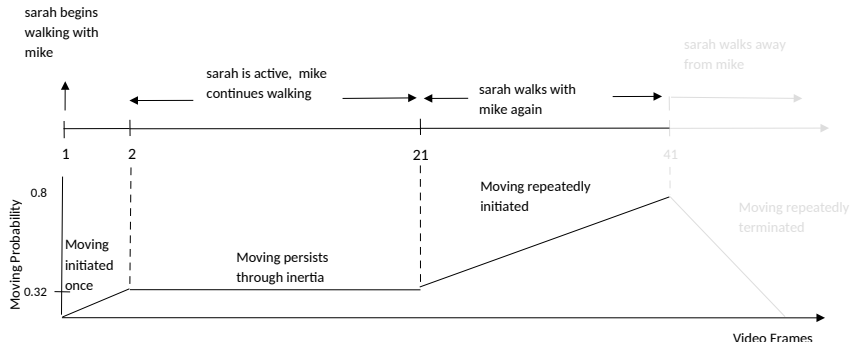
$\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$1.00 :: \text{happensAt}(\text{walking}(\text{mike}), 49).$

$0.96 :: \text{happensAt}(\text{inactive}(\text{sarah}), 49).$

$P(\text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49)) =$
 $P(\text{happensAt}(\text{walking}(\text{mike}), 49)) \times$
 $P(\text{holdsAt}(\text{close}(\text{mike}, \text{sarah}) = \text{false}, 49))$
 $= 1 \times 1 = 1$

Instantaneous Recognition

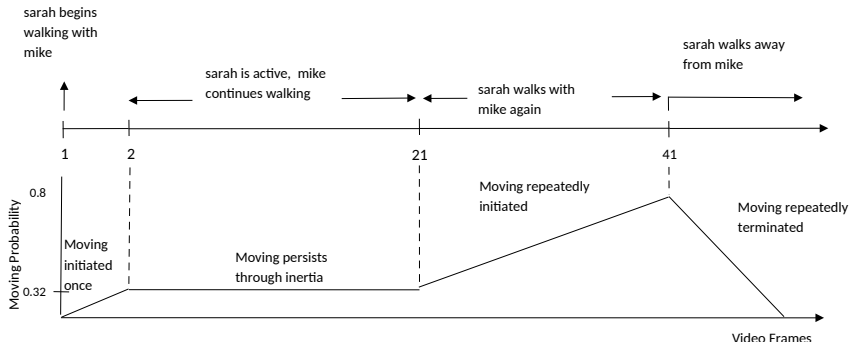


$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$
 $\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$1.00 :: \text{happensAt}(\text{walking}(\text{mike}), 49).$
 $0.96 :: \text{happensAt}(\text{inactive}(\text{sarah}), 49).$

$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 50)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49) \vee$
 $(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49)))$
 $= 0 + 0.07 \times 0 - 0 \times 0.07 \times 0 = 0$

Instantaneous Recognition

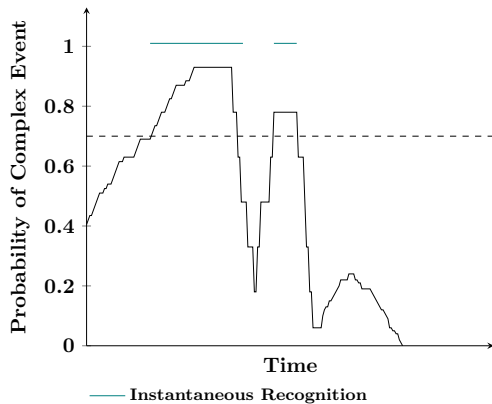


$\text{initiatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{happensAt}(\text{walking}(P_2), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{true}, T),$
 $\text{holdsAt}(\text{orientation}(P_1, P_2) = \text{true}, T).$
 $\text{terminatedAt}(\text{moving}(P_1, P_2) = \text{true}, T) \leftarrow$
 $\text{happensAt}(\text{walking}(P_1), T),$
 $\text{holdsAt}(\text{close}(P_1, P_2) = \text{false}, T).$

$1.00 :: \text{happensAt}(\text{walking}(\text{mike}), 49).$
 $0.96 :: \text{happensAt}(\text{inactive}(\text{sarah}), 49).$

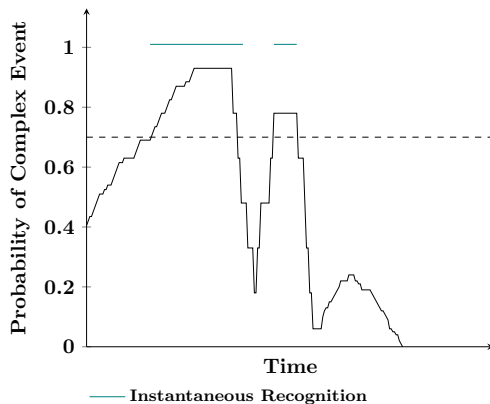
$P(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 50)) =$
 $P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49) \vee$
 $(\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49) \wedge$
 $\neg \text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 49)))$
 $= 0 + 0.07 \times 0 - 0 \times 0.07 \times 0 = 0$

Instantaneous Recognition*



*Skarlatidis et al, A Probabilistic Logic Programming Event Calculus. Theory & Practice of Logic Programming, 2015.

Instantaneous Recognition*

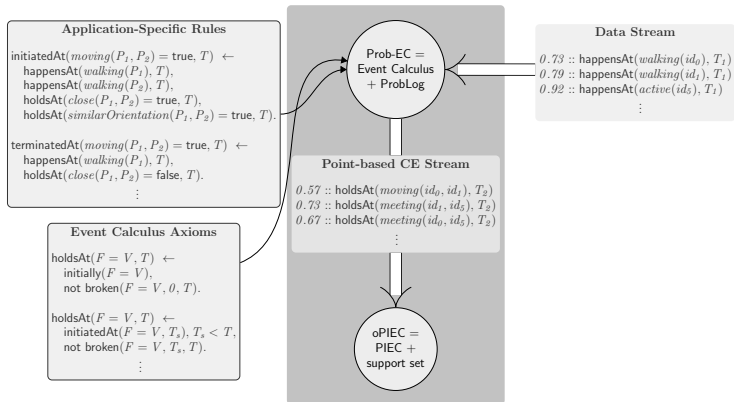


Higher accuracy than crisp reasoning in the presence of:

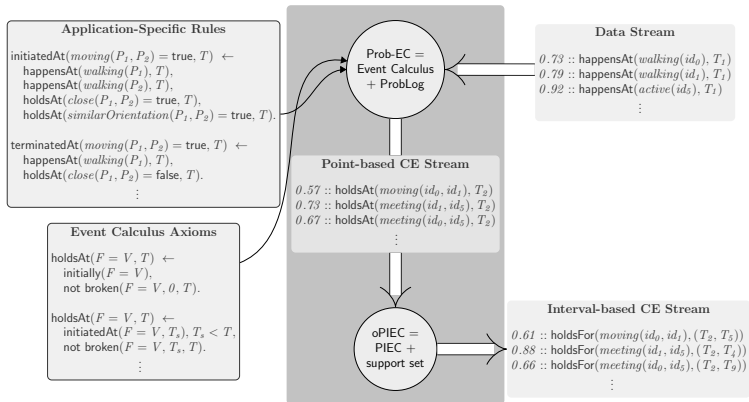
- several initiations and terminations;
- few probabilistic conjuncts.

*Skarlatidis et al, A Probabilistic Logic Programming Event Calculus. Theory & Practice of Logic Programming, 2015.

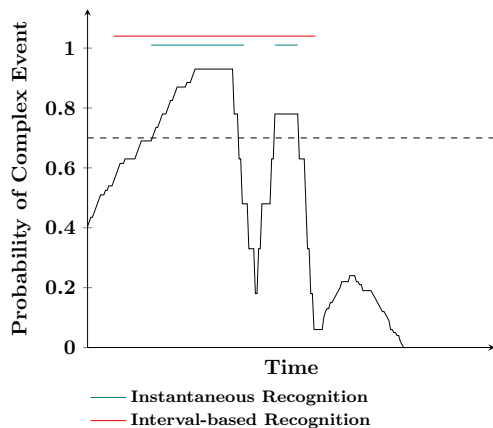
Online Probabilistic Interval-Based Event Calculus



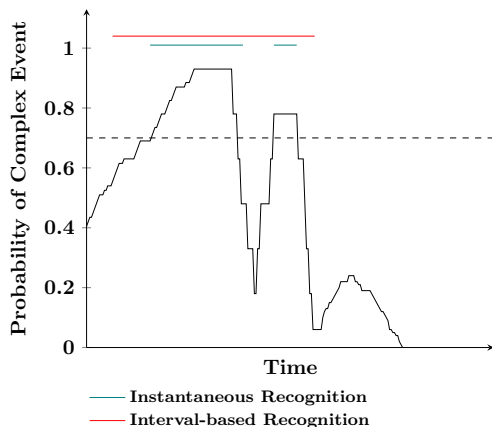
Online Probabilistic Interval-Based Event Calculus



Instantaneous vs Interval-based Recognition

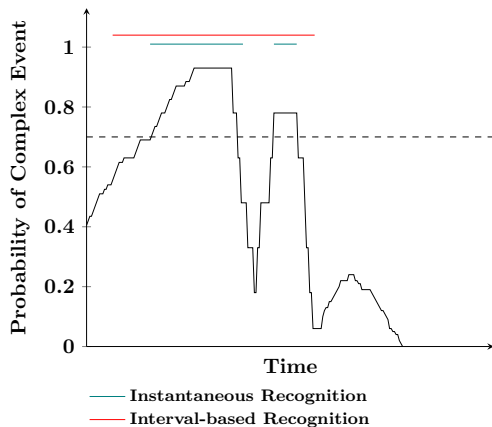


Instantaneous vs Interval-based Recognition



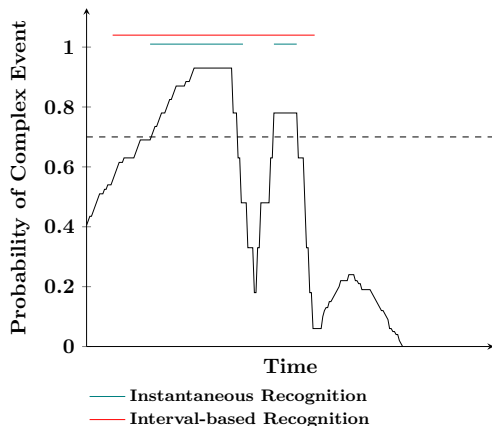
- **Interval Probability:** average probability of the time-points it contains.

Instantaneous vs Interval-based Recognition



- **Interval Probability:** average probability of the time-points it contains.
- **Probabilistic Maximal Interval:**
 - interval probability above a given threshold;
 - no super-interval with probability above the threshold.

Instantaneous vs Interval-based Recognition



- **Interval Probability:** average probability of the time-points it contains.
- **Probabilistic Maximal Interval:**
 - interval probability above a given threshold;
 - no super-interval with probability above the threshold.
- Probabilistic maximal interval computation via **maximal non-negative sum interval** computation.

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	<i>0</i>	<i>0.5</i>	<i>0.7</i>	<i>0.9</i>	<i>0.4</i>	<i>0.1</i>	<i>0</i>	<i>0</i>	<i>0.5</i>	<i>1</i>

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5

$$L[i] = ln[i] - \mathcal{T}$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
l_n	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
L	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5

$$\sum_{i=s}^e L[i] \geq 0 \Leftrightarrow P([s, e]) \geq \mathcal{T}$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9

$$prefix[i] = \sum_{j=1}^i L[j]$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>										

$$dp[i] = \max_{i \leq j \leq n} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>										-0.9

$$dp[10] = \max_{10 \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>									-0.9	-0.9

$$dp[9] = \max_{9 \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>								-0.9	-0.9	-0.9

$$dp[8] = \max_{8 \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>							-0.9	-0.9	-0.9	-0.9

$$dp[7] = \max_{7 \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>						-0.4	-0.9	-0.9	-0.9	-0.9

$$dp[6] = \max_{6 \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dp[i] = \max_{i \leq j \leq 10} (prefix[j])$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[s, e] = \begin{cases} dp[e] - prefix[s-1] & \text{if } s > 1 \\ dp[e] & \text{if } s = 1 \end{cases}$$

Interval-based Recognition

Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[s, e] = \begin{cases} dp[e] - prefix[s-1] & \text{if } s > 1 \\ dp[e] & \text{if } s = 1 \end{cases}$$

$$dprange[s, e] \geq 0 \Rightarrow \exists e^* : e^* \geq e, P([s, e^*]) \geq \mathcal{T}$$

Interval-based Recognition

	$\uparrow\downarrow$									
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

Interval-based Recognition

	$\uparrow\downarrow$									
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 1] = dp[1] = 0.1 \geq 0$$

Interval-based Recognition

	$\uparrow$	$\downarrow$								
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

Interval-based Recognition

	$\uparrow$	$\downarrow$								
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 2] = dp[2] = 0.1 \geq 0$$

Interval-based Recognition

	$\uparrow$		$\downarrow$							
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 3] = dp[3] = 0.1 \geq 0$$

Interval-based Recognition

	$\uparrow$			$\downarrow$						
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 4] = dp[4] = 0.1 \geq 0$$

Interval-based Recognition

	$\uparrow$				$\downarrow$					
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 5] = dp[5] = 0 \geq 0$$

Interval-based Recognition

	$\uparrow$					$\downarrow$				
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 6] = dp[6] = -0.4 < 0$$

Interval-based Recognition

	↑↑					↓↓				
Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[1, 6] = dp[6] = -0.4 < 0$$

Interval-based Recognition

		↑				↓				
Time	1	2	3	4	5	6	7	8	9	10
<i>ln</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[2, 6] = dp[6] - prefix[1] = 0.1 \geq 0$$

Interval-based Recognition

		↑					↓			
Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[2, 7] = dp[7] - prefix[1] = -0.4 < 0$$

Interval-based Recognition



Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

$$dprange[2, 7] = dp[7] - prefix[1] = -0.4 < 0$$

Interval-based Recognition



Time	1	2	3	4	5	6	7	8	9	10
<i>In</i>	0	0.5	0.7	0.9	0.4	0.1	0	0	0.5	1
<i>L</i>	-0.5	0	0.2	0.4	-0.1	-0.4	-0.5	-0.5	0	0.5
<i>prefix</i>	-0.5	-0.5	-0.3	0.1	0	-0.4	-0.9	-1.4	-1.4	-0.9
<i>dp</i>	0.1	0.1	0.1	0.1	0	-0.4	-0.9	-0.9	-0.9	-0.9

Interval-based Recognition*

Interval Computation Correctness

An interval is computed iff it is a probabilistic maximal interval.

* Artikis et al, A Probabilistic Interval-based Event Calculus for Activity Recognition. Annals of Mathematics and Artificial Intelligence, 2021.

Interval-based Recognition*

Interval Computation Correctness

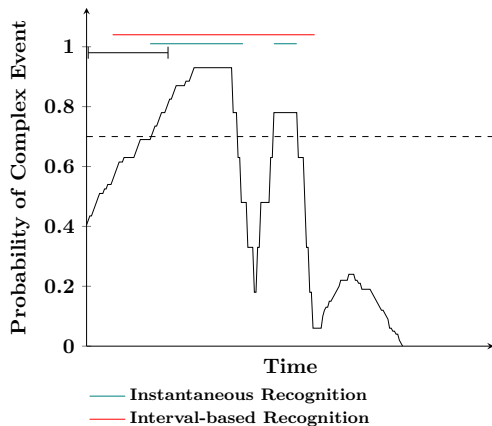
An interval is computed iff it is a probabilistic maximal interval.

Complexity

The computation of probabilistic maximal intervals is linear to the dataset size.

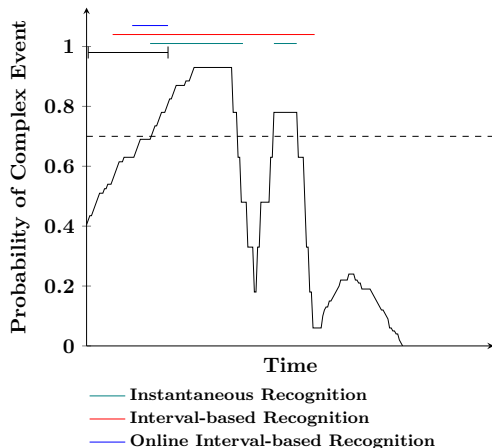
* Artikis et al, A Probabilistic Interval-based Event Calculus for Activity Recognition. Annals of Mathematics and Artificial Intelligence, 2021.

Online Interval-based Recognition



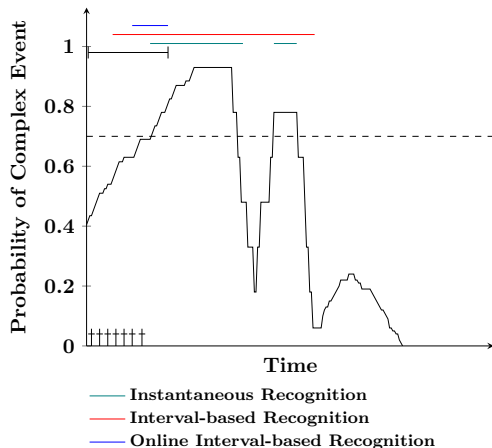
- Windowing.

Online Interval-based Recognition



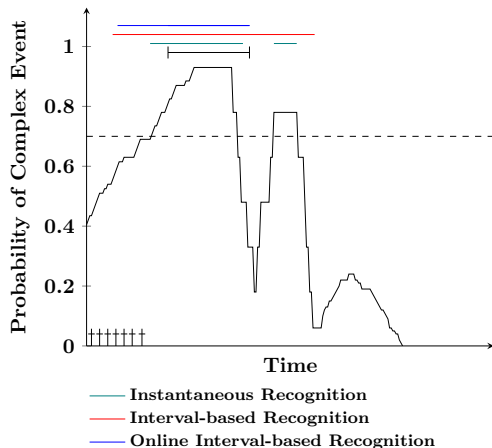
- Windowing.
- Probabilistic maximal interval computation.

Online Interval-based Recognition



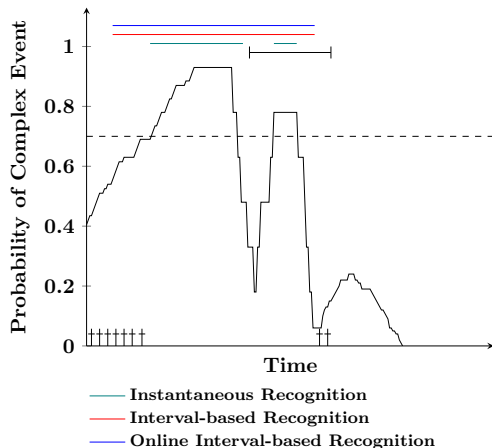
- Windowing.
- Probabilistic maximal interval computation.
- Caching **potential starting points**.

Online Interval-based Recognition



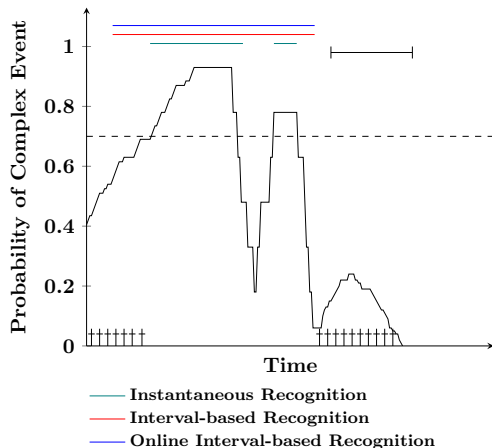
- Windowing.
- Probabilistic maximal interval computation.
- Caching **potential starting points**.

Online Interval-based Recognition



- Windowing.
- Probabilistic maximal interval computation.
- Caching potential starting points.

Online Interval-based Recognition



- Windowing.
- Probabilistic maximal interval computation.
- Caching **potential starting points**.

Online Interval-based Recognition: Properties

Memory Minimality

A time-point is cached iff it may be the starting point of a future probabilistic maximal interval.

Online Interval-based Recognition: Properties

Memory Minimality

A time-point is cached iff it may be the starting point of a future probabilistic maximal interval.

Interval Computation Correctness

An interval is computed iff it is a probabilistic maximal interval given the data seen so far.

Online Interval-based Recognition: Properties

Memory Minimality

A time-point is cached iff it may be the starting point of a future probabilistic maximal interval.

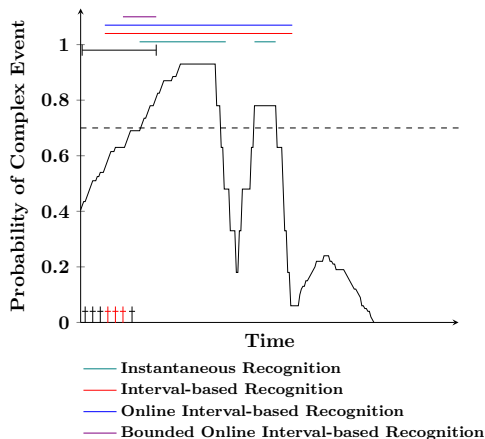
Interval Computation Correctness

An interval is computed iff it is a probabilistic maximal interval given the data seen so far.

Complexity

The computation of probabilistic maximal intervals is linear to the window and memory size.

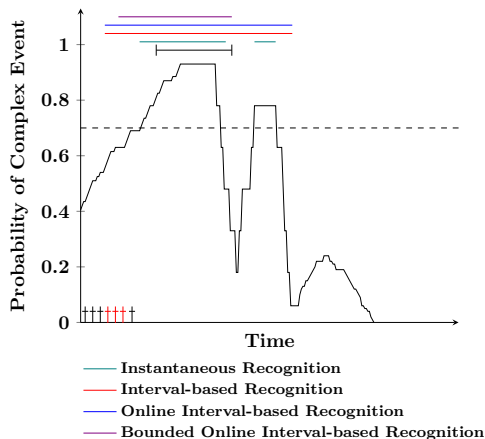
Bounded Online Interval-based Recognition*



- Complex event duration statistics favor more recent potential starting points.

* Mantenoglou et al, Online Event Recognition over Noisy Data Streams. International Journal of Approximate Reasoning, 2023. <https://github.com/Periklismant/oPIEC>

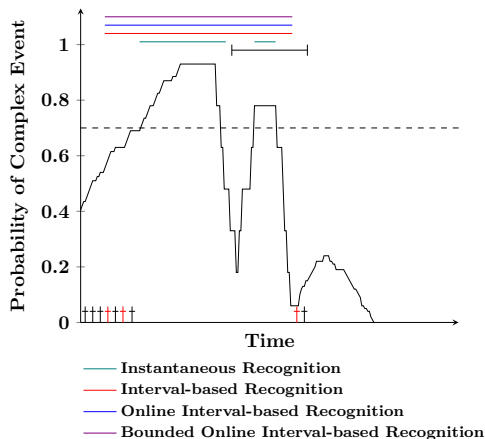
Bounded Online Interval-based Recognition*



- Complex event duration statistics favor more recent potential starting points.

* Mantenoglou et al, Online Event Recognition over Noisy Data Streams. International Journal of Approximate Reasoning, 2023. <https://github.com/Periklismant/oPIEC>

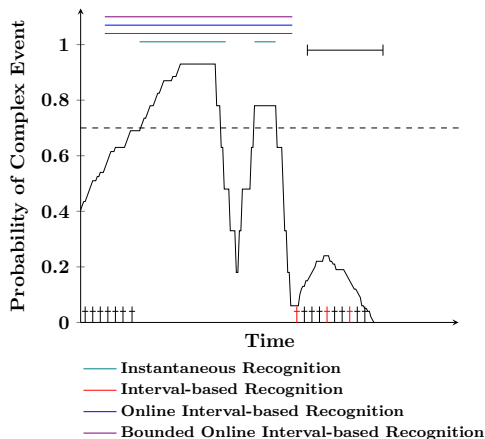
Bounded Online Interval-based Recognition*



- Complex event duration statistics favor more recent potential starting points.

* Mantenoglou et al, Online Event Recognition over Noisy Data Streams. International Journal of Approximate Reasoning, 2023. <https://github.com/Periklismant/oPIEC>

Bounded Online Interval-based Recognition*



- Complex event duration statistics favor more recent potential starting points.
- Comparable accuracy to batch reasoning.

* Mantenoglou et al, Online Event Recognition over Noisy Data Streams. International Journal of Approximate Reasoning, 2023. <https://github.com/Periklismant/oPIEC>

Summary

Complex event recognition over noisy streams:

- Probabilistic reasoning $\rightarrow$ robust complex event recognition.

Summary

Complex event recognition over noisy streams:

- Probabilistic reasoning → robust complex event recognition.
- Interval-based reasoning → improved predictive accuracy.

Summary

Complex event recognition over noisy streams:

- Probabilistic reasoning → robust complex event recognition.
- Interval-based reasoning → improved predictive accuracy.
- Optimal stream compression →
 - run-time performance;
 - correct complex event recognition.

Summary

Complex event recognition over noisy streams:

- Probabilistic reasoning → robust complex event recognition.
- Interval-based reasoning → improved predictive accuracy.
- Optimal stream compression →
 - run-time performance;
 - correct complex event recognition.
- Direct routes to neuro-symbolic learning → end-to-end optimisation of simple and complex event recognition.

DIY: Computing the probability of holdsAt

- Consider the initiation and termination probabilities for “*moving(mike, sarah) = true*” below. $P(x)$ denotes the probability of x .

Time	1	2	3	...	25
$P(\text{initiatedAt}(\text{moving}(\text{mike}, \text{sarah})=\text{true}, T))$	0.4	0.5	0	0	0
$P(\text{terminatedAt}(\text{moving}(\text{mike}, \text{sarah})=\text{true}, T))$	0	0	0	0	0.7

- What is the probability of:
 - $\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 3)?$
 - $\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 21)?$
 - $\text{holdsAt}(\text{moving}(\text{mike}, \text{sarah}) = \text{true}, 26)?$

Course Structure

- Introduction to Complex Event Recognition (CER).
- Formal Models for CER
- Probabilistic CER.

Course Structure

- Introduction to Complex Event Recognition (CER).
- Formal Models for CER
- Probabilistic CER.
- Tensor-based CER.
- Topics not covered.