



Timed Petri Nets

Timed Petri Nets

Model

Configurations

Transitions

Ordering

Monotonicity

Upward Closed Sets

Computing Predecessors

Backward Reachability

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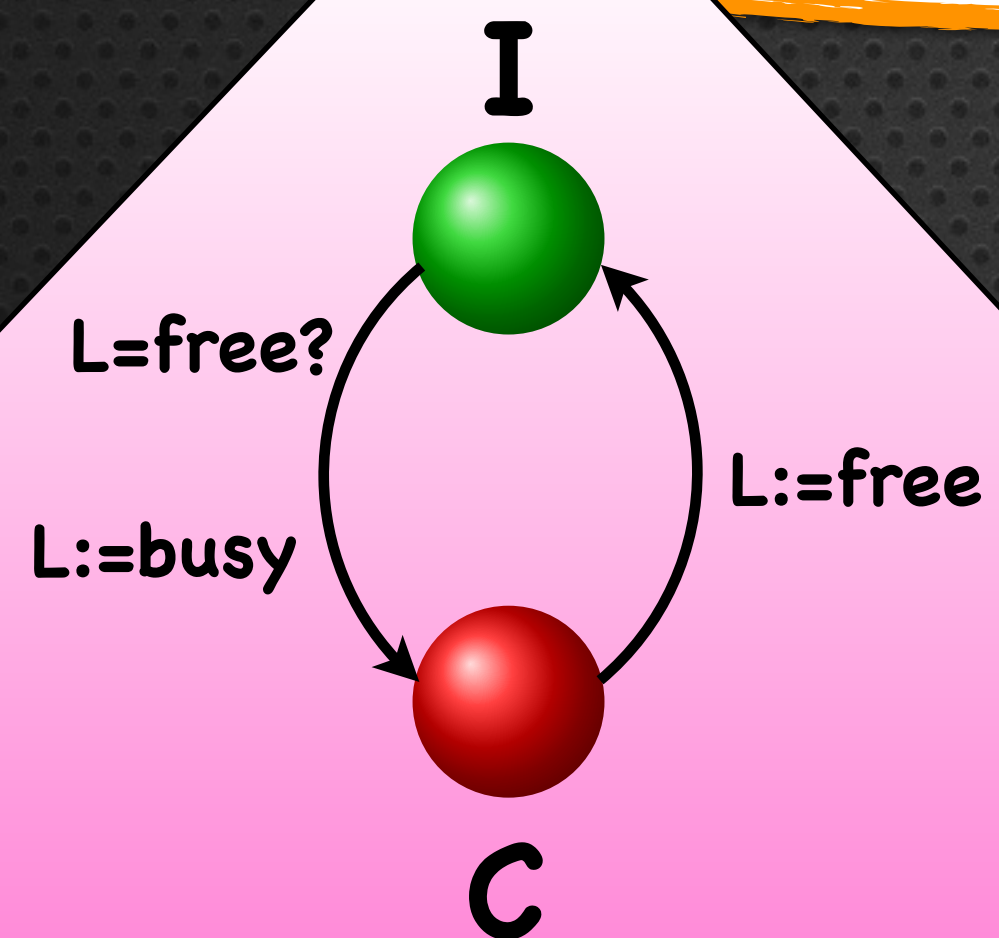
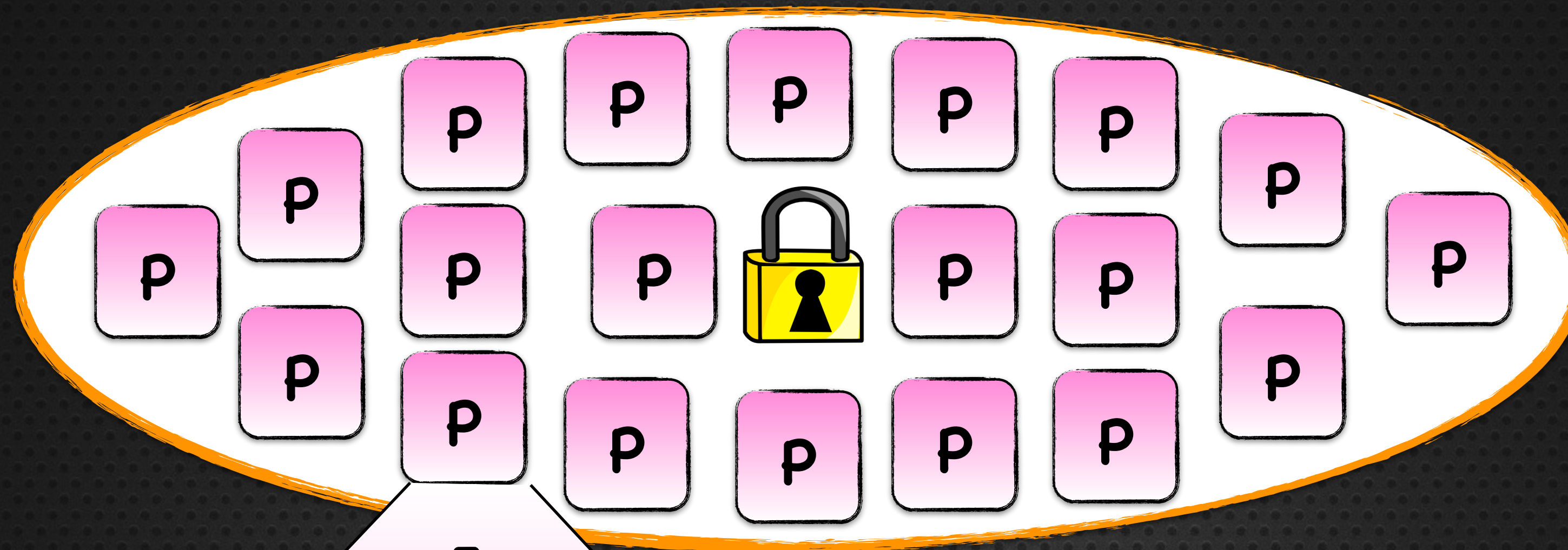
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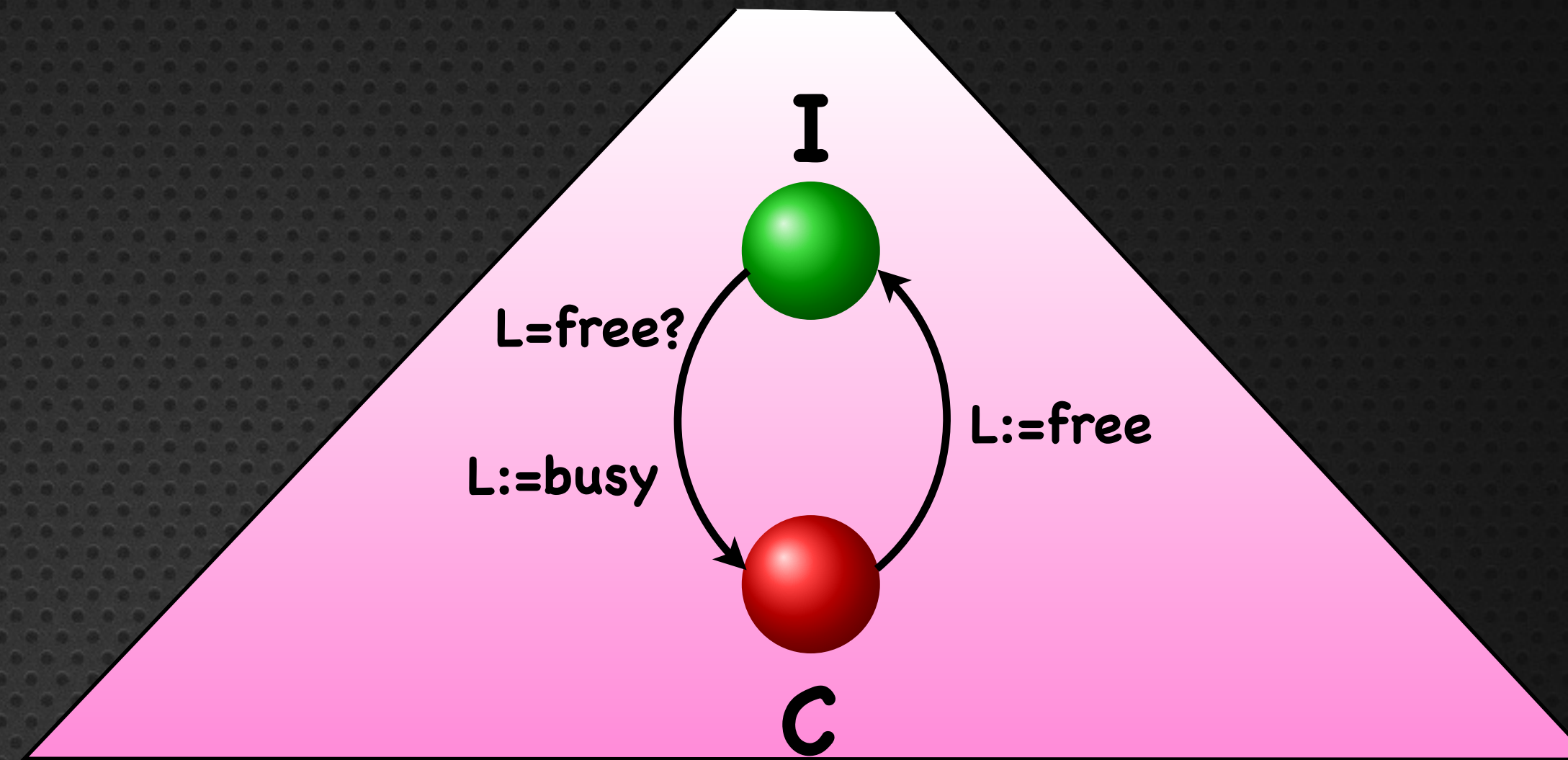
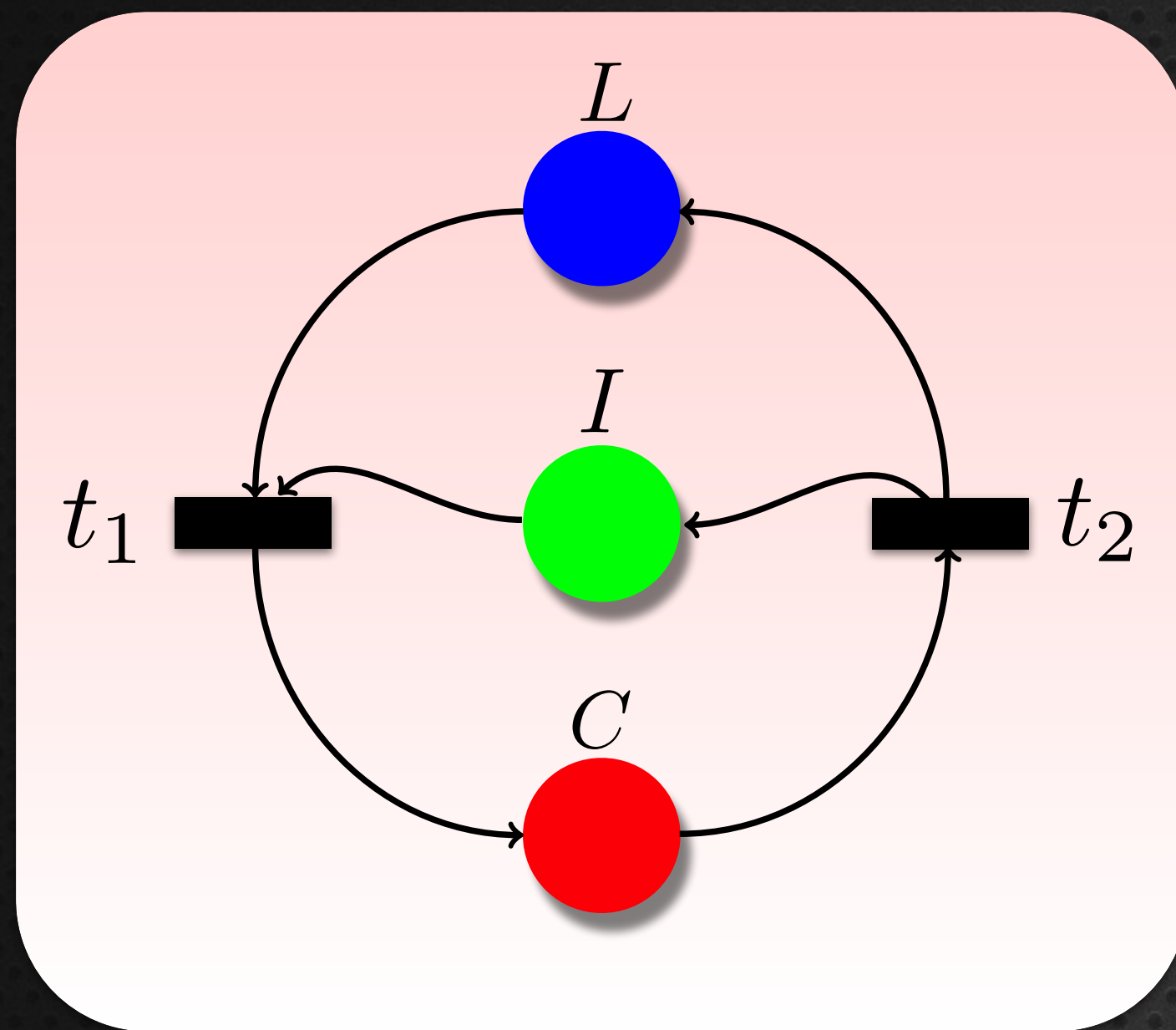
Parameterized Systems



- Specification

- Mutual Exclusion (MutEx):
- At most one process in C

Modeling

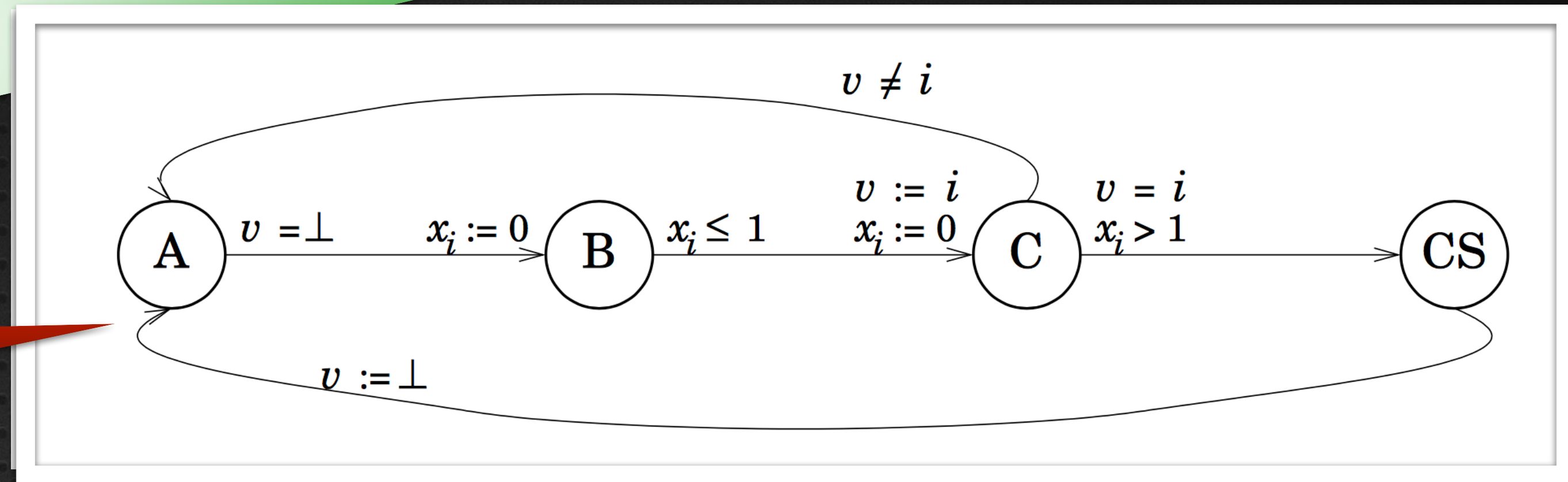


- Encoding (counter abstraction)
 - # tokens in = # processes in
 - # tokens in = # processes in
 - one/no token in = lock free/busy

Parameterized Timed Systems

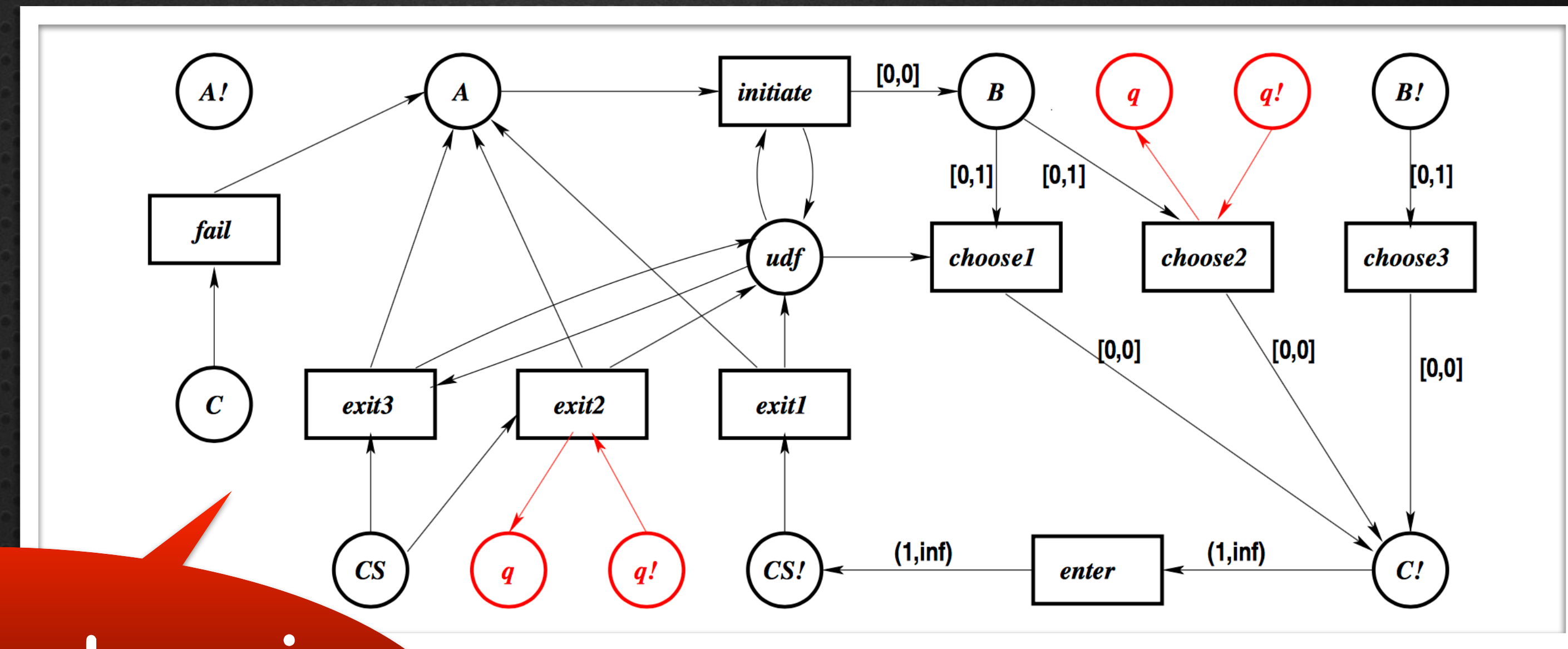
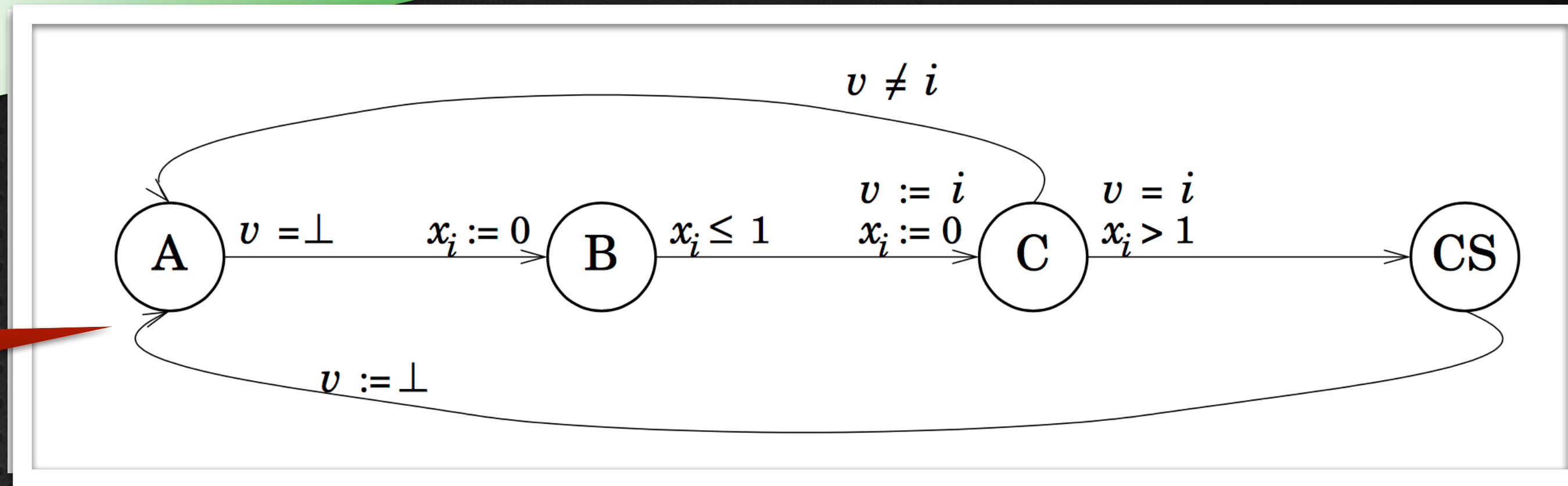
Parameterized Timed Systems

Fischer's
protocol



Parameterized Timed Systems

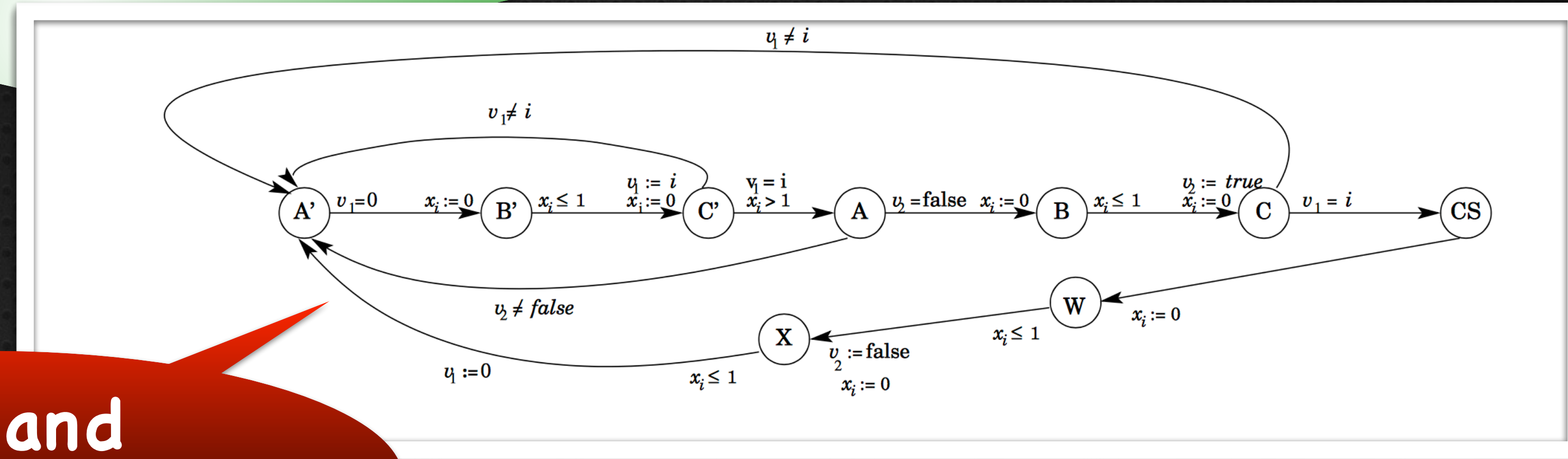
Fischer's protocol



Parameterized version
=
Timed Petri Net

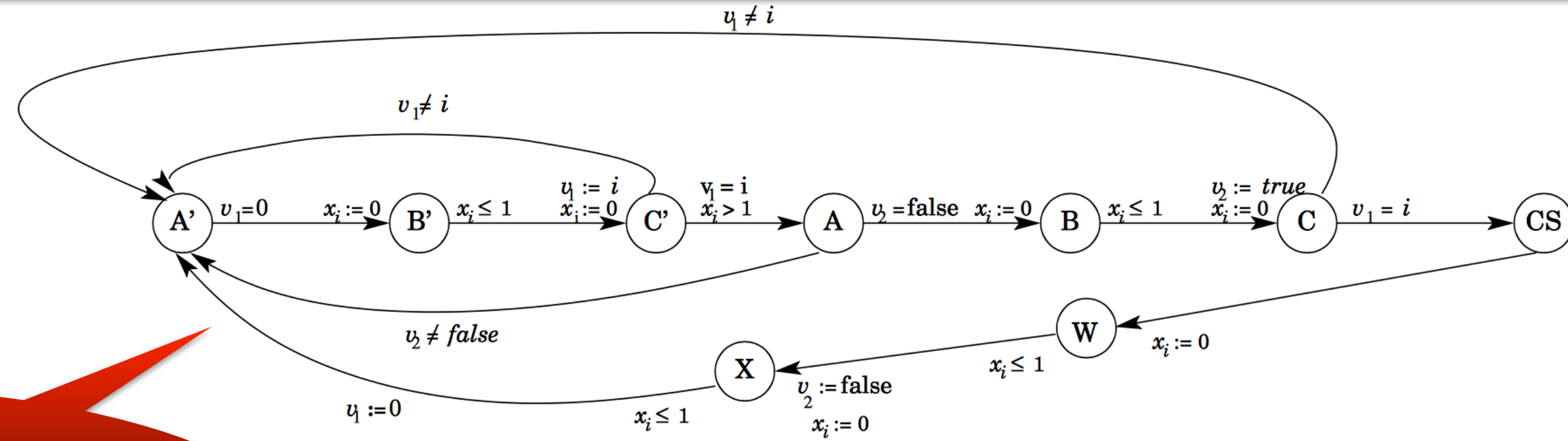
Parameterized Timed Systems

Parameterized Timed Systems



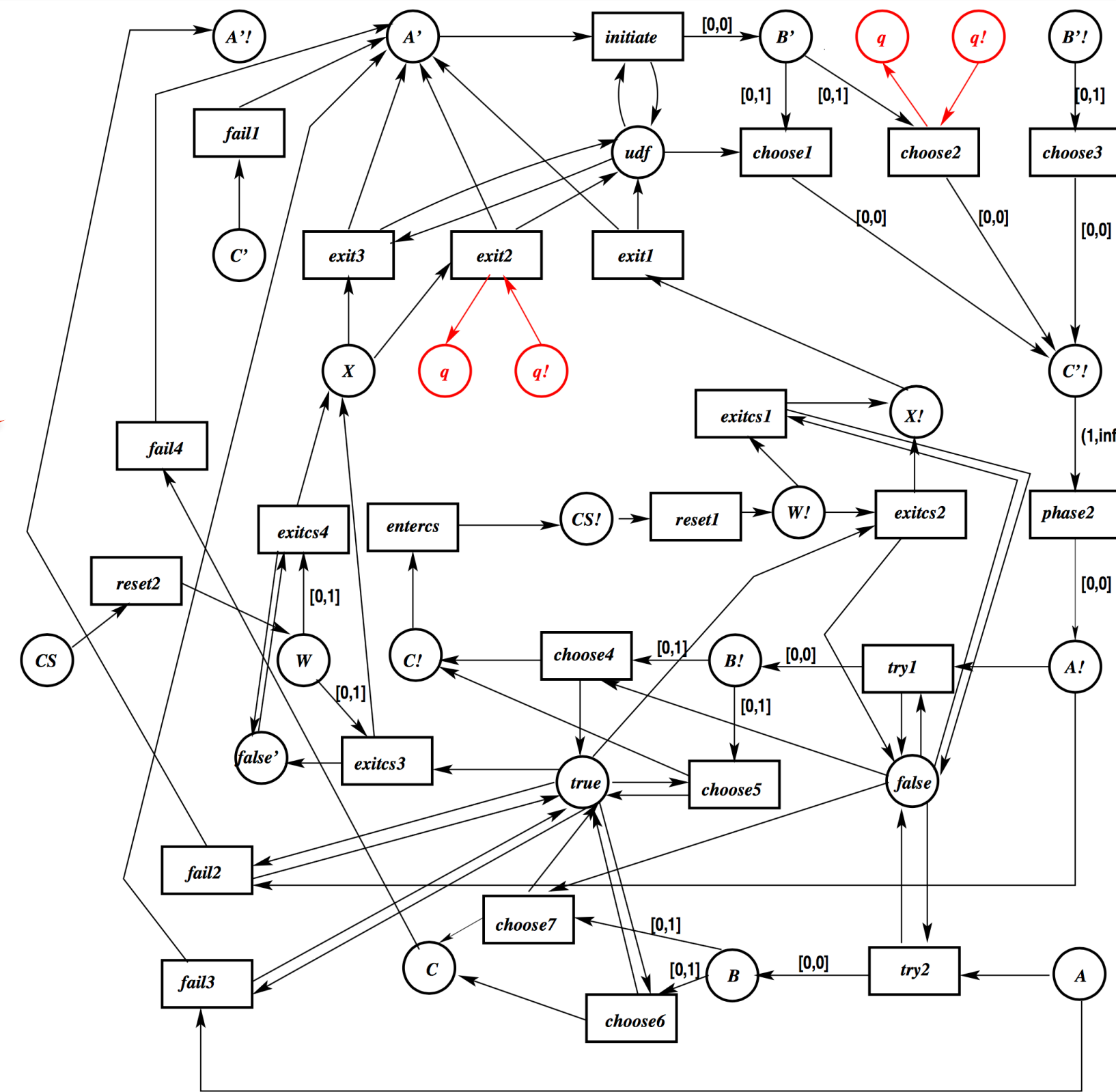
Lynch and Shavit's protocol

Parameterized Timed Systems

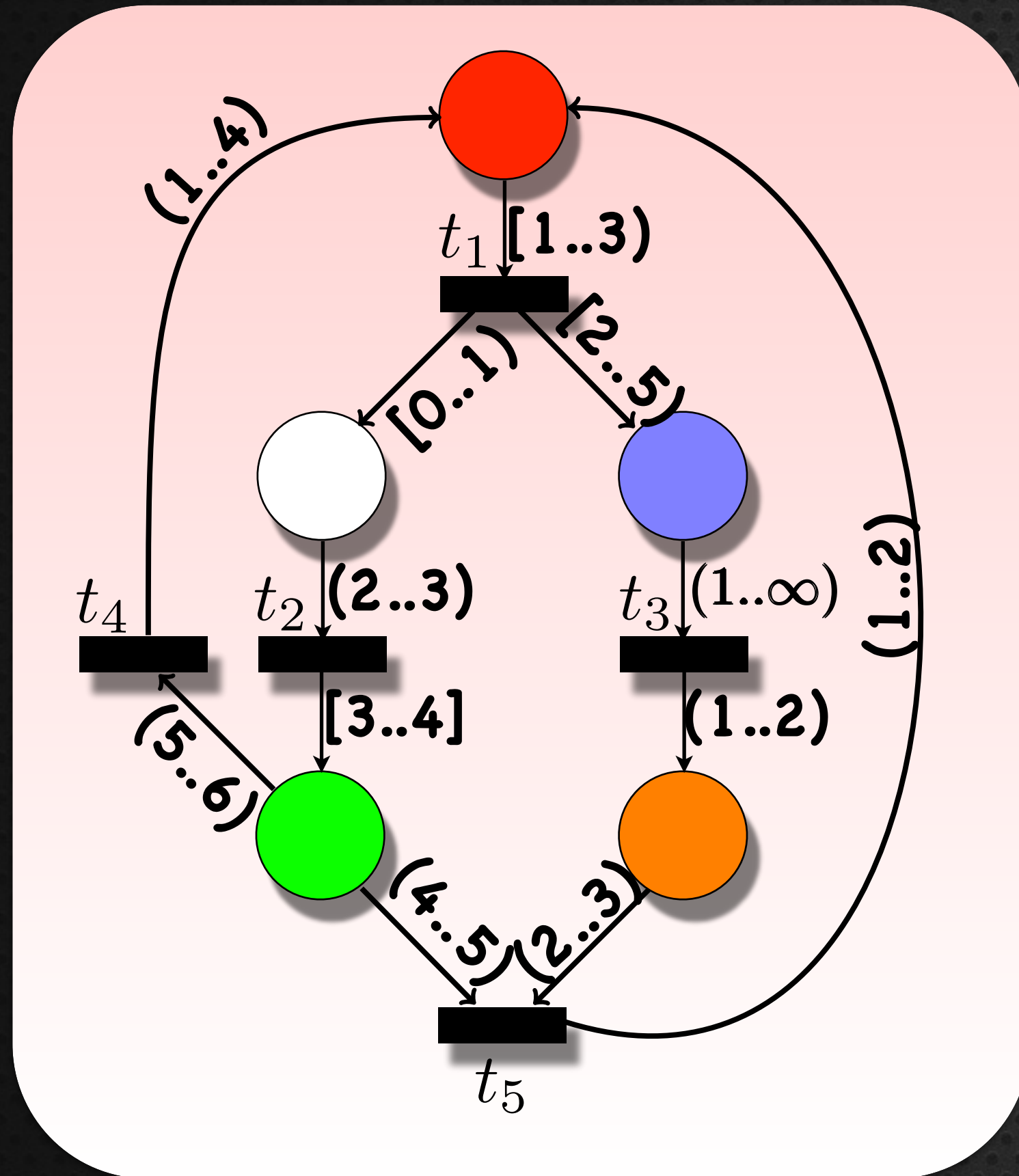


Lynch and Shavit's protocol

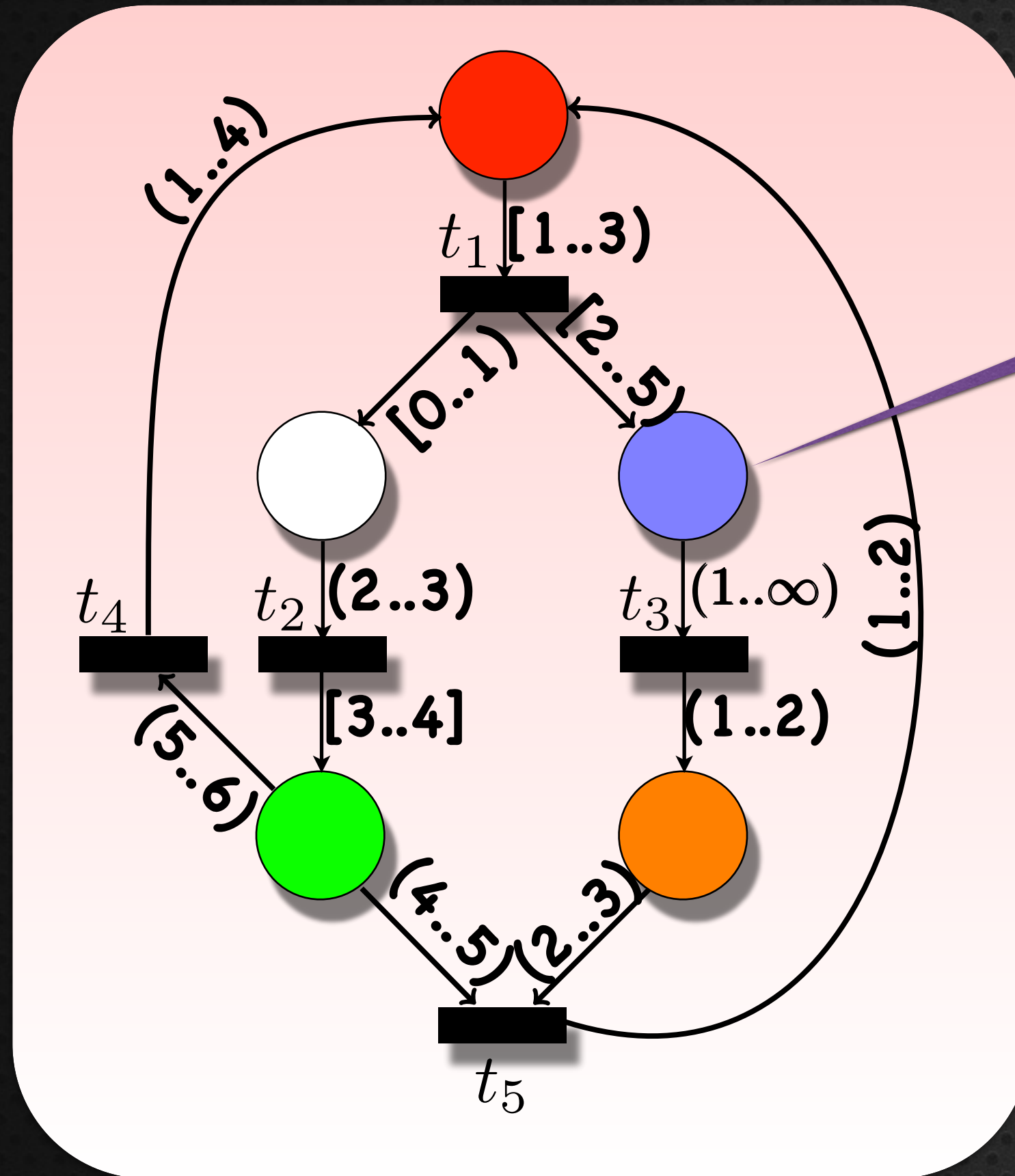
Parameterized version
= Timed Petri Net



Timed Petri Nets

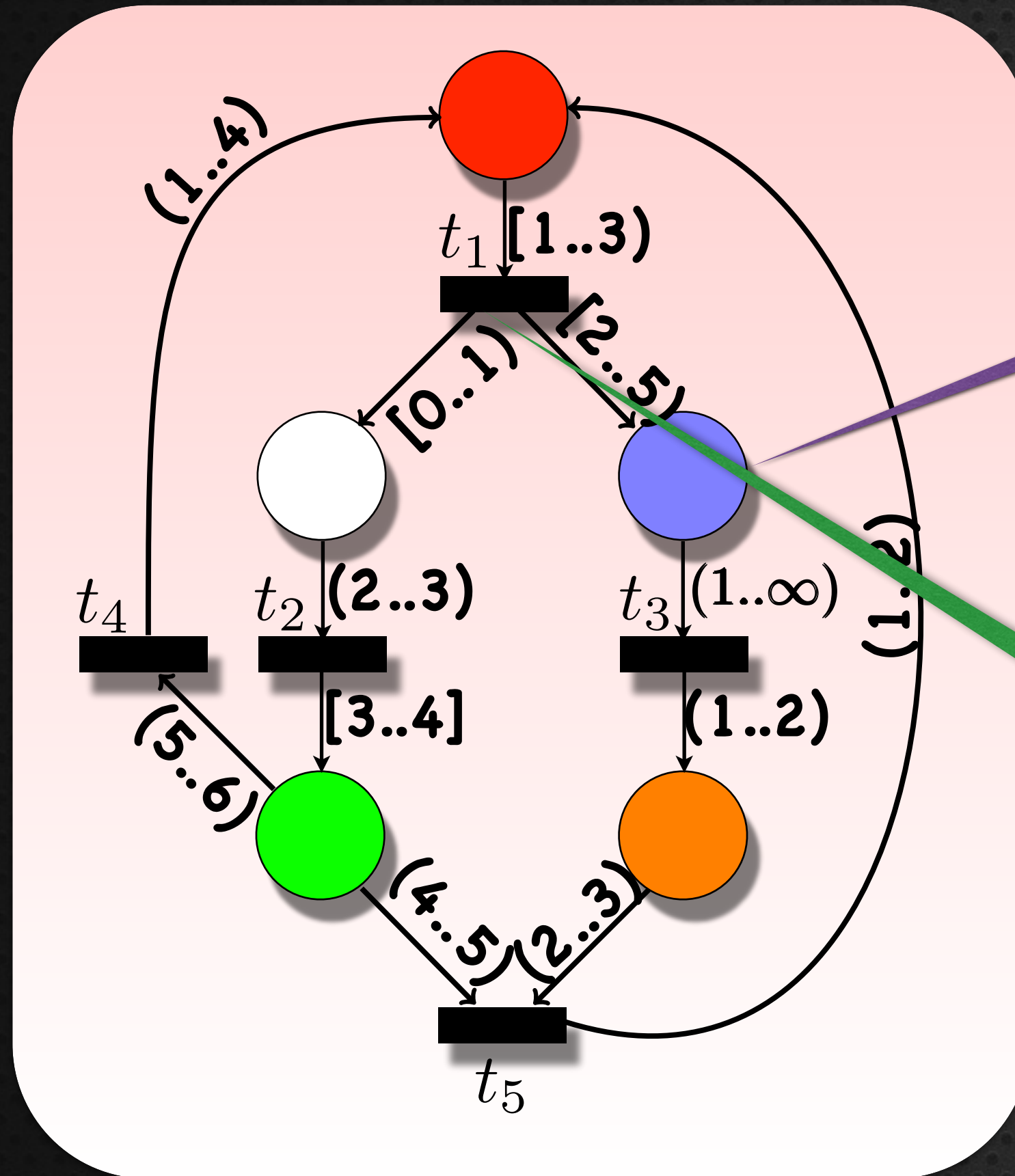


Timed Petri Nets



places

Timed Petri Nets



places

transitions

Timed Petri Nets

✓
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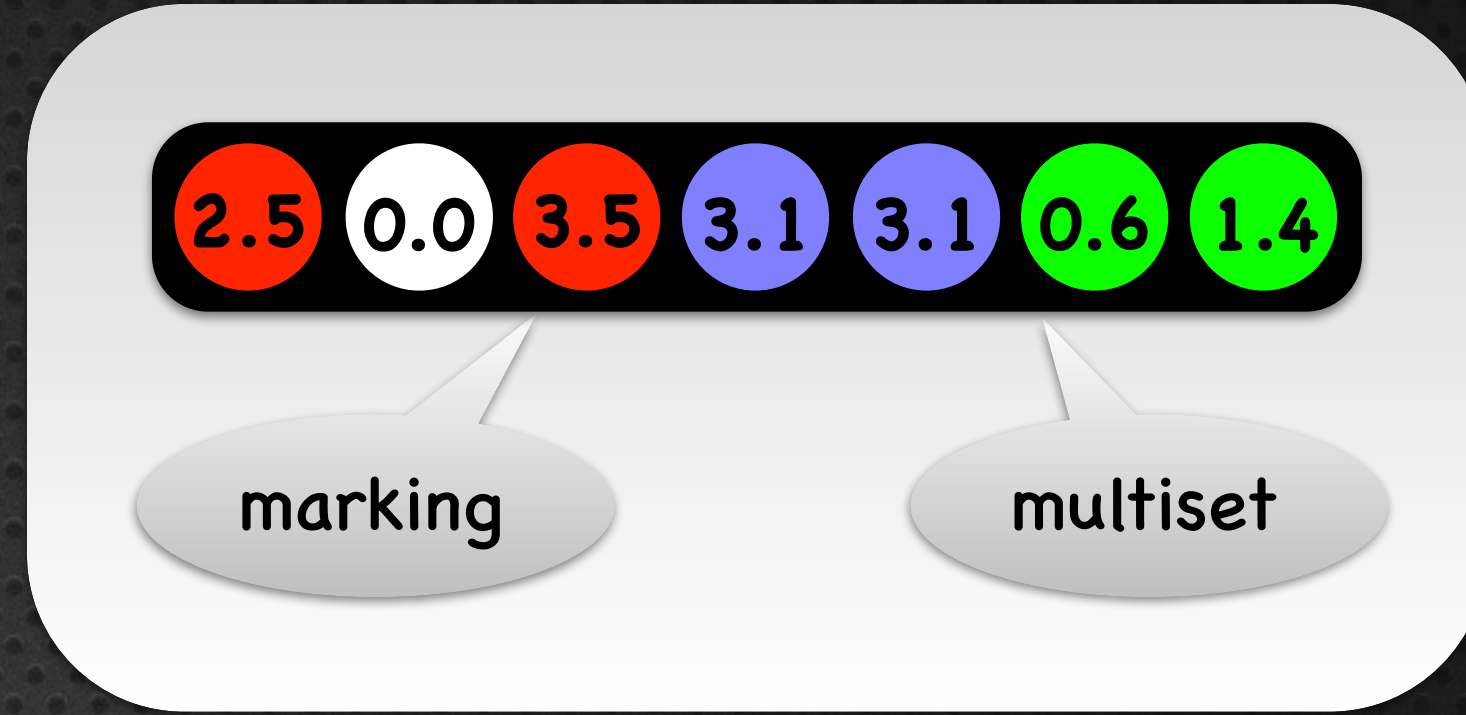
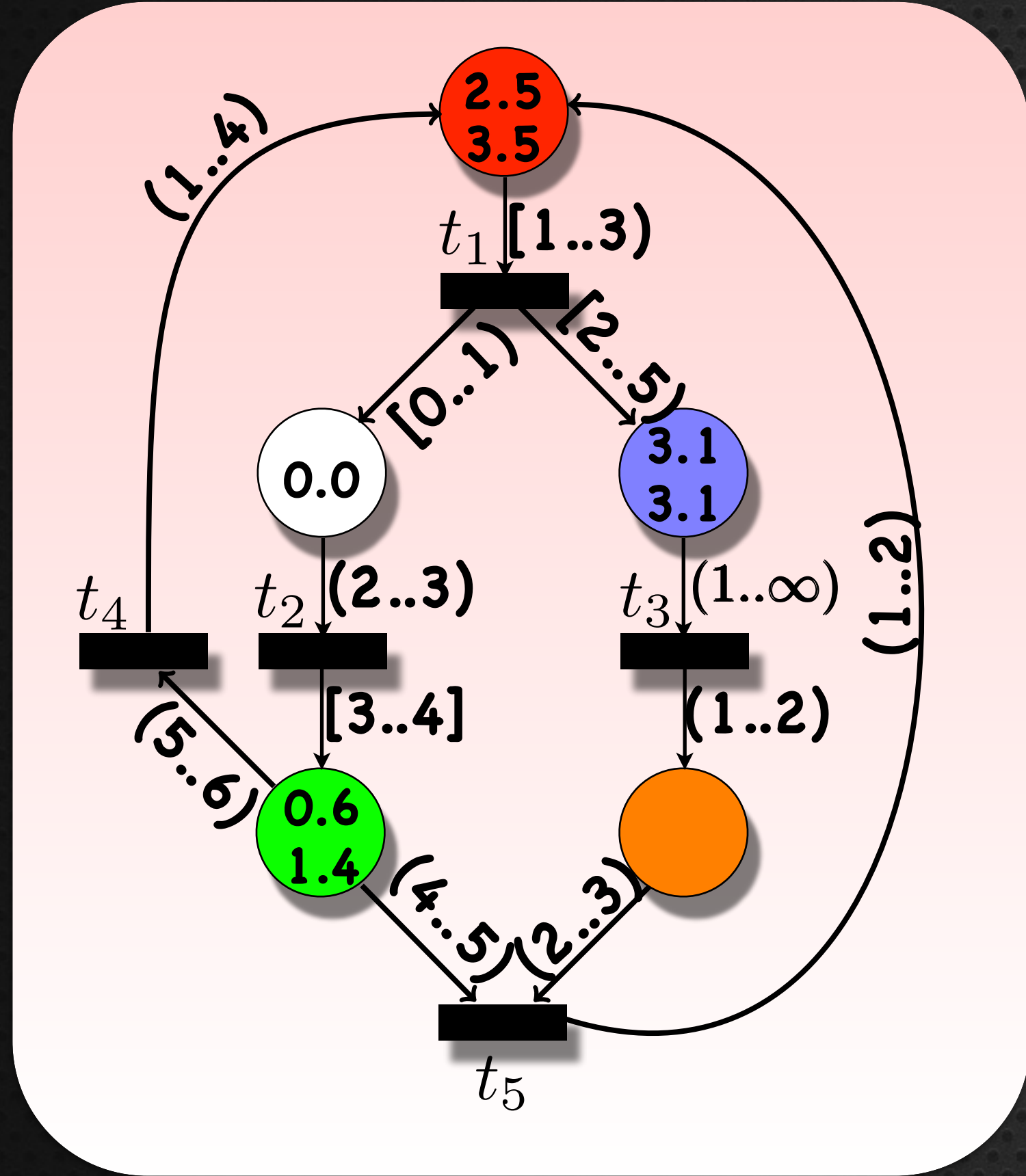
Upward Closed Sets

Computing Predecessors

Backward Reachability



Markings



Timed Petri Nets

Model ✓

Configurations ✓

Transitions

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Upward Closed Sets

Computing Predecessors

Backward Reachability

Timed Petri Nets

Model ✓

Configurations ✓

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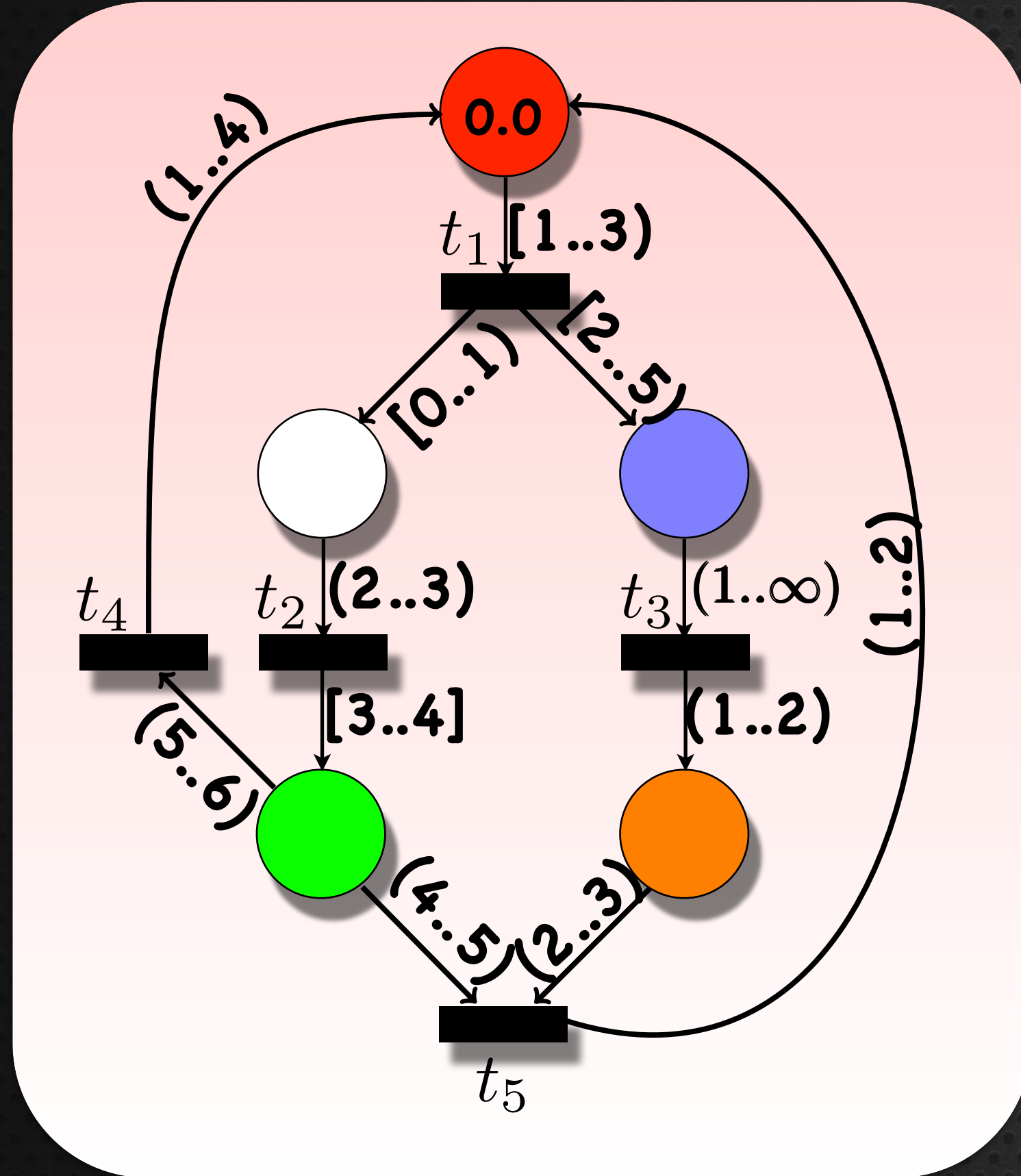
Upward Closed Sets

Computing Predecessors

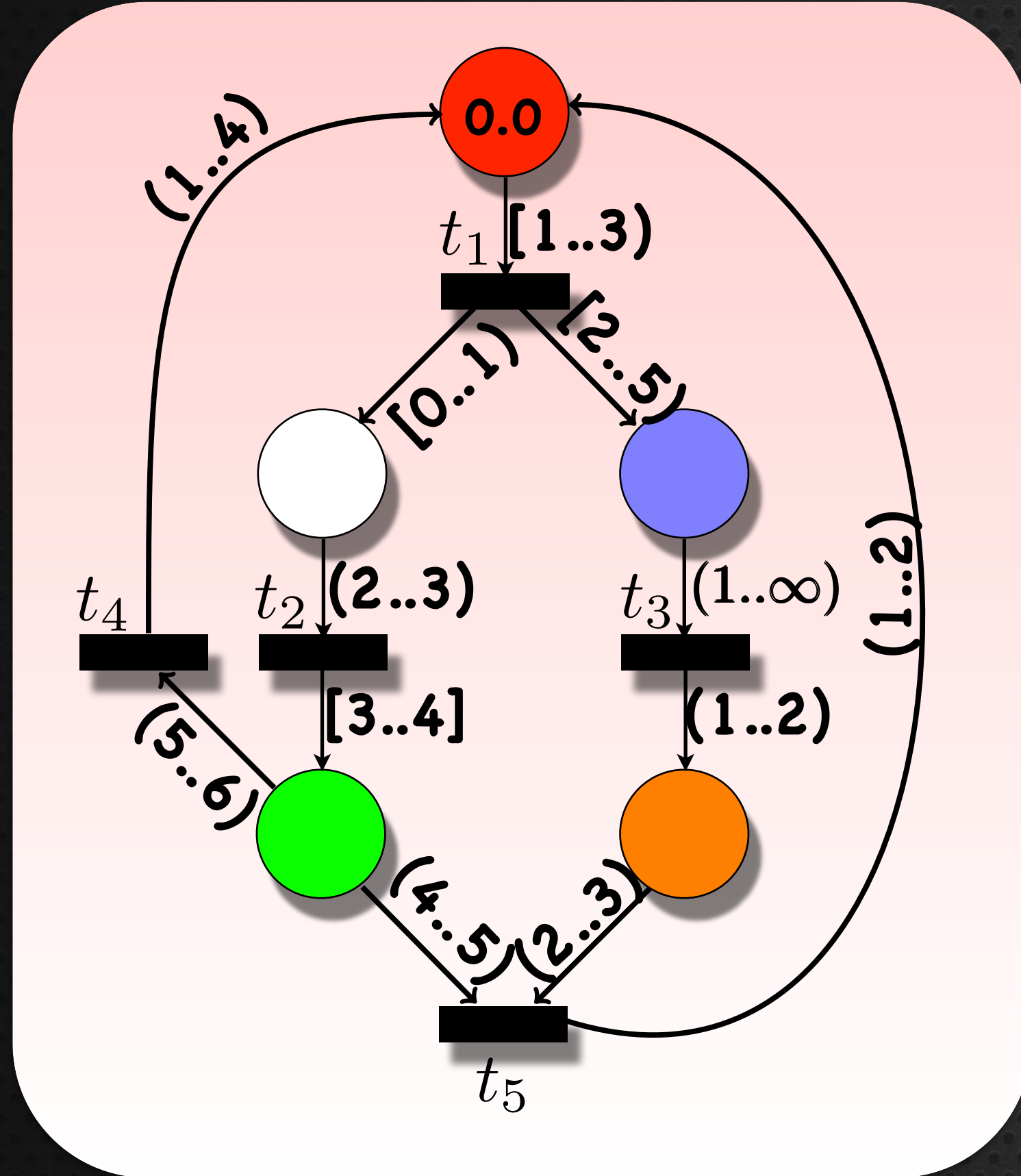
Backward Reachability



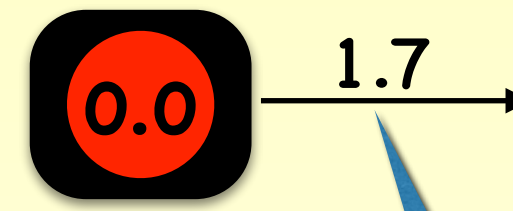
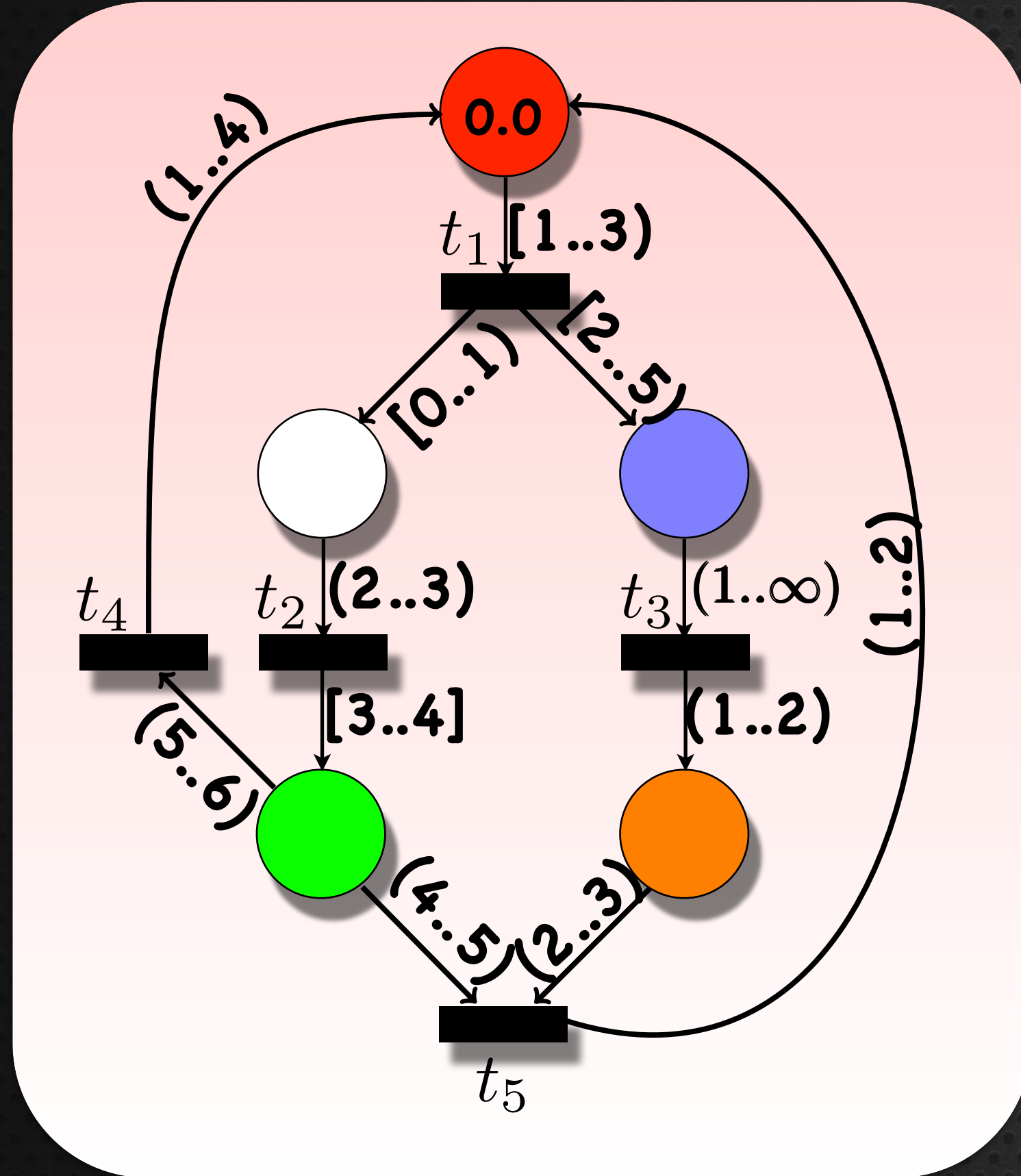
Transitions



Transitions

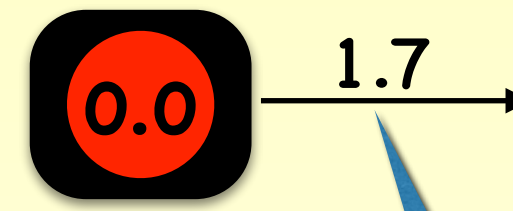
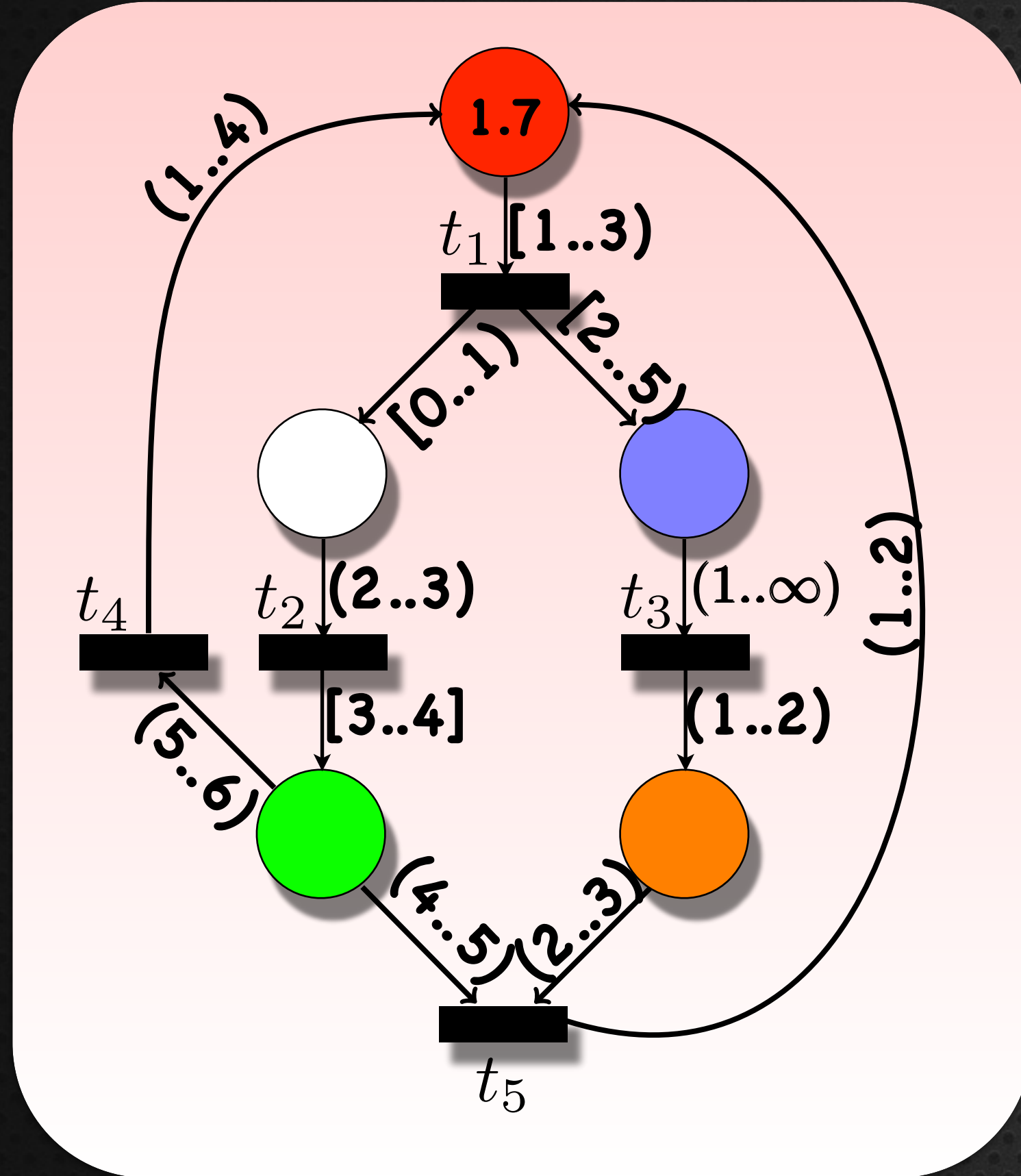


Transitions



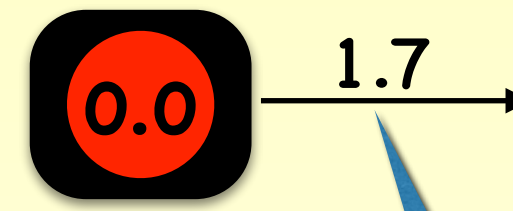
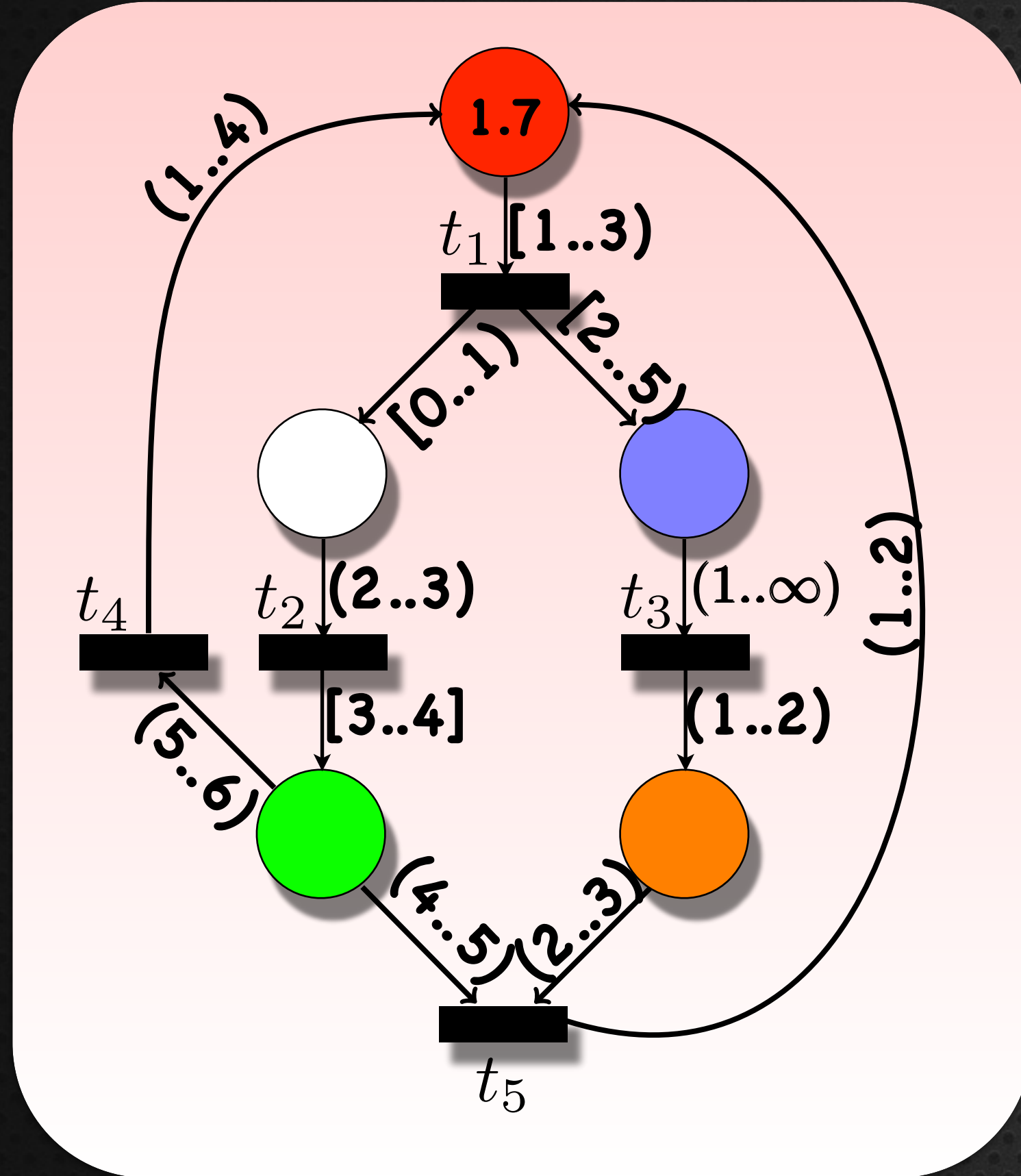
timed
transition

Transitions



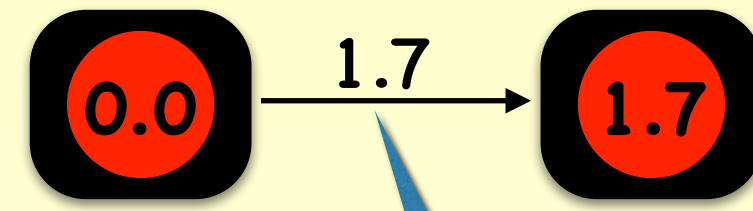
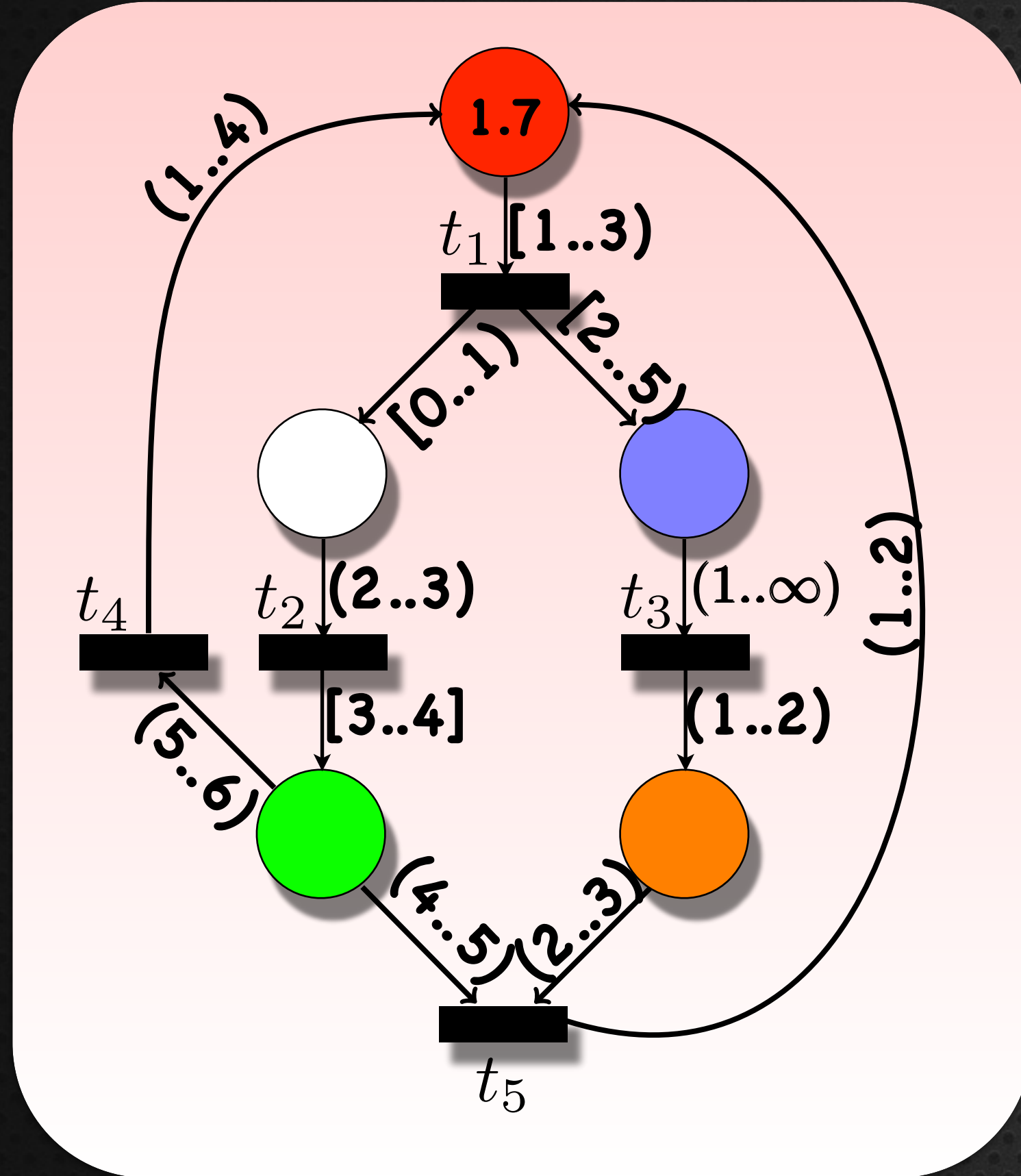
timed transition

Transitions



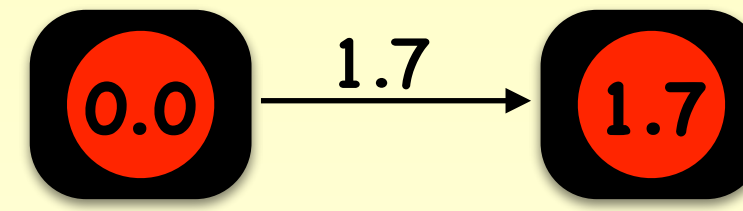
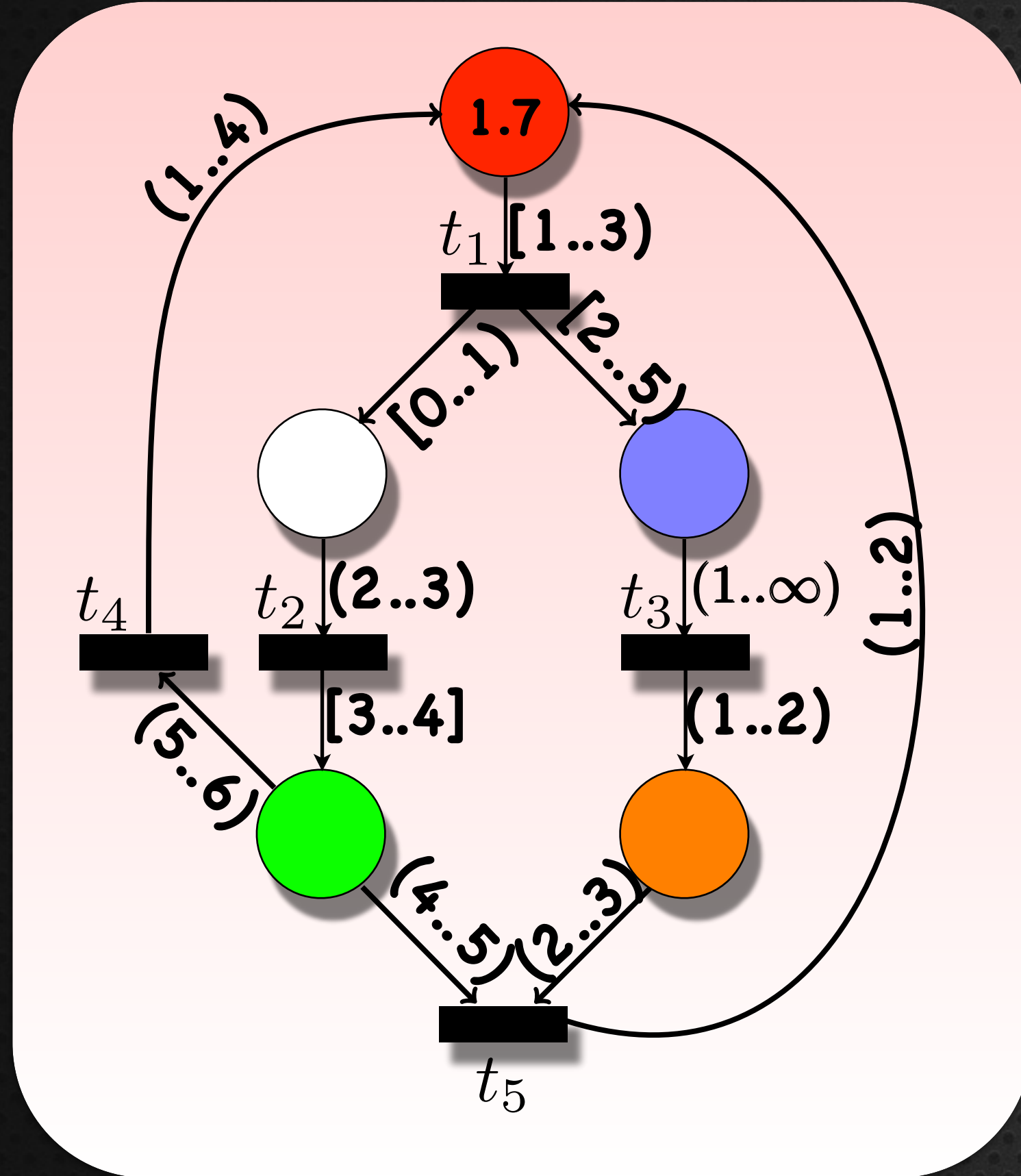
timed transition

Transitions

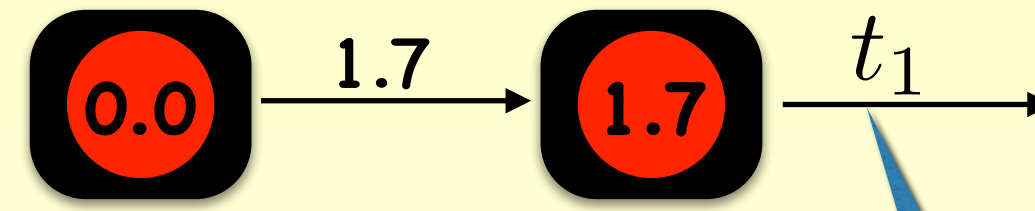
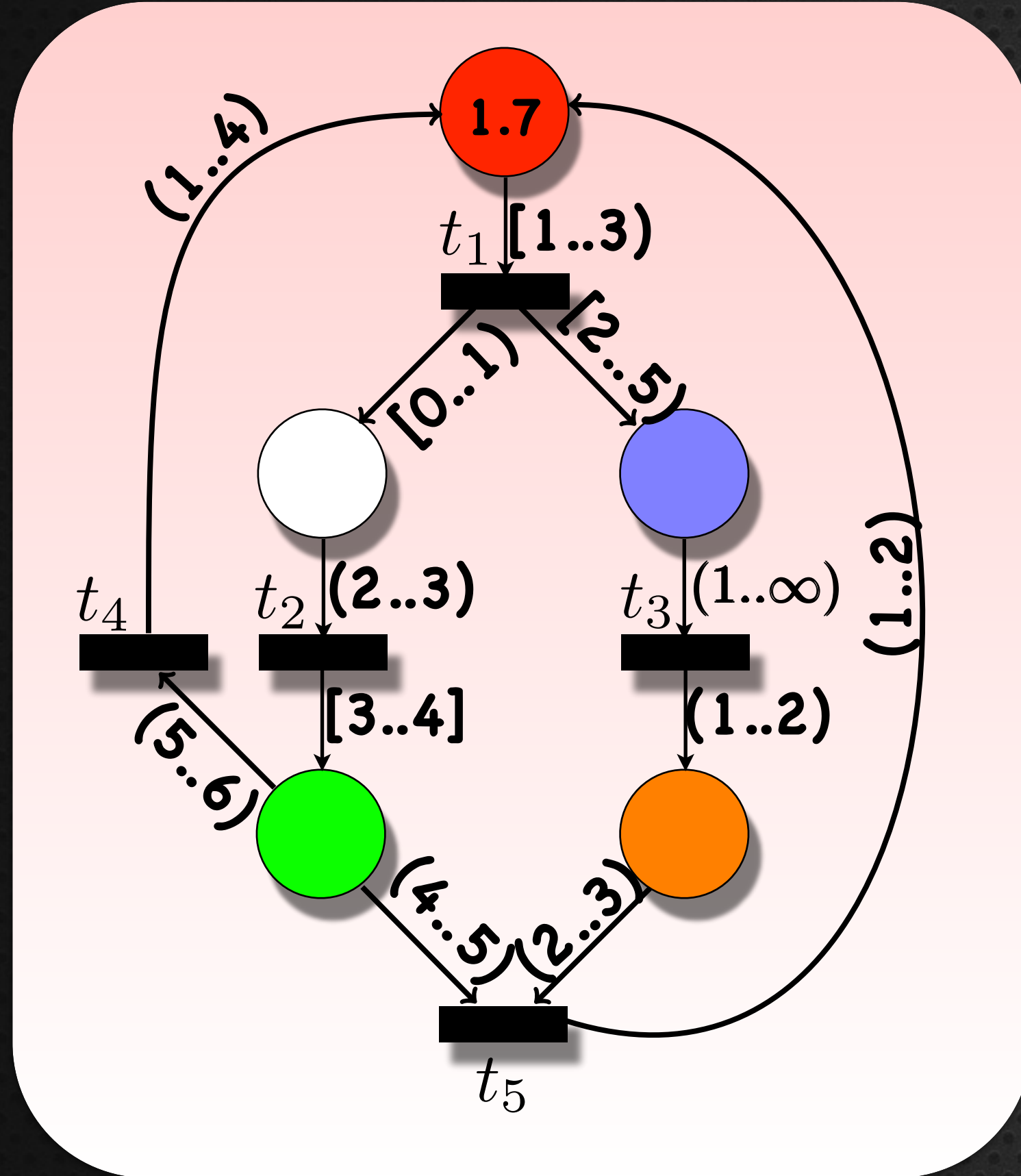


timed transition

Transitions

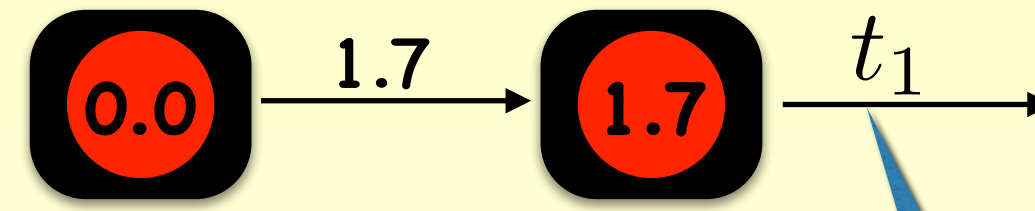
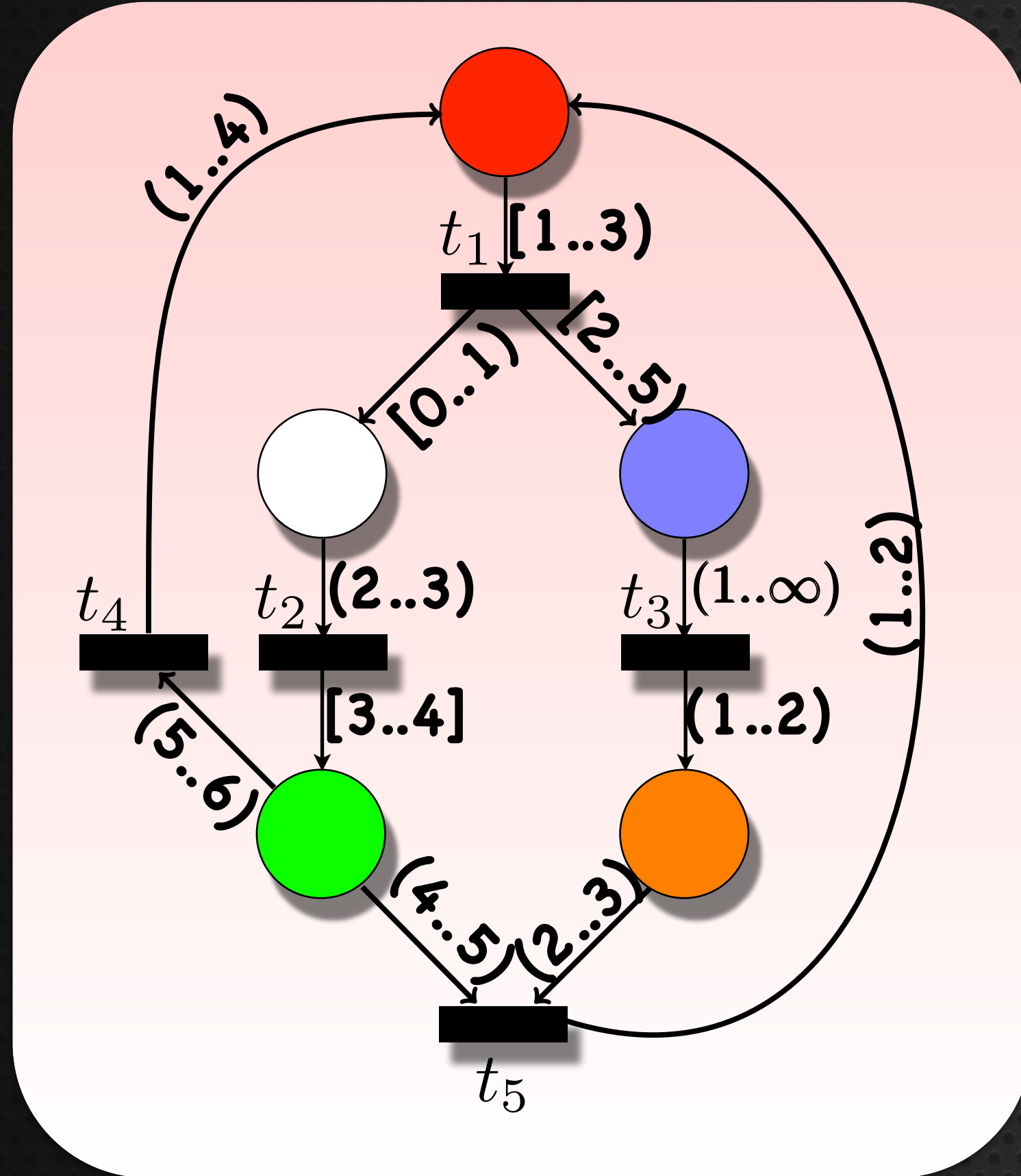


Transitions



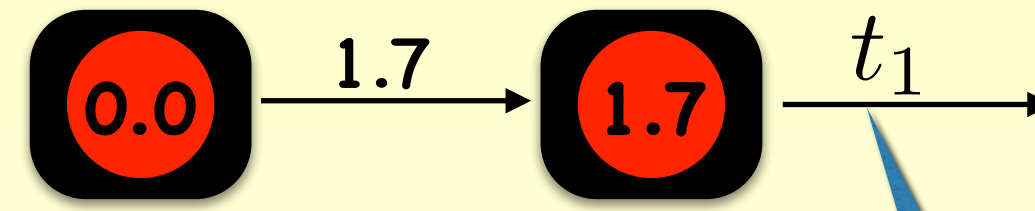
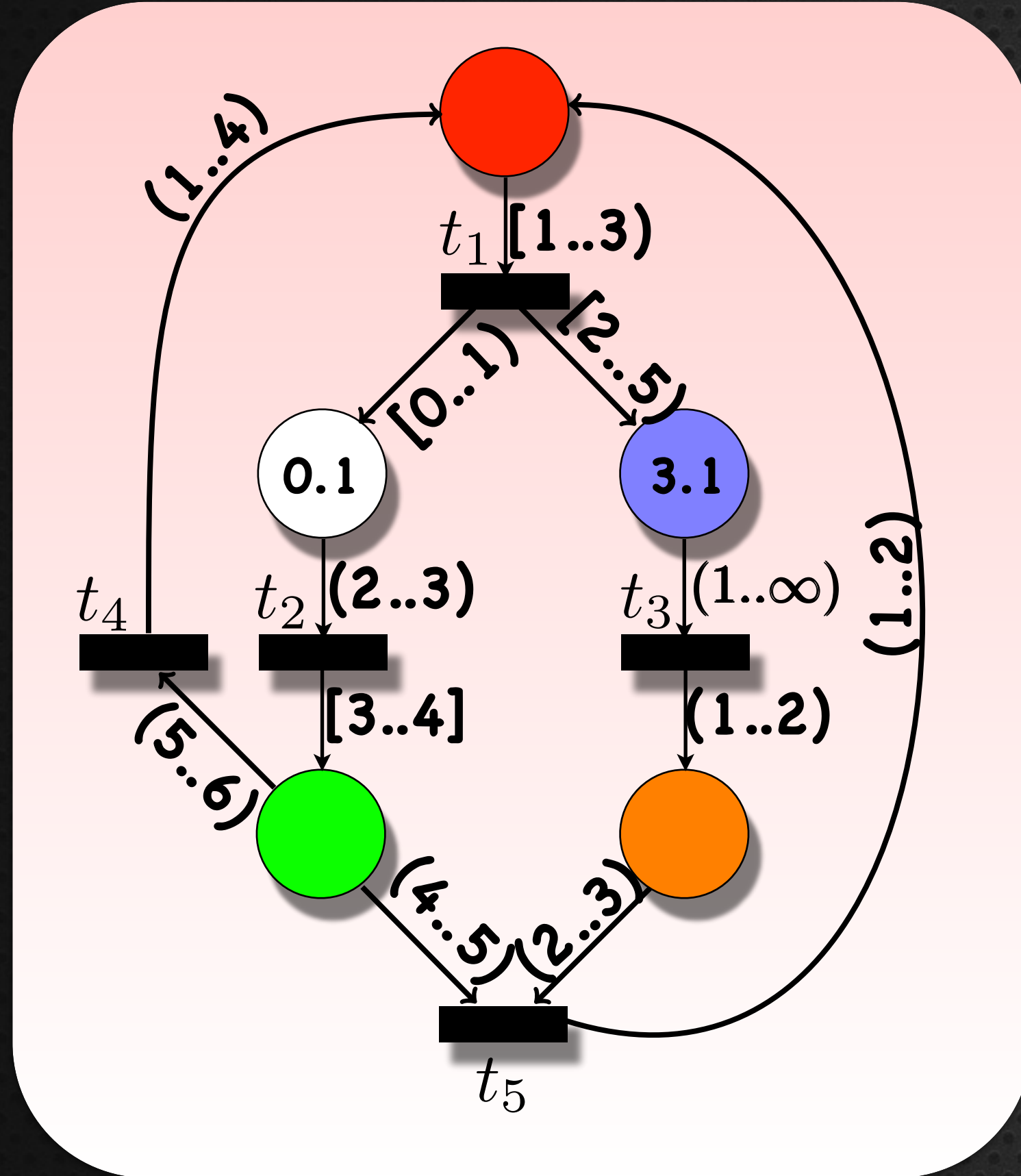
discrete transition

Transitions



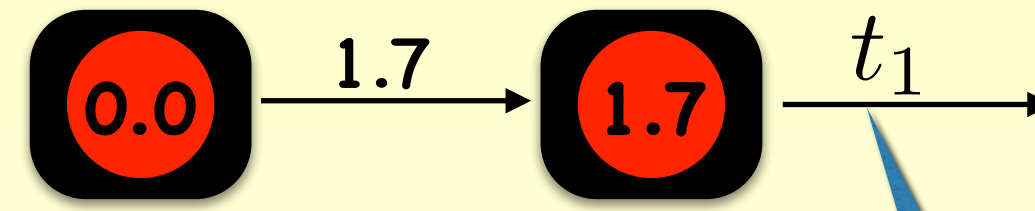
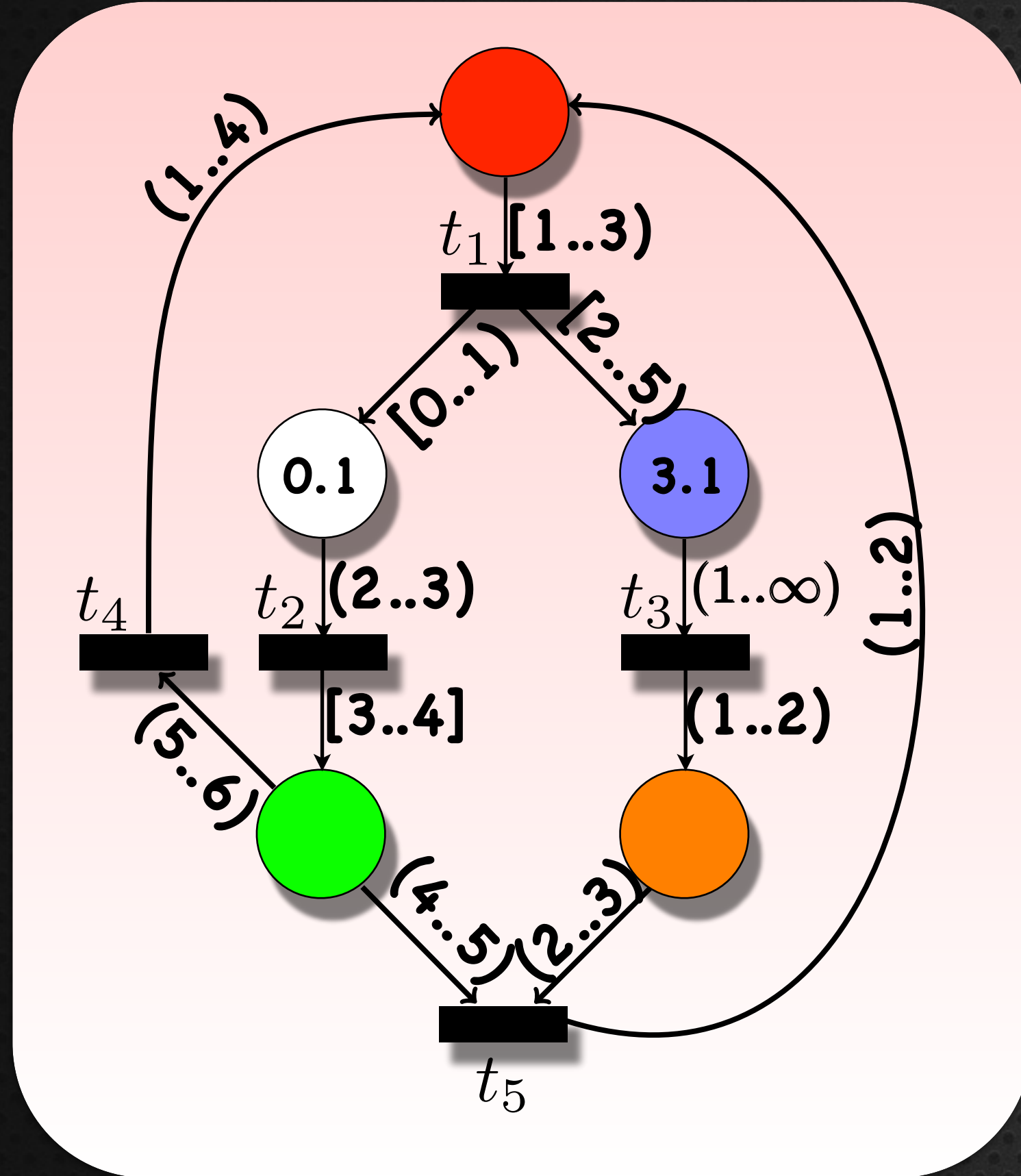
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Transitions



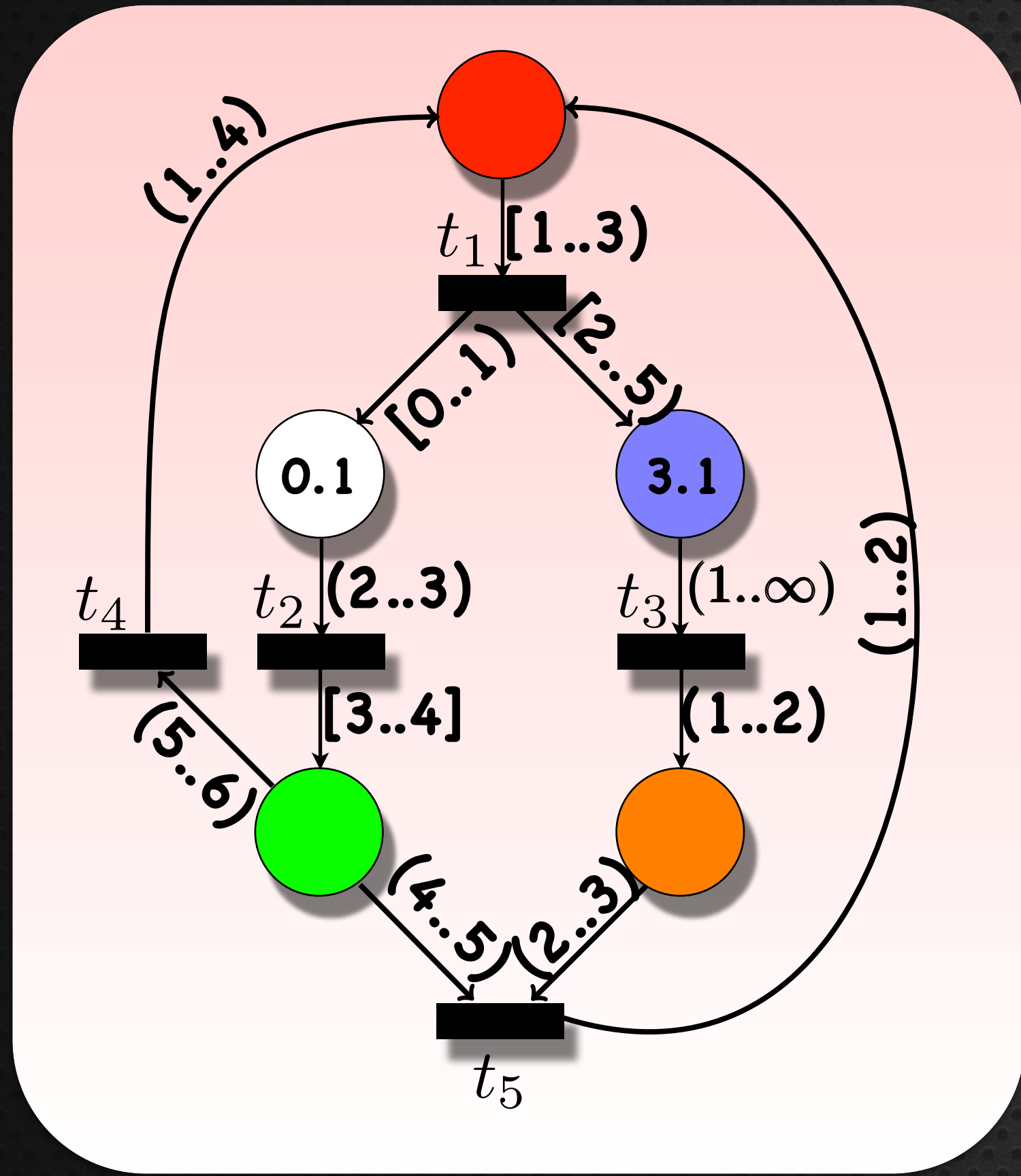
discrete transition

Transitions



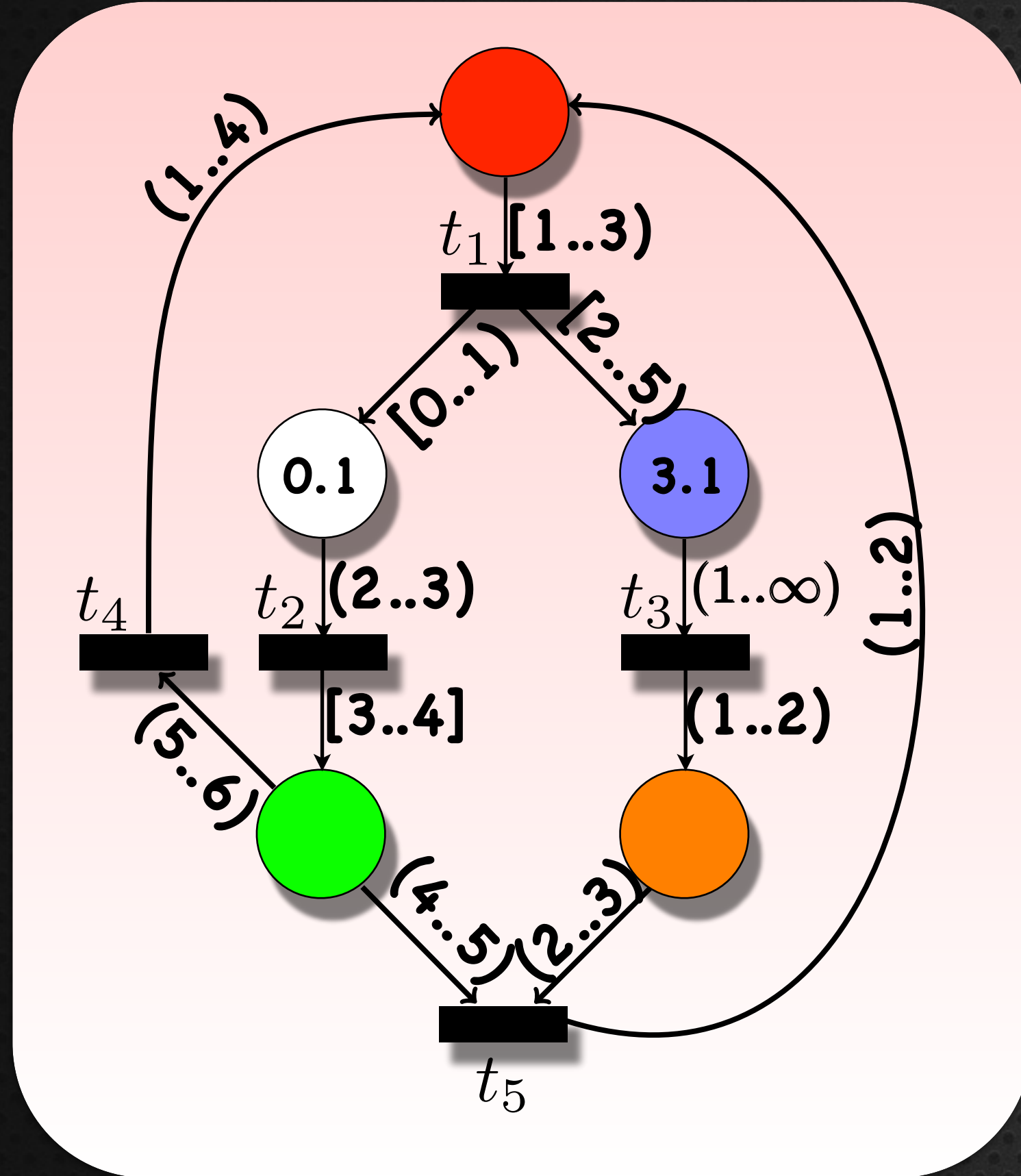
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Transitions

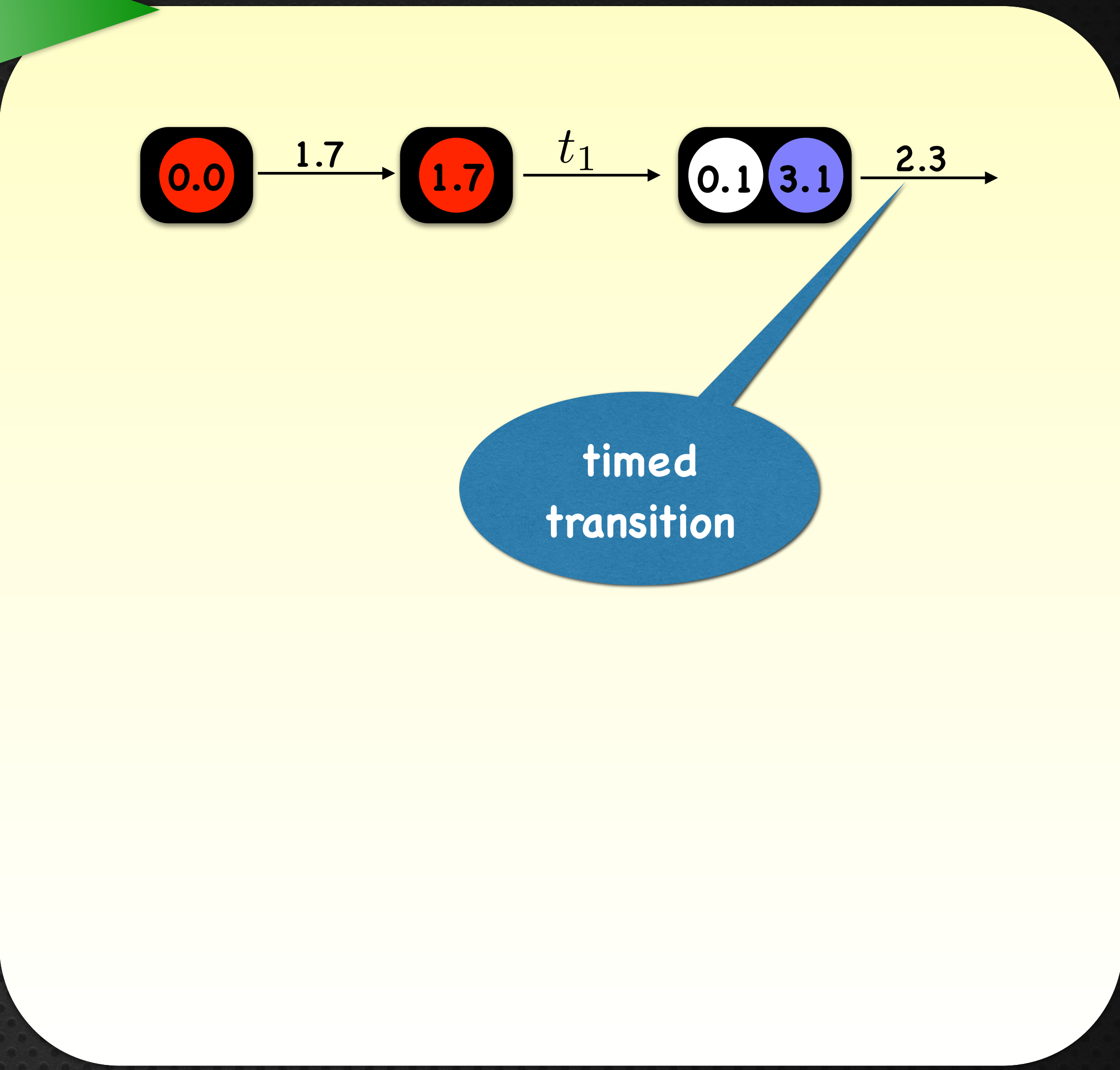
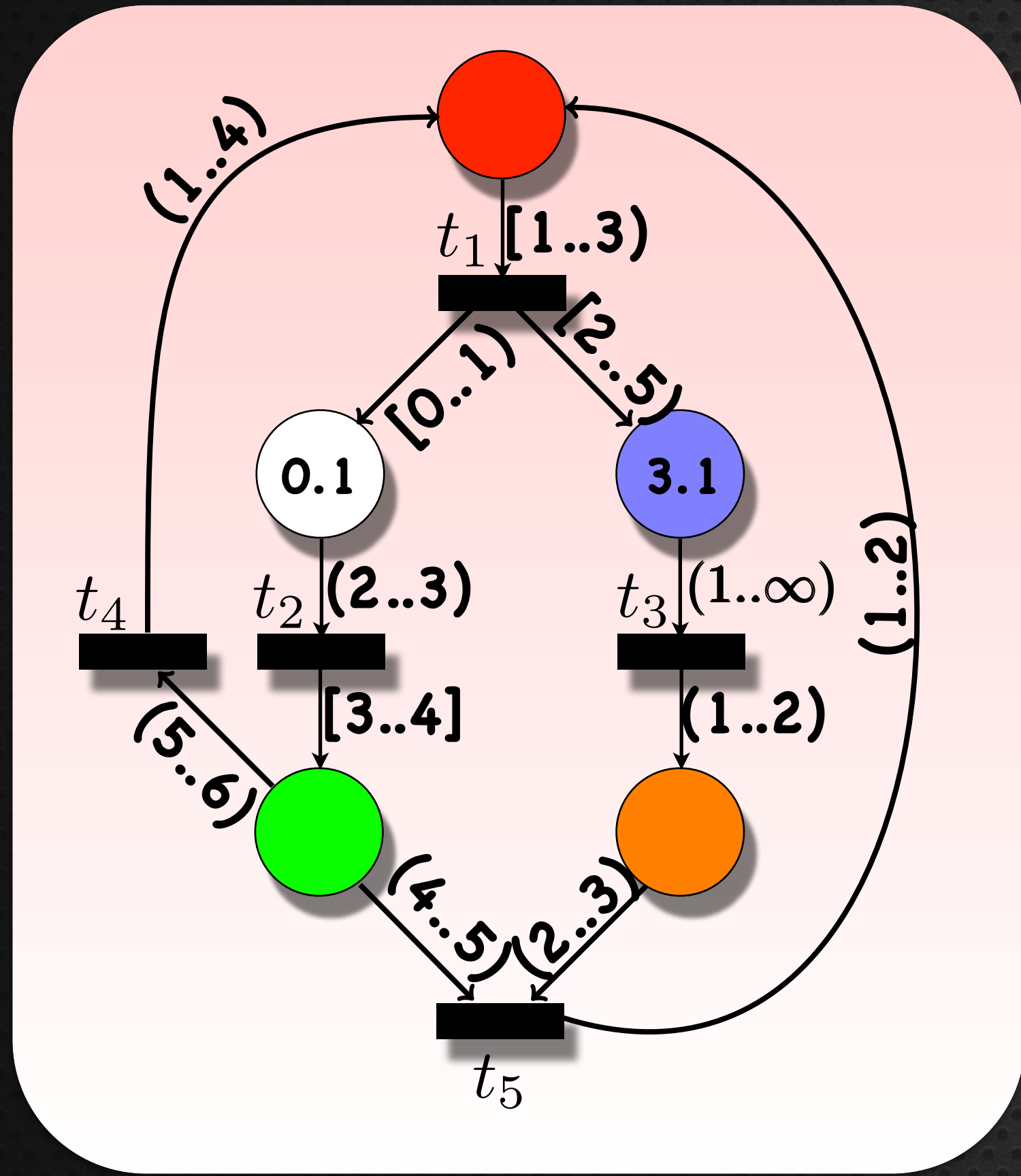


discrete transition

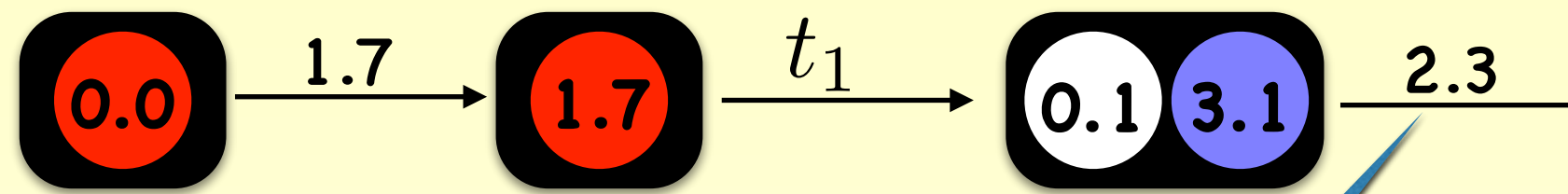
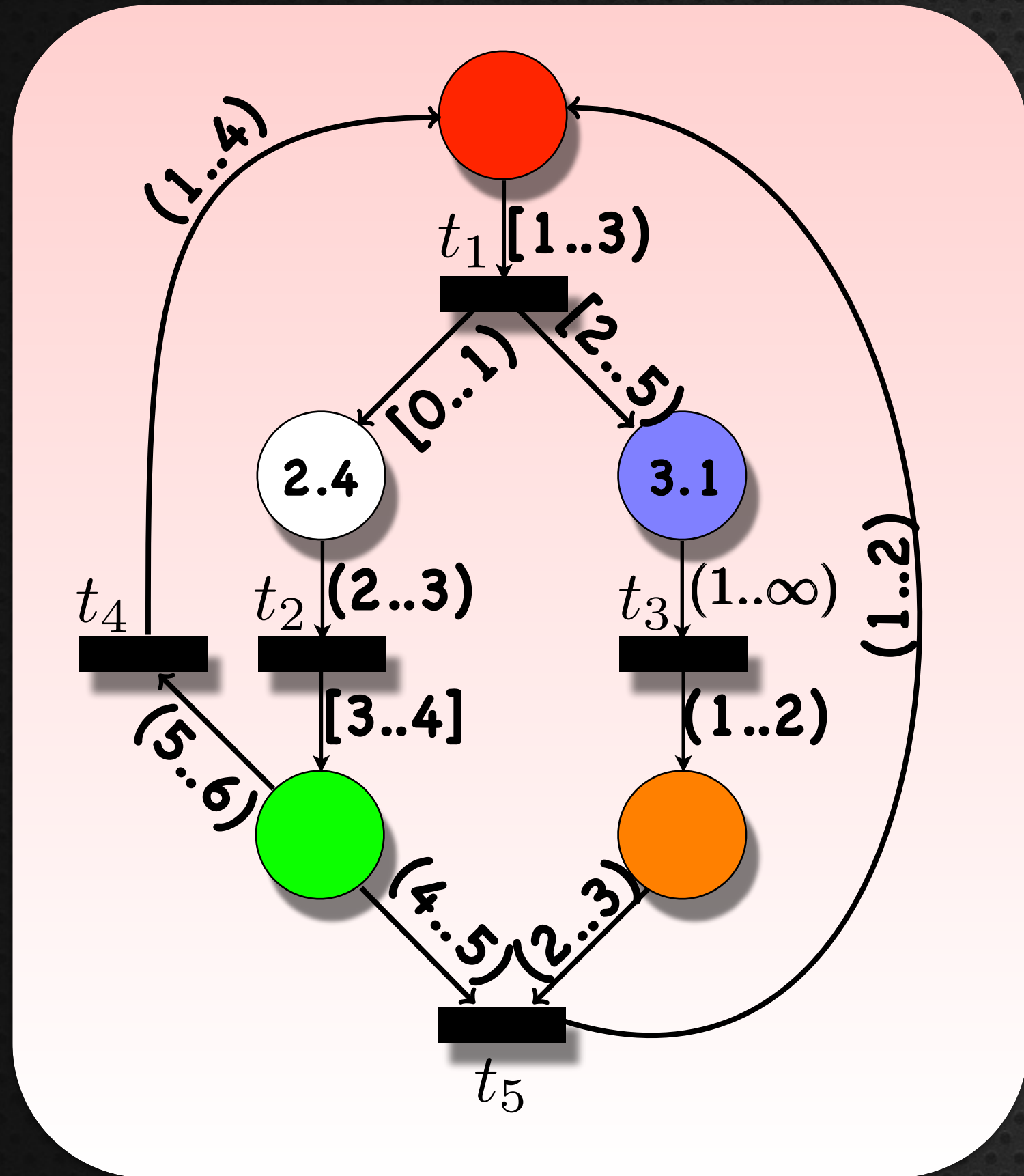
Transitions



Transitions

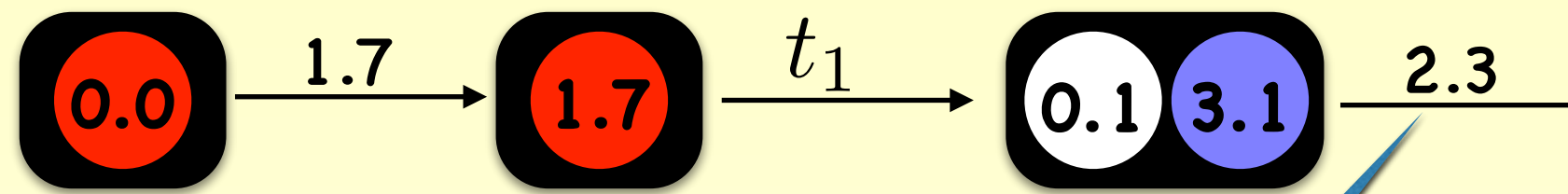
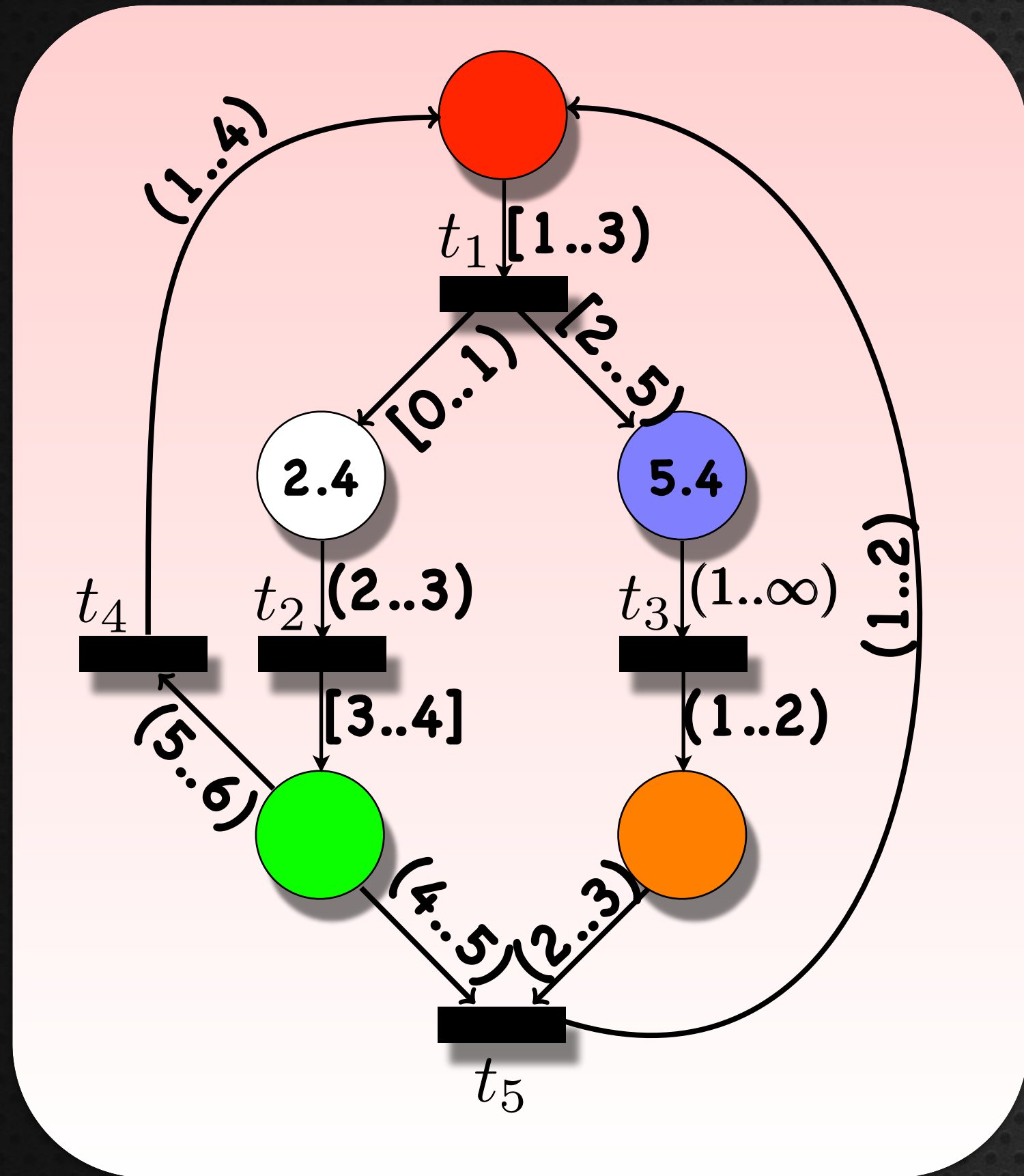


Transitions



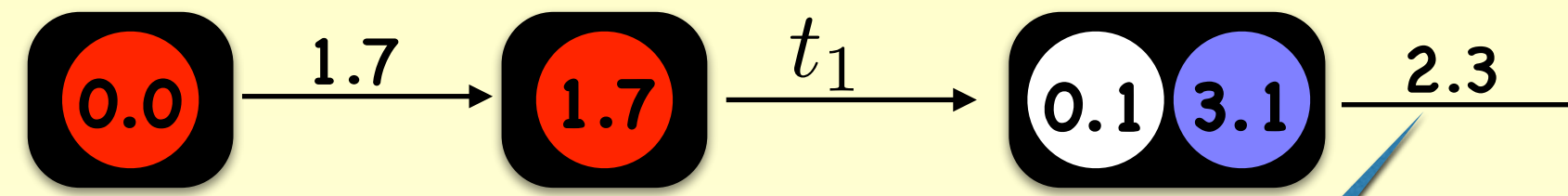
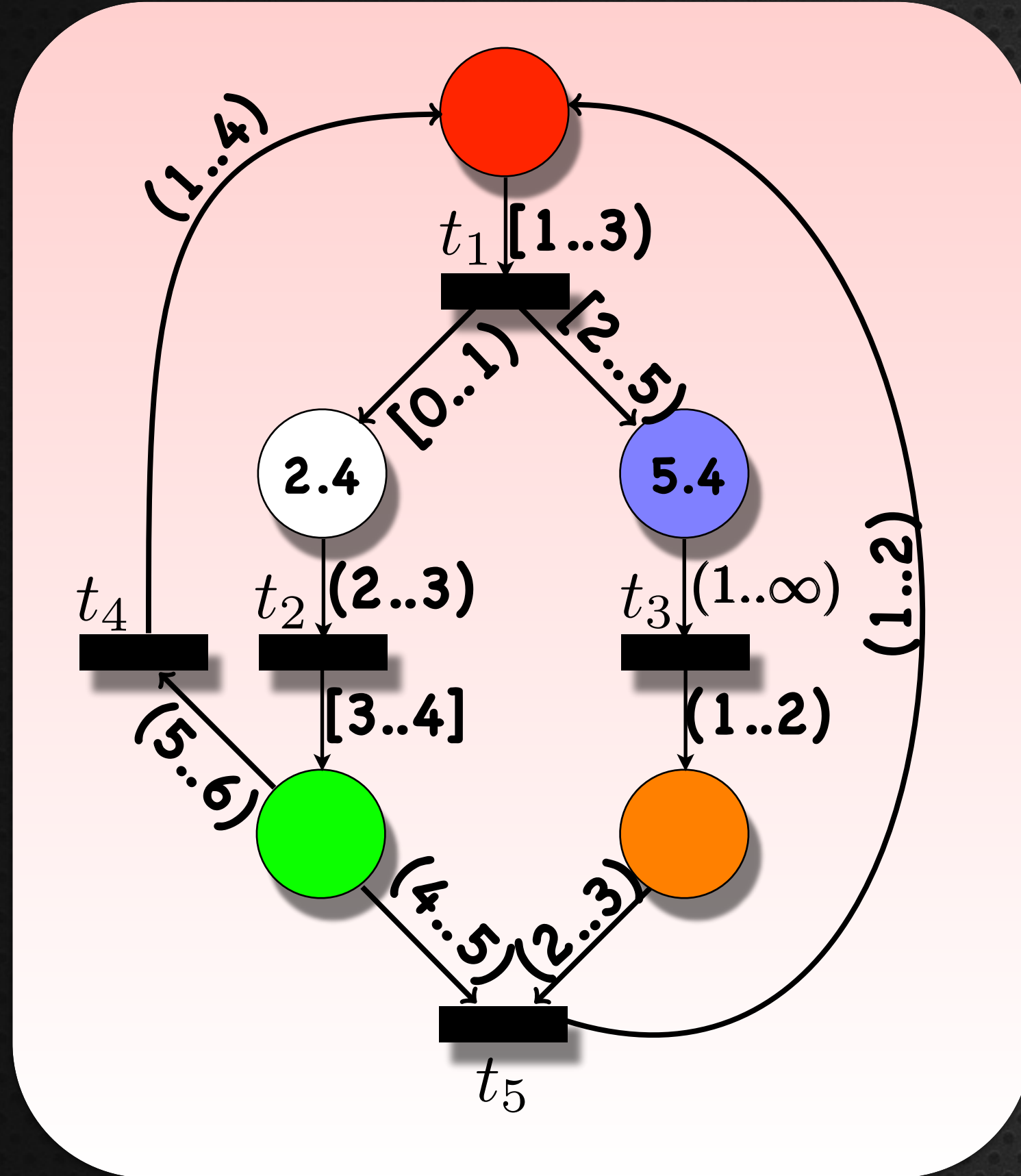
timed transition

Transitions



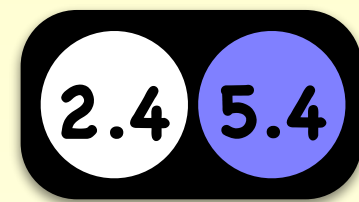
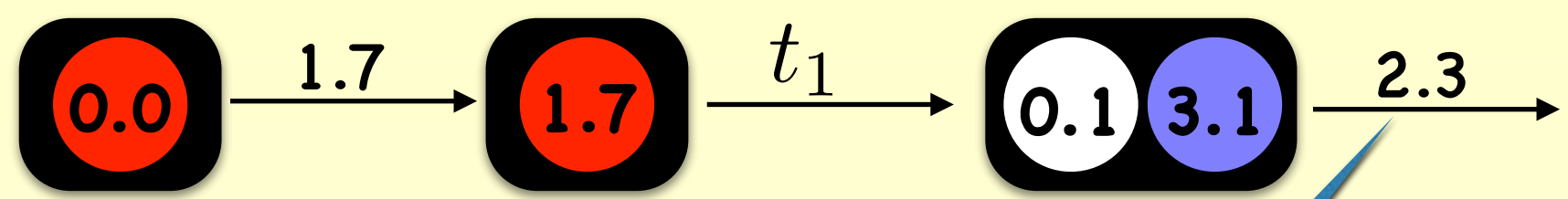
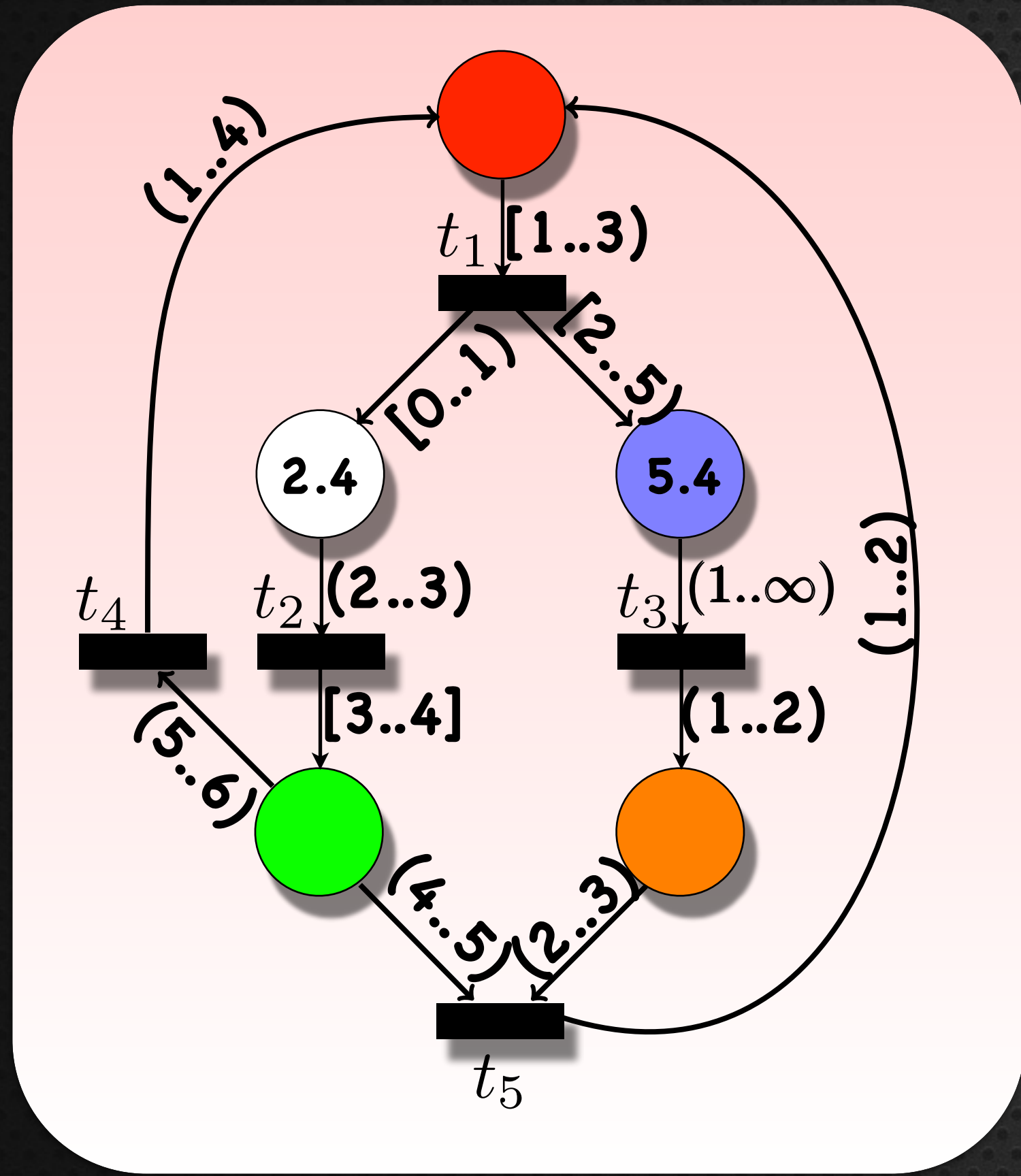
timed transition

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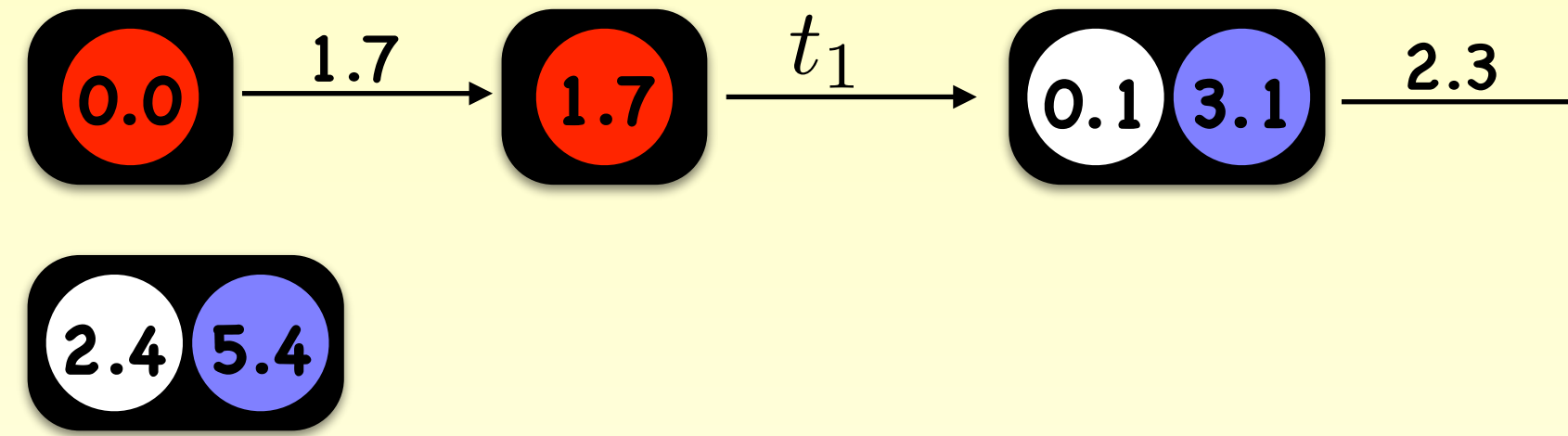
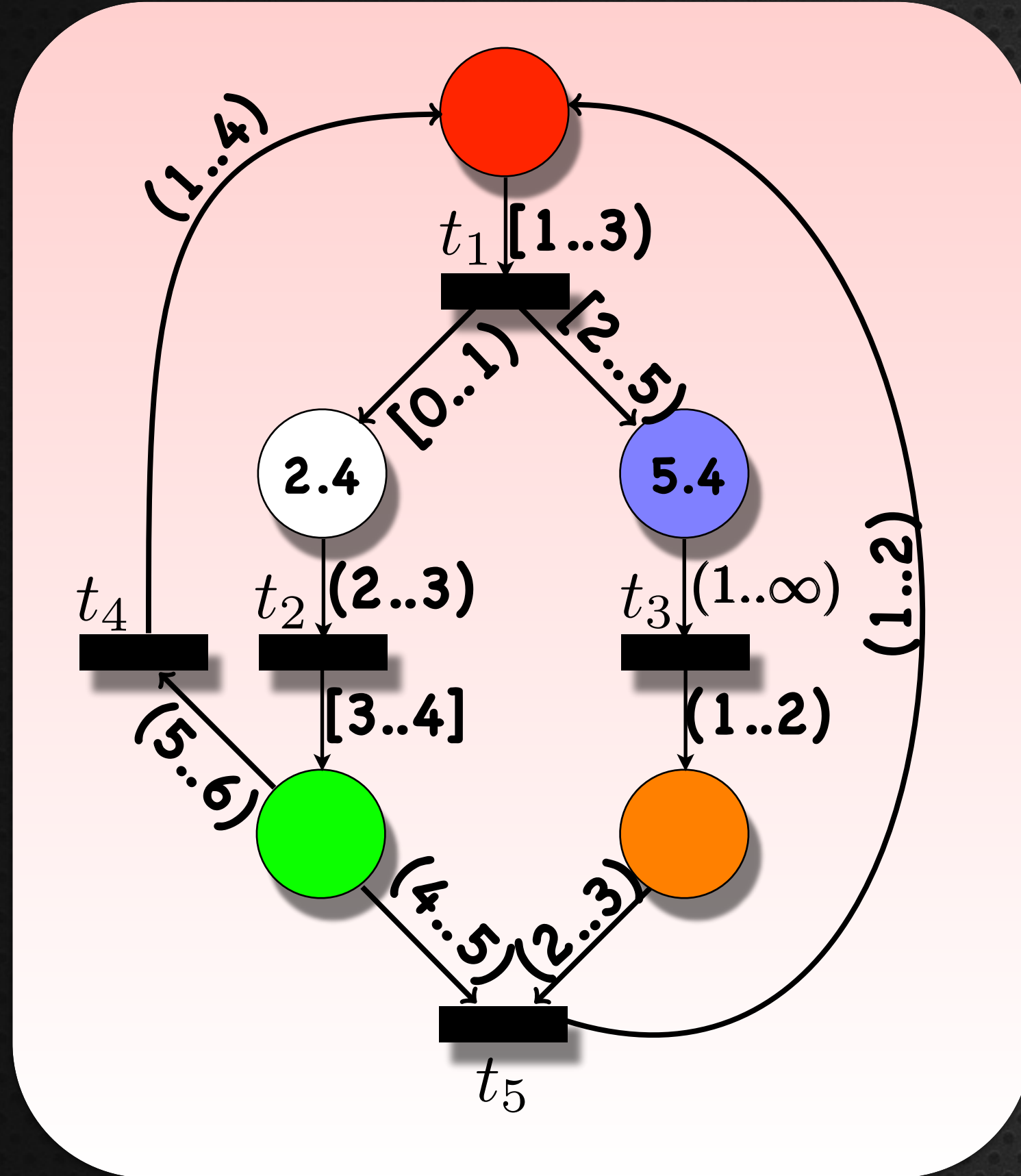
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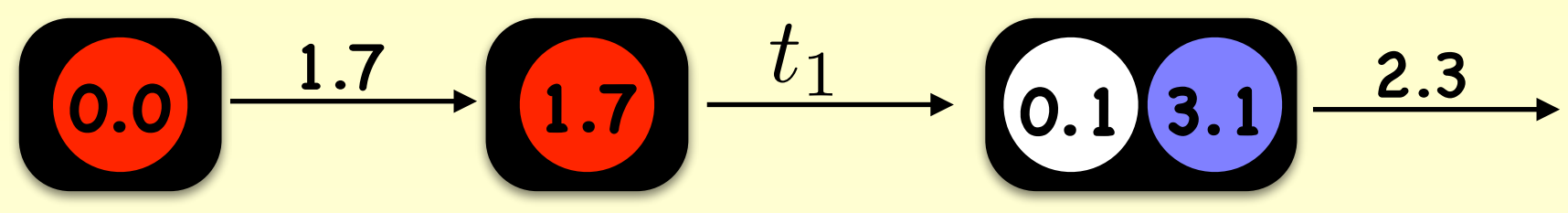
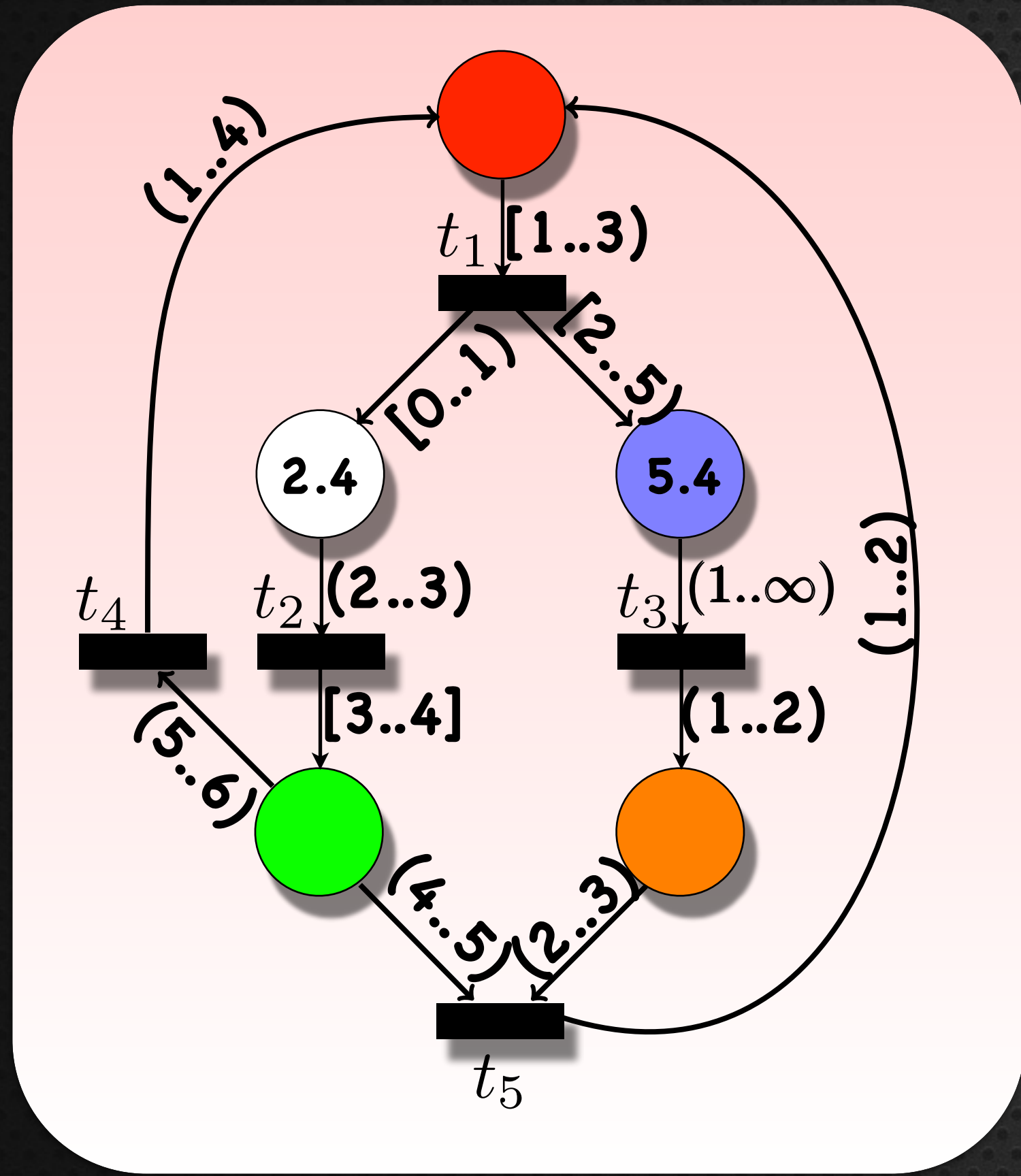


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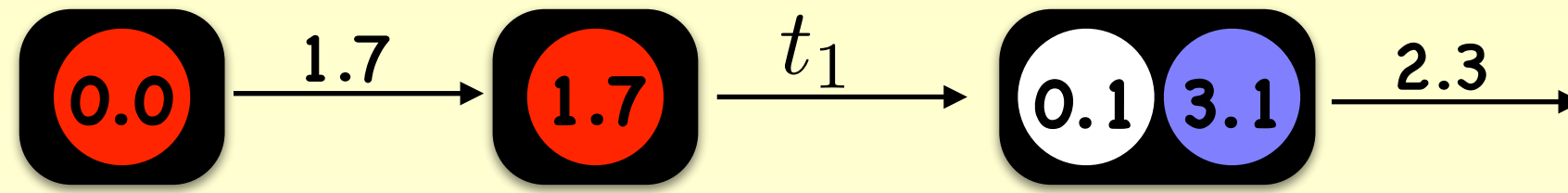
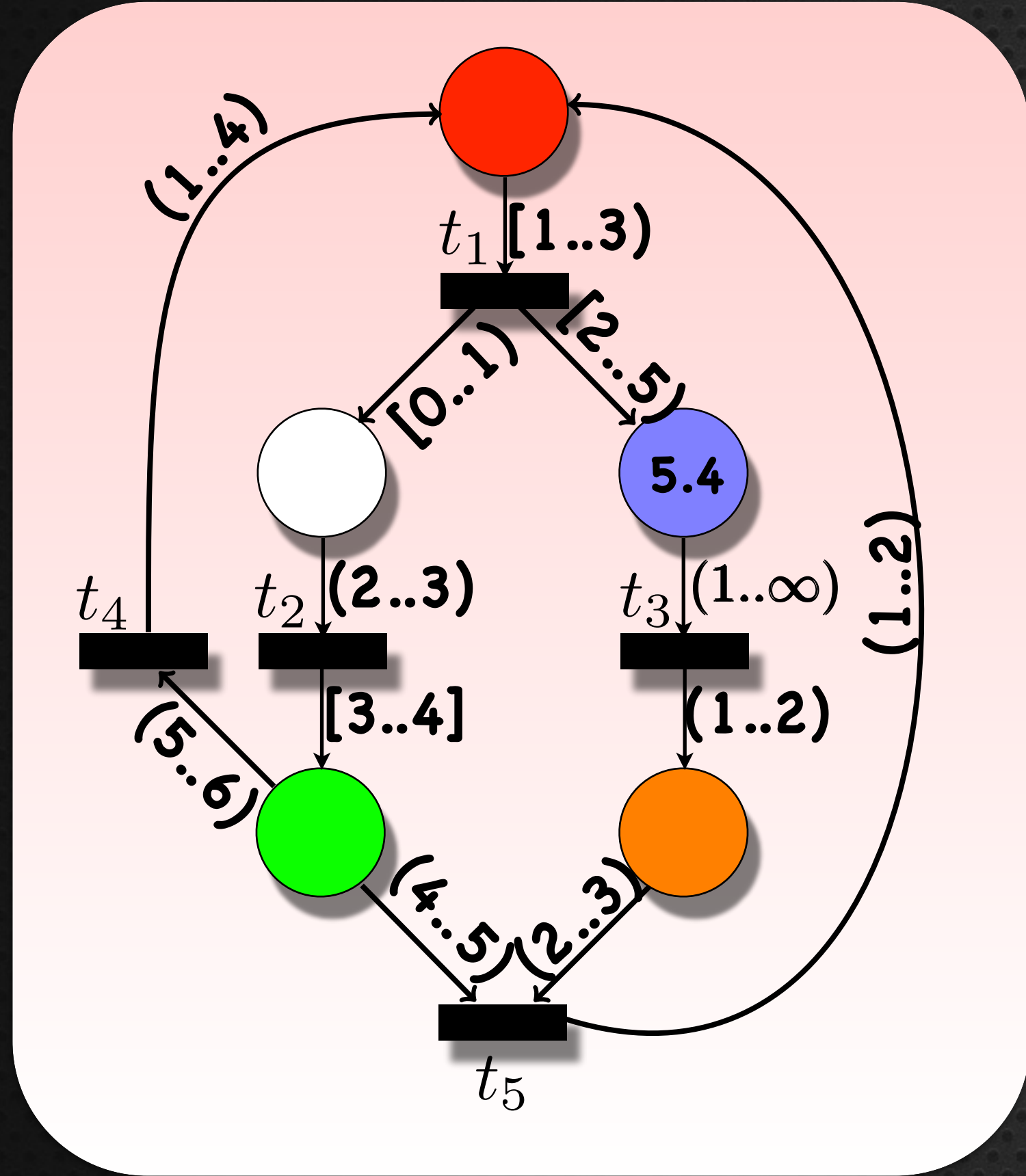


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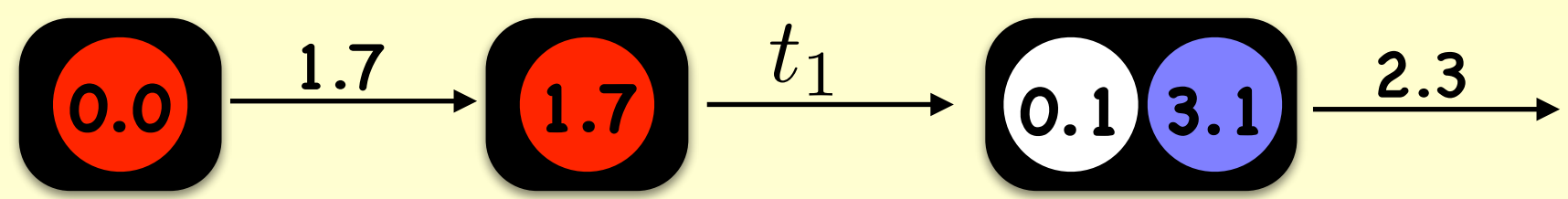
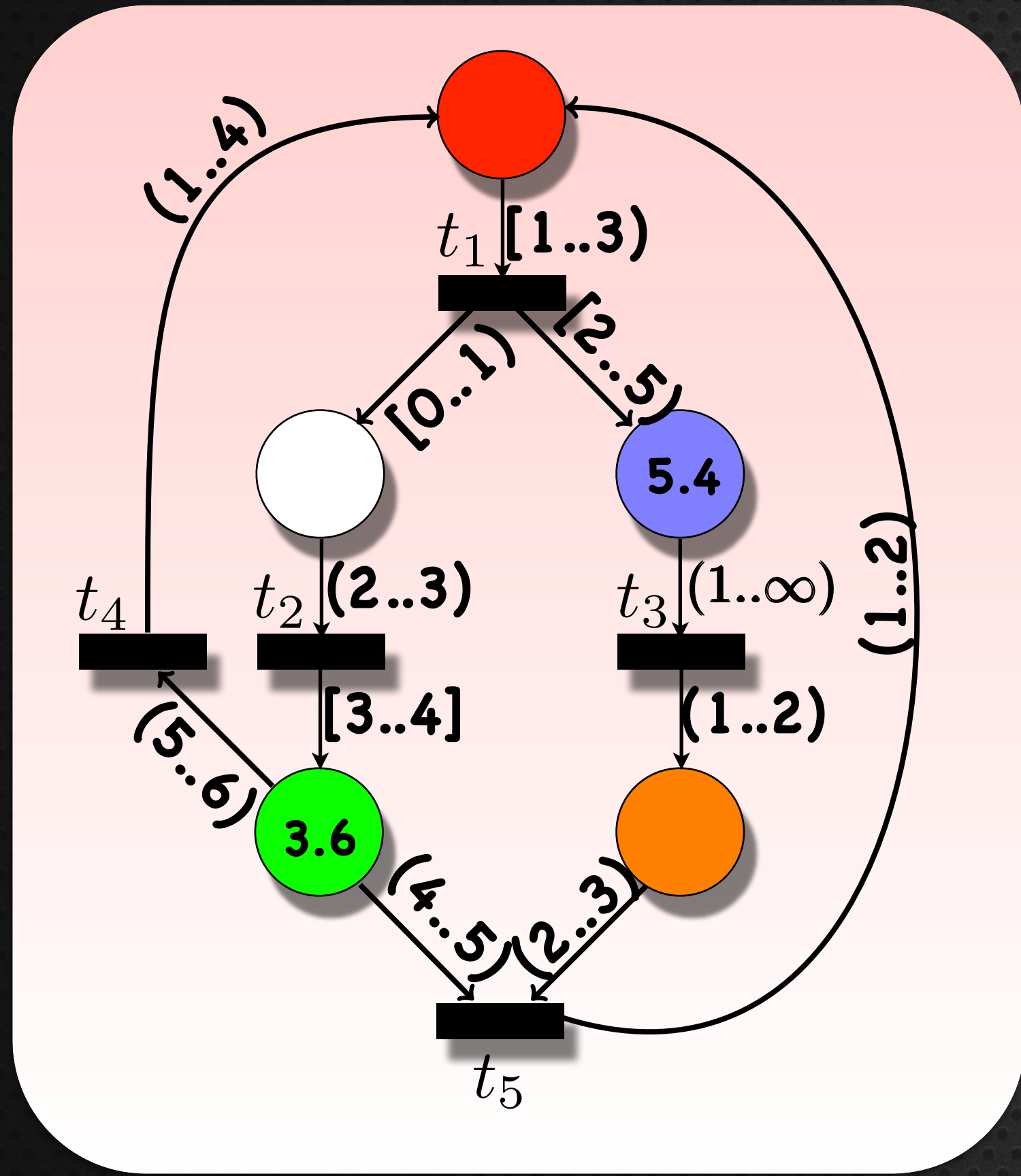
discrete transition

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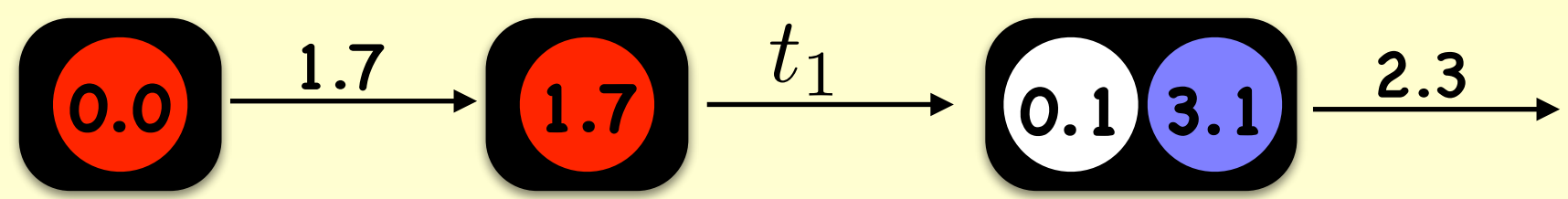
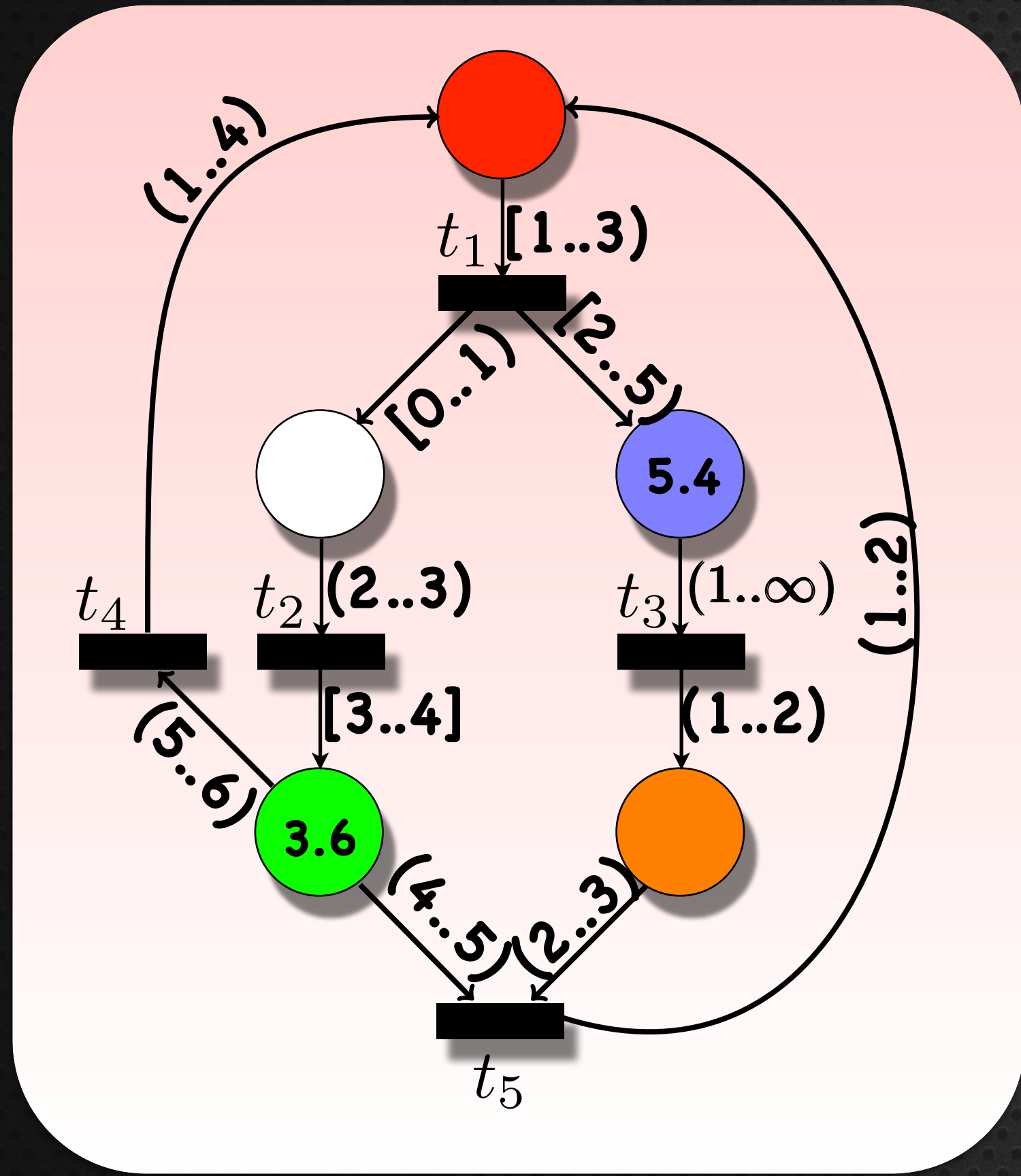
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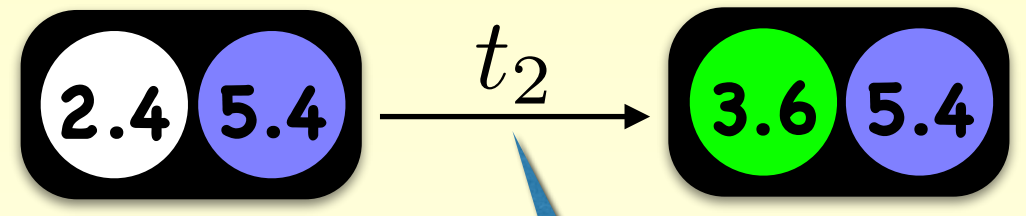
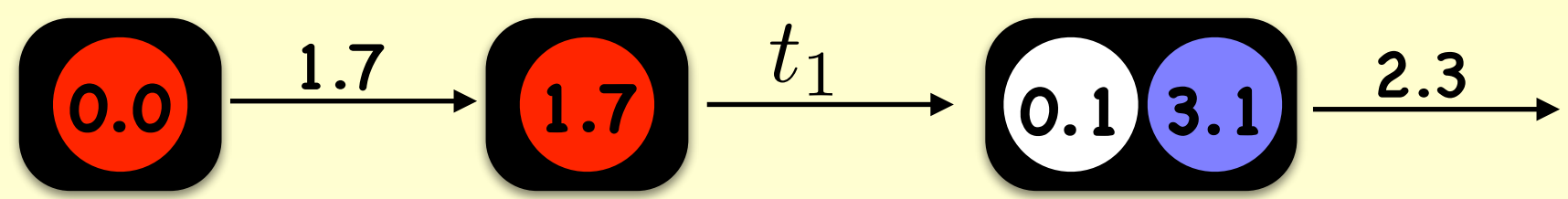
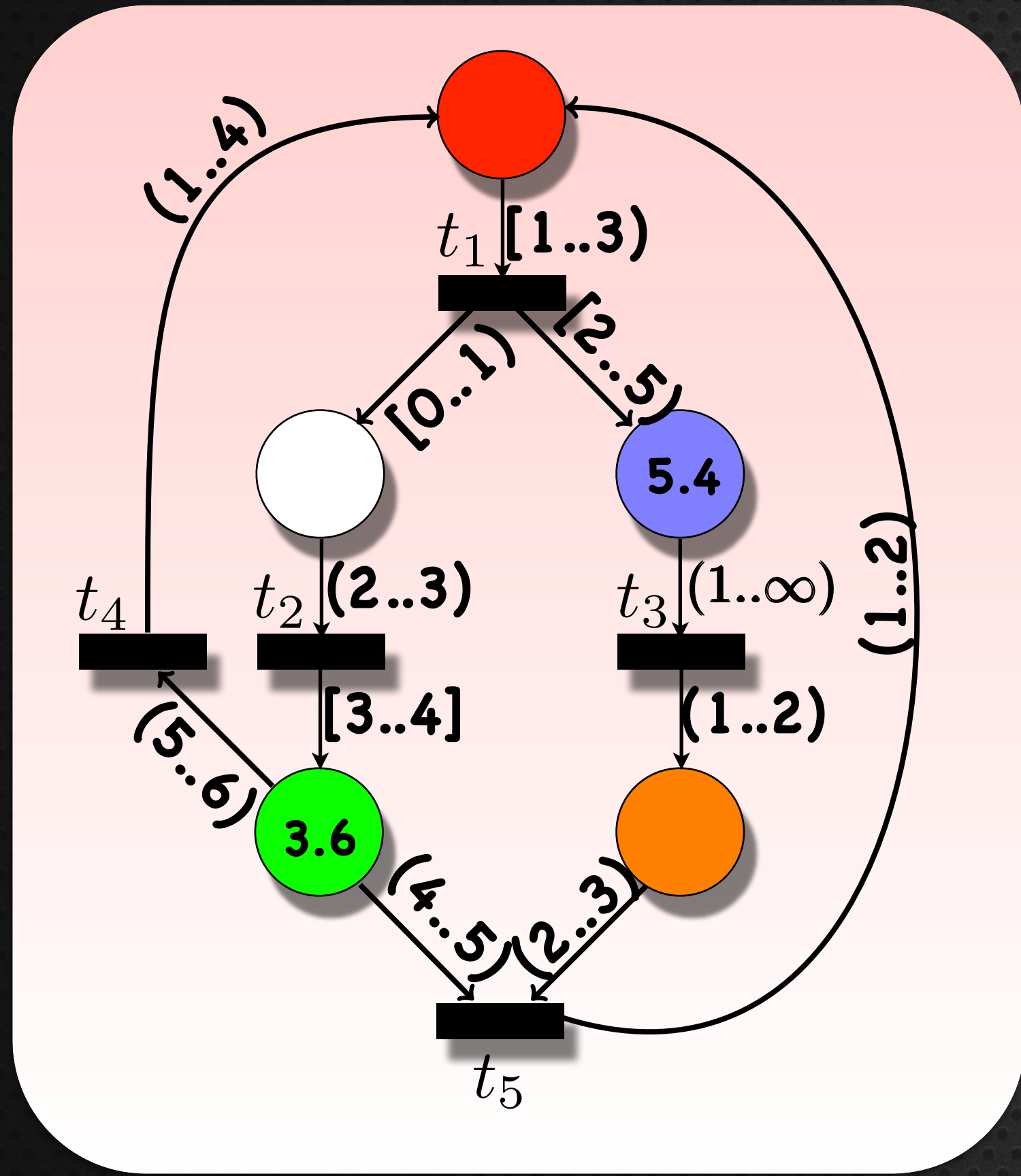
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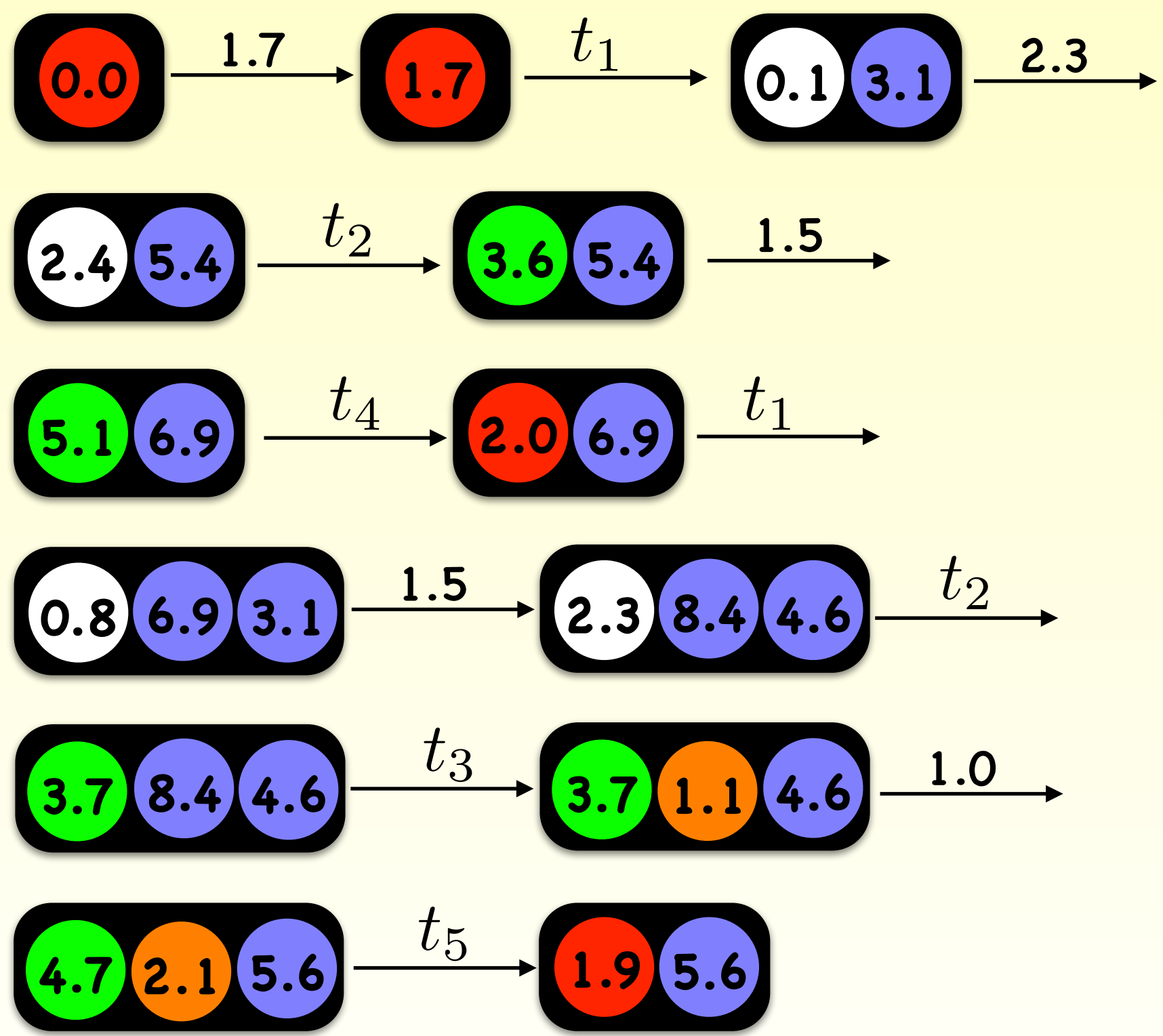
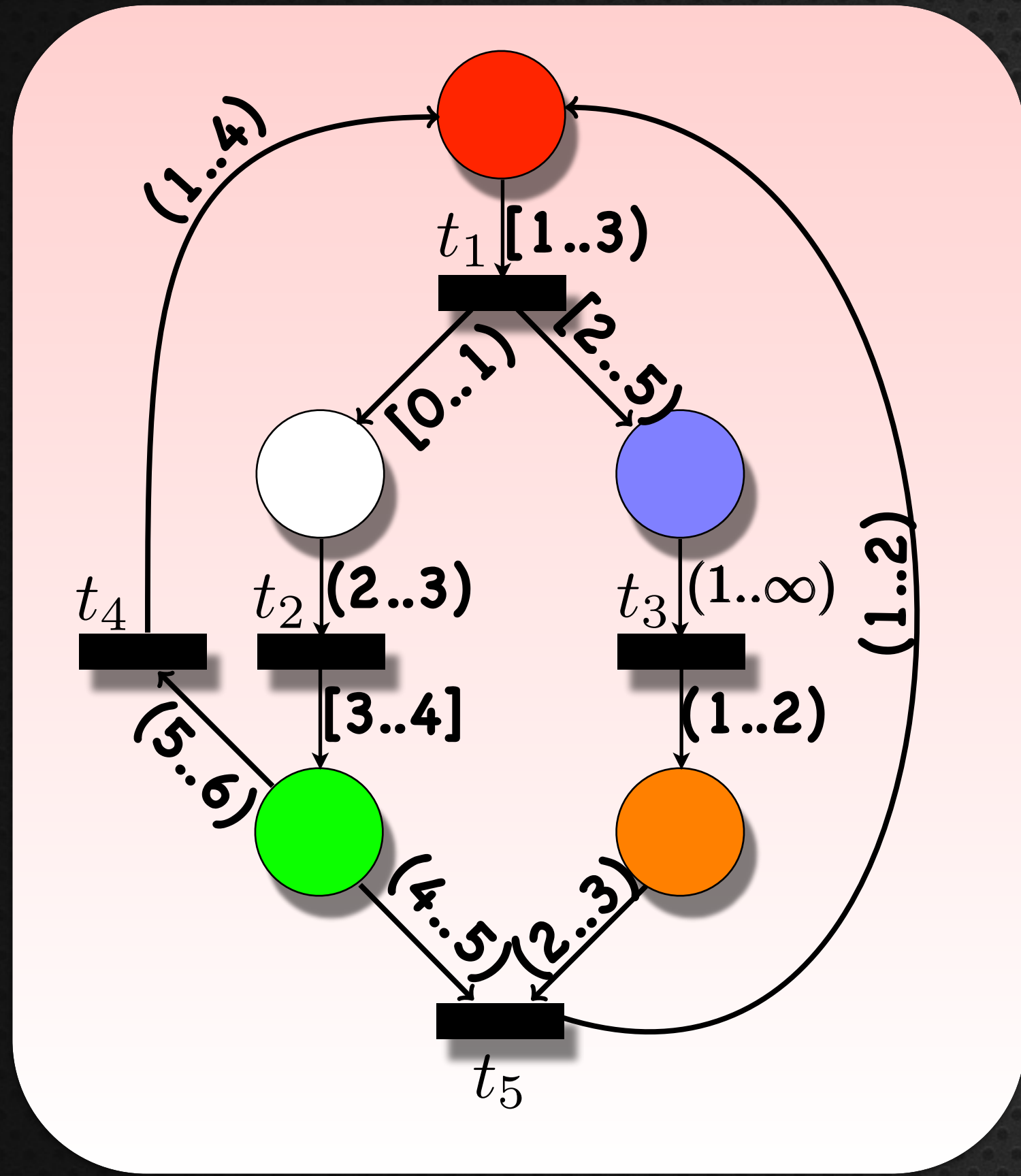
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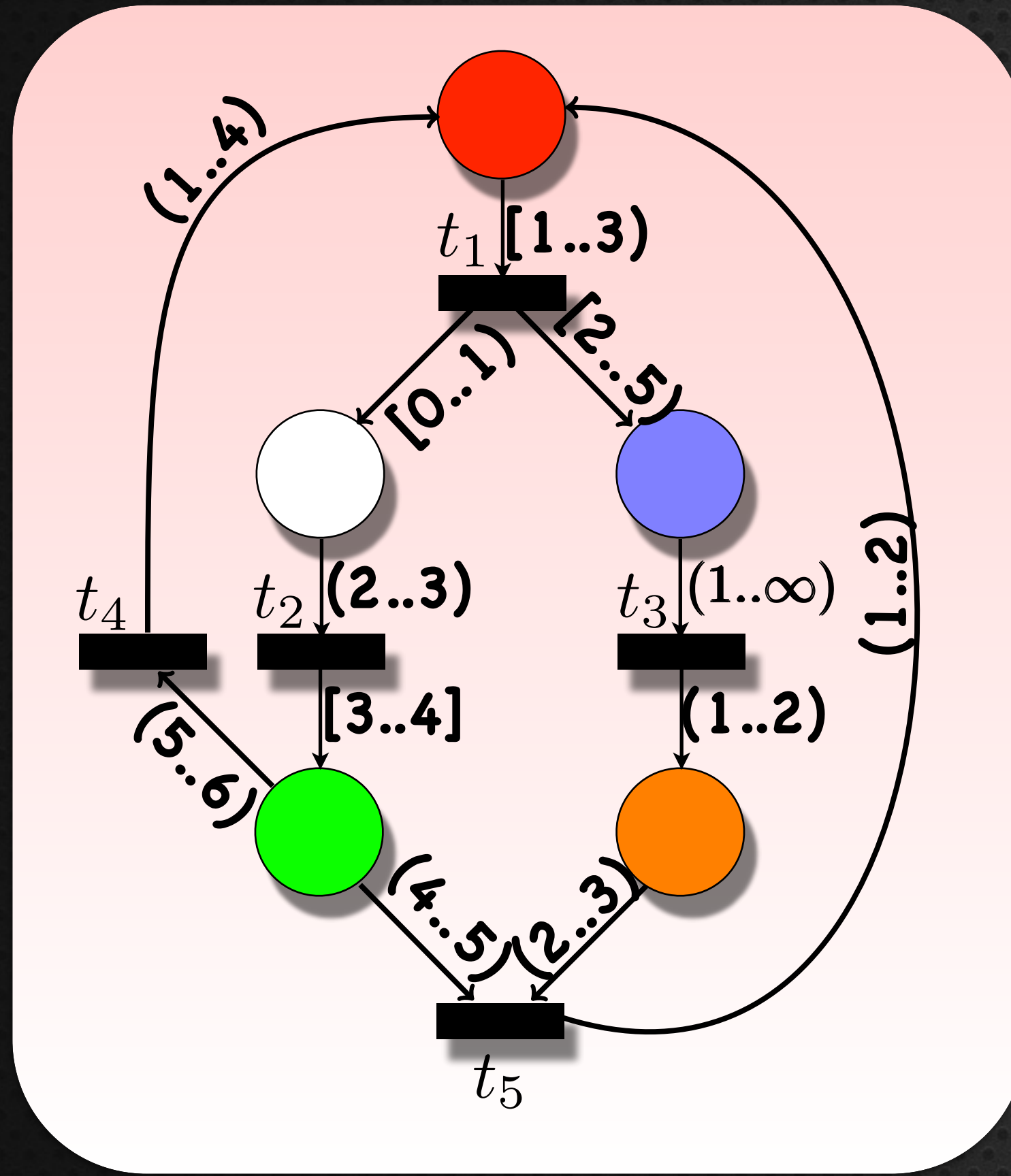


discrete transition

Transitions



Timed Petri Nets



$c_{max}=6$

Timed Petri Nets

Model ✓

Configurations ✓

Transitions ✓

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signatures
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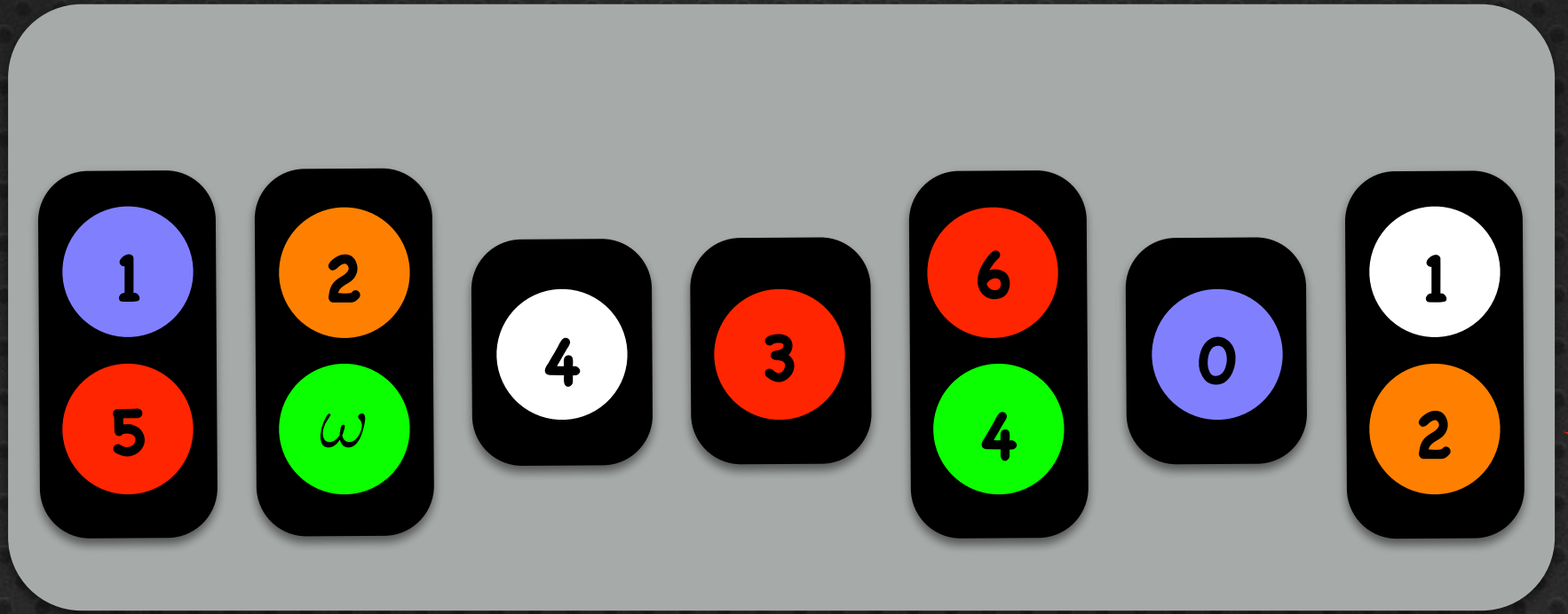
Signatures

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Timed Per

Signatures

$c_{max}=6$

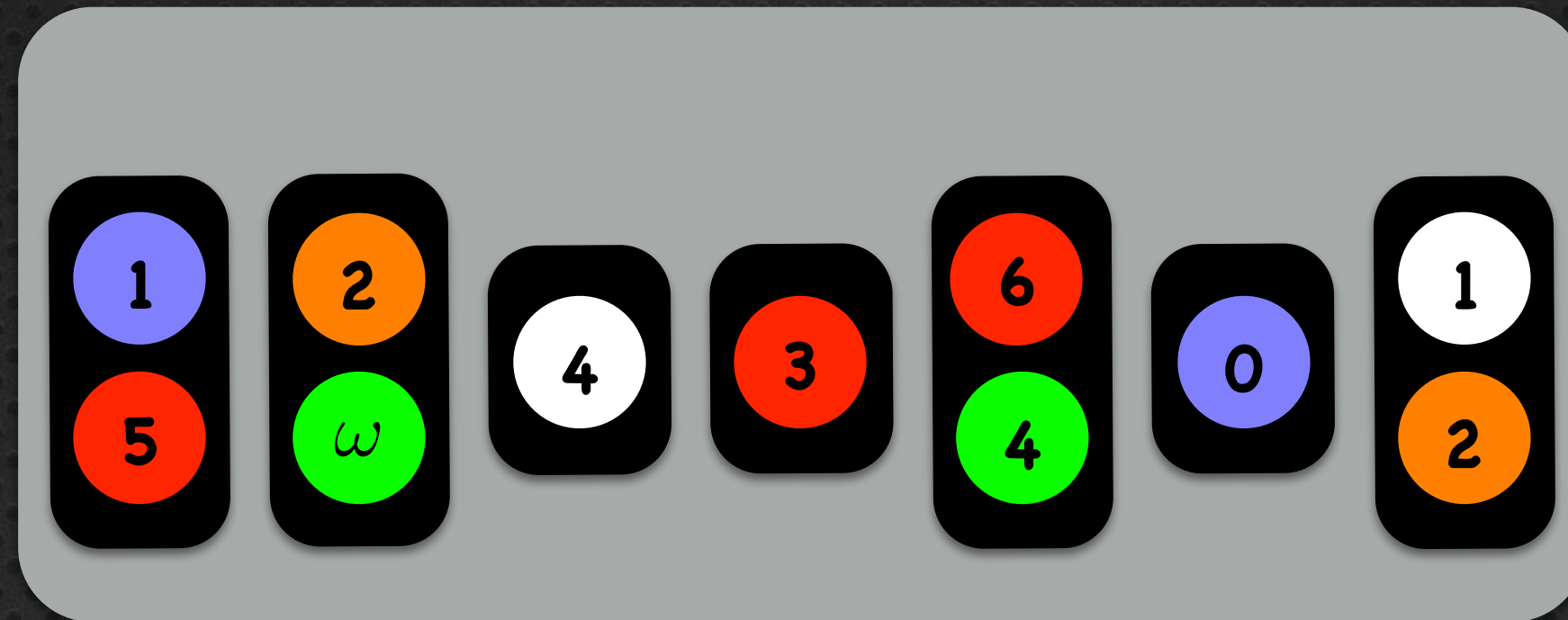


s:
signature

Timed Per.

Signatures

$c_{max}=6$



s:
signature

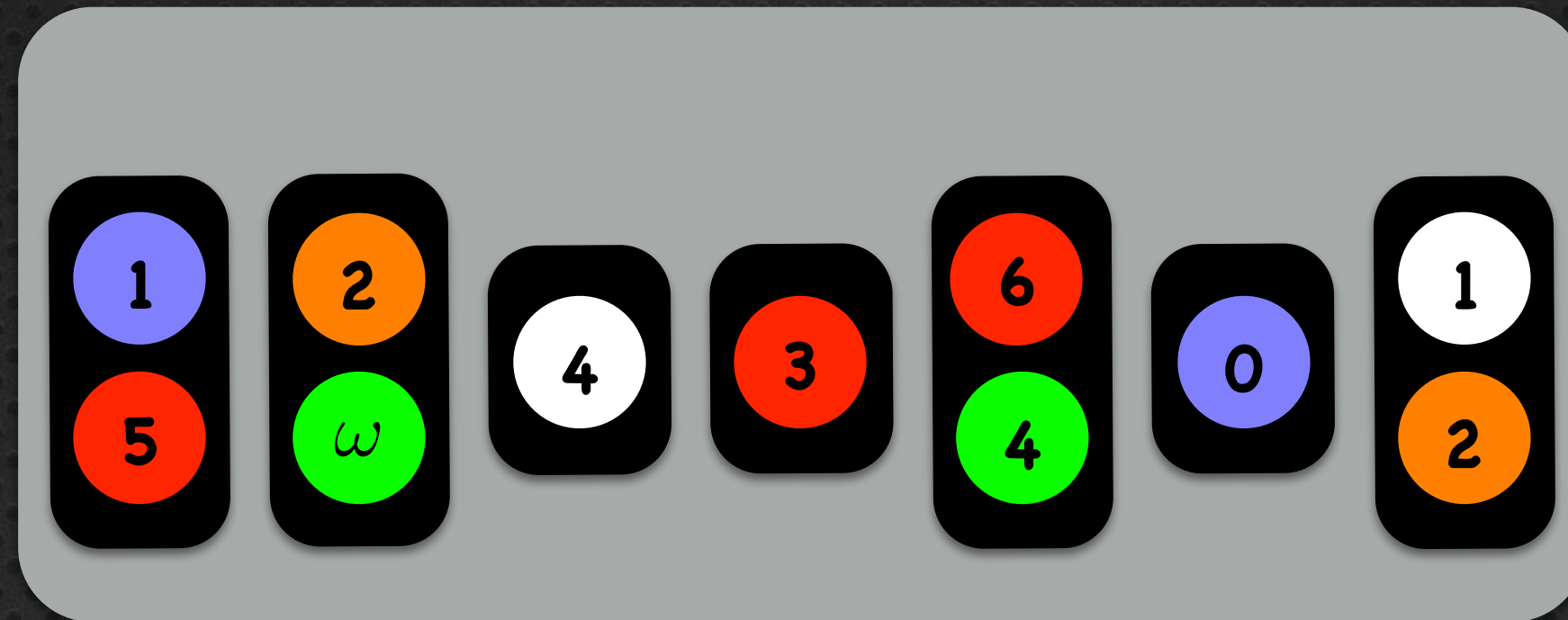
signature:

"sequence of multisets of
colored natural numbers"

Timed Per.

Signatures

$c_{max}=6$



s:
signature

signature:

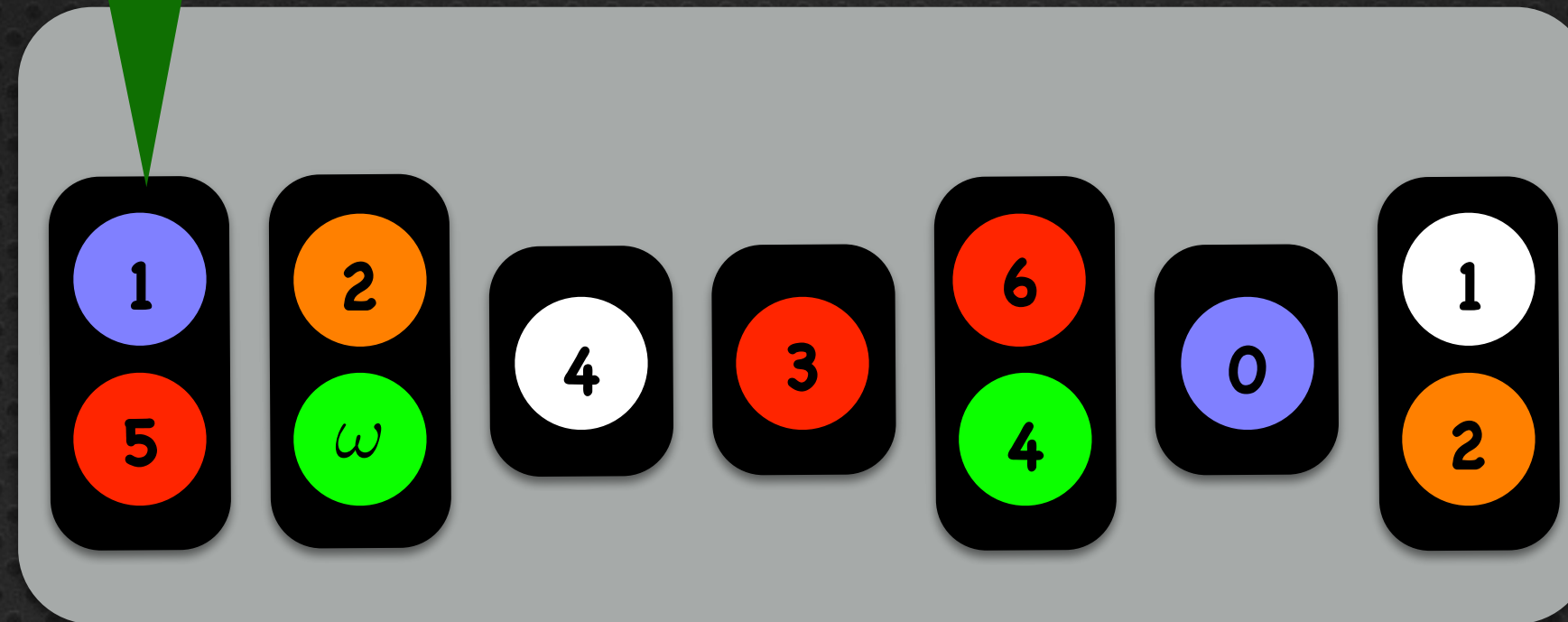
"sequence of multisets of
colored natural numbers"

Timed Per.

Signatures

$c_{max}=6$

multiset



s:
signature

signature:

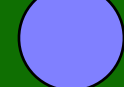
"sequence of multisets of
colored natural numbers"

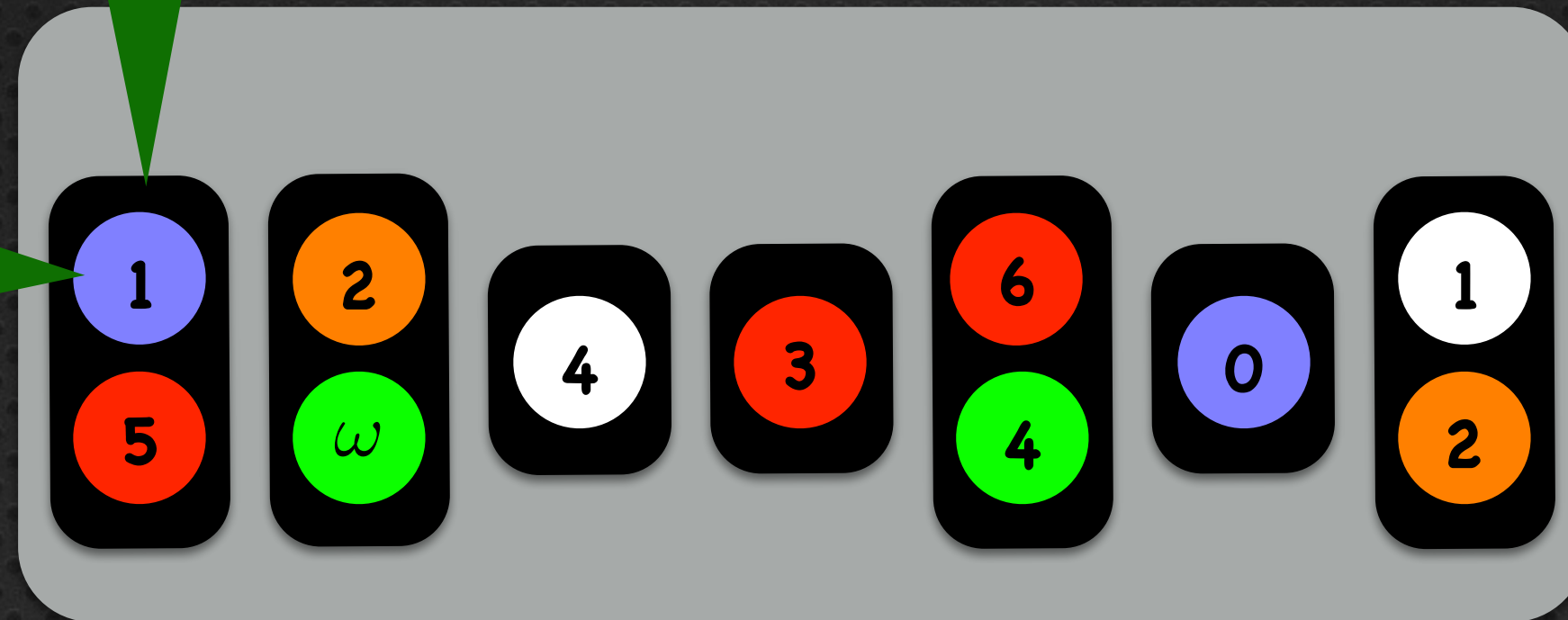
Timed Per.

Signatures

$c_{max}=6$

multiset

- integer part = 1
- place: 



s:
signature

signature:

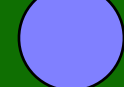
“sequence of multisets of colored natural numbers”


Timed Per.

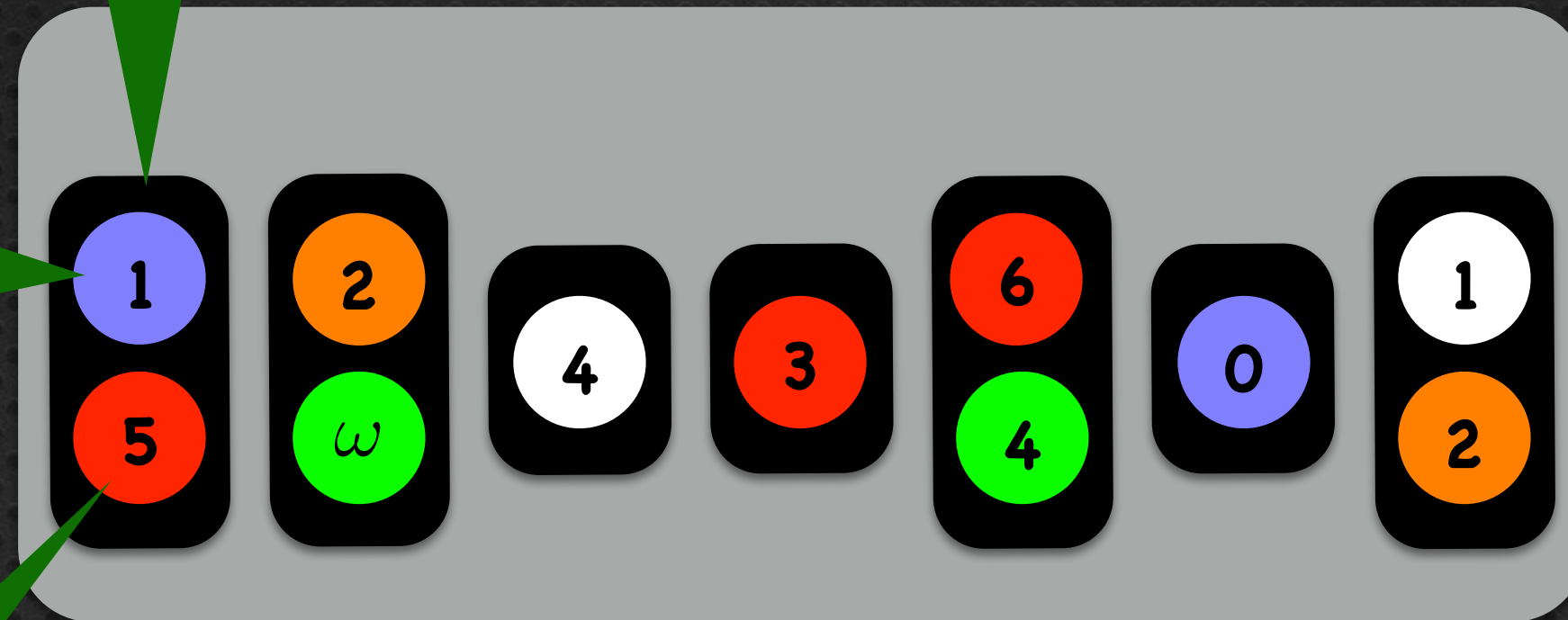
Signatures

$c_{max}=6$

multiset

- integer part = 1
- place: 

- integer part = 5
- place: 



s:
signature

signature:

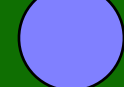
“sequence of multisets of colored natural numbers”

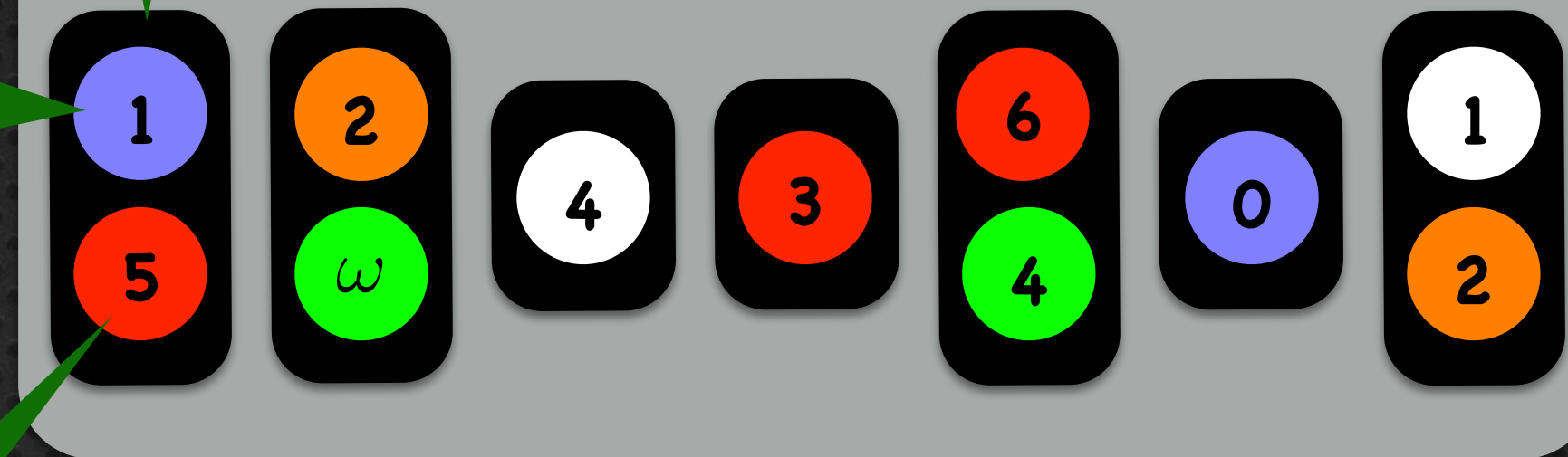
Timed Per.


Signatures

$c_{max}=6$

multiset

- integer part = 1
- place: 



- integer part = 5
- place: 

s:
signature

signature:

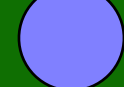
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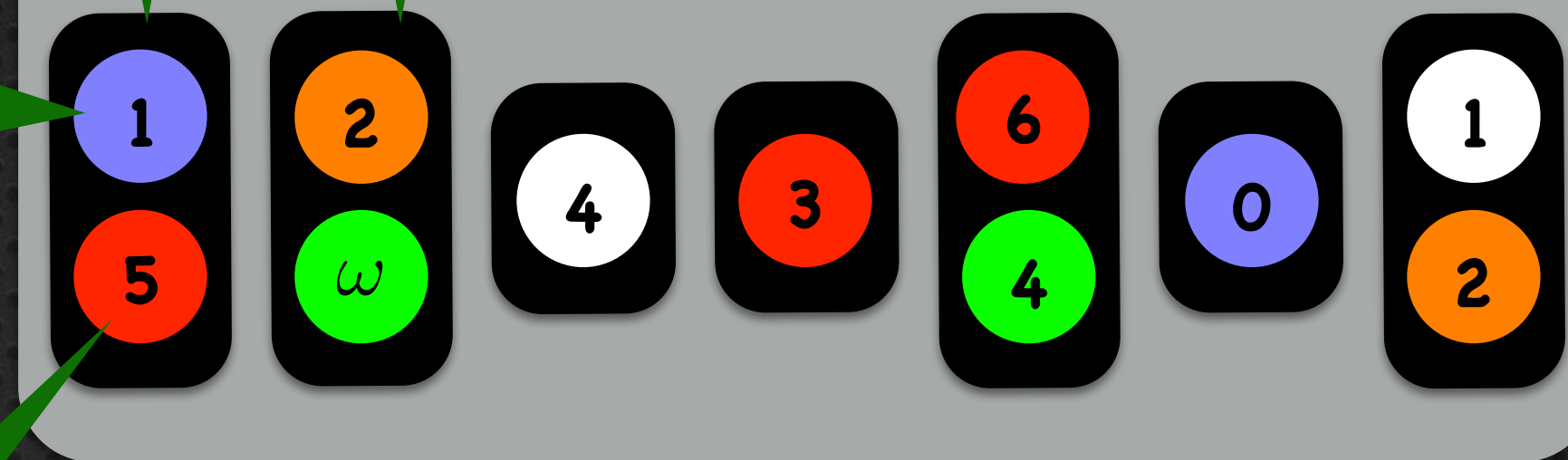
Timed Per.


Signatures

$c_{max}=6$

multiset multiset

- integer part = 1
- place: 



- integer part = 5
- place: 

s:
signature

signature:
"sequence of multisets of
colored natural numbers"

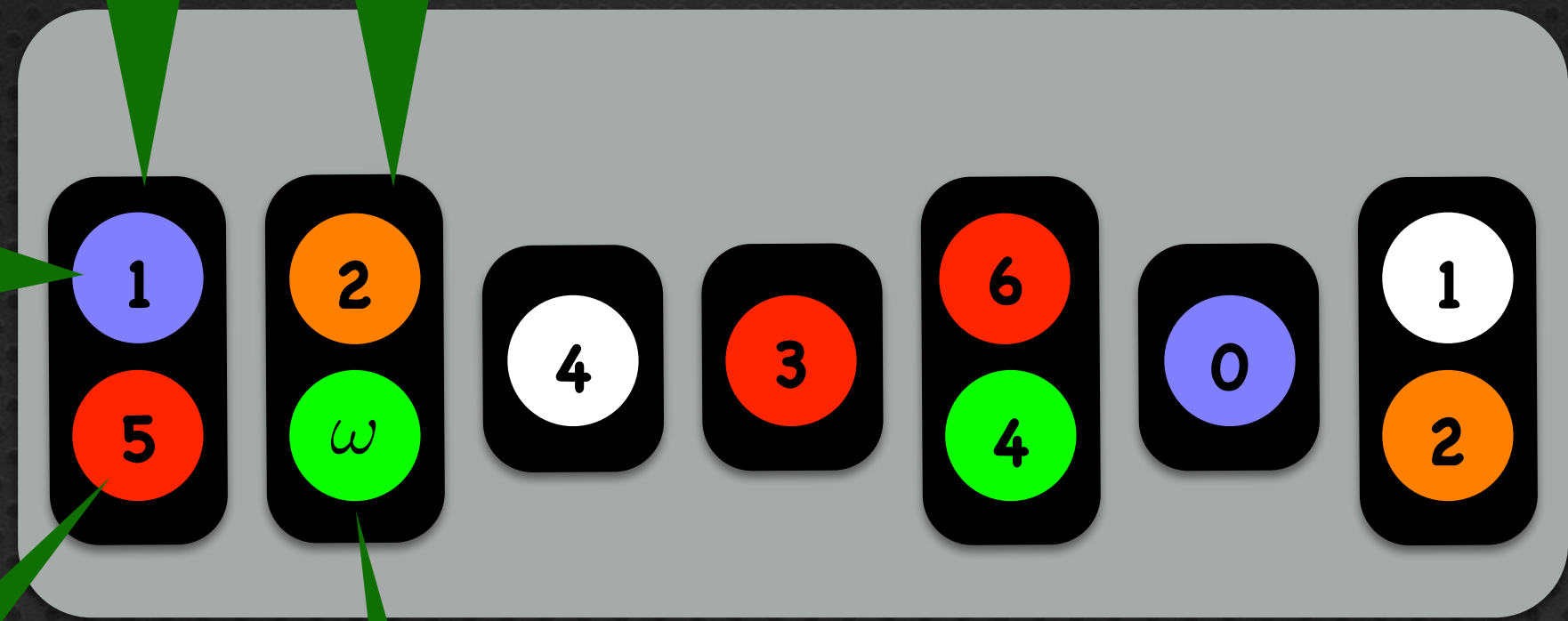
Timed Per.

Signatures

$c_{max}=6$

multiset multiset

- integer part = 1
- place: ●



s:
signature

- integer part = 5
- place: ●

- integer part > c_{max}
- place: ●

signature:
"sequence of multisets of colored natural numbers"

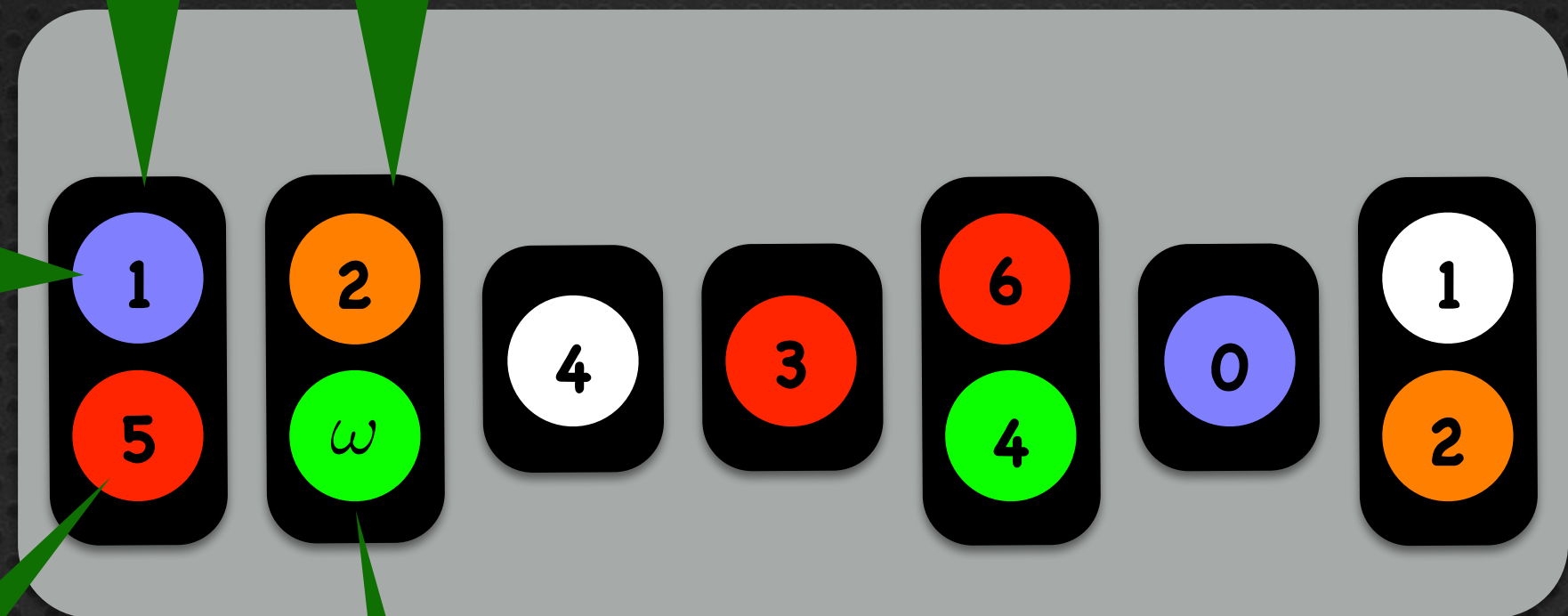
Timed Per.

Signatures

$c_{max}=6$

multiset multiset

• integer part = 1
• place: ●



s:
signature

• integer part = 5
• place: ●

• integer part > c_{max}
• place: ●

signature:
"sequence of multisets of colored natural numbers"

Timed Per.

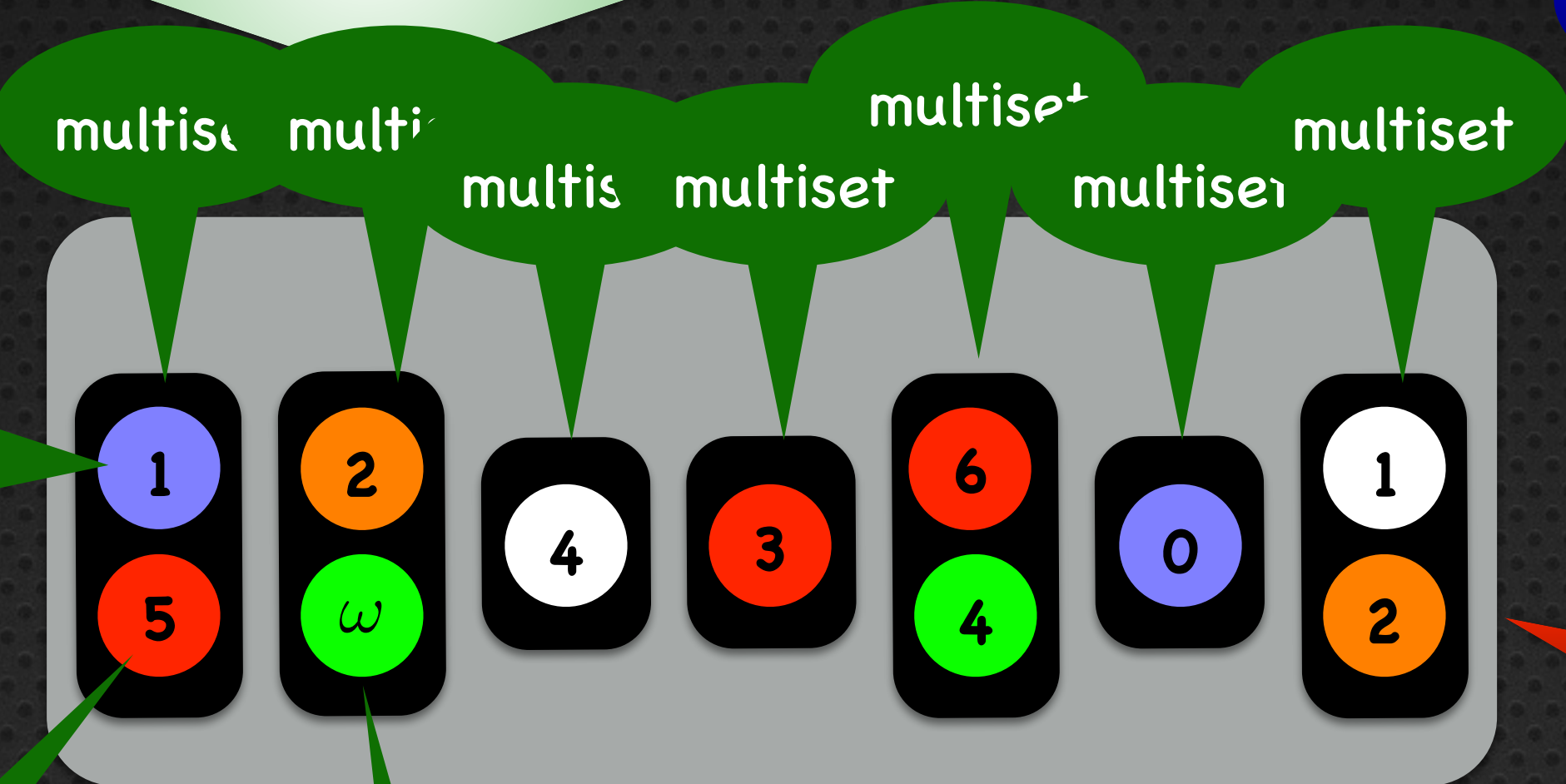
Signatures

$c_{max}=6$

- integer part = 1
- place: ●

- integer part = 5
- place: ●

- integer part > c_{max}
- place: ●



s:
signature

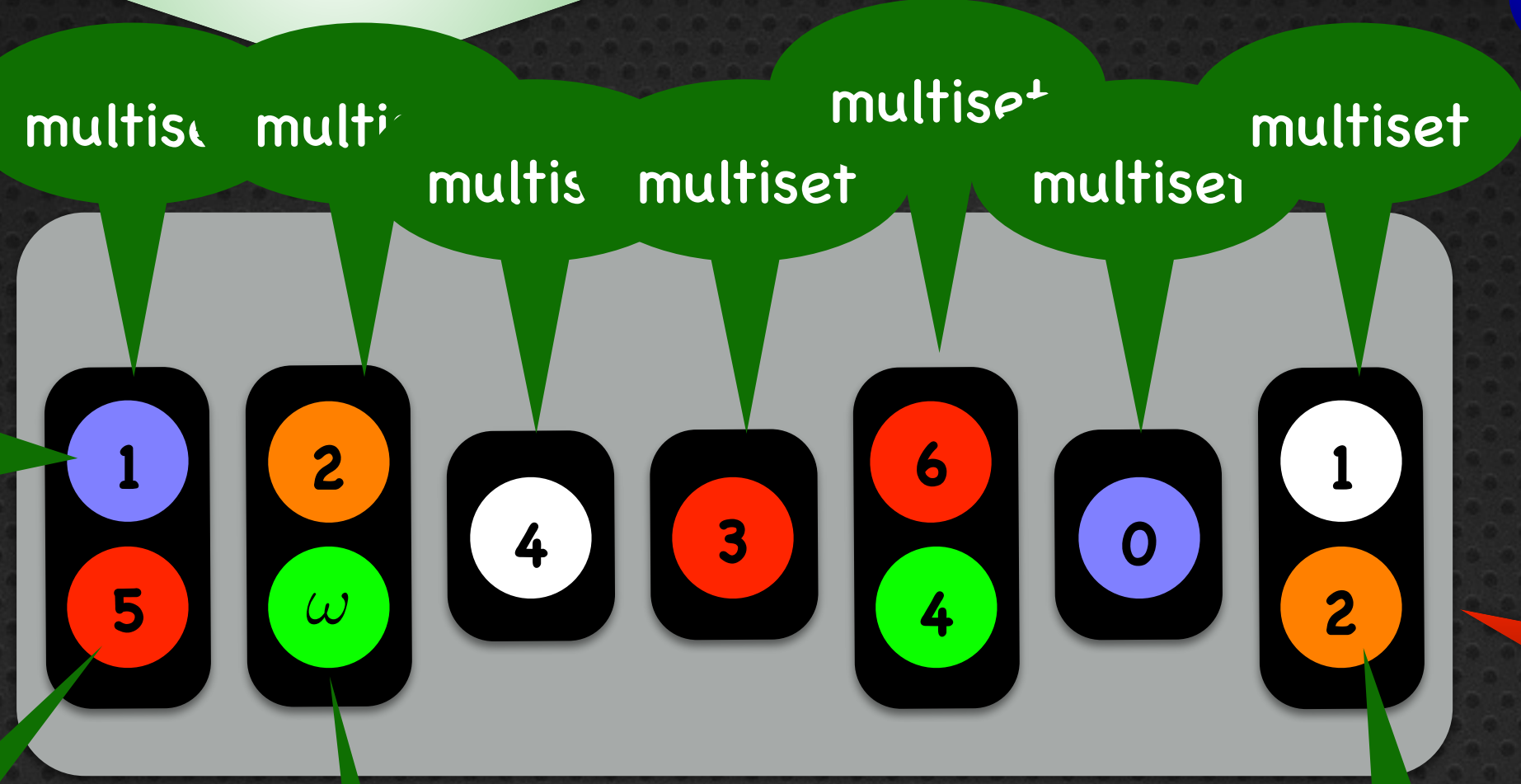
signature:
"sequence of multisets of colored natural numbers"

Timed Per.

Signatures

$c_{max}=6$

- integer part = 1
- place: ●



- integer part = 5
- place: ●

- integer part > c_{max}
- place: ●

- integer part = 2
- place: ●

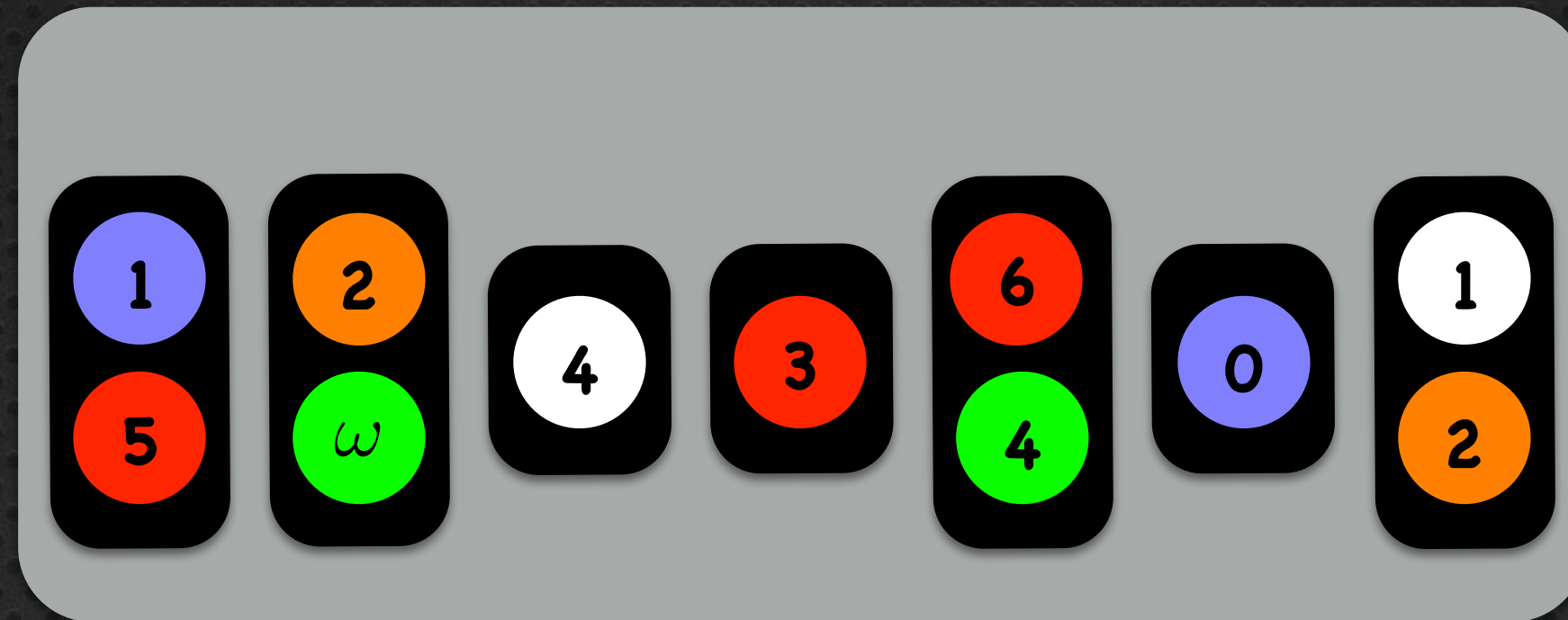
s:
signature

signature:
"sequence of multisets of colored natural numbers"

Timed Per.

Signatures

$c_{max}=6$



s:
signature

signature:

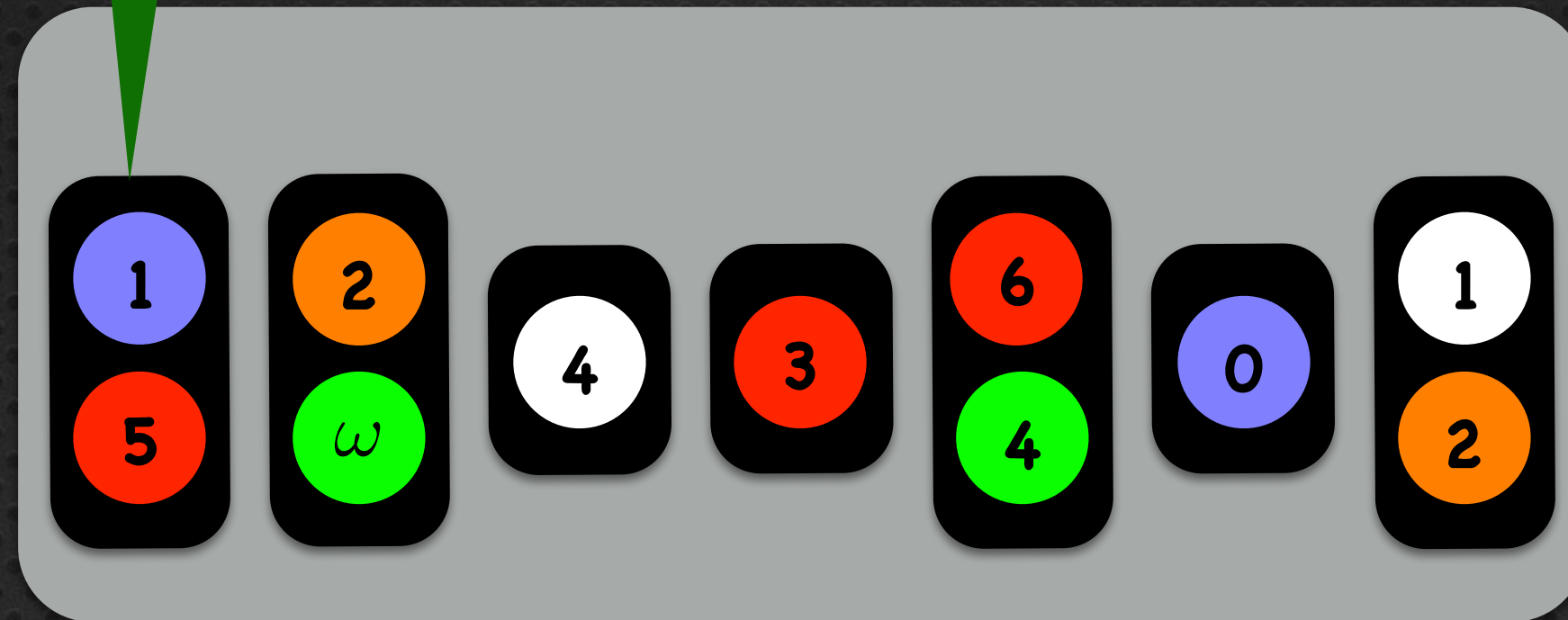
"sequence of multisets of
colored natural numbers"

Timed Per.

Signatures

$c_{max}=6$

zero
fractional
part



s:
signature

signature:

"sequence of multisets of
colored natural numbers"

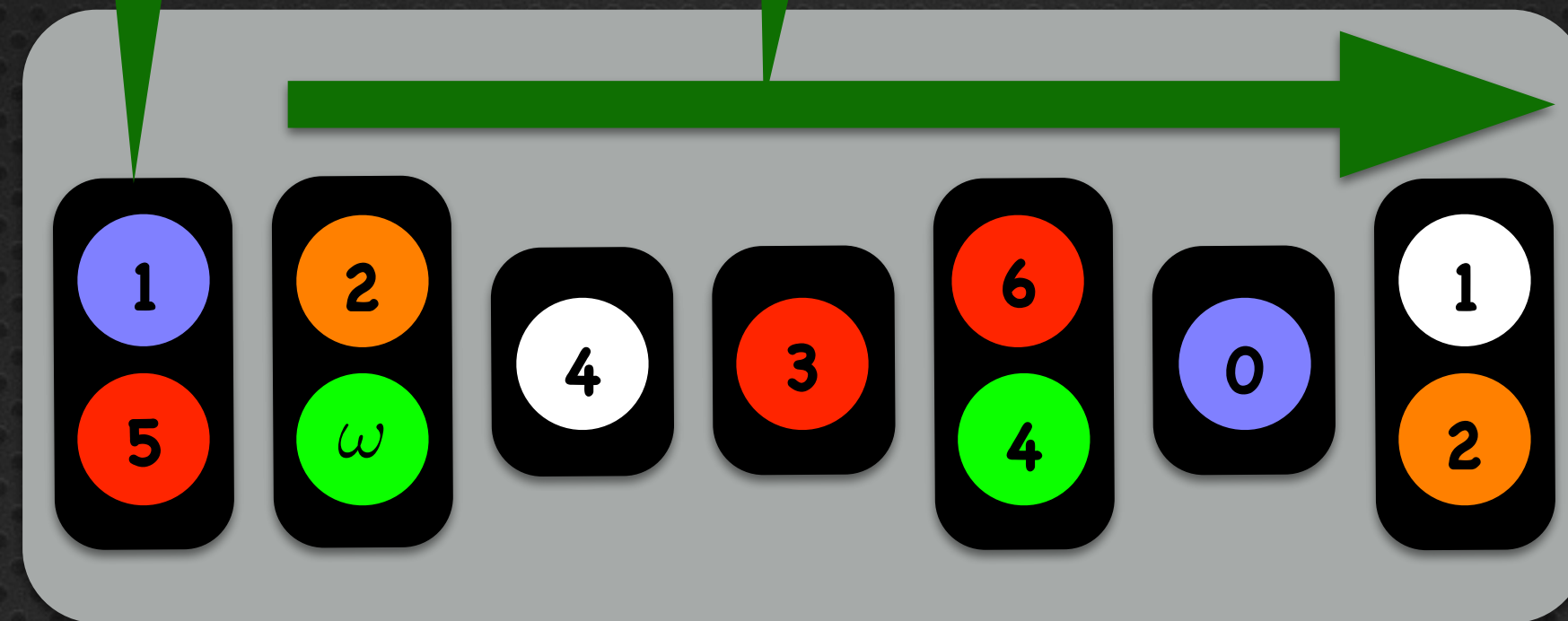
Timed Per.

Signatures

zero fractional part

increasing fractional parts

$c_{max}=6$



s:
signature

signature:

"sequence of multisets of colored natural numbers"

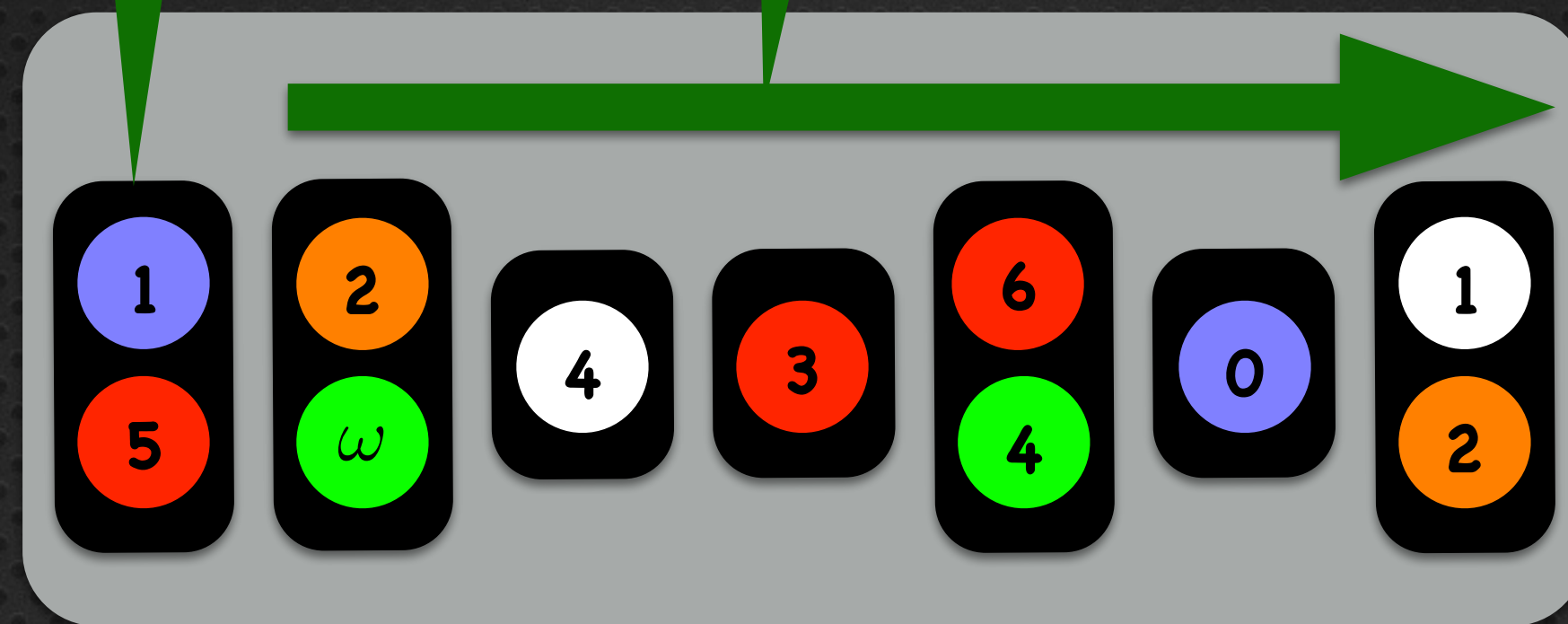
Timed Per.

Signatures

zero fractional part

increasing fractional parts

$c_{max}=6$



s:
signature

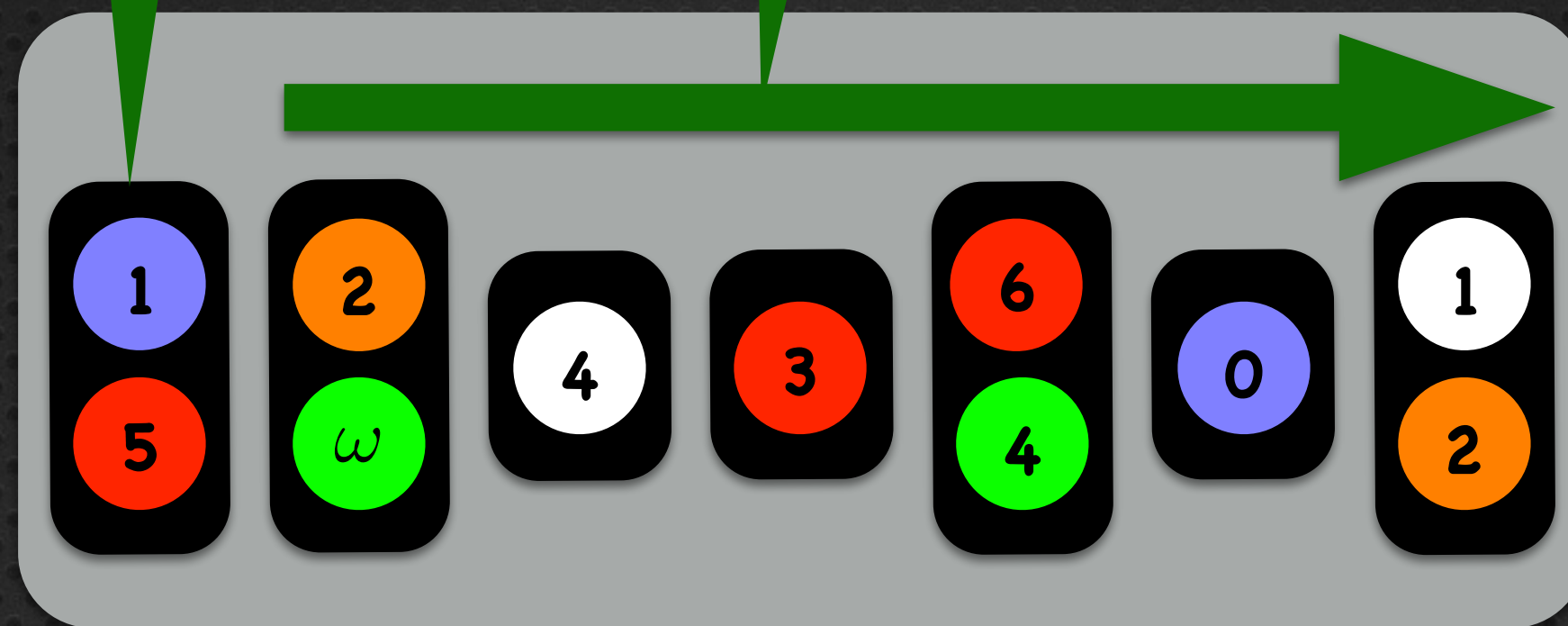
Timed Per.

Signatures

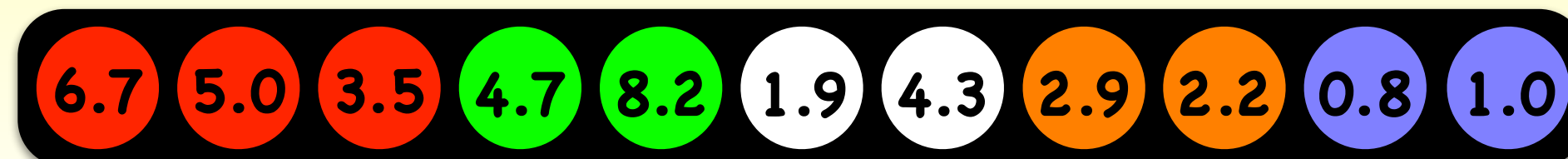
zero fractional part

increasing fractional parts

$c_{max}=6$



s:
signature



c:
configuration

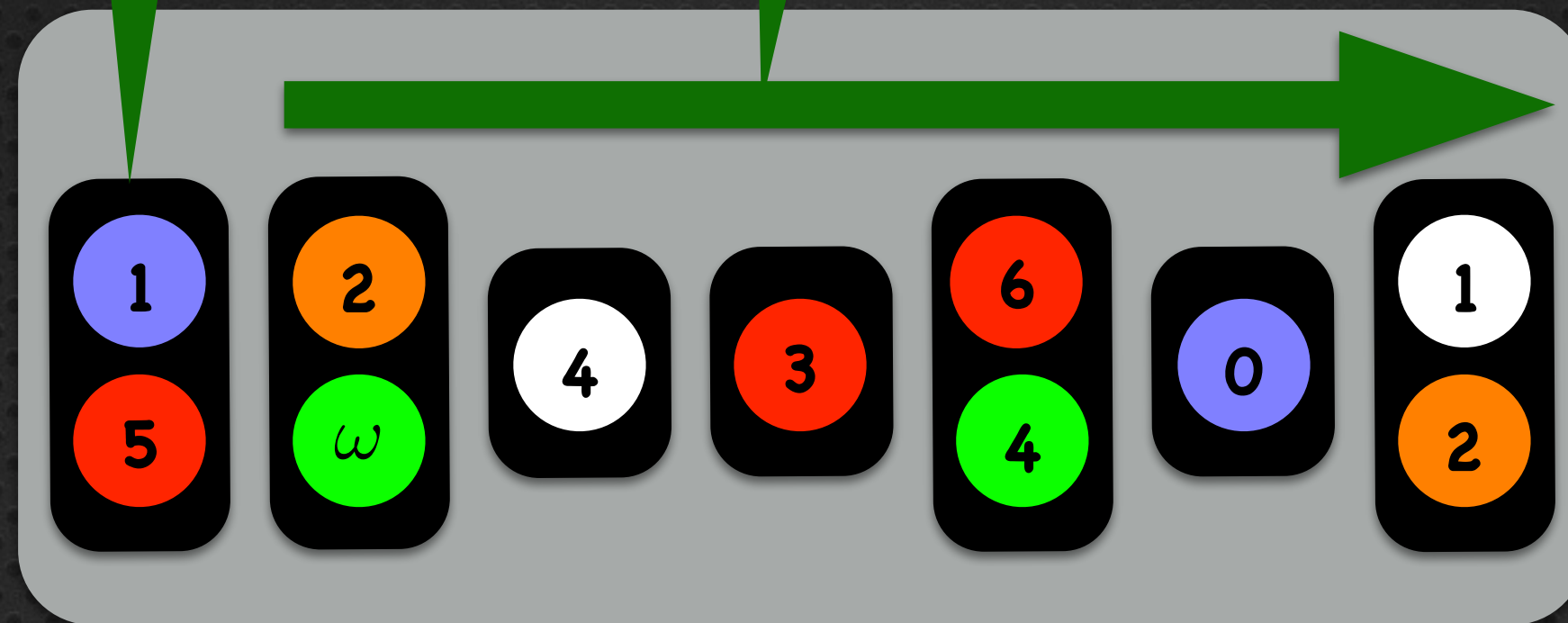
Timed Per.

Signatures

zero fractional part

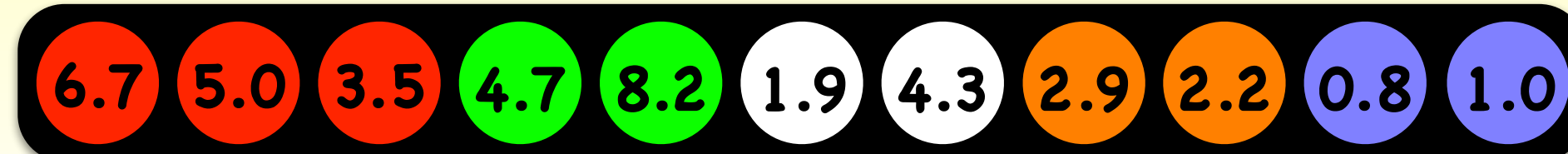
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

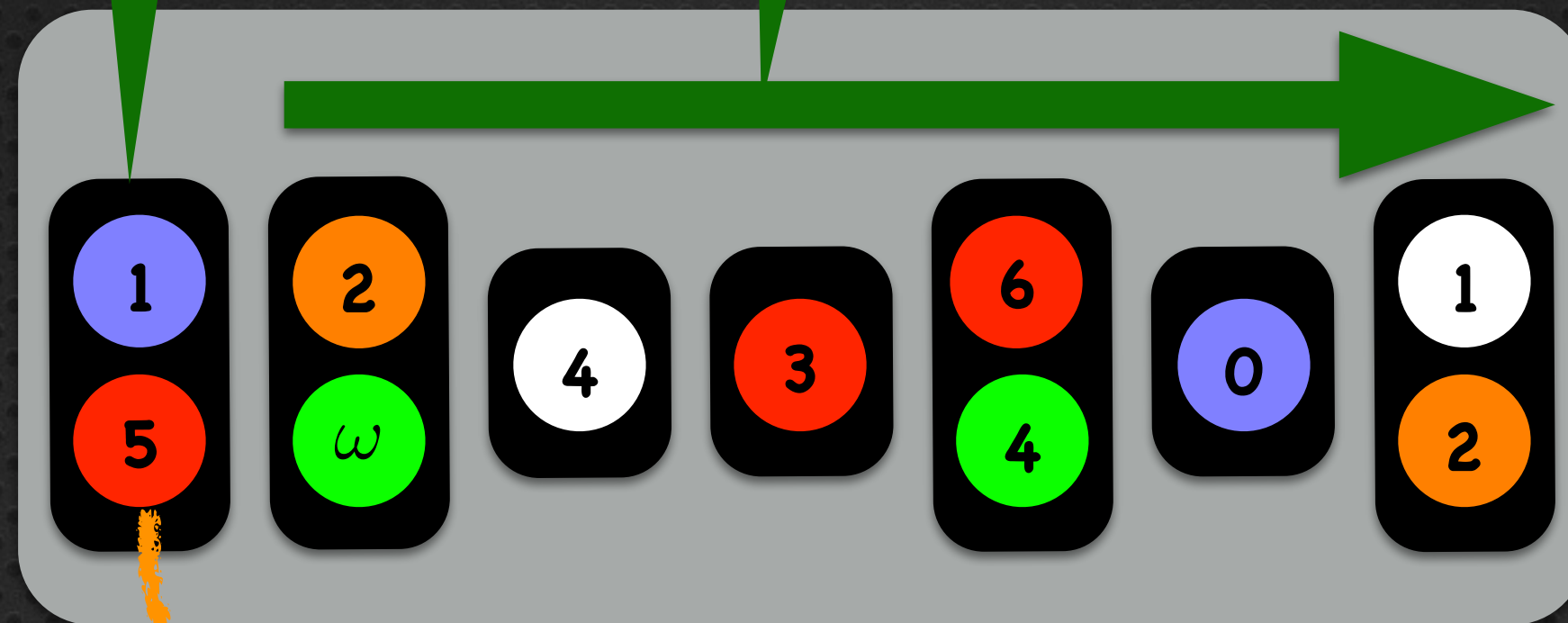
Timed Per.

Signatures

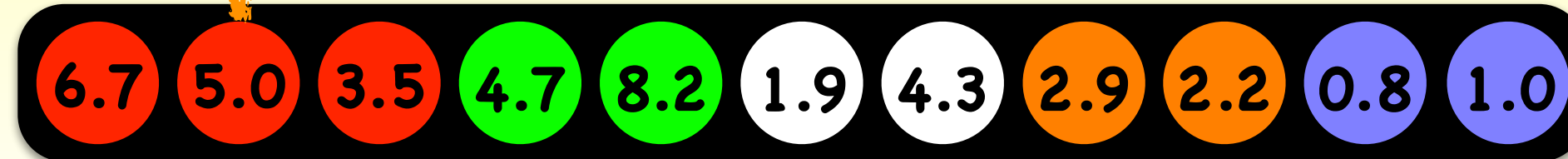
$c_{max}=6$

zero fractional part

increasing fractional parts



$$\text{sig}(c) = s$$



c:
configuration

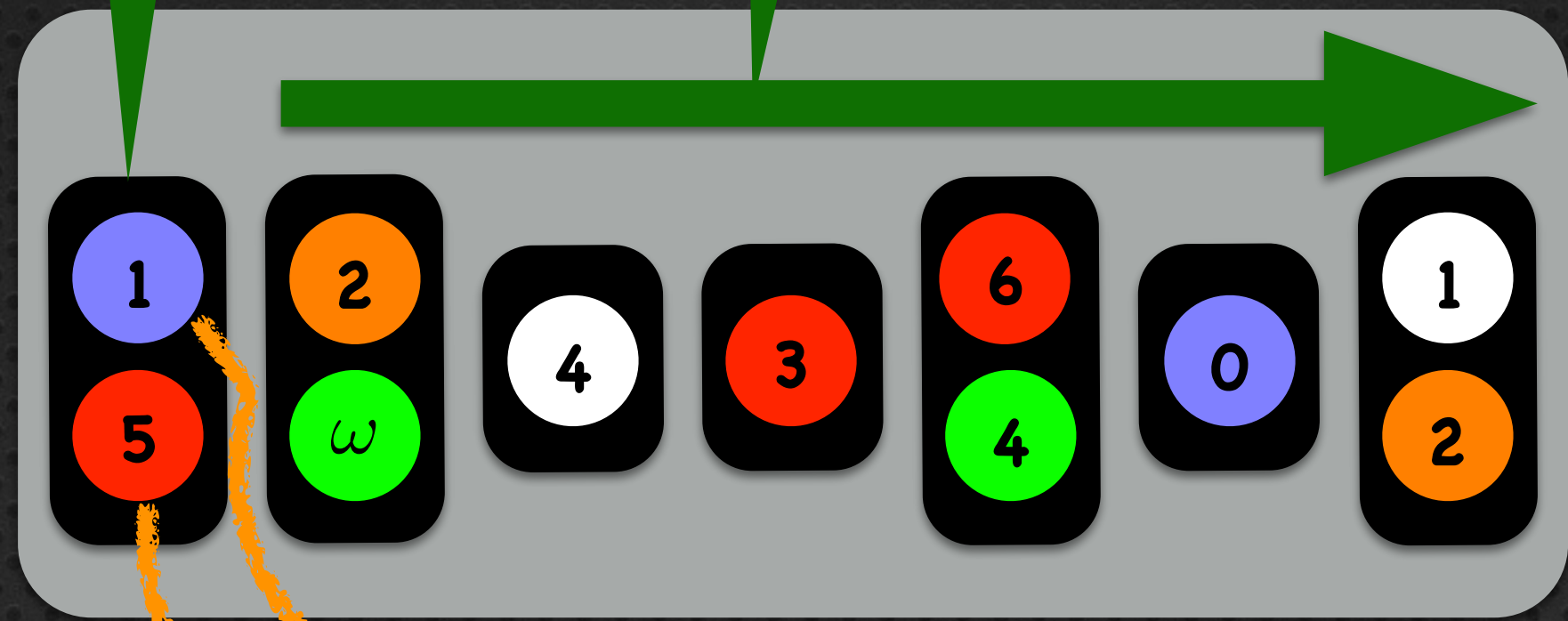
Timed Per.

Signatures

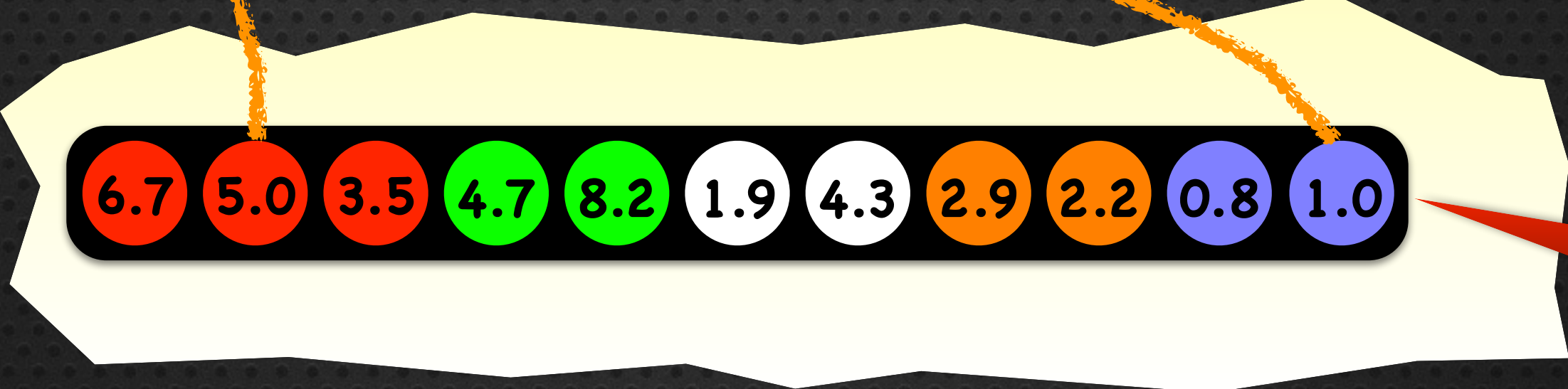
$c_{max}=6$

zero fractional part

increasing fractional parts



$\text{sig}(c) = s$



c:
configuration

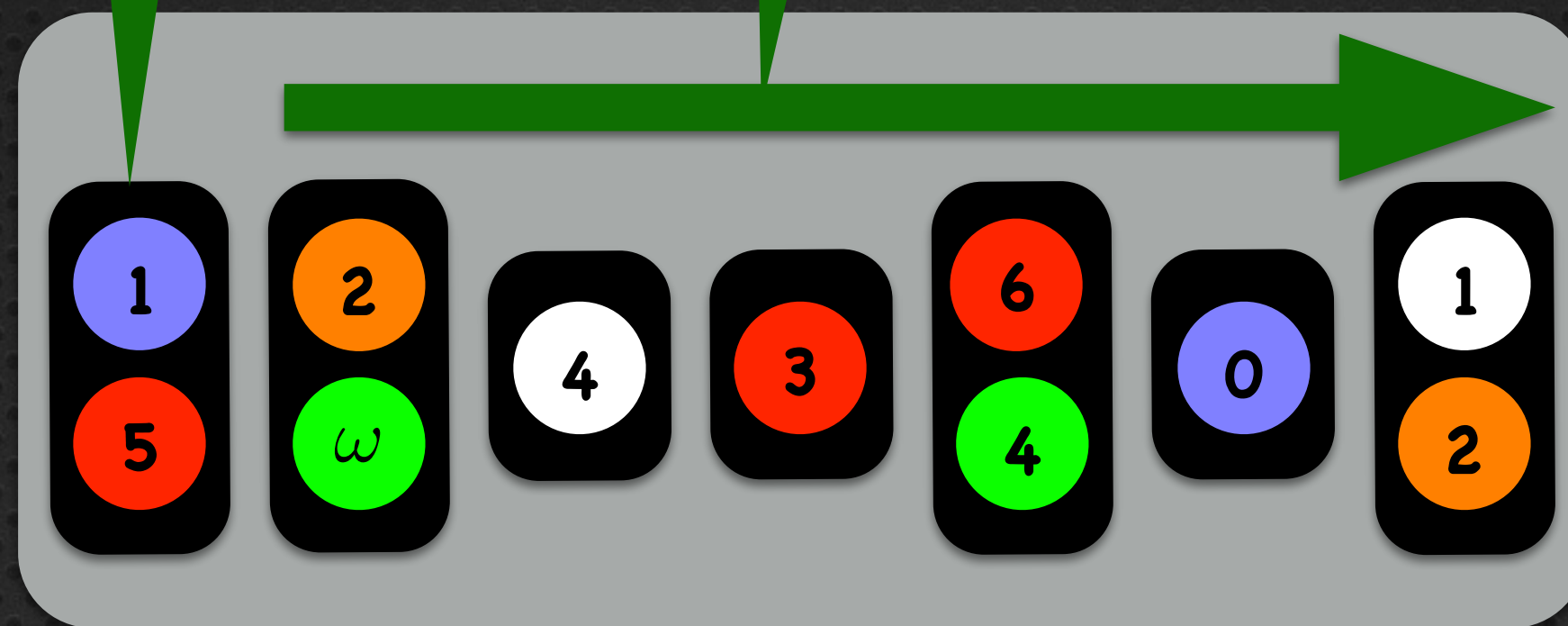
Timed Per.

Signatures

zero fractional part

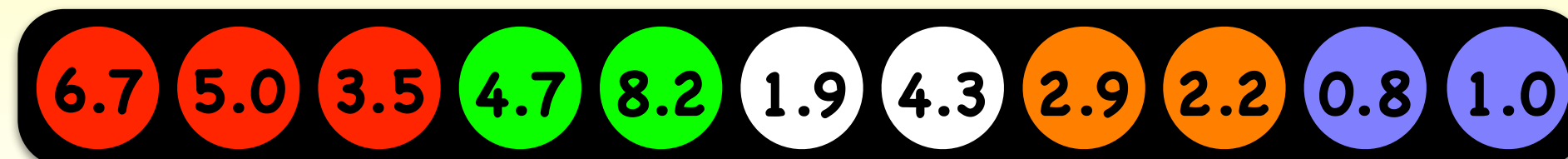
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

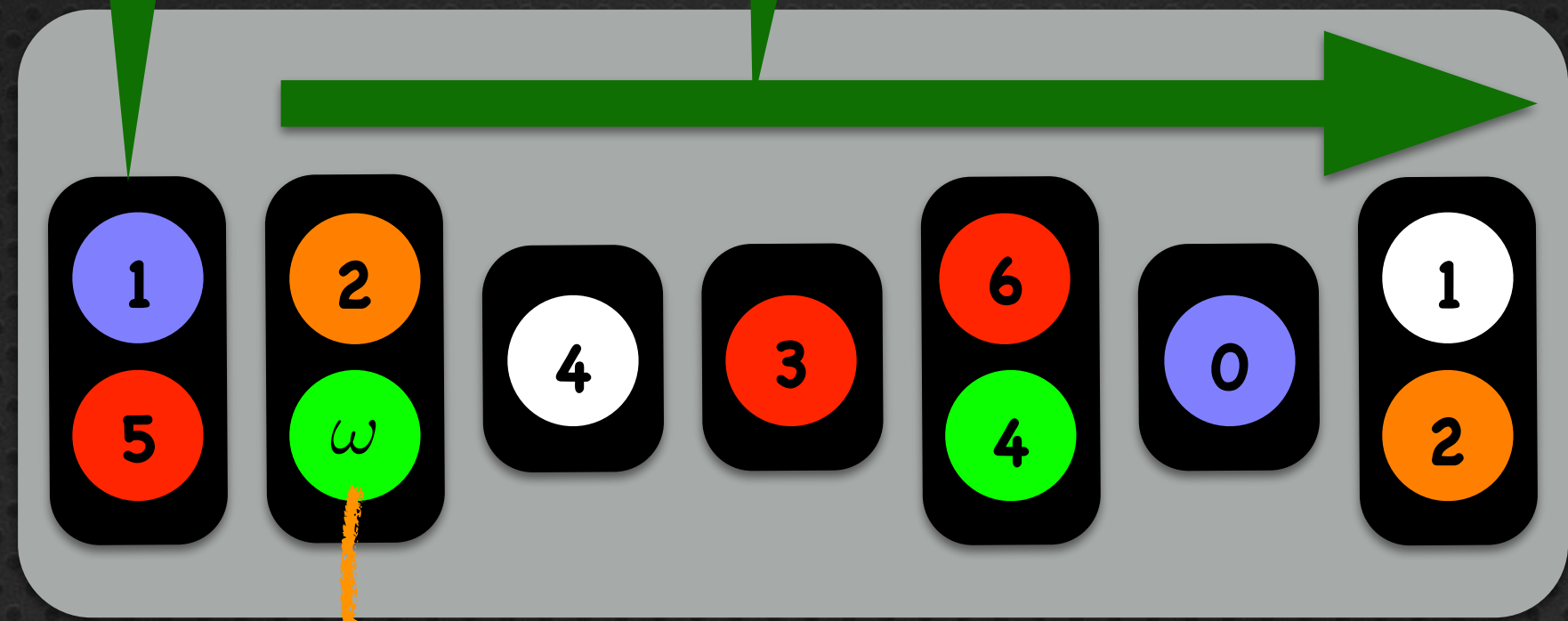
Timed Per.

Signatures

$c_{max}=6$

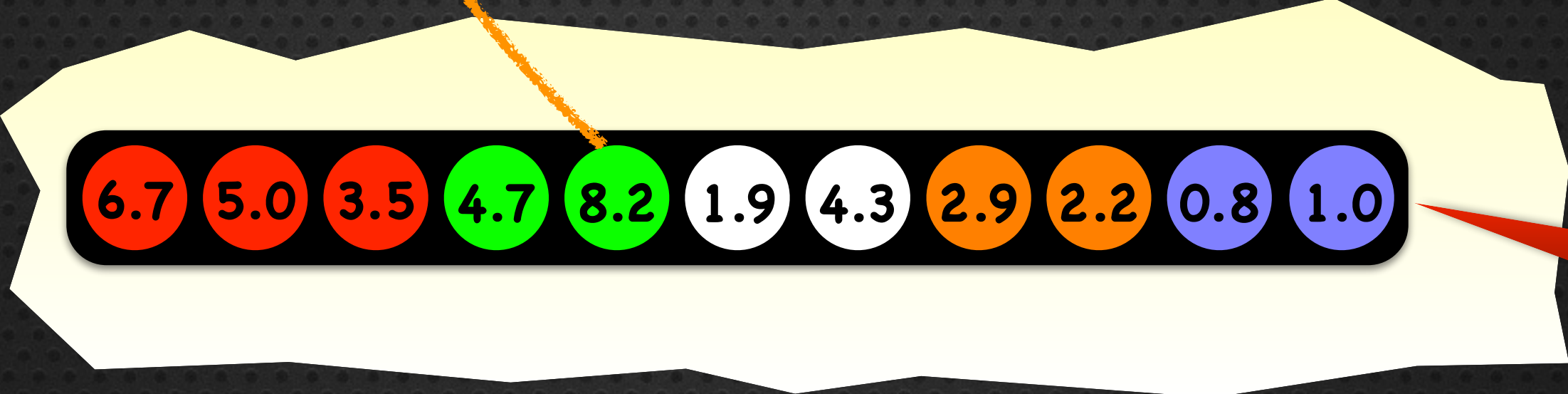
zero fractional part

increasing fractional parts



s:
signature

$\text{sig}(c) = s$



c:
configuration

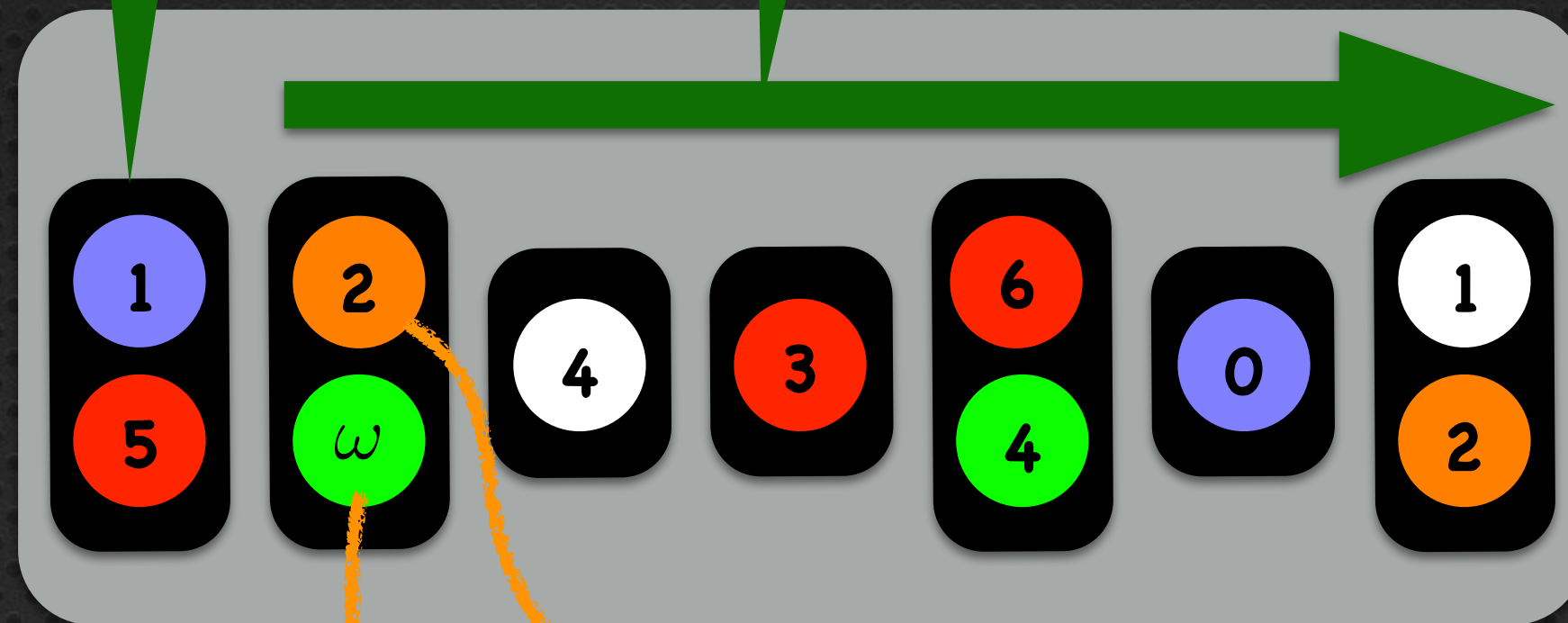
Timed Per.

Signatures

$c_{max}=6$

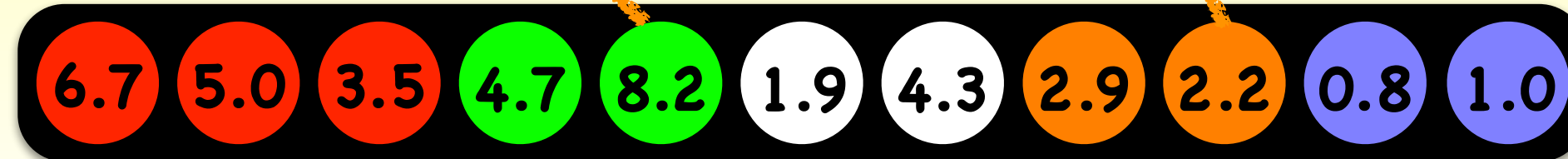
zero fractional part

increasing fractional parts



$$\text{sig}(c) = s$$

s:
signature



c:
configuration

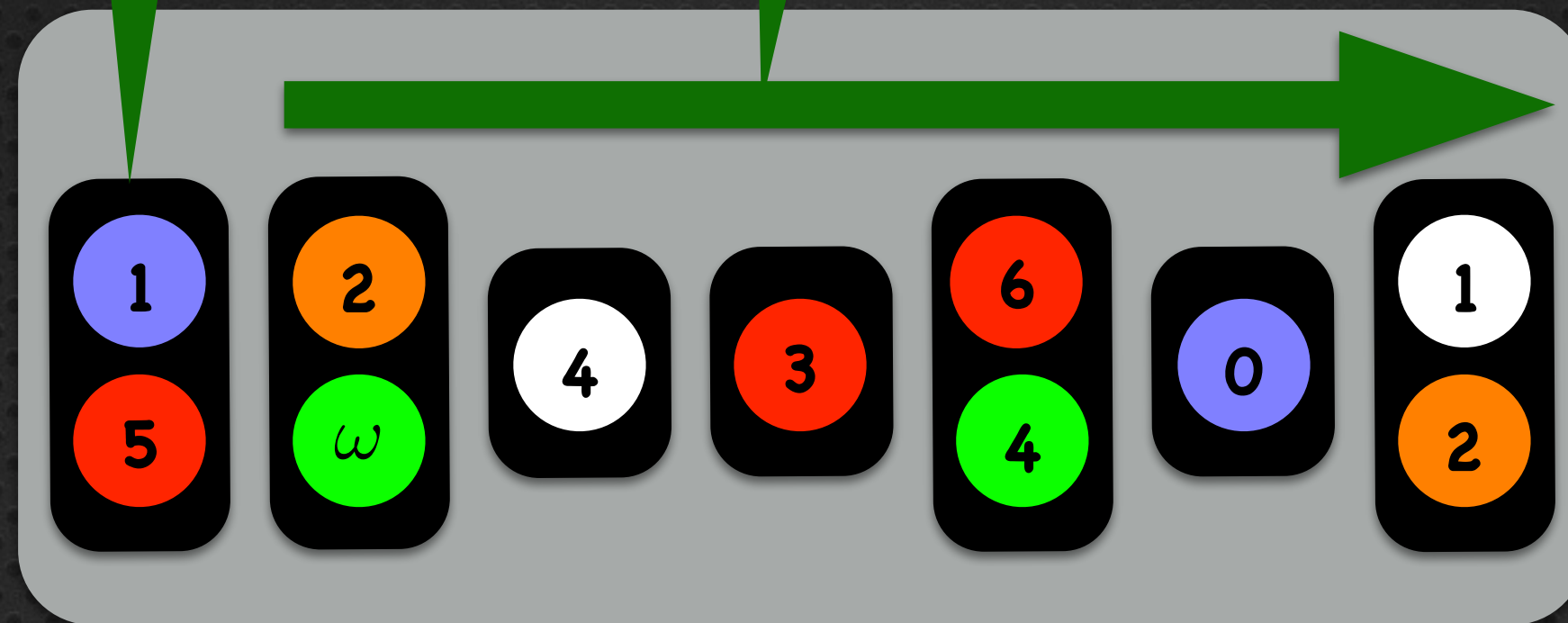
Timed Per.

Signatures

zero fractional part

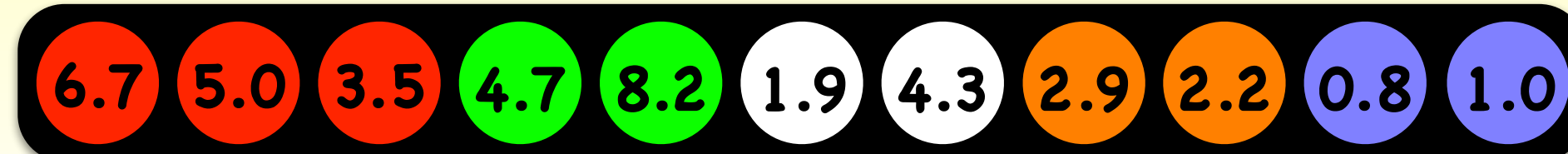
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

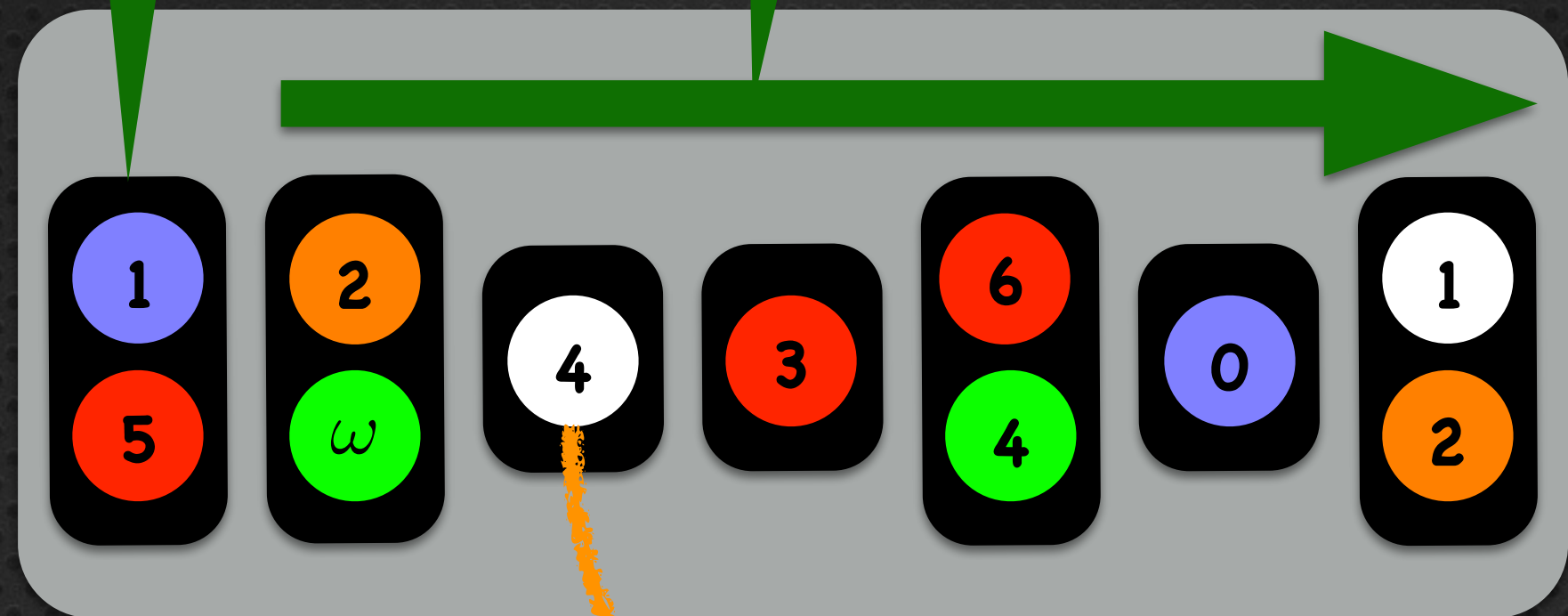
Timed Per.

Signatures

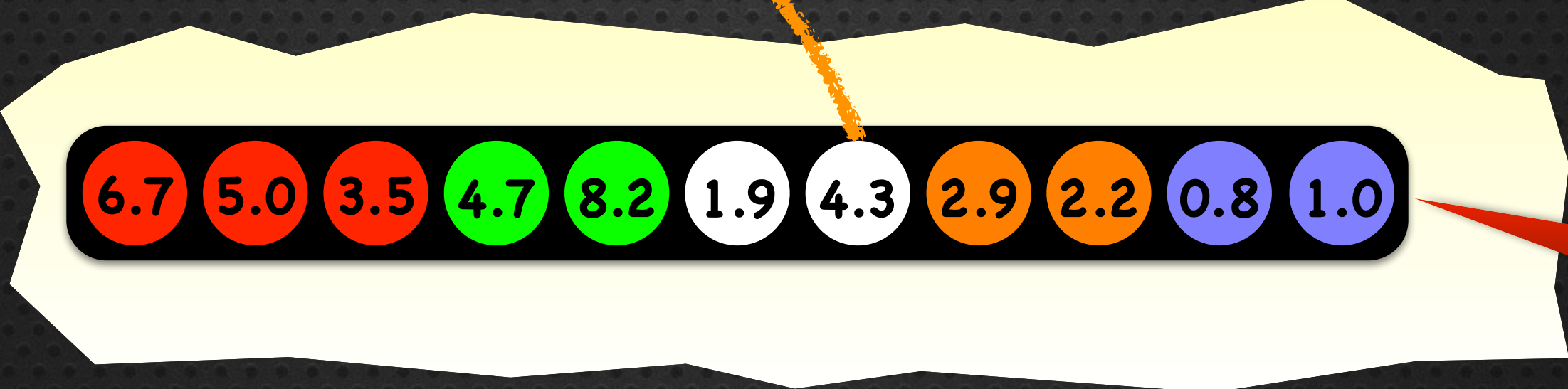
$c_{max}=6$

zero fractional part

increasing fractional parts



$\text{sig}(c) = s$



c:
configuration

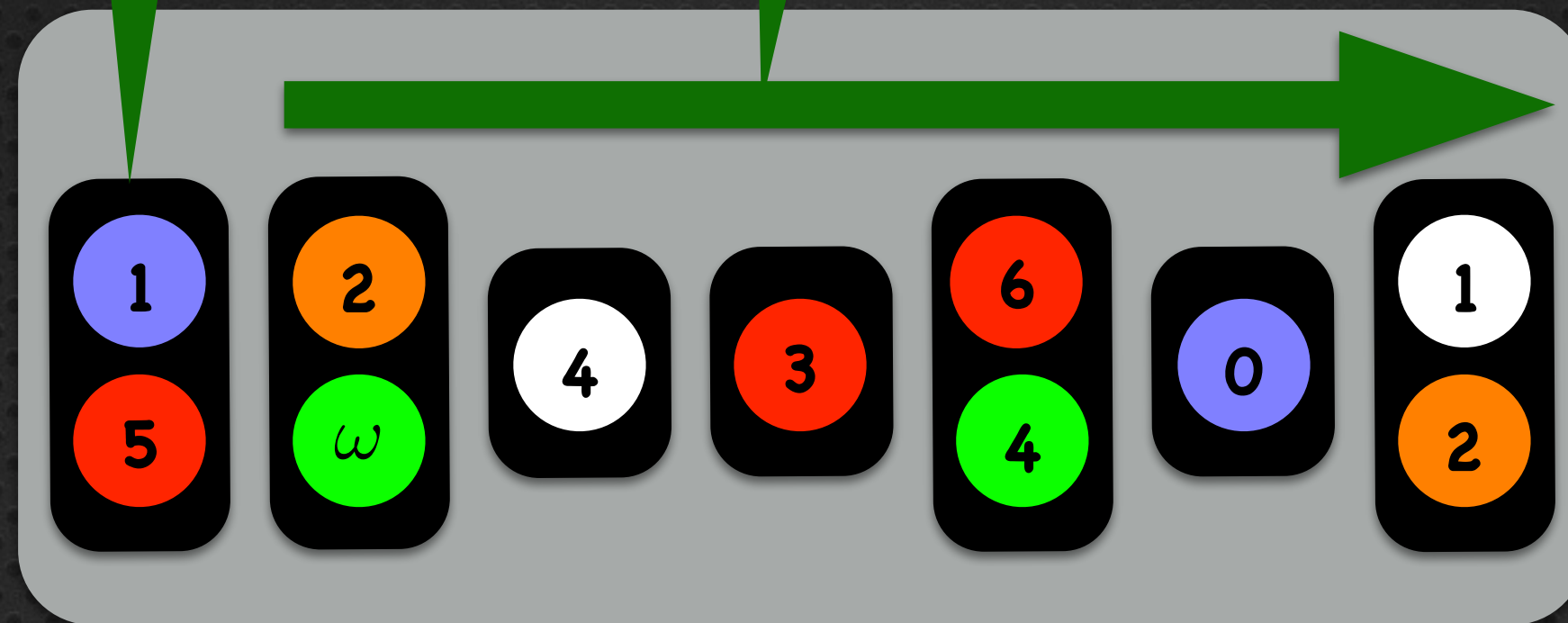
Timed Per.

Signatures

zero fractional part

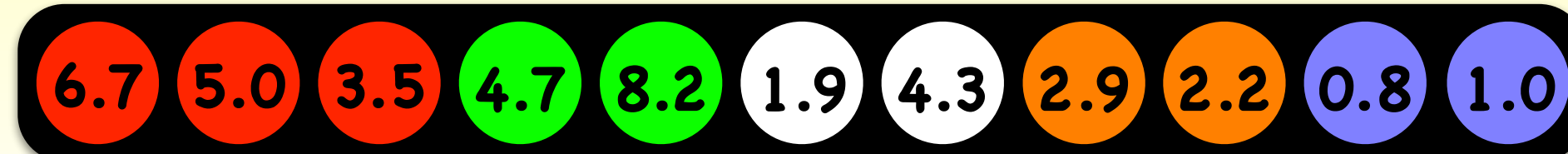
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

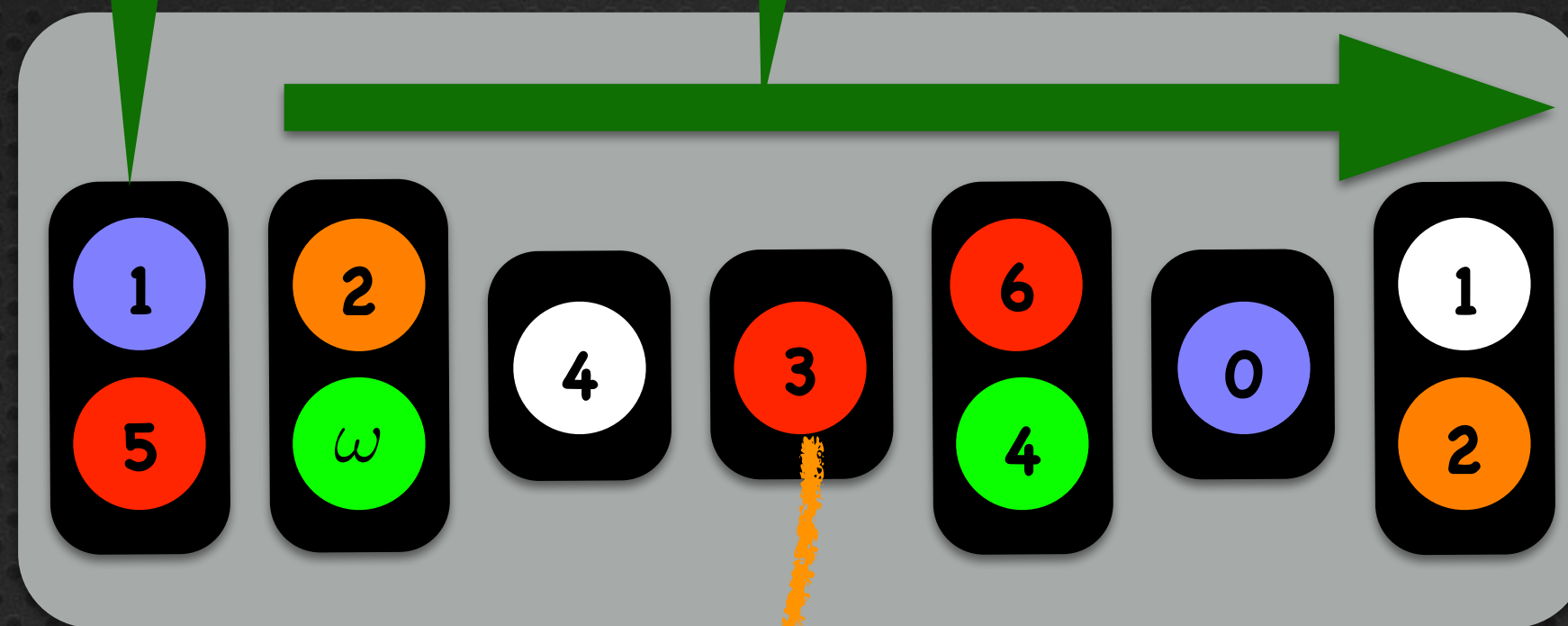
Timed Per.

Signatures

zero fractional part

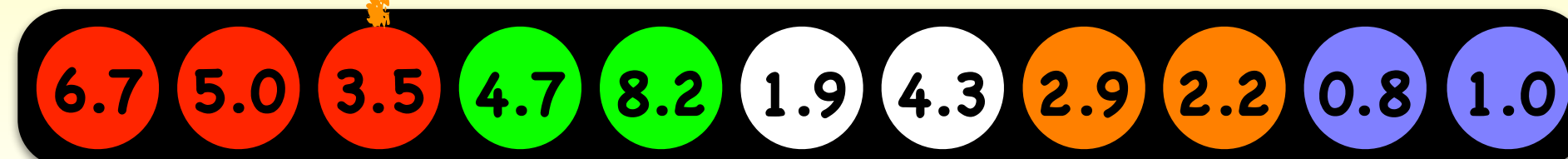
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

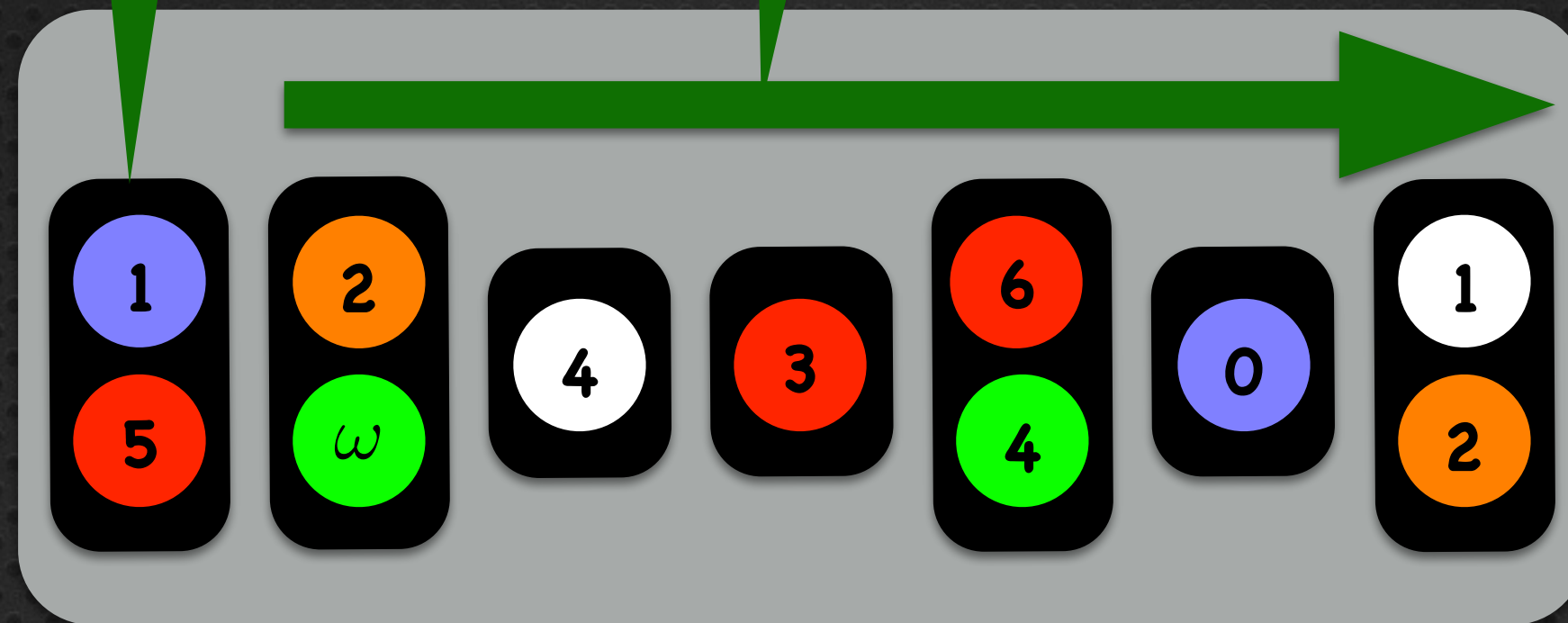
Timed Per.

Signatures

zero fractional part

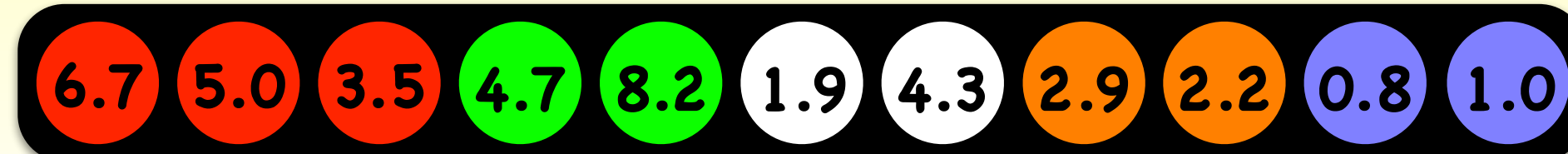
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

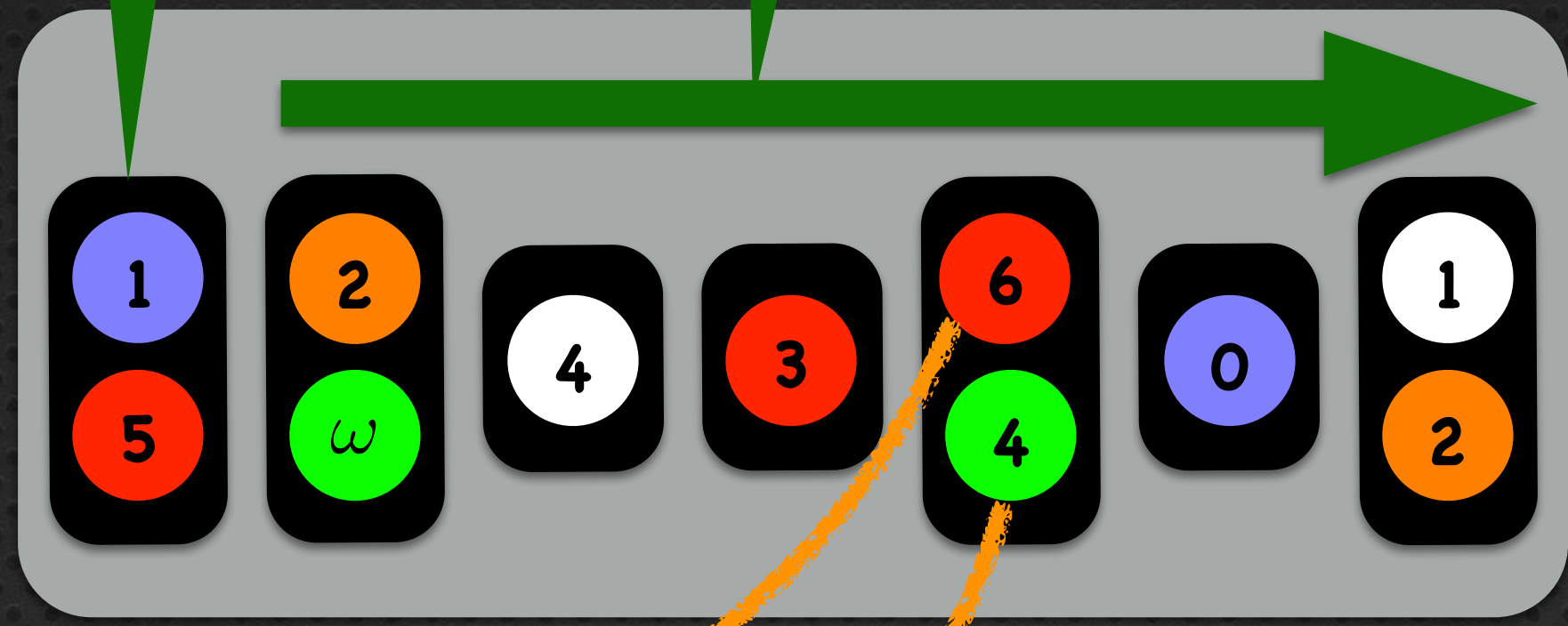
Timed Per.

Signatures

$c_{max}=6$

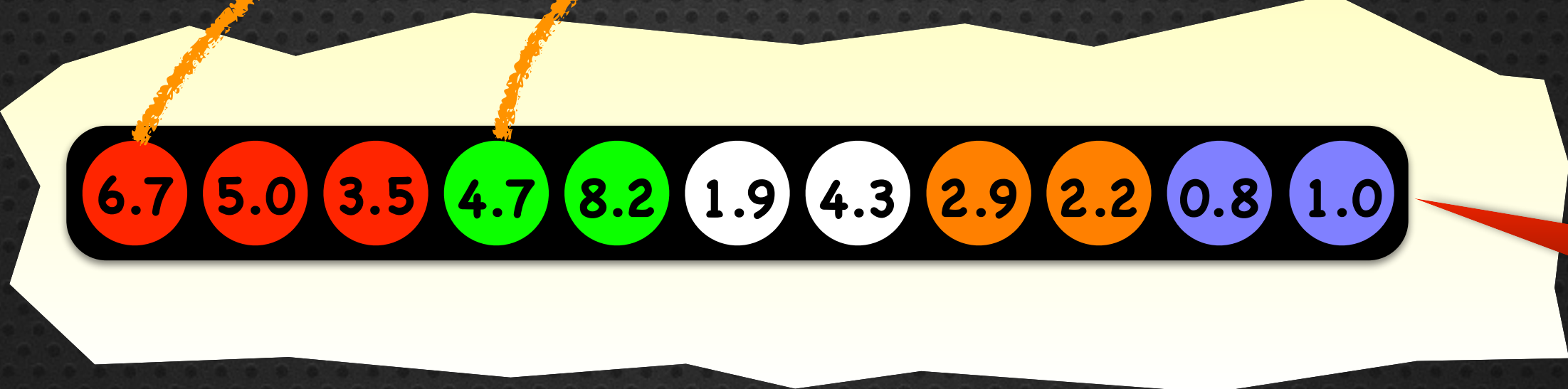
zero fractional part

increasing fractional parts



s:
signature

$sig(c) = s$



c:
configuration

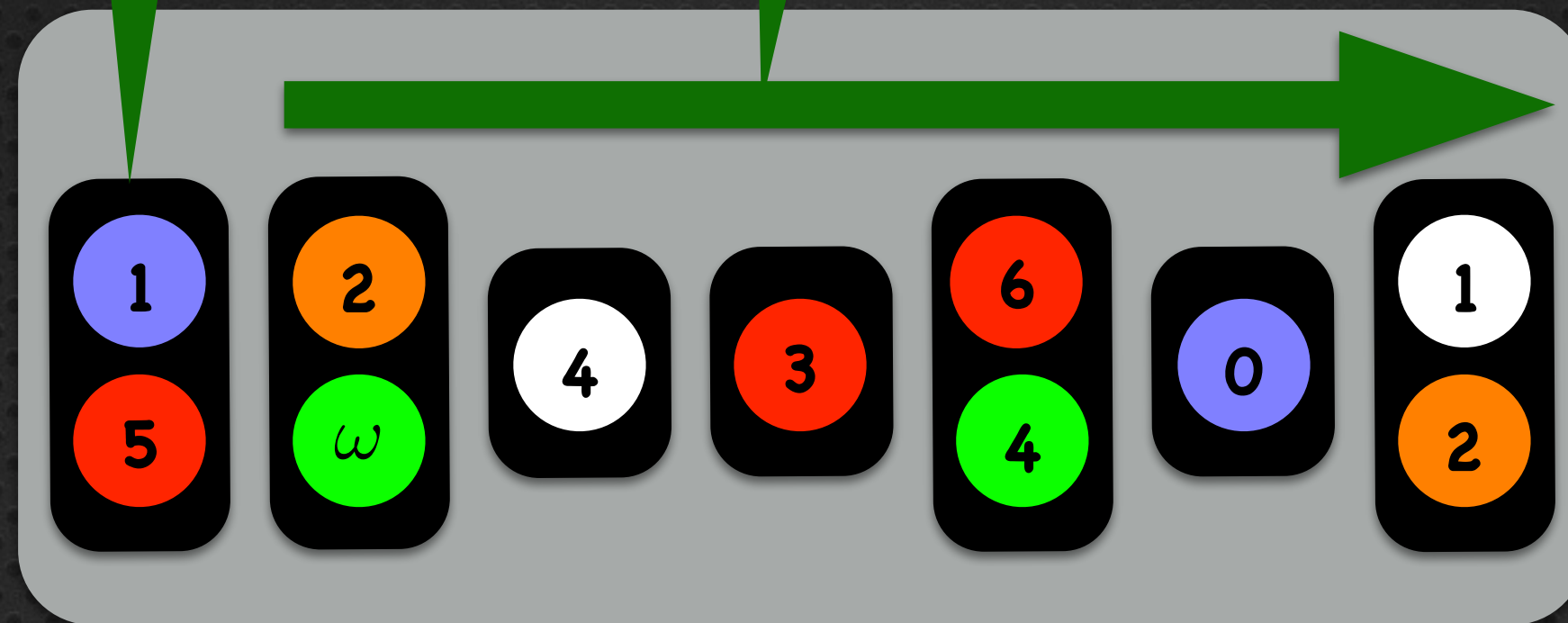
Timed Per.

Signatures

zero fractional part

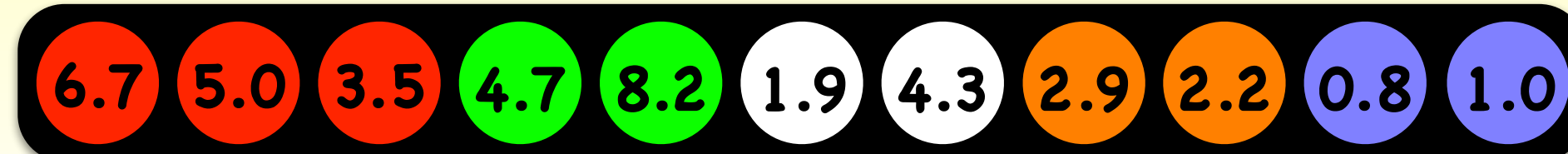
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

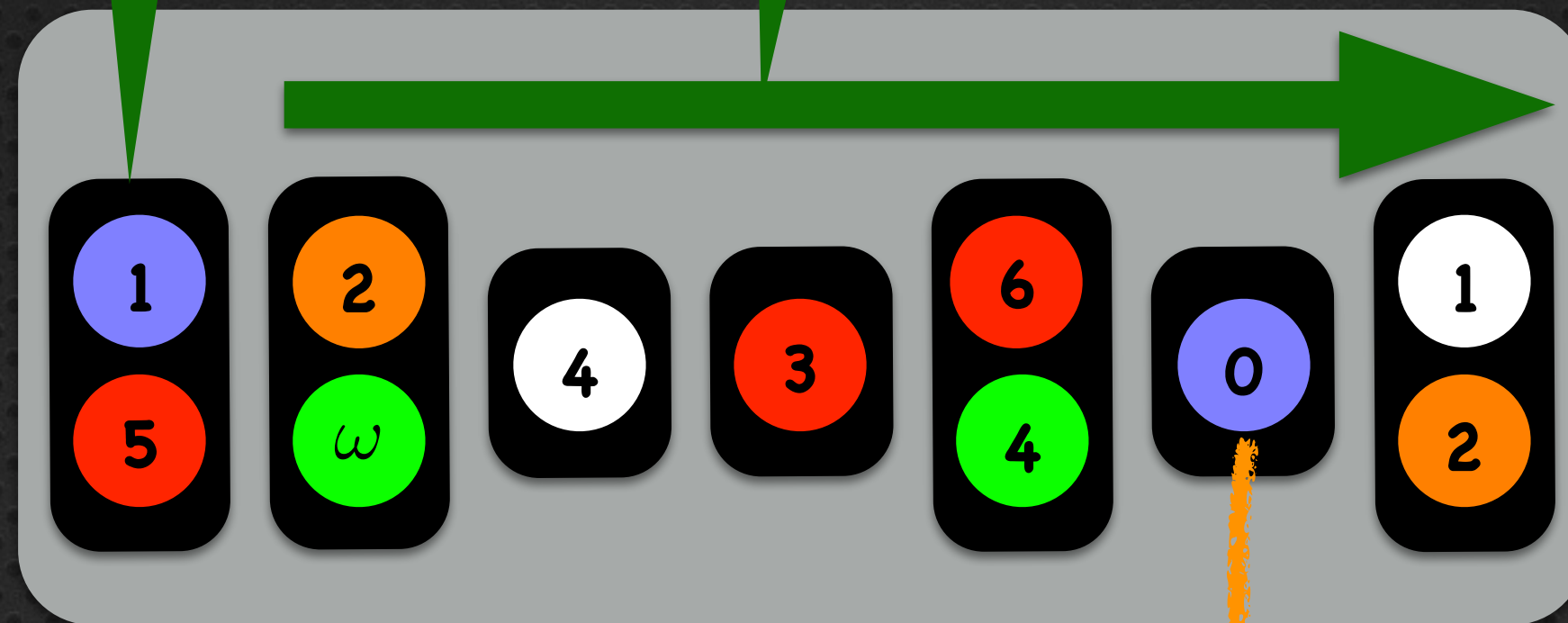
Timed Per.

Signatures

zero fractional part

increasing fractional parts

$c_{max}=6$



$$\text{sig}(c) = s$$



c:
configuration

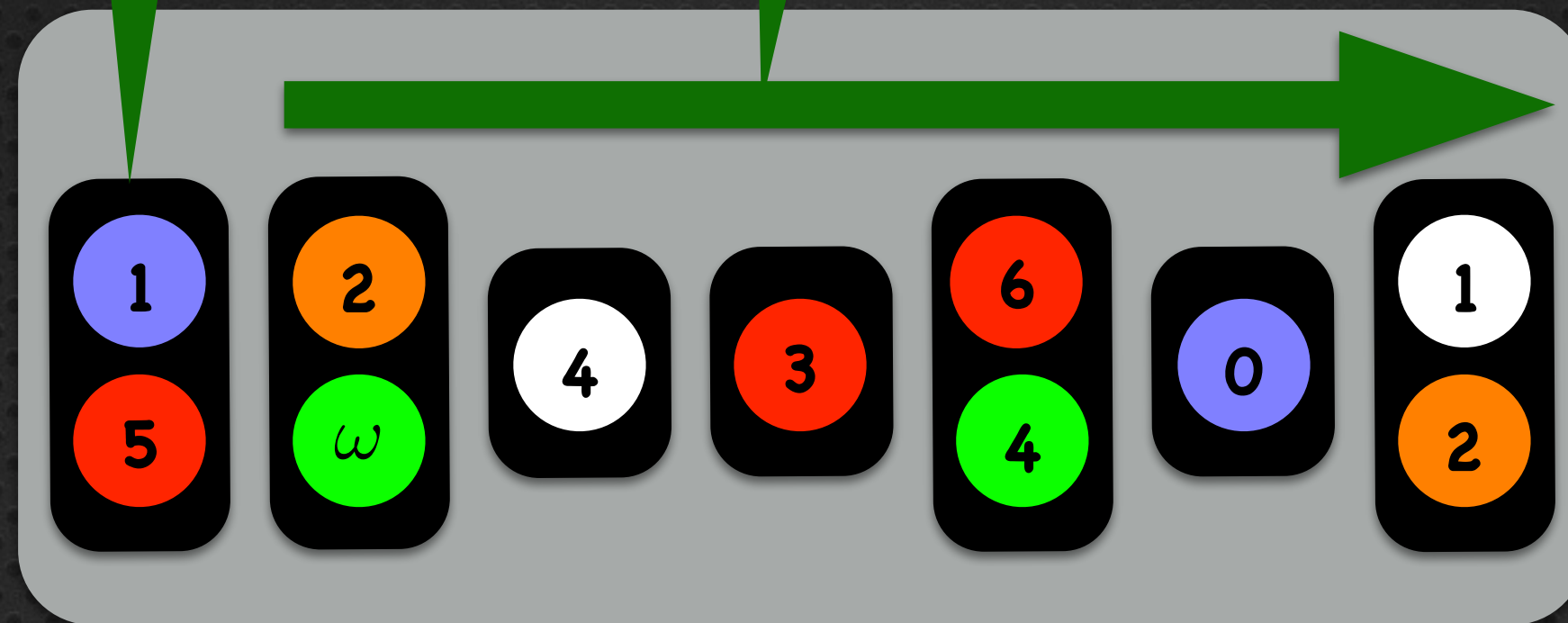
Timed Per.

Signatures

zero fractional part

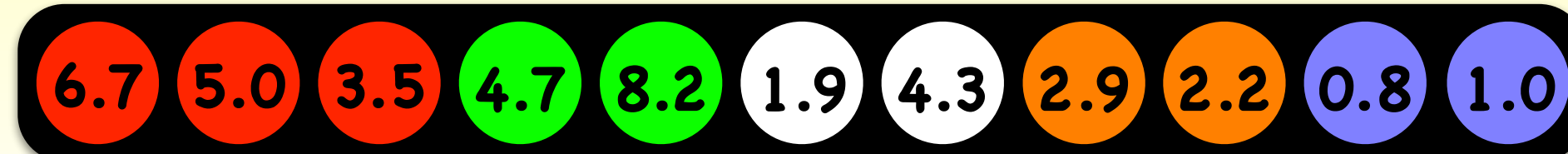
increasing fractional parts

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

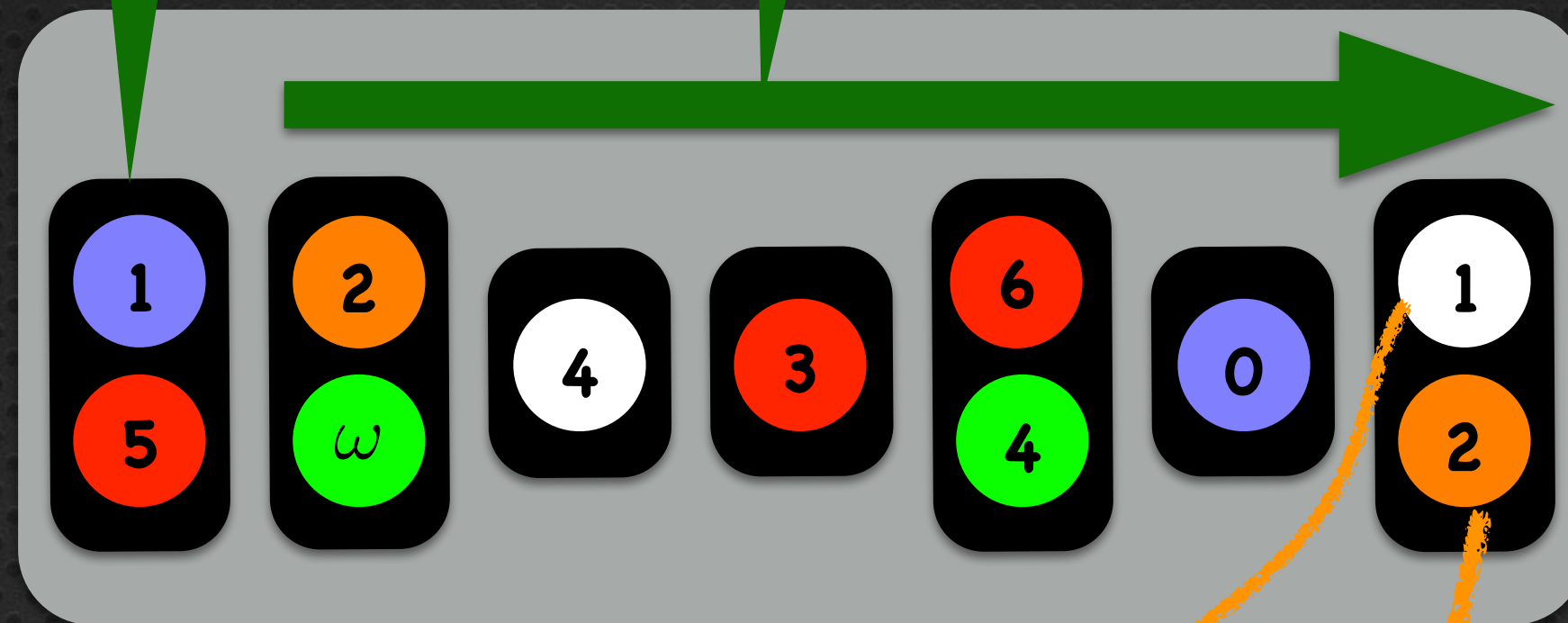
Timed Per.

Signatures

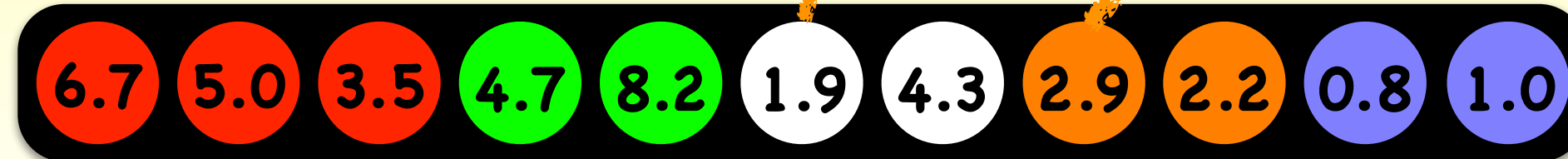
zero fractional part

increasing fractional parts

$c_{max}=6$



$$\text{sig}(c) = s$$

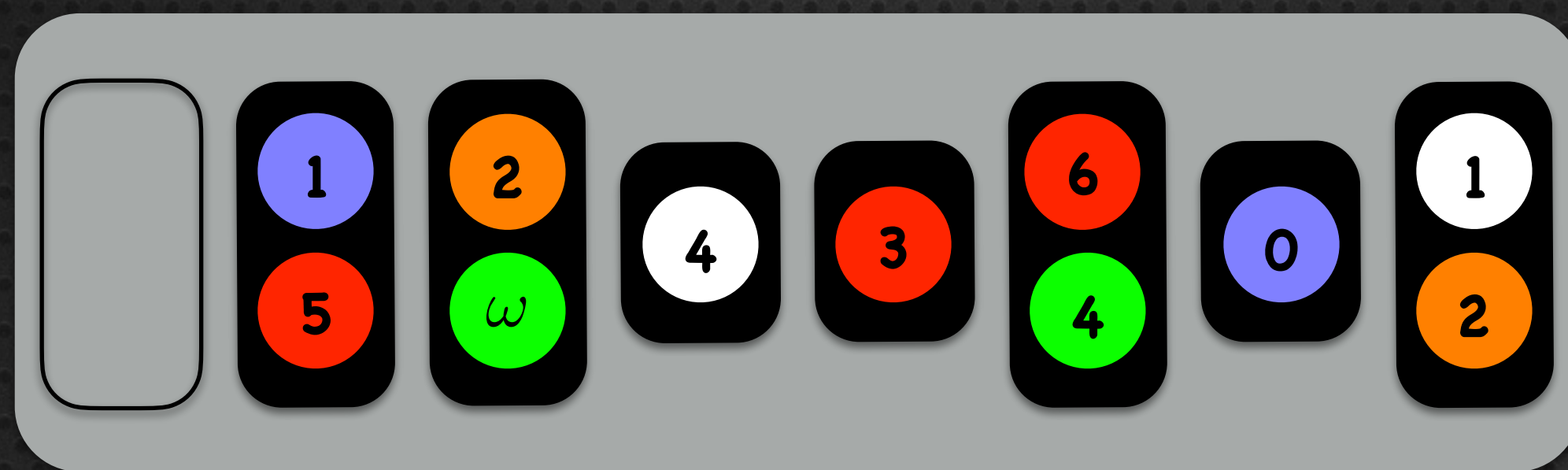


c:
configuration

Timed Per

Signatures

$c_{max}=6$

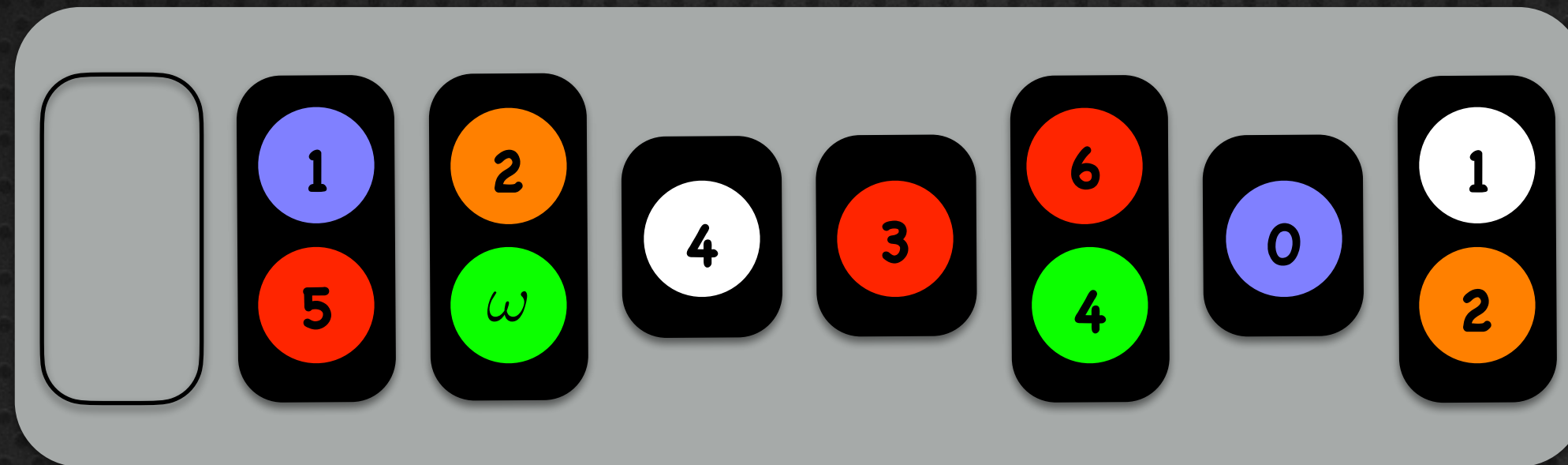


s:
signature

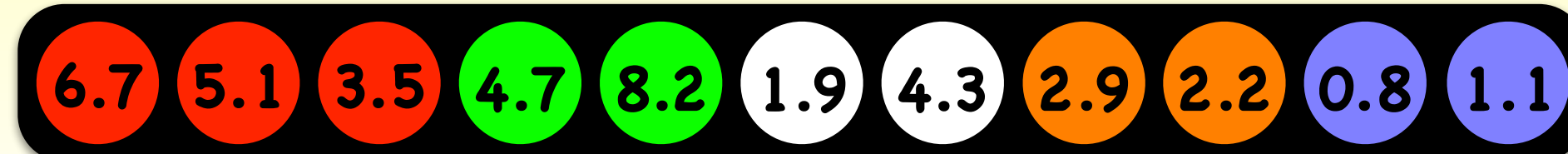
Timed Per

Signatures

$c_{max}=6$



s:
signature

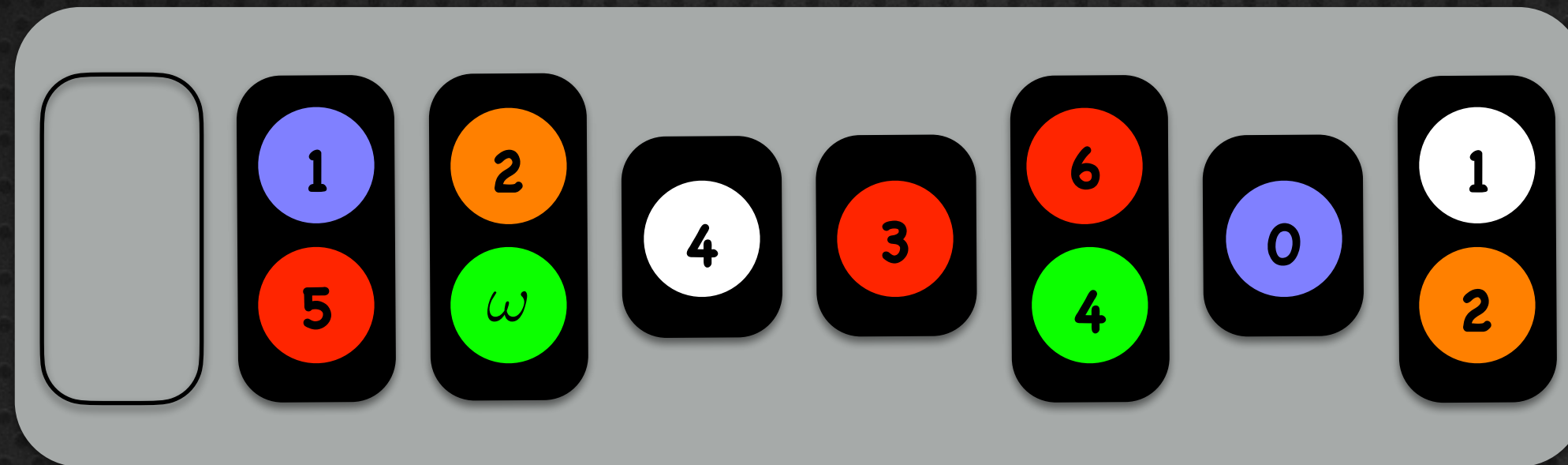


c:
configuration

Timed Per.

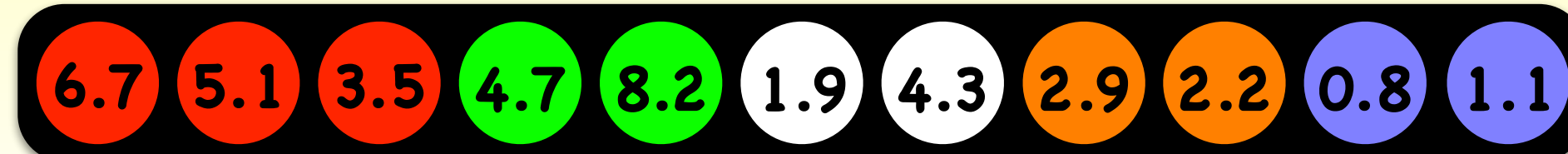
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) = s$



c:
configuration

Timed Per.

Signatures

$c_{max}=6$



s:
signature

$$\text{sig}(c) = s$$

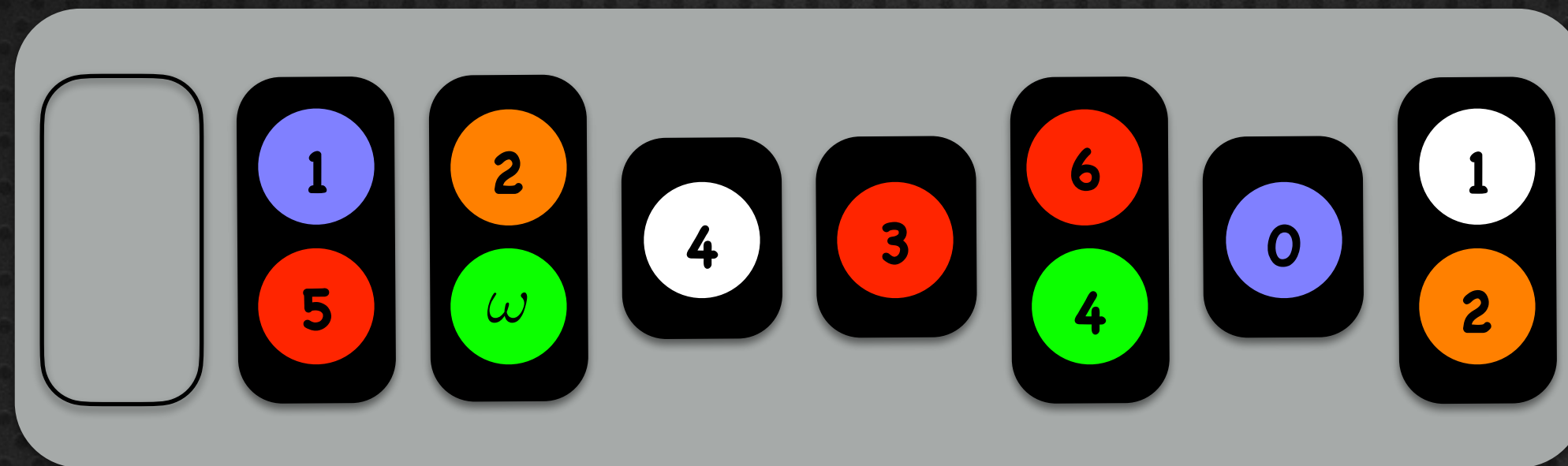


c:
configuration

Timed Per

Signatures

$c_{max}=6$



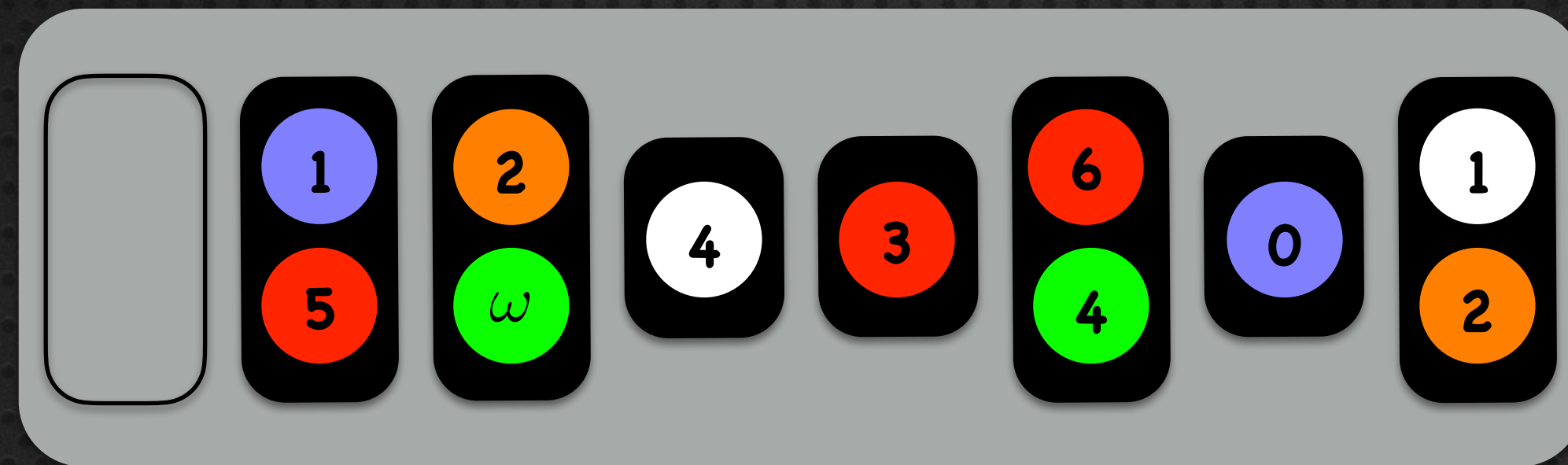
s:
signature

c:
configuration

Timed Per

Signatures

$c_{max}=6$



s:
signature

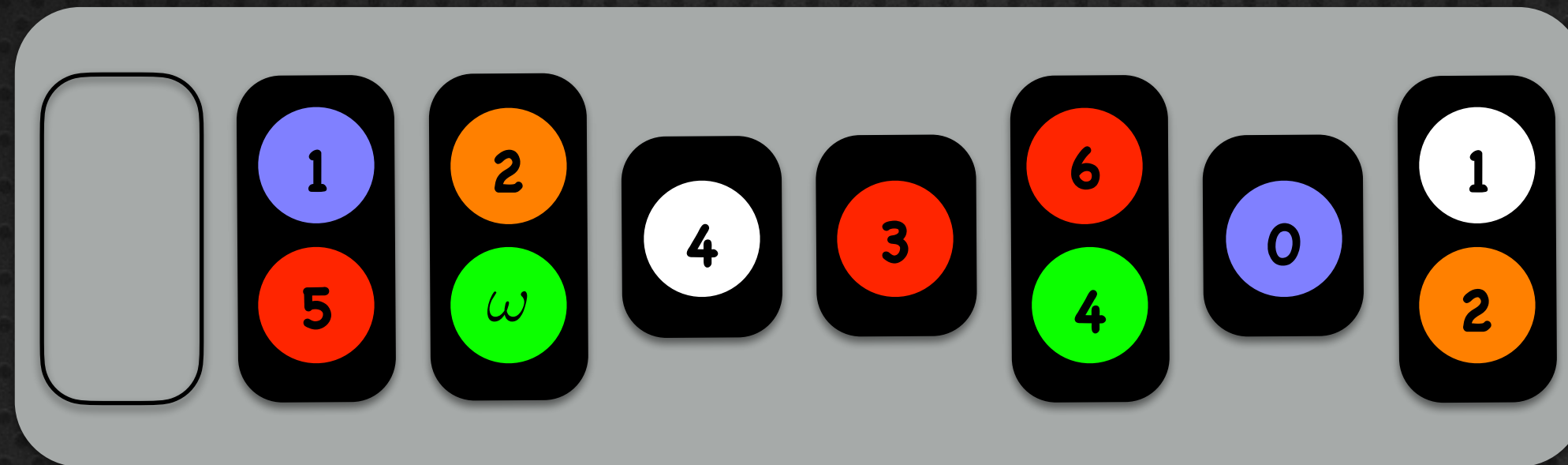


c:
configuration

Timed Per.

Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

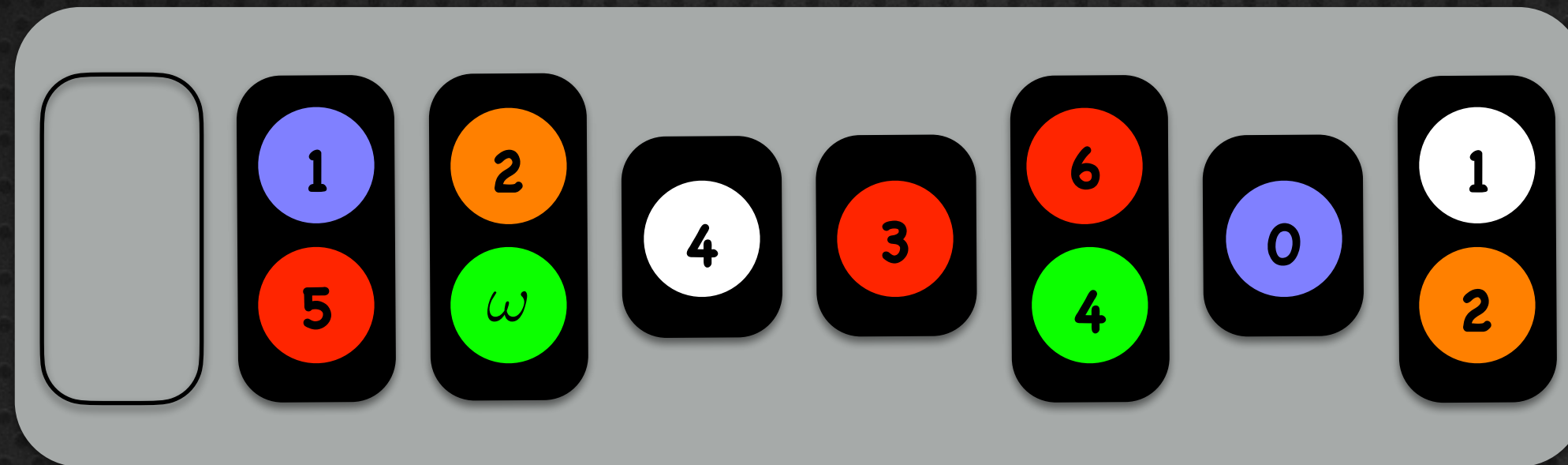


c:
configuration

Timed Per.

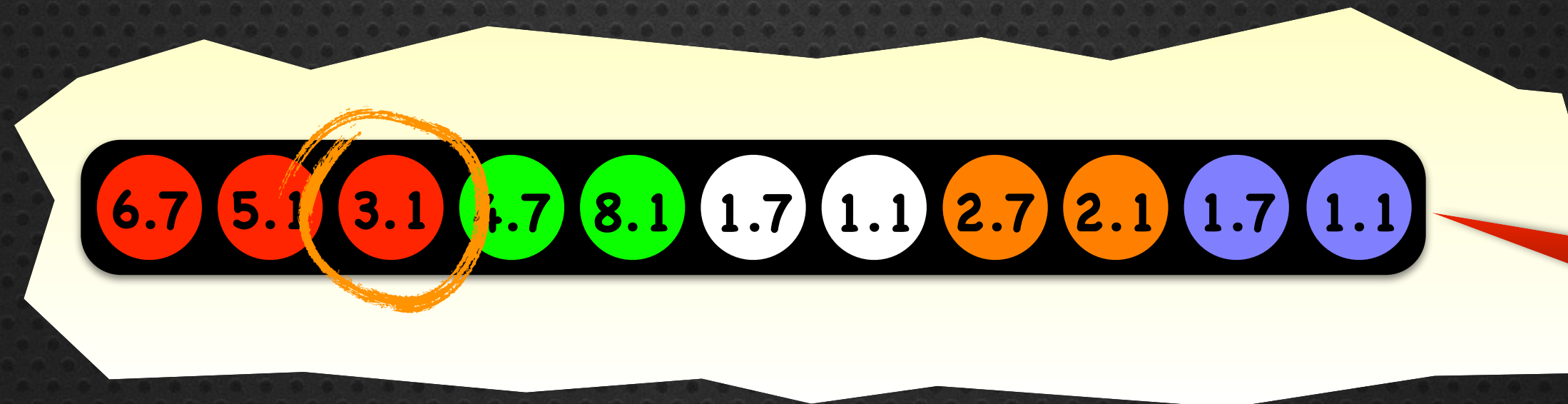
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

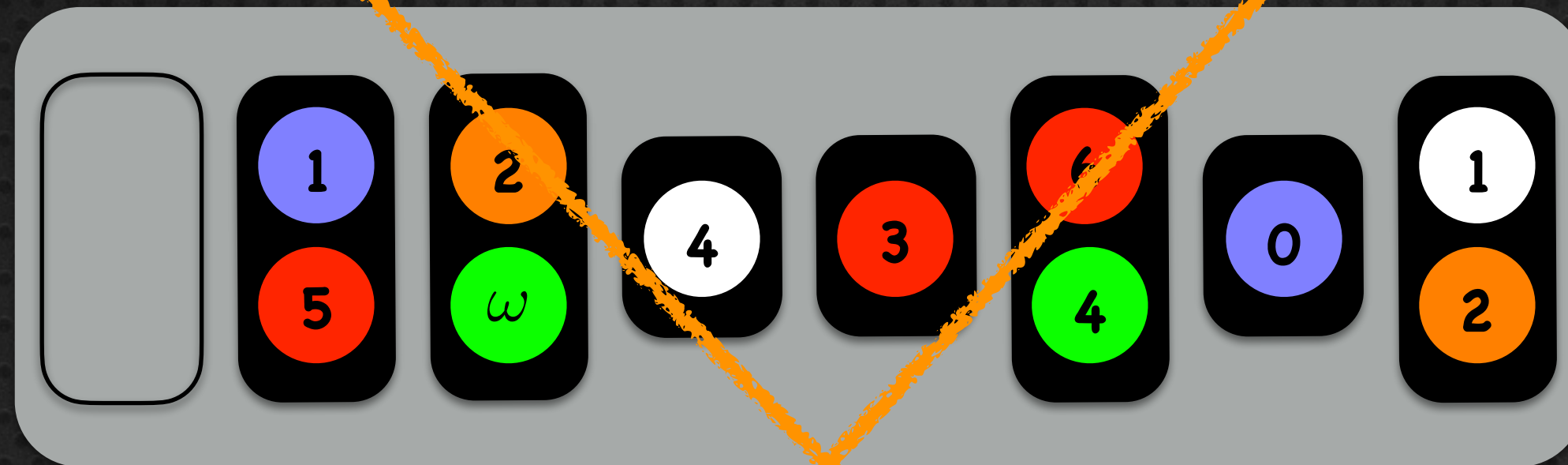


c:
configuration

Timed Per.

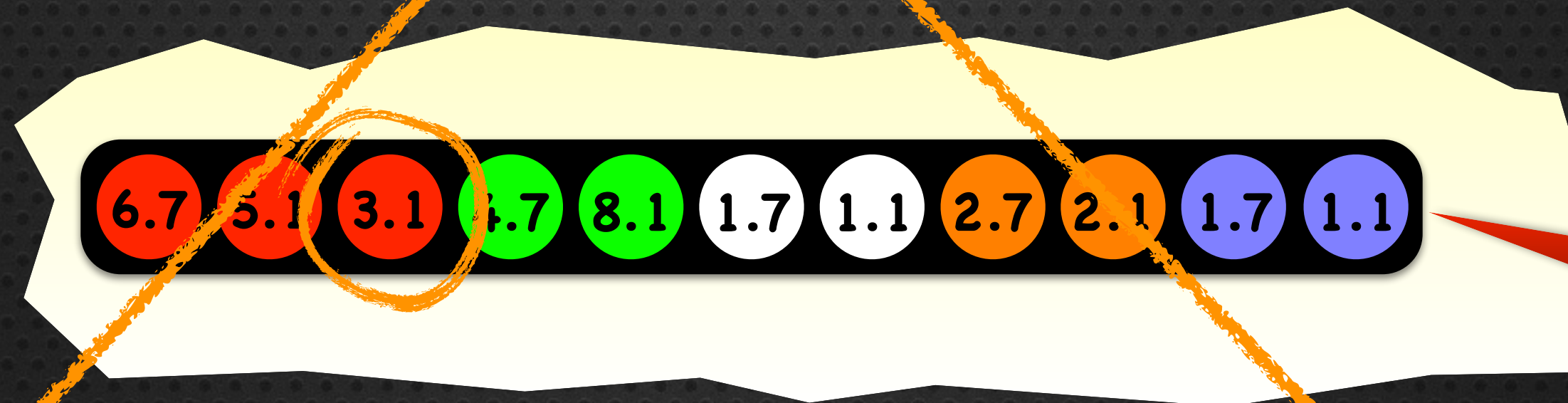
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

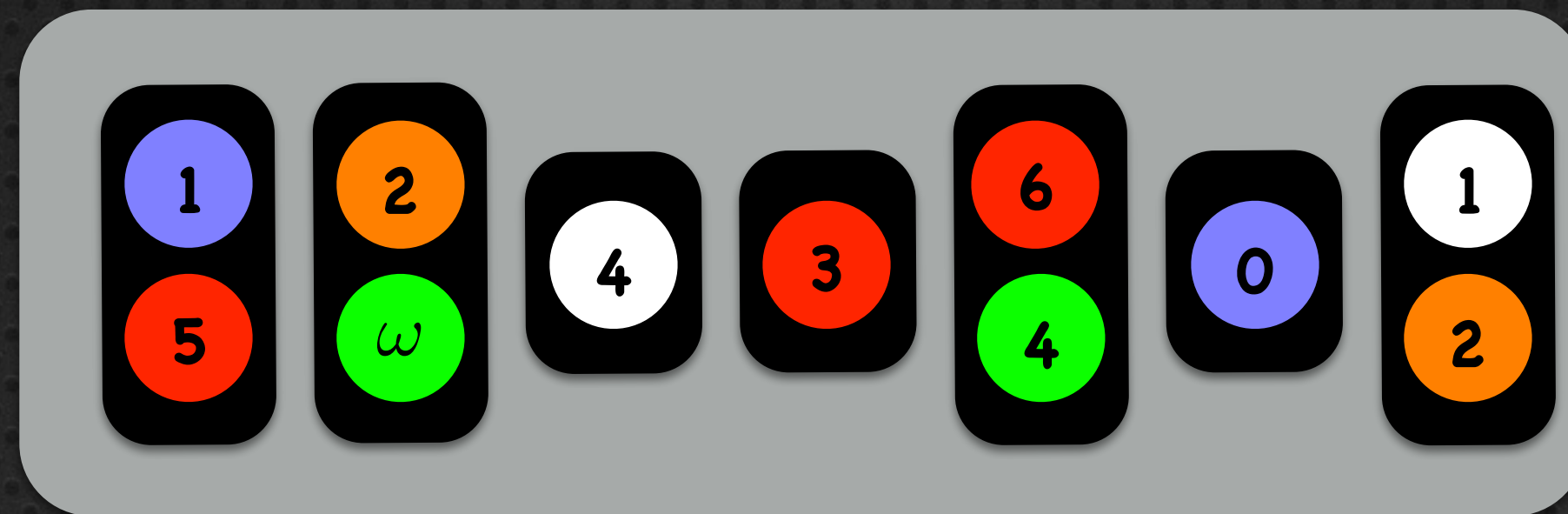


c:
configuration

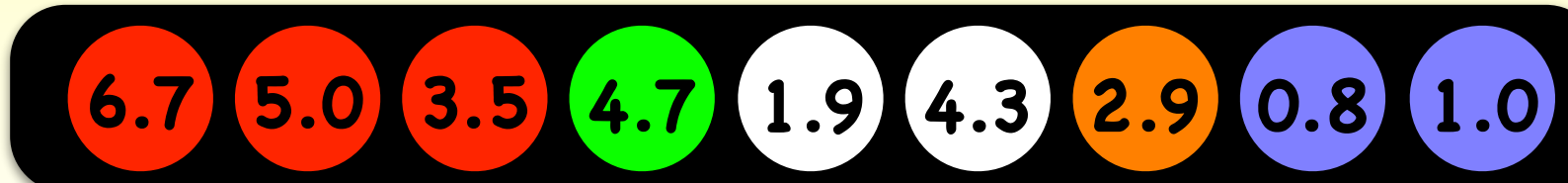
Timed Per

Signatures

$c_{max}=6$



s:
signature

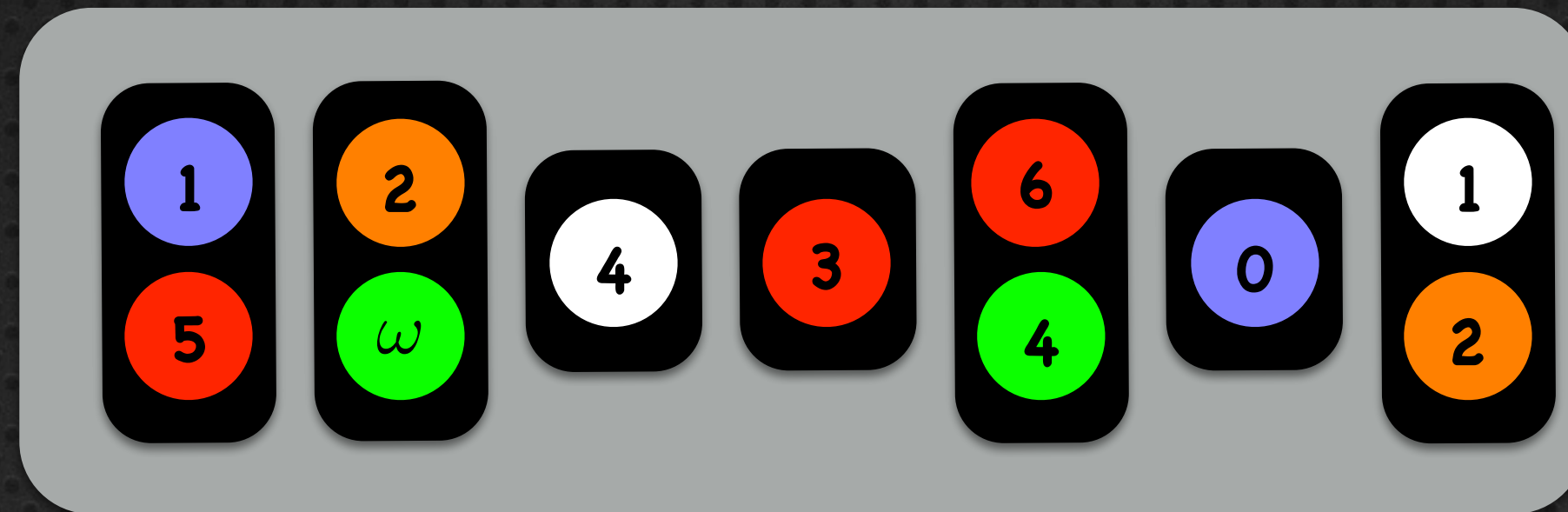


c:
configuration

Timed Per.

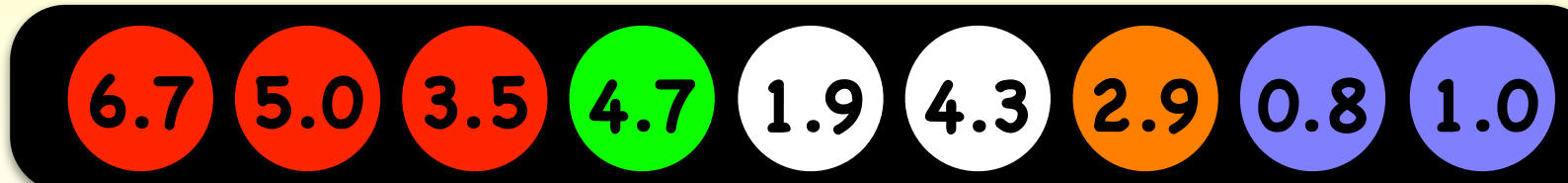
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$



c:
configuration

Timed Per.

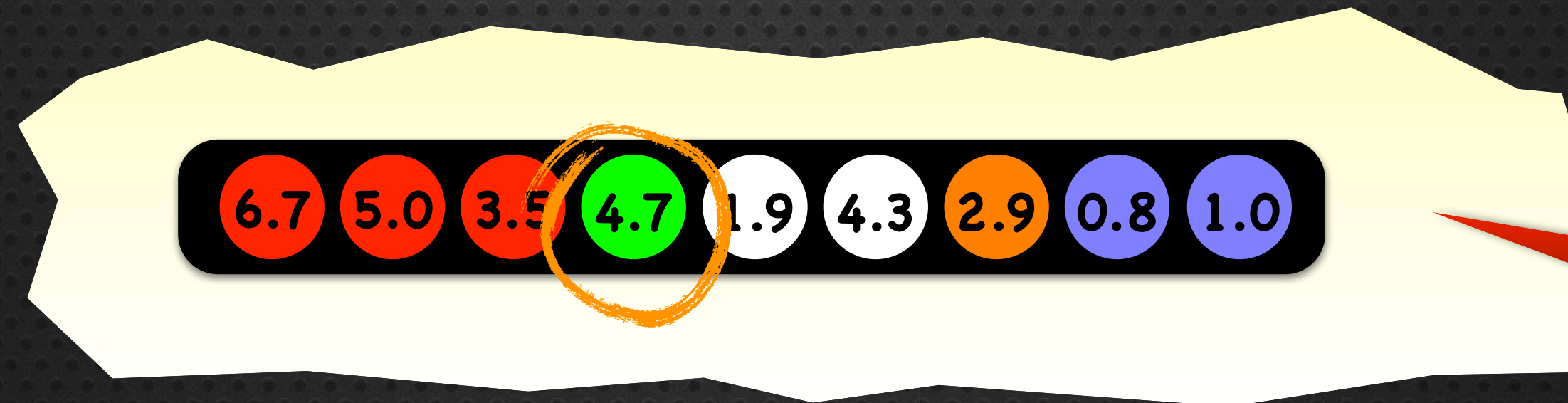
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

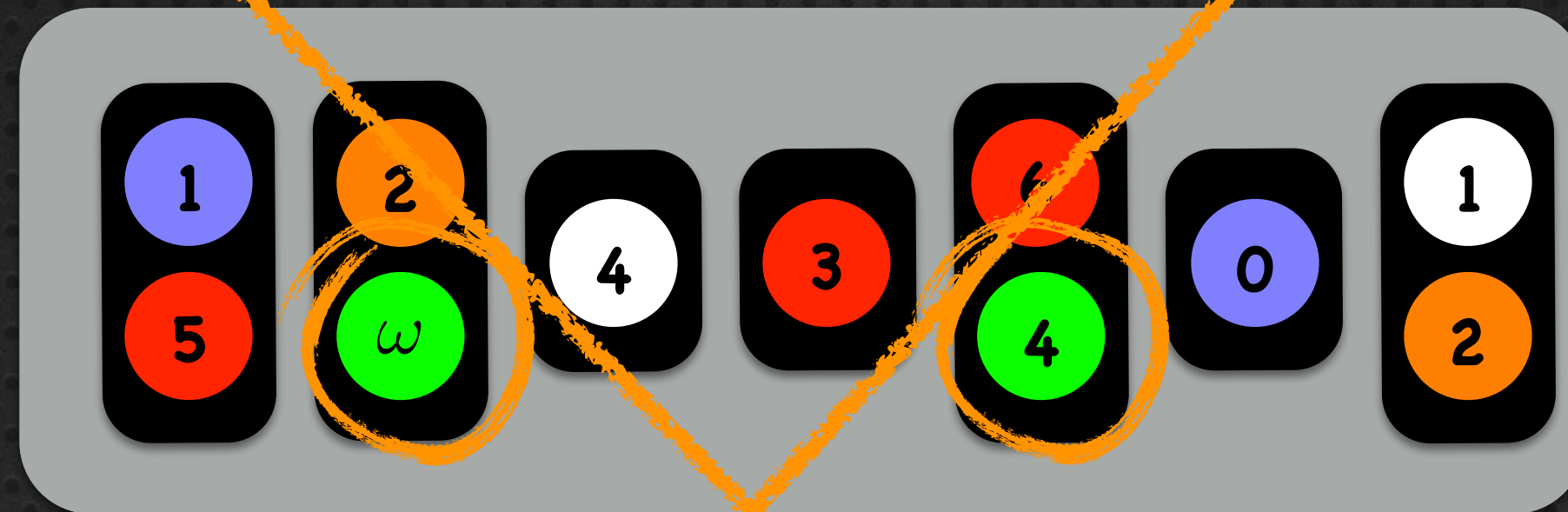


c:
configuration

Timed Per.

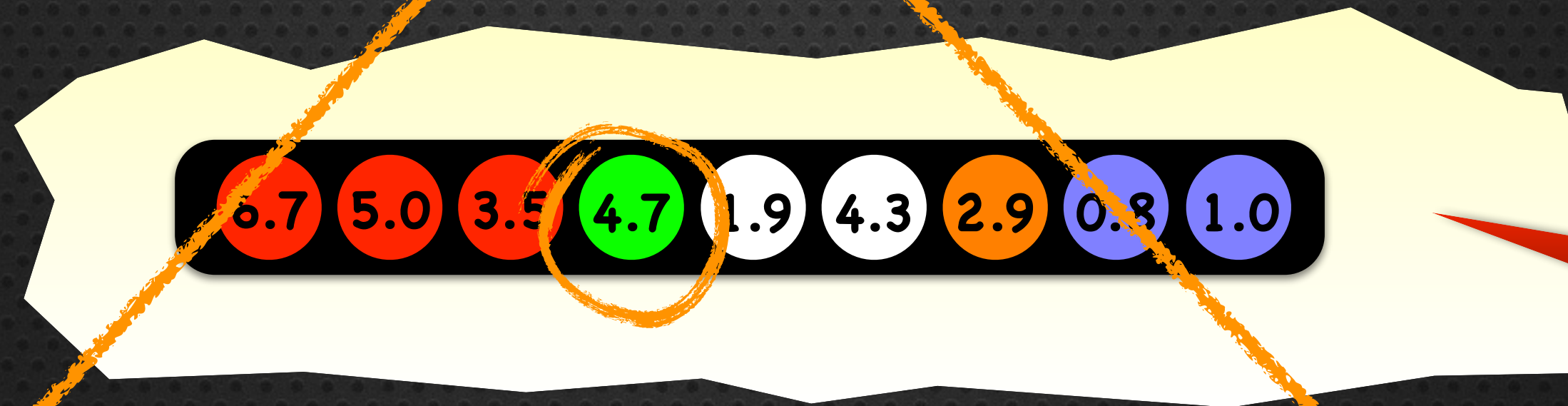
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

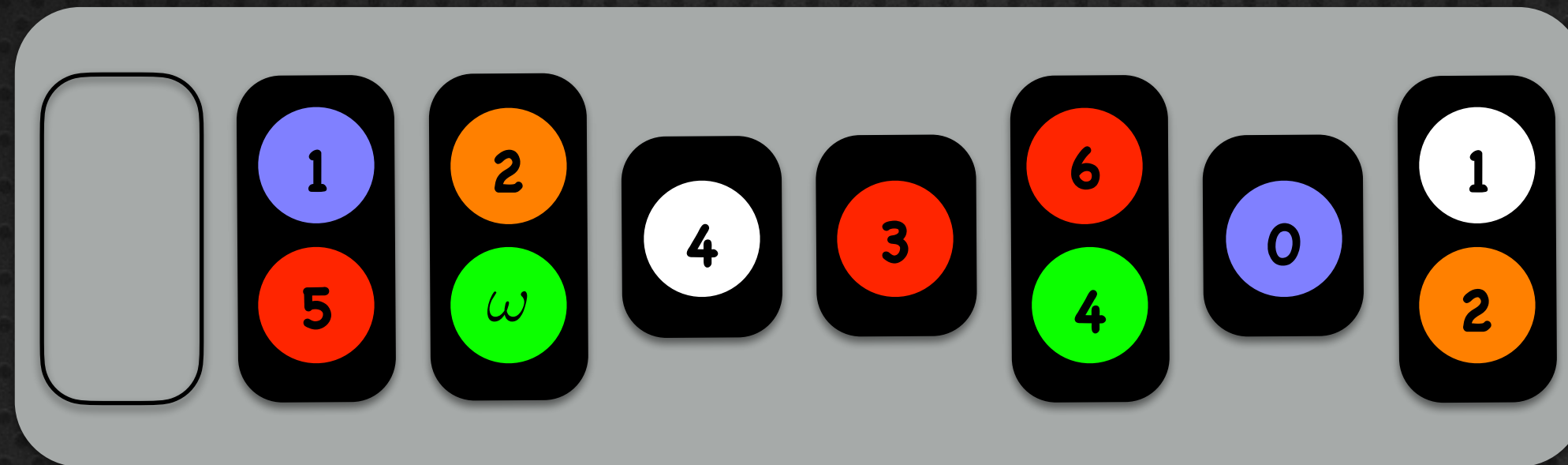


c:
configuration

Timed Per

Signatures

$c_{max}=6$



s:
signature

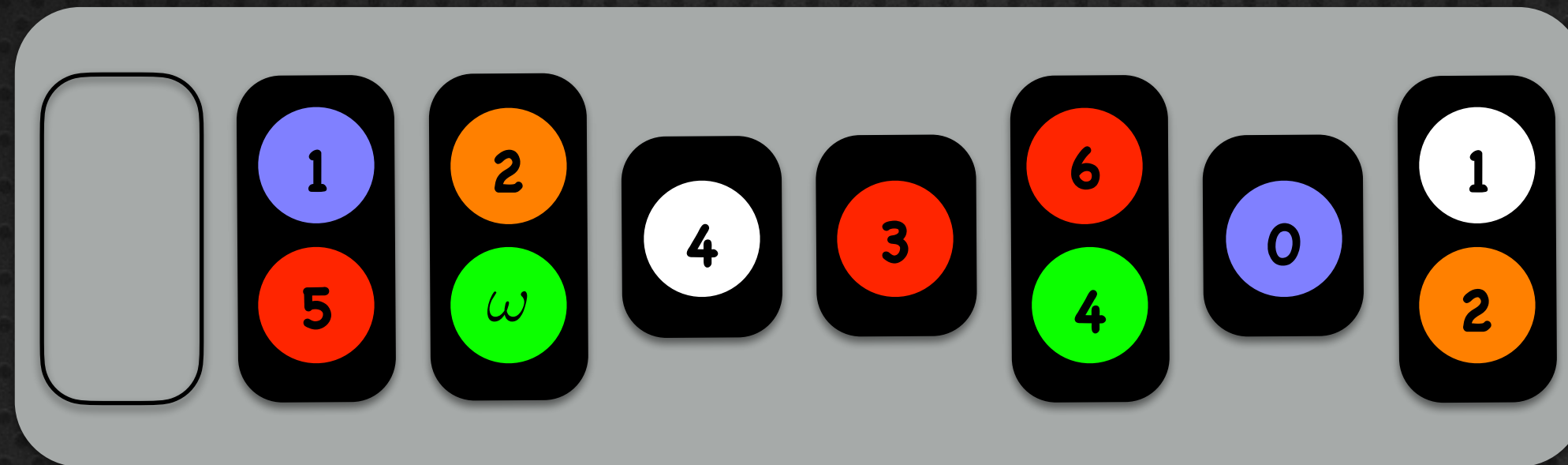


c:
configuration

Timed Per.

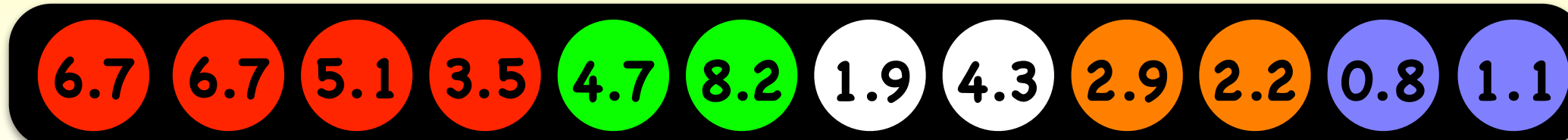
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$

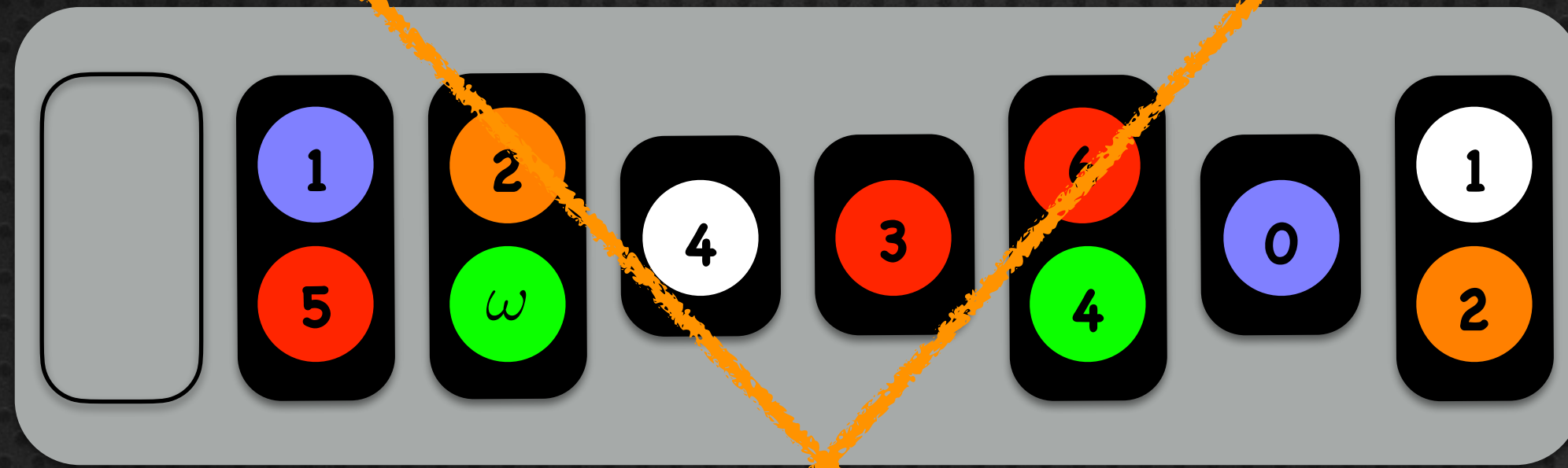


c:
configuration

Timed Per.

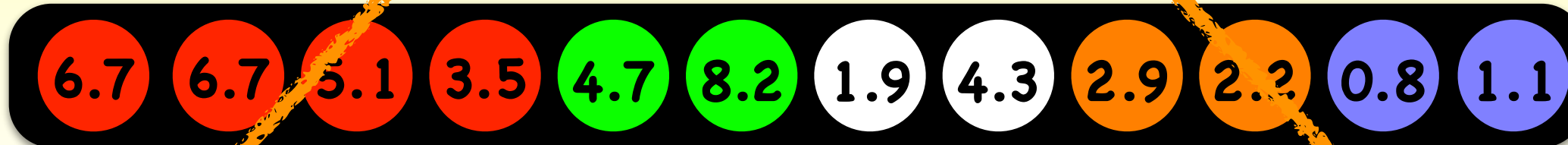
Signatures

$c_{max}=6$



s:
signature

$\text{sig}(c) \neq s$



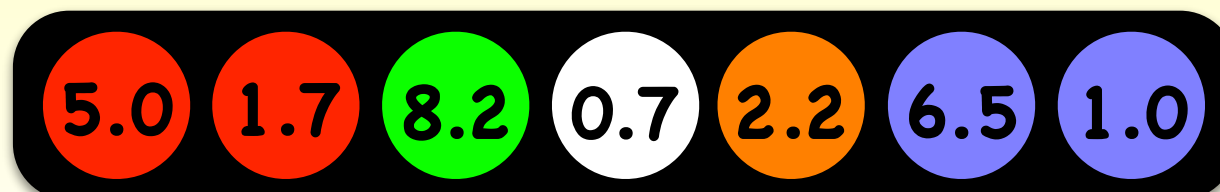
c:
configuration

Timed Per

Signatures



s:
signature



c:
configuration

Timed Per...

Signatures



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

Timed Per...

Signatures



s:
signature

$$\text{sig}(c) = s$$

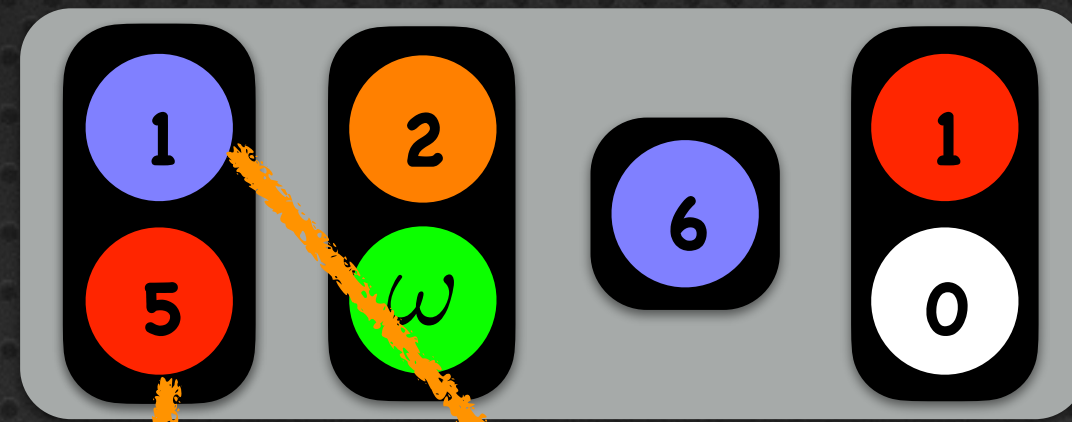


c:
configuration

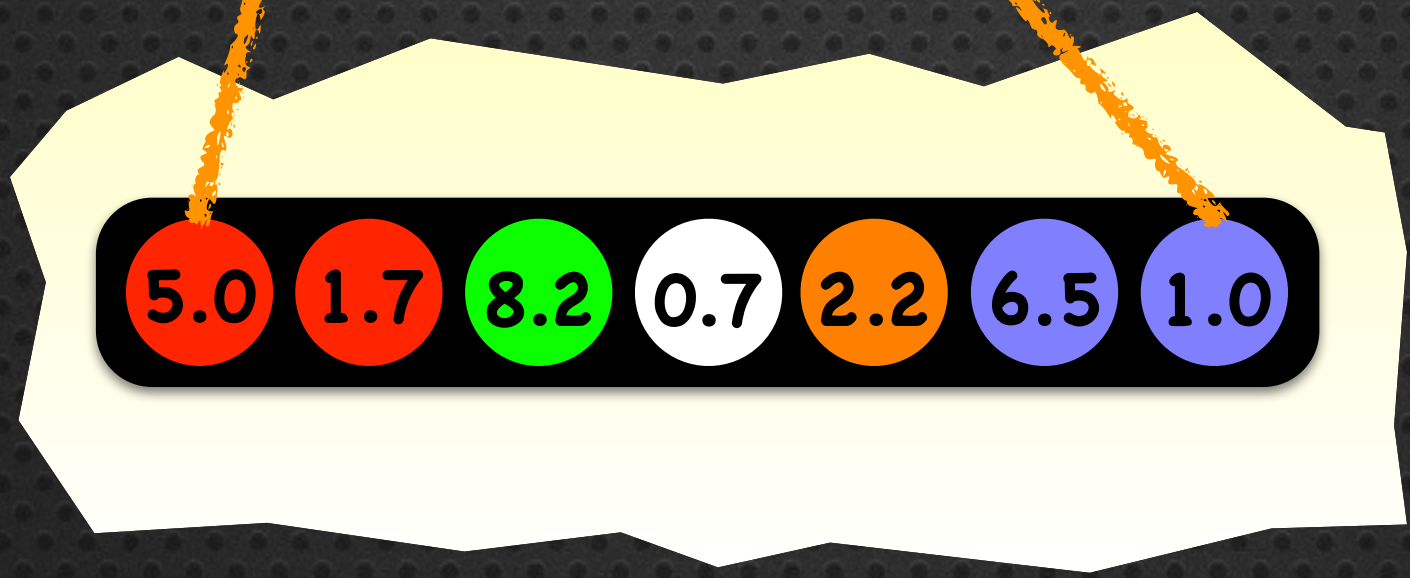
Timed Per...

Signatures

$$\text{sig}(c) = s$$



s:
signature



c:
configuration

Timed Per...

Signatures



s:
signature

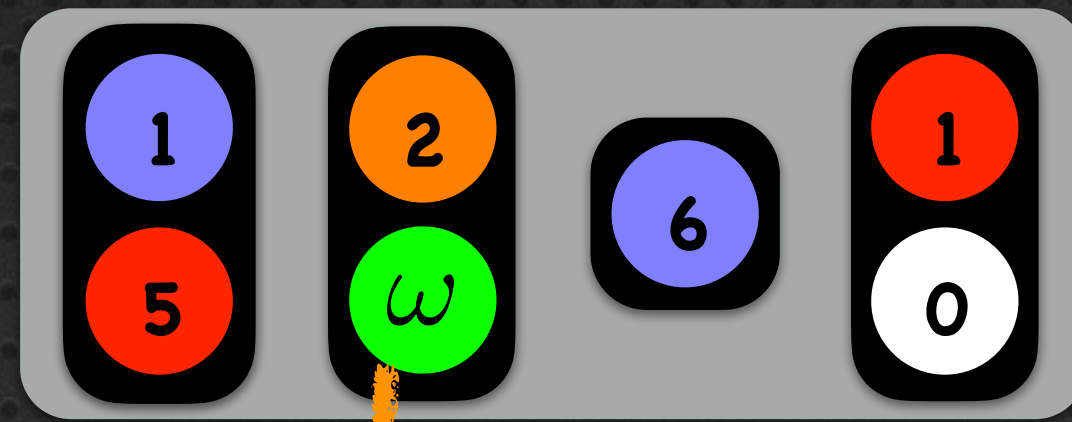
$$\text{sig}(c) = s$$



c:
configuration

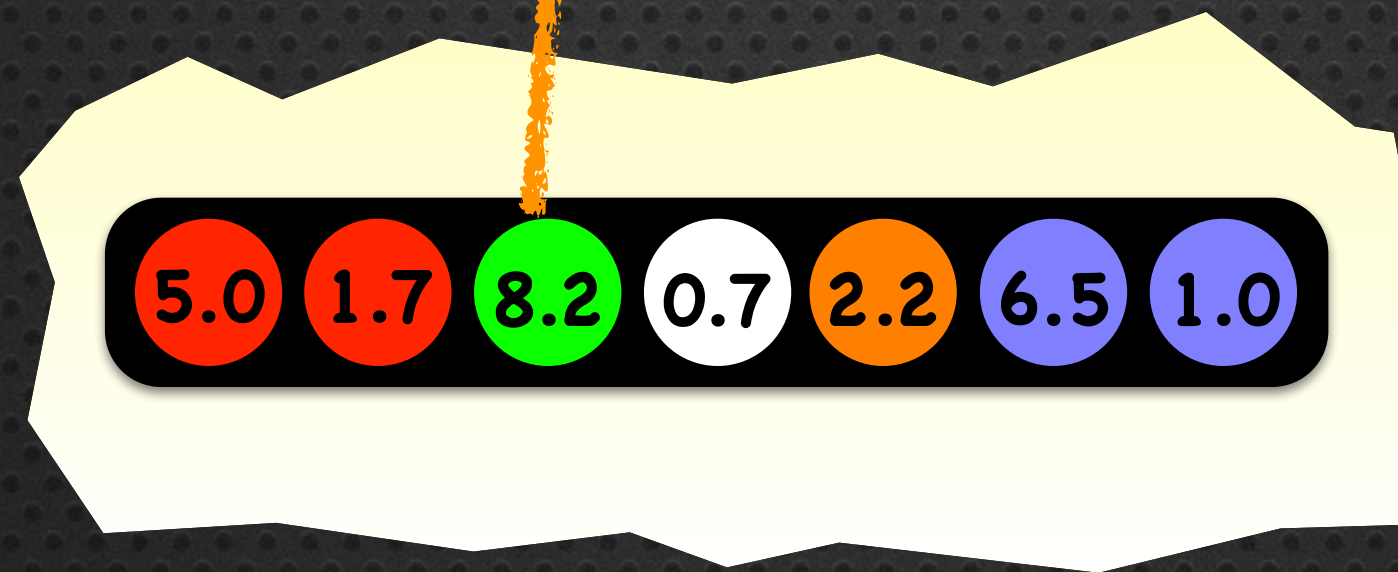
Timed Per.

Signatures



s:
signature

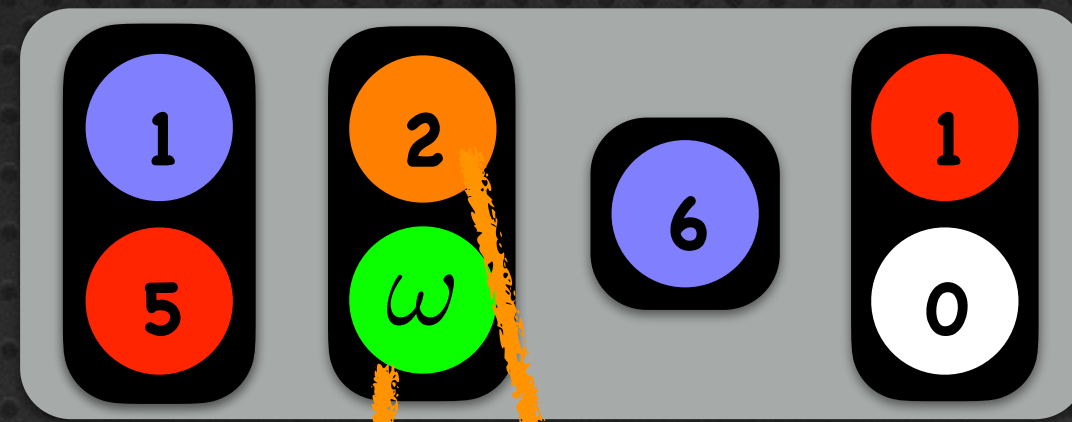
$$\text{sig}(c) = s$$



c:
configuration

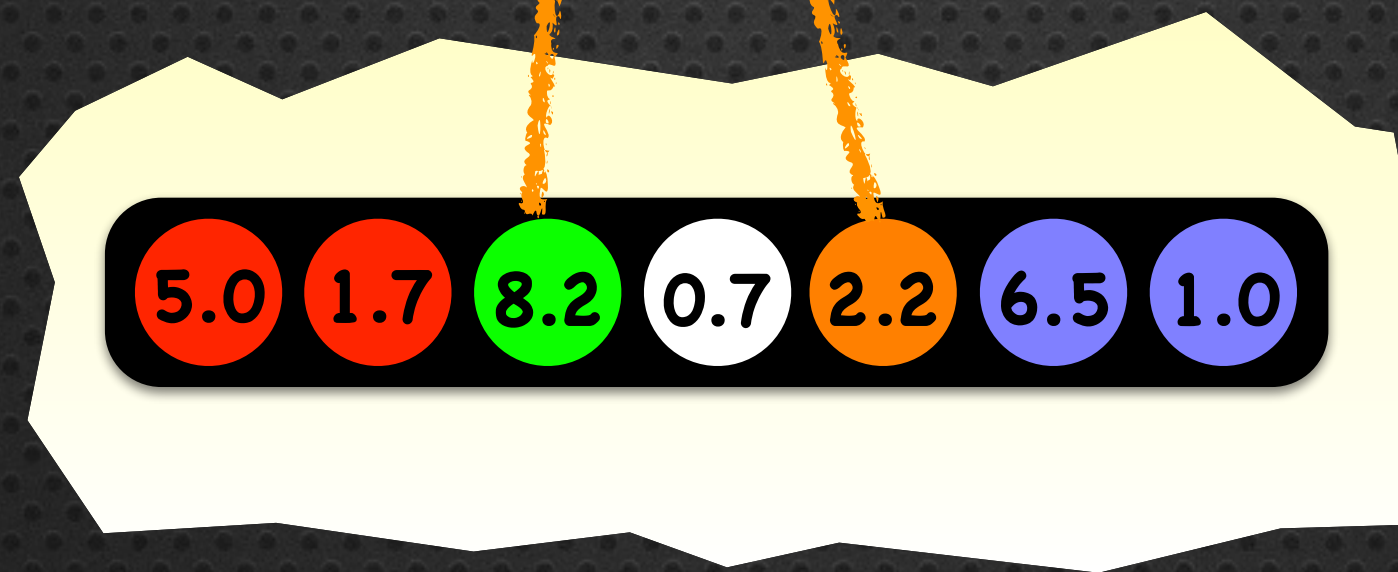
Timed Per.

Signatures



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

Timed Per...

Signatures



s:
signature

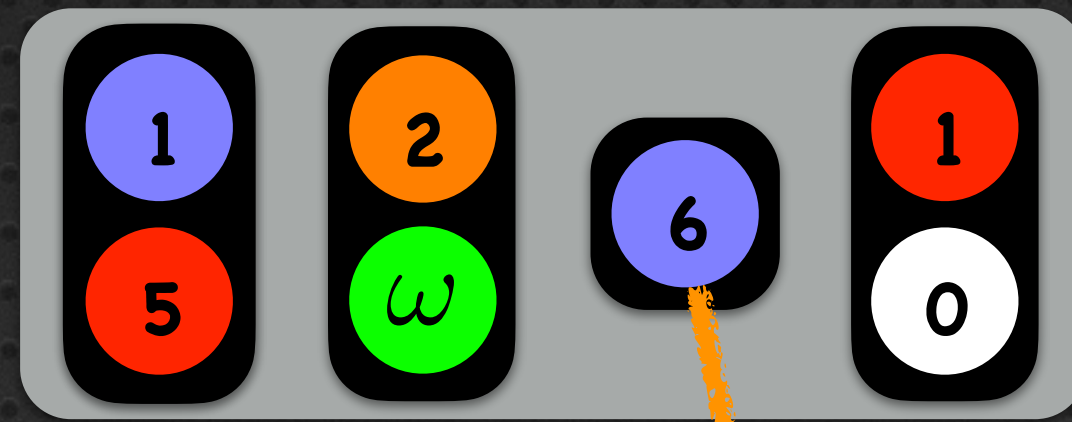
$$\text{sig}(c) = s$$



c:
configuration

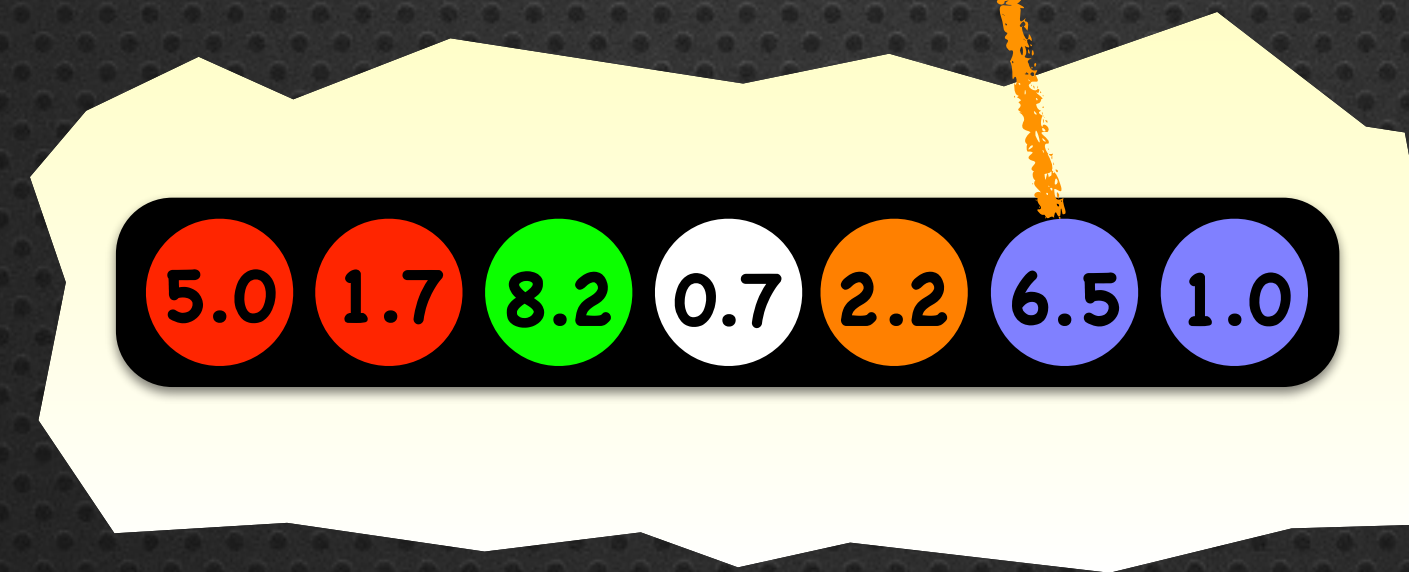
Timed Per...

Signatures



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

Timed Per...

Signatures



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

Timed Per...

Signatures



s:
signature

$$\text{sig}(c) = s$$



c:
configuration

Timed Per.

Signatures



s:
signature

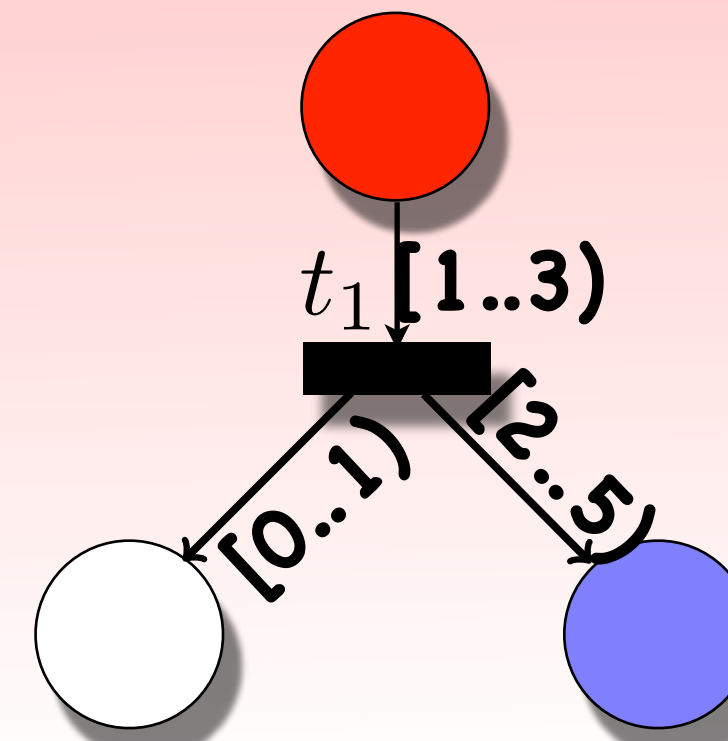
$$\text{sig}(c) = s$$



c:
configuration

Timed Petri

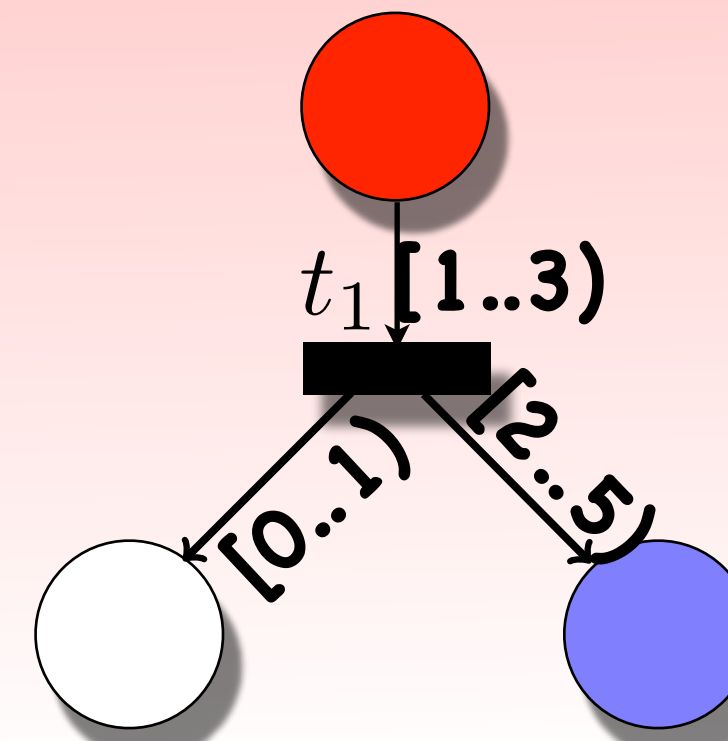
Signatures



Timed Petri

Signatures

$\text{sig}(c)=s$:
c and s are "bisimilar"

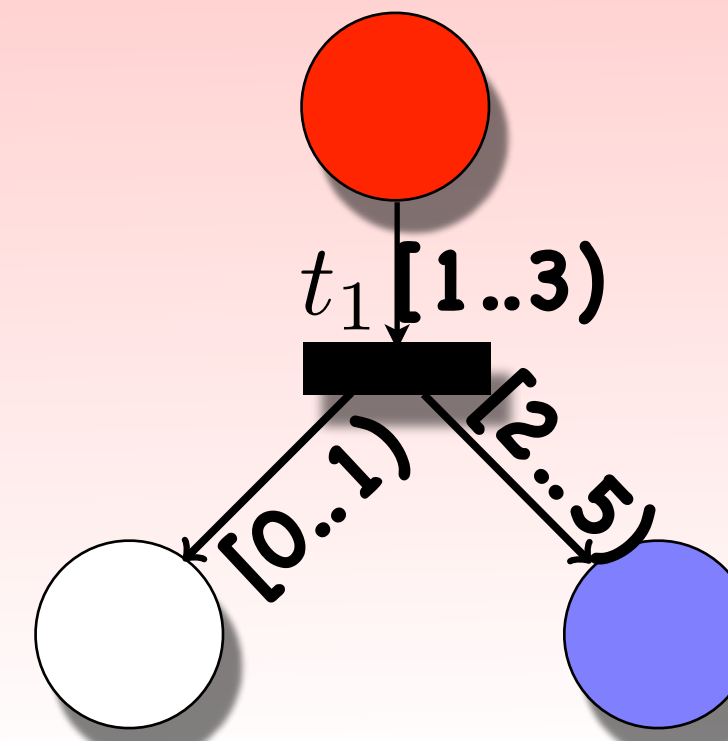


Timed Petri

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5.0 1.7 8.2 4.7 2.2 6.5 1.0

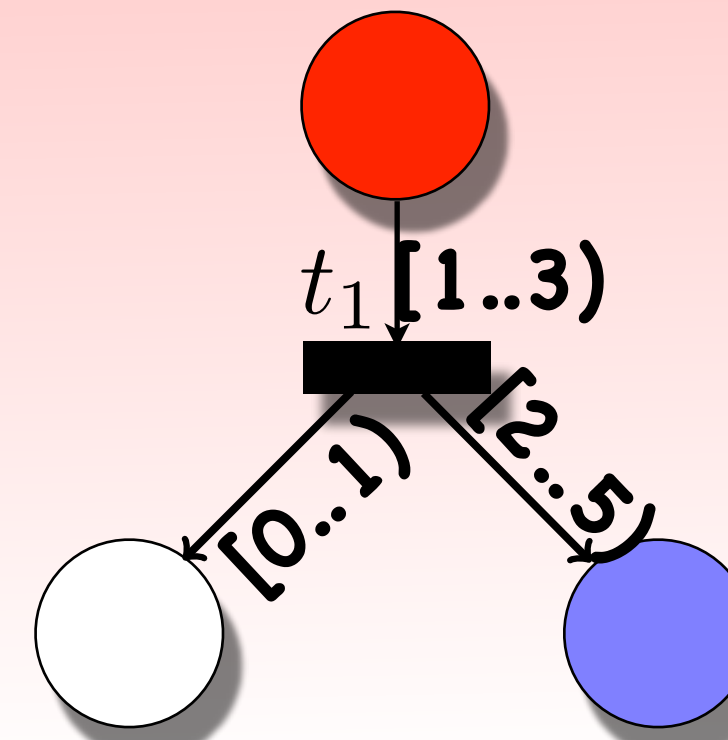


Timed Petri

Signatures

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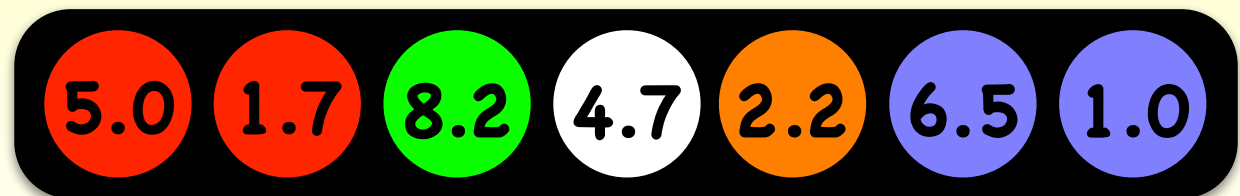
5.0 1.7 8.2 4.7 2.2 6.5 1.0



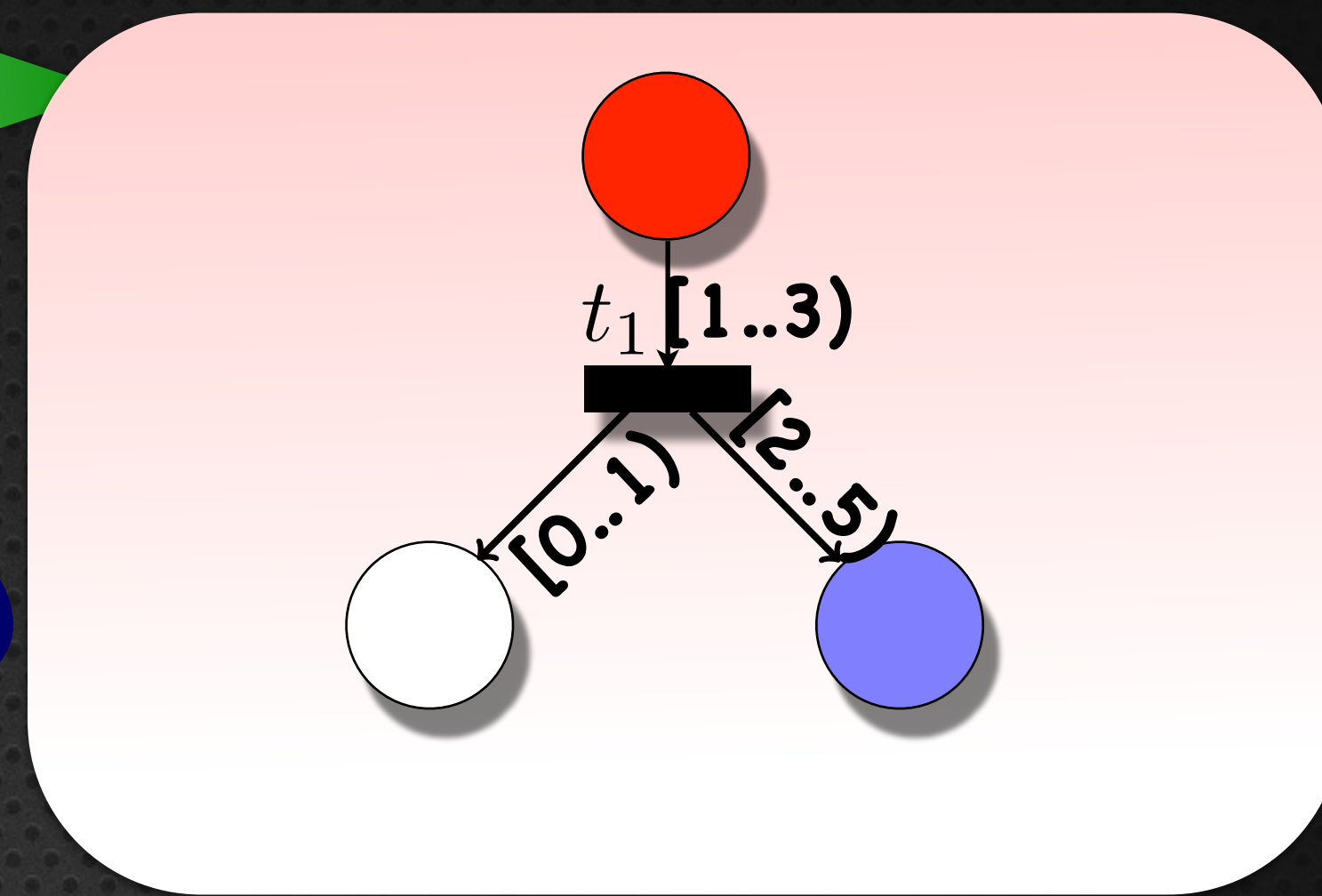
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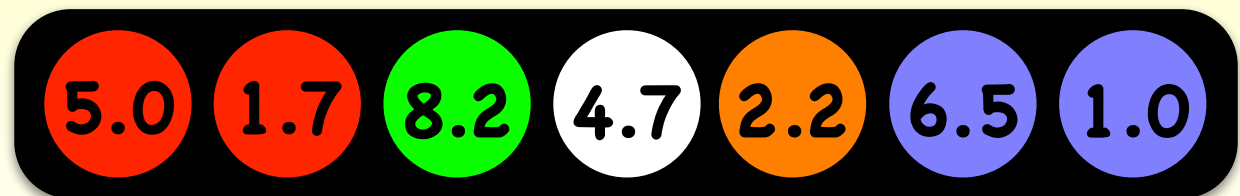
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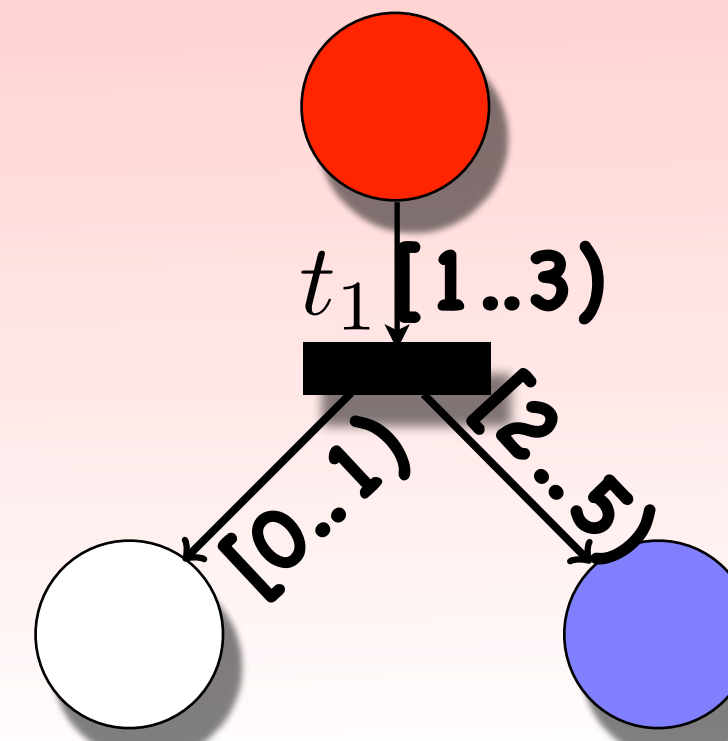
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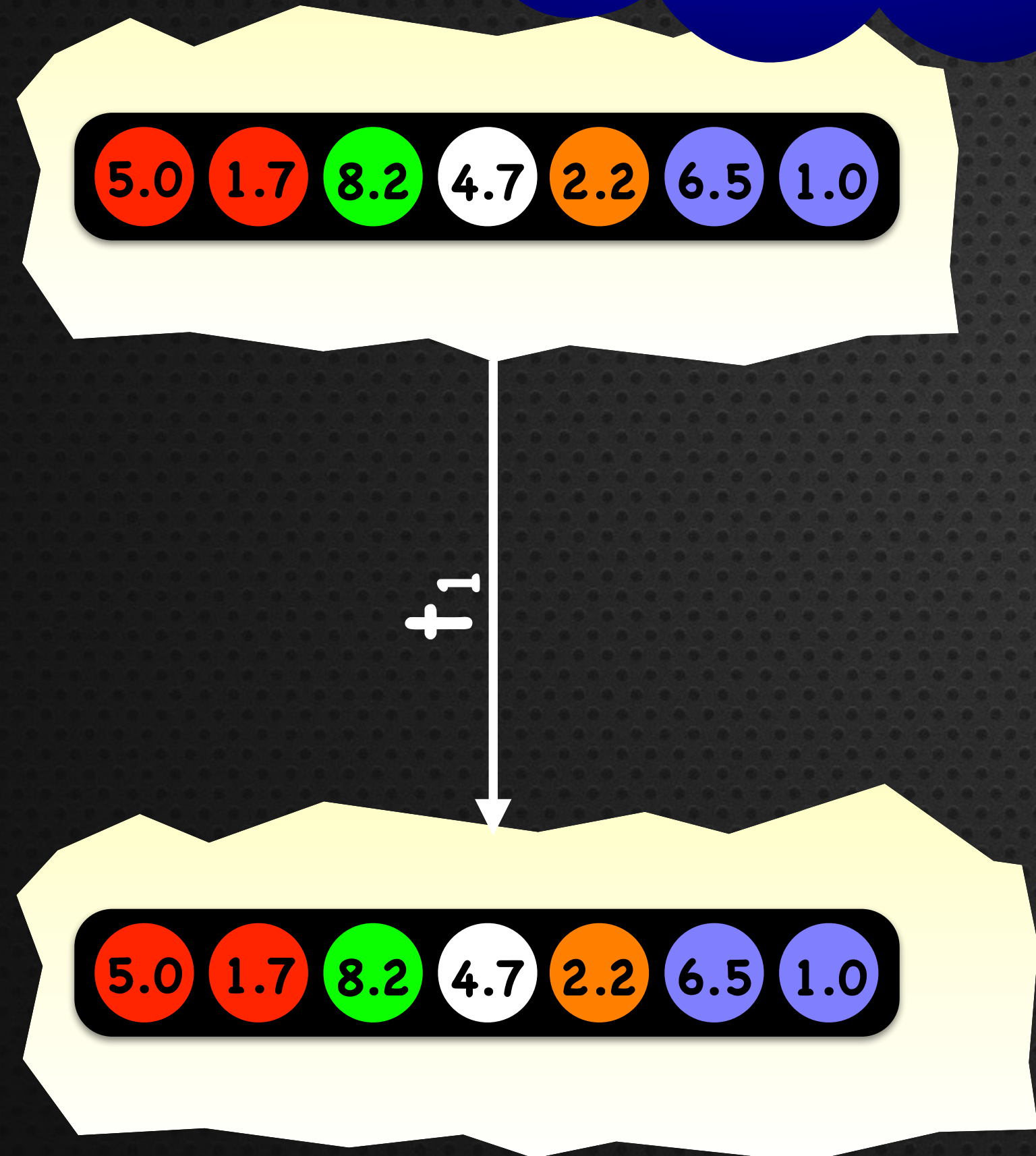
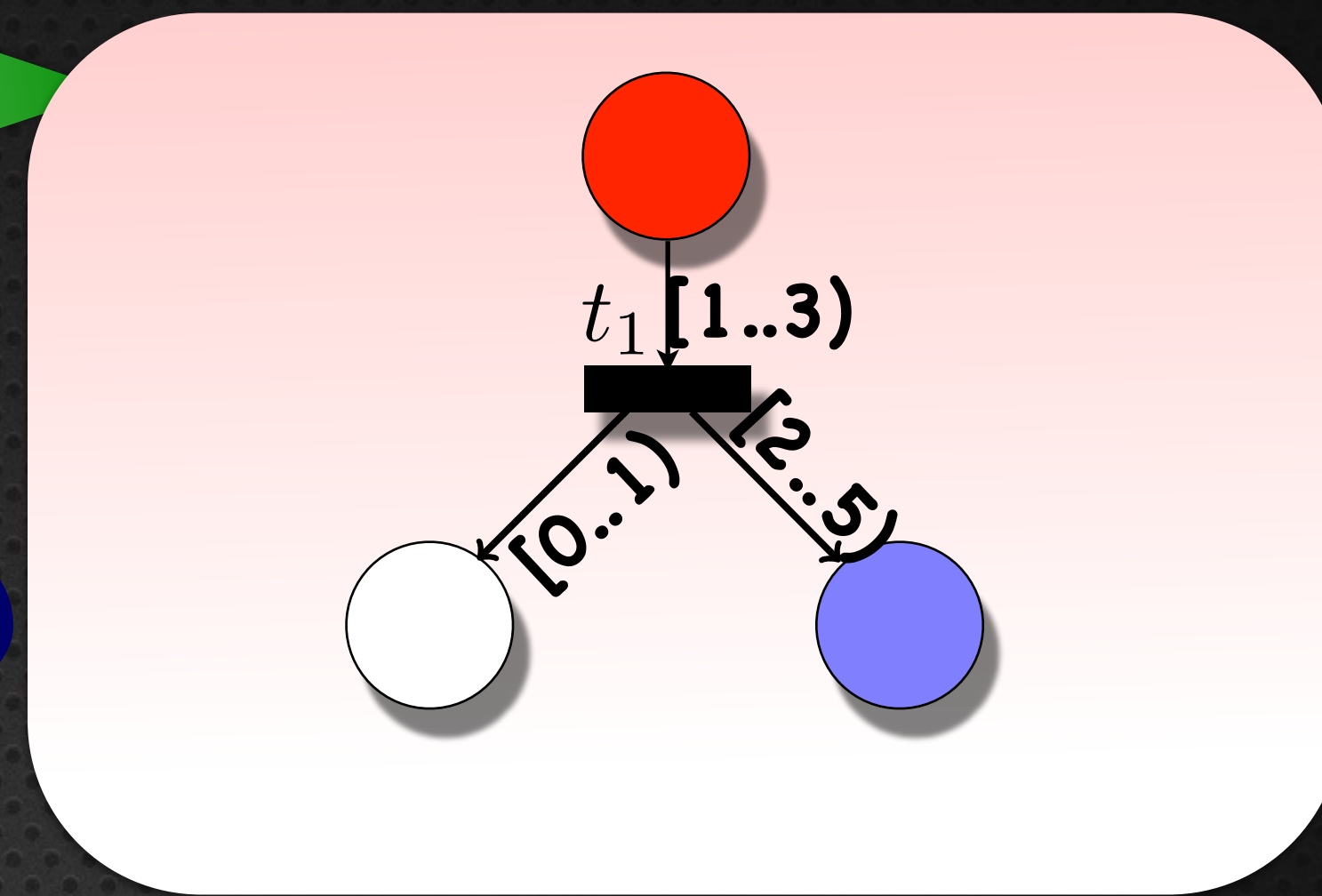
t_1



Timed Petri

Signatures

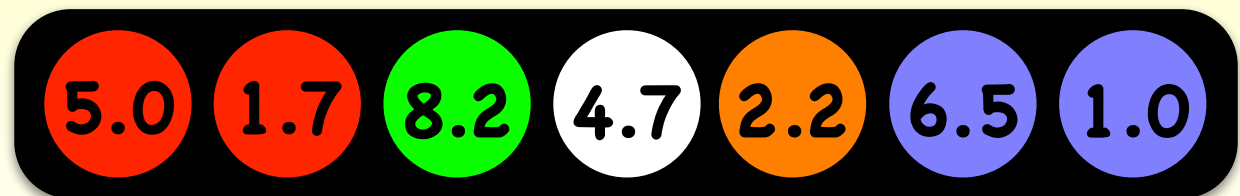
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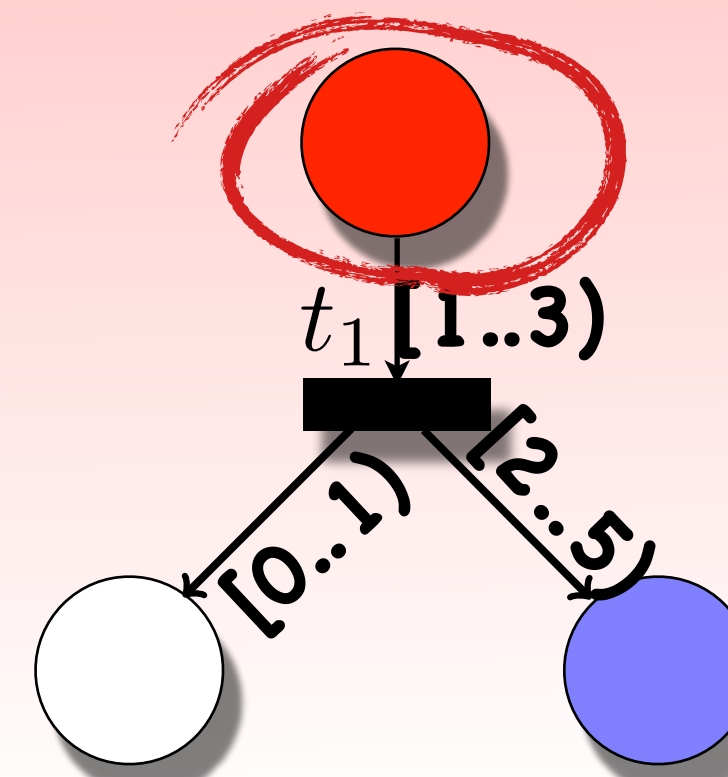
Timed Petri

Signatures

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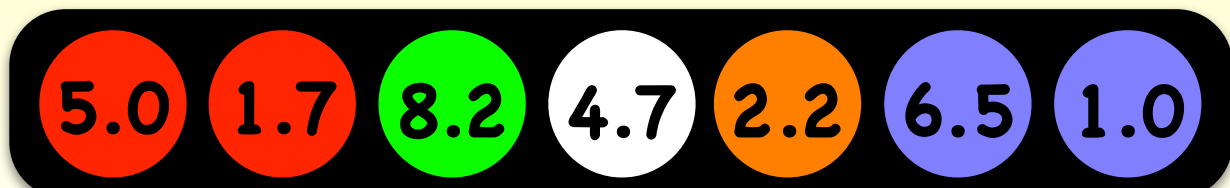
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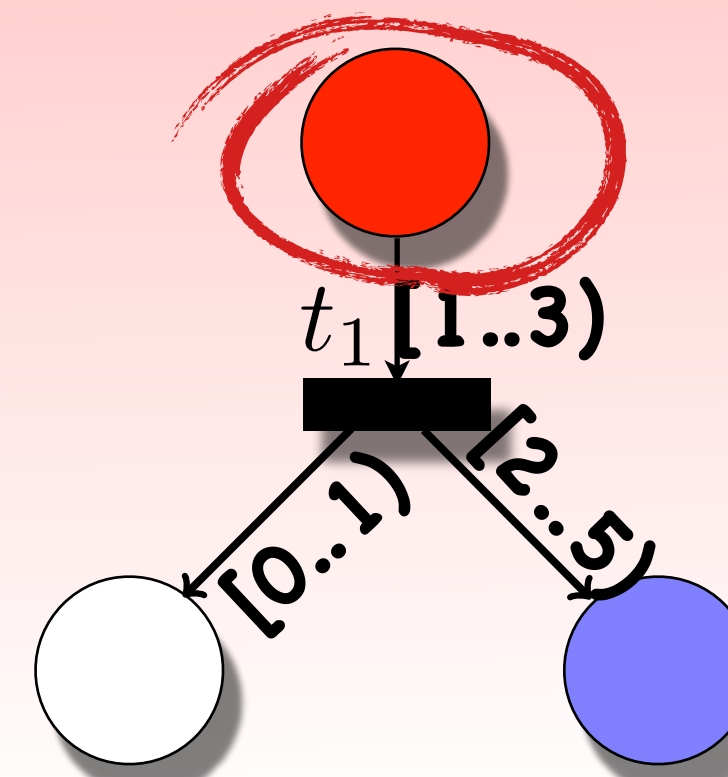
Timed Petri

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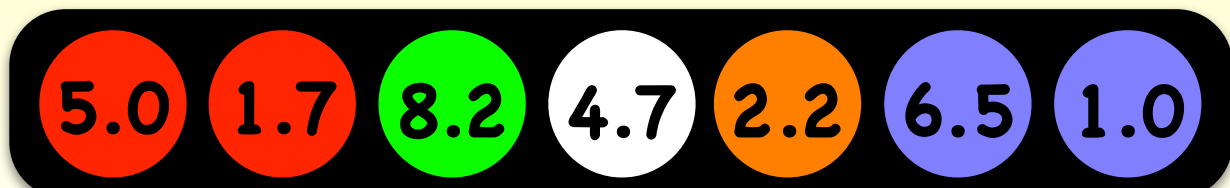
t_1



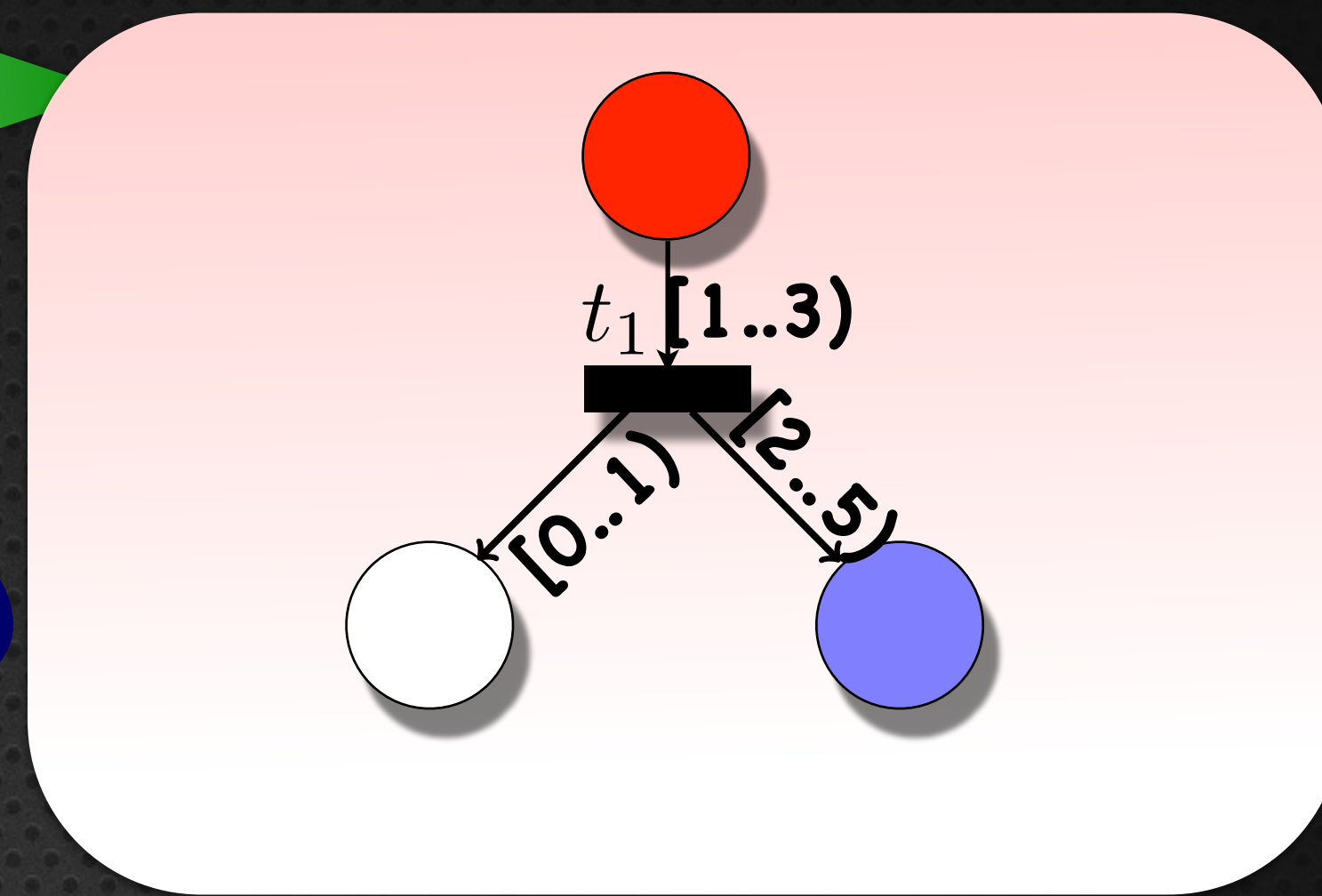
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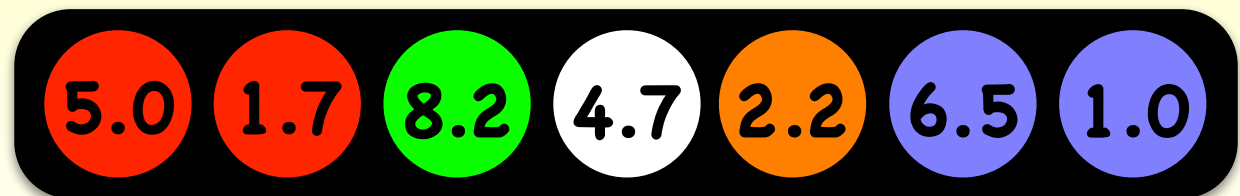
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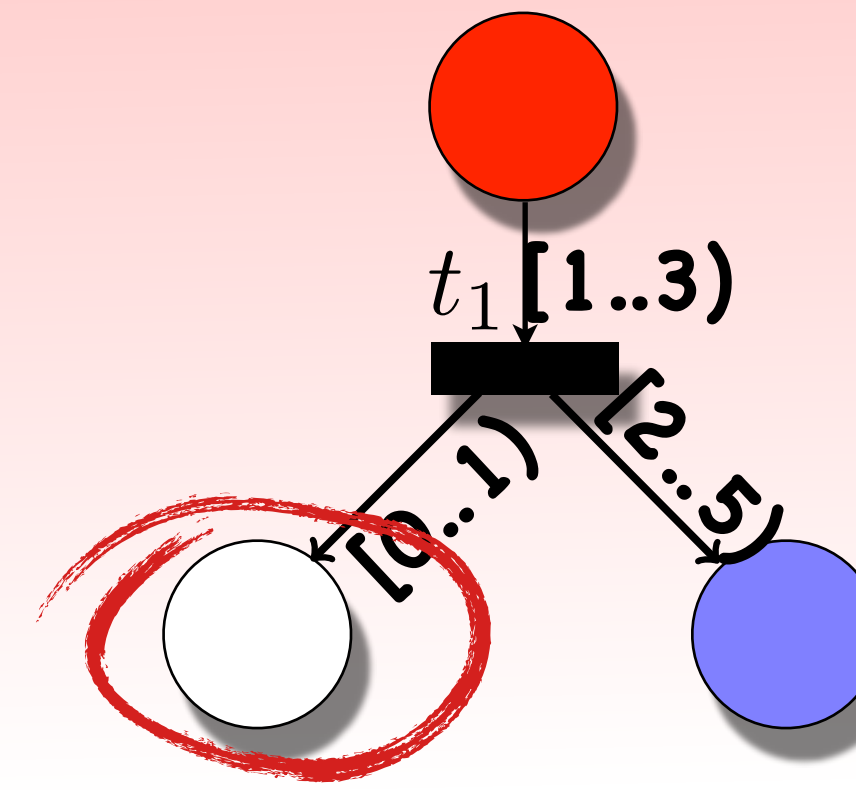
Timed Petri

Signatures

$\text{sig}(c)=s$:
c and s are "bisimilar"



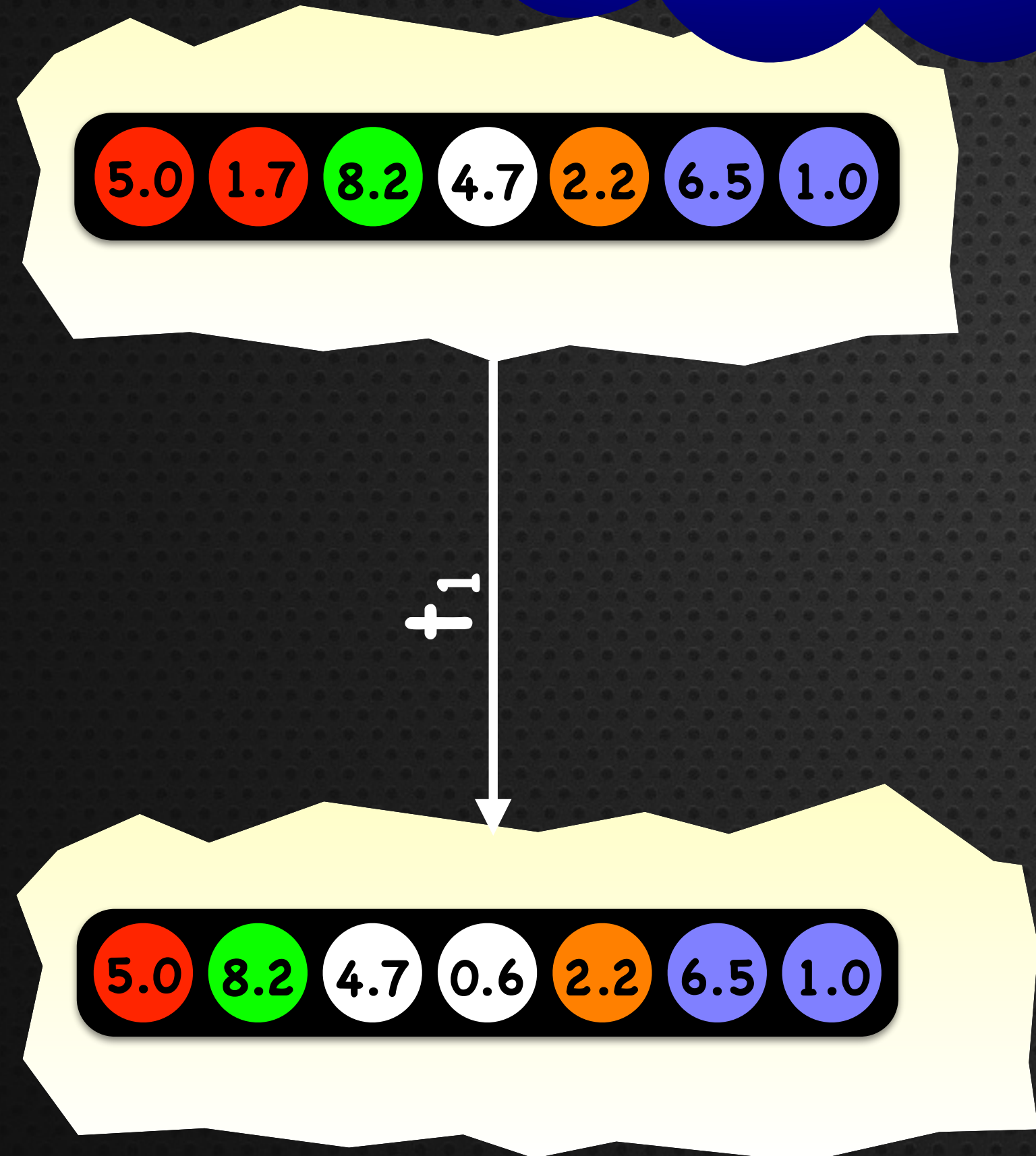
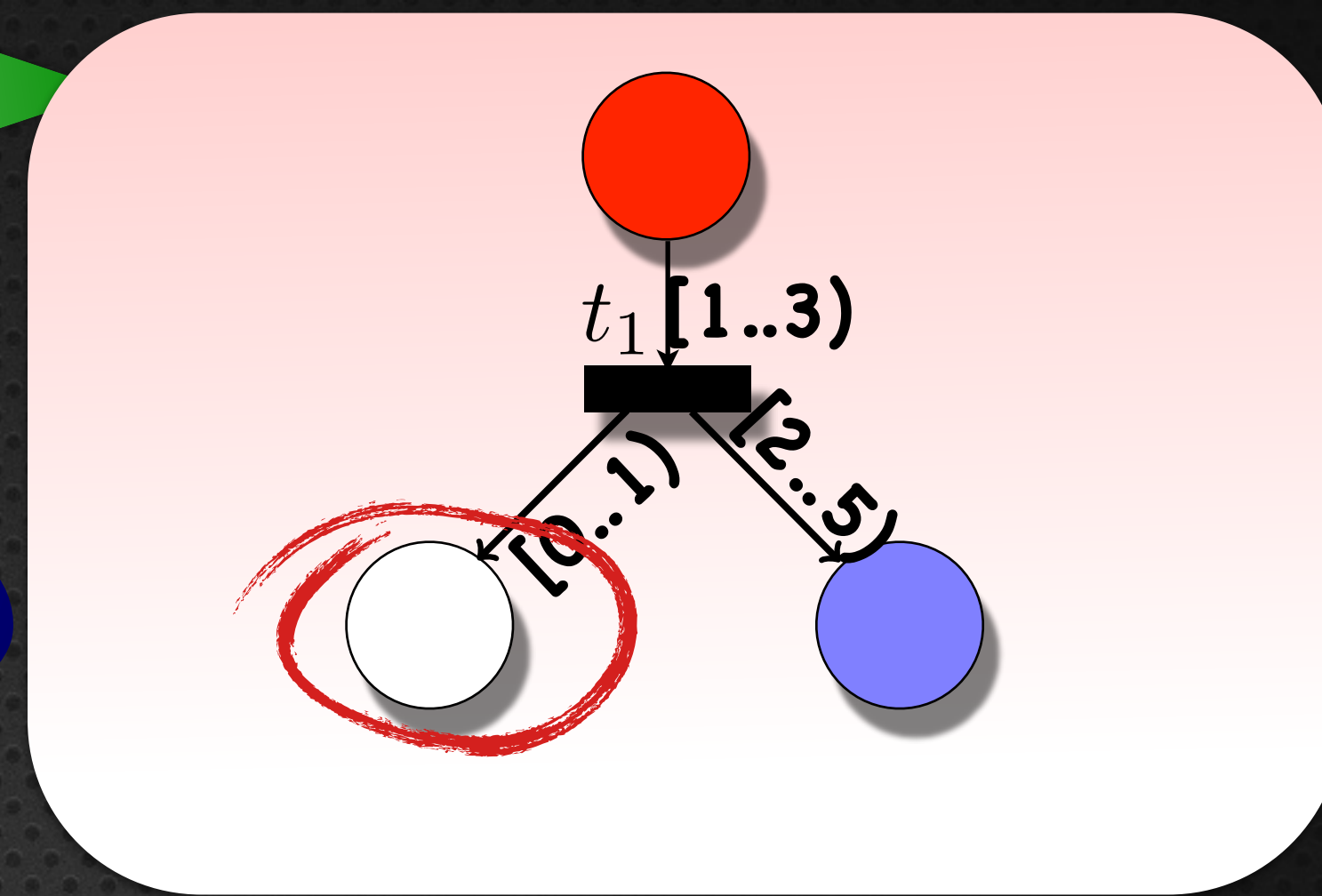
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Timed Petri

Signatures

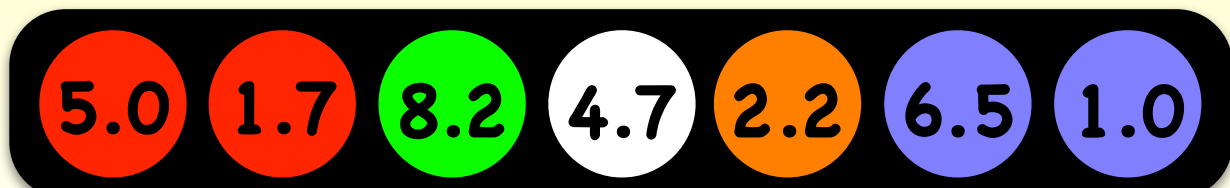
$\text{sig}(c)=s$:
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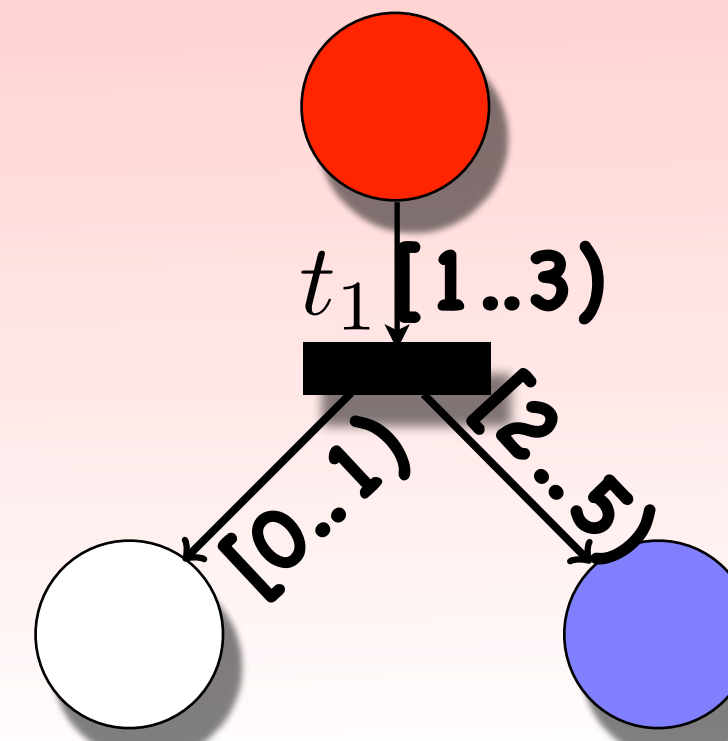
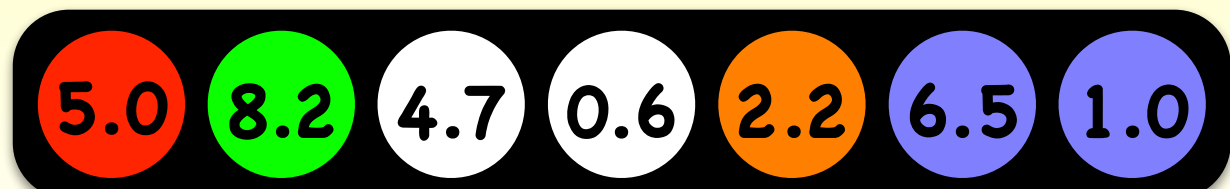
Timed Petri

Signatures

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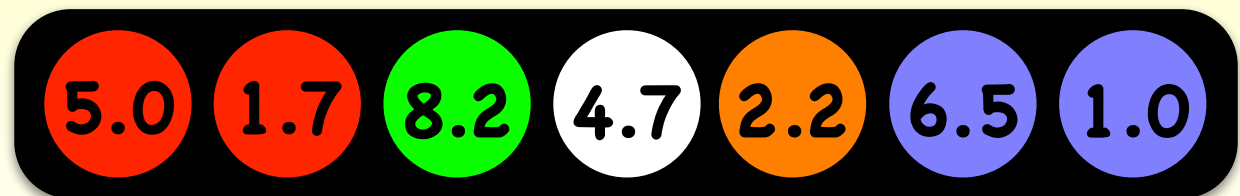
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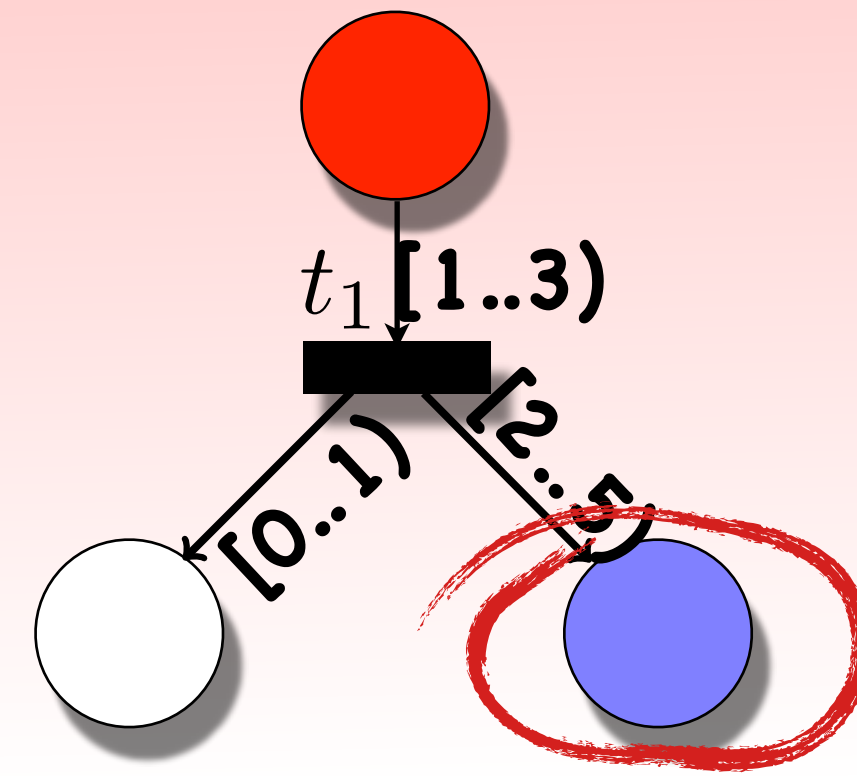
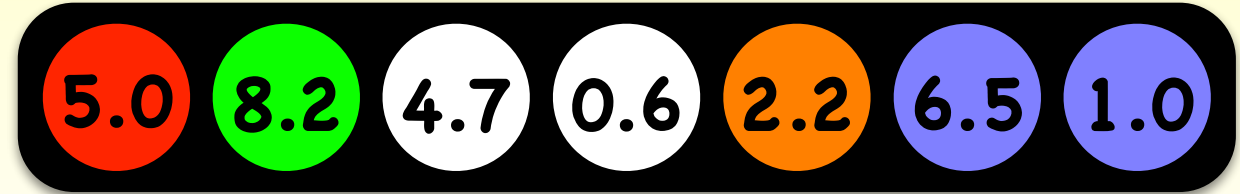
Timed Petri

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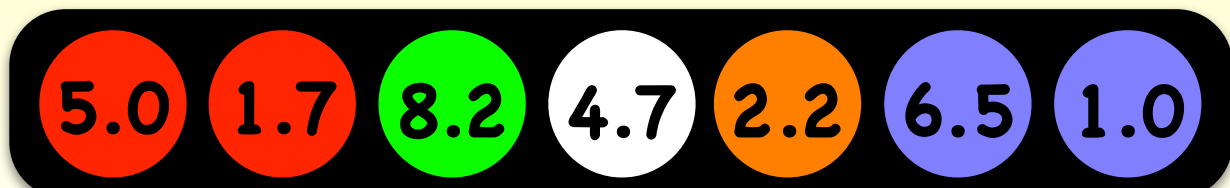
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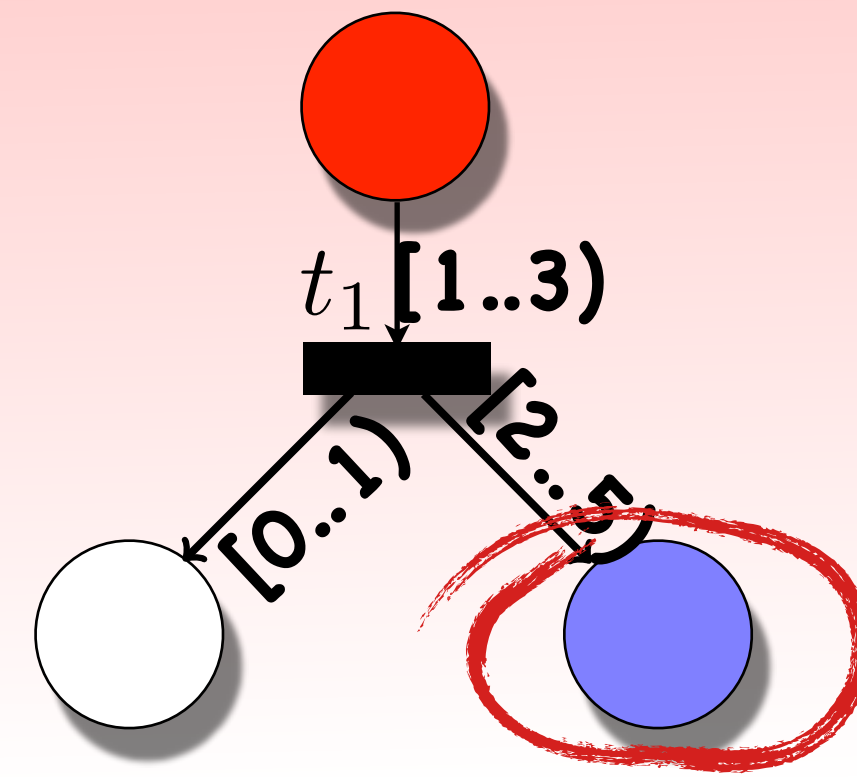
Timed Petri

Signatures

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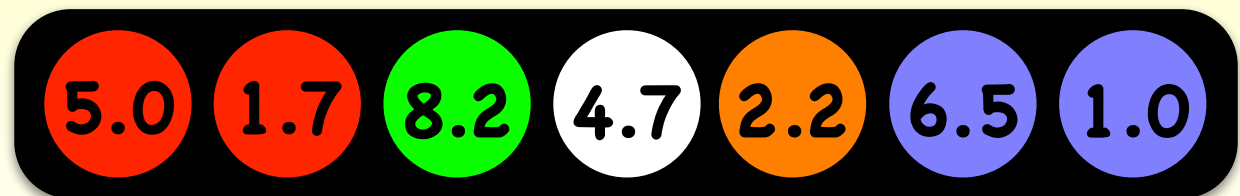
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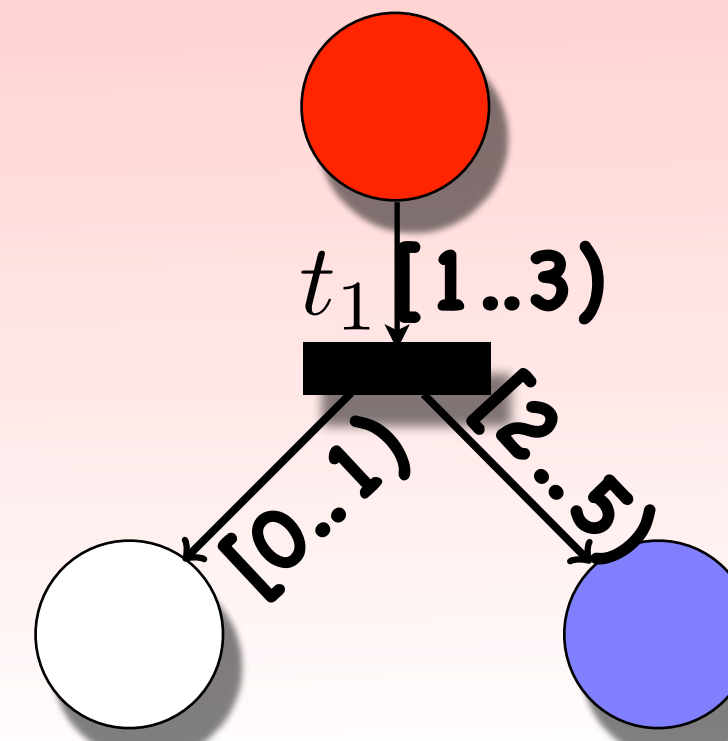
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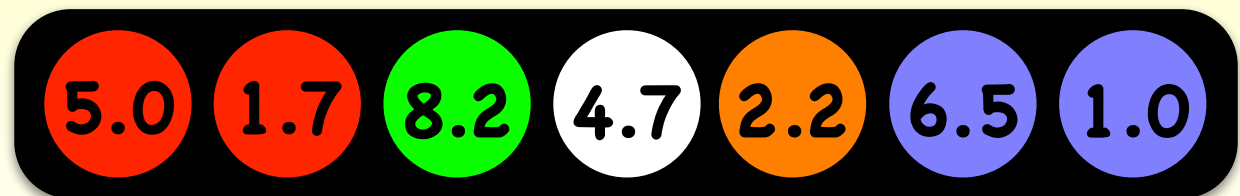
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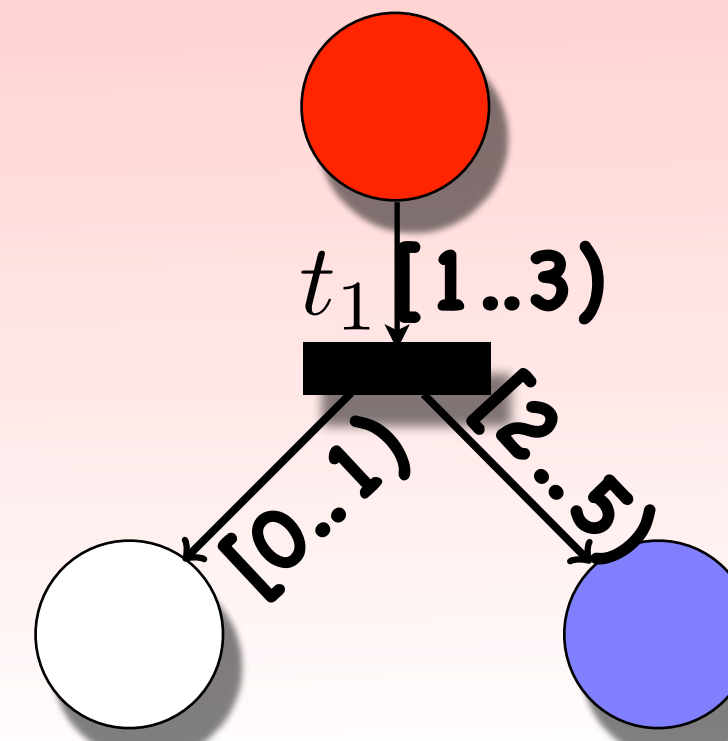
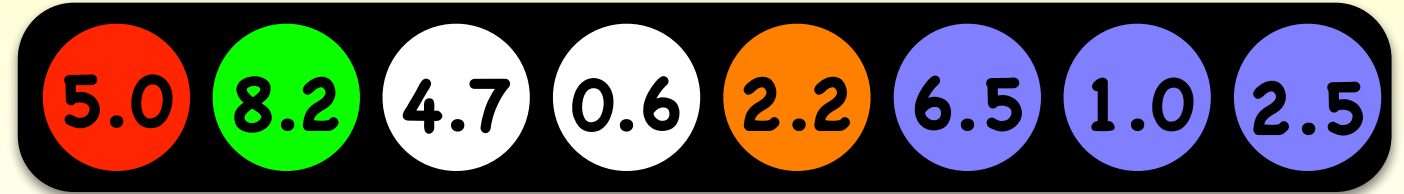
Timed Petri

Signatures

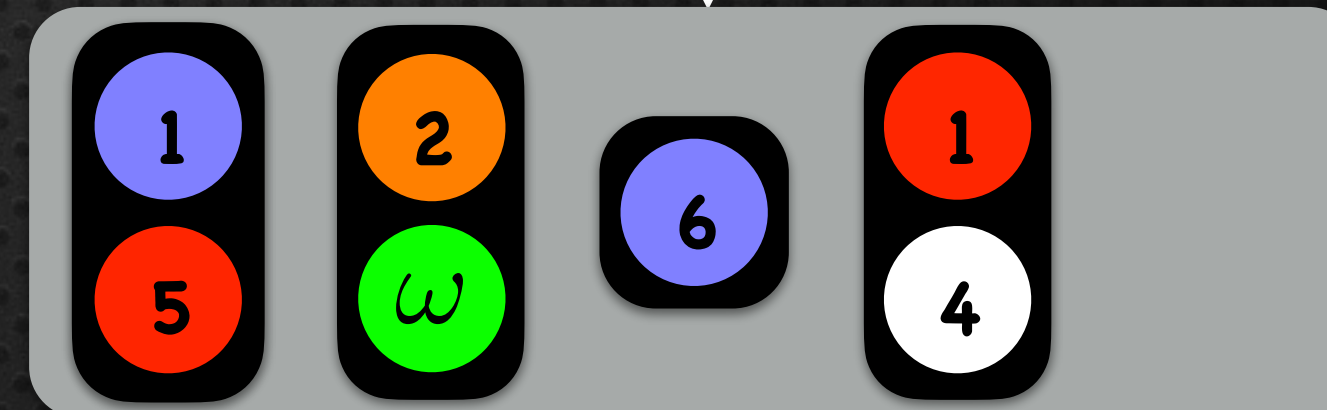
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c and s are "bisimilar"



t_1



t_1



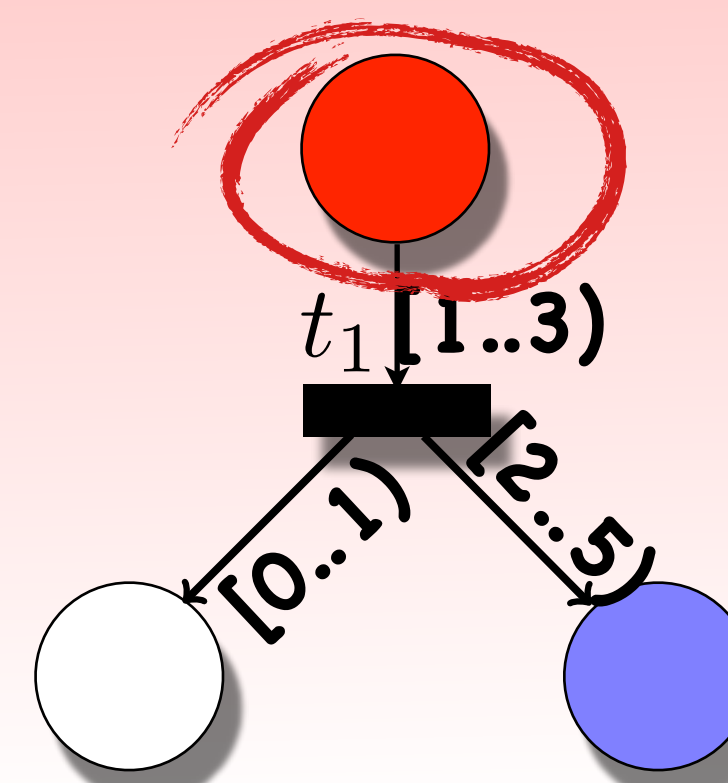
Timed Petri

Signatures

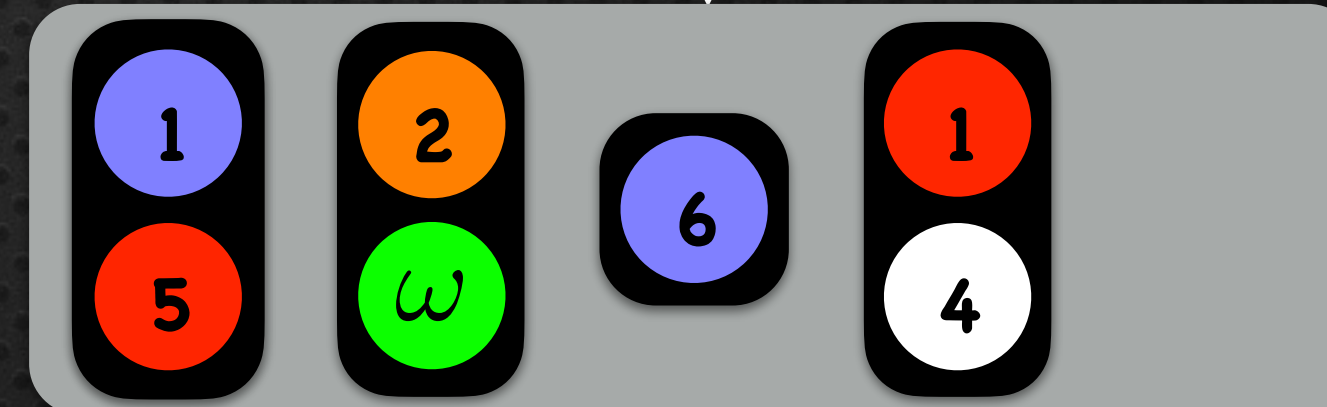
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t_1



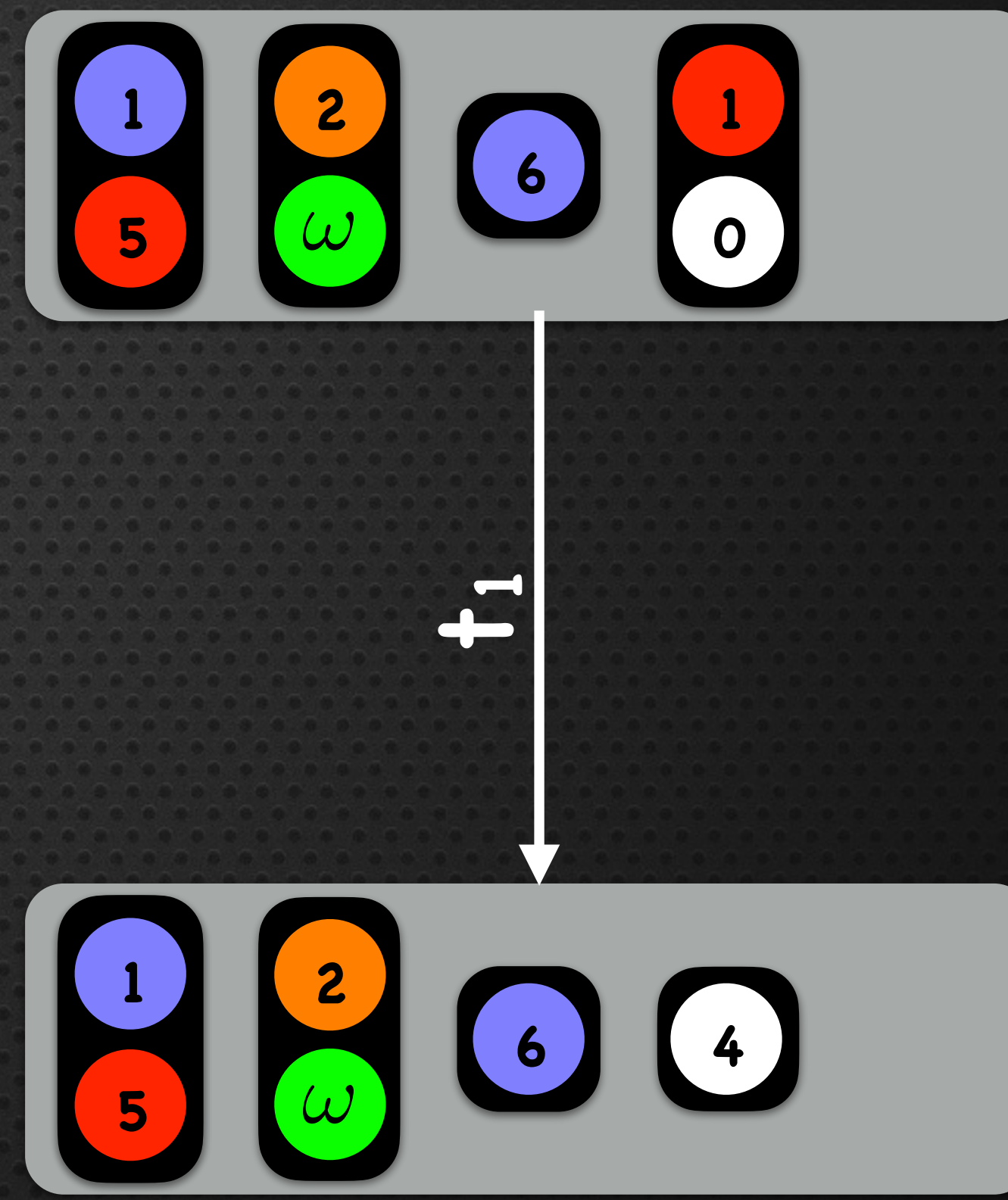
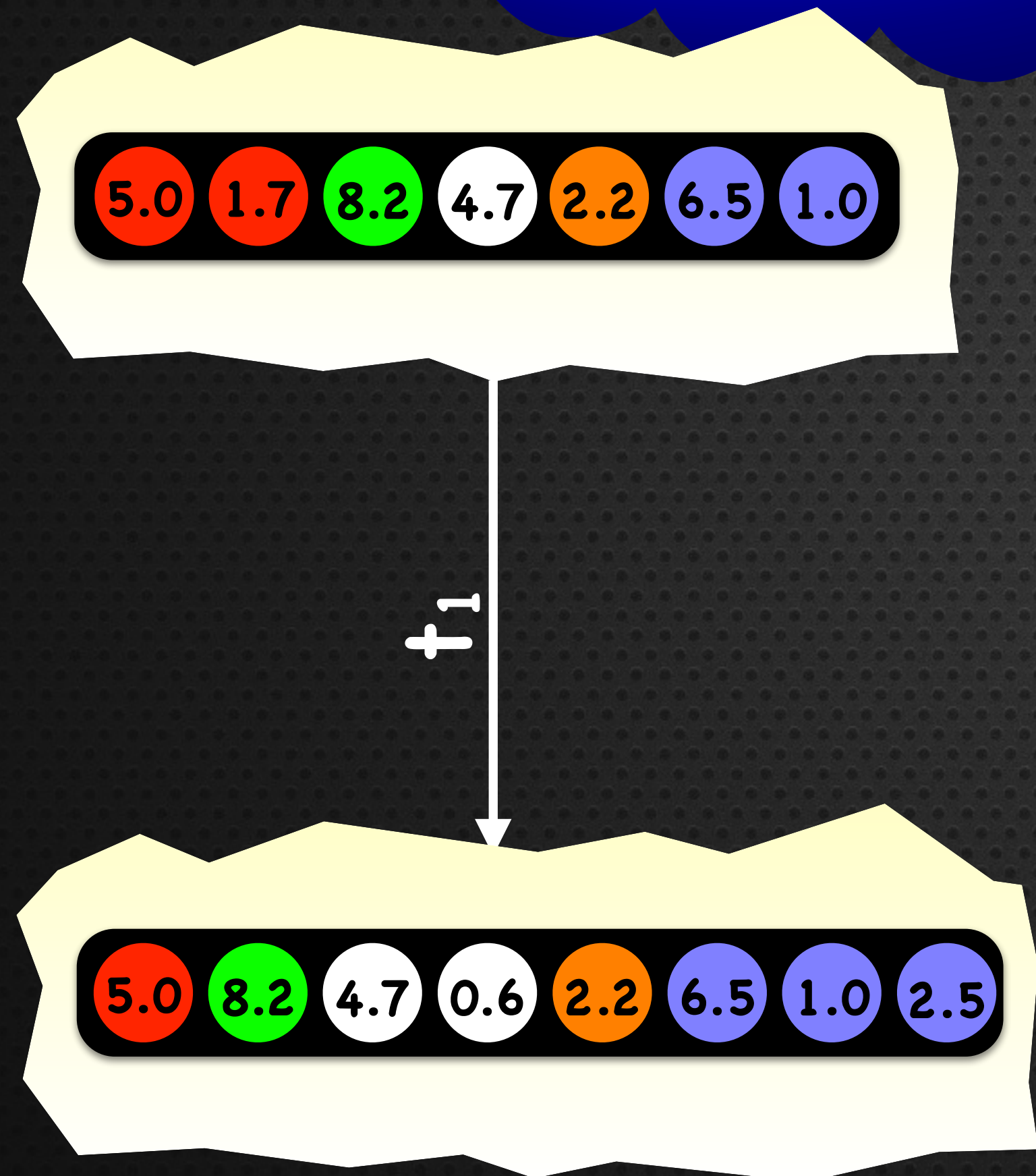
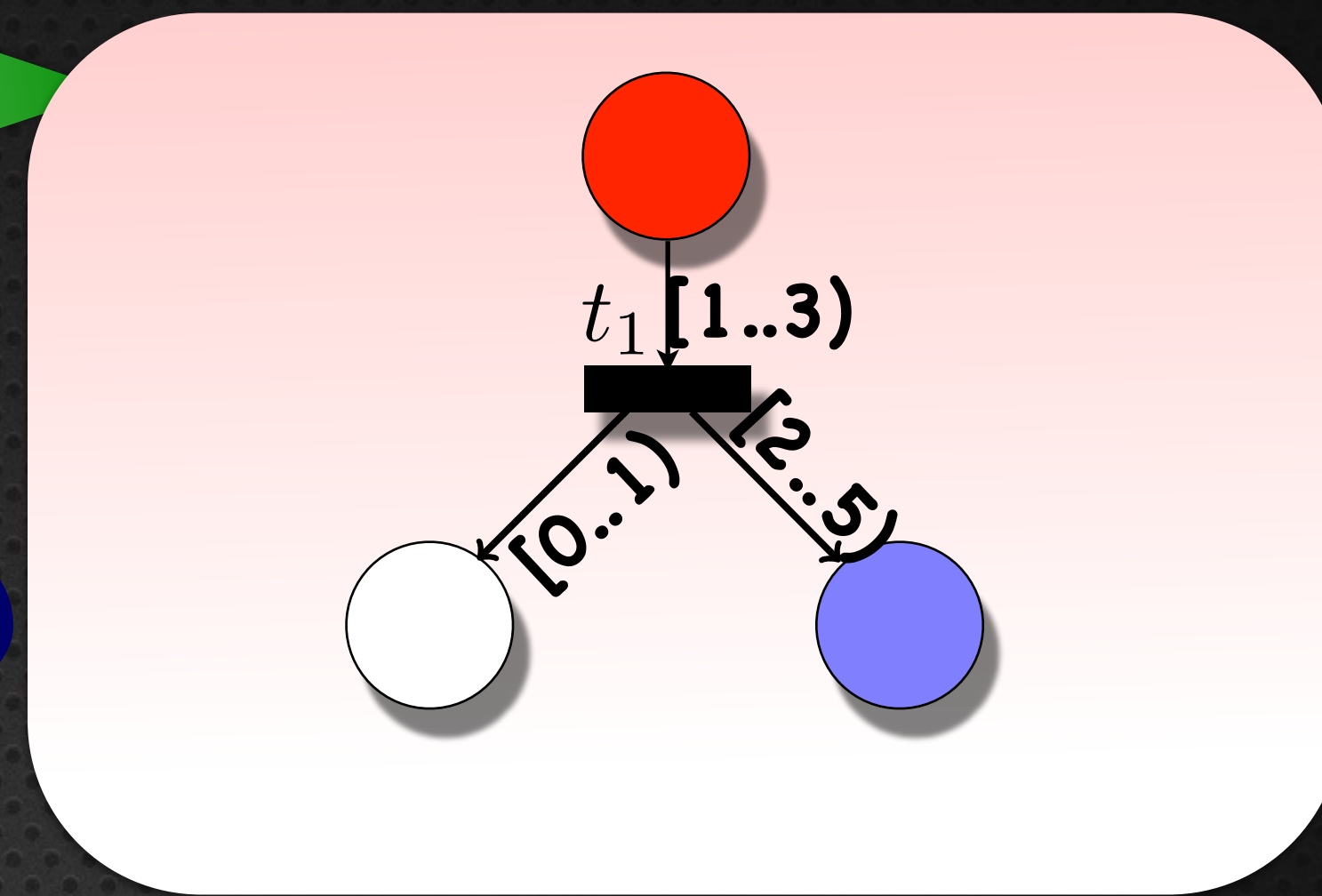
t_1



Timed Petri

Signatures

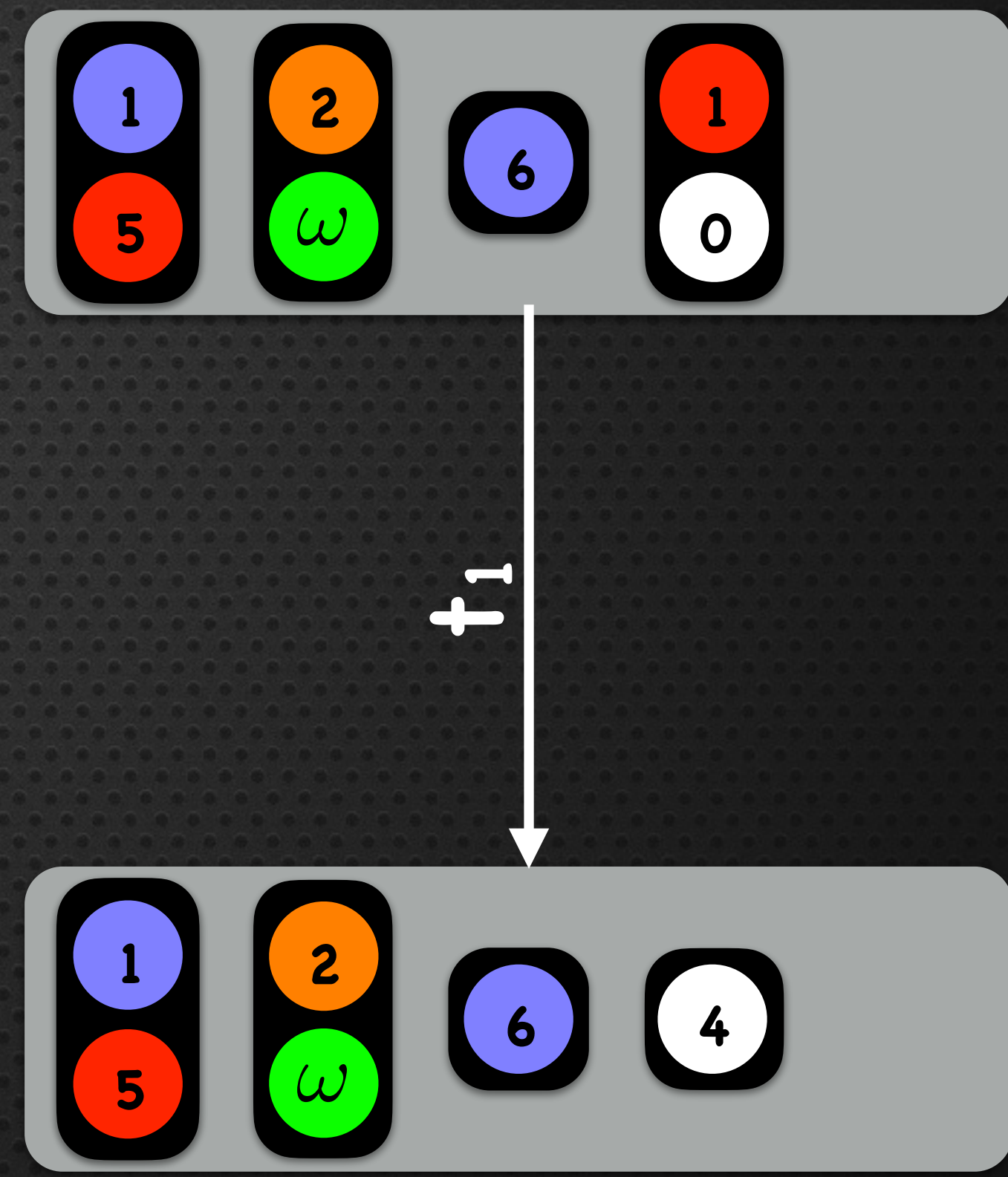
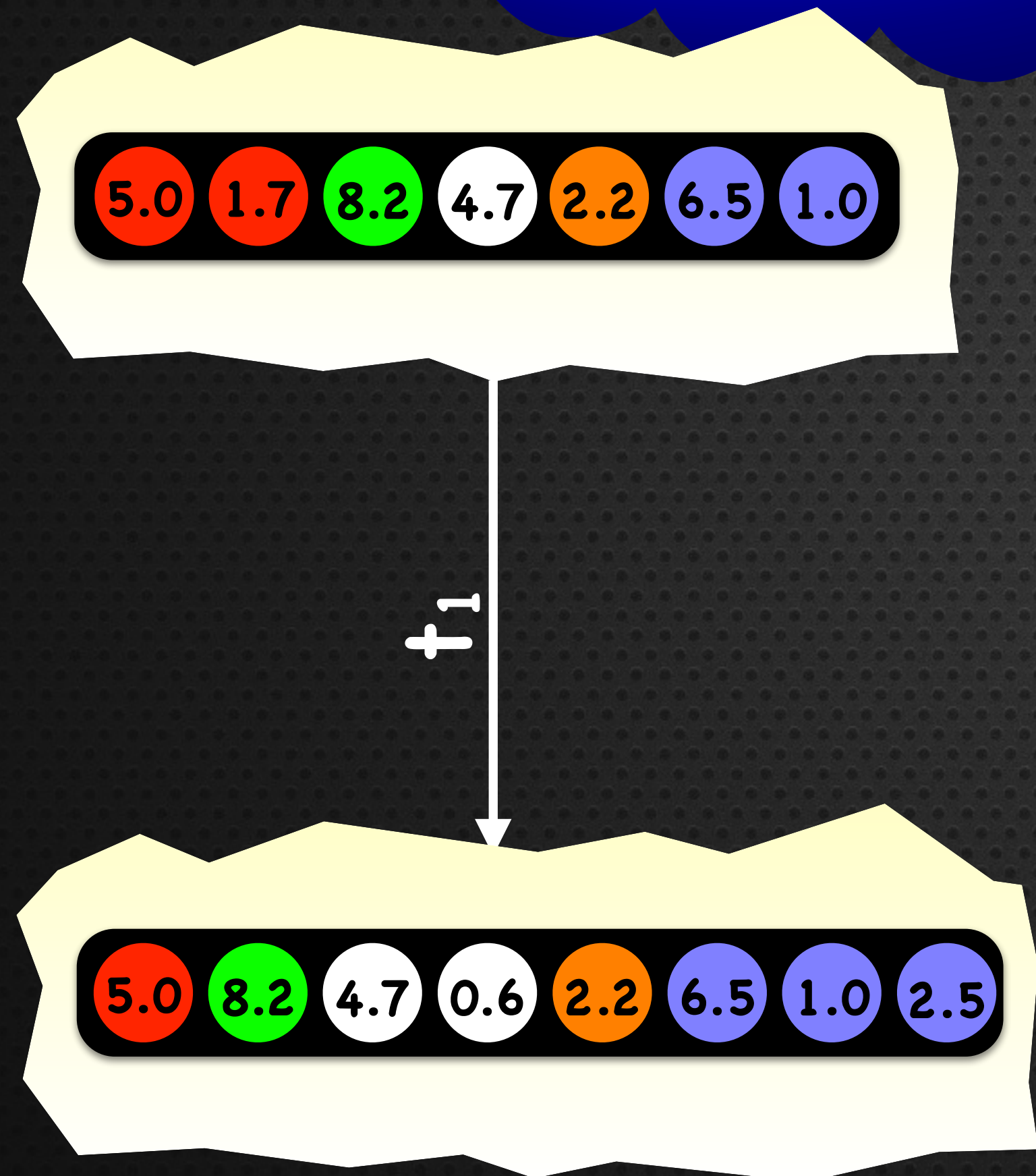
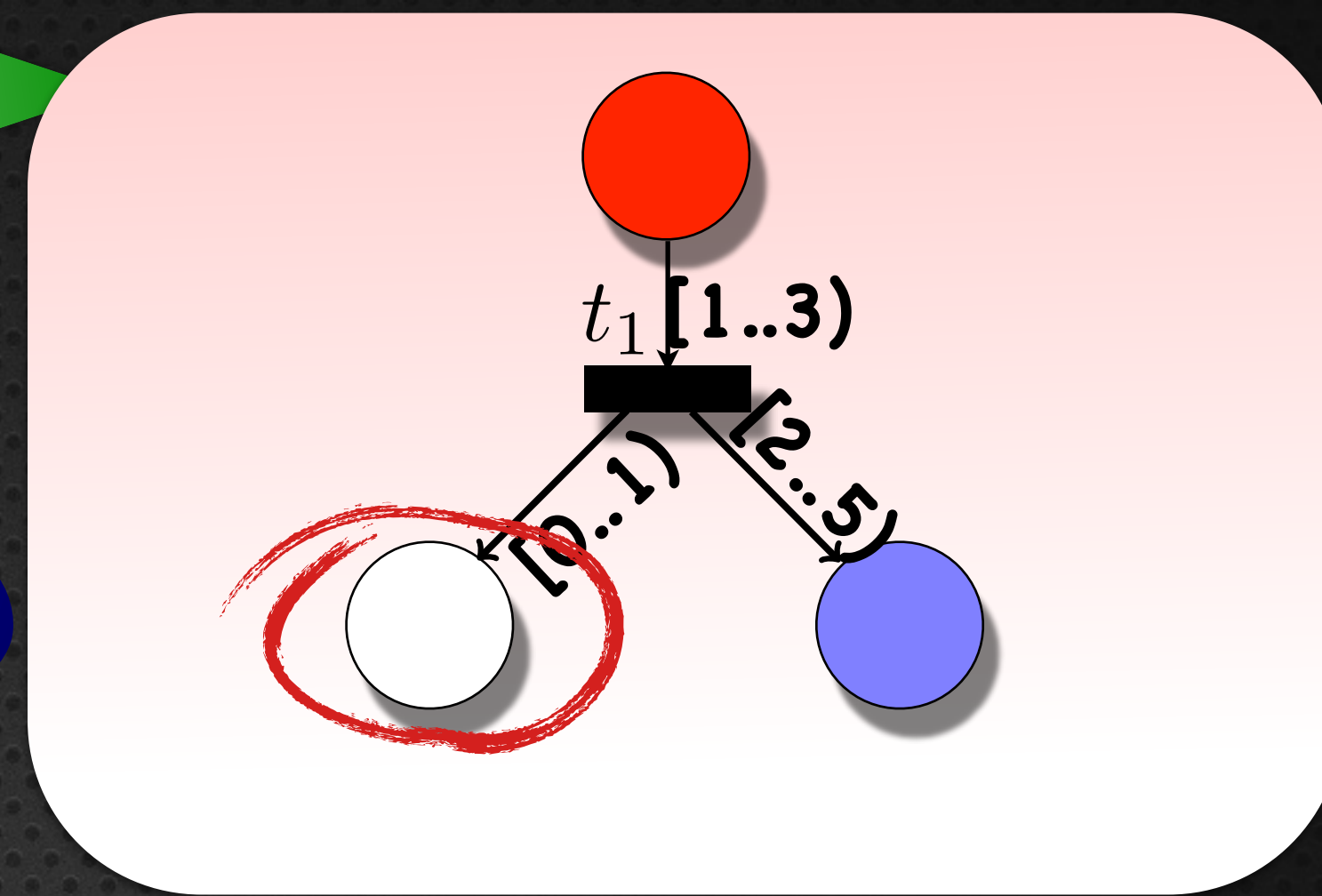
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Timed Petri

Signatures

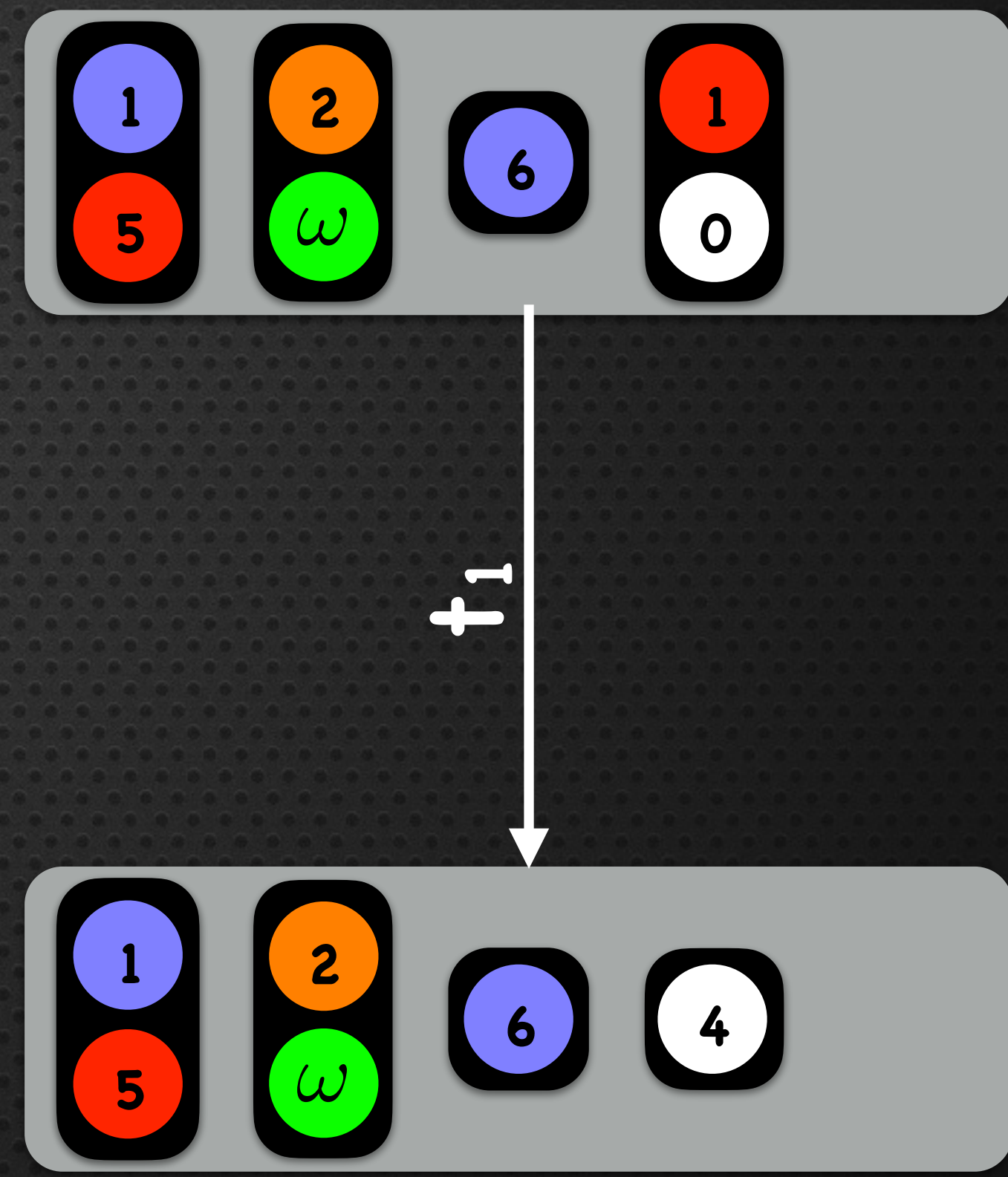
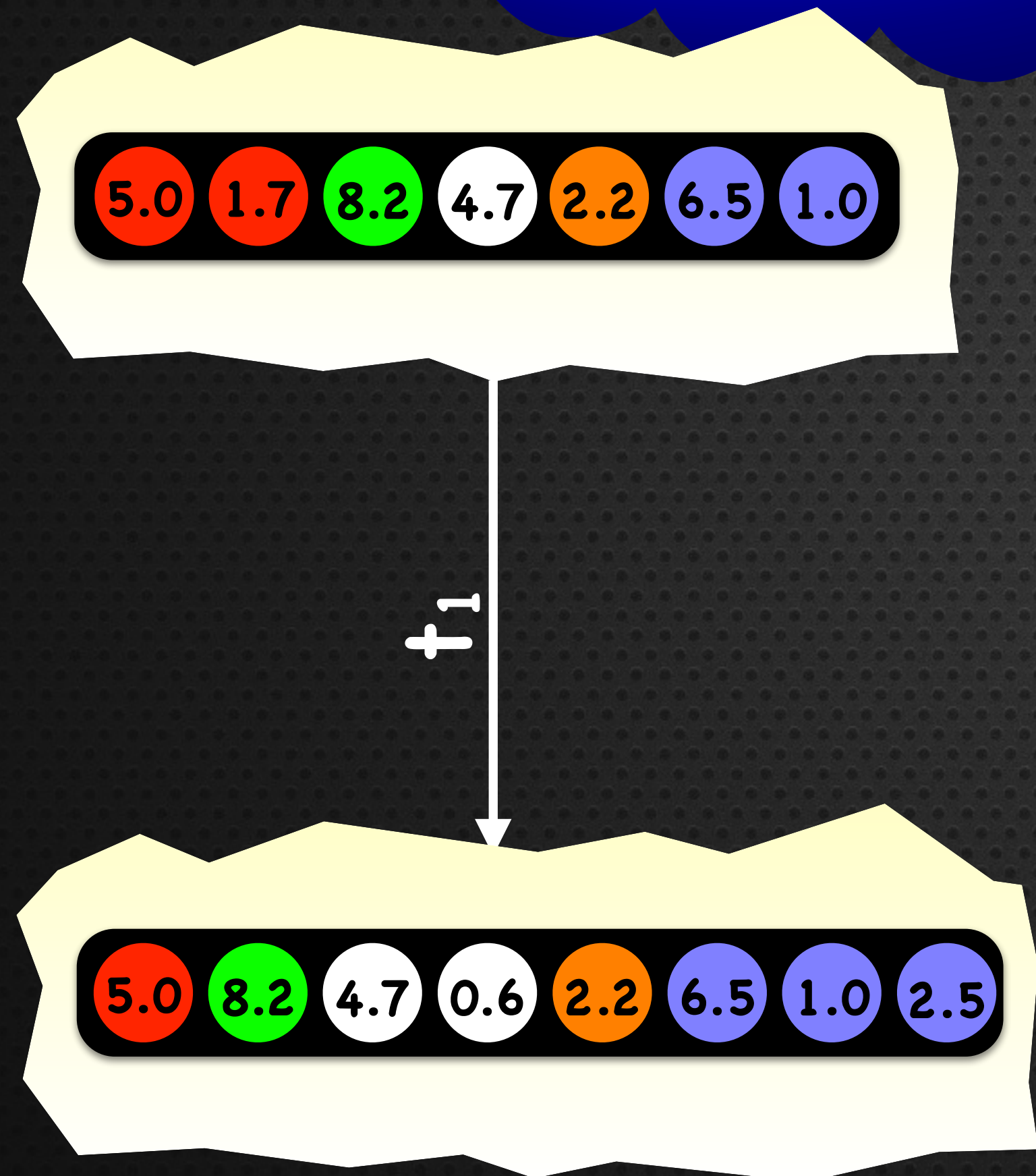
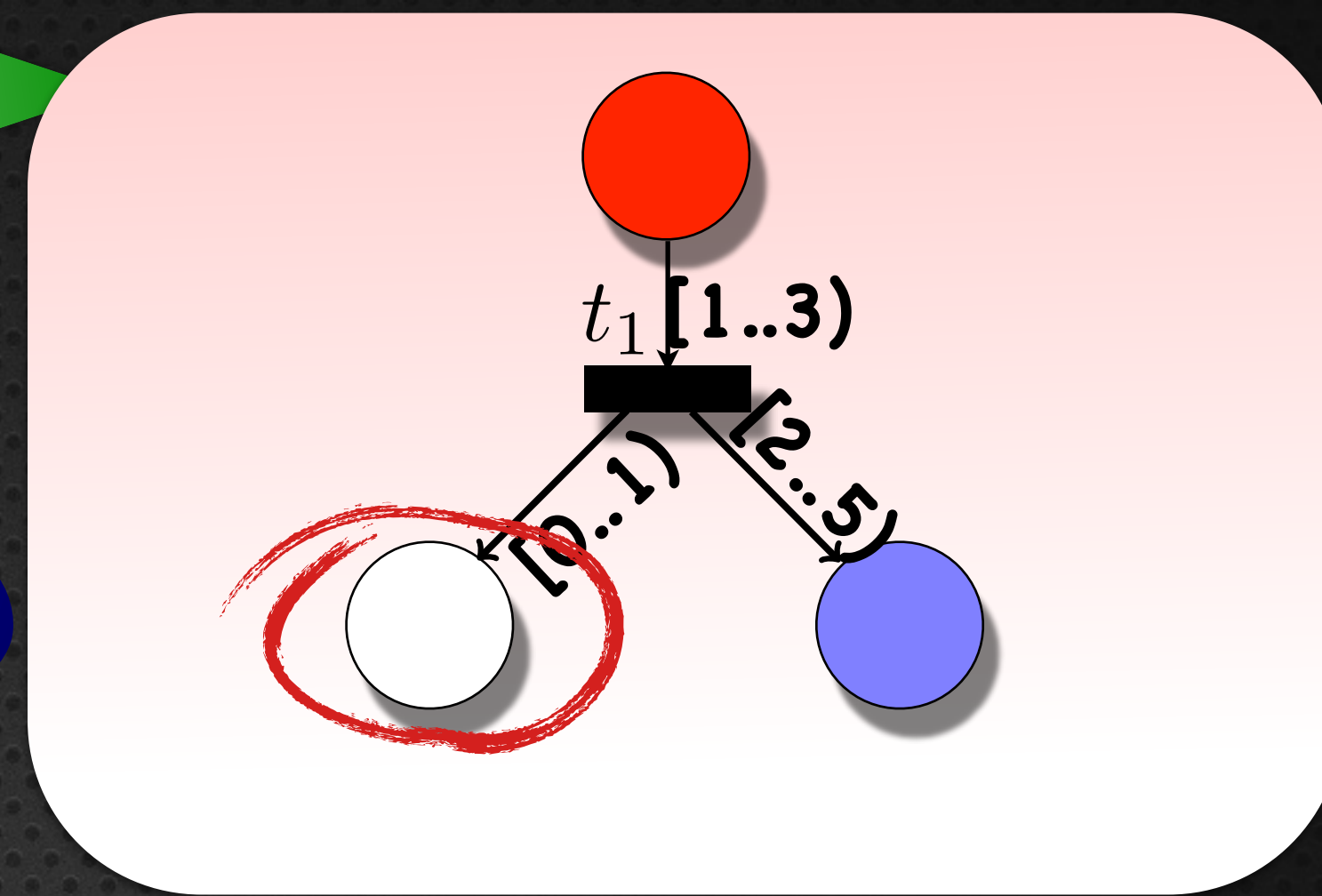
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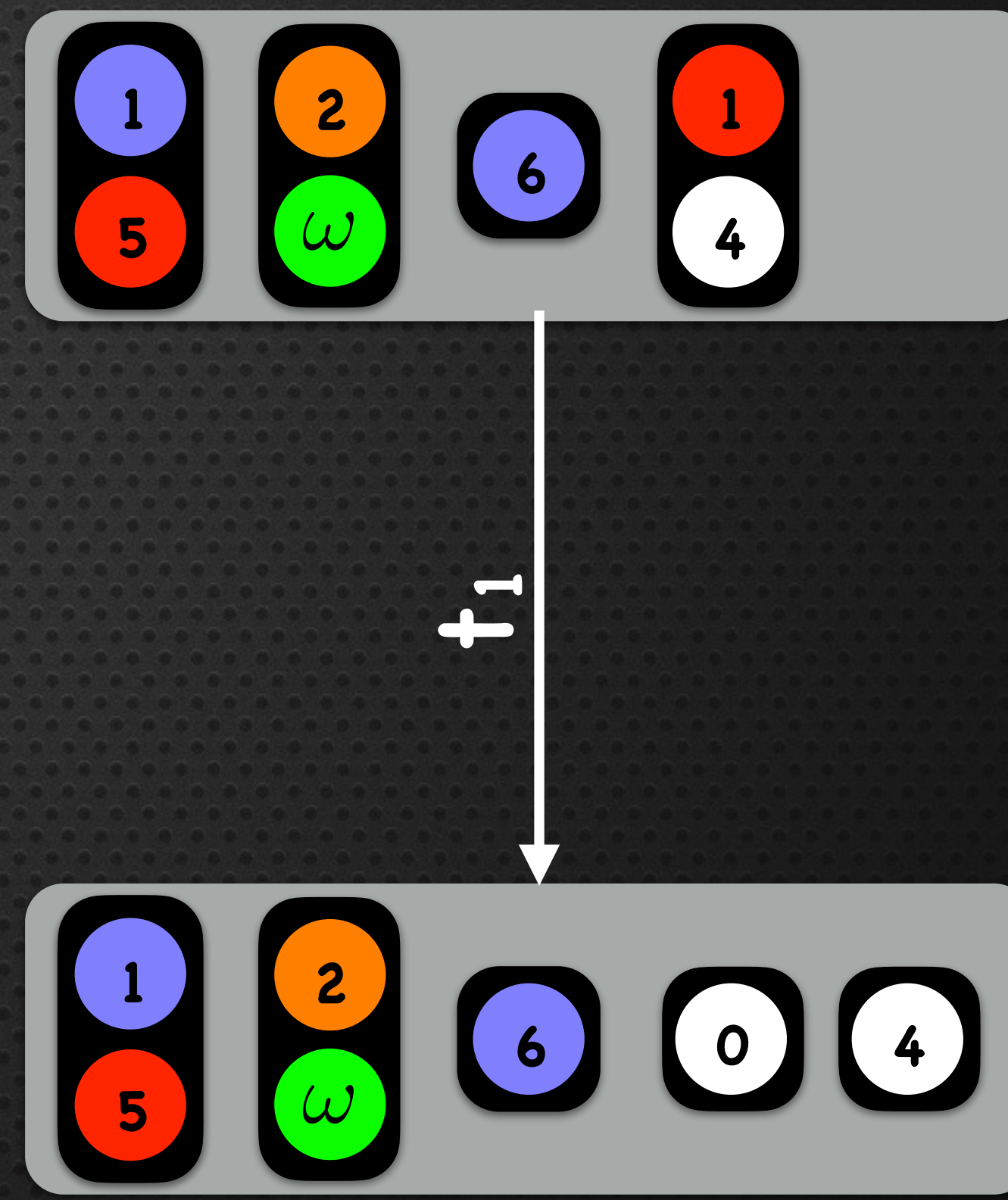
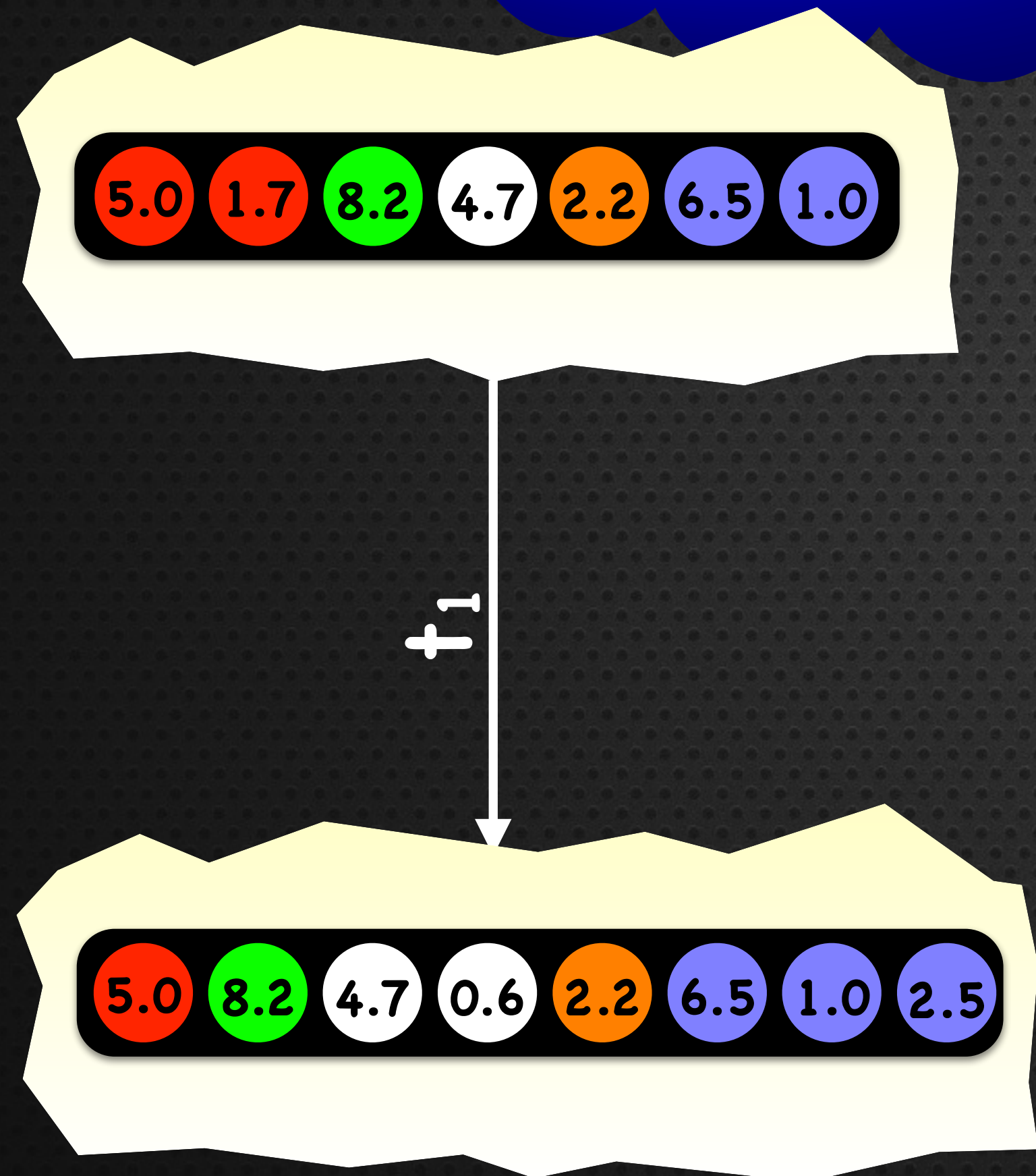
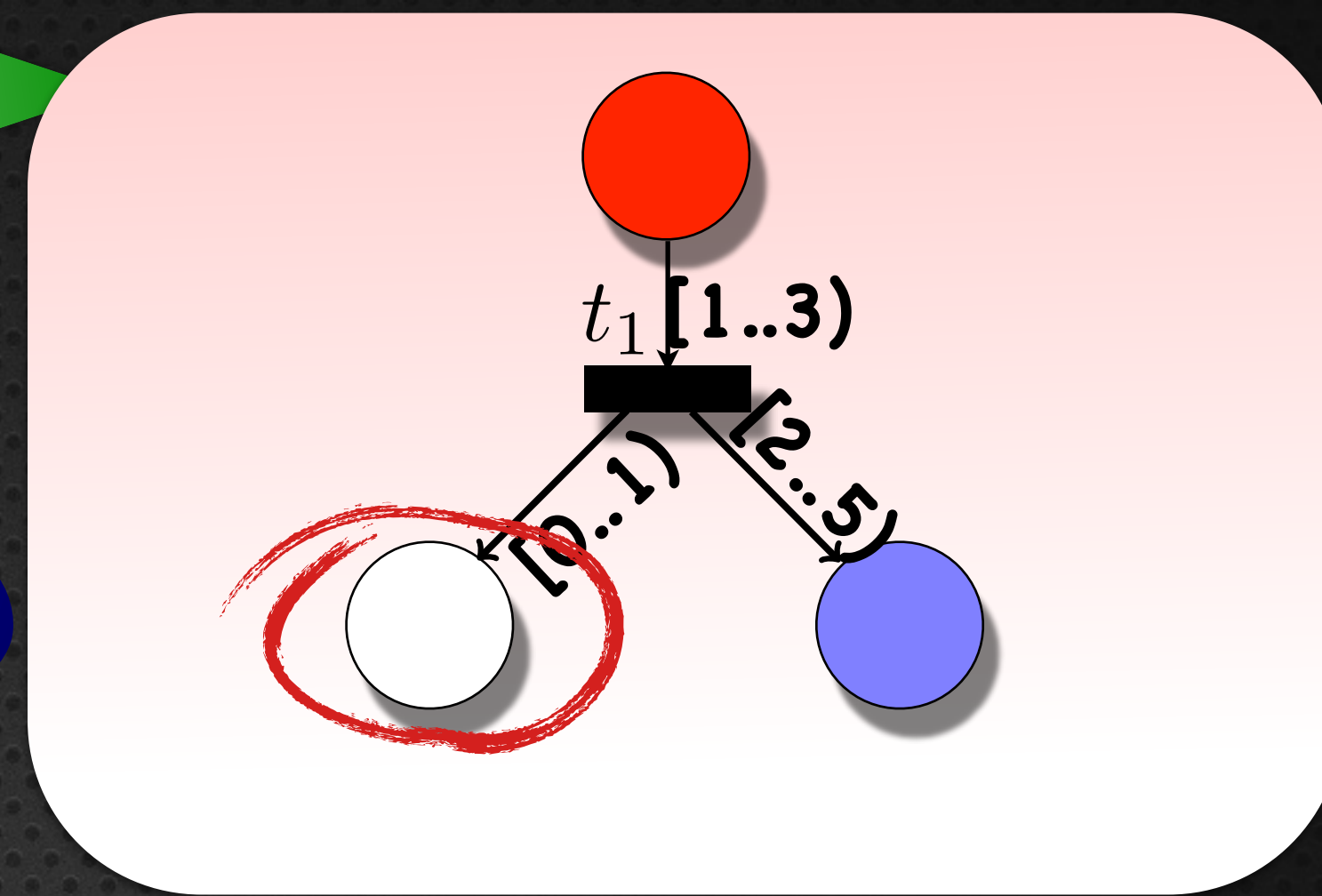
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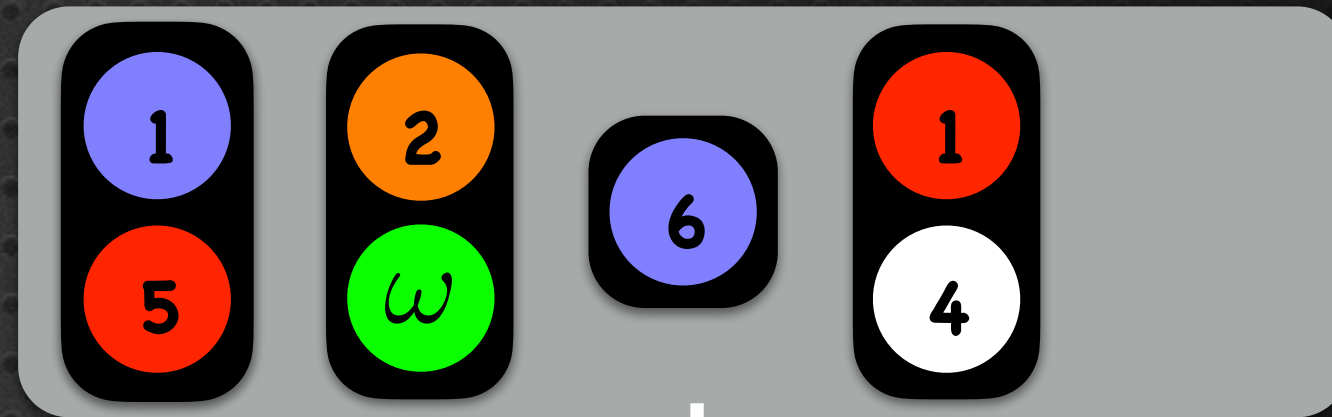
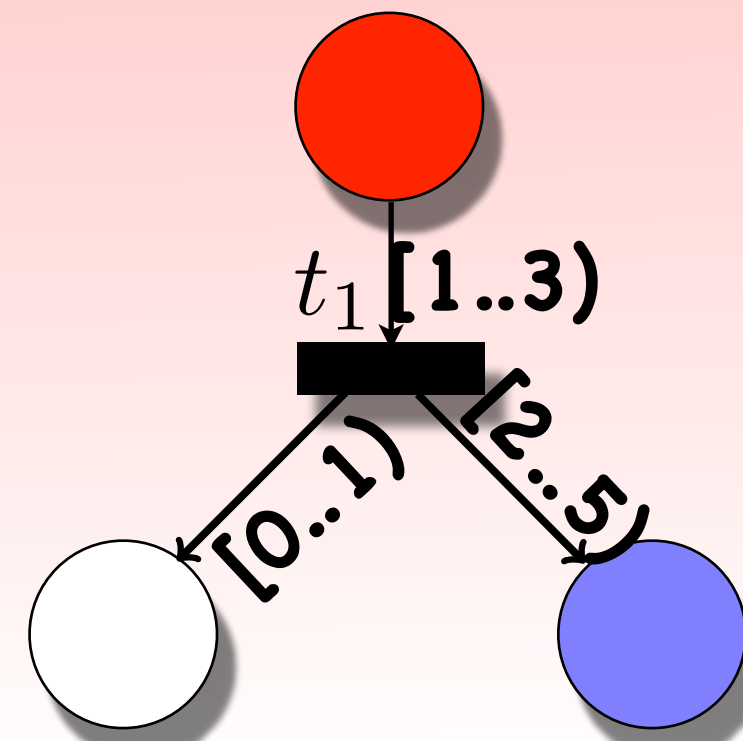
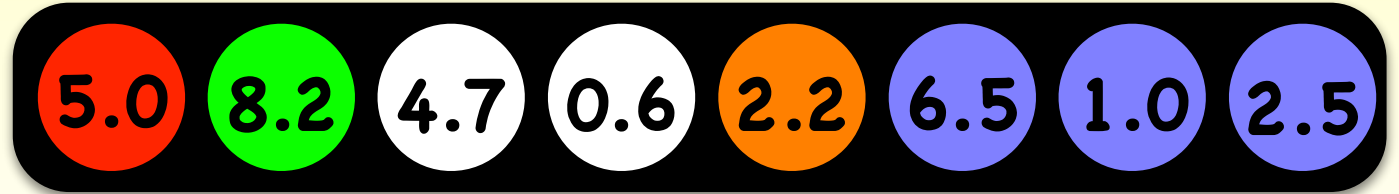
Timed Petri

Signatures

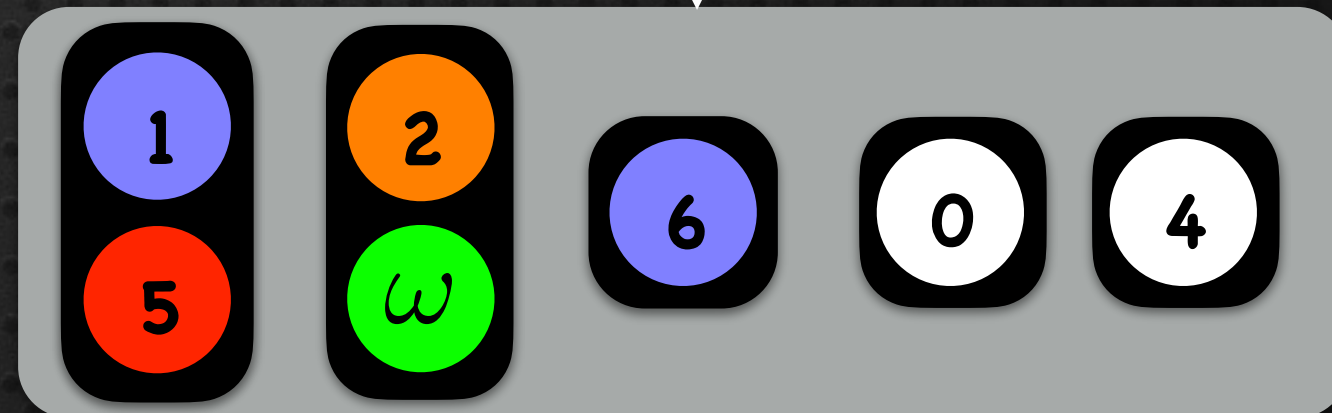
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t_1



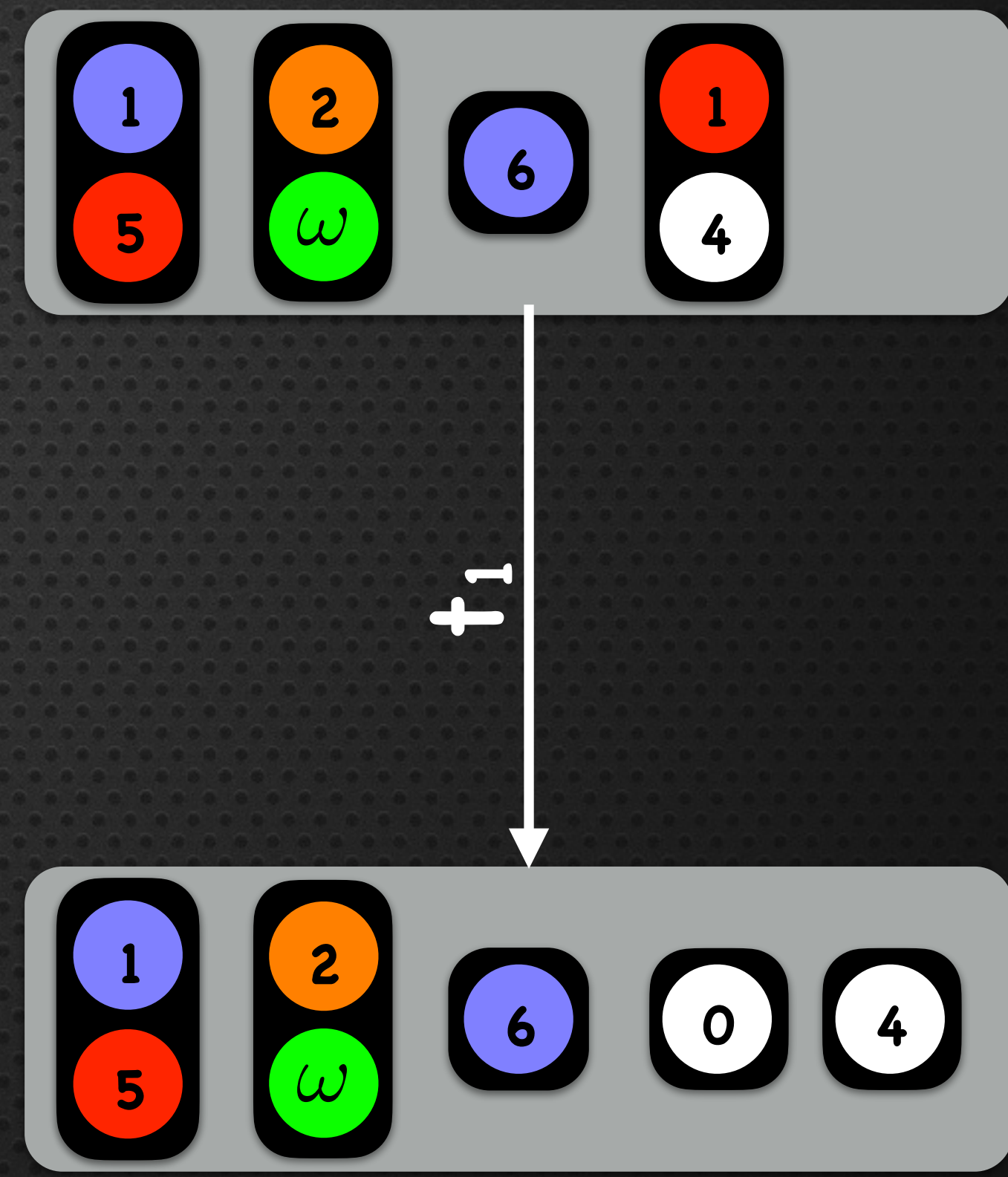
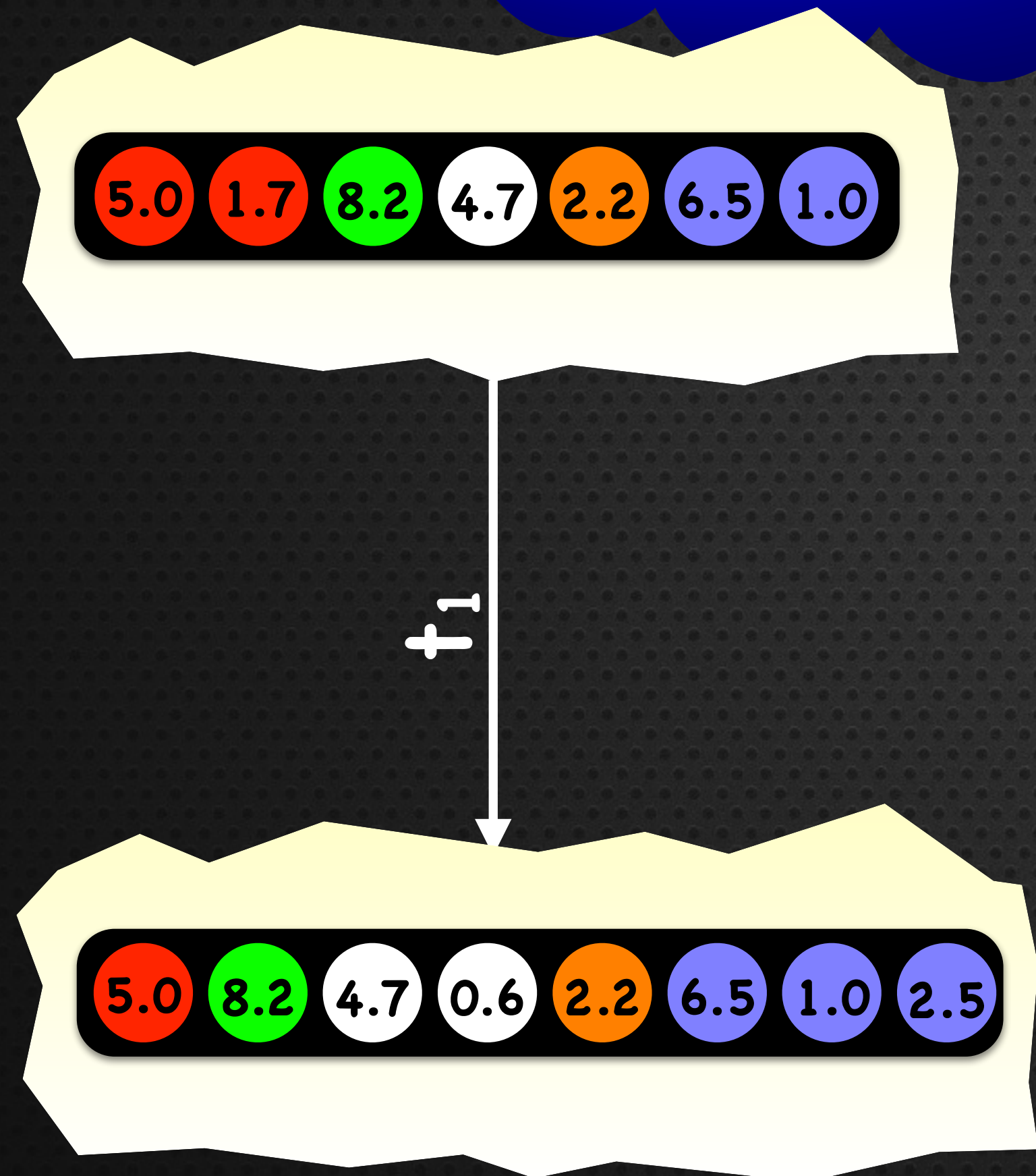
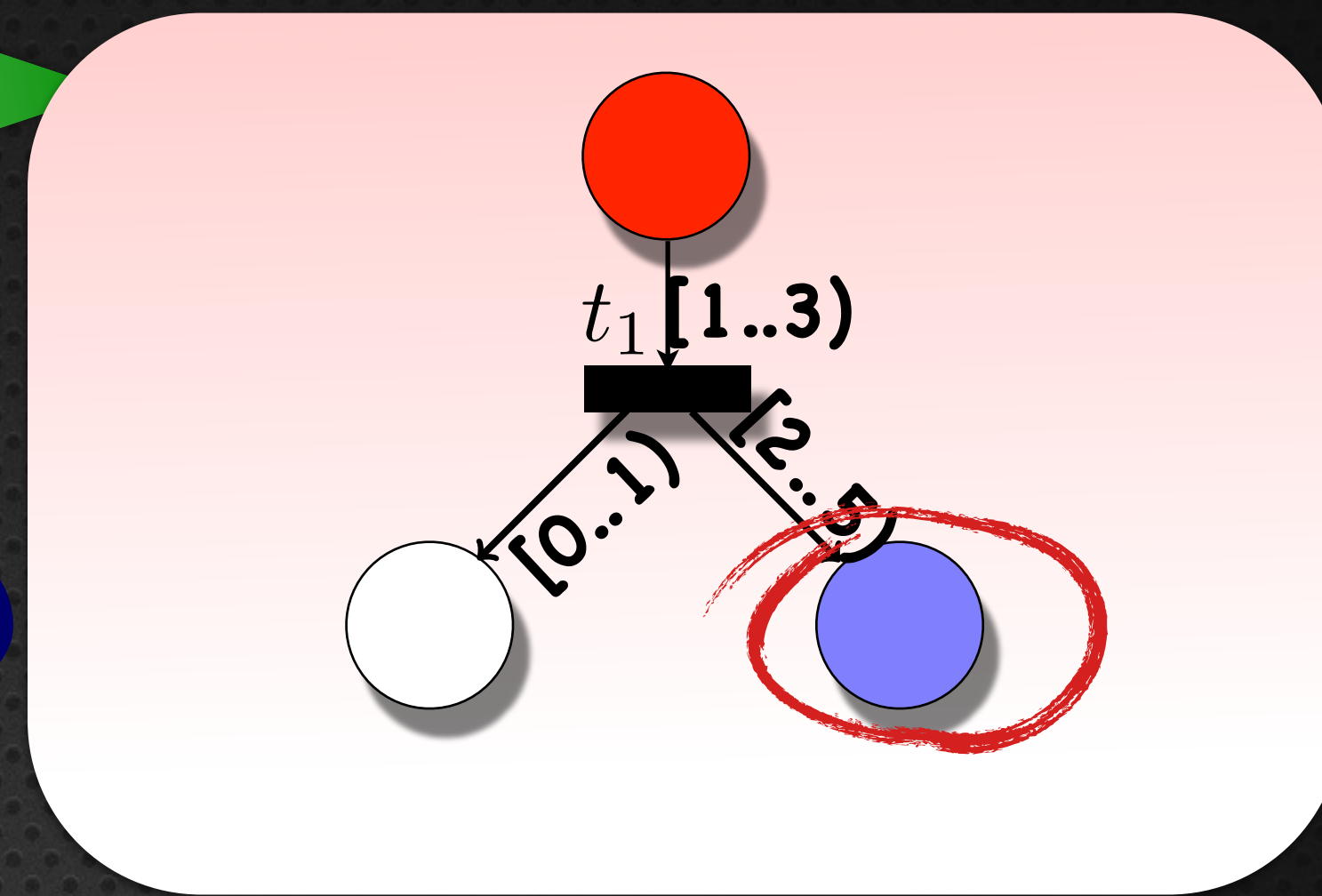
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Timed Petri

Signatures

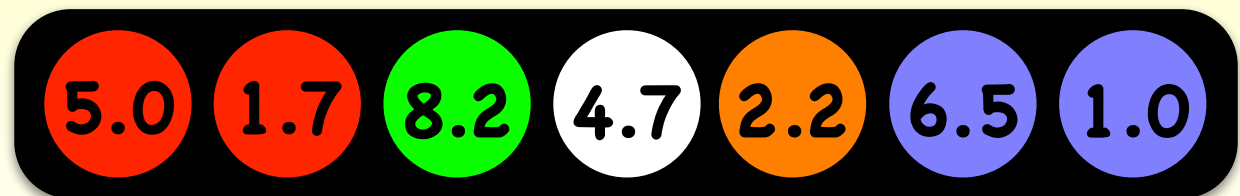
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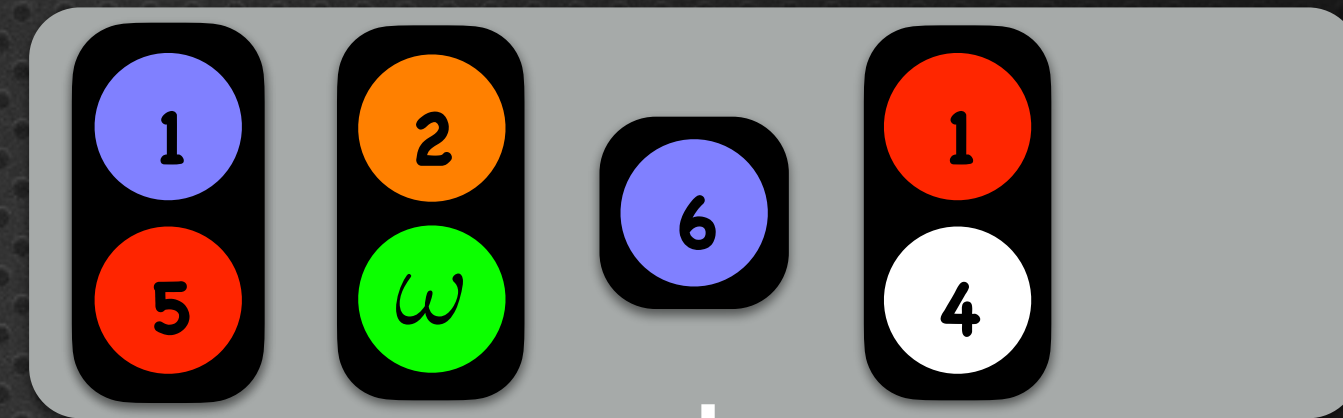
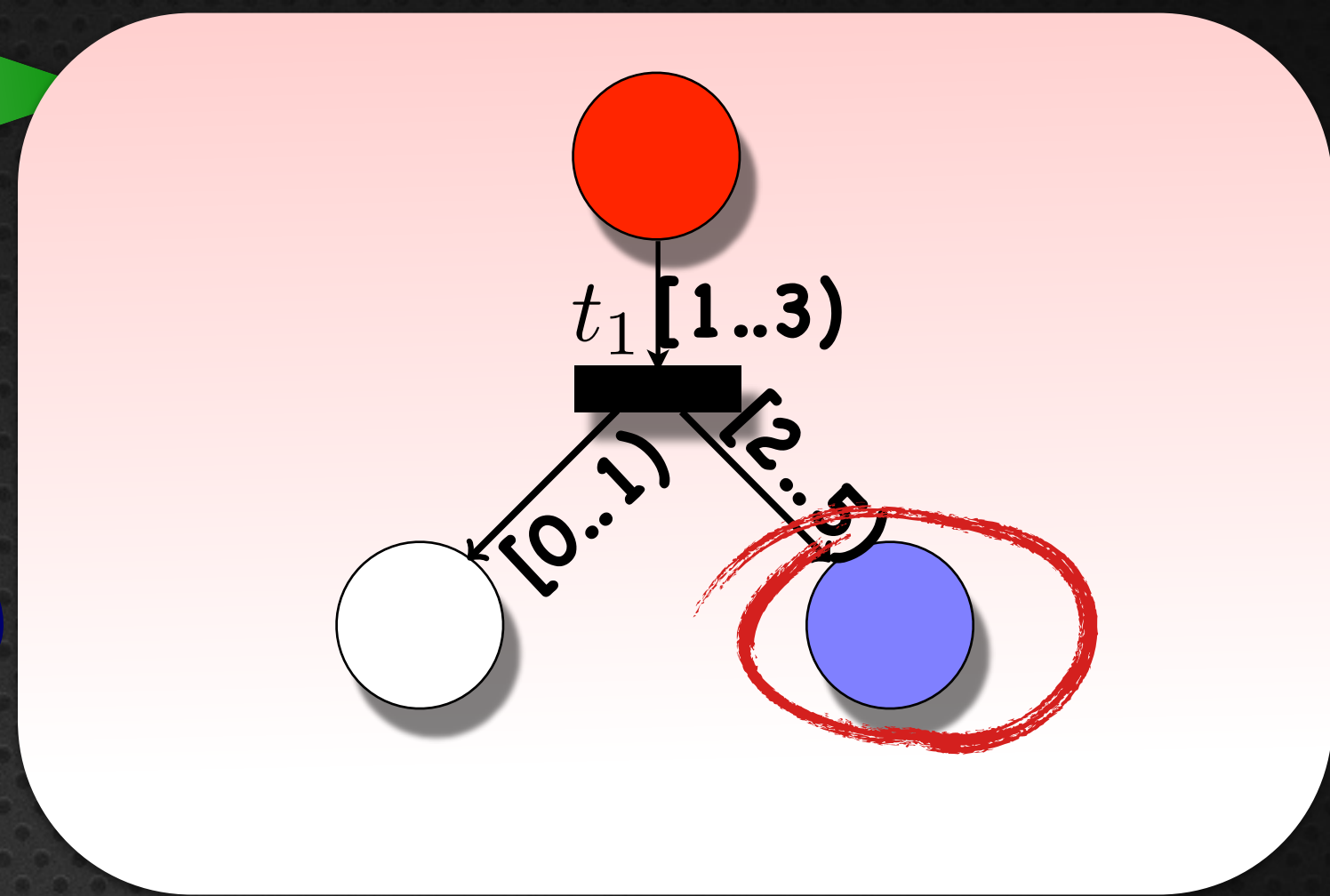
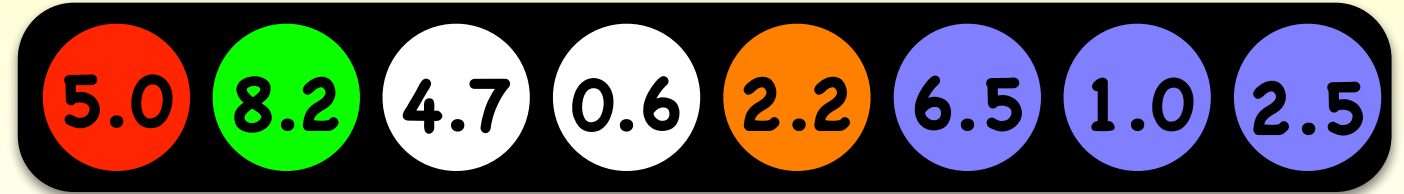
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t_1



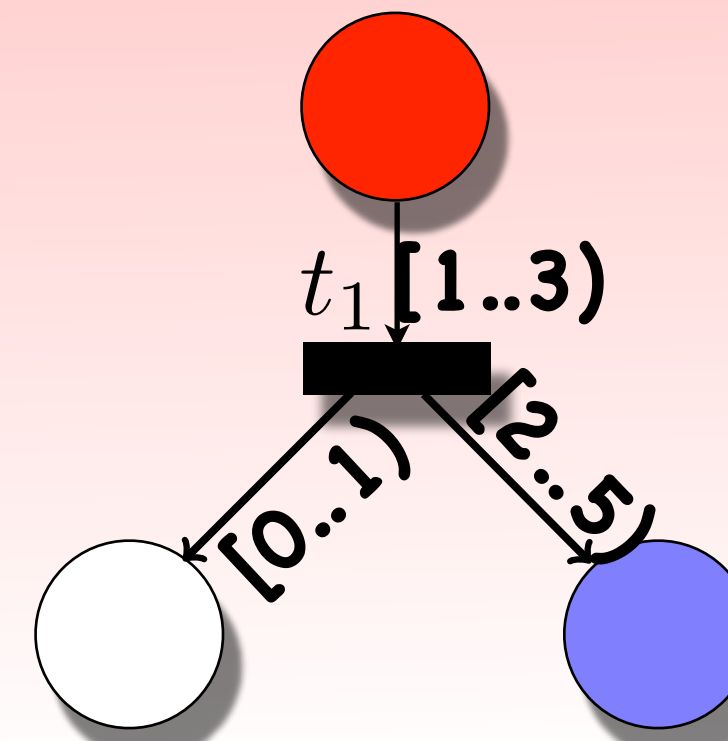
t_1



Timed Petri

Signatures

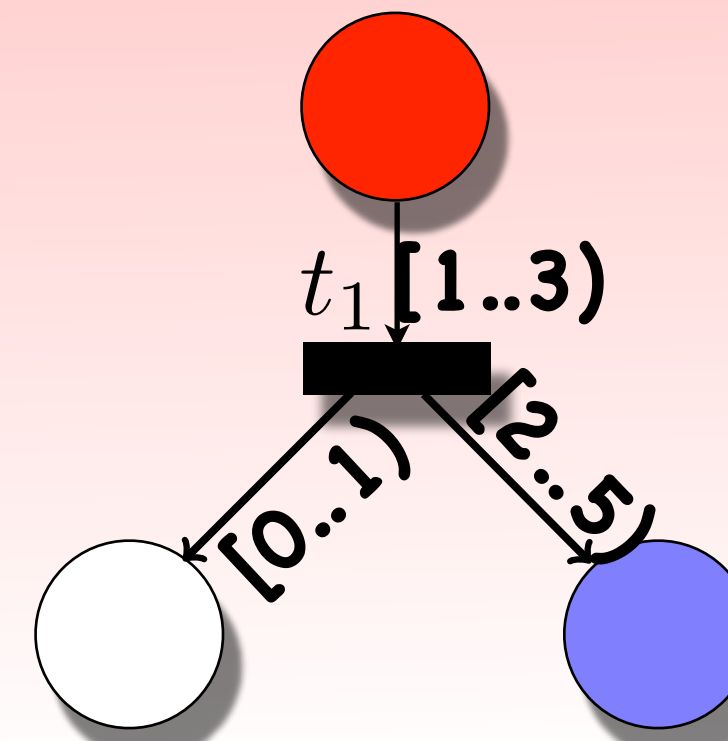
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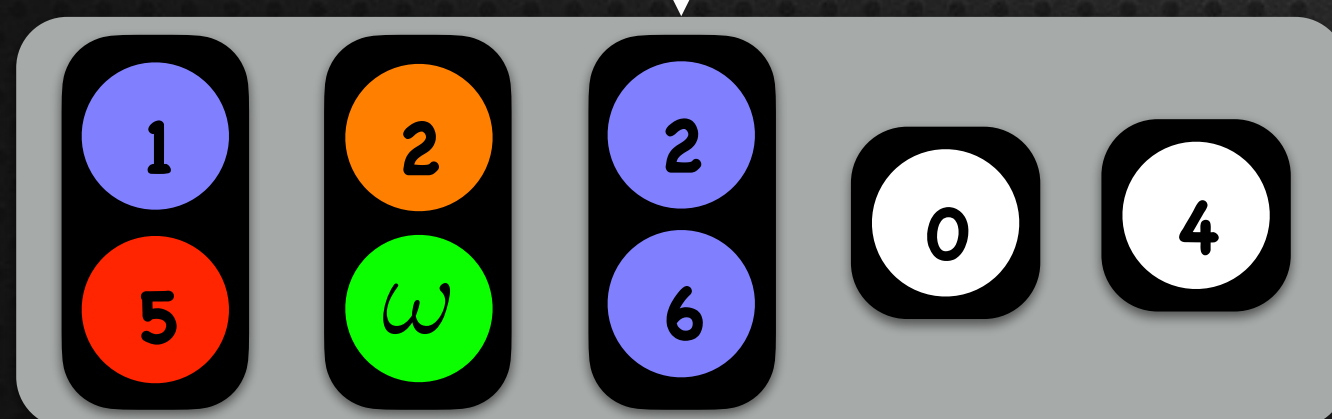
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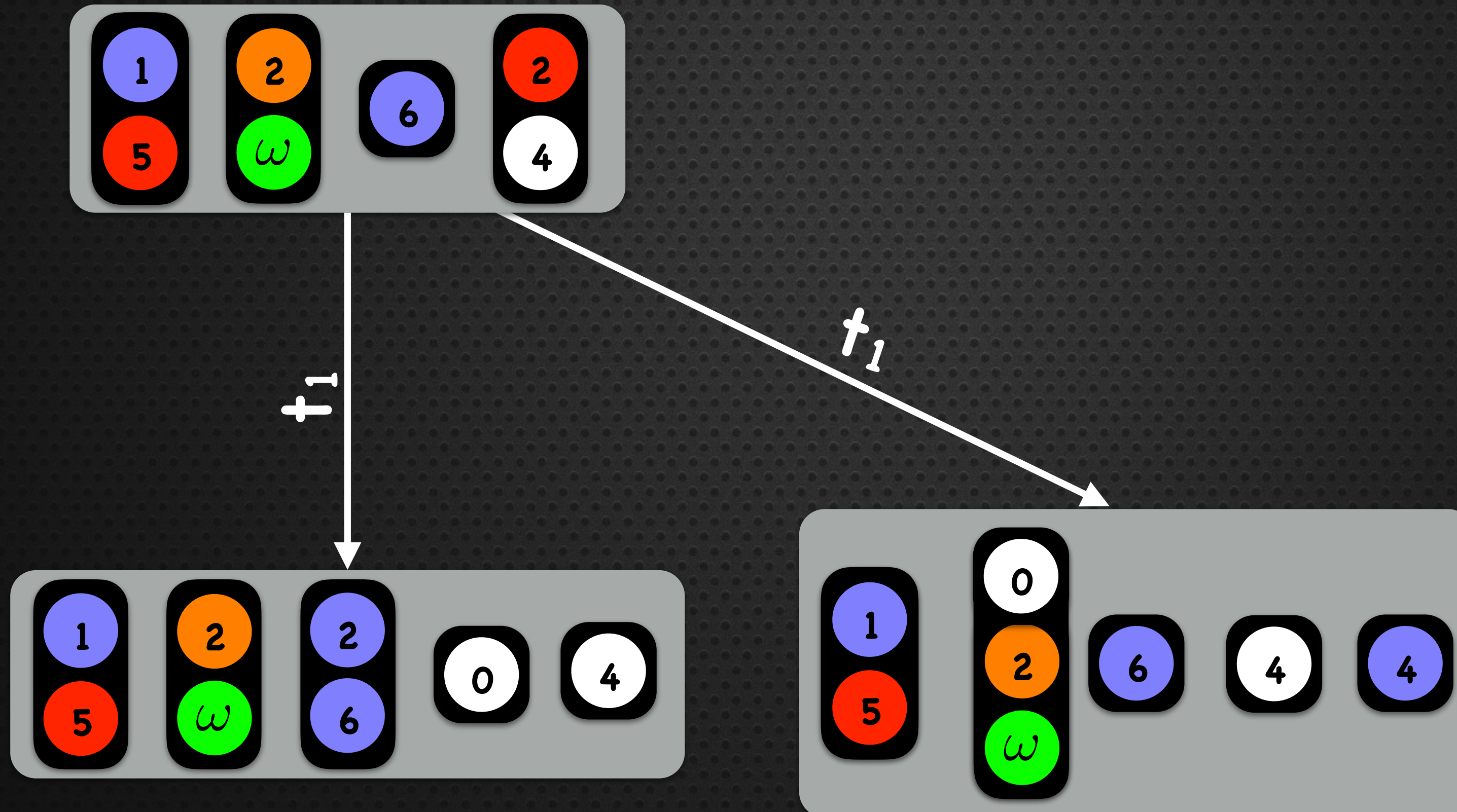
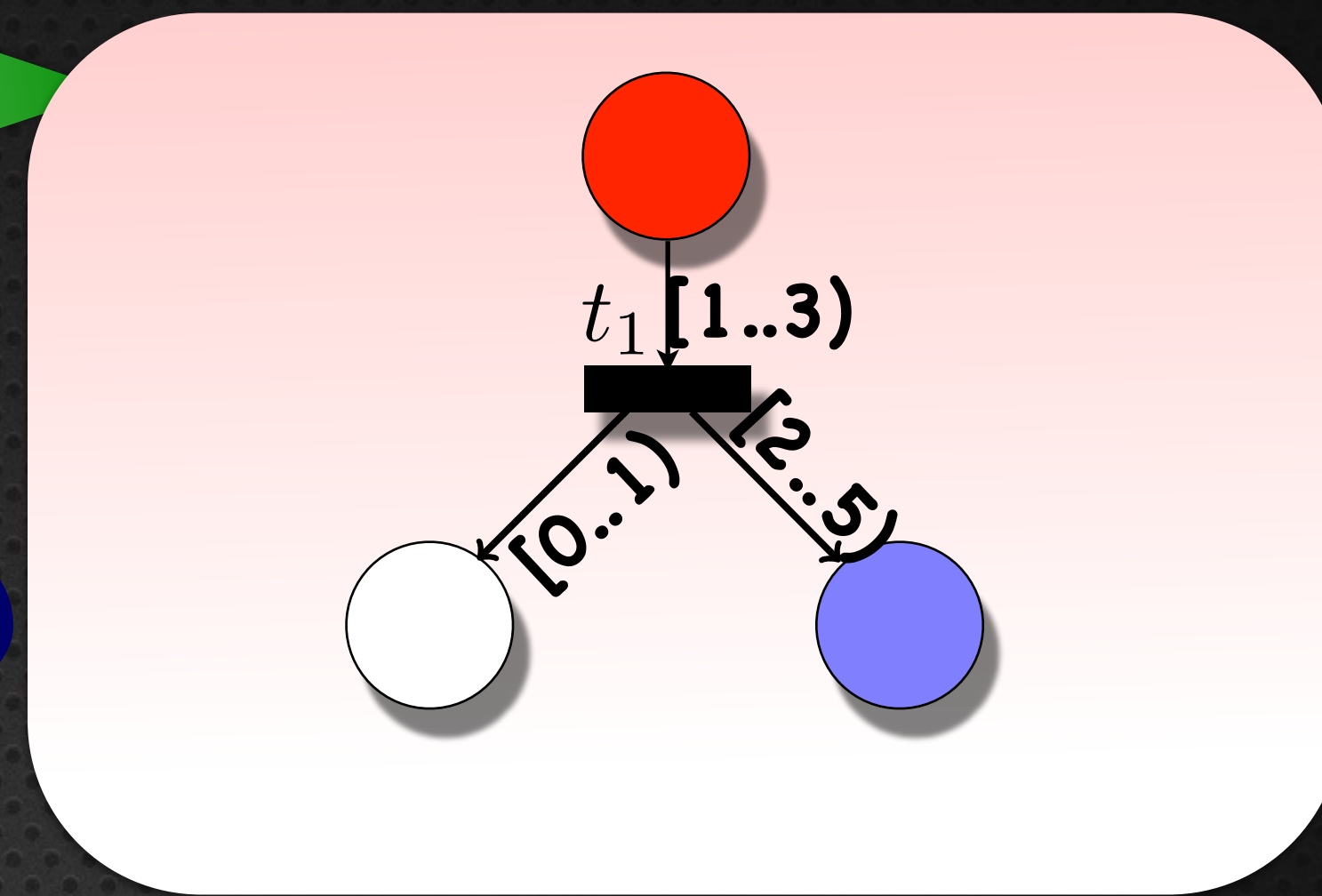
t_1



Timed Petri

Signatures

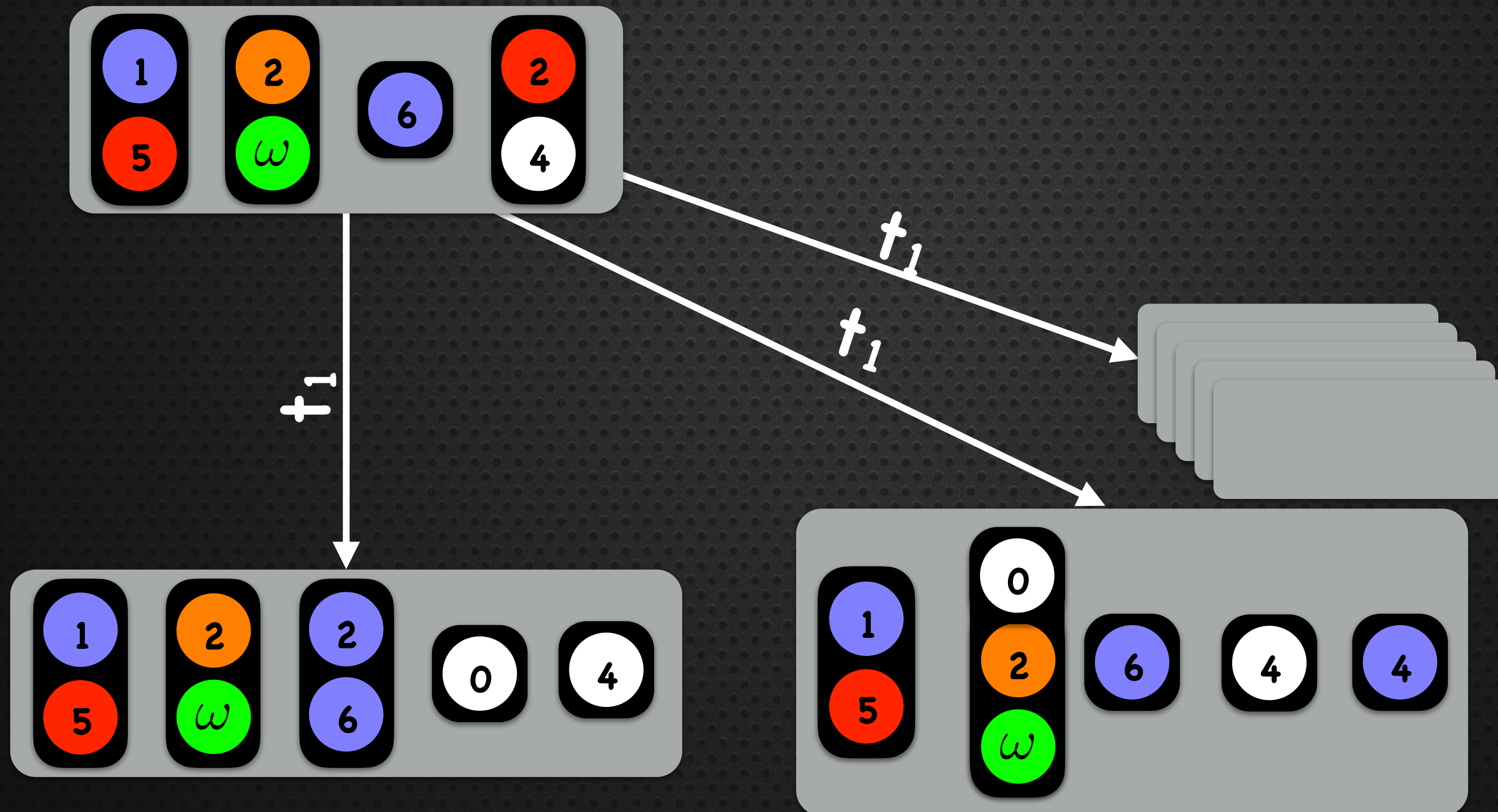
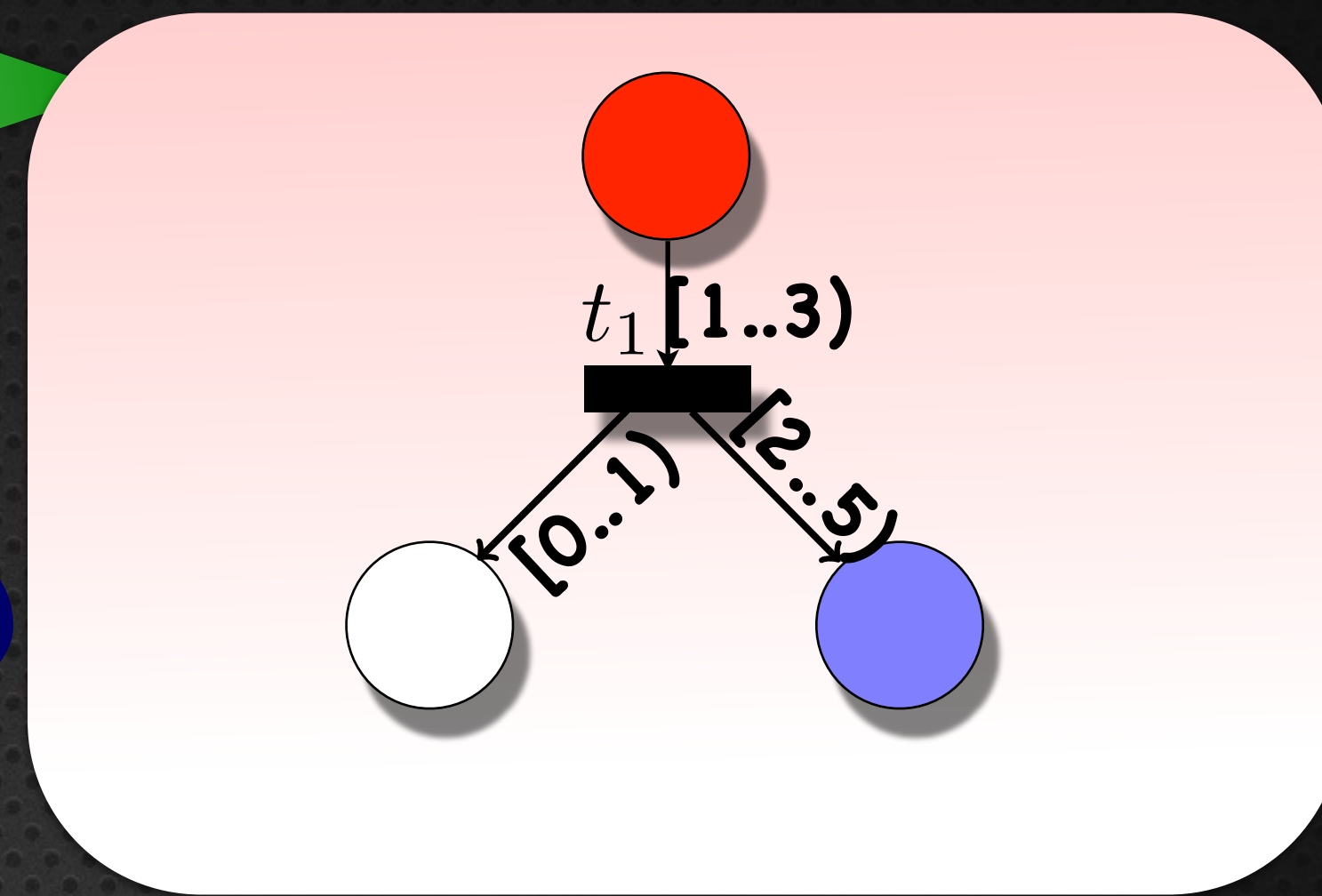
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Signatures

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Timed Petri

Signature

$\text{sig}(c)=s:$

c and s are "bisimilar"

5.0 3.7 8.2 0.7 2.2 6.5 1.0

1 2 3
5 ω 6 0

Timed Petri

Signature

$\text{sig}(c)=s:$

c and s are "bisimilar"

5.0 3.7 8.2 0.7 2.2 6.5 1.0

1	2	6	3
5	ω		0

Timed Petri

Signature

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1

5.0 3.7 8.2 0.7 2.2 6.5 1.0

5.1 3.8 8.3 0.8 2.3 6.6 1.1



Timed Petri

Signature

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1

5.0 3.7 8.2 0.7 2.2 6.5 1.0

5.1 3.8 8.3 0.8 2.3 6.6 1.1



Timed Petri

Signature

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1

5.0 3.7 8.2 0.7 2.2 6.5 1.0

5.1 3.8 8.3 0.8 2.3 6.6 1.1



time

Timed Petri

Signature

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time=0.1

5.0 3.7 8.2 0.7 2.2 6.5 1.0

5.1 3.8 8.3 0.8 2.3 6.6 1.1



time

Timed Petri

Signature

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time=0.1

5.0 3.7 8.2 0.7 2.2 6.5 1.0

5.1 3.8 8.3 0.8 2.3 6.6 1.1



time

Timed Petri

Signal

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1 time=0.1



time

Timed Petri

Signal

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1 time=0.1



time

Timed Petri

Signal

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c and s are "bisimilar"

time=0.1 time=0.1



time

time

Timed Petri

Signal

$\text{sig}(c)=s:$

c and s are "bisimilar"

time=0.1 time=0.1



time

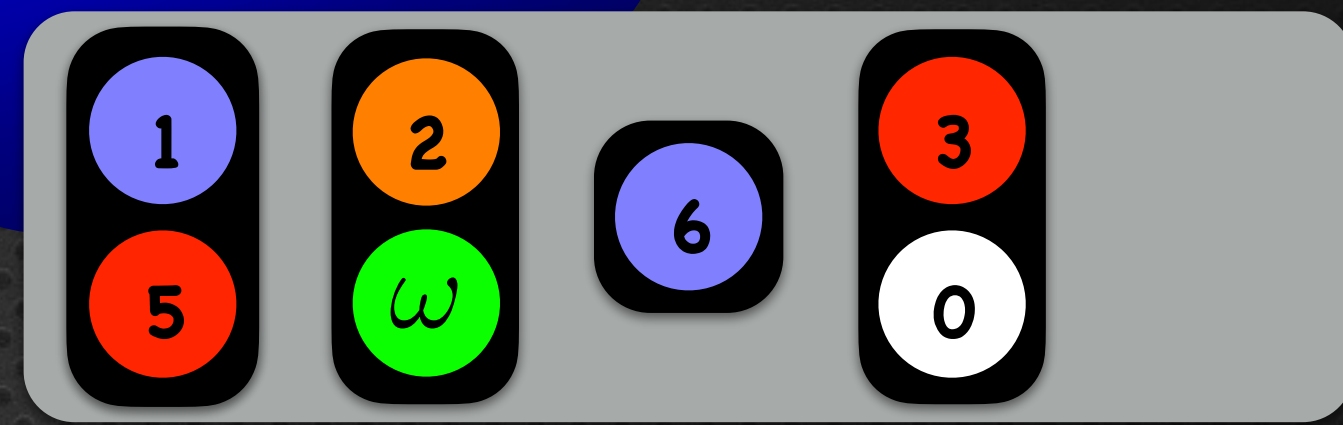
time

Timed Petri

Signature

sig(c)=s:
c and s are "bisimilar"

time=0.1 time=0.1 time=0.1 time=0.1



time

time

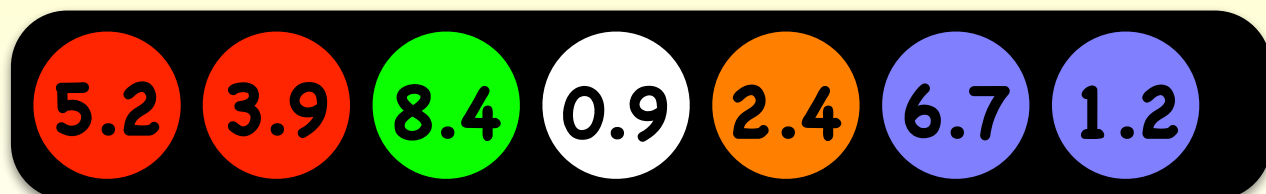
Timed Petri

Signal

$\text{sig}(c)=s:$

c and g are "bisimilar"

time=0.1 time=0.1 time=0.1 time=0.1



time

time

Timed Petri

Signal

$\text{sig}(c)=s:$

c and g are "bisimilar"

time=0.1 time=0.1 time=0.1 time=0.1



time

time

time

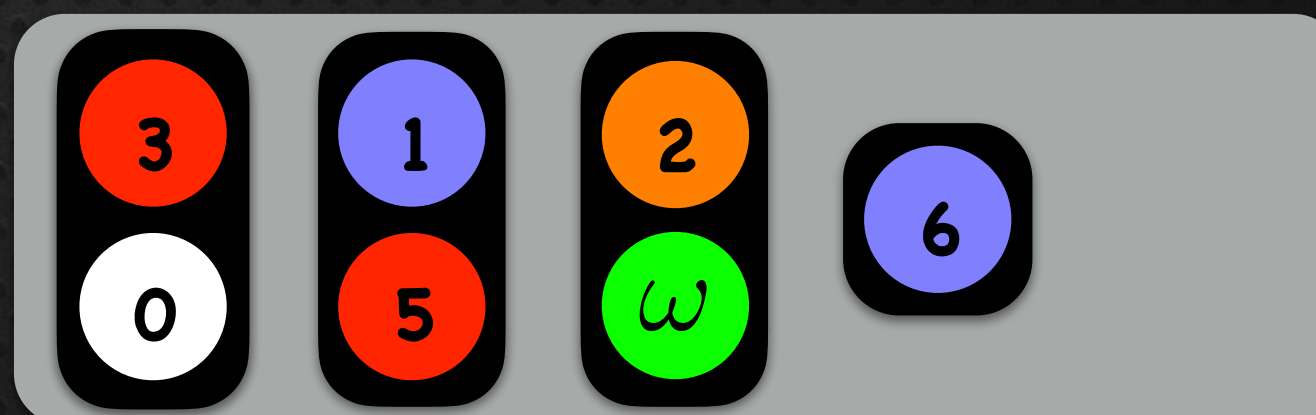
Timed Petri

Signature

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c and g are "bisimilar"

time=0.1 time=0.1 time=0.1 time=0.1



time

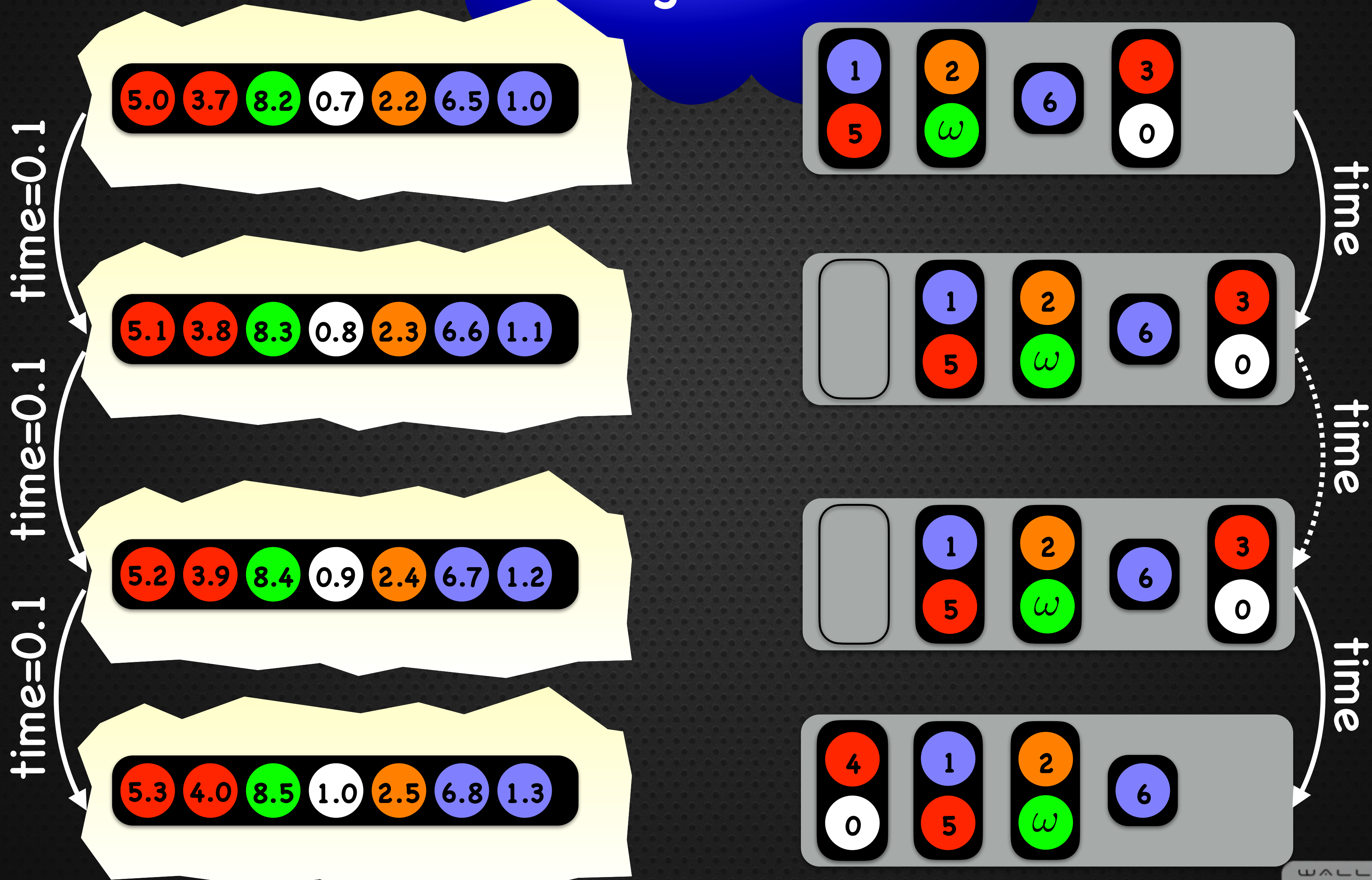
time

time

Timed Petri

Signal

$\text{sig}(c)=s:$
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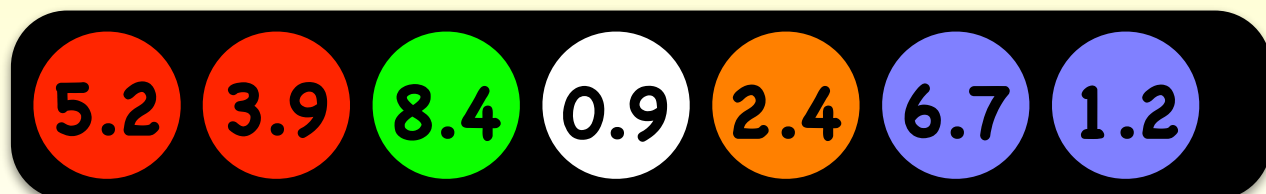


Timed Petri

Signal

$\text{sig}(c)=s:$
c and g are "bisimilar"

time=0.1 time=0.1 time=0.1 time=0.1



time

time

time