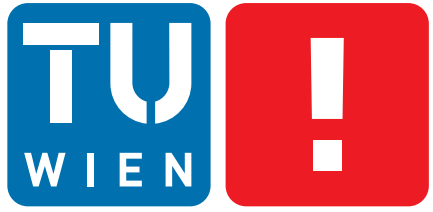
LARS: A Logic-based Framework for Analyzing Reasoning over Streams

Harald Beck Minh Dao-Tran Thomas Eiter Michael Fink

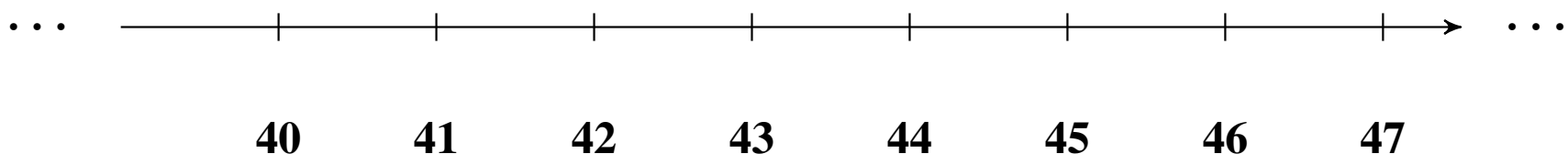
AAAI 2015

January 27, 2015



FAKULTÄT
FÜR !NFORMATIK

Faculty of Informatics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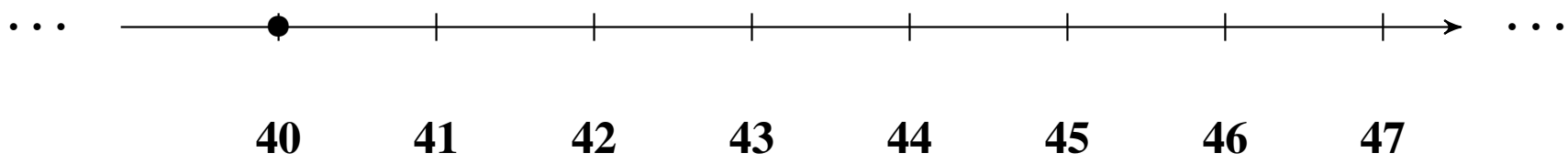
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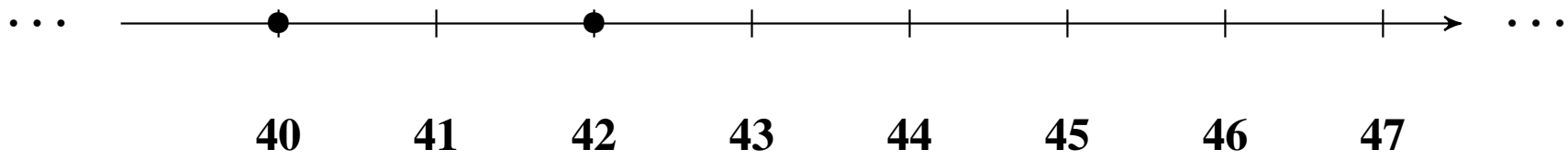
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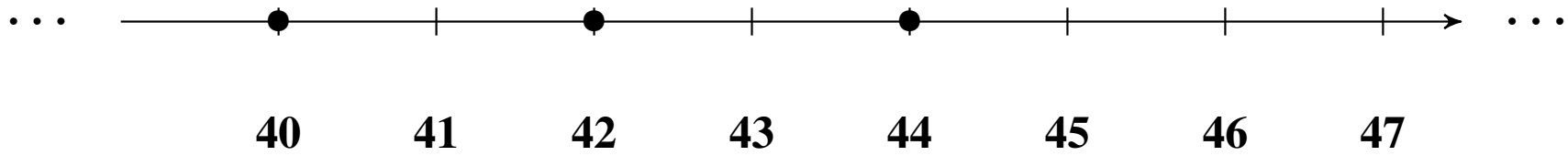
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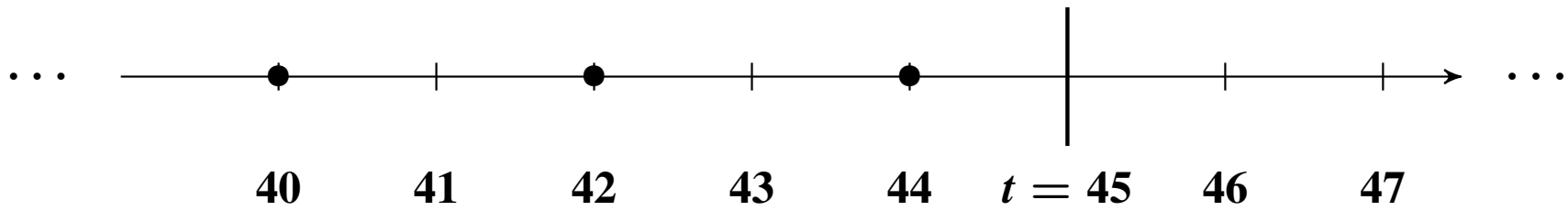
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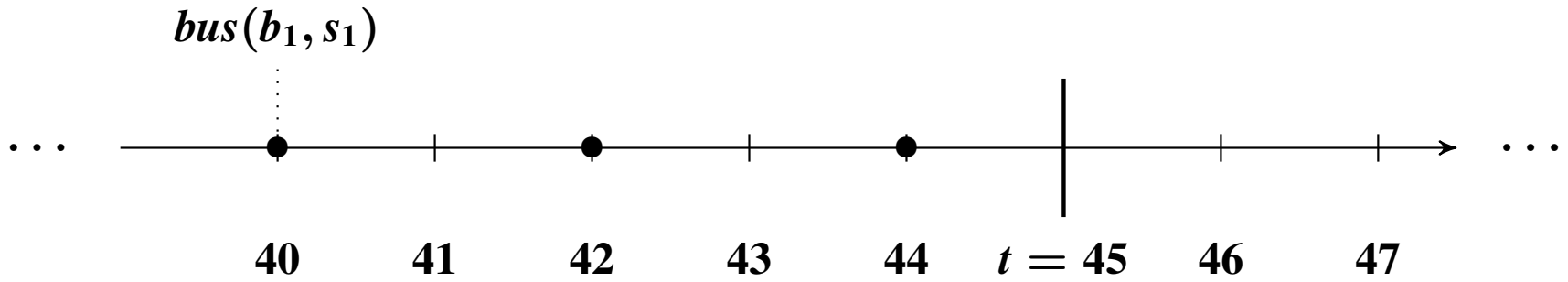
Public transport scenario



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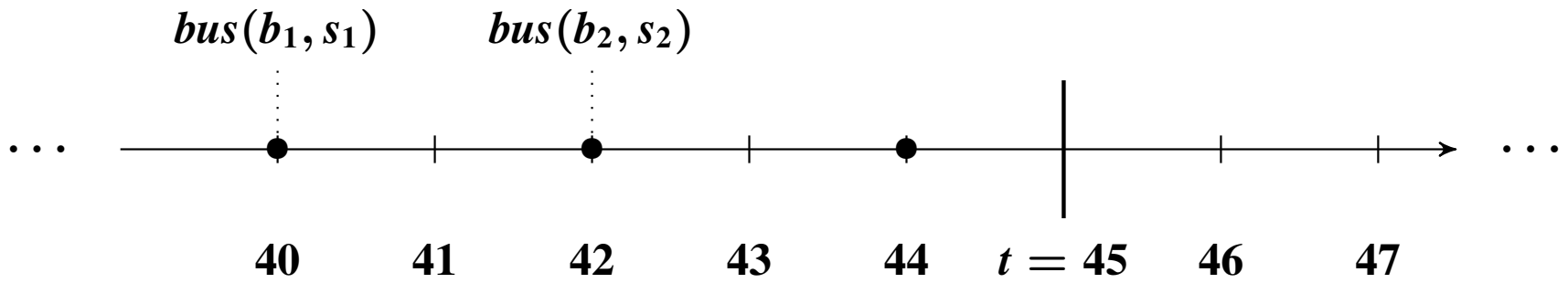

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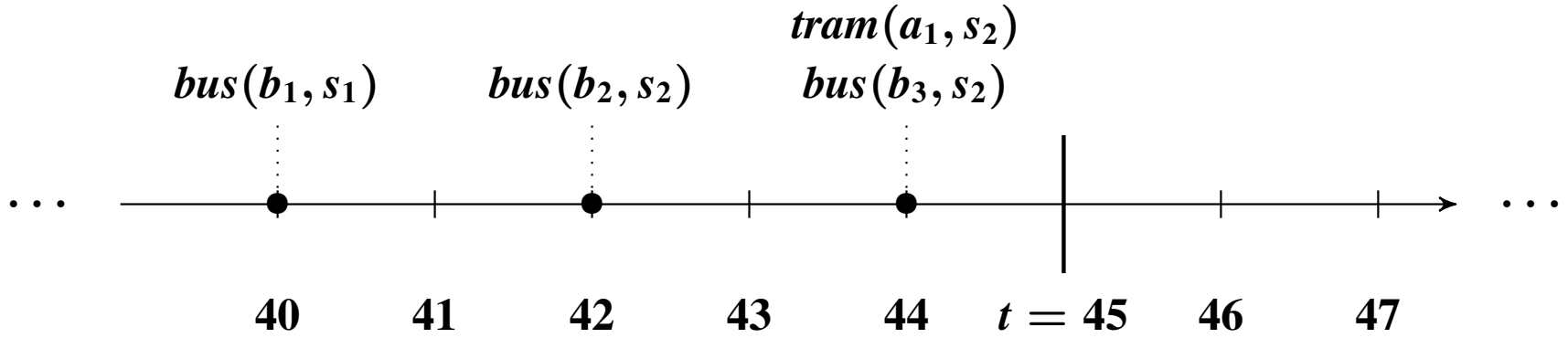

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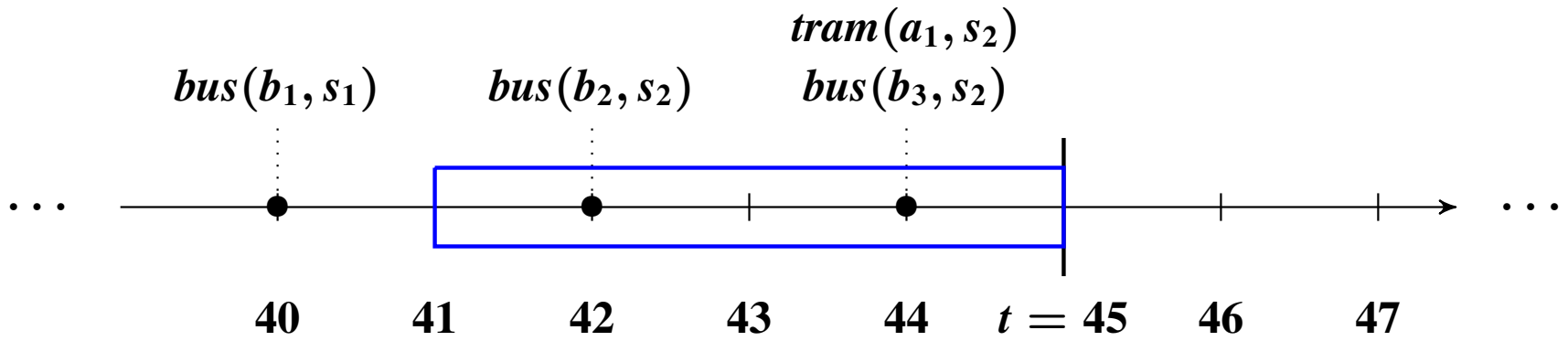
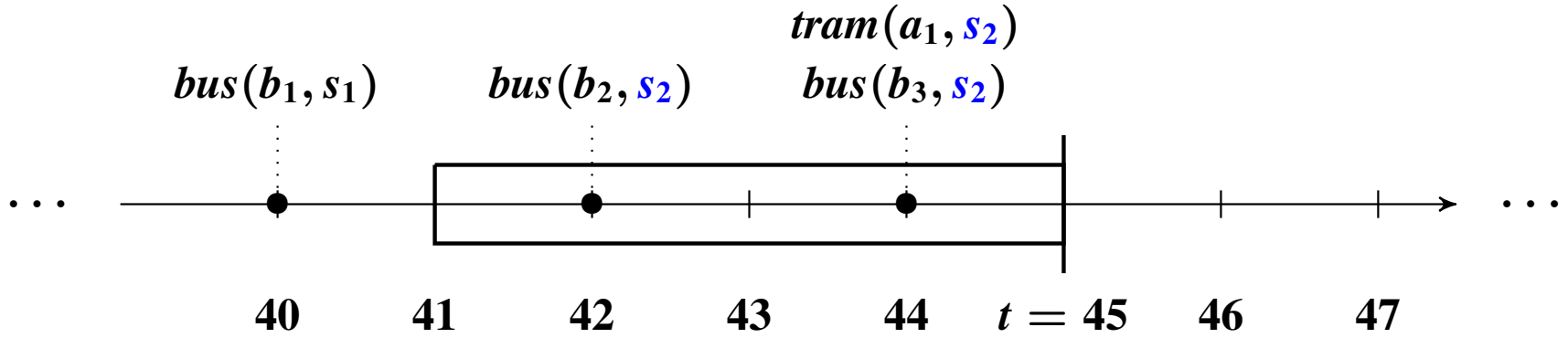


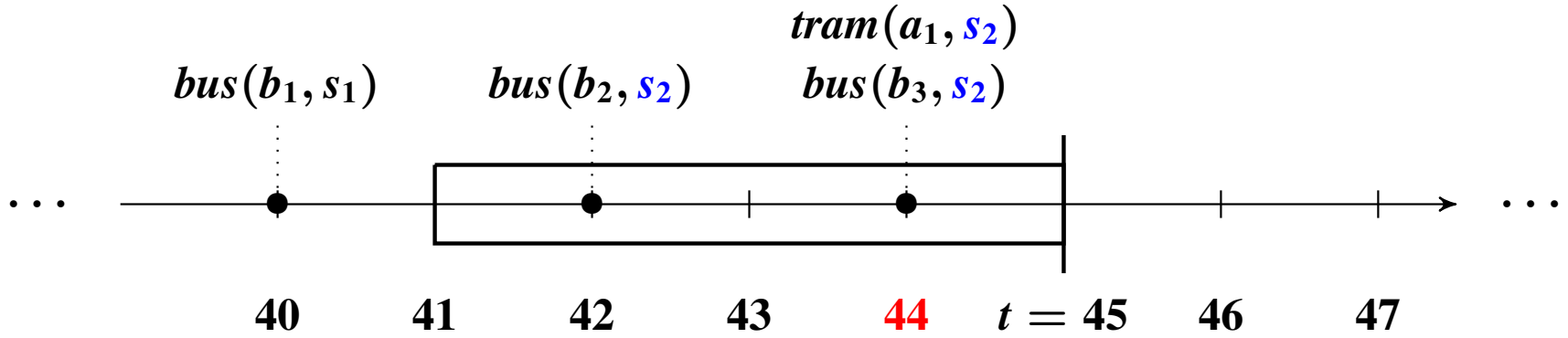
- Trams and buses appearing within the last 4 minutes,

Public transport scenario



- Trams and buses appearing within the last 4 minutes,
- at the same station

Public transport scenario



- Trams and buses appearing within the last 4 minutes,
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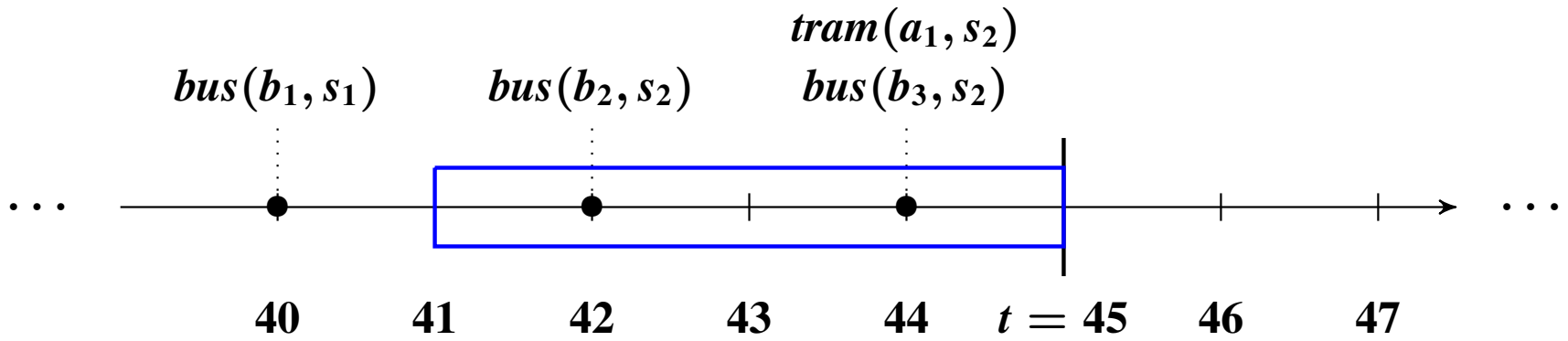
Public transport scenario



- Trams and buses appearing within the last 4 minutes,
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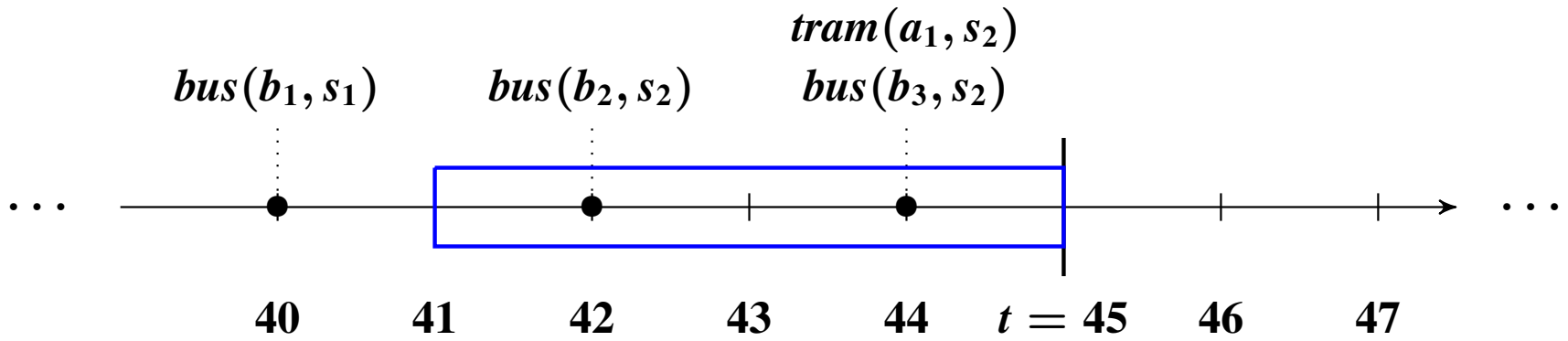
- **CQL** (continuous query language)

```
SELECT * FROM tram [RANGE 4], bus [RANGE 4]
WHERE tram.S = bus.S
```

Public transport scenario



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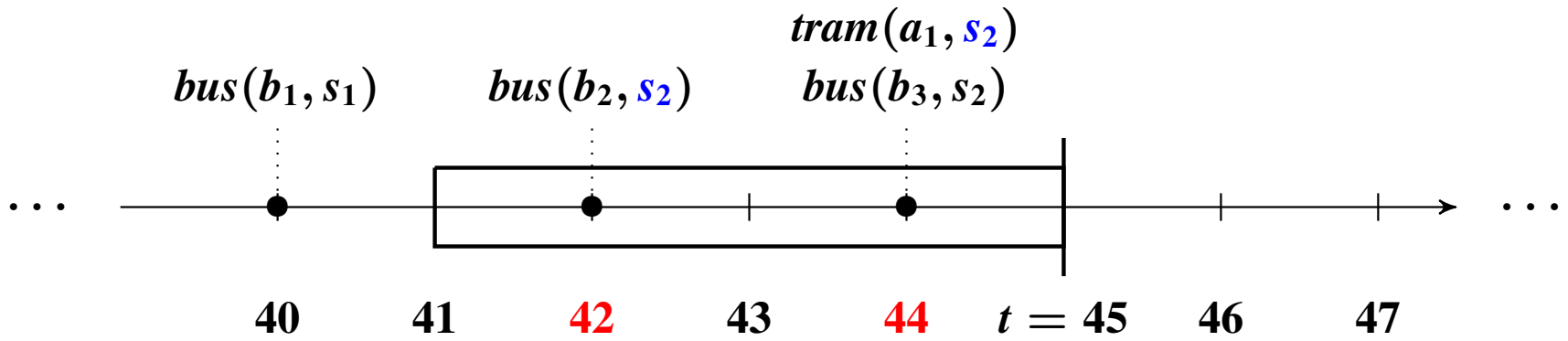
- **:-(**

Public transport scenario



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- at the same station, at the same time?
- **CQL** (continuous query language)

```
SELECT * FROM tram [RANGE 4], bus [RANGE 4]
WHERE tram.S = bus.S
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- **:-(** Query also reports bus at 42 with tram at 44

Diverse Approaches - Lack of Unifying Theory

- **Data Management**: low-level, high frequency
- **Semantic Web**: SPARQL extensions
- **KR & R**: *high-level*, lower frequency

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Diverse Approaches - Lack of Unifying Theory

- **Data Management**: low-level, high frequency
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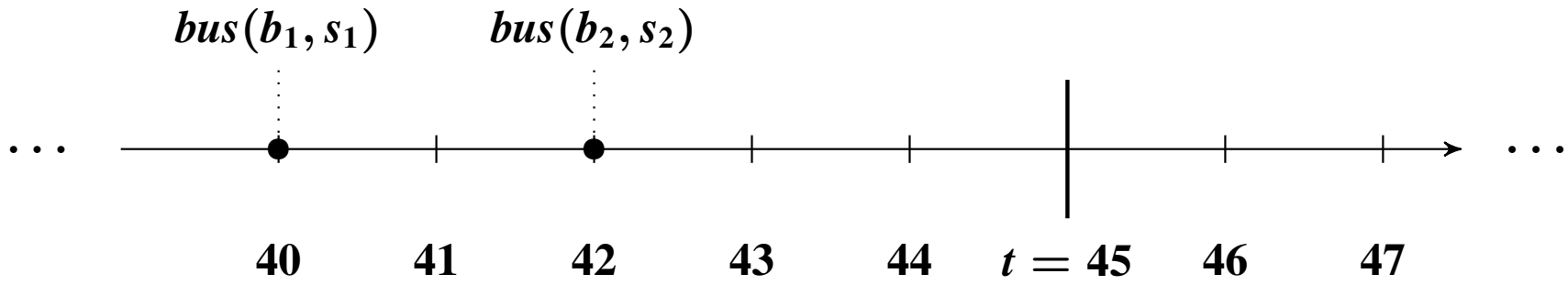
- Hard to understand and compare semantics
- $\Rightarrow$ Need language for formal **analysis**
- Formal semantics for advanced reasoning over streams


$bus(b_1, s_1)$
$bus(b_2, s_2)$
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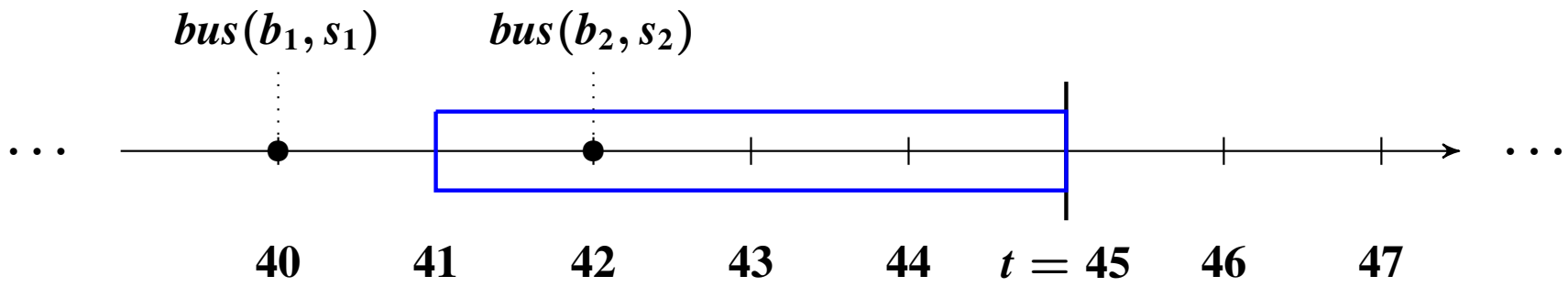
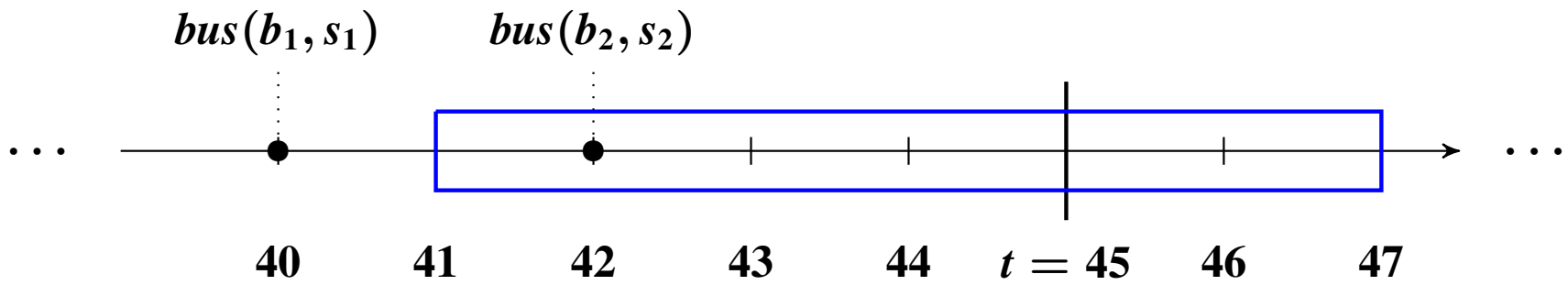


$\boxplus^{4}_{\tau}$

- Window operators

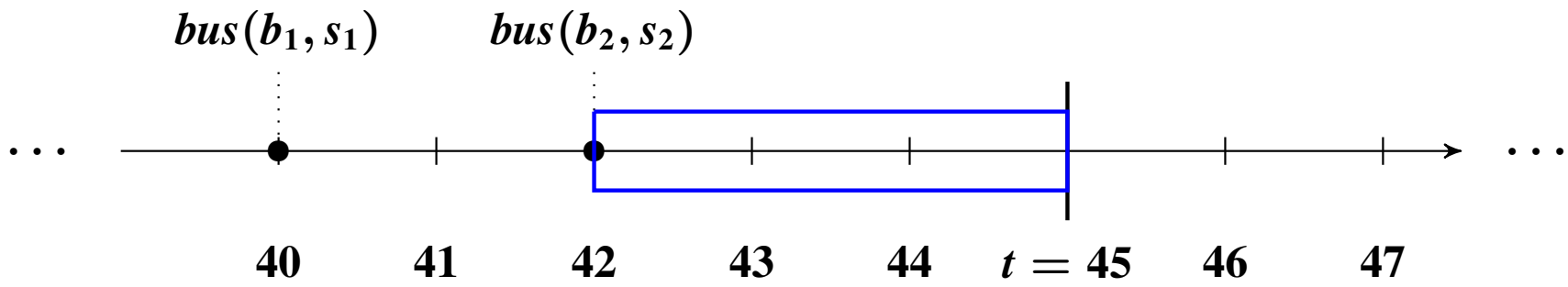
  $\boxplus_{\tau}$ time-based window



$\boxplus_{\tau}^{(4,2)}$

- Window operators

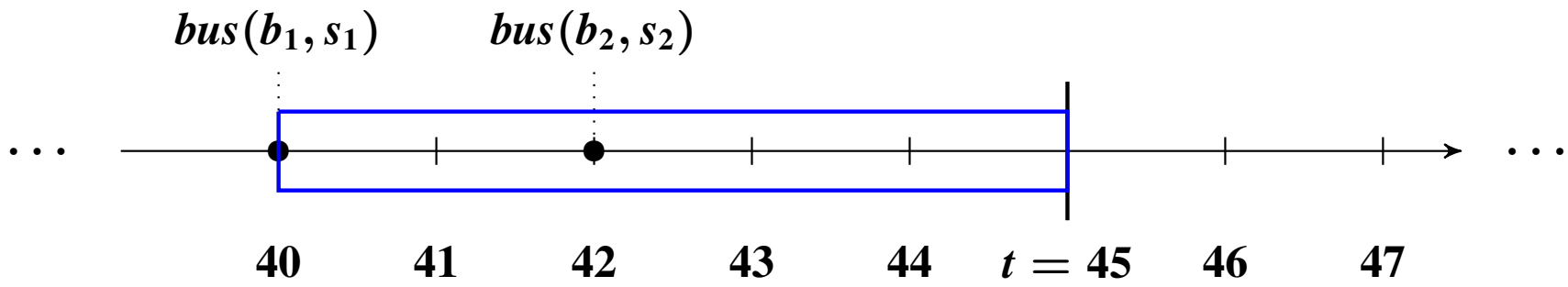
  $\boxplus_{\tau}$ time-based window



$\boxplus^{1}_{\#}$

- Window operators

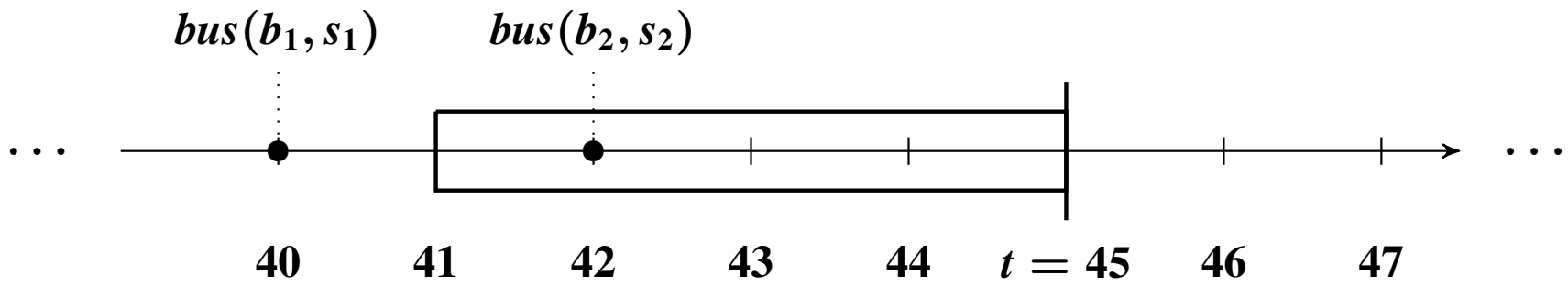
  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window



$\boxplus^{2}_{\#}$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window

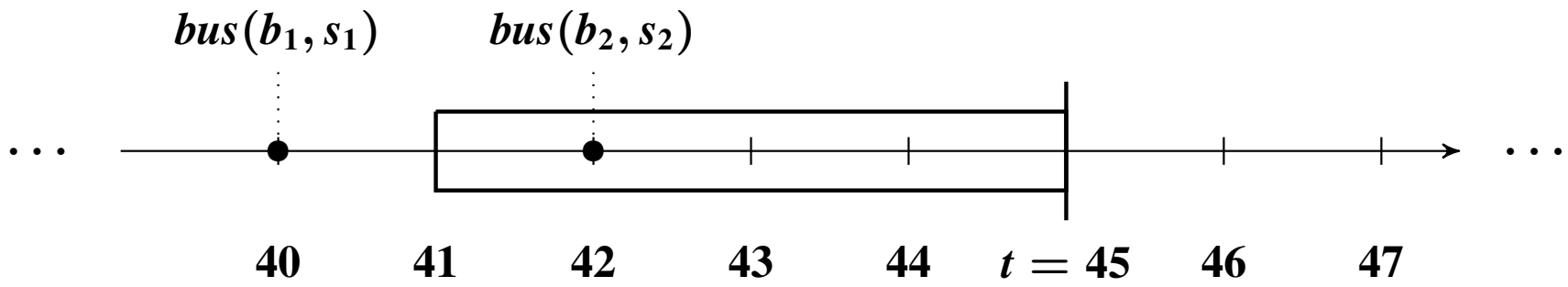


$\boxplus^{4}_{\tau}$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference



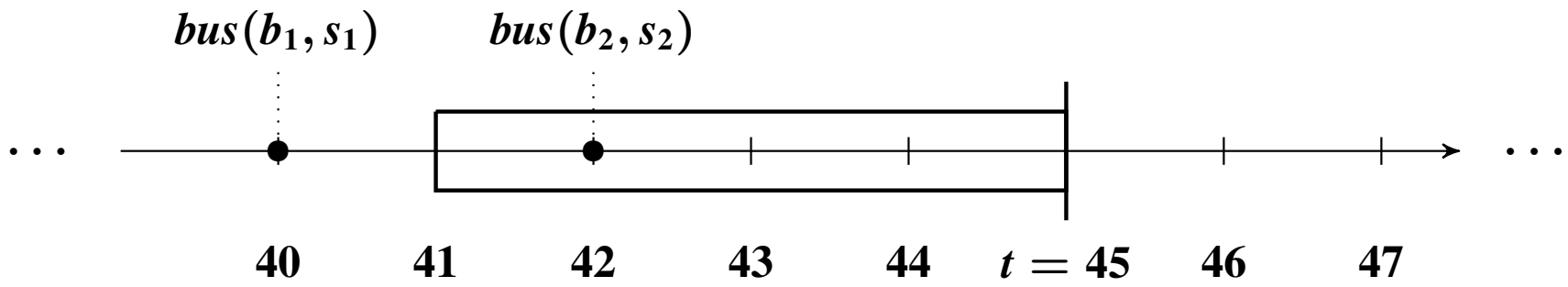
$$\boxplus^{4}_{\tau} \Diamond\, bus(b_2, s_2)$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time



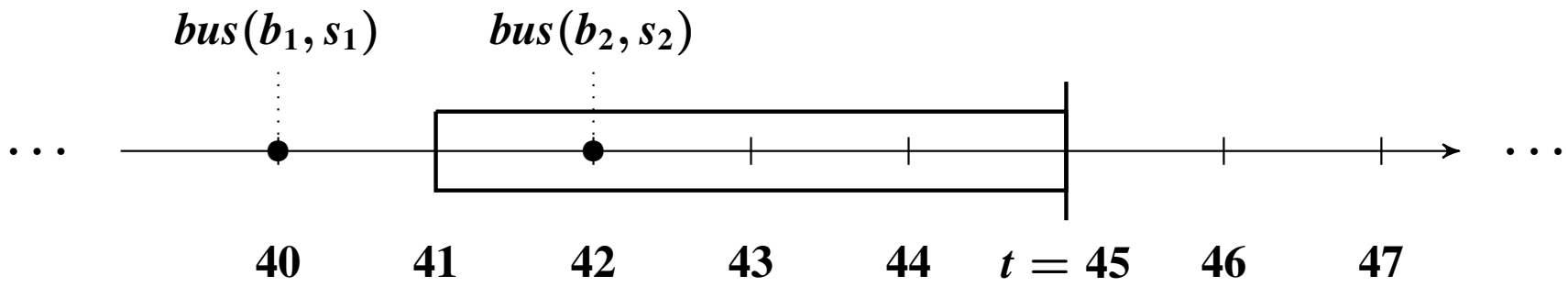
$$\boxplus^{4}_{\tau} \Diamond\, bus(b_2, s_2) \quad \rightsquigarrow \quad yes$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time



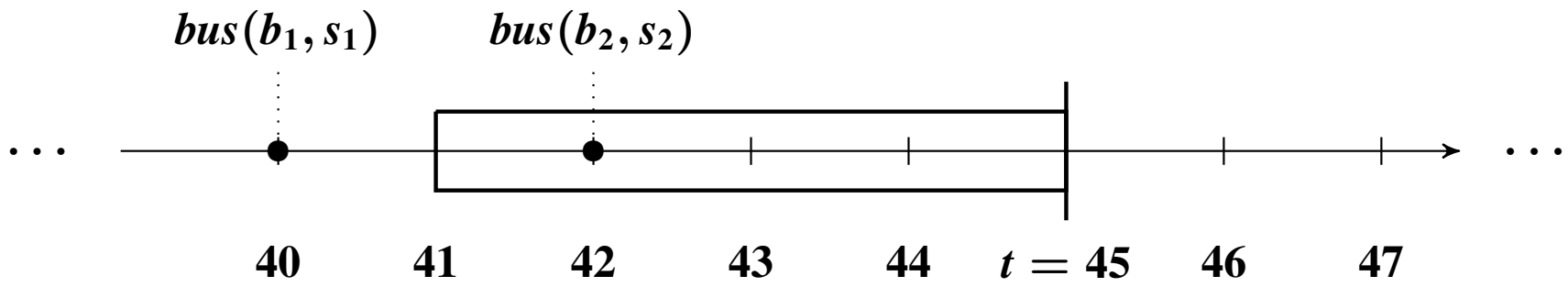
$$\boxplus_{\tau}^{4} \Box \neg jam$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time



$$\boxplus_{\tau}^{4} \Box \neg jam \quad \rightsquigarrow \quad yes$$

- Window operators

  $\boxplus_{\tau}$ time-based window
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- Time reference

  $\Diamond$ some time
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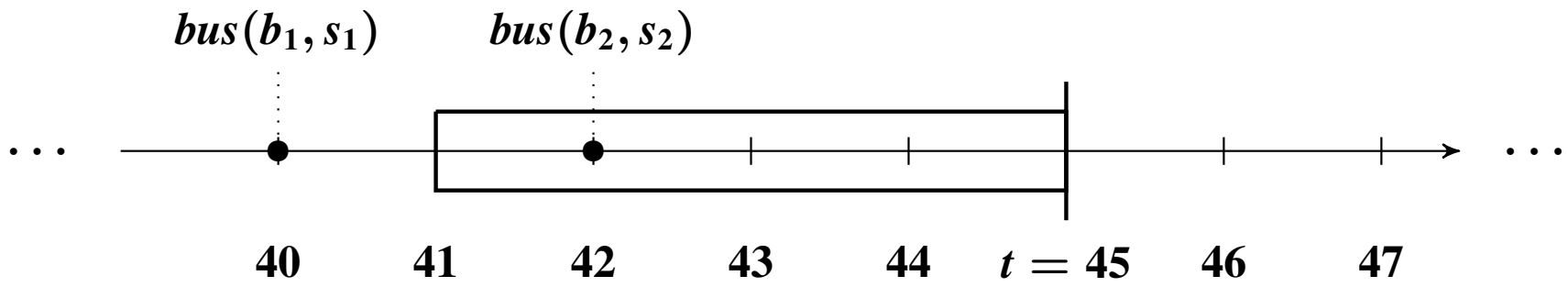


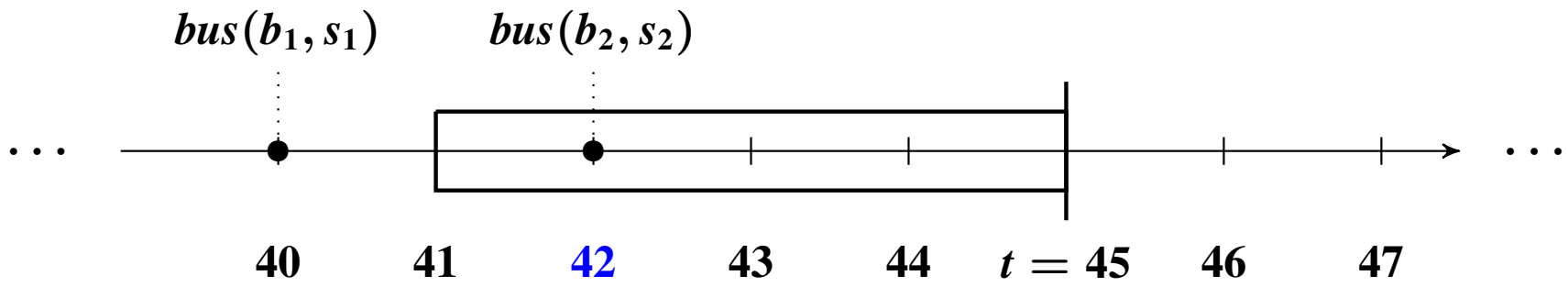
$$\boxplus^{4}_{\tau} \, @_{42} \, bus(b_2, s_2)$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



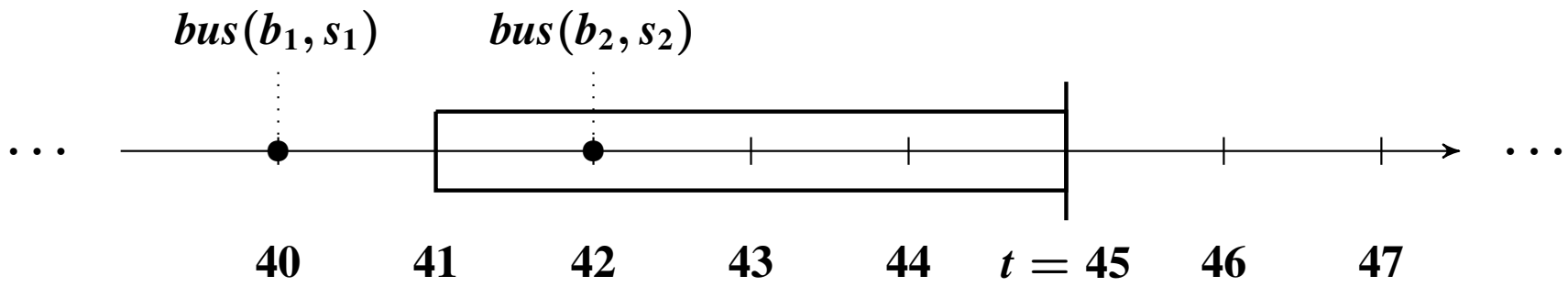
$$\boxplus^{4}_{\tau}\ @_{42}\ bus(b_2, s_2) \quad \rightsquigarrow \quad yes$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



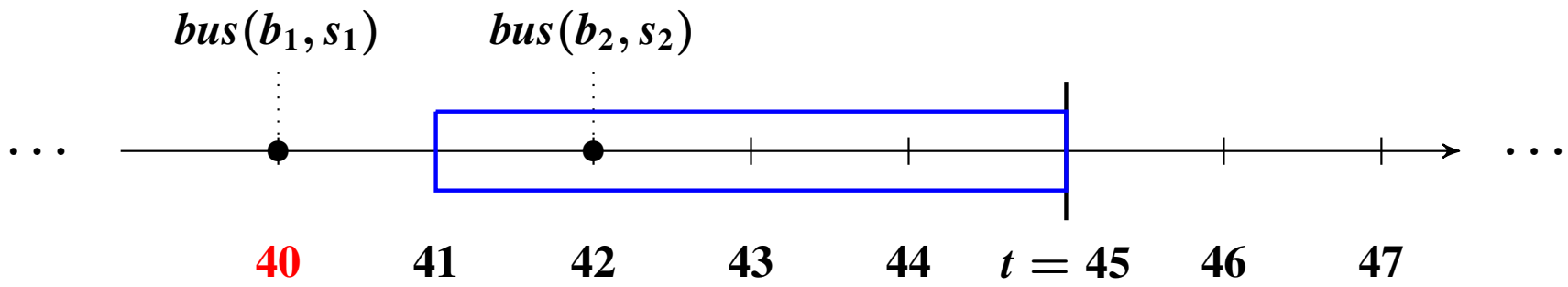
$$\boxplus_{\tau}^{4} @_{40}\, bus(b_1, s_1)$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



$$\boxplus^{4}_{\tau}\ @_{40}\ bus(b_1, s_1) \quad \rightsquigarrow \quad no$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
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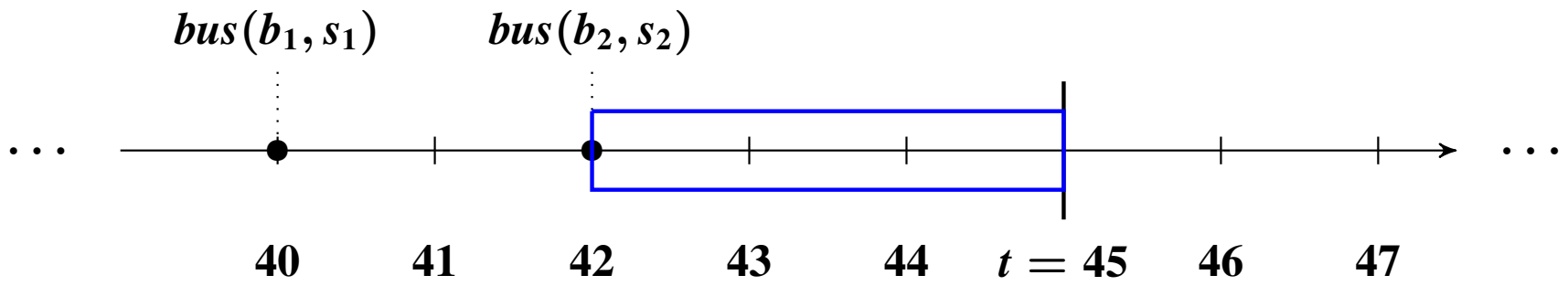
  $@_{t'}$ exact time



$\boxplus^{1}_{\#}$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
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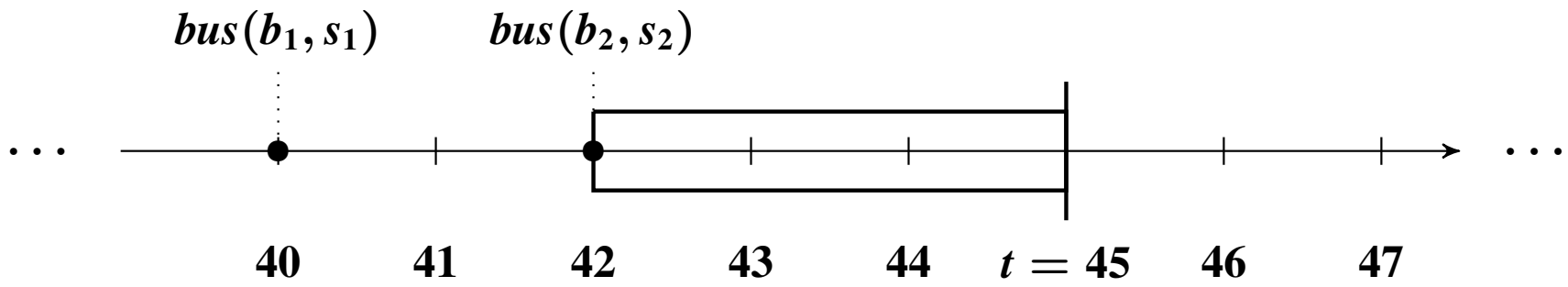


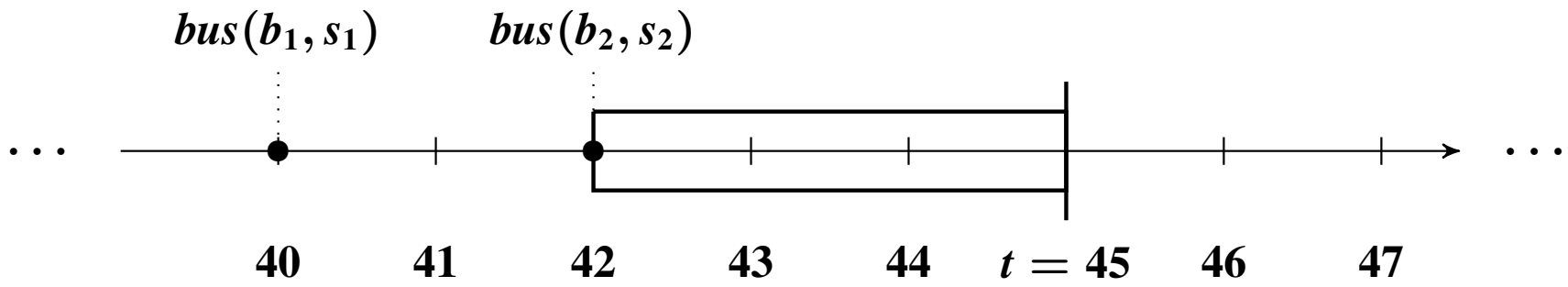
$$\boxplus^{1}_{\#}@_{T}$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



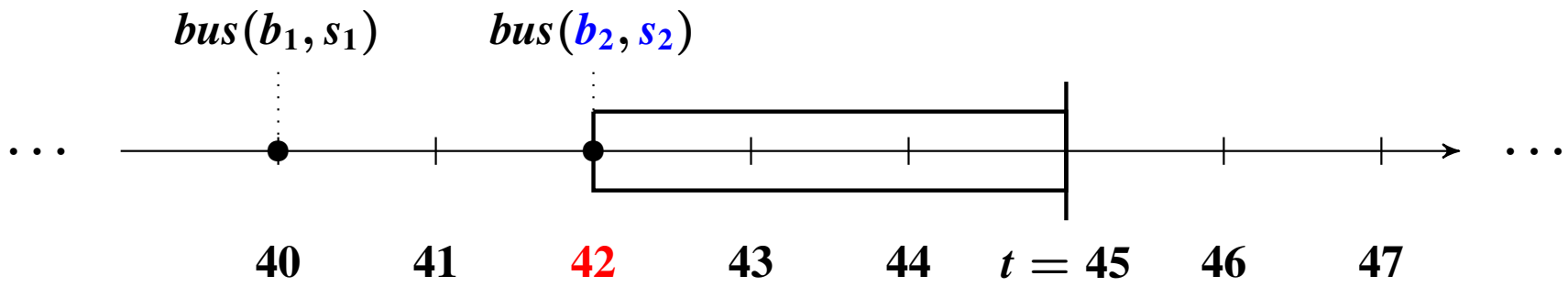
$$\boxplus^{1}_{\#} @_T \, bus(B, S)$$

- Window operators

  $\boxplus_\tau$ time-based window
  $\boxplus_\#$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



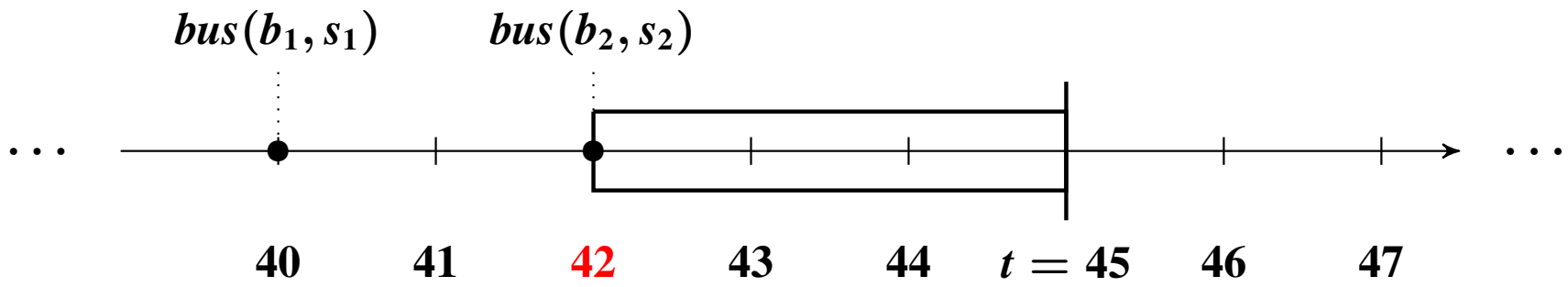
$$\boxplus^{1}_{\#} @_{T}\, bus(B, S) \quad \rightsquigarrow \quad T = 42,\ B = b_2,\ S = s_2$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



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  $\boxplus_{\tau}$ time-based window
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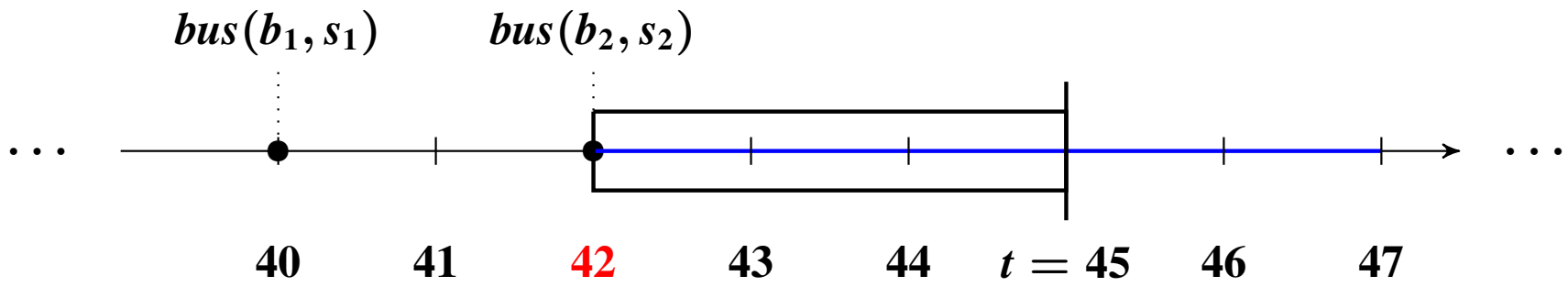


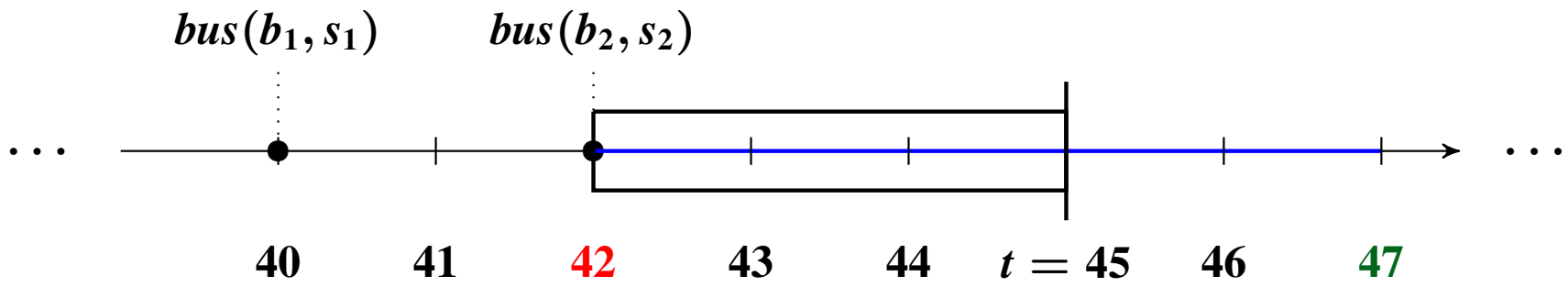
$$\boxplus^{1}_{\#} @_{T}\, bus(B, S), reach(S, S', D),$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



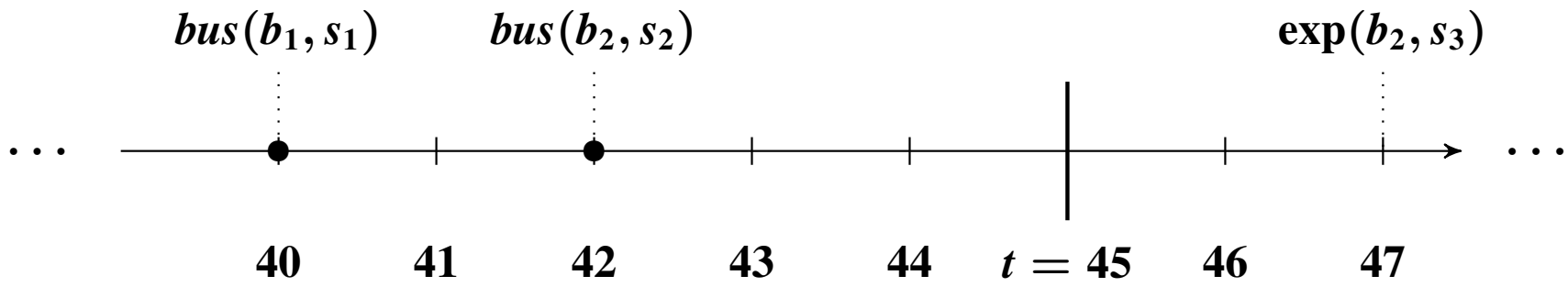
$$\boxplus^{1}_{\#} @_{T}\, bus(B, S), reach(S, S', D),$$
$$T' = T + D$$

- Window operators

  $\boxplus_{\tau}$ time-based window
  $\boxplus_{\#}$ tuple-based window
  ...

- Time reference

  $\Diamond$ some time
  $\Box$ all the time
  $@_{t'}$ exact time



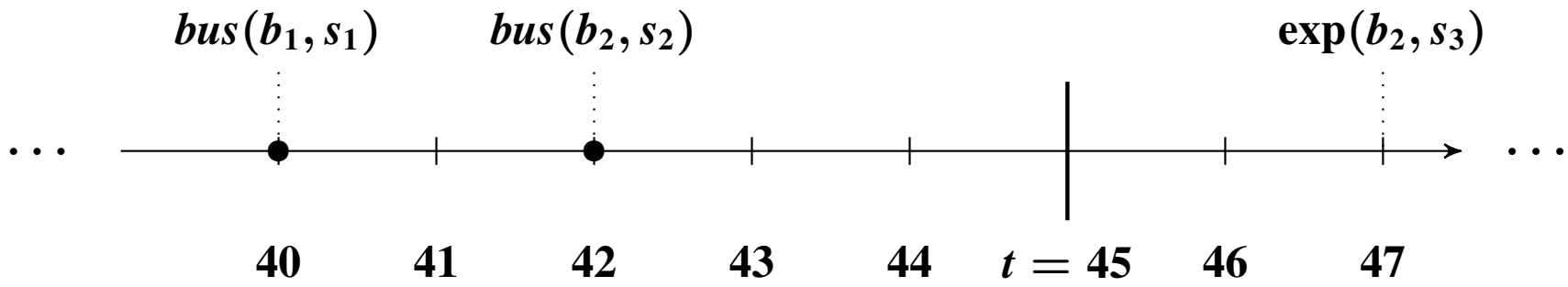
$$@_{T'} exp(B, S') \quad \leftarrow \quad \boxplus^{1}_{\#} @_{T} bus(B, S), reach(S, S', D), \; T' = T + D$$

- Window operators

$\boxplus_{\tau}$	time-based window
$\boxplus_{\#}$	tuple-based window
...	

- Time reference

$\Diamond$	some time
$\Box$	all the time
$@_{t'}$	exact time



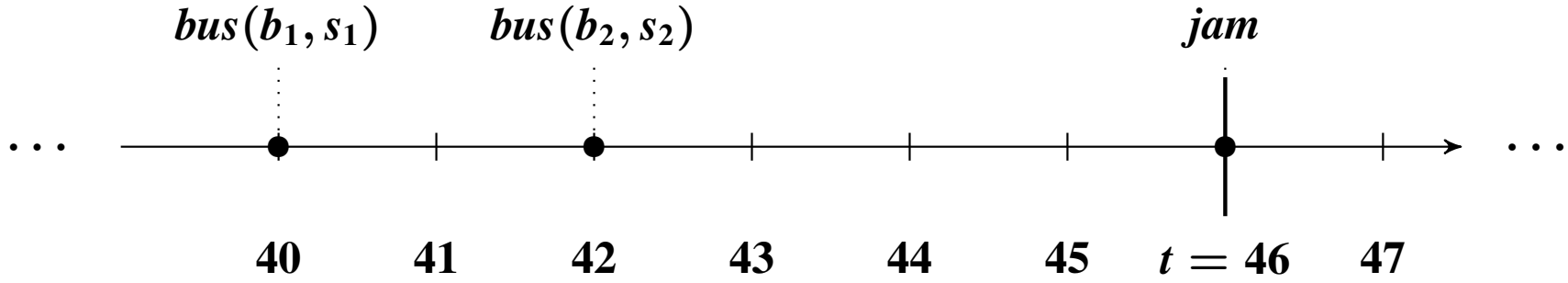
$$@_{T'} exp(B, S') \quad \leftarrow \quad \boxplus^{1}_{\#} @_{T} bus(B, S), reach(S, S', D), \\ T' = T + D, not \boxplus^{20}_{\tau} \Diamond jam.$$

- Window operators

$\boxplus_\tau$	time-based window
$\boxplus_\#$	tuple-based window
...	

- Time reference

$\Diamond$	some time
$\Box$	all the time
$@_{t'}$	exact time



$$@_{T'} exp(B, S') \leftarrow \boxplus^{1}_{\#} @_T bus(B, S), reach(S, S', D), T' = T + D, not \boxplus^{20}_{\tau} \Diamond jam.$$

- Window operators

$\boxplus_\tau$	time-based window
$\boxplus_\#$	tuple-based window
...	

- Time reference

$\Diamond$	some time
$\Box$	all the time
$@_{t'}$	exact time

In the paper . . .

- Formal language
  - Streams, windows, formulas, rules
  - Stable model semantics
- Complexity
  - Model Checking: co-NP-c
  - SAT: Σ_2^P-c
  - If Nesting of $\boxplus$ unbounded: both PSPACE-c

$$\boxplus_{\tau}^{60} \Box \boxplus_{\tau}^{5} \Diamond \mathit{bus}$$

- Capturing CQL (continuous query language)
- Relation to ETALIS (complex event processing; intervals)

Summary

- Goal: Theoretical underpinning for stream reasoning
  - Analysis
  - Model-based, non-monotonic semantics
- LARS
  - Window operators $\boxplus$
  - Time reference: $\Diamond$, $\Box$, $@_t$
  - Rule-based; ASP-like semantics
  - Not an end user language
- Future work
  - Compare existing semantics
  - Implementation of tractable fragments
  - Incremental evaluation
  - ...