Incremental Graph Queries with openCypher

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GraphDevroom @ FOSDEM 2017

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McGill University, Montréal

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Live railway model

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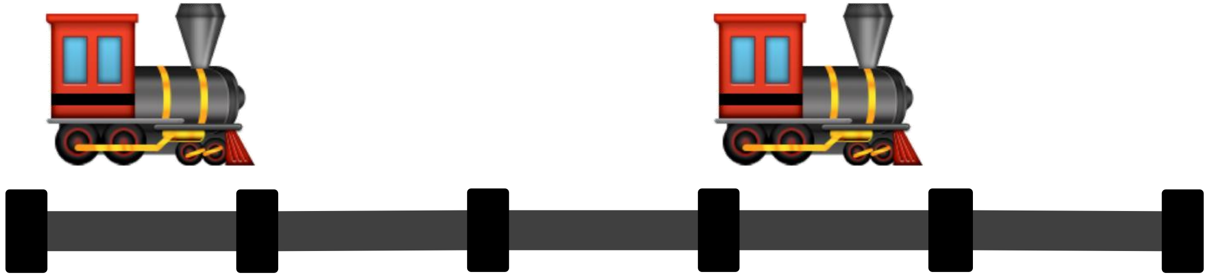
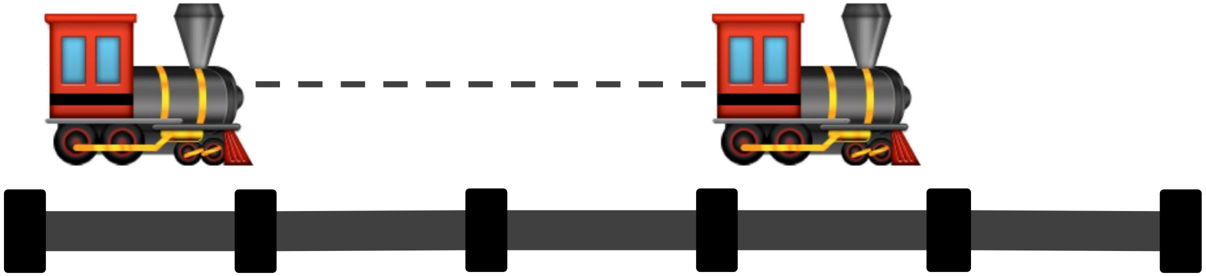


Live railway model



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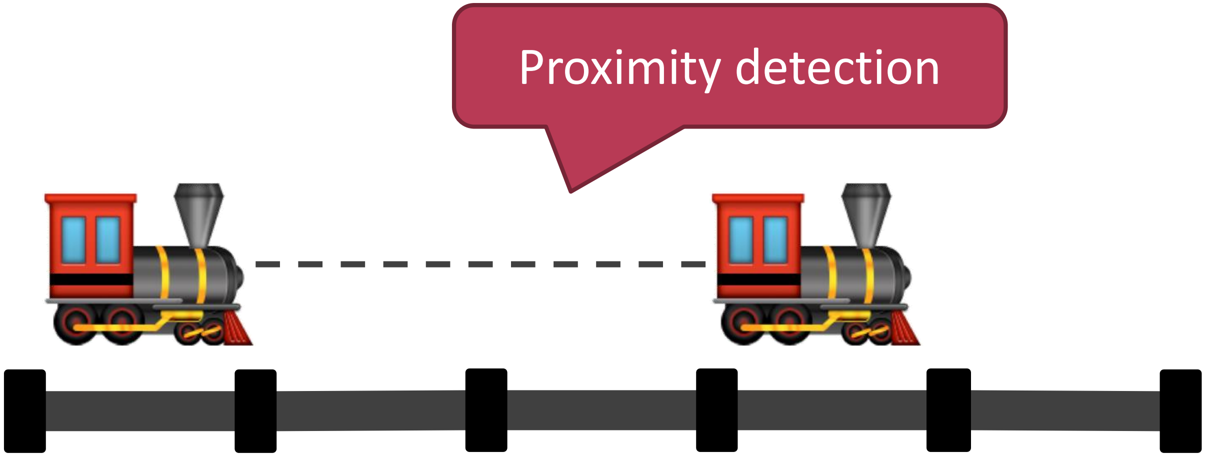

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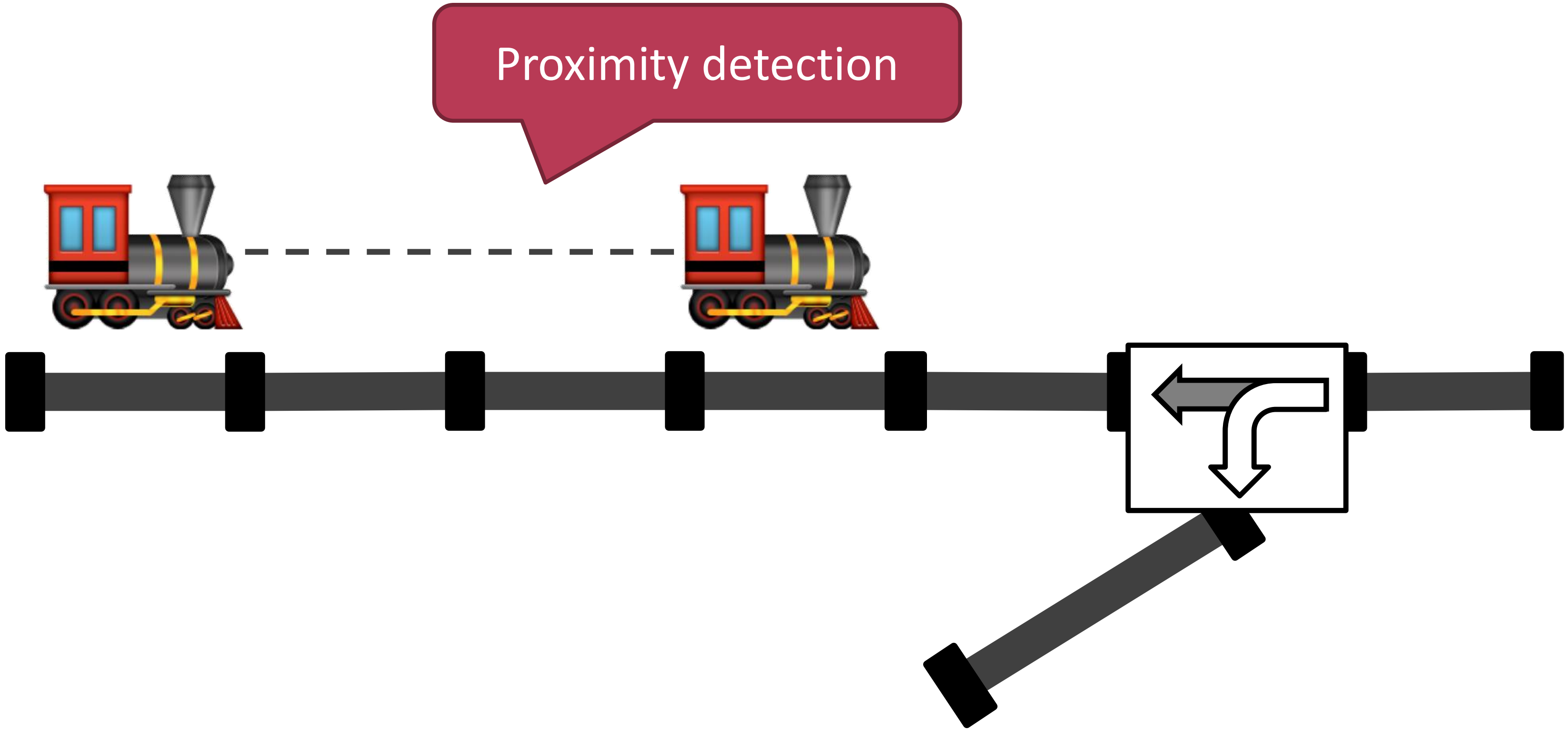

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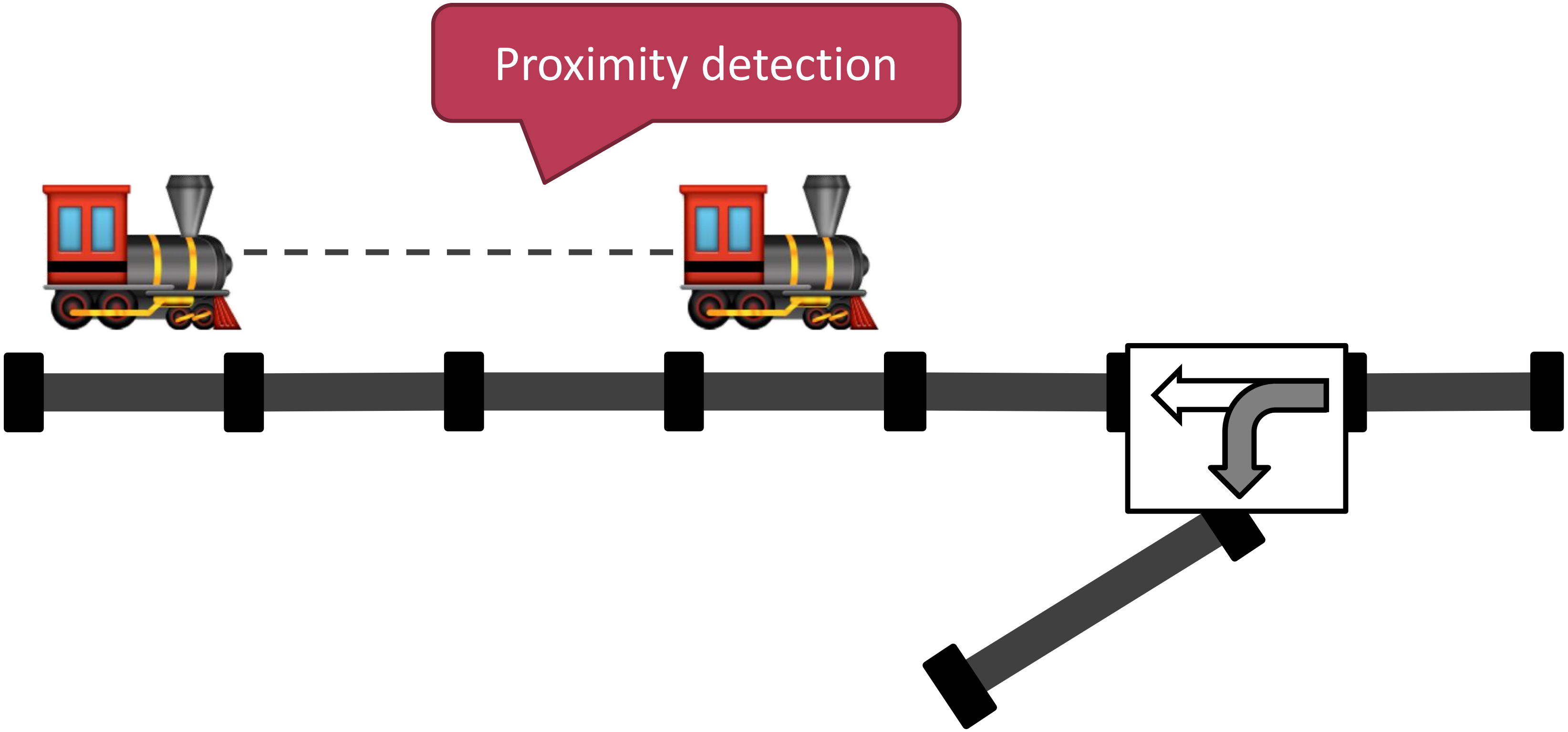

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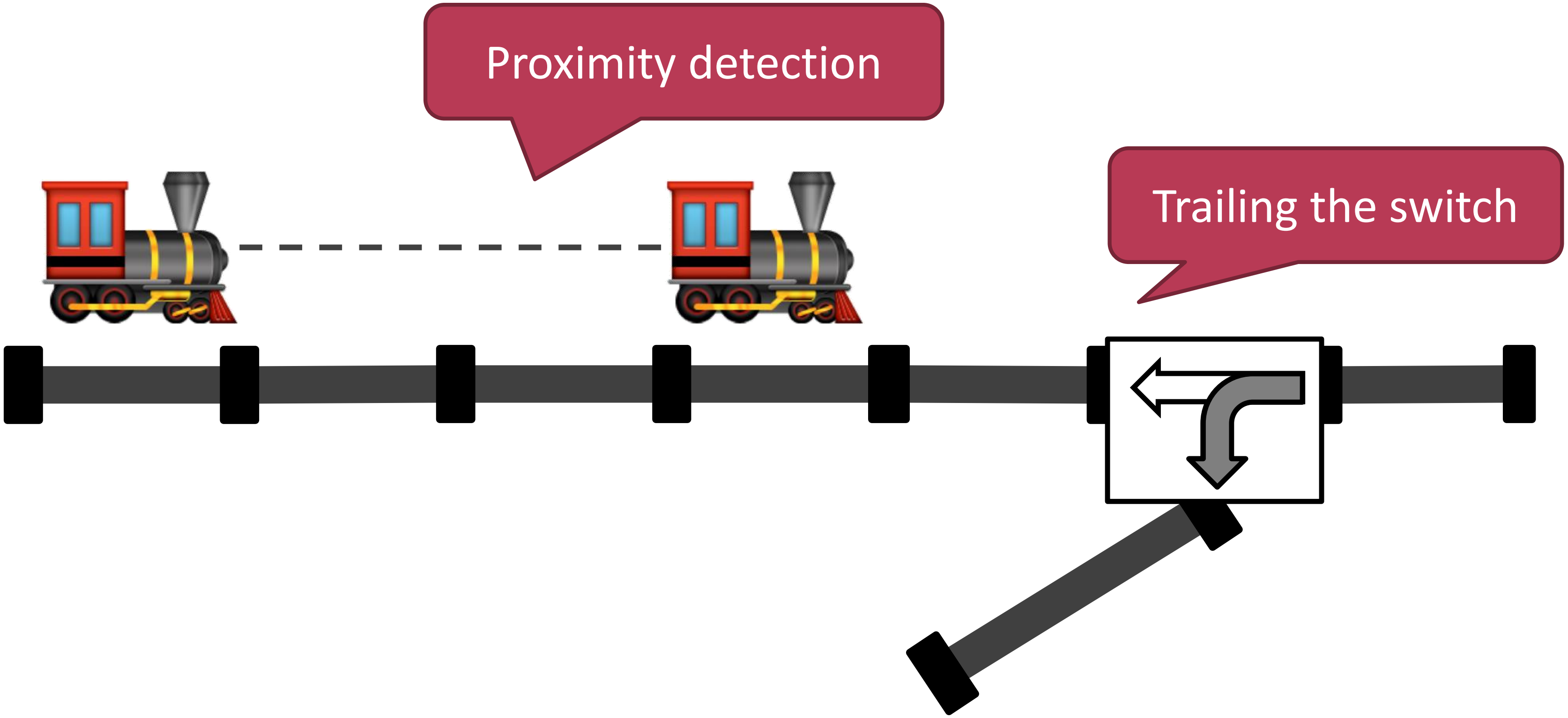

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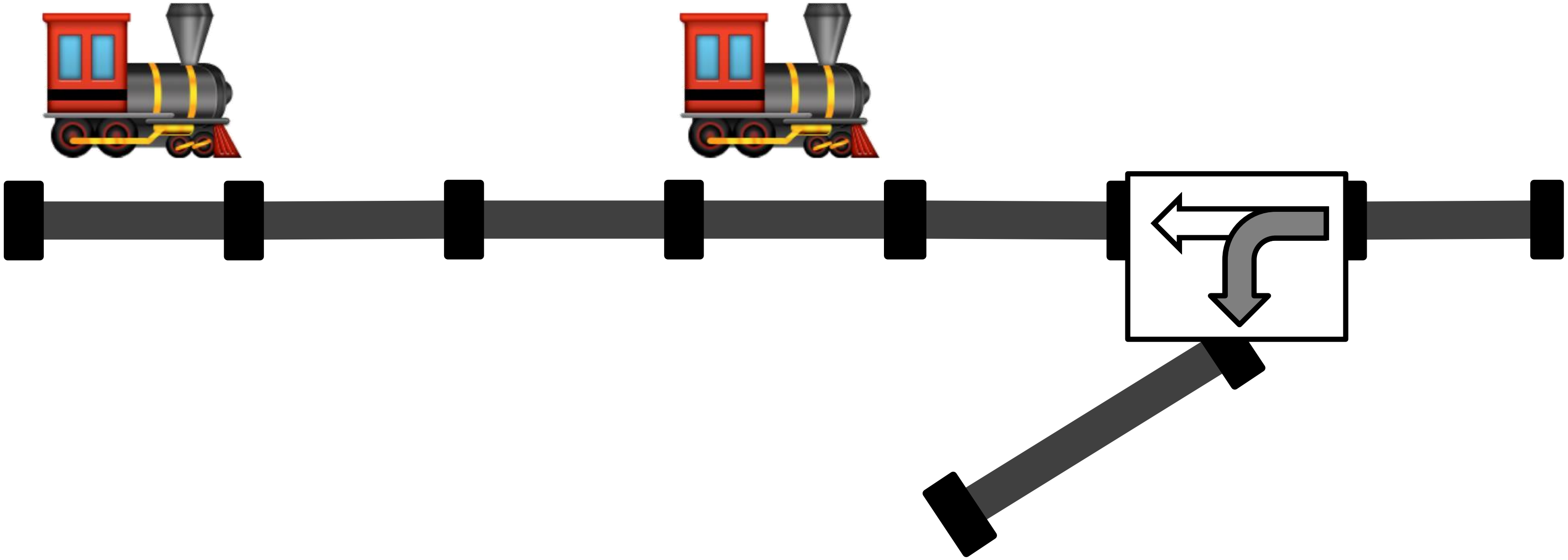
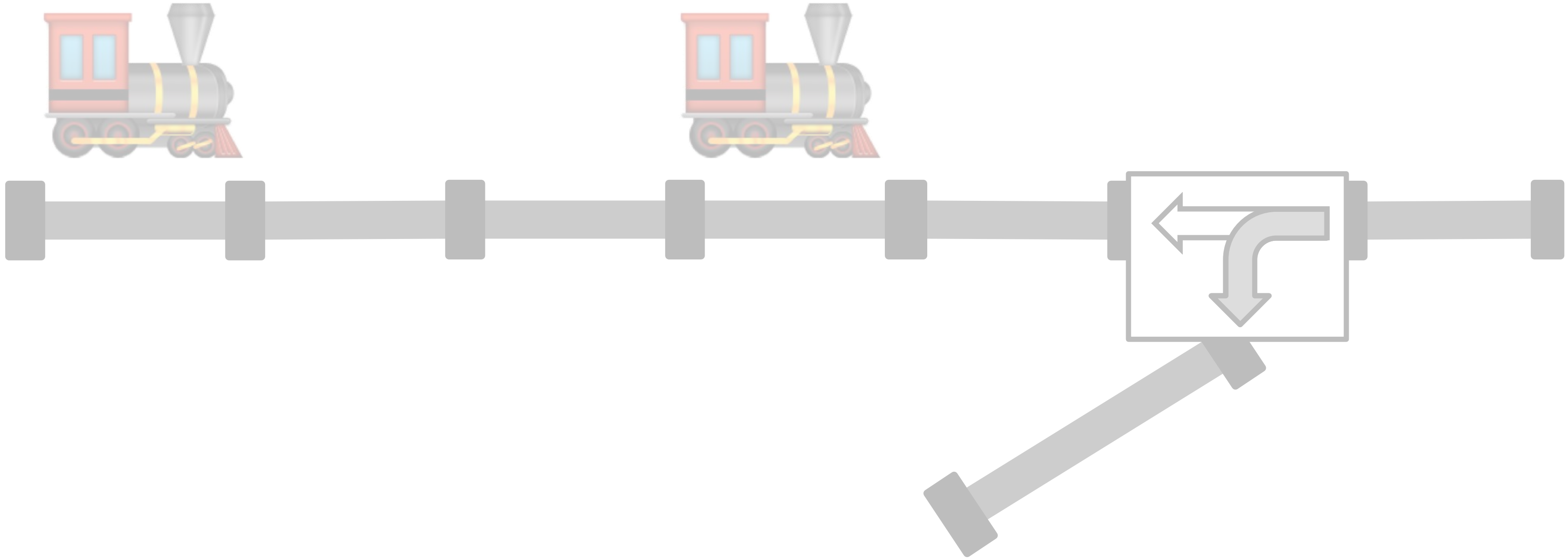


Live railway model



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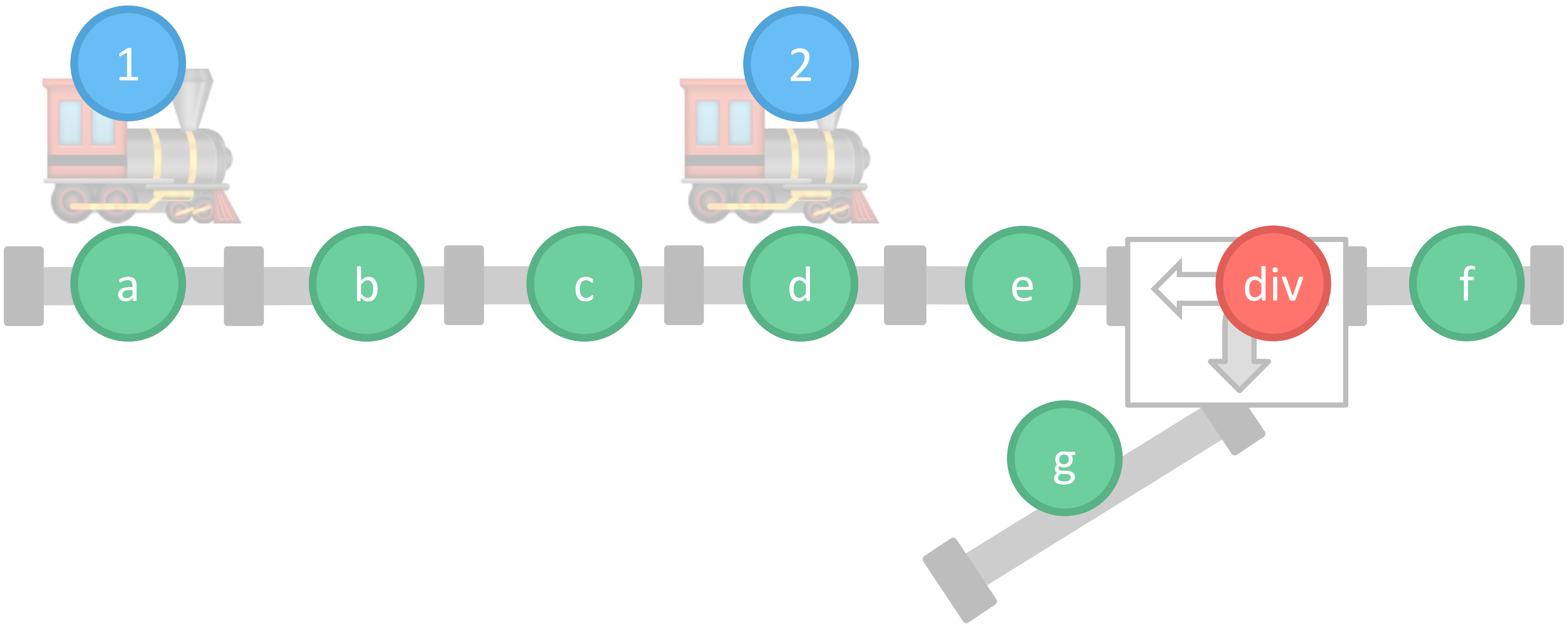
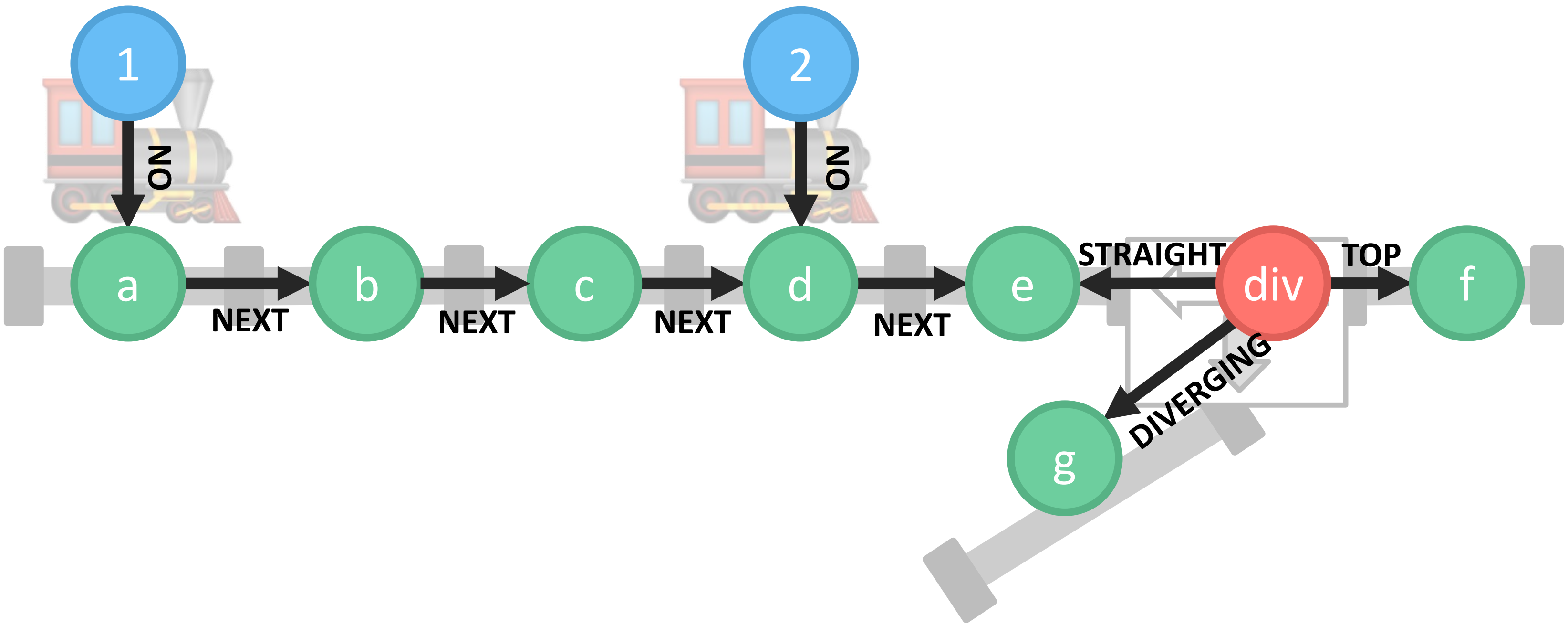
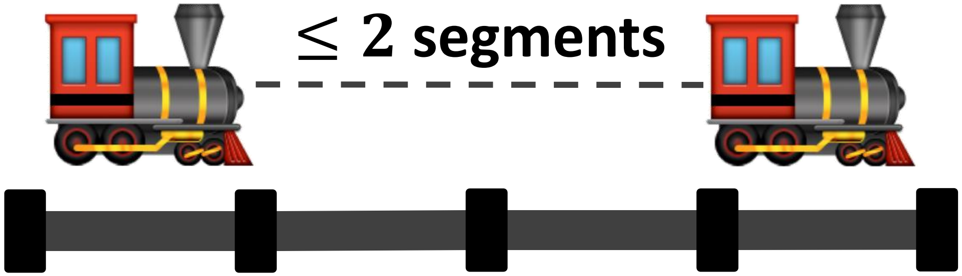


Live railway model



Proximity detection

Proximity detection



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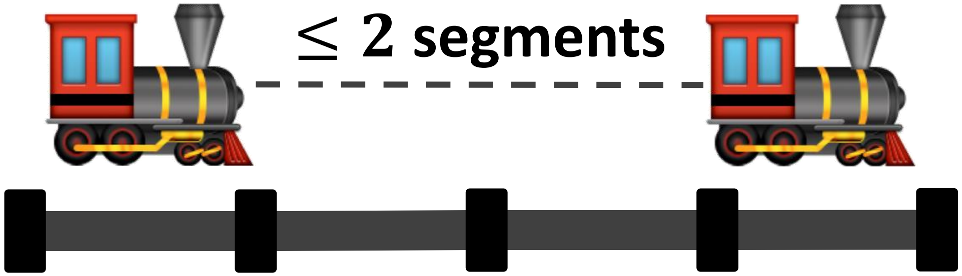

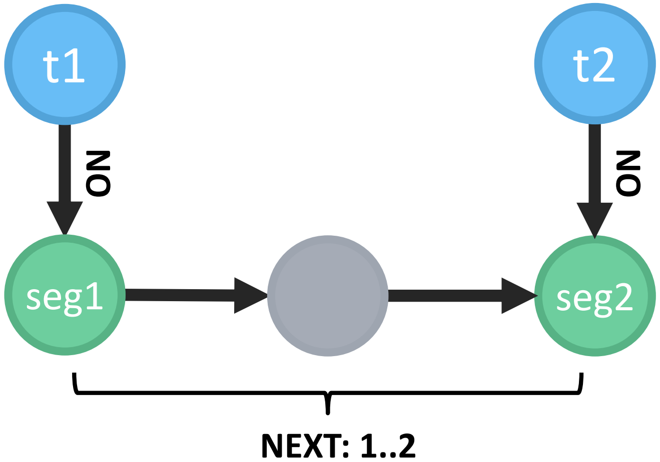

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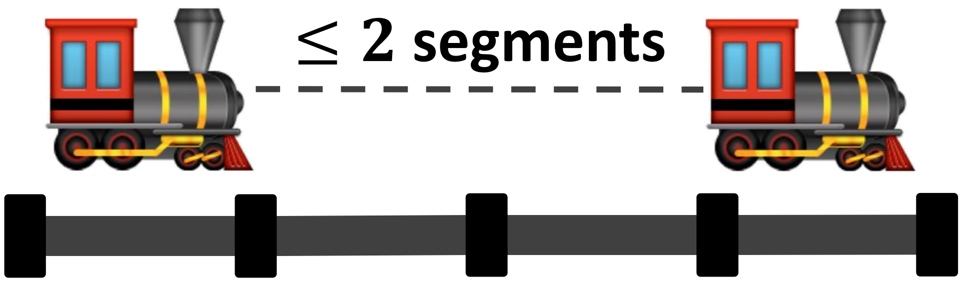
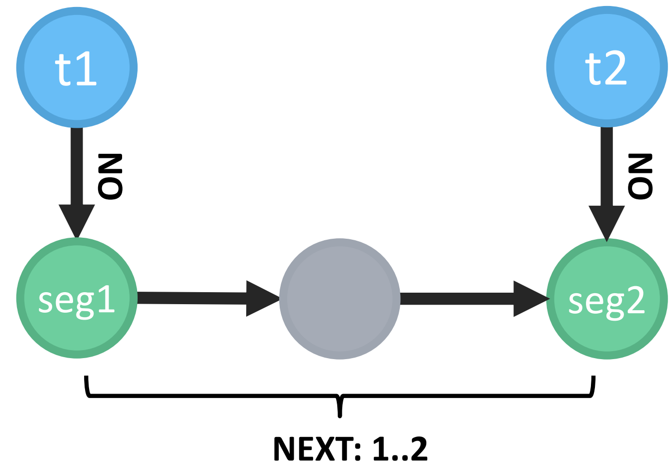
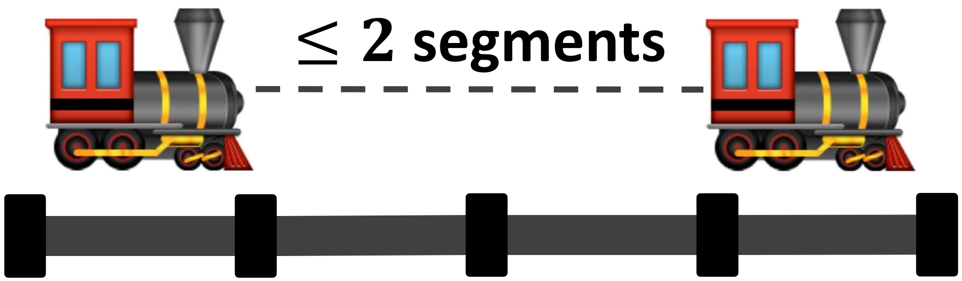


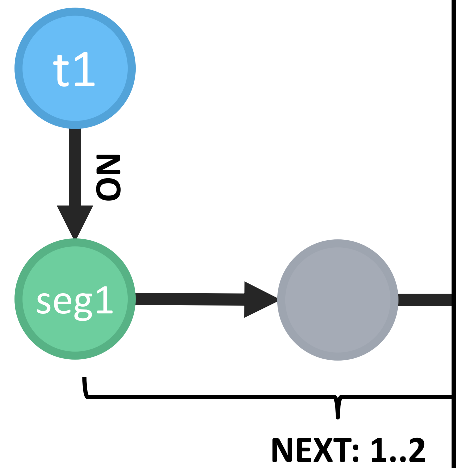


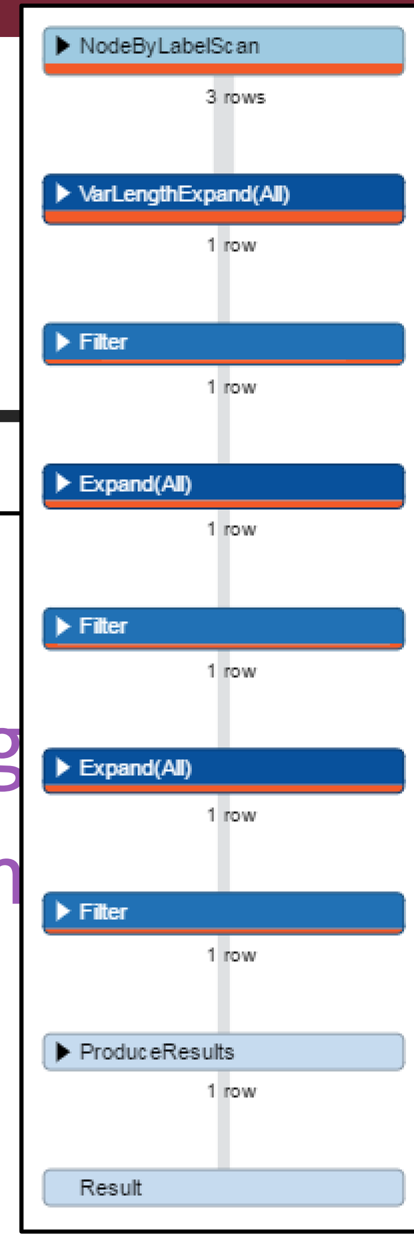

```
MATCH
   (t1:Train)-[:ON]->(seg1:Segment)
   -[:NEXT*1..2]->(seg2:Segment)
   <-[:ON]-(t2:Train)
RETURN t1, t2, seg1, seg2
```

Proximity detection

Proximity detection

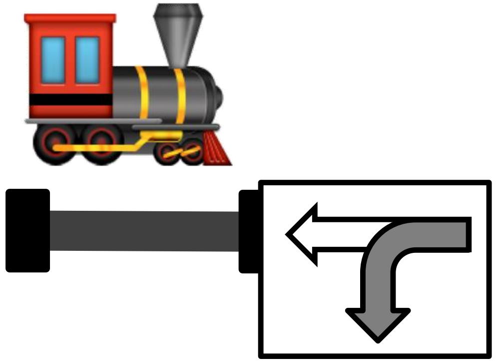







```
MATCH
   (t1:Train)-[:ON]->(seg1:Seg
   -[:NEXT*1..2]->(seg2:Segmen
   <-[:ON]-(t2:Train)
RETURN t1, t2, seg1, seg2
```

Trailing the switch



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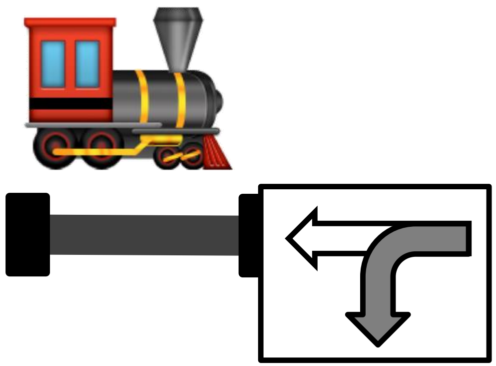

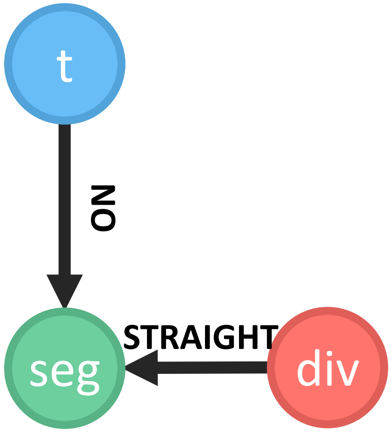

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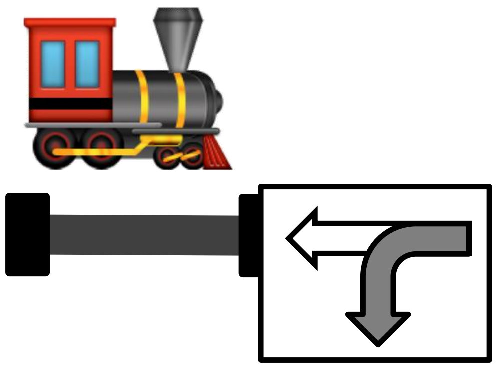
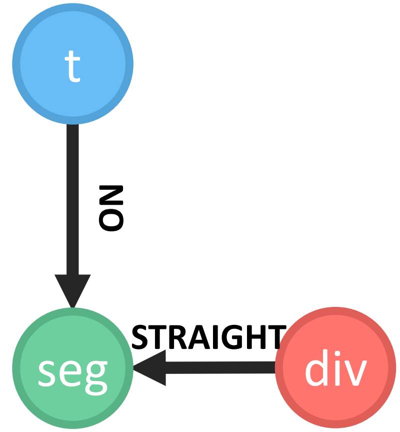
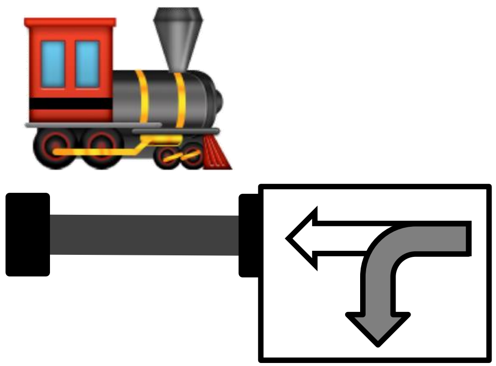
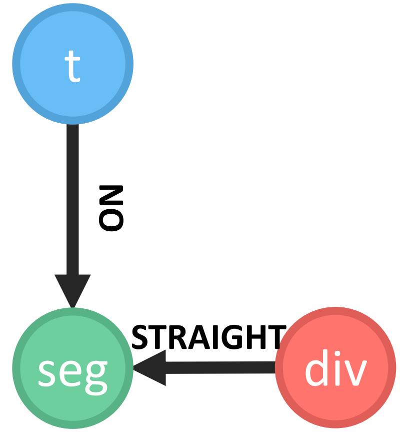




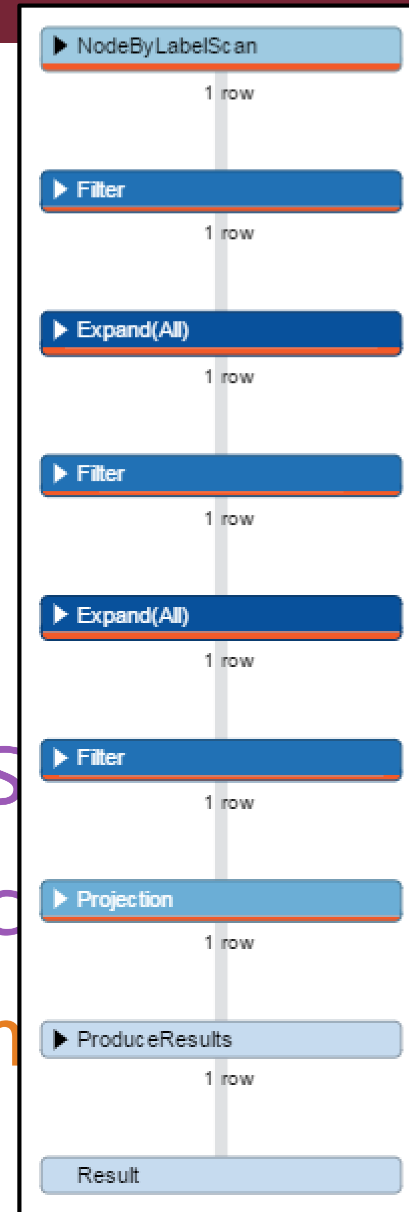

```
MATCH (t:Train)-[:ON]->(seg:Segment)
      <-[:STRAIGHT]-(sw:Switch)
WHERE sw.position = 'diverging'
RETURN t.number, sw
```

Trailing the switch

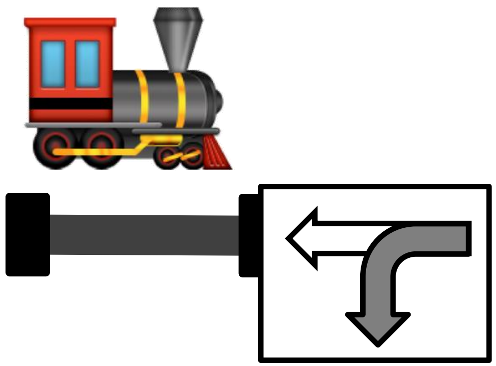


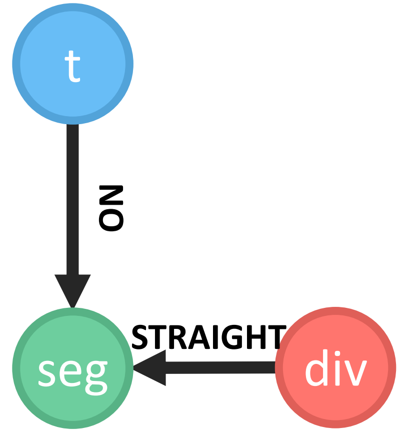


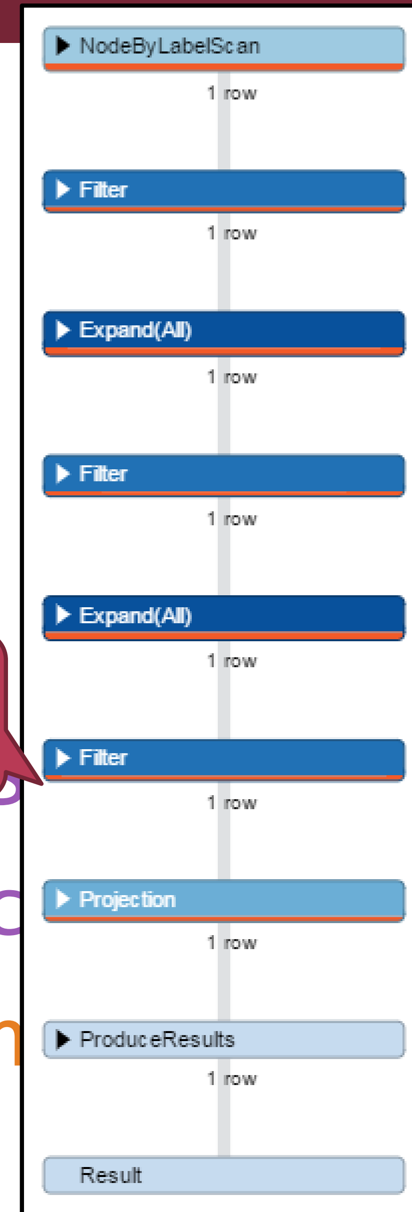

```
MATCH (t:Train)-[:ON]->(seg:S
      <-[:STRAIGHT]-(sw:Switc
WHERE sw.position = 'divergin
RETURN t.number, sw
```



Trailing the switch







Evaluate continuously

```
MATCH (t:Train)-[:ON]
      <-[:STRAIGHT]-(sw:Switc
WHERE sw.position = 'divergin
RETURN t.number, sw
```

Incremental queries

Incremental queries

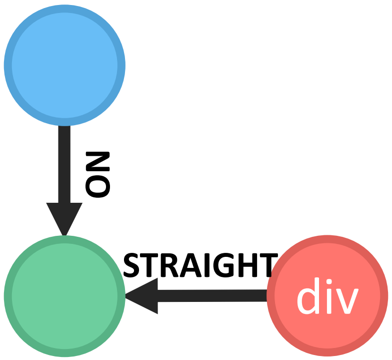
- Register a set of **standing queries**
- **Continuously evaluate** queries on changes

Incremental queries

- Register a set of **standing queries**
- **Continuously evaluate** queries on changes

- The **Rete algorithm** (1974)
  - Originally for rule-based expert systems
  - Indexes the graph and caches interim query results

Trailing the switch



$\pi_{t.number,\ sw}$

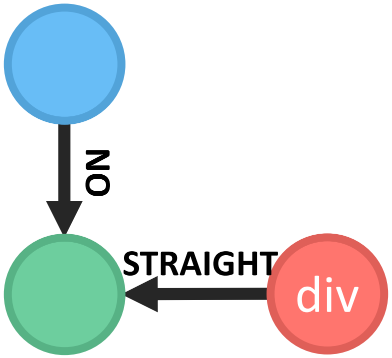
$\sigma_{sw.position\ =\ 'diverging'}$

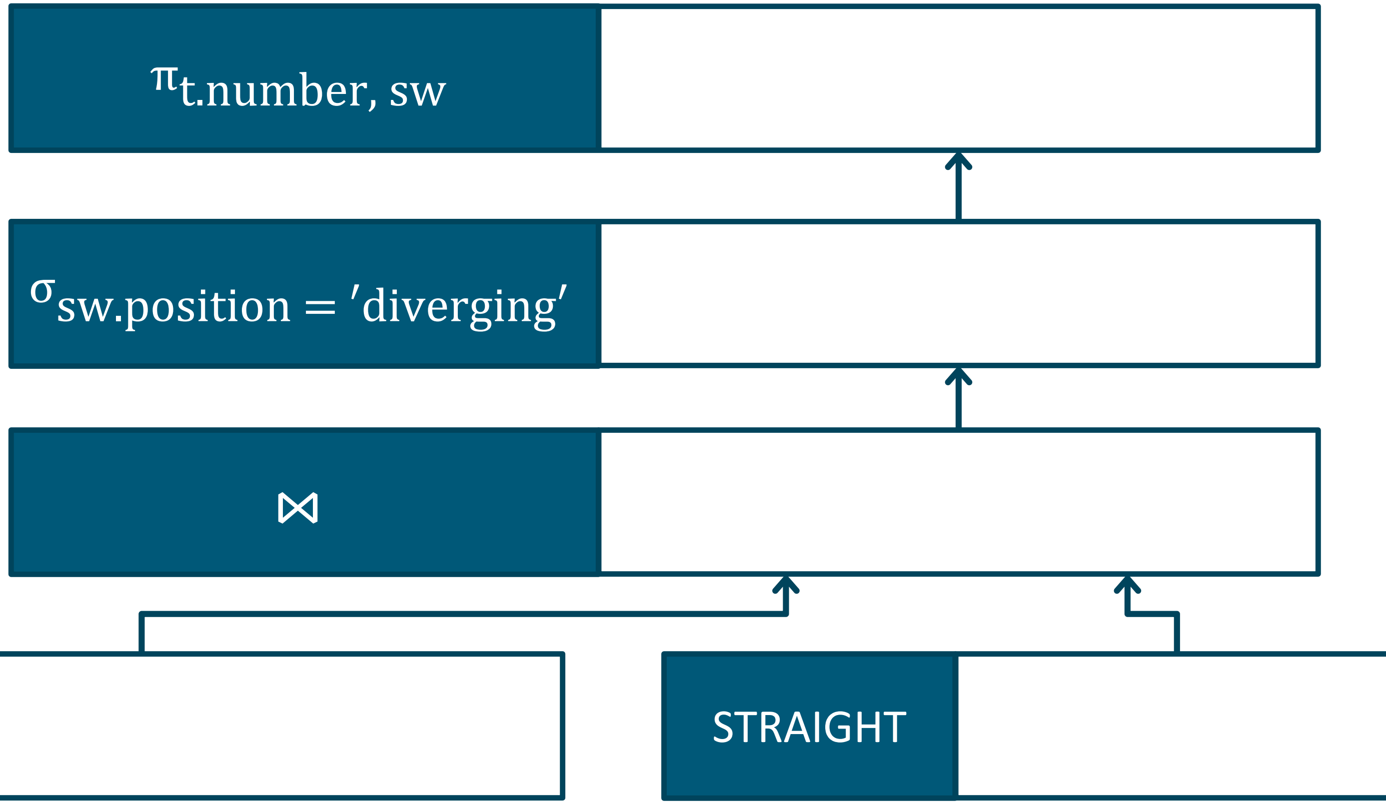
$\bowtie$

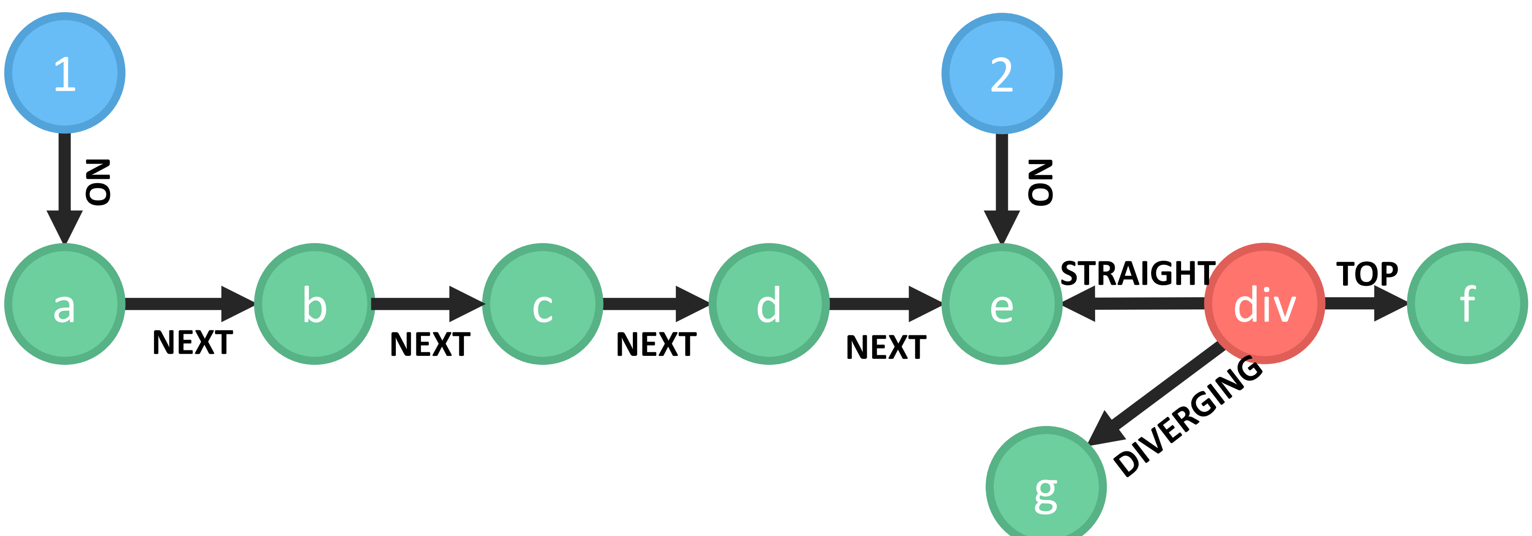
ON

STRAIGHT

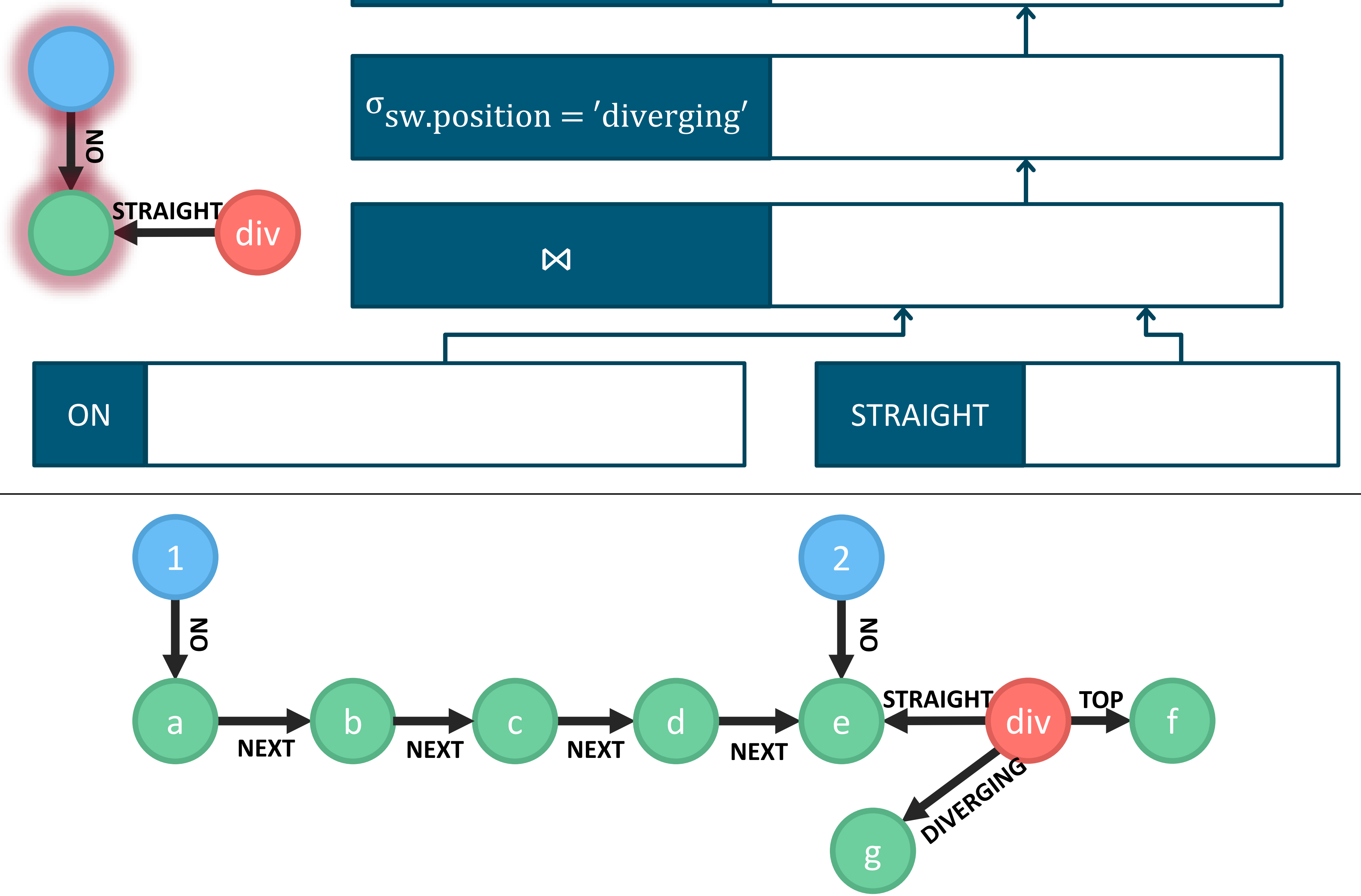
Trailing the switch

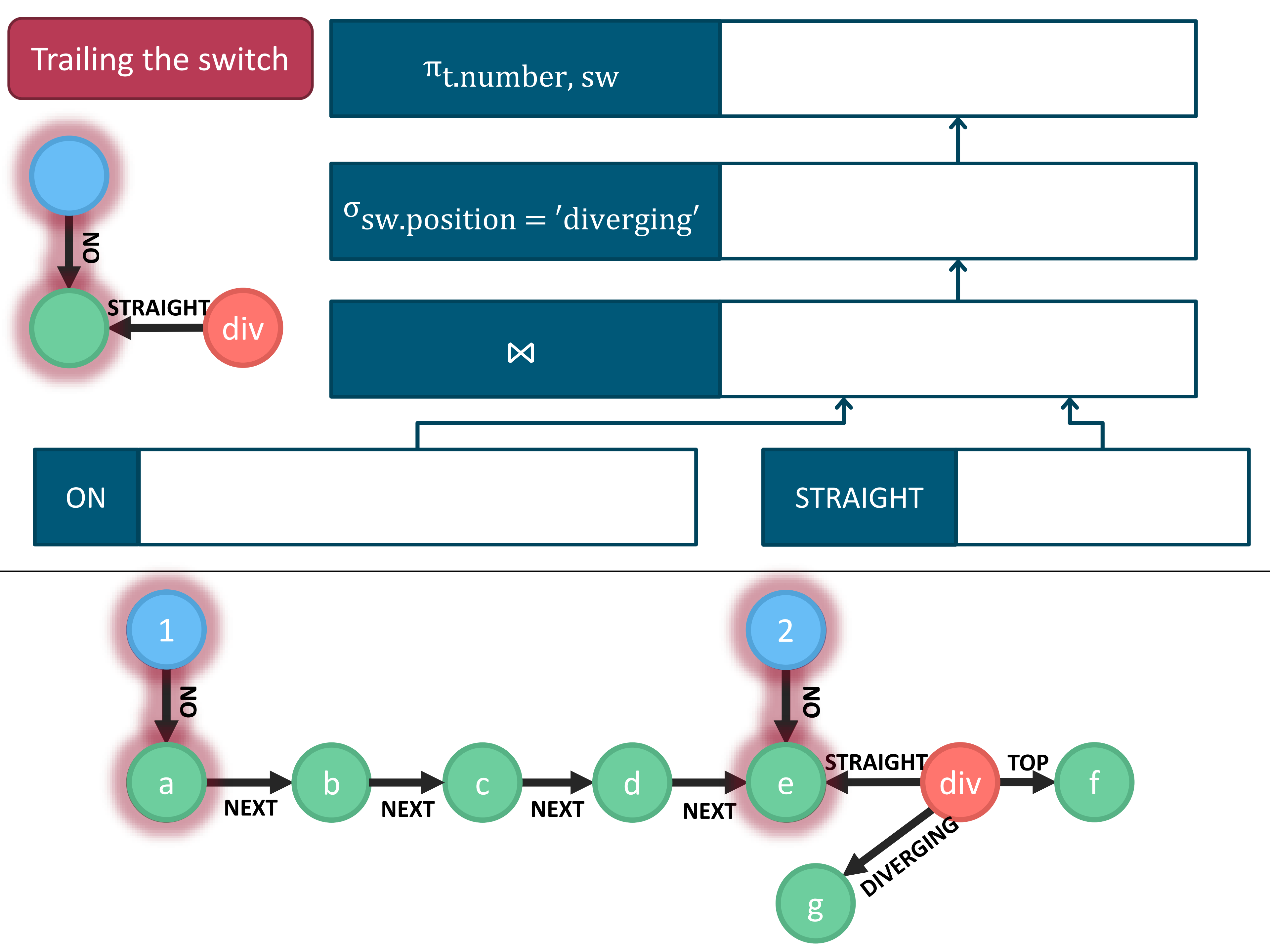






Trailing the switch




Trailing the switch
$\pi_{t.number,\ sw}$
$\sigma_{sw.position\ =\ 'diverging'}$
$\bowtie$
ON
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STRAIGHT
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b
c
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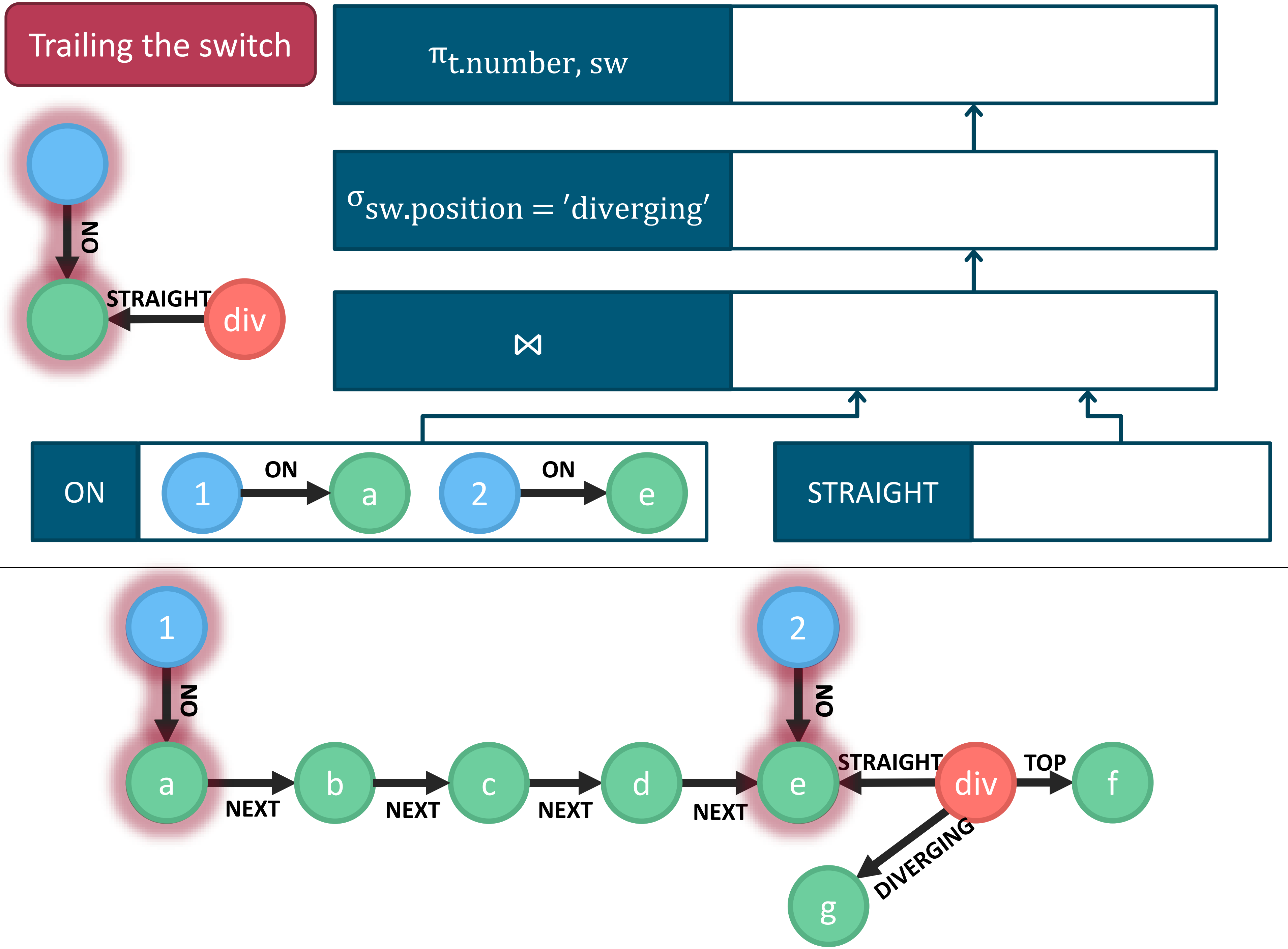
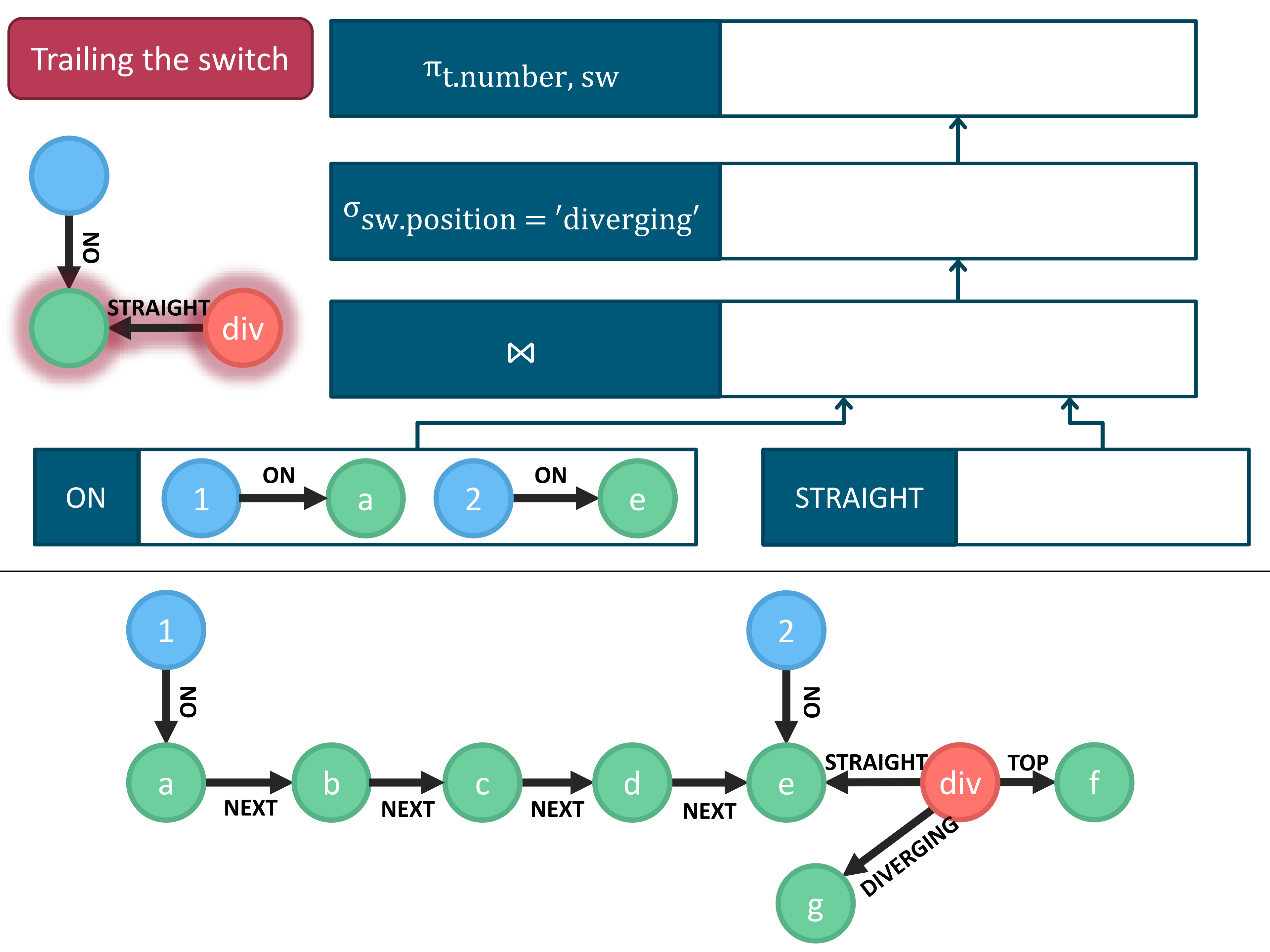
div
f
g
NEXT
NEXT
NEXT
NEXT
STRAIGHT
TOP
DIVERGING

Trailing the switch





Trailing the switch
$\pi_{t.number,\, sw}$
$\sigma_{sw.position\, =\, 'diverging'}$
$\bowtie$
ON
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ON
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STRAIGHT
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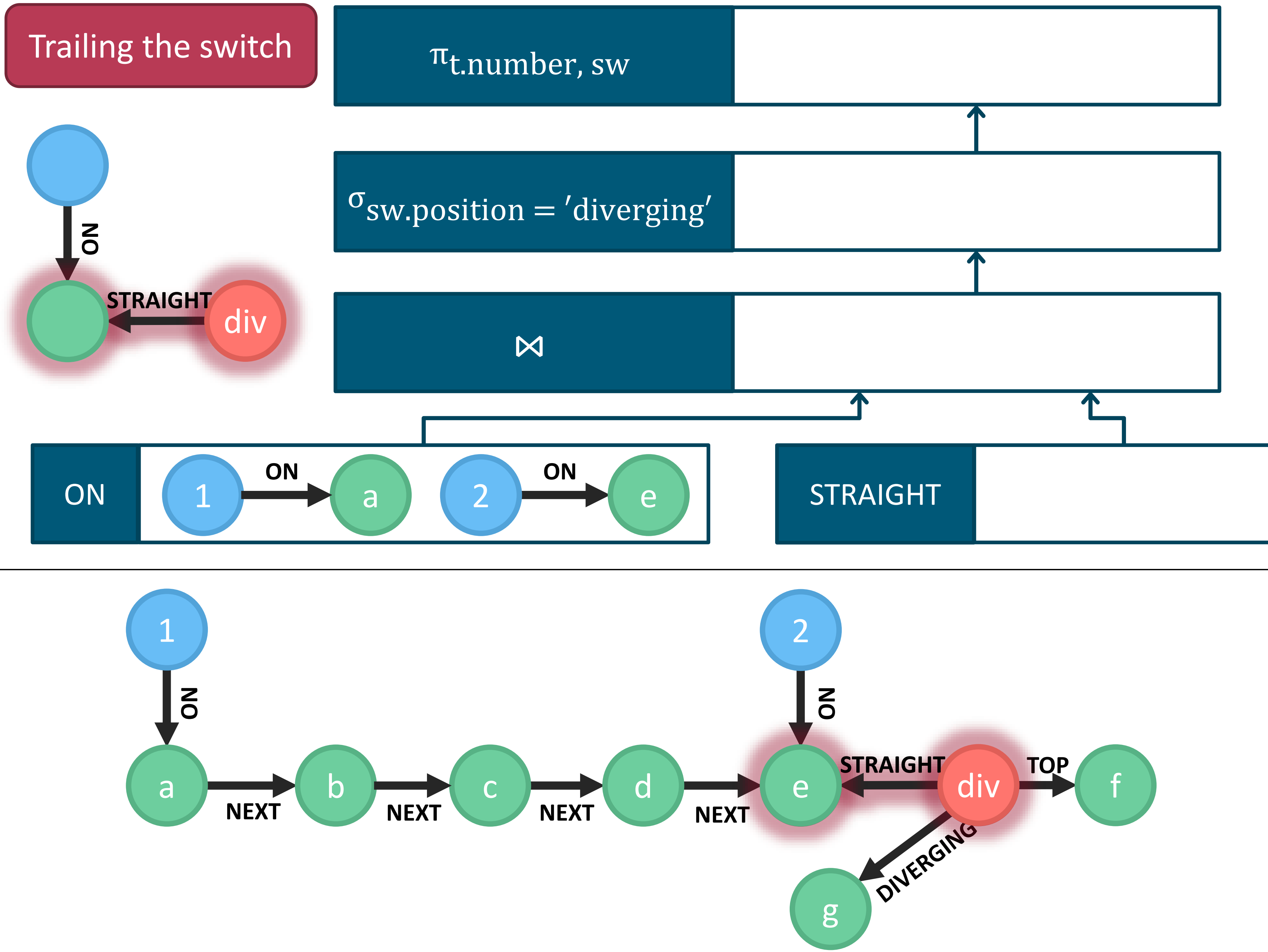
ON
a
NEXT
b
NEXT
c
NEXT
d
NEXT
2
ON
e
STRAIGHT
div
TOP
f
DIVERGING
g



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$\pi_{t.number,\ sw}$
$\sigma_{sw.position\ =\ 'diverging'}$
$\bowtie$
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DIVERGING
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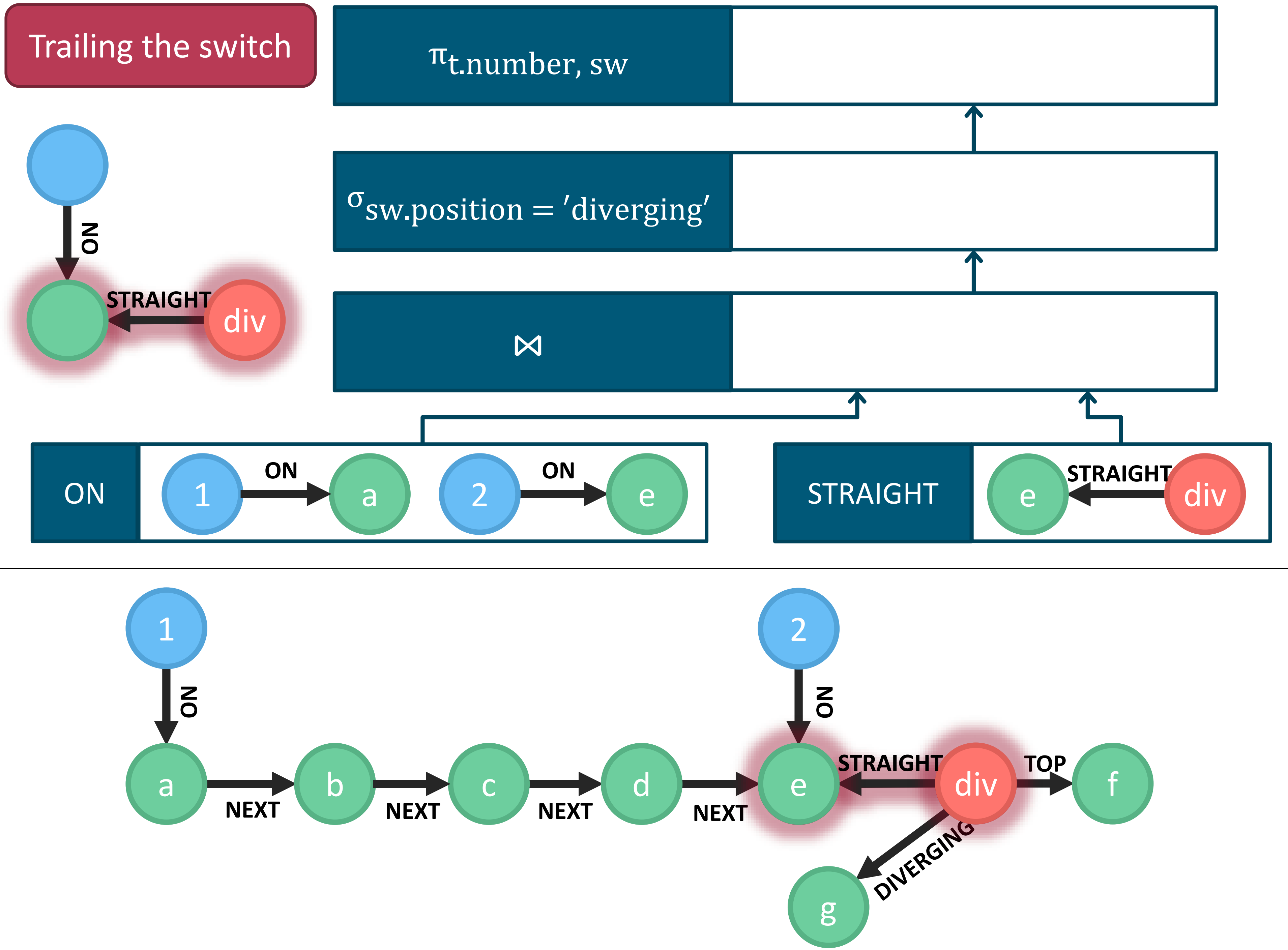
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$\bowtie$
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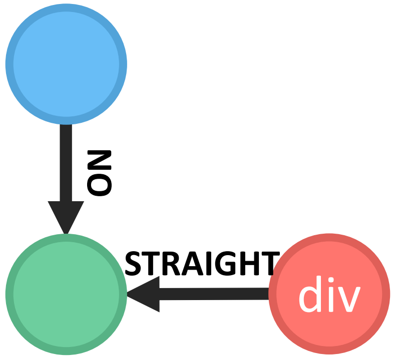

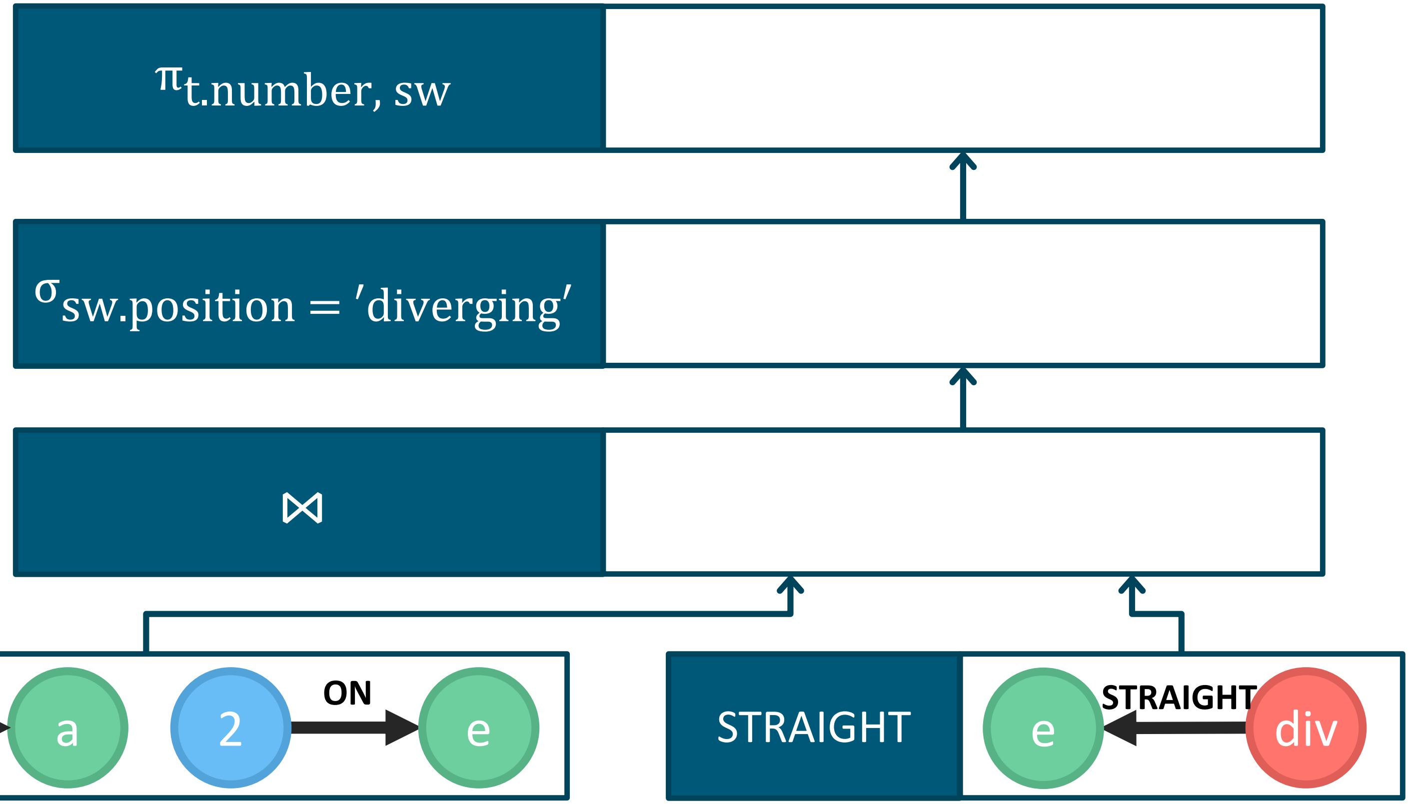

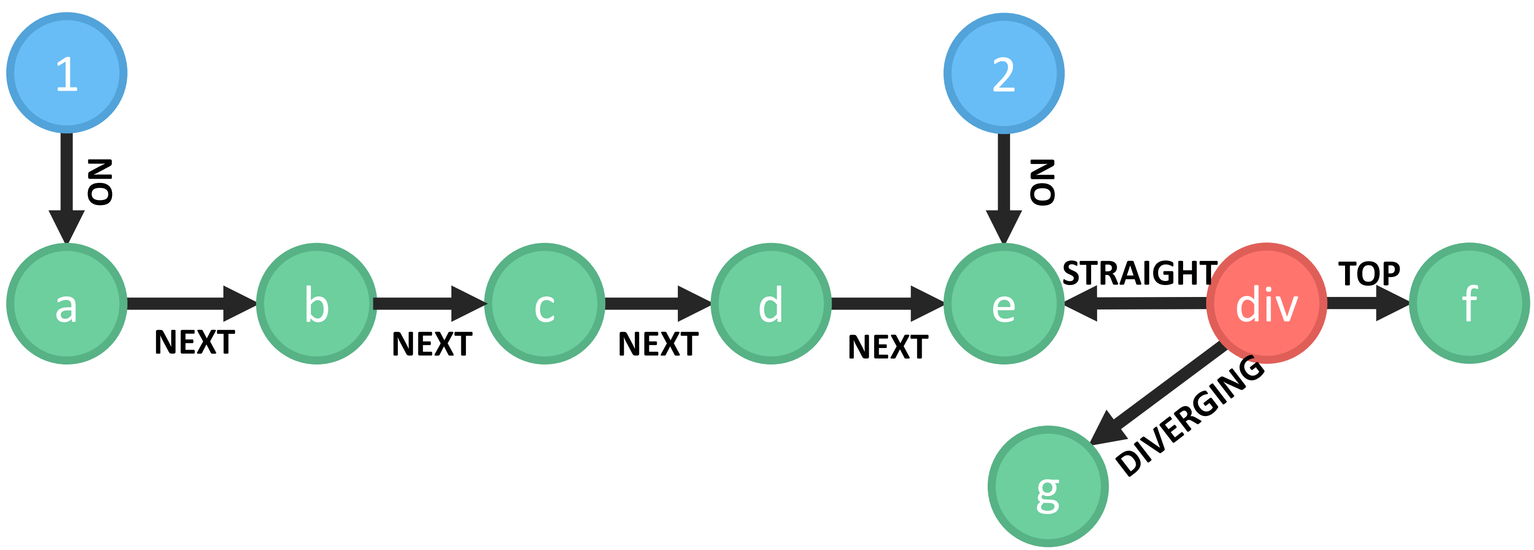

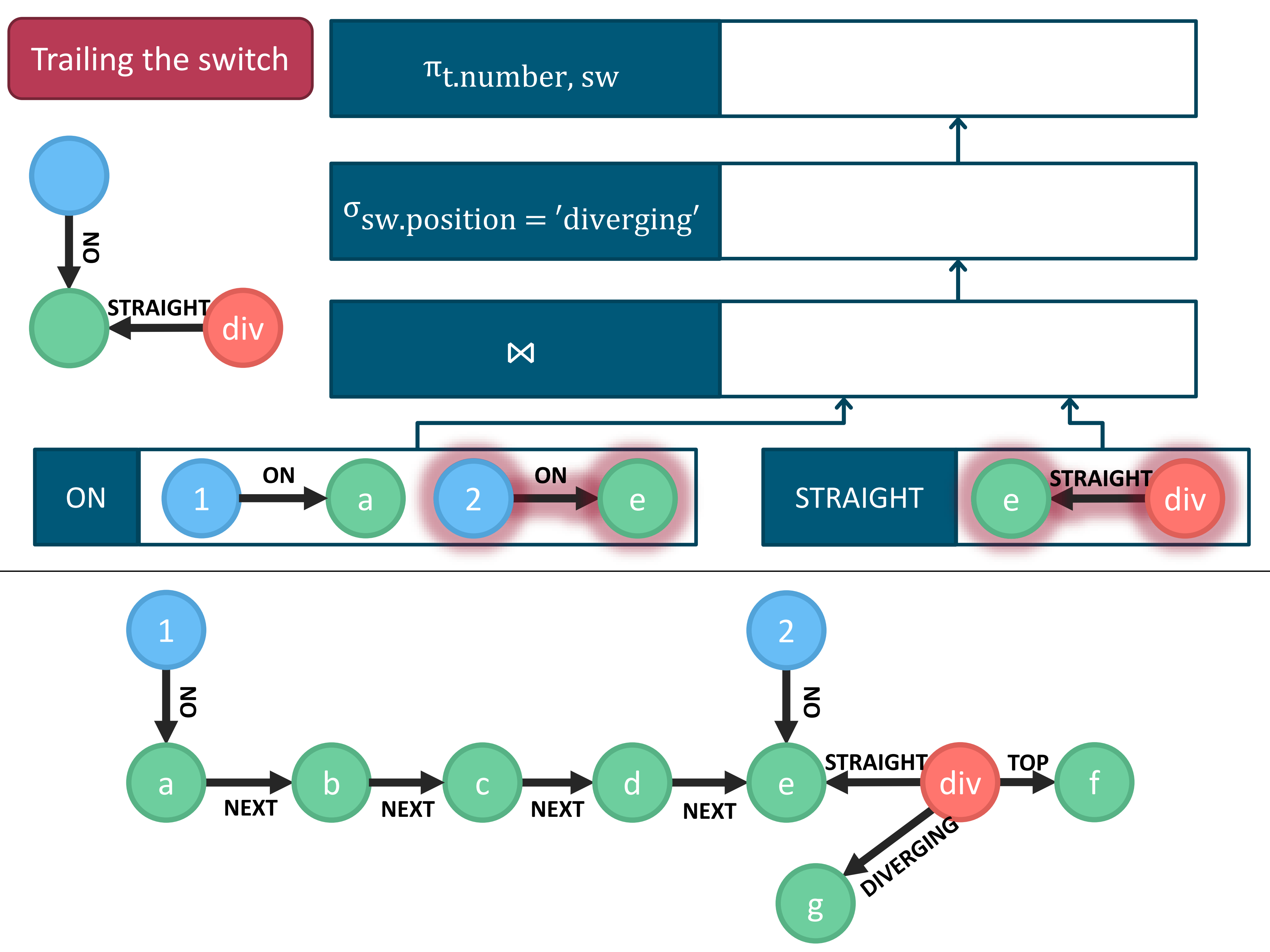
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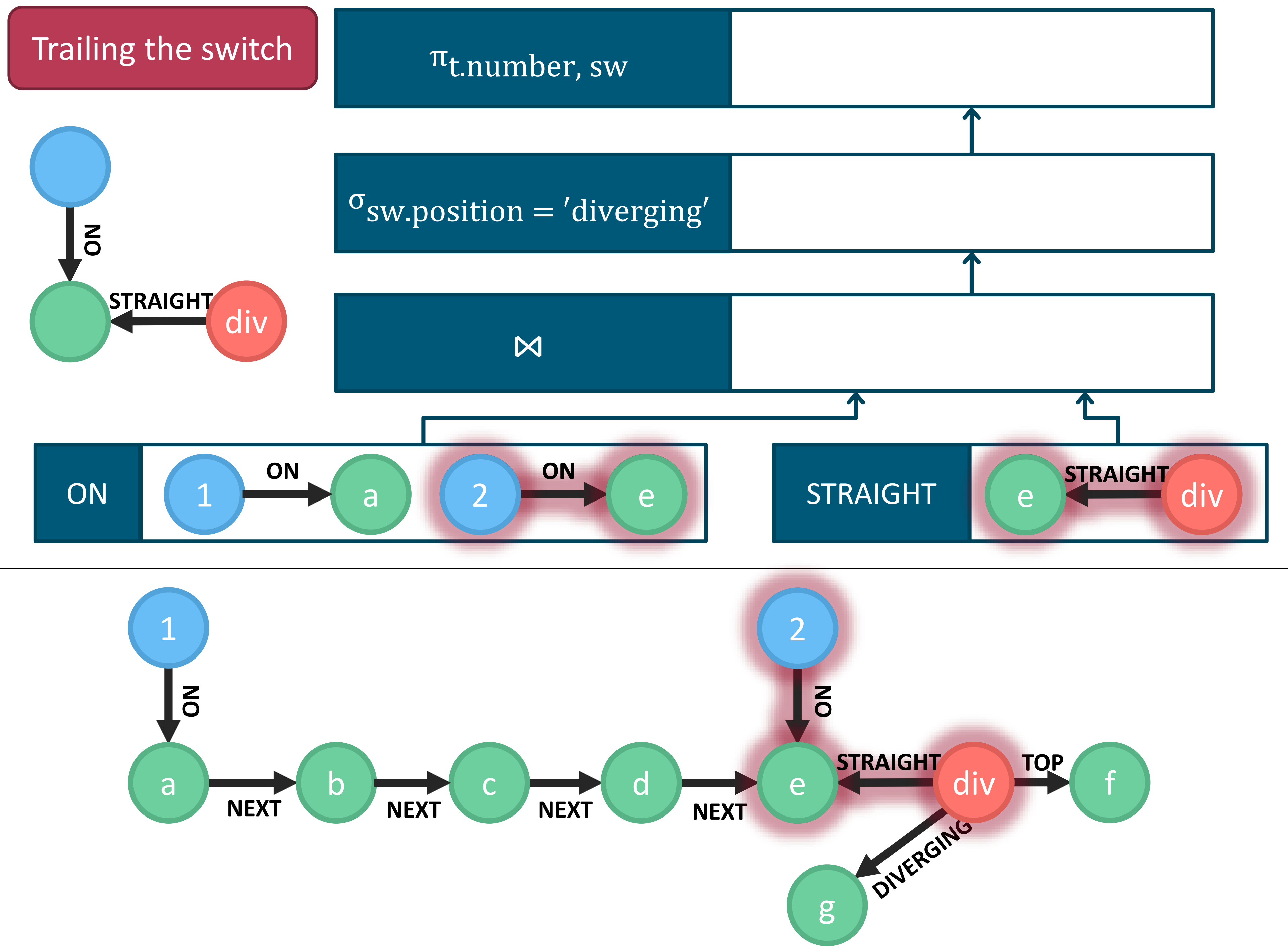

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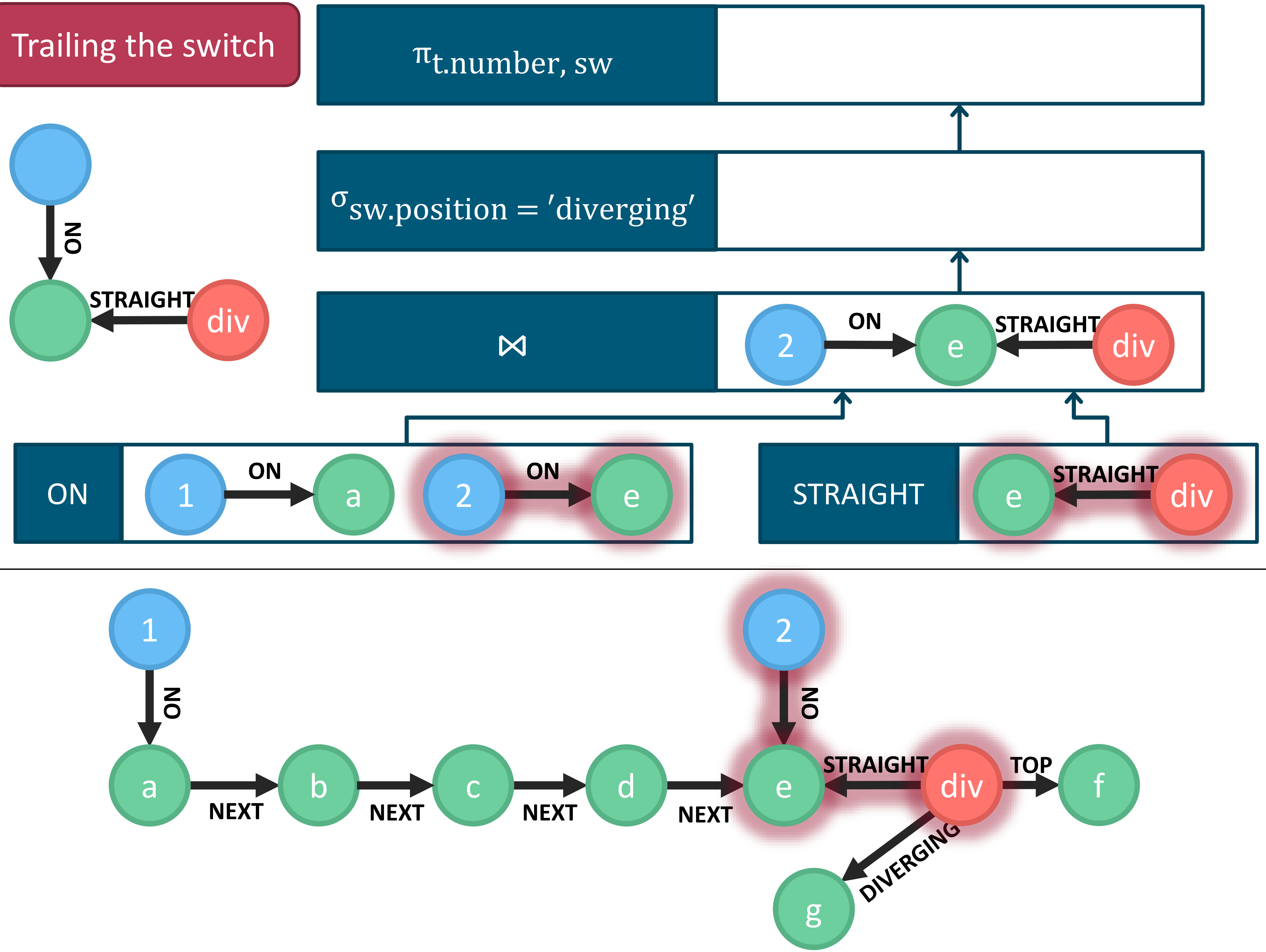

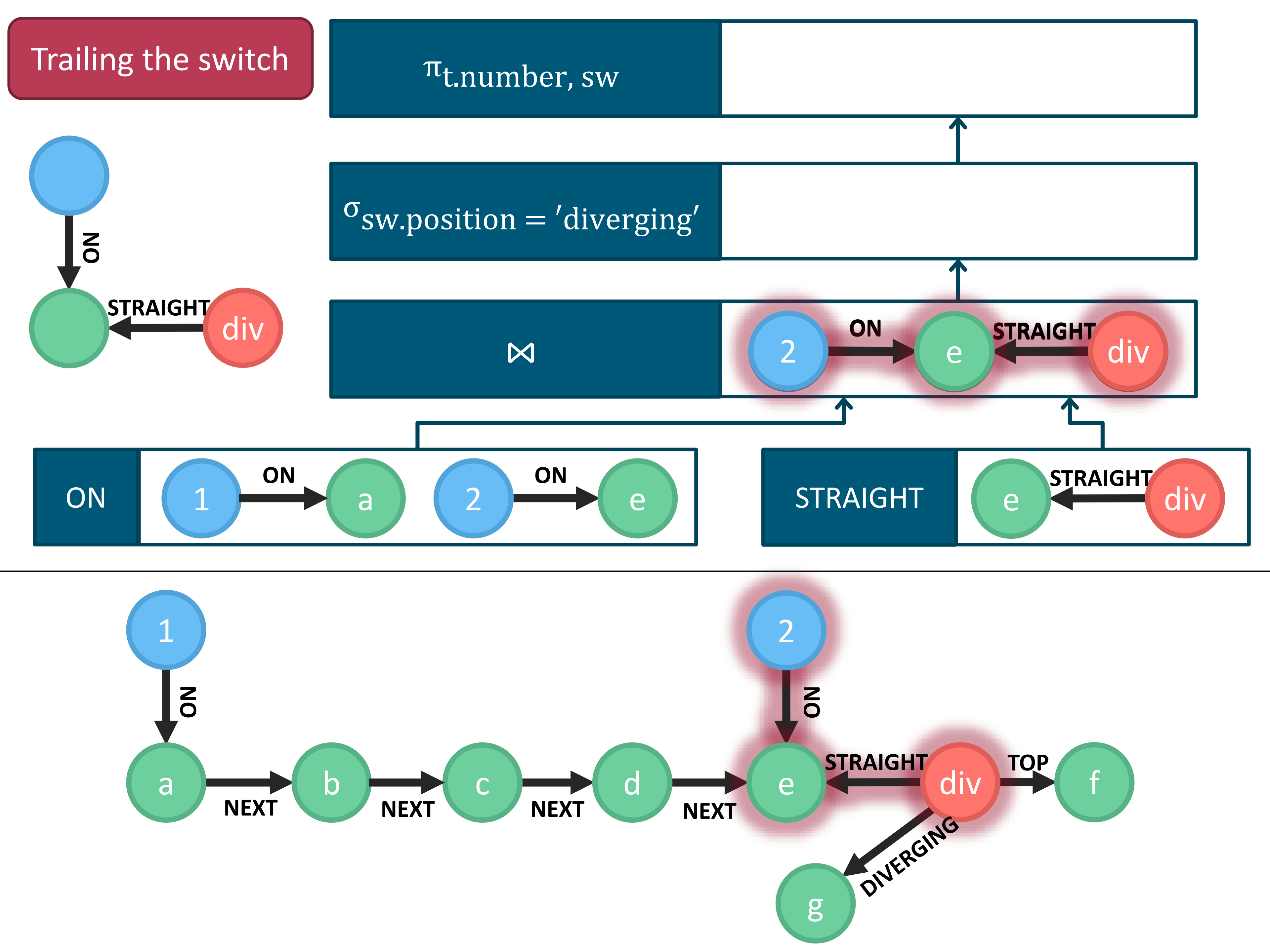

Trailing the switch
πt.number, sw
σsw.position = 'diverging'
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div
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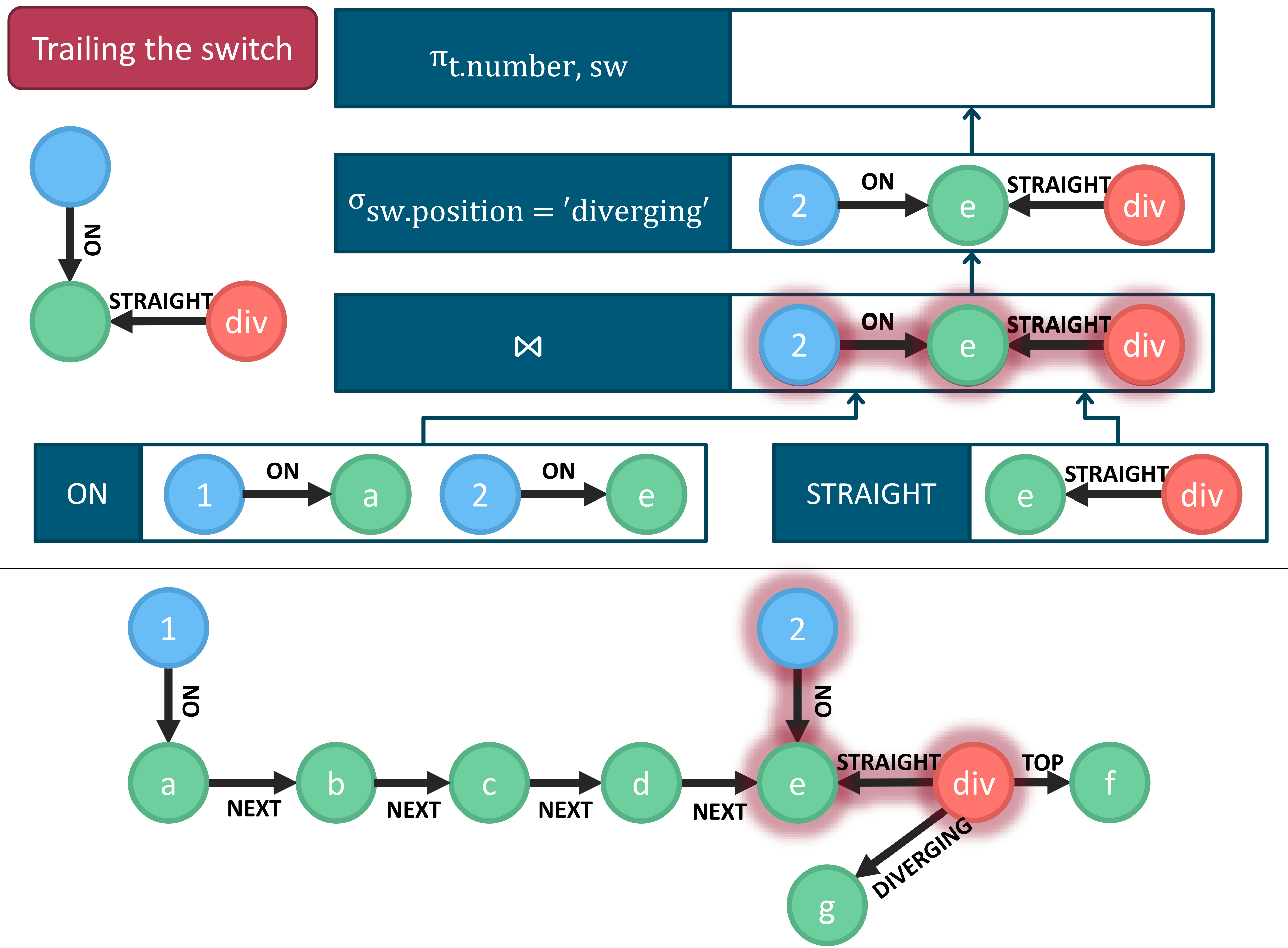
NEXT
NEXT
NEXT
NEXT
STRAIGHT
TOP
DIVERGING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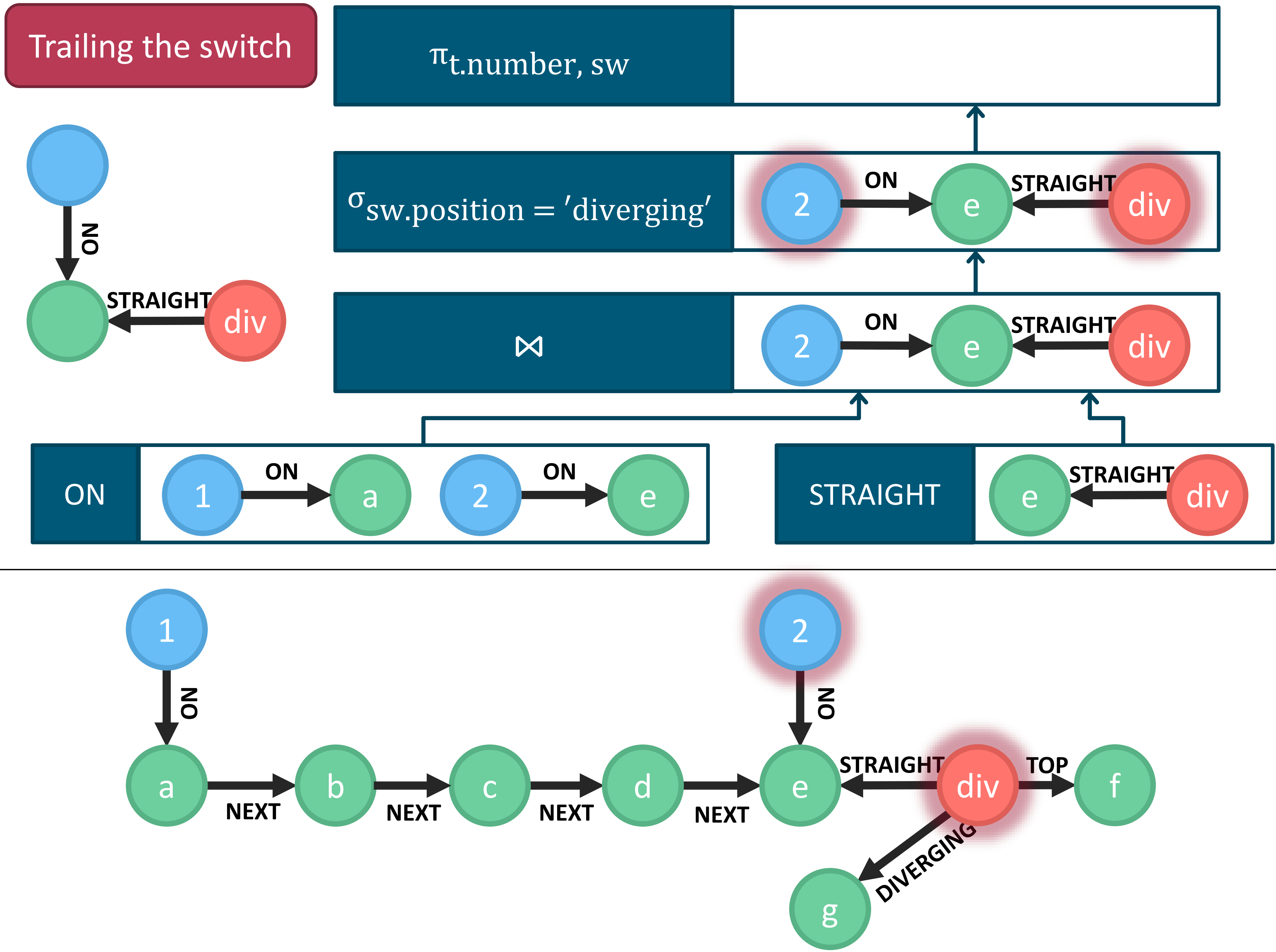
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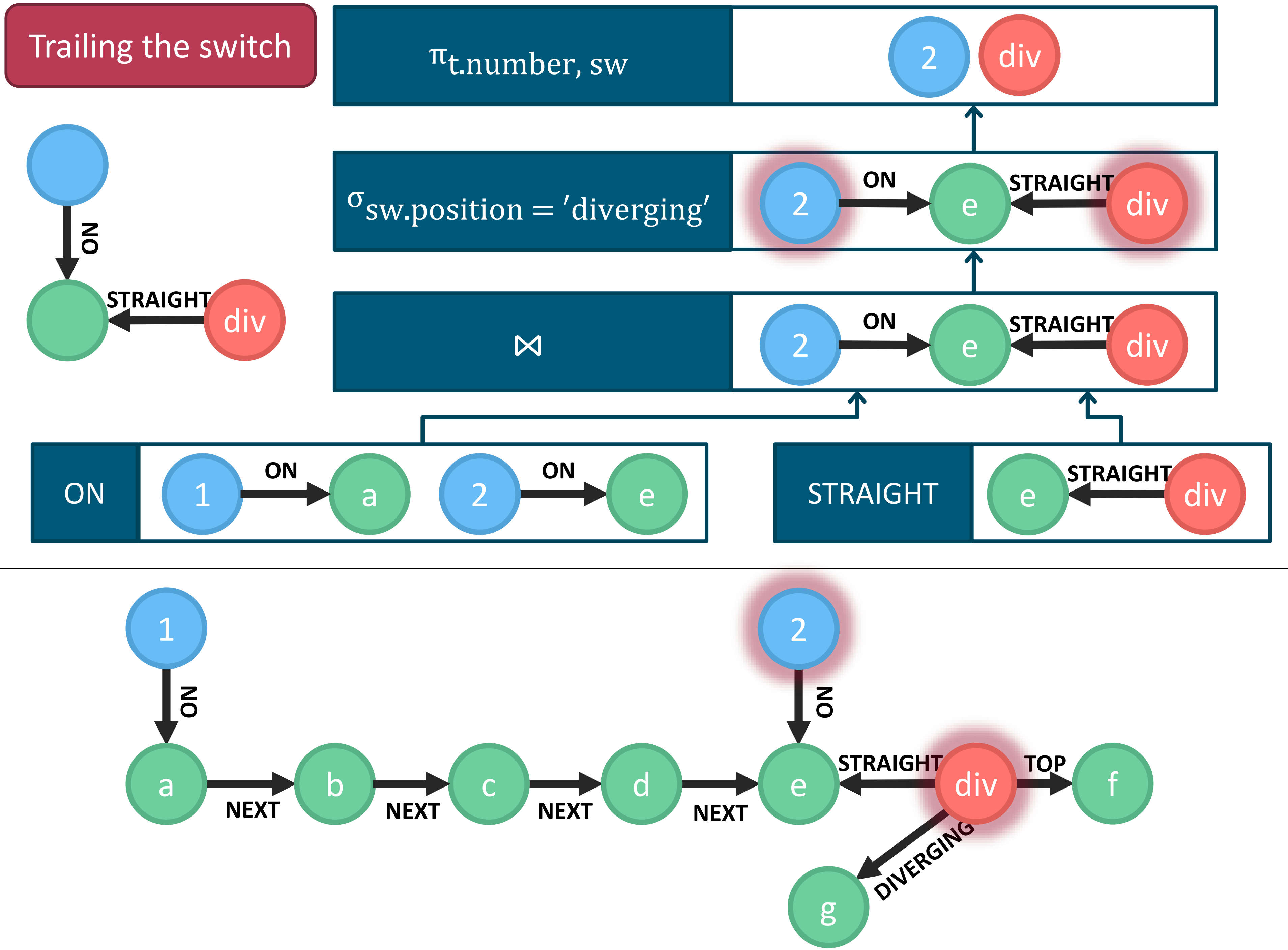

Trailing the switch
$\pi_{t.number,\ sw}$
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div
$\sigma_{sw.position\ =\ 'diverging'}$
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ON
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STRAIGHT
div
$\bowtie$
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e
STRAIGHT
div
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ON
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ON
e
STRAIGHT
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div
ON
STRAIGHT
div
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b
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c
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d
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e
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ON
STRAIGHT
div
TOP
f
DIVERGING
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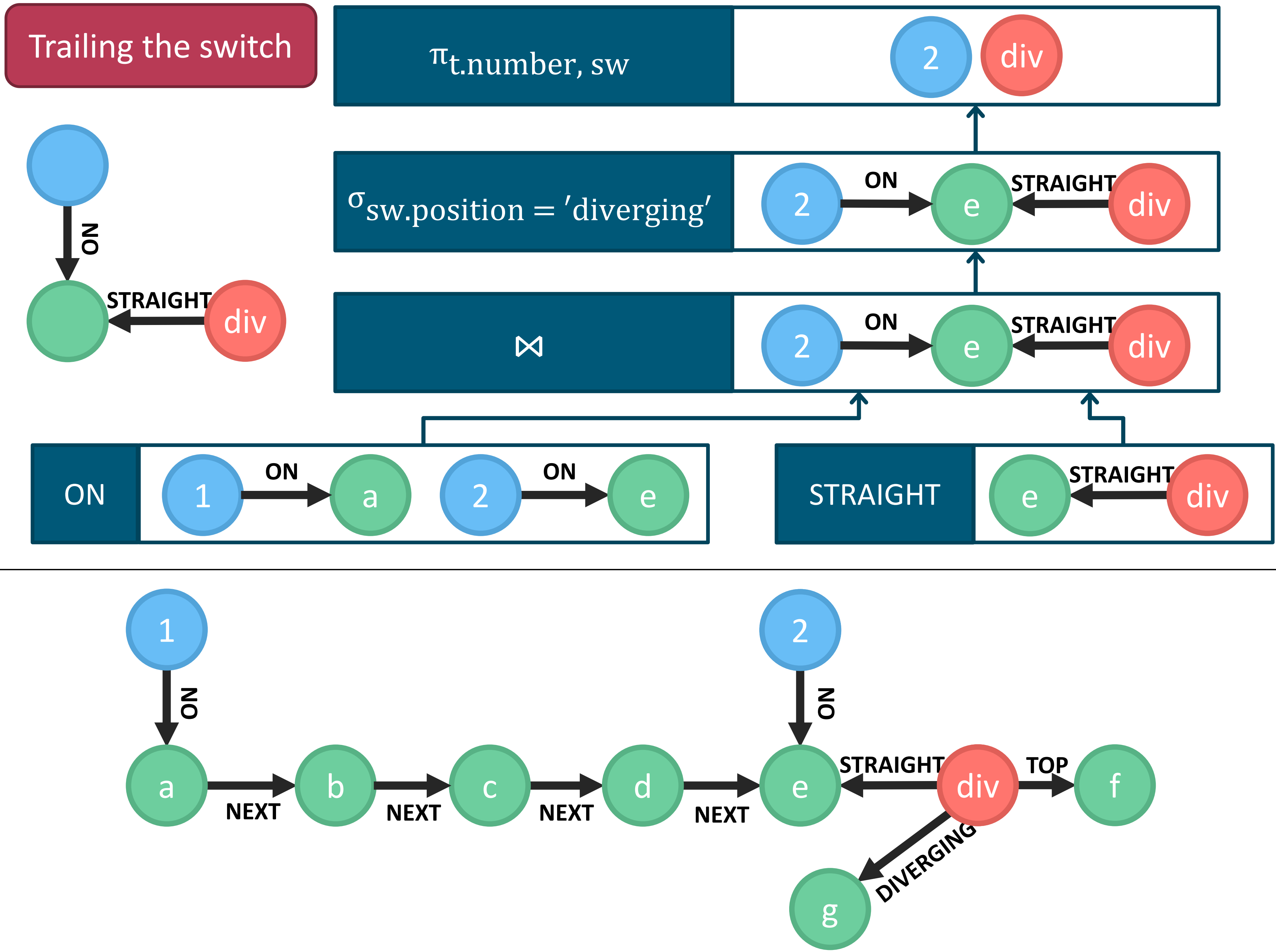

Trailing the switch
$\pi_{t.number,\ sw}$
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$\sigma_{sw.position\ =\ 'diverging'}$
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$\bowtie$
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NEXT
NEXT
STRAIGHT
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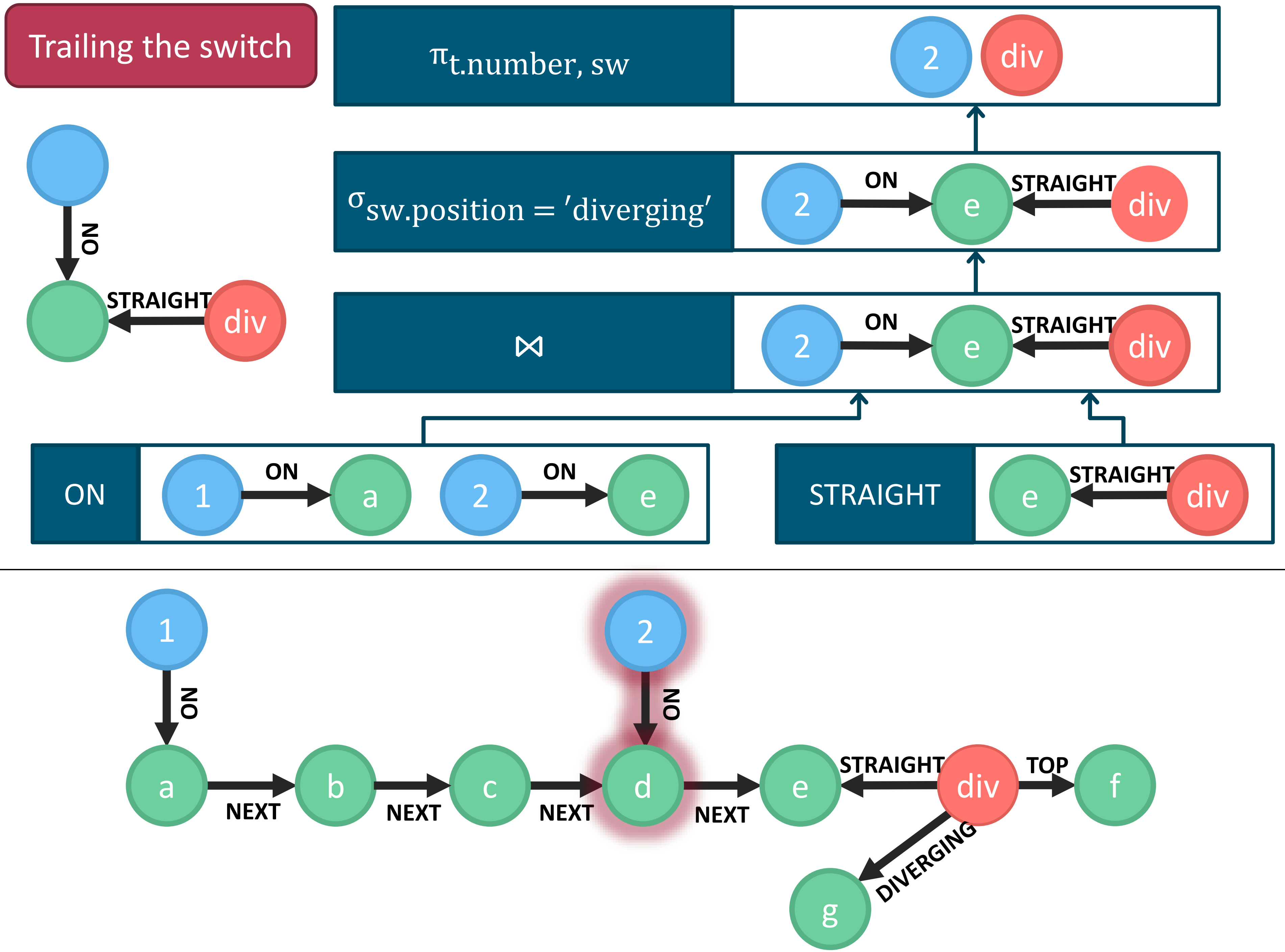

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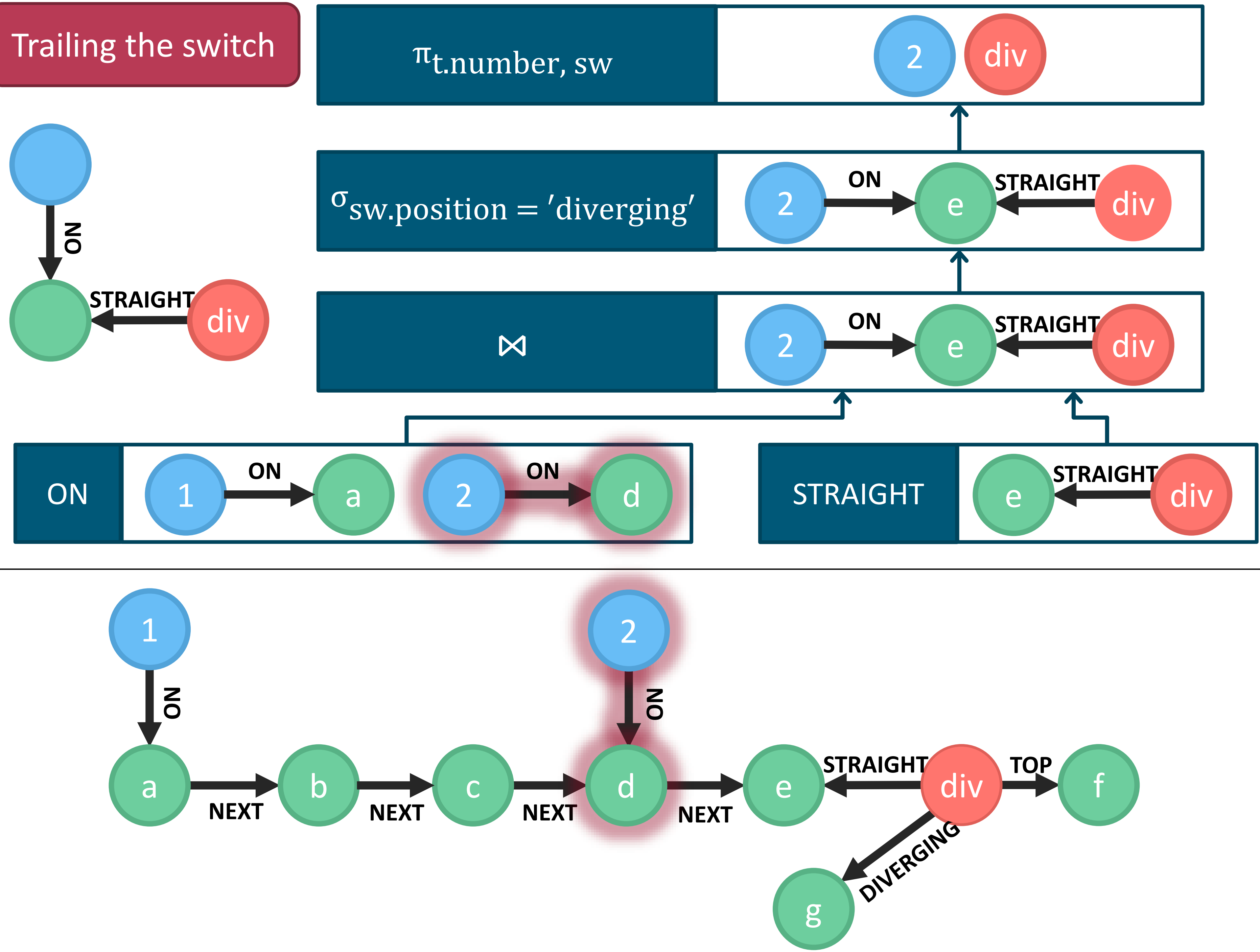

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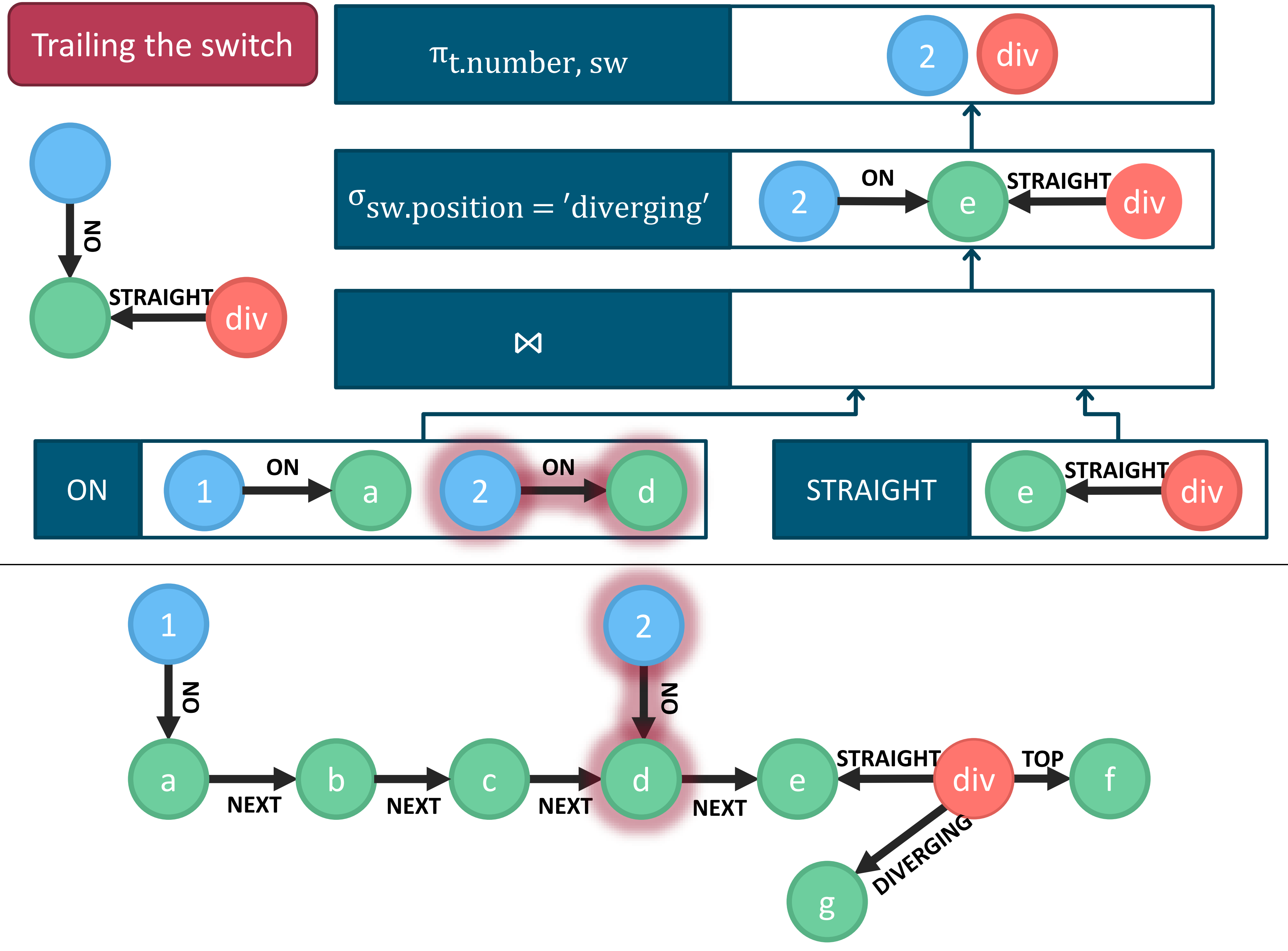

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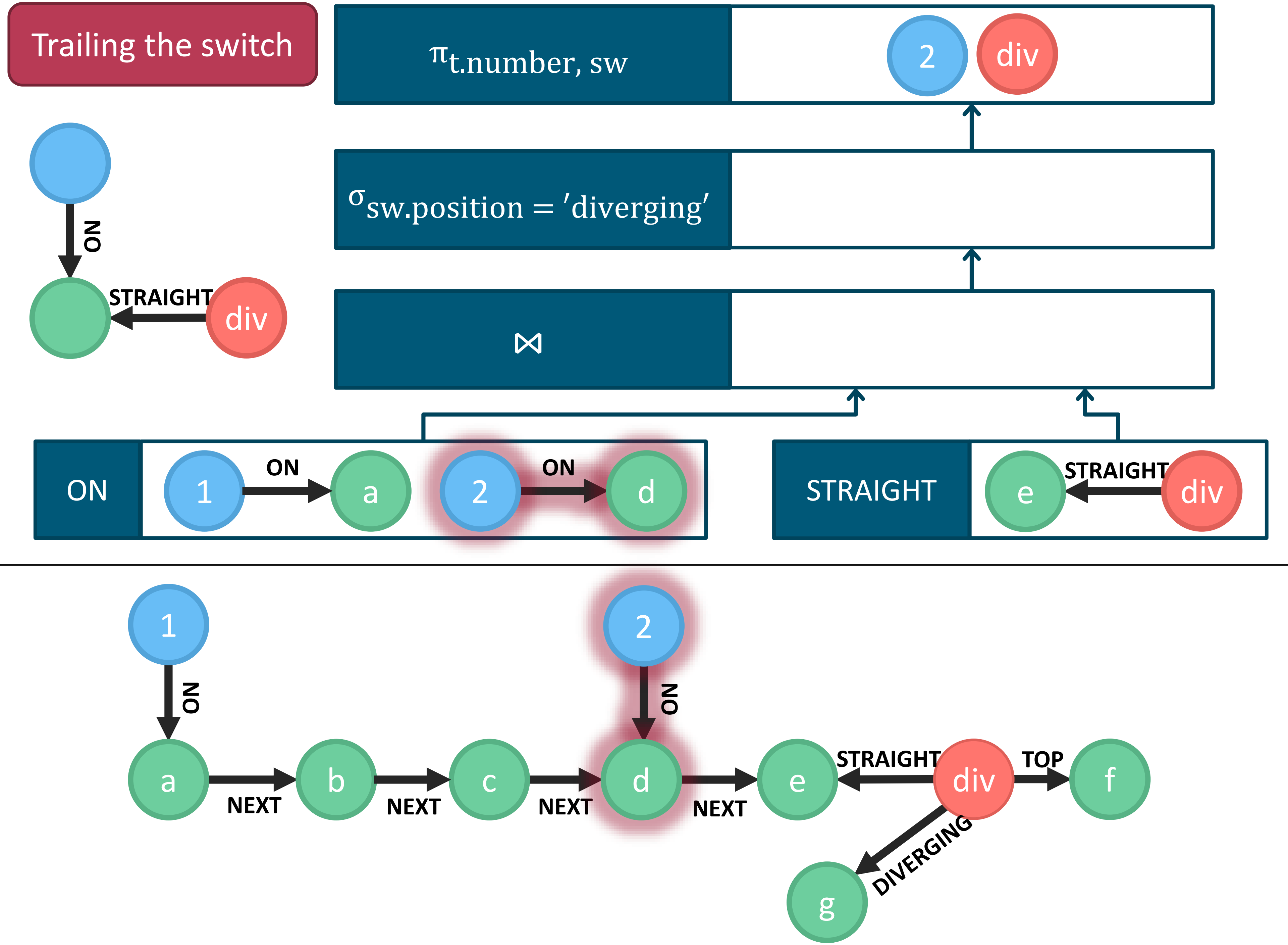

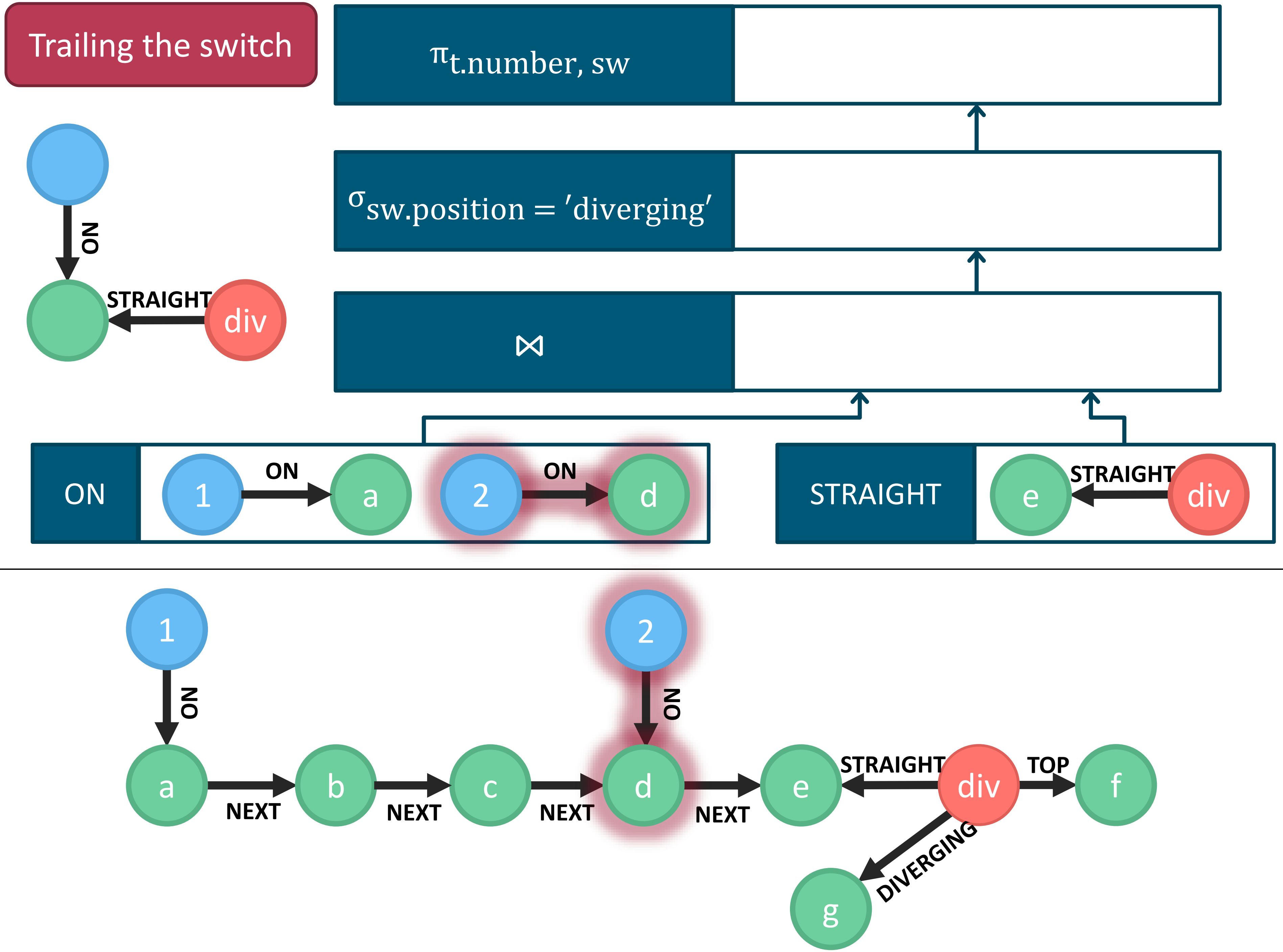

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$\bowtie$
ON
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div
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ON
d
STRAIGHT
e
STRAIGHT
div
1
ON
a
NEXT
b
NEXT
c
NEXT
2
ON
d
NEXT
e
STRAIGHT
div
TOP
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Batch vs. incremental queries

- **Batch queries**
  (pull / request-driven):
  1. Client selects a query
  2. Results are calculated
- Query results
  obtained on demand

Batch vs. incremental queries

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  2. Results are calculated
- Query results obtained on demand

- **Incremental queries** (push / event-driven):
  1. Client registers queries
  2. Graph is changed
  3. Results are maintained
  4. Goto 2
- Query results are always available

Incremental query engines

CLIPS	C structures	NASA
Drools	POJO	Red Hat
VIATRA	EMF	BME / IncQuery Labs.

Incremental query engines

- CLIPS C structures NASA
- Drools POJO Red Hat
- VIATRA EMF BME / IncQuery Labs.

- INSTANS RDF Aalto University
- i3QL POJO TU Darmstadt
- IncQuery-D RDF BME

Incremental query engines

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INSTANS	RDF	Aalto University
i3QL	POJO	TU Darmstadt
IncQuery-D	RDF	BME

- **No implementations for property graphs yet**

Incremental Graph Queries with openCypher

Incremental Graph Queries **with openCypher**

openCypher

„The openCypher project aims to deliver a full and open specification of the industry’s most widely adopted graph database query language: Cypher.”

- Grammar specification
- Technology Compatibility Kit (TCK)
- Reference implementation

openCypher constructs

- Standard constructs
  - pattern matching
  - filtering
  - lists, maps
  - data manipulation
  - variable length paths

openCypher constructs

- Standard constructs
  - pattern matching
  - filtering
  - lists, maps
  - data manipulation
  - variable length paths
- Legacy constructs
  - indexing, constraints
  - regular expressions
  - some list functions, including `reduce`
  - most predicate functions
  - shortest path functions
  - CASE expressions
  - `id()`

openCypher constructs

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  - `CASE` expressions
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Difficult to handle incrementally

Mapping openCypher to relational algebra

Combining and filtering pattern matches	
`MATCH «p»`	$\not\equiv_{\text{edges of p}}(\mathsf{p})$
`MATCH «p1», «p2»`	$\not\equiv_{\text{edges of p1 and p2}}(\mathsf{p}_1 \bowtie \mathsf{p}_2)$
`MATCH «p1»` `MATCH «p2»`	$\not\equiv_{\text{edges of p1}}(\mathsf{p}_1) \bowtie \not\equiv_{\text{edges of p2}}(\mathsf{p}_2)$
`MATCH «p1»` `OPTIONAL MATCH «p2»`	$\not\equiv_{\text{edges of p1}}(\mathsf{p}_1) \mathbin{⟕} \not\equiv_{\text{edges of p2}}(\mathsf{p}_2)$
`MATCH «p»` `WHERE «condition»`	$\sigma_{\text{condition}}(r)$, where condition may specify patterns and arithmetic constraints on existing variables
Result and sub-result operations. Rules for `RETURN` also apply to `WITH`.	
`RETURN «variables»`	$\pi_{\text{variables}}(r)$
`RETURN «v1» AS «alias1» ...`	$\pi_{\text{v1}\rightarrow\text{alias1},\ldots}(r)$
`RETURN DISTINCT «variables»`	$\delta\left(\pi_{\text{variables}}(r)\right)$
`RETURN «variables», «aggregates»`	$\gamma_{\text{variables,aggregates}}(r)$
List operations	
`ORDER BY «v1» [ASC|DESC] ...`	$\tau_{\Uparrow/\Downarrow\text{v1},\ldots}(r)$
`LIMIT «l»`	$\lambda_l(r)$

Mapping openCypher to relational algebra

Combining and filtering pattern matches	
`MATCH «p»`	$\dot{\neq}_{\text{edges of p}}(\mathsf{p})$
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`MATCH «p1»` `OPTIONAL MATCH «p2»`	$\dot{\neq}_{\text{edges of p1}}(\mathsf{p}_1)$ ⟕ $\dot{\neq}_{\text{edges of p2}}(\mathsf{p}_2)$
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List operations	
`ORDER BY «v1» [ASC|DESC] ...`	$\tau_{\Uparrow/\Downarrow\text{v1}}$
`LIMIT «l»`	$\lambda_l(r)$

Technical report

Query specification (query-18)

```
MATCH (tom:Person {name:"Tom Hanks"})-[:ACTED_IN]->(m)<-[:ACTED_IN]-(coActors)
RETURN coActors.name
```

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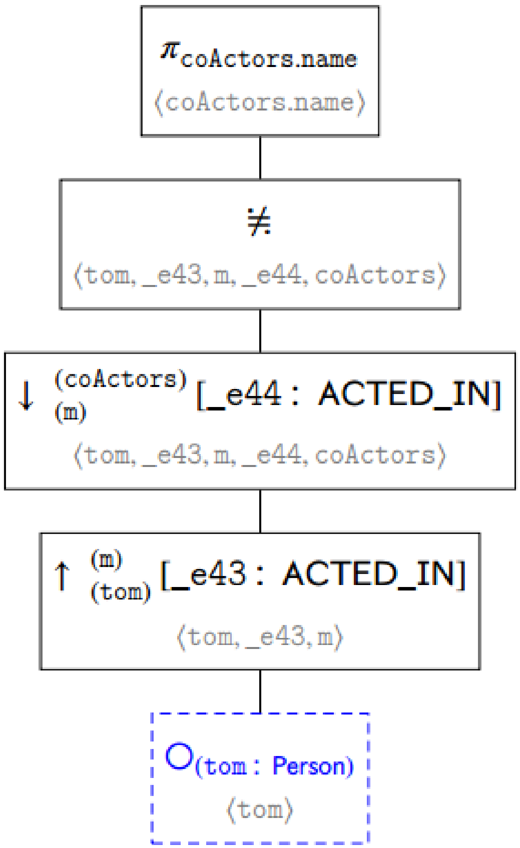

Batch search plan

Query specification (query-18)

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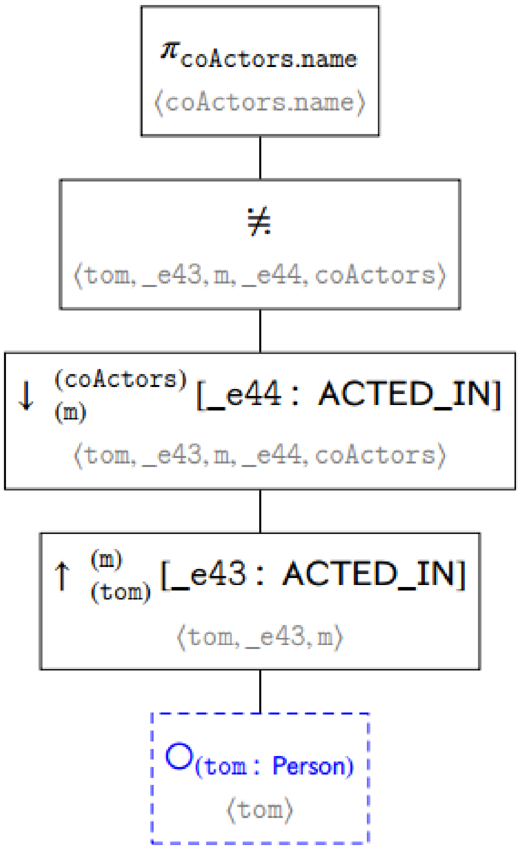
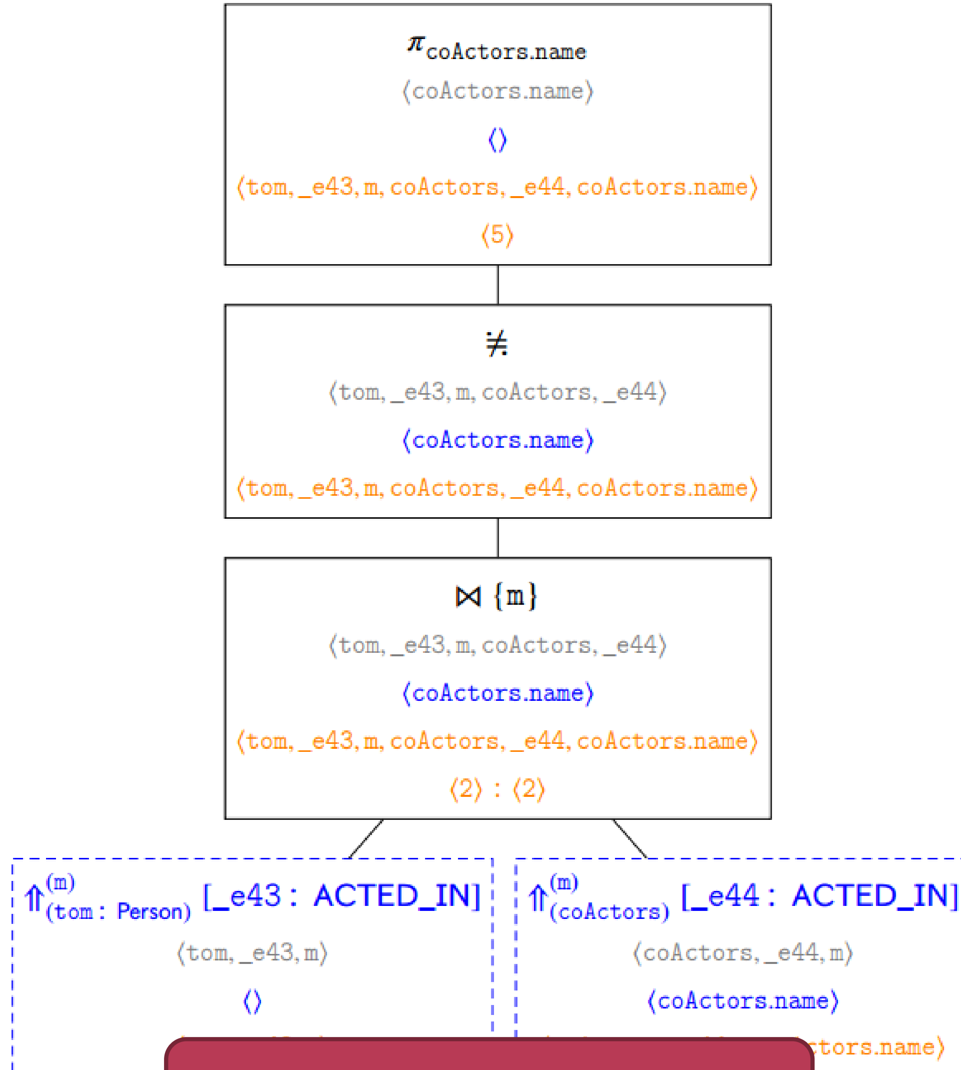


Batch search plan



Incremental search plan

Incremental openCypher challenges

- Lists
  - `['a', 1, 2, true]`
  - `['a', [1, [2]], true]`
  - `UNWIND`
  - `collect()`
- Bag semantics, `ORDER BY`, `SKIP` and `LIMIT`
- Legacy constructs
  - `shortestPath()`, `allShortestPaths()`
  - `reduce()`

Incremental openCypher challenges

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- Legacy constructs
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These are not handled by traditional Rete implementations

ingraph

- An incremental, in-memory graph query engine

ingraph

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ingraph

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ingraph

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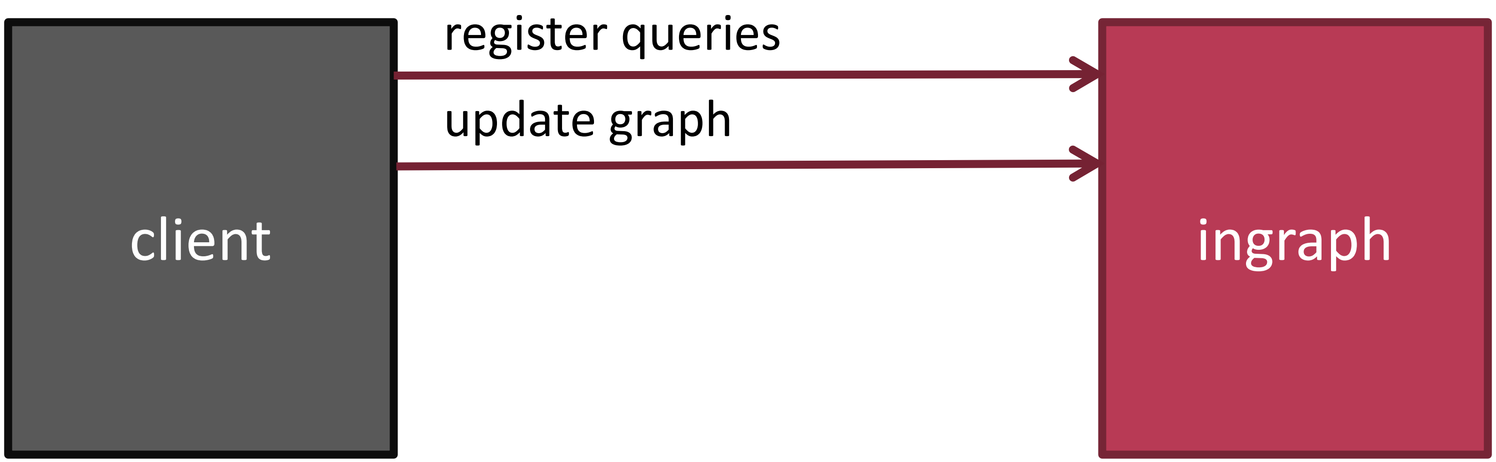
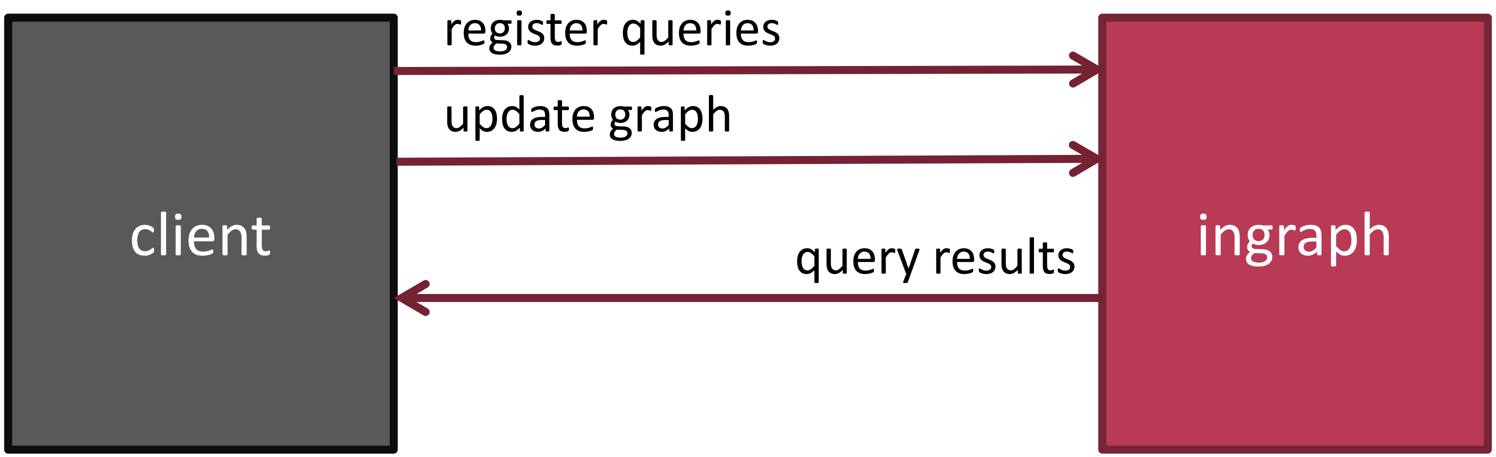


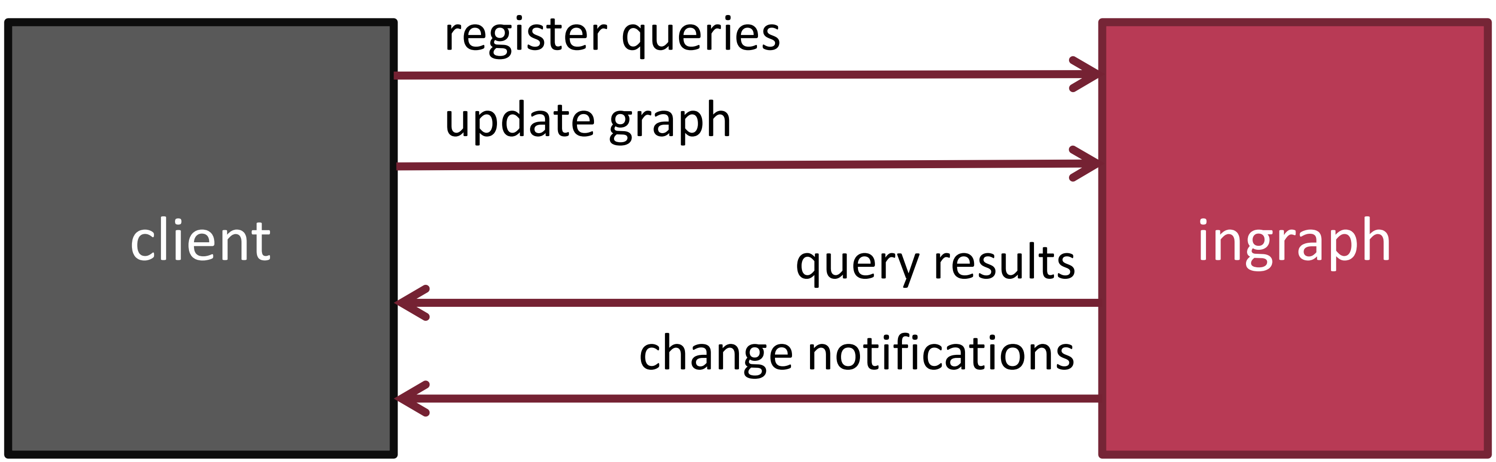
ingraph

- An incremental, in-memory graph query engine



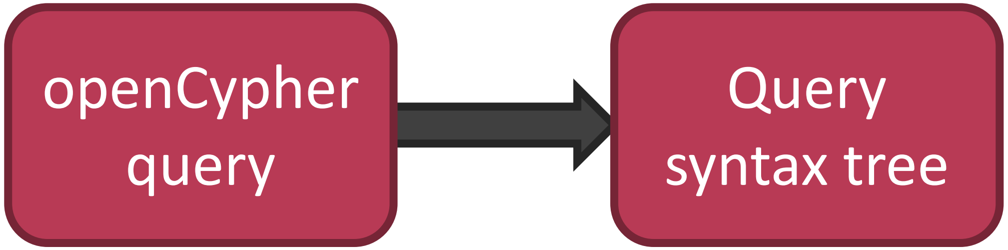
ingraph

- An incremental, in-memory graph query engine



openCypher query

```
MATCH (t:Train)-[:ON]->(seg:Segment)
      <-[:STRAIGHT]-(sw:Switch)
WHERE sw.position = 'diverging'
RETURN t.number, sw
```

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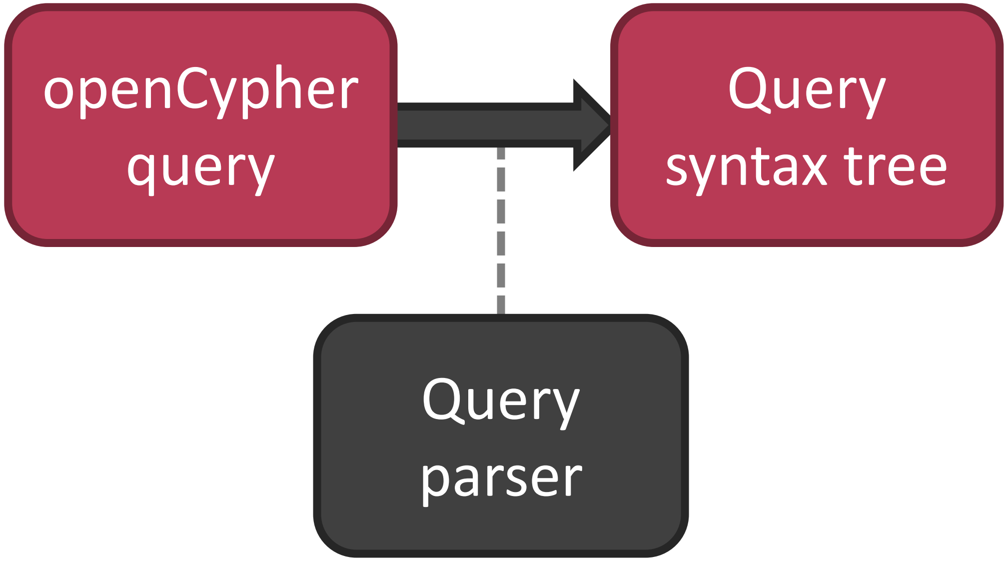


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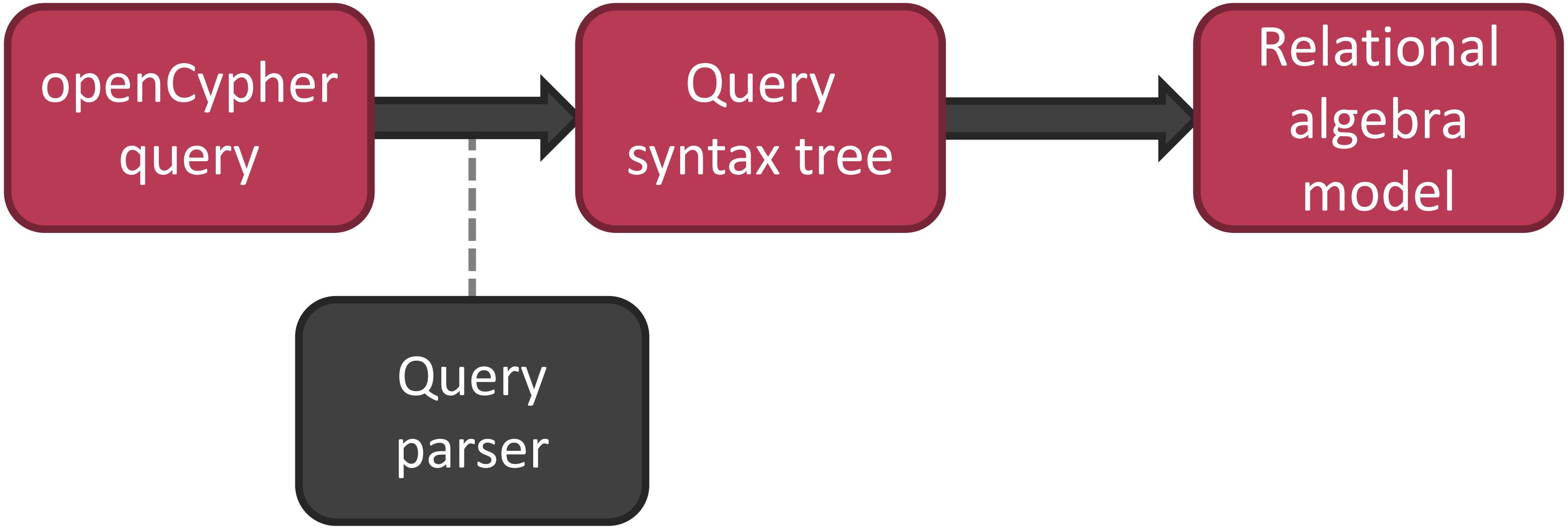


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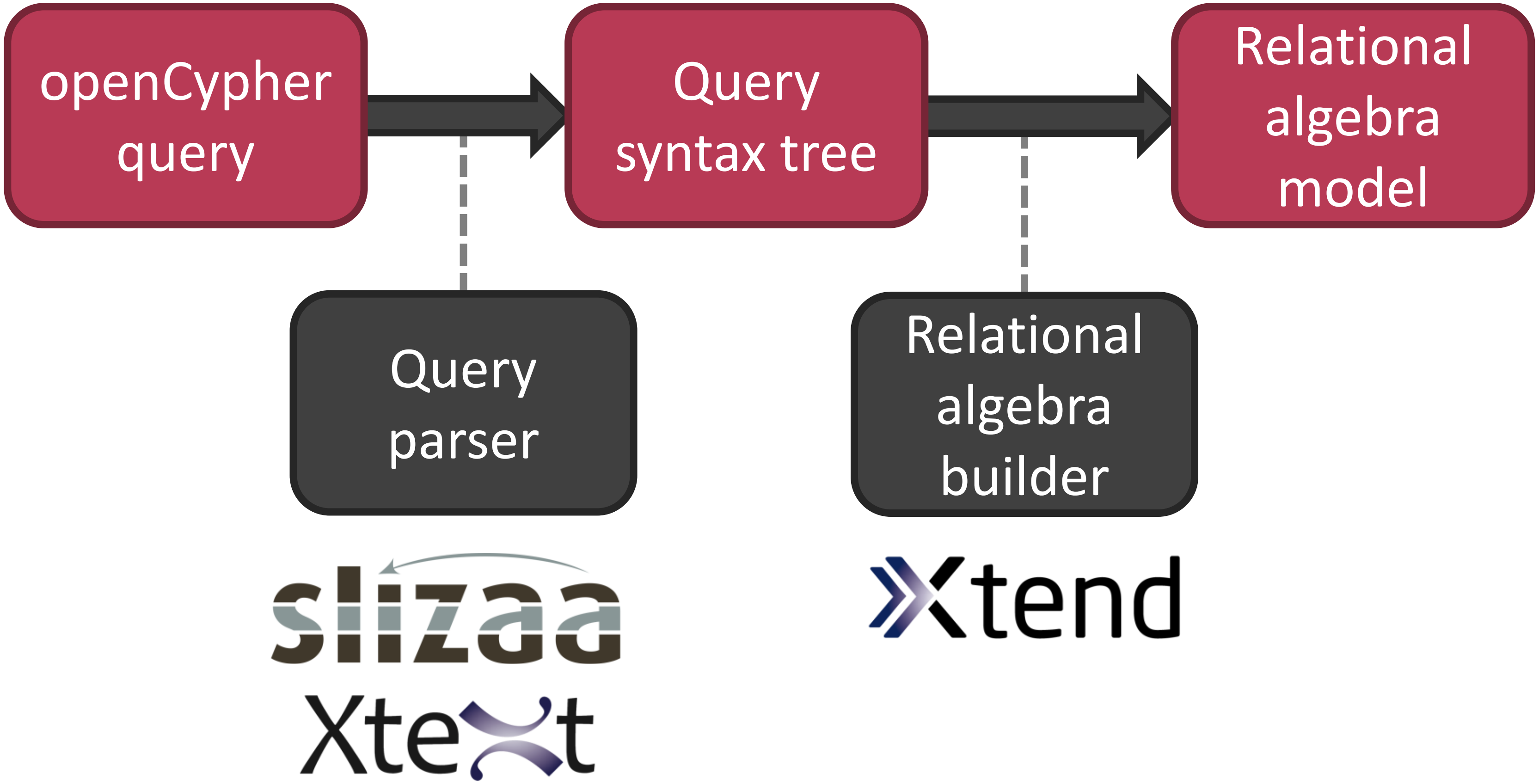


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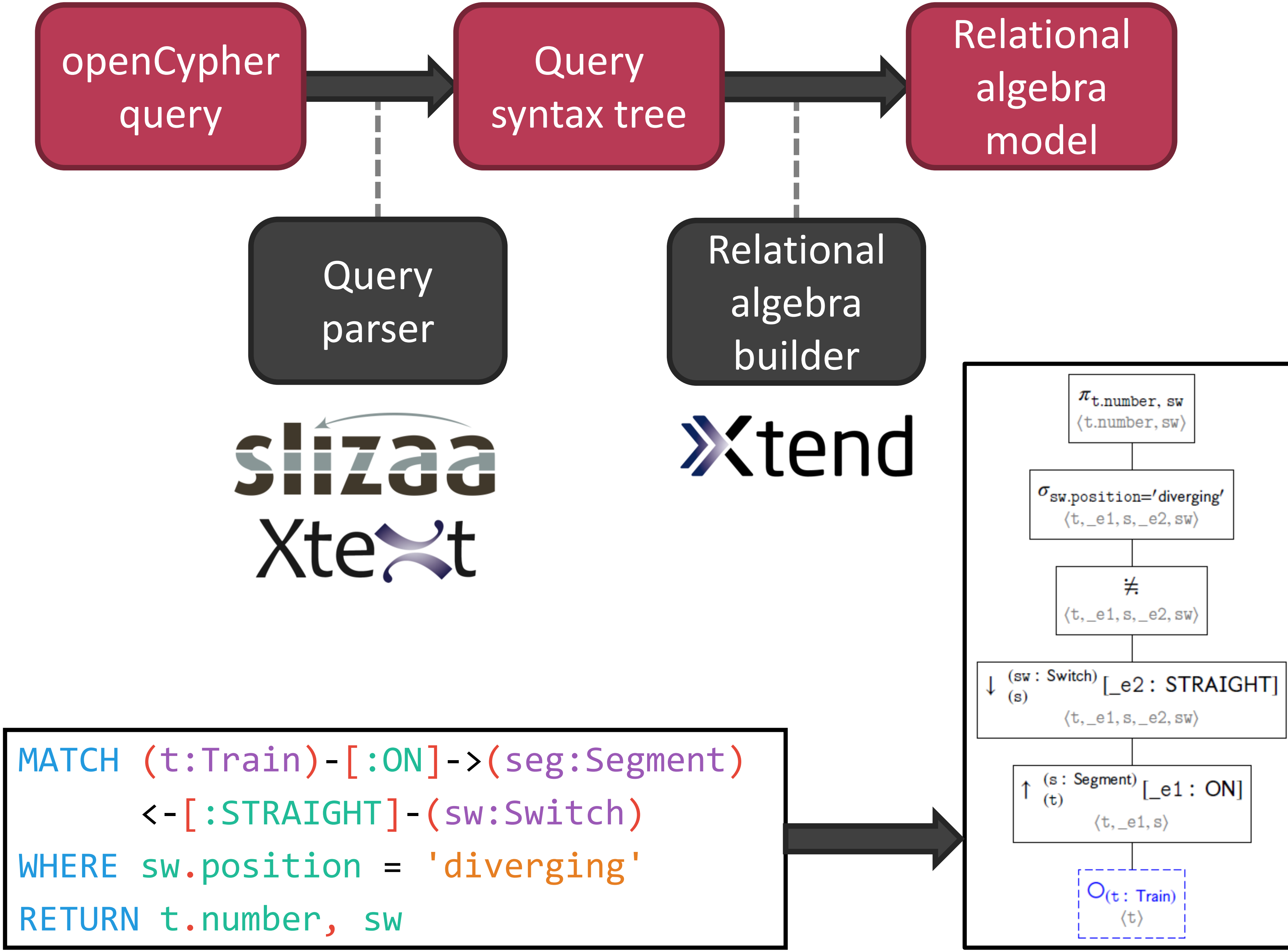

openCypher query
Query syntax tree
Relational algebra model
Query parser
Relational algebra builder
slizaa
Xtext
Xtend
$\pi_{\text{t.number, sw}}$
⟨t.number, sw⟩
$\sigma_{\text{sw.position='diverging'}}$
⟨t, _e1, s, _e2, sw⟩
$\not\equiv$
⟨t, _e1, s, _e2, sw⟩
$\downarrow^{(\text{sw : Switch})}_{(\text{s})}$ [_e2 : STRAIGHT]
⟨t, _e1, s, _e2, sw⟩
$\uparrow^{(\text{s : Segment})}_{(\text{t})}$ [_e1 : ON]
⟨t, _e1, s⟩
$\bigcirc_{(\text{t : Train})}$
⟨t⟩
MATCH (t:Train)-[:ON]->(seg:Segment)
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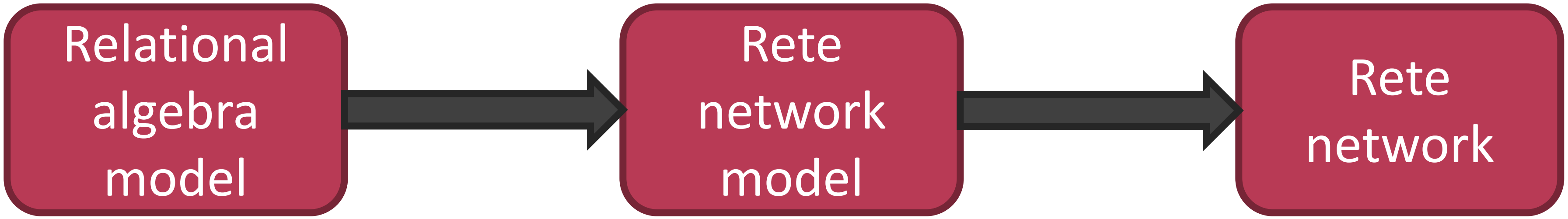
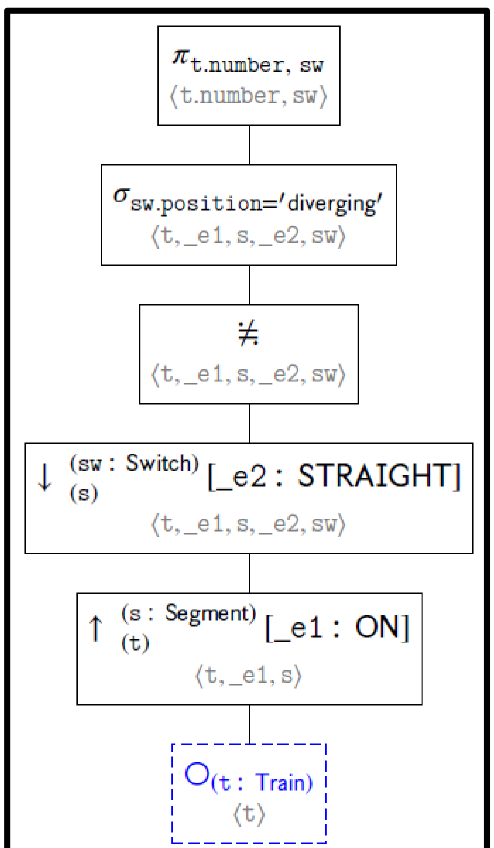
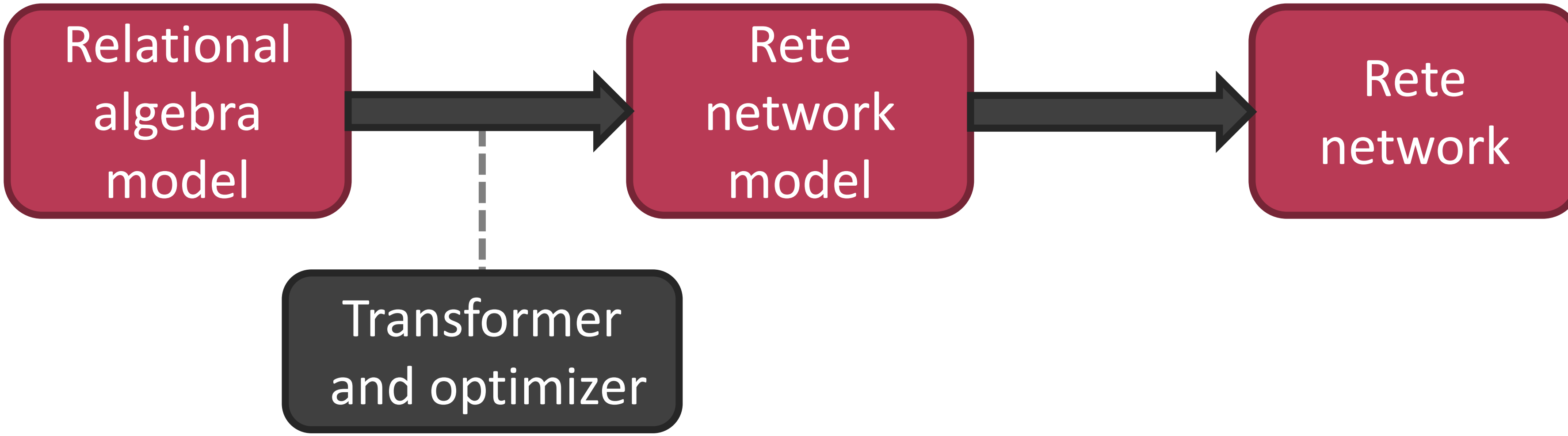
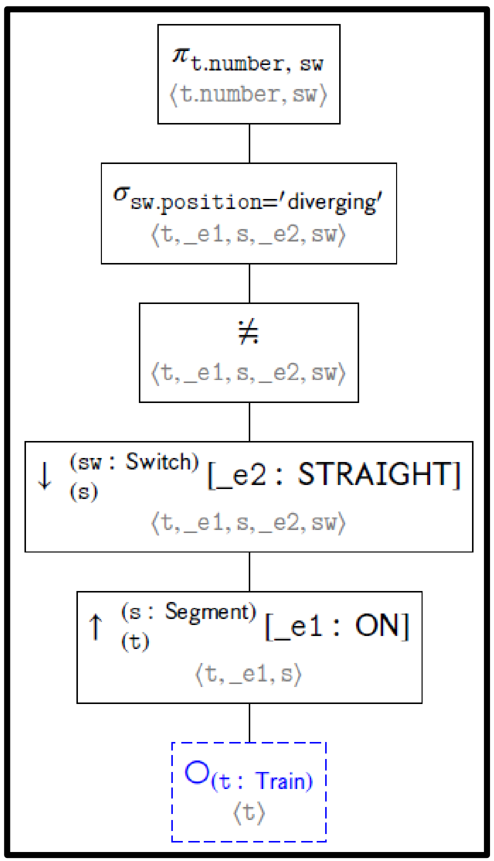

Relational algebra model
Rete network model
Rete network


$\pi_{\mathtt{t.number,\ sw}}$
$\langle \mathtt{t.number, sw} \rangle$
$\sigma_{\mathtt{sw.position}='\mathsf{diverging}'}$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\not\asymp$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\downarrow^{(\mathtt{sw}:\ \mathsf{Switch})}_{(\mathtt{s})} [\mathsf{\_e2} : \mathsf{STRAIGHT}]$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\uparrow^{(\mathtt{s}:\ \mathsf{Segment})}_{(\mathtt{t})} [\mathsf{\_e1} : \mathsf{ON}]$
$\langle \mathtt{t, \_e1, s} \rangle$
$\bigcirc_{(\mathtt{t}:\ \mathsf{Train})}$
$\langle \mathtt{t} \rangle$

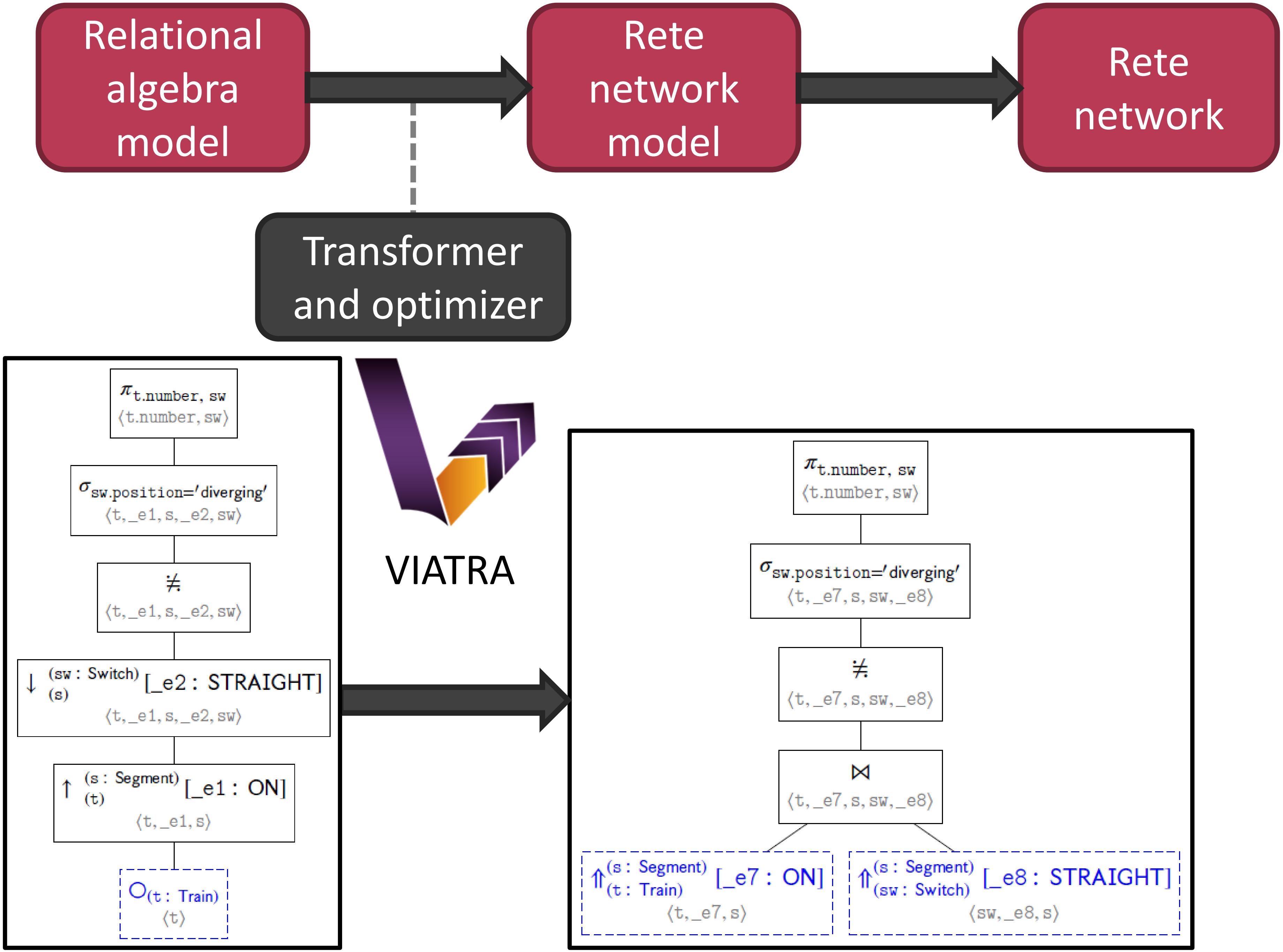


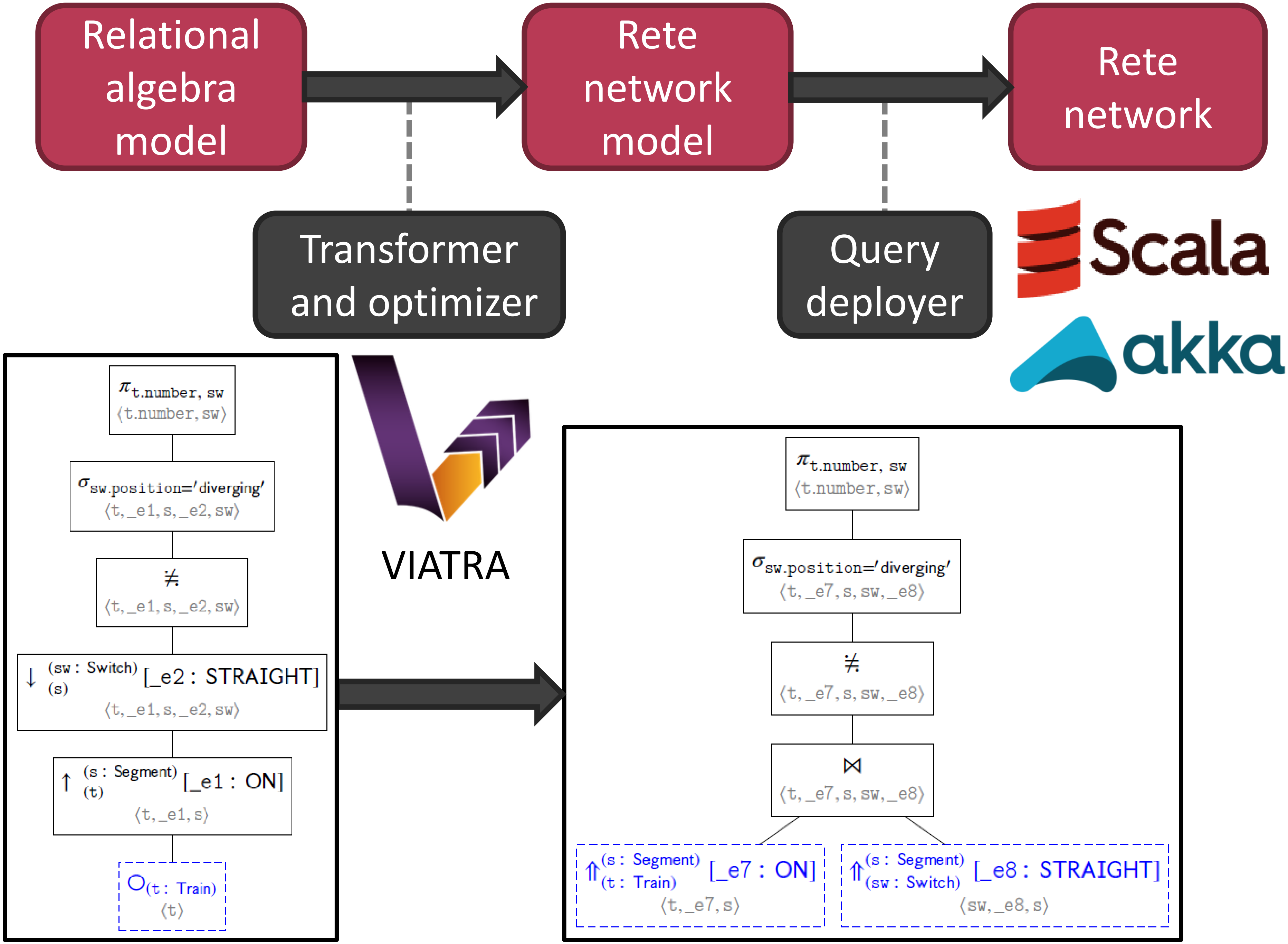
Relational algebra model
Rete network model
Rete network
Transformer and optimizer



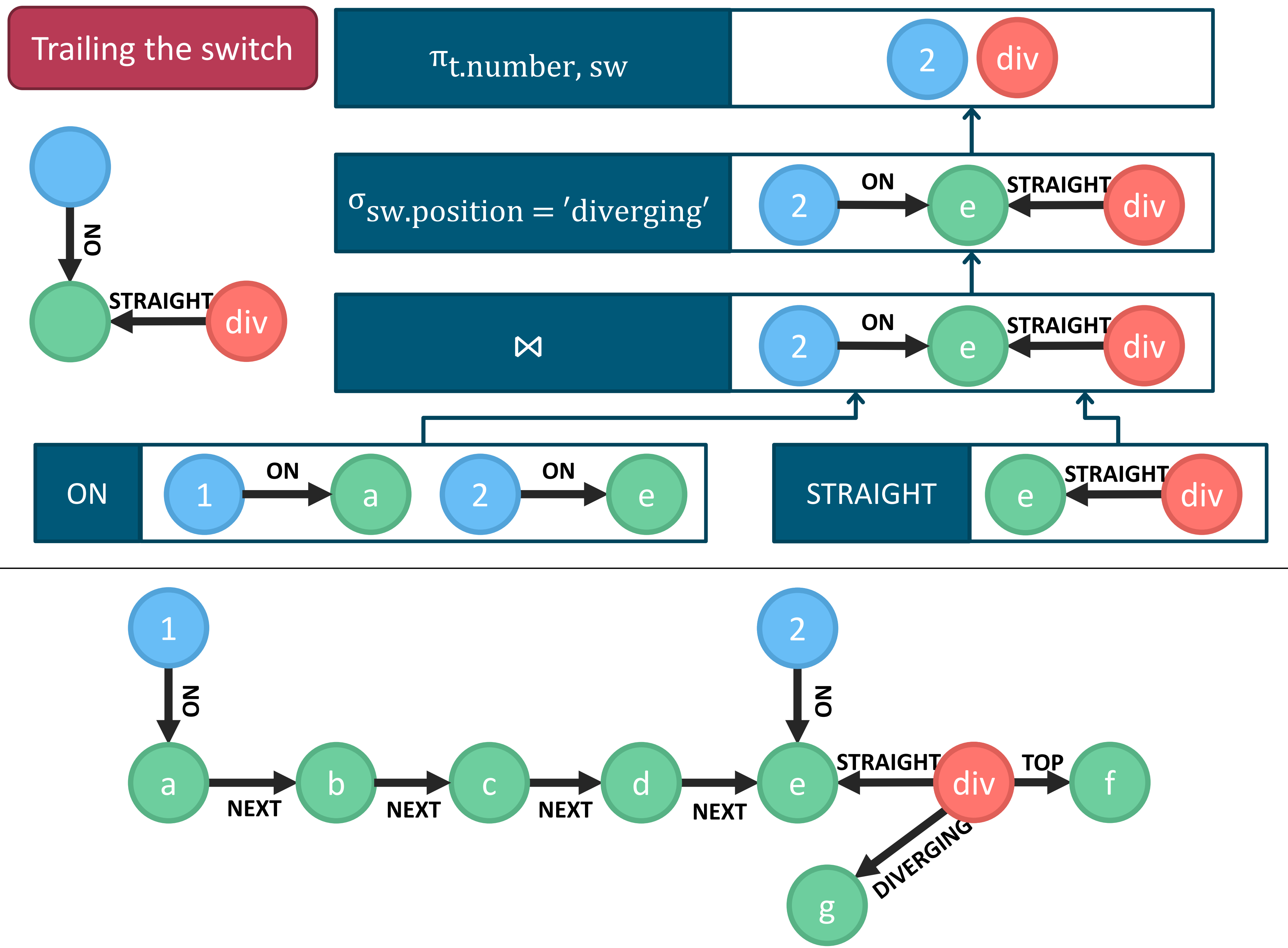
$\pi_{\mathtt{t.number,\ sw}}$
$\langle \mathtt{t.number, sw} \rangle$
$\sigma_{\mathtt{sw.position}='\mathsf{diverging}'}$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\not\equiv$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\downarrow^{(\mathtt{sw}:\ \mathsf{Switch})}_{(\mathtt{s})} [\_\mathsf{e2}:\ \mathsf{STRAIGHT}]$
$\langle \mathtt{t, \_e1, s, \_e2, sw} \rangle$
$\uparrow^{(\mathtt{s}:\ \mathsf{Segment})}_{(\mathtt{t})} [\_\mathsf{e1}:\ \mathsf{ON}]$
$\langle \mathtt{t, \_e1, s} \rangle$
$\bigcirc_{(\mathtt{t}:\ \mathsf{Train})}$
$\langle \mathtt{t} \rangle$

VIATRA

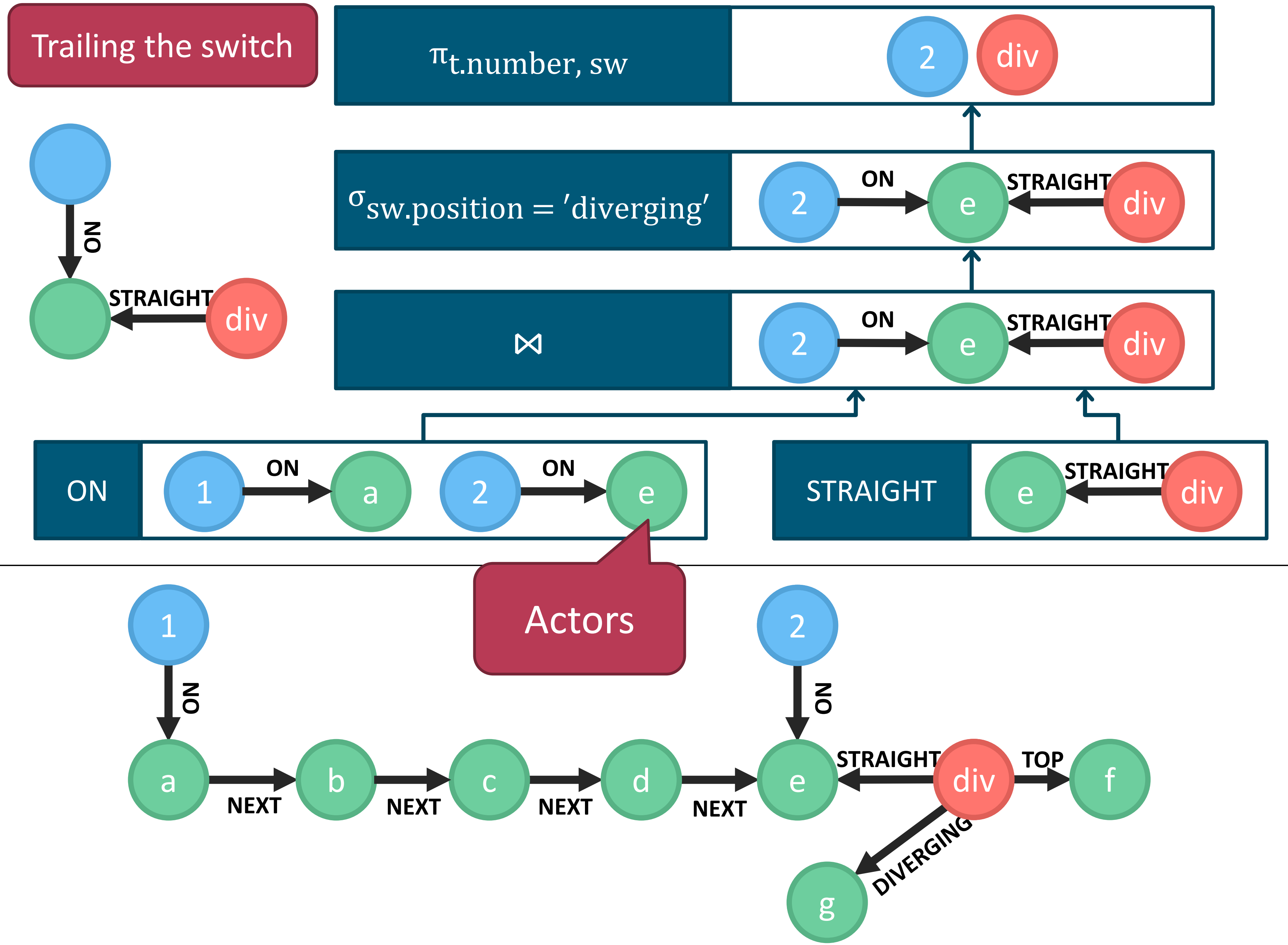

Relational algebra model
Rete network model
Rete network
Transformer and optimizer
VIATRA
π t.number, sw
⟨t.number, sw⟩
σ sw.position='diverging'
⟨t, _e1, s, _e2, sw⟩
≉
⟨t, _e1, s, _e2, sw⟩
↓ (sw : Switch) (s) [_e2 : STRAIGHT]
⟨t, _e1, s, _e2, sw⟩
↑ (s : Segment) (t) [_e1 : ON]
⟨t, _e1, s⟩
○ (t : Train)
⟨t⟩
π t.number, sw
⟨t.number, sw⟩
σ sw.position='diverging'
⟨t, _e7, s, sw, _e8⟩
≉
⟨t, _e7, s, sw, _e8⟩
⋈
⟨t, _e7, s, sw, _e8⟩
⇑ (s : Segment) (t : Train) [_e7 : ON]
⟨t, _e7, s⟩
⇑ (s : Segment) (sw : Switch) [_e8 : STRAIGHT]
⟨sw, _e8, s⟩



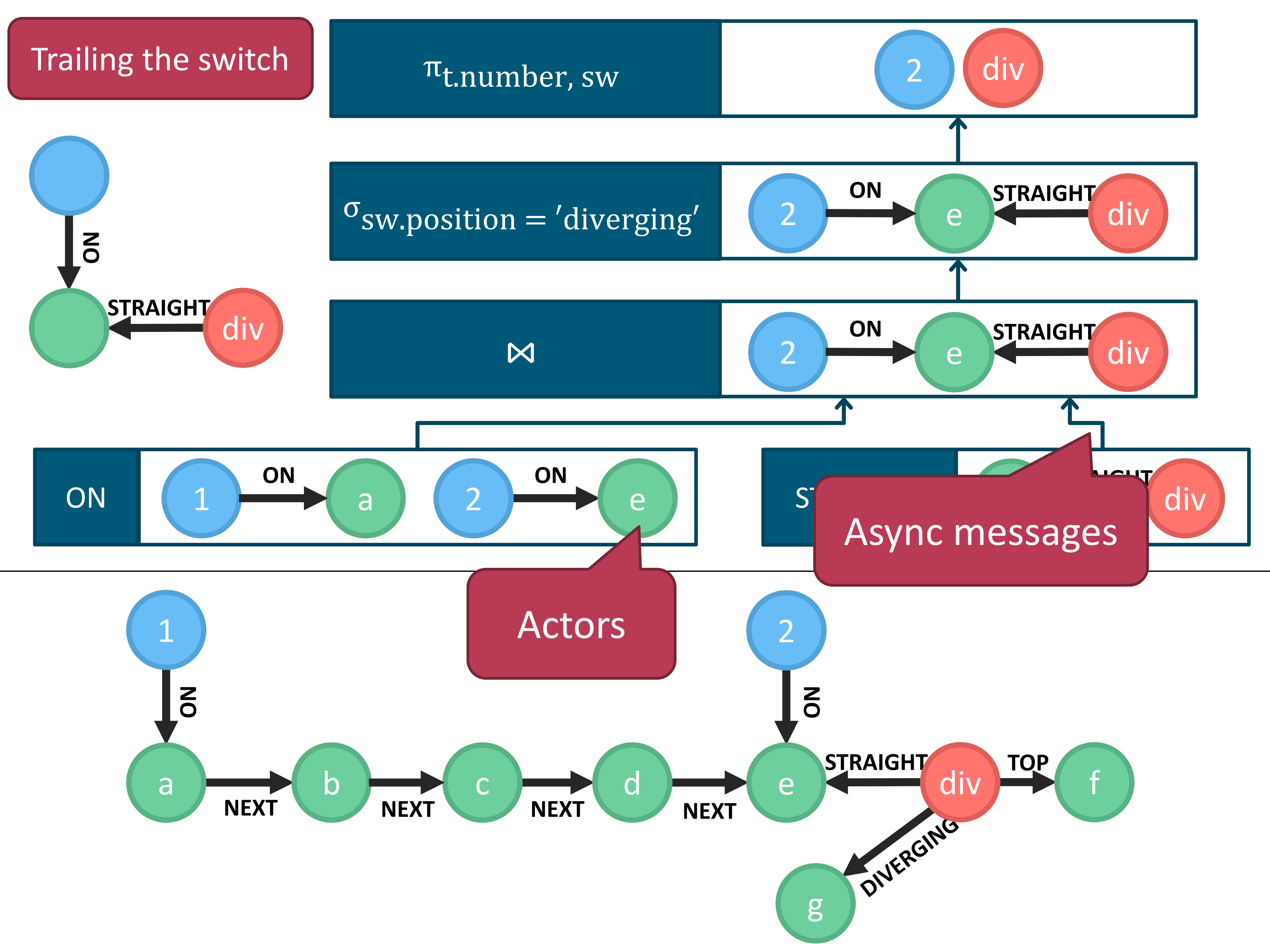
Relational algebra model
Rete network model
Rete network
Transformer and optimizer
Query deployer
VIATRA
$\pi_{\mathtt{t.number,\ sw}}$ ⟨t.number, sw⟩
$\sigma_{\mathtt{sw.position='diverging'}}$ ⟨t, _e1, s, _e2, sw⟩
$\neq$ ⟨t, _e1, s, _e2, sw⟩
$\downarrow^{\mathsf{(sw:\ Switch)}}_{\mathsf{(s)}}$ [_e2 : STRAIGHT] ⟨t, _e1, s, _e2, sw⟩
$\uparrow^{\mathsf{(s:\ Segment)}}_{\mathsf{(t)}}$ [_e1 : ON] ⟨t, _e1, s⟩
$\bigcirc_{\mathsf{(t:\ Train)}}$ ⟨t⟩
$\pi_{\mathtt{t.number,\ sw}}$ ⟨t.number, sw⟩
$\sigma_{\mathtt{sw.position='diverging'}}$ ⟨t, _e7, s, sw, _e8⟩
$\neq$ ⟨t, _e7, s, sw, _e8⟩
$\bowtie$ ⟨t, _e7, s, sw, _e8⟩
$\Uparrow^{\mathsf{(s:\ Segment)}}_{\mathsf{(t:\ Train)}}$ [_e7 : ON] ⟨t, _e7, s⟩
$\Uparrow^{\mathsf{(s:\ Segment)}}_{\mathsf{(sw:\ Switch)}}$ [_e8 : STRAIGHT] ⟨sw, _e8, s⟩



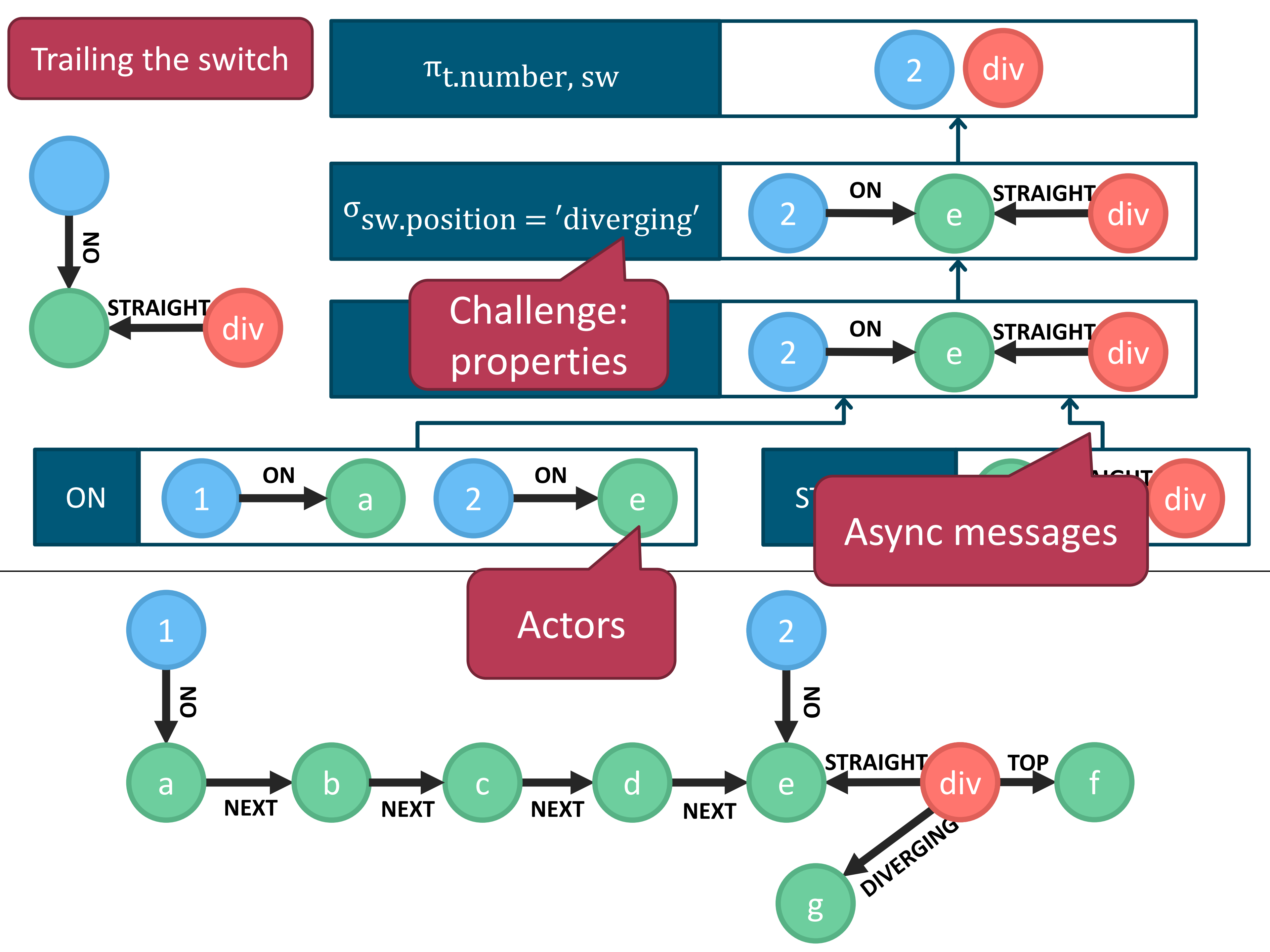
Trailing the switch
ON
STRAIGHT
div
$\pi_{t.number, sw}$
2
div
$\sigma_{sw.position = 'diverging'}$
2
ON
e
STRAIGHT
div
$\bowtie$
2
ON
e
STRAIGHT
div
ON
1
ON
a
2
ON
e
STRAIGHT
e
STRAIGHT
div
1
ON
a
NEXT
b
NEXT
c
NEXT
d
NEXT
2
ON
e
STRAIGHT
div
TOP
f
DIVERGING
g



Trailing the switch
$\pi_{t.number, sw}$
$\sigma_{sw.position = 'diverging'}$
$\bowtie$
ON
STRAIGHT
div
2
e
1
a
Actors
b
c
d
f
g
NEXT
TOP
DIVERGING

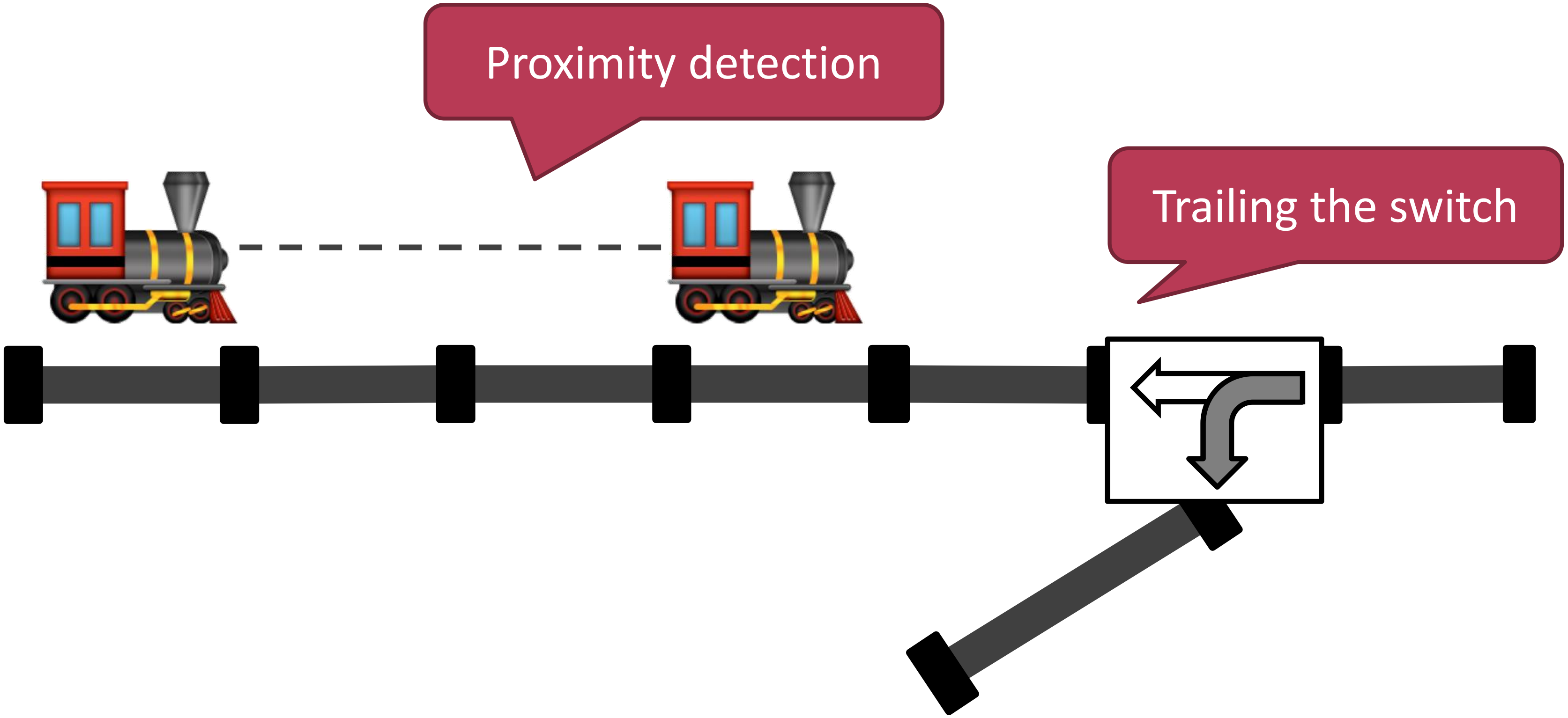


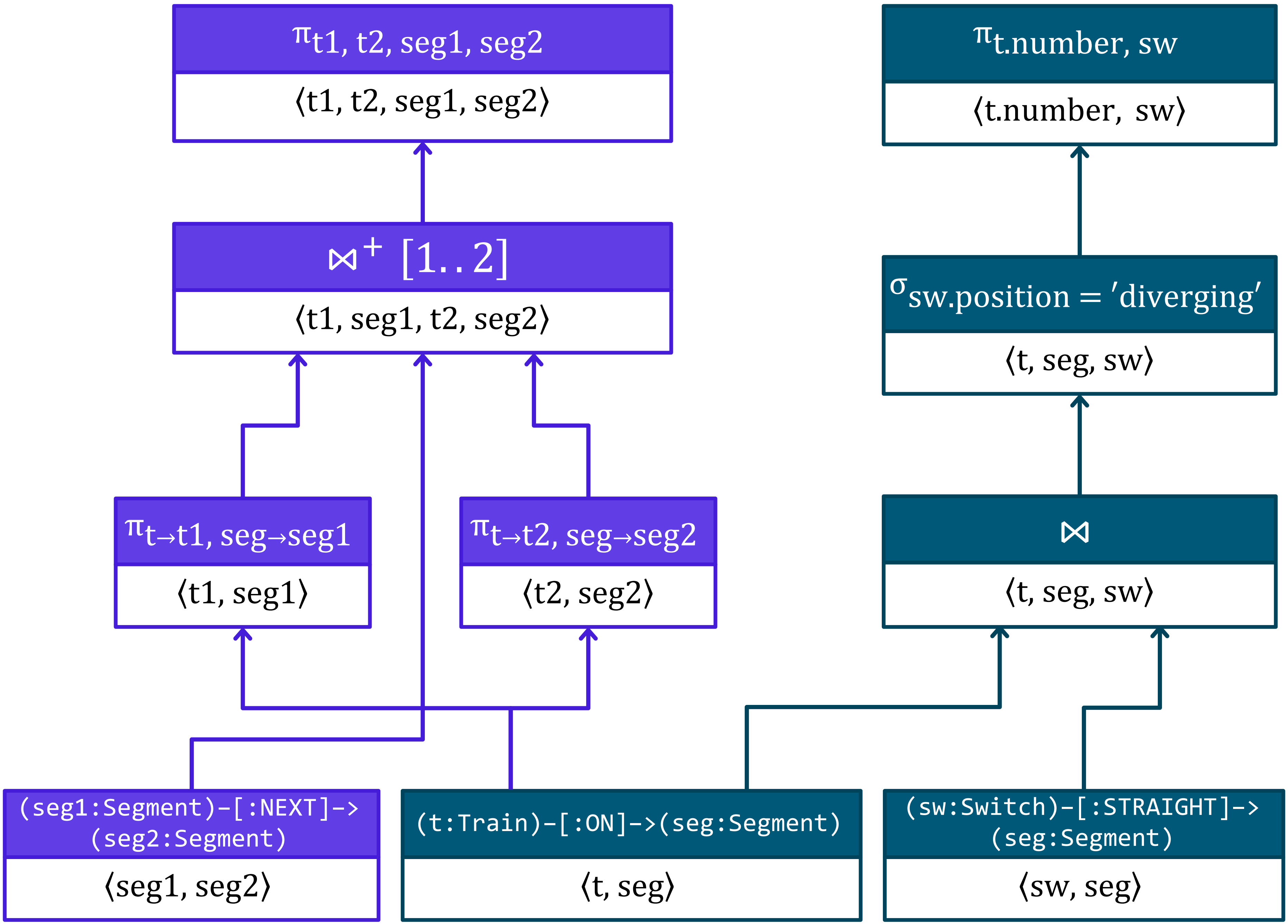
Trailing the switch
$\pi_{t.number,\ sw}$
2
div
$\sigma_{sw.position\ =\ 'diverging'}$
ON
STRAIGHT
e
⋈
ON
1
a
Async messages
Actors
NEXT
b
c
d
TOP
f
DIVERGING
g



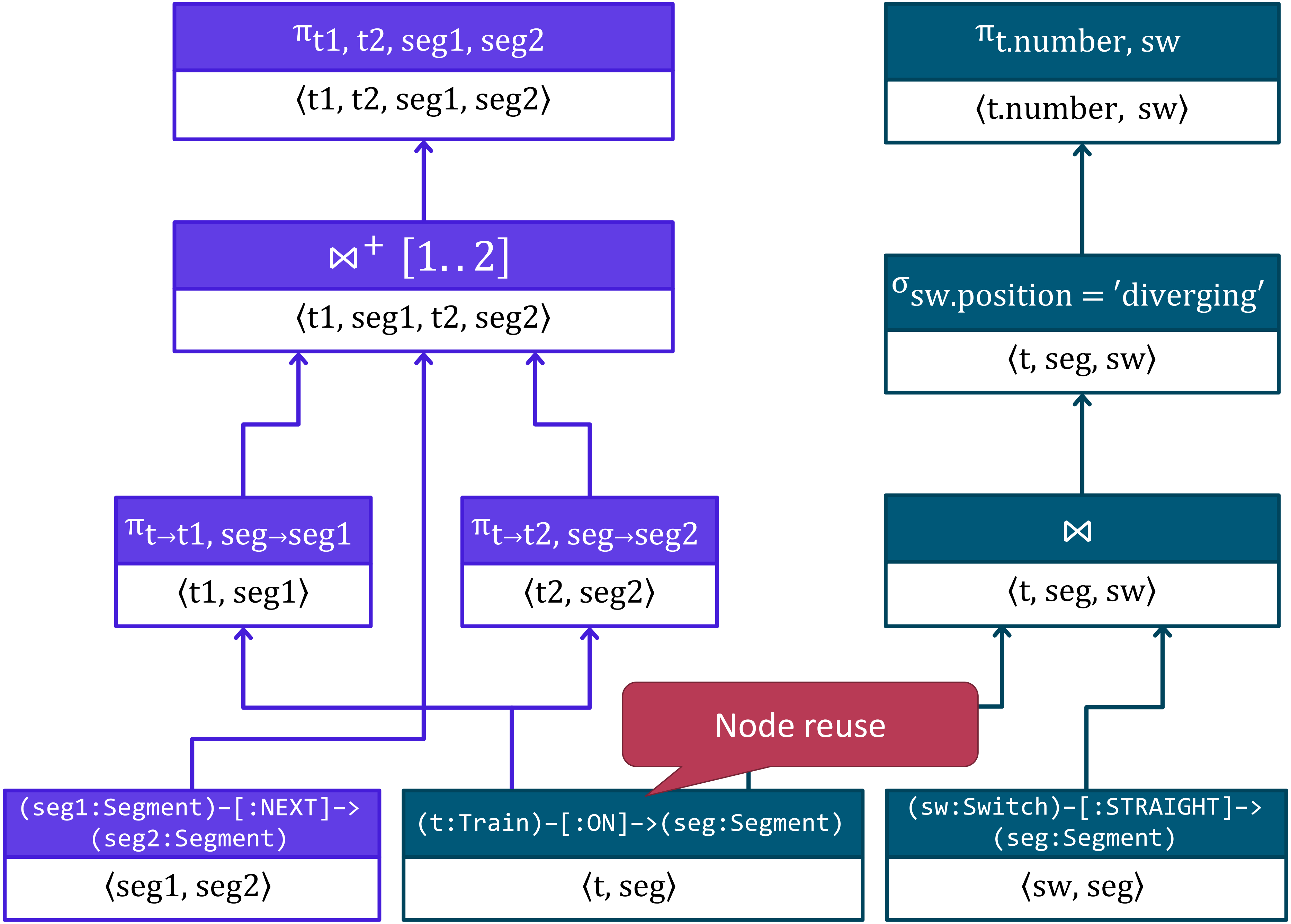
Trailing the switch
$\pi_{t.number,\ sw}$
2
div
$\sigma_{sw.position\ =\ 'diverging'}$
ON
e
STRAIGHT
Challenge: properties
ON
1
a
Async messages
Actors
NEXT
b
c
d
TOP
f
DIVERGING
g

Live railway model (revisited)

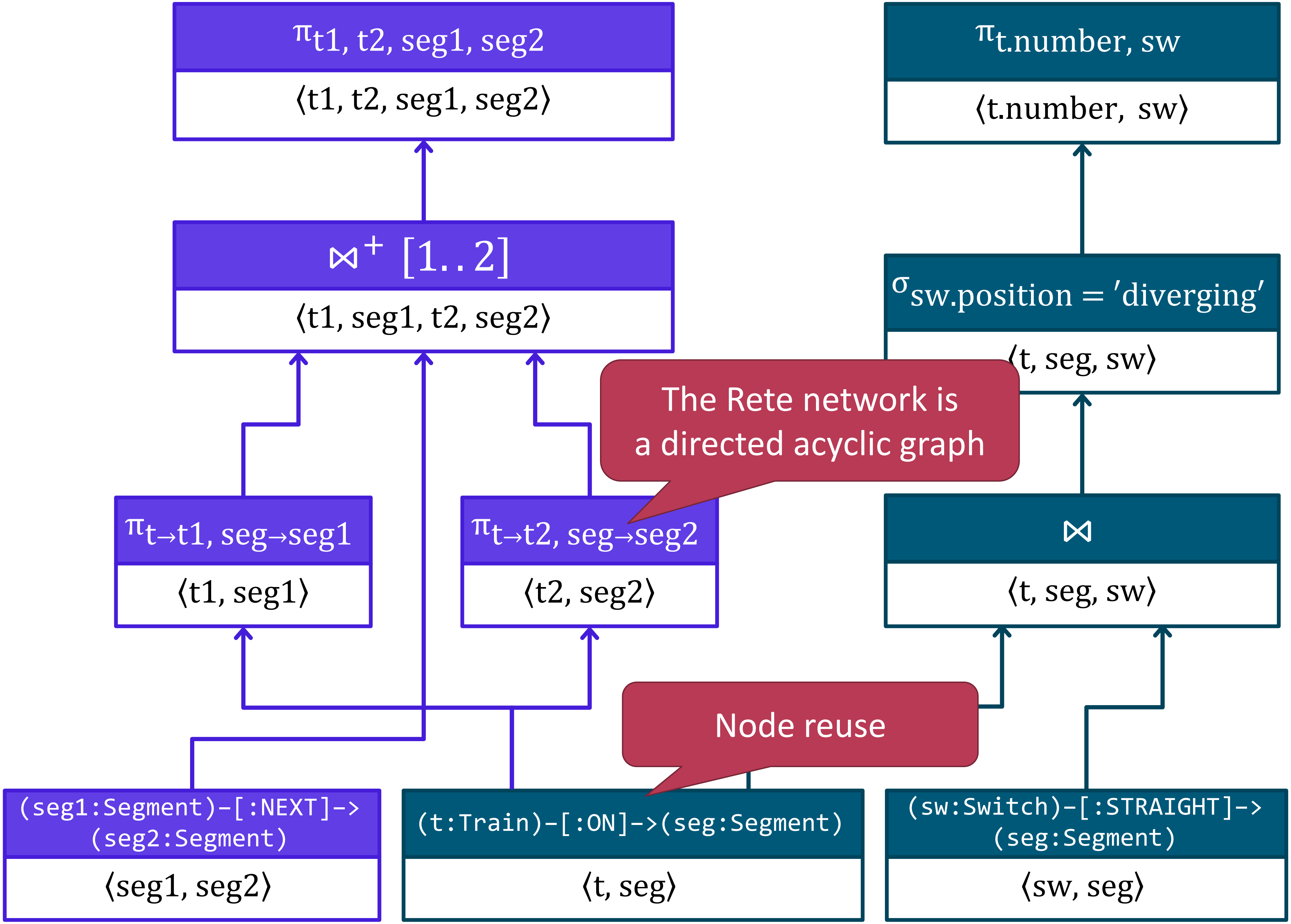




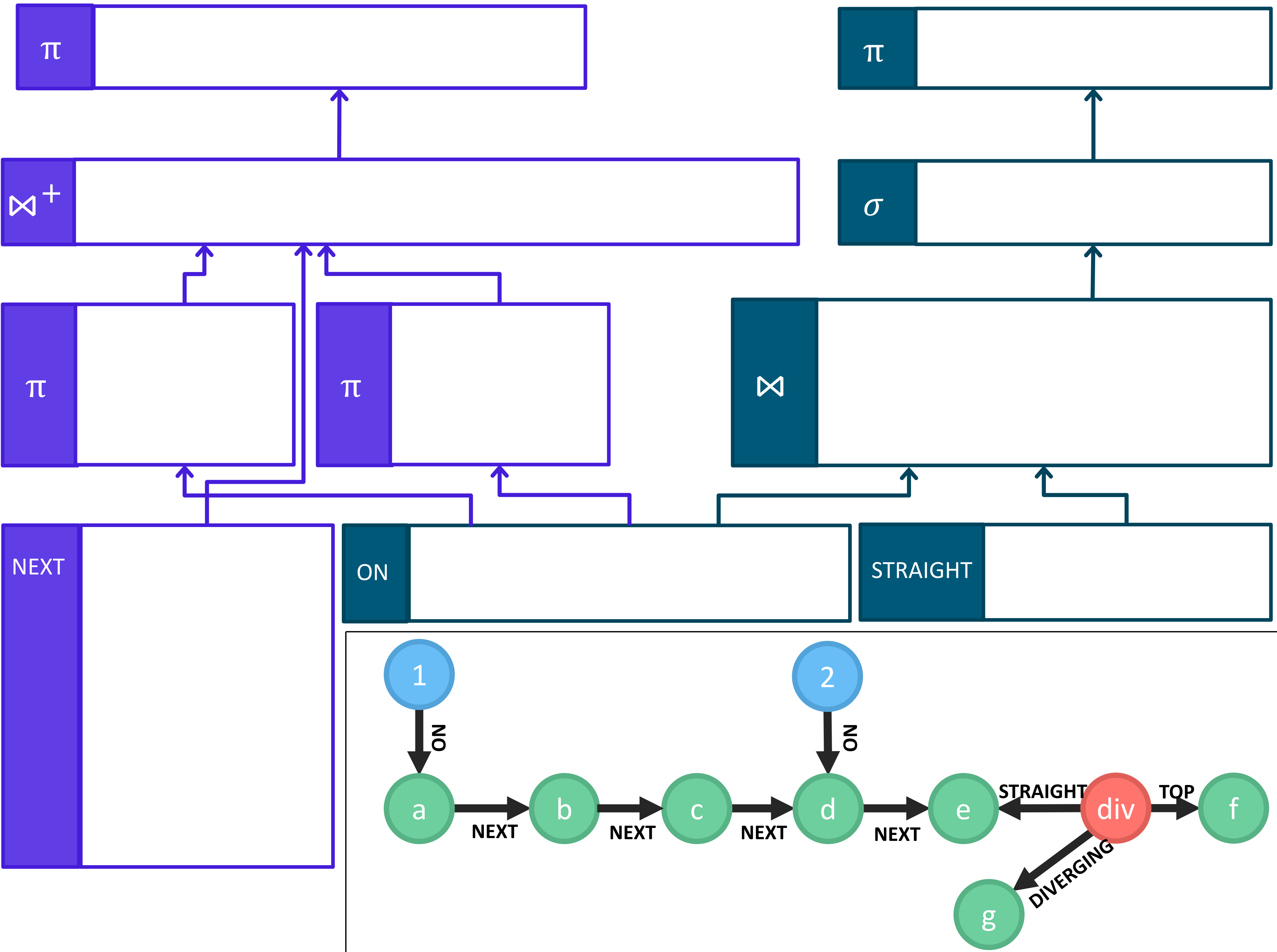
$\pi_{t1,\, t2,\, seg1,\, seg2}$
⟨t1, t2, seg1, seg2⟩
$\bowtie^{+}$ [1..2]
⟨t1, seg1, t2, seg2⟩
$\pi_{t \to t1,\, seg \to seg1}$
⟨t1, seg1⟩
$\pi_{t \to t2,\, seg \to seg2}$
⟨t2, seg2⟩
(seg1:Segment)-[:NEXT]->(seg2:Segment)
⟨seg1, seg2⟩
(t:Train)-[:ON]->(seg:Segment)
⟨t, seg⟩
(sw:Switch)-[:STRAIGHT]->(seg:Segment)
⟨sw, seg⟩
$\bowtie$
⟨t, seg, sw⟩
$\sigma_{sw.position\, =\, 'diverging'}$
⟨t, seg, sw⟩
$\pi_{t.number,\, sw}$
⟨t.number, sw⟩



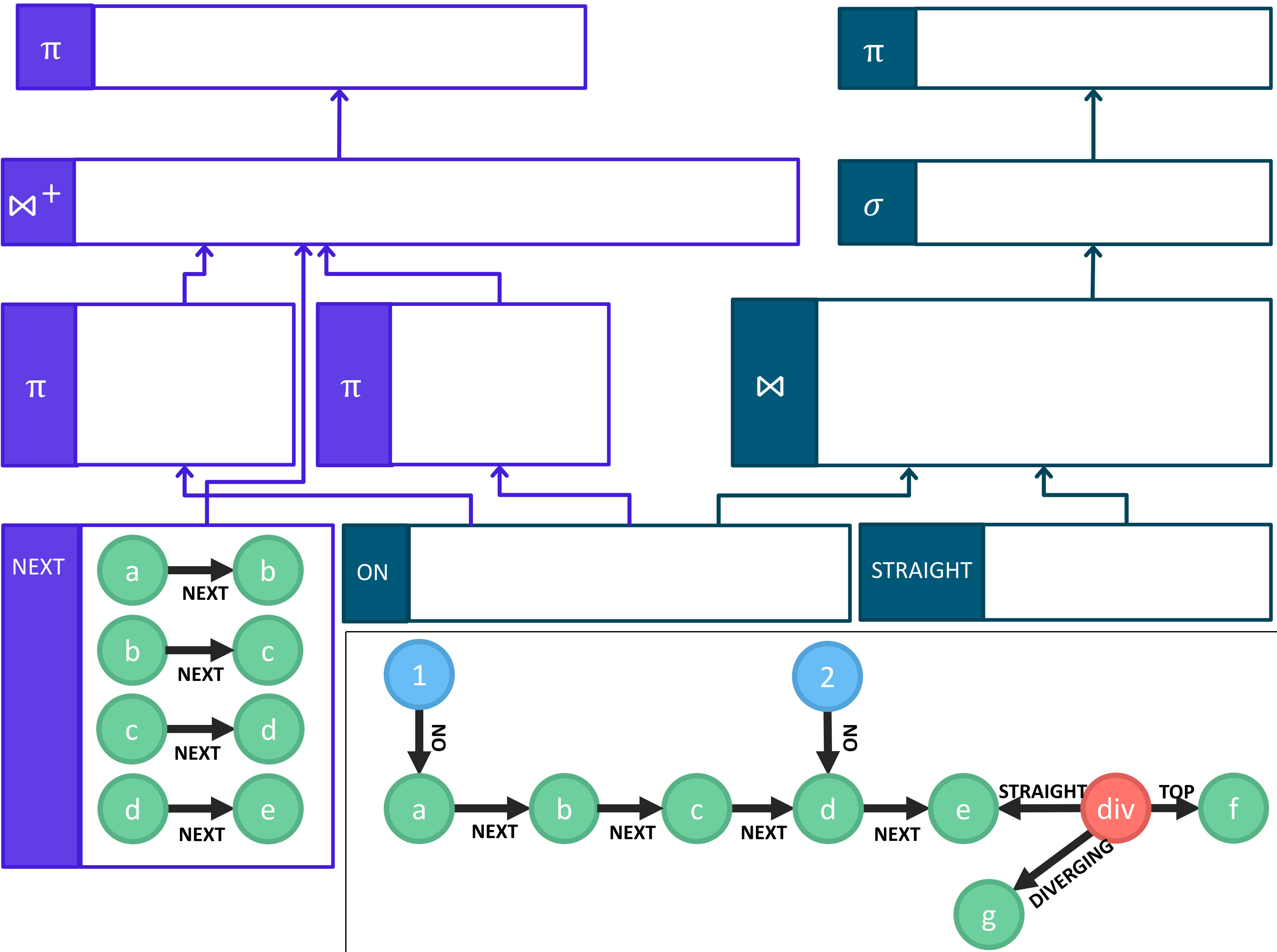
$\pi_{t1, t2, seg1, seg2}$
⟨t1, t2, seg1, seg2⟩
$\bowtie^{+}$ [1..2]
⟨t1, seg1, t2, seg2⟩
$\pi_{t \to t1, seg \to seg1}$
⟨t1, seg1⟩
$\pi_{t \to t2, seg \to seg2}$
⟨t2, seg2⟩
(seg1:Segment)-[:NEXT]-> (seg2:Segment)
⟨seg1, seg2⟩
(t:Train)-[:ON]->(seg:Segment)
⟨t, seg⟩
Node reuse
$\pi_{t.number, sw}$
⟨t.number, sw⟩
$\sigma_{sw.position = 'diverging'}$
⟨t, seg, sw⟩
$\bowtie$
⟨t, seg, sw⟩
(sw:Switch)-[:STRAIGHT]-> (seg:Segment)
⟨sw, seg⟩



$\pi_{t1,\ t2,\ seg1,\ seg2}$
⟨t1, t2, seg1, seg2⟩
$\bowtie^{+}\ [1..2]$
⟨t1, seg1, t2, seg2⟩
$\pi_{t \to t1,\ seg \to seg1}$
⟨t1, seg1⟩
$\pi_{t \to t2,\ seg \to seg2}$
⟨t2, seg2⟩
(seg1:Segment)-[:NEXT]-> (seg2:Segment)
⟨seg1, seg2⟩
(t:Train)-[:ON]->(seg:Segment)
⟨t, seg⟩
(sw:Switch)-[:STRAIGHT]-> (seg:Segment)
⟨sw, seg⟩
$\bowtie$
⟨t, seg, sw⟩
$\sigma_{sw.position\ =\ 'diverging'}$
⟨t, seg, sw⟩
$\pi_{t.number,\ sw}$
⟨t.number, sw⟩
The Rete network is a directed acyclic graph
Node reuse



π
⋈+
π
π
NEXT
ON
π
σ
⋈
STRAIGHT
1
2
ON
ON
a
b
c
d
e
div
f
g
NEXT
NEXT
NEXT
NEXT
STRAIGHT
TOP
DIVERGING



π
⋈+
π
π
NEXT
a NEXT b
b NEXT c
c NEXT d
d NEXT e
π
σ
⋈
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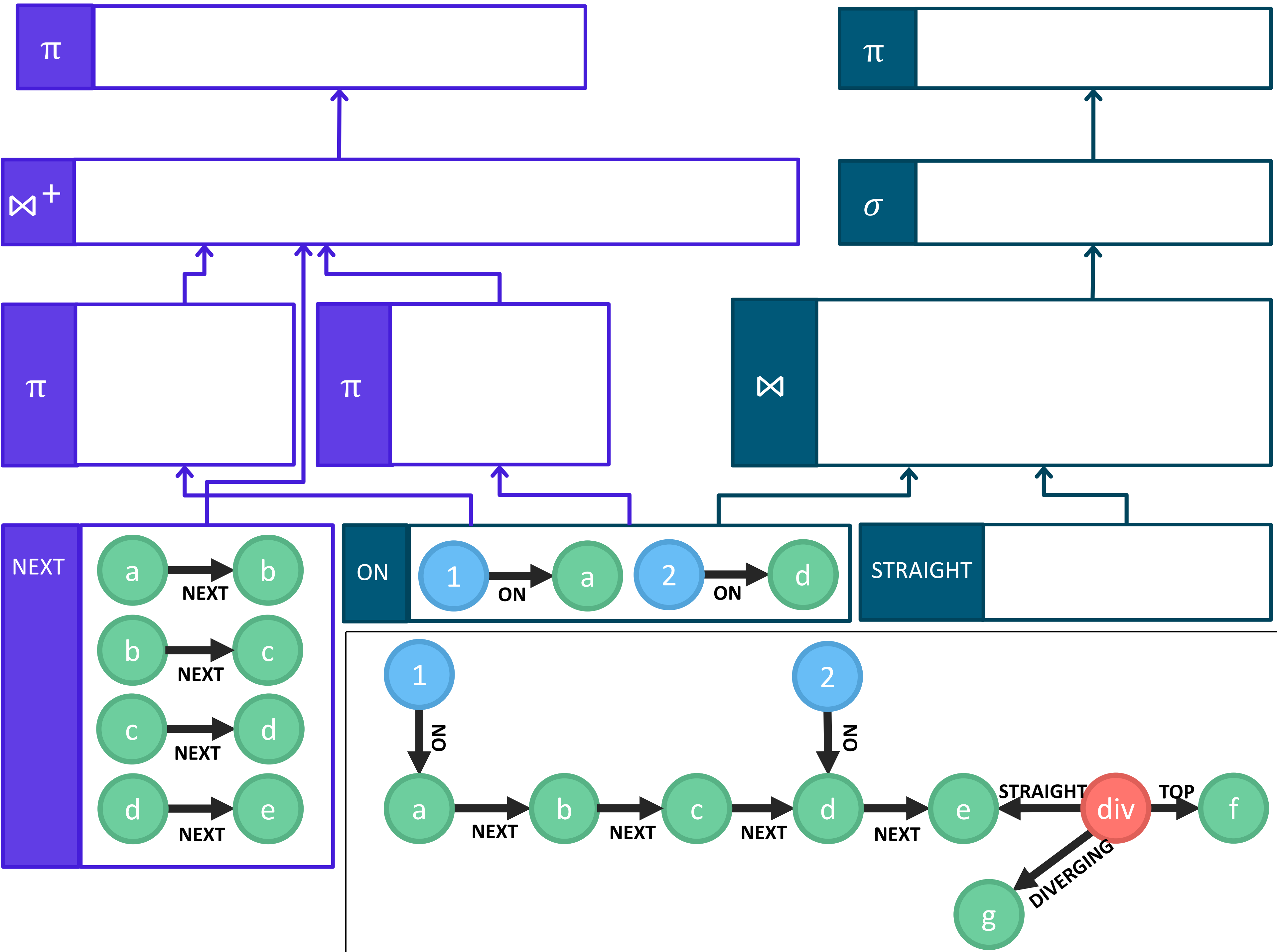

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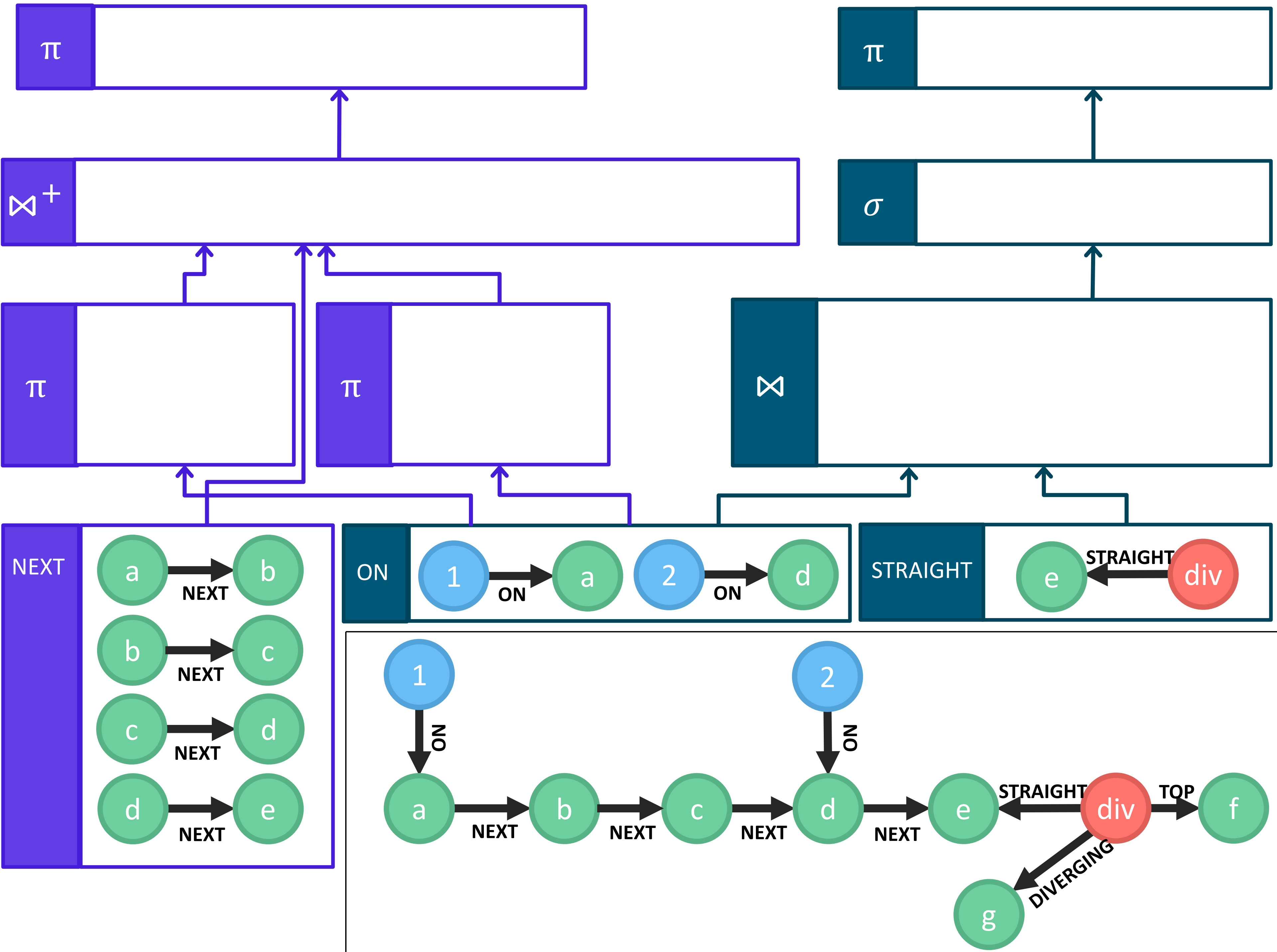

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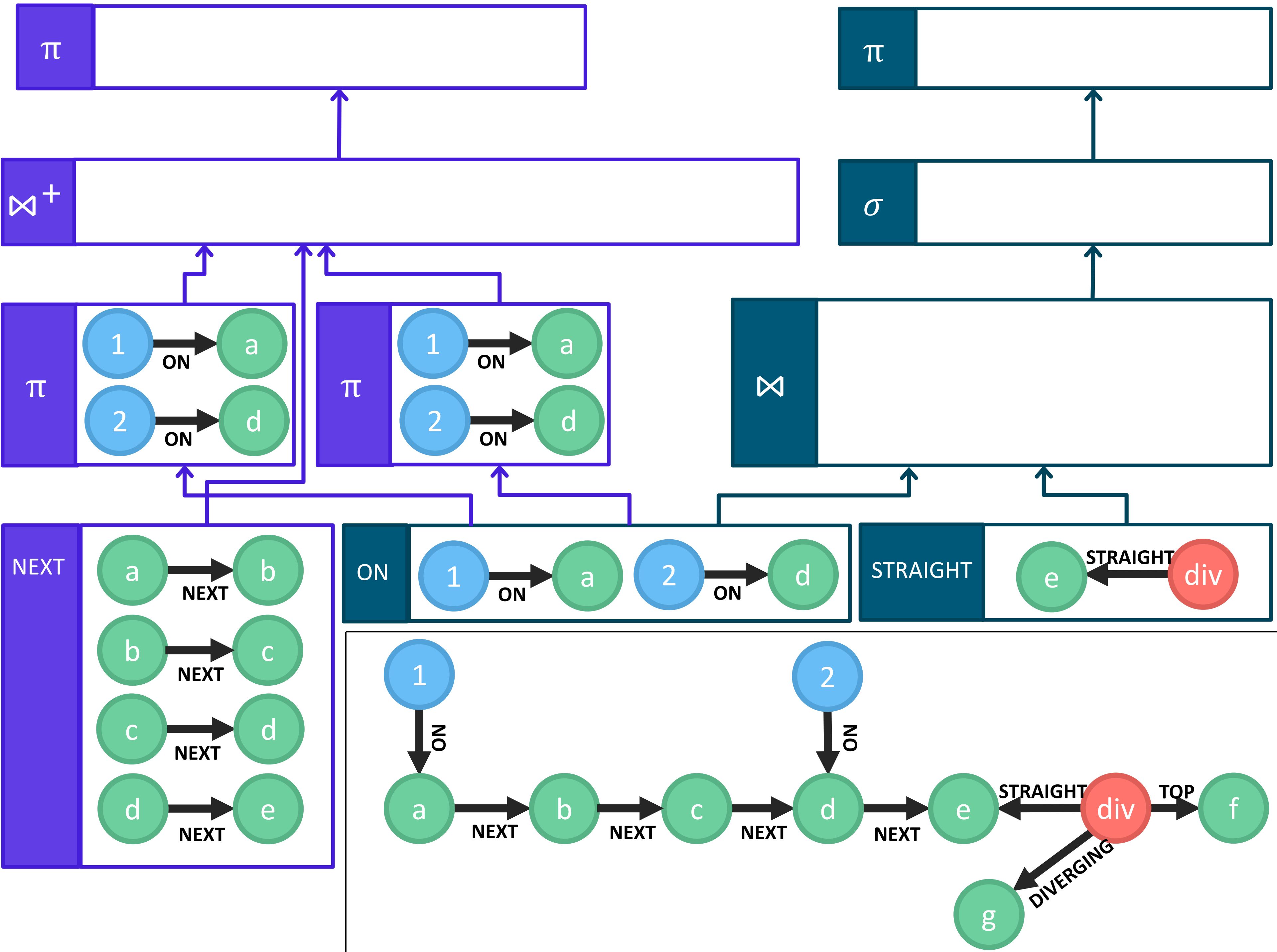
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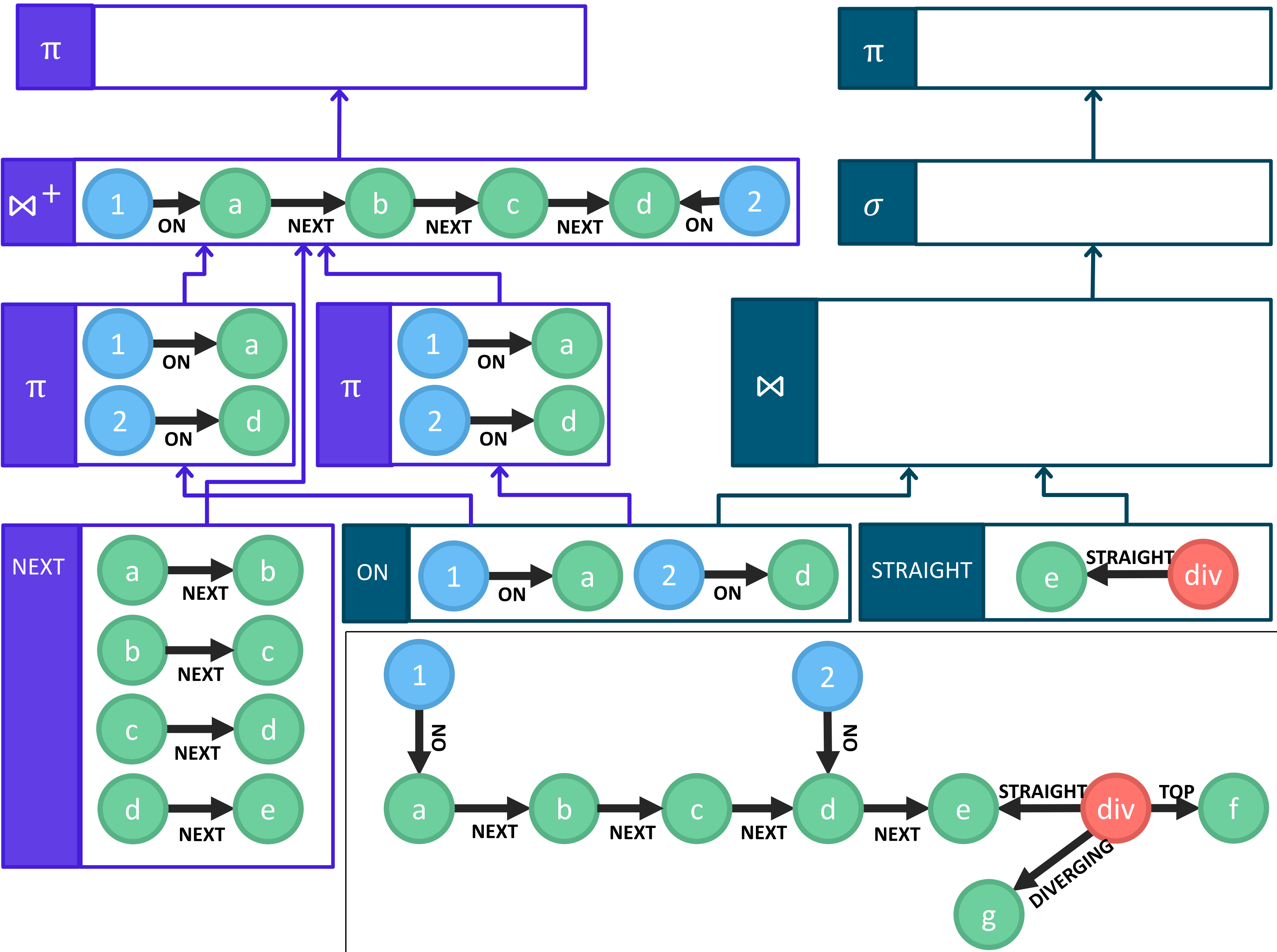
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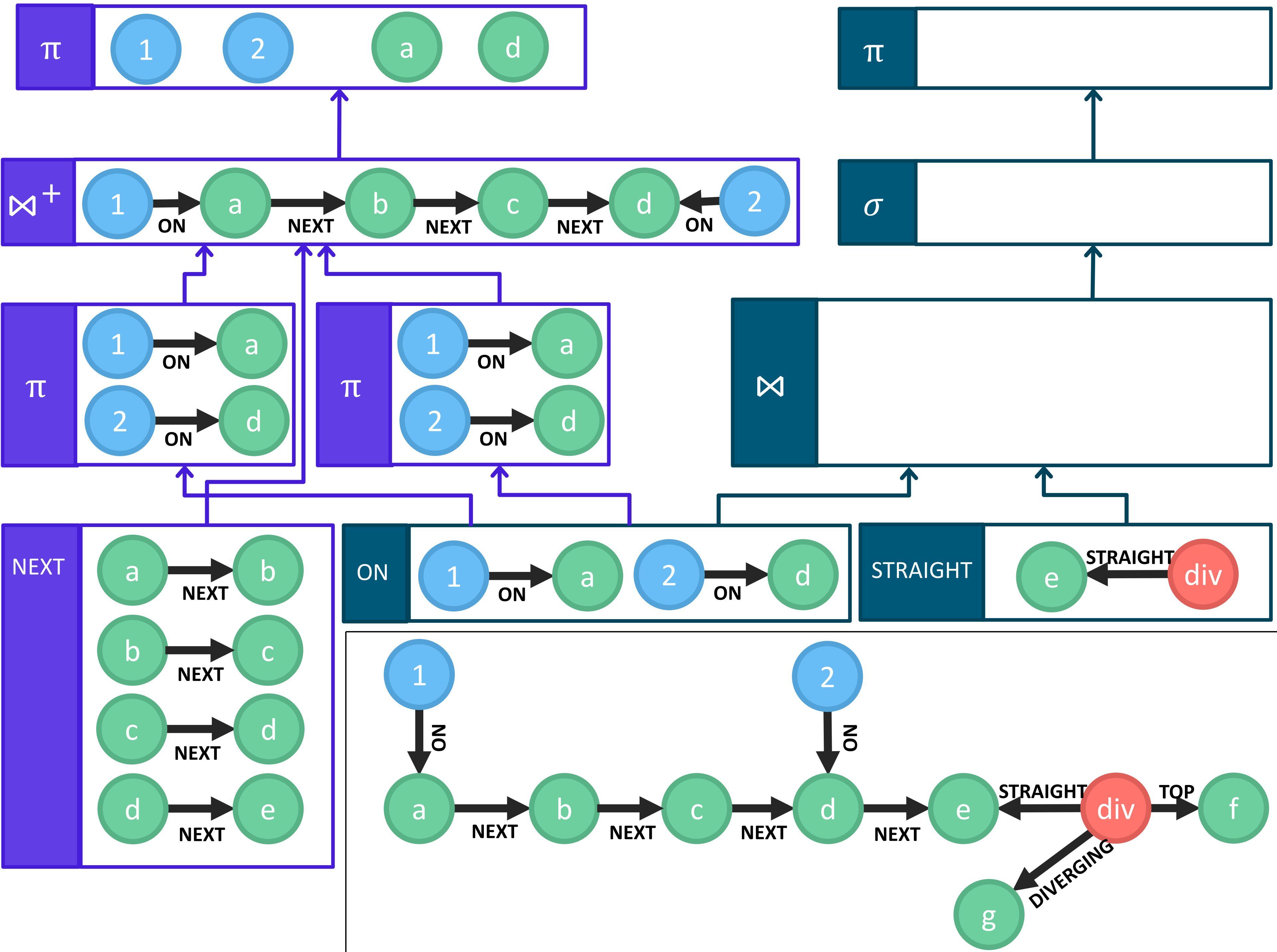

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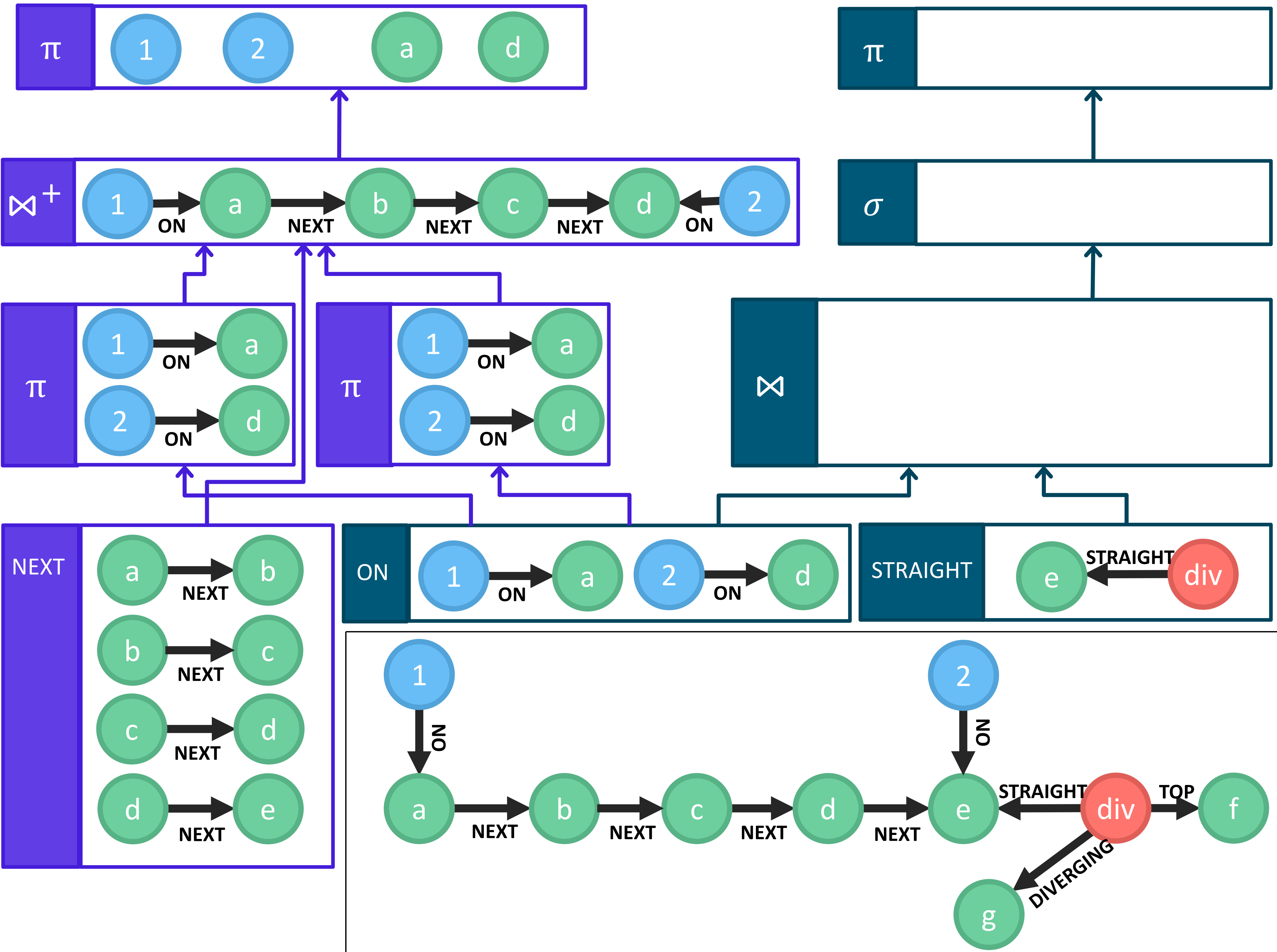

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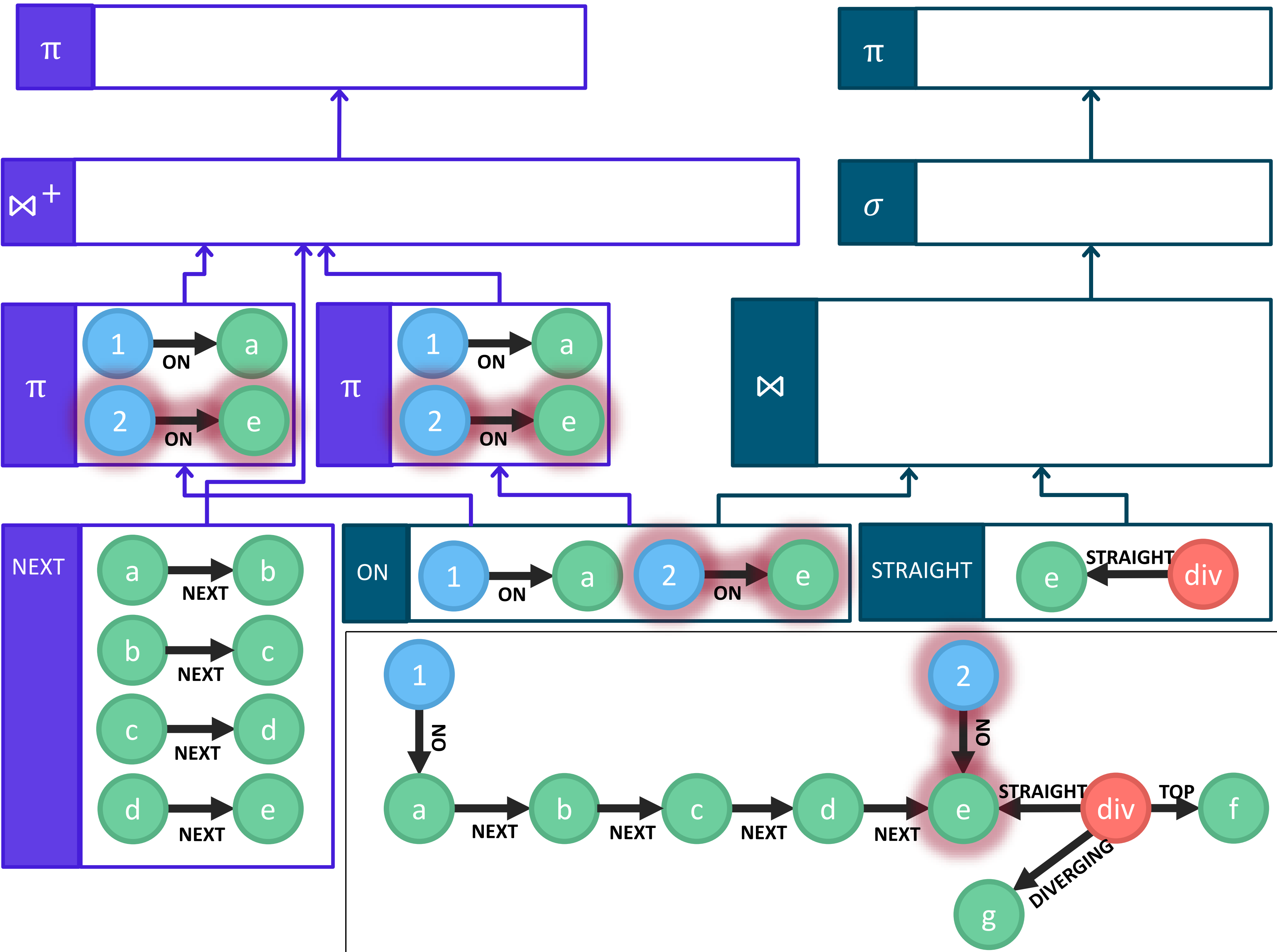

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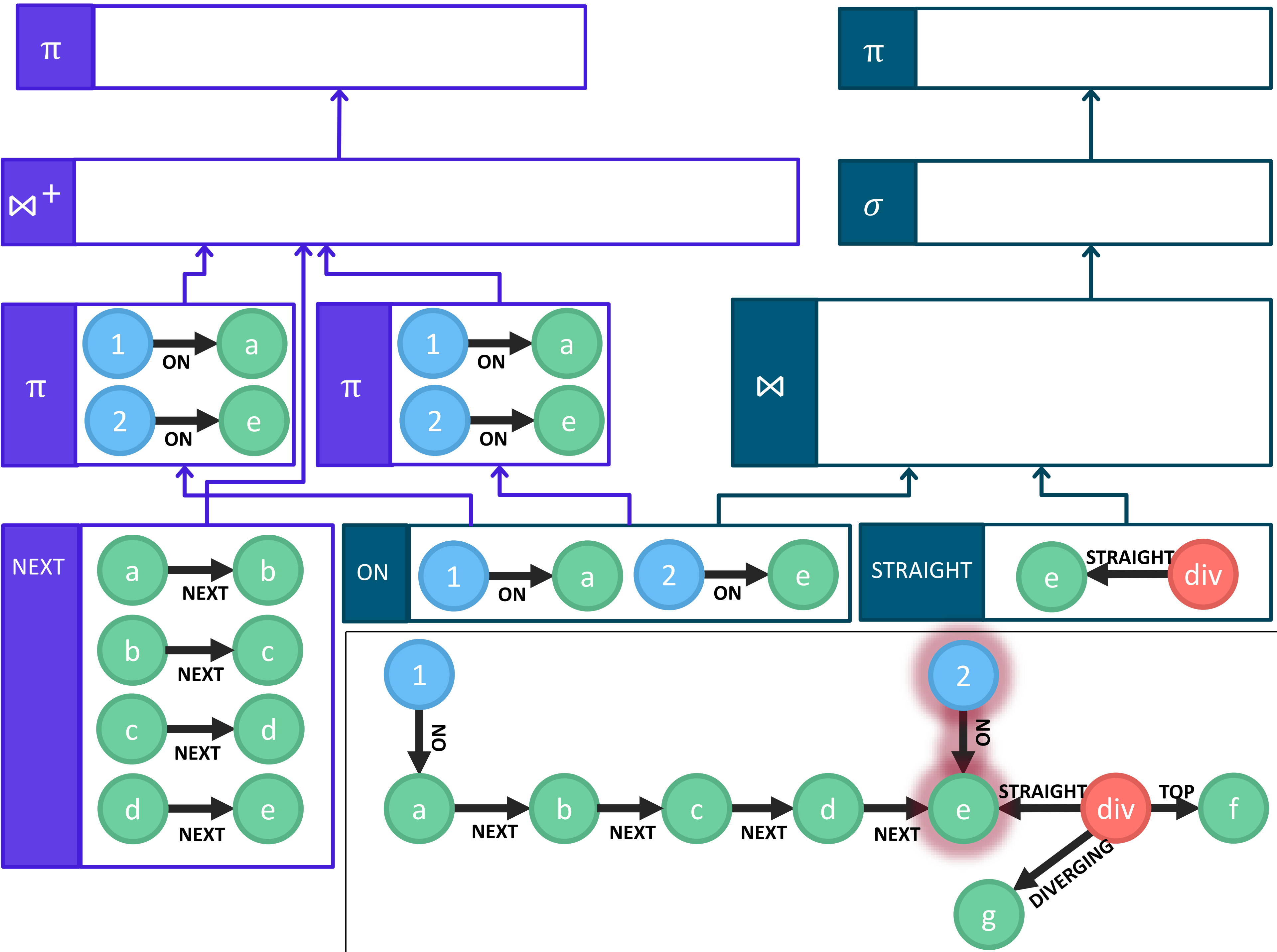
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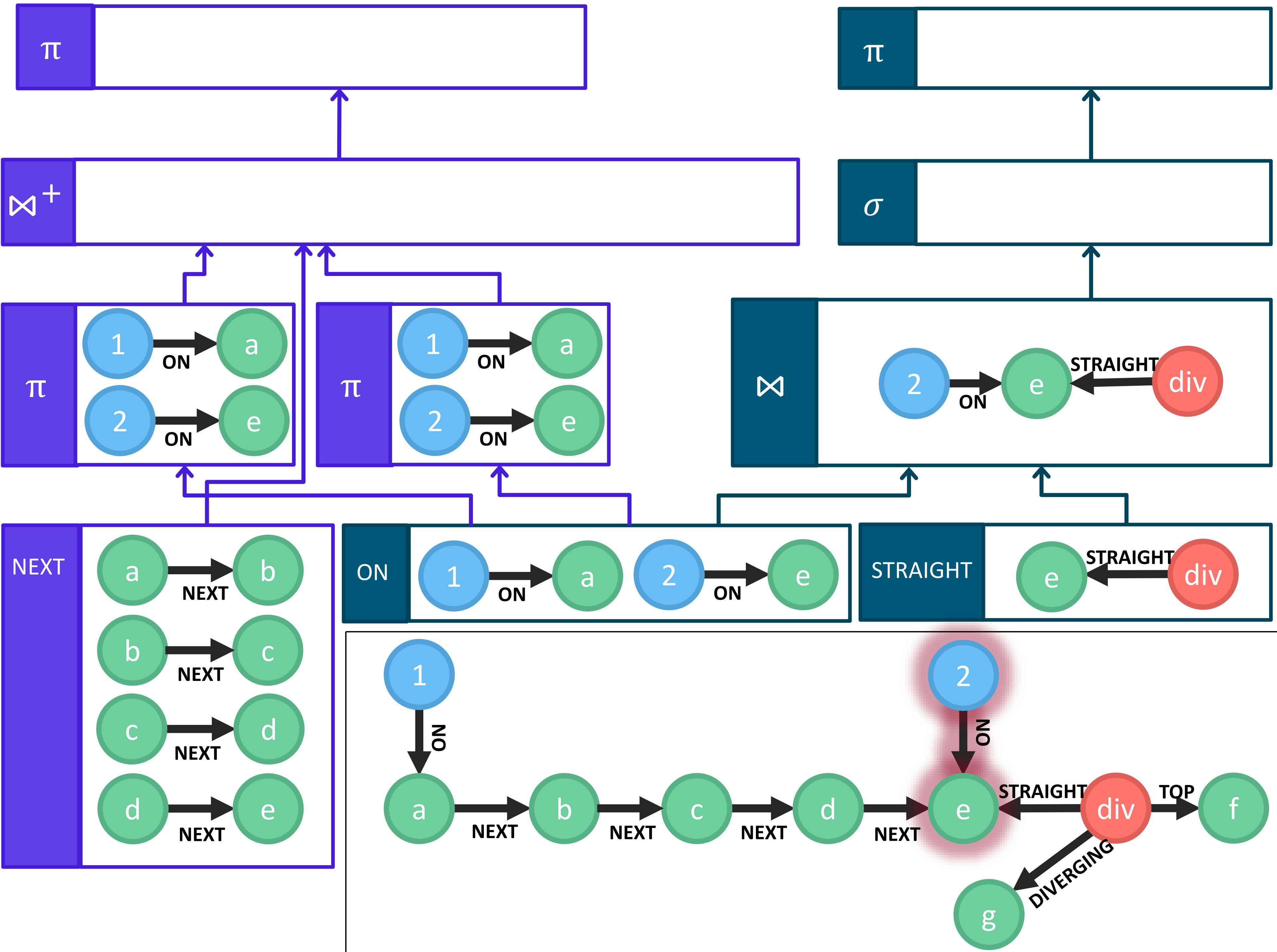

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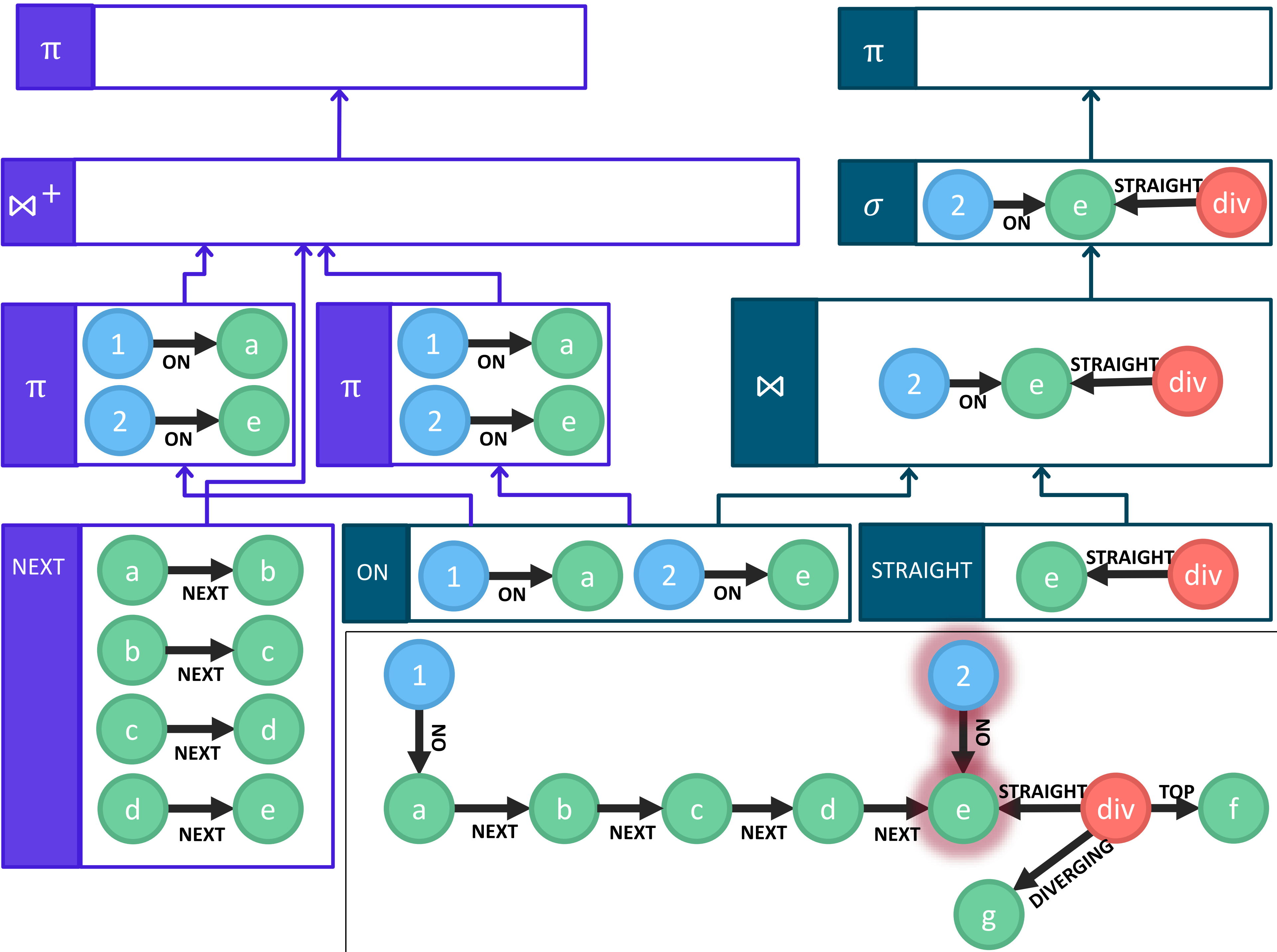

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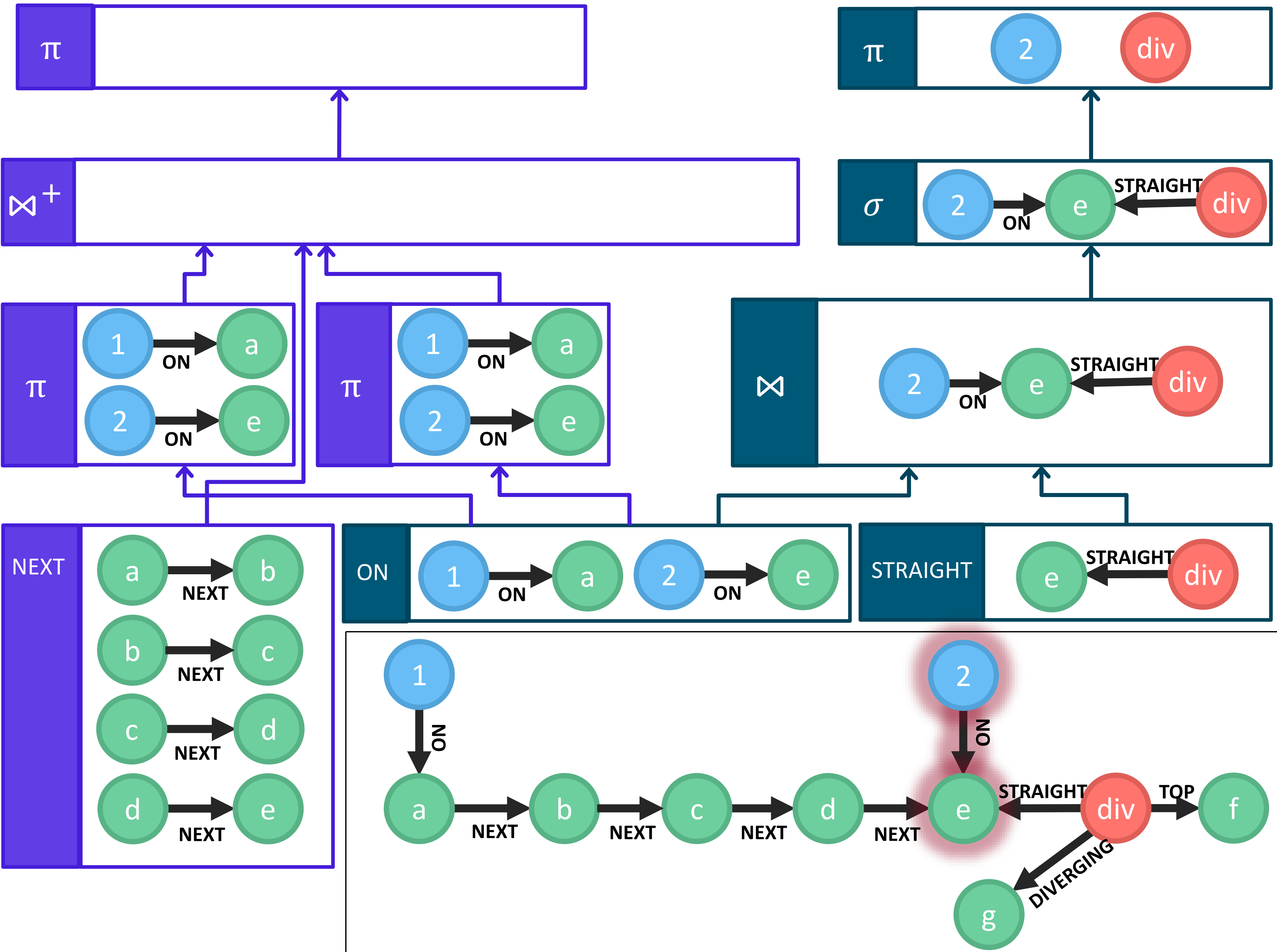

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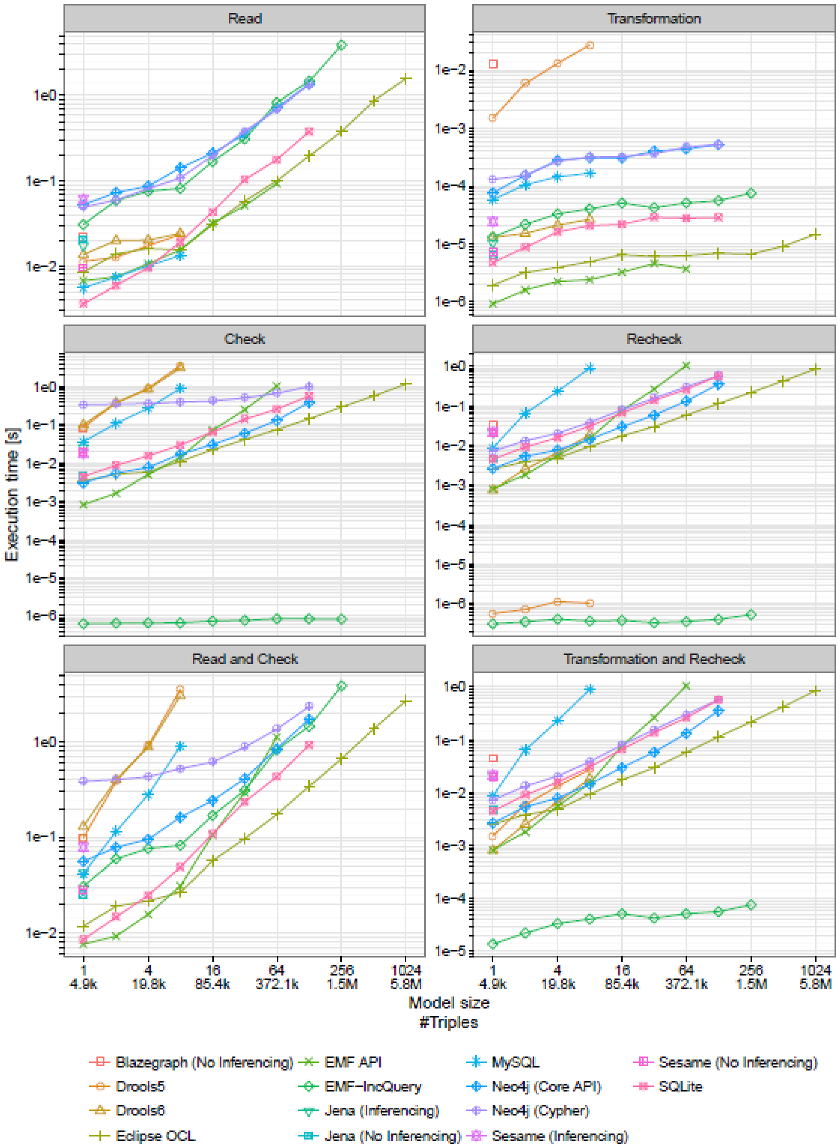
ingraph use cases

Standing queries on large & quickly changing graphs

- Model validation: The Train Benchmark
- Static analysis of JavaScript source code
- Fraud detection
- IT infrastructure monitoring

Model validation: the Train Benchmark

- Scalable graph generator
  - EMF
  - Property graph
  - RDF
  - SQL
- Realistic workload
  - 6 validation queries
  - 12 transformations
  - Implemented for 12+ tools
- Visualization and reporting



Static analysis of JavaScript

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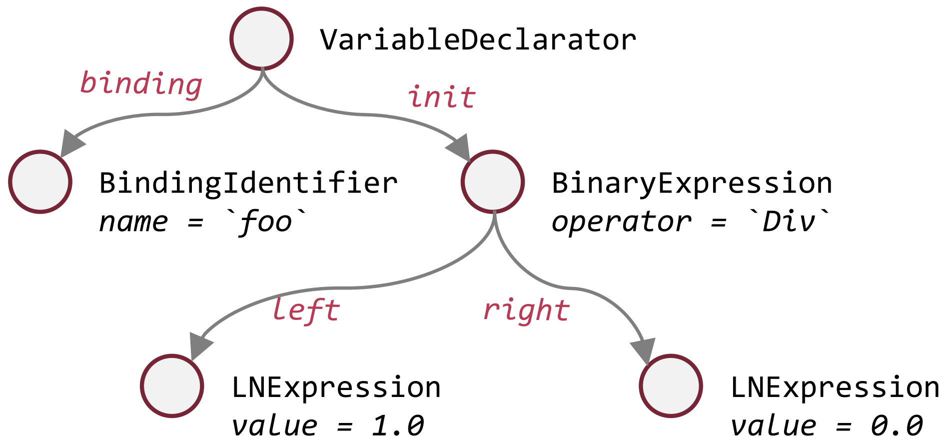

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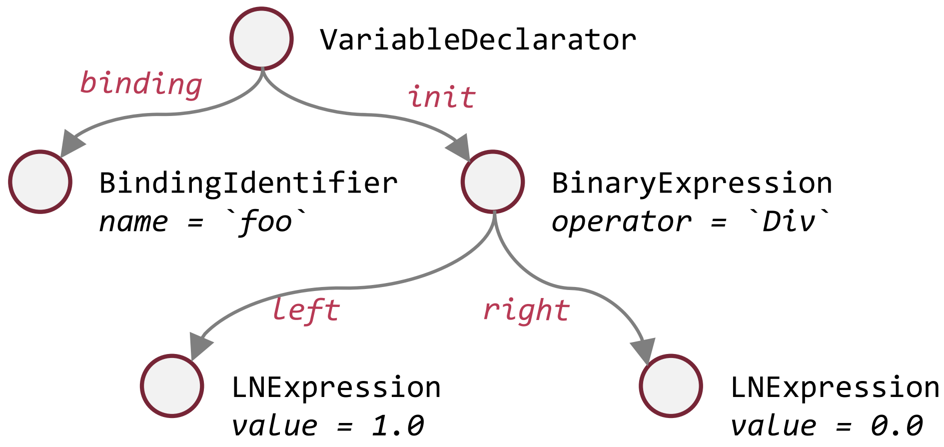


```
MATCH
  (binding:BindingIdentifier)<-[:binding]-()-->
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  (right:LNExpression)
WHERE be.operator = 'Div'
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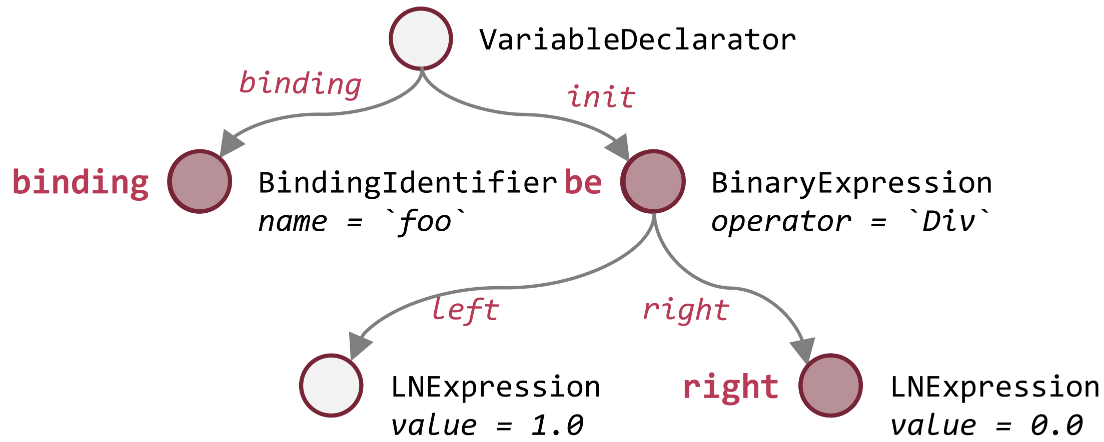


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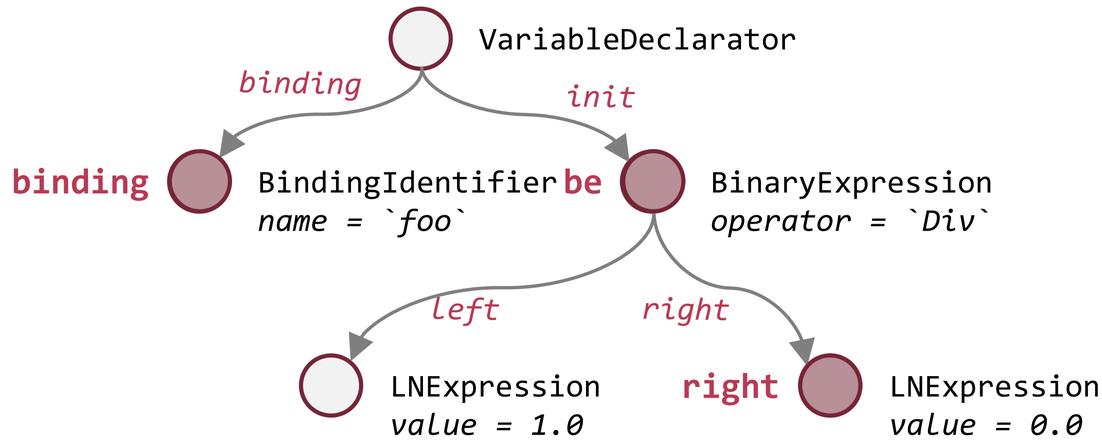


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- Dead code detection
- Type inferencing
- Test generation

Project roadmap

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- Until now
  - formalization for most standard openCypher constructs [technical report]
  - research prototype for model validation queries

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Spark Catalyst or Apache Calcite

Open-Source Projects

Incremental Graph Engine:

https://github.com/ftsrg/ingraph

Train Benchmark:

https://github.com/ftsrg/trainbenchmark

BME-MODES3:

https://github.com/ftsrg/bme-modes3

Available under EPL v1.0.

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