Self-stabilising Byzantine clock synchronisation is almost as easy as consensus

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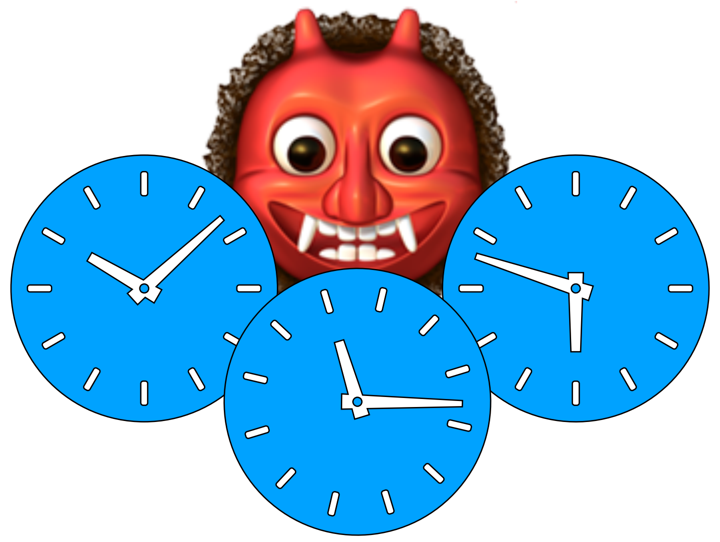
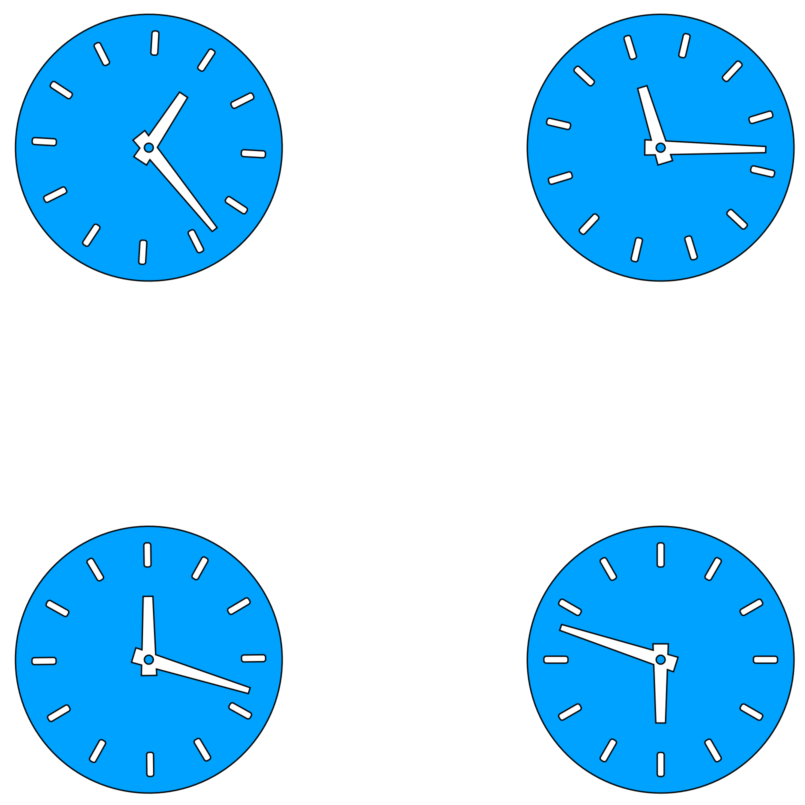
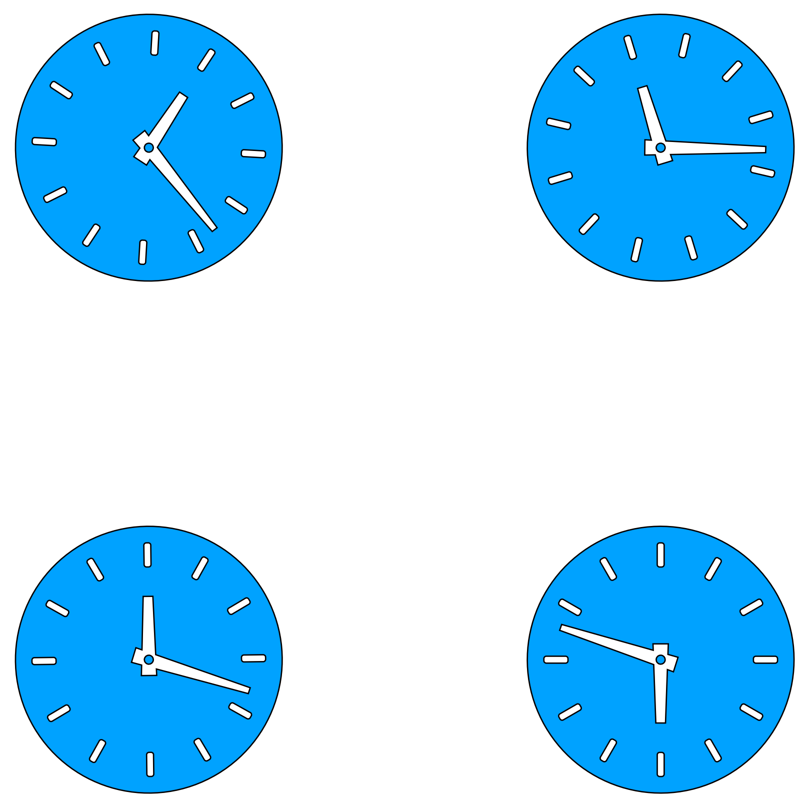


Clock synchronisation



Question:
How to efficiently synchronise a network of **imprecise clocks** in a **fault-tolerant** manner?

Clock synchronisation

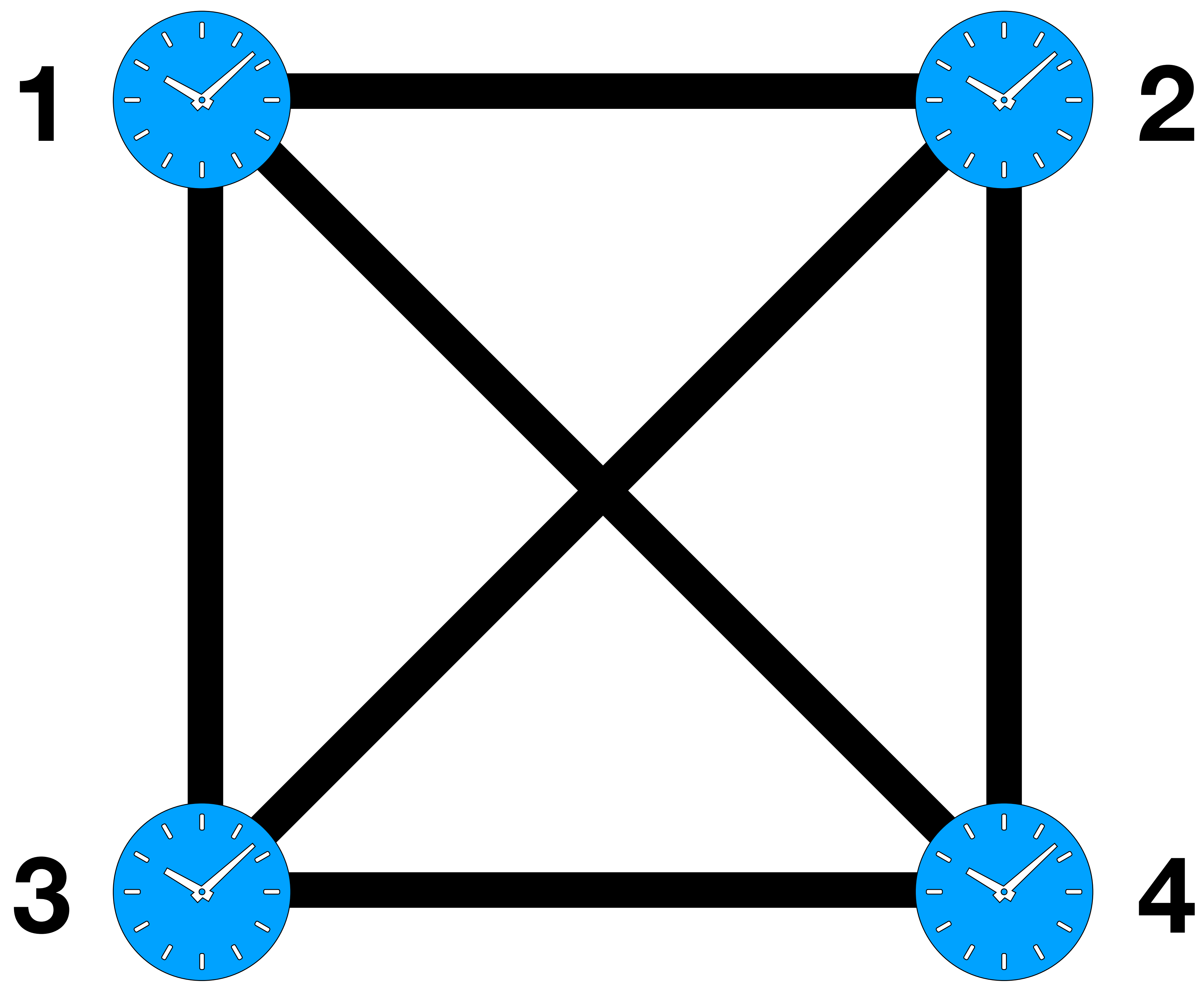


Question:
How to efficiently synchronise a network of **imprecise clocks** in a **fault-tolerant** manner?

Real clocks exhibit **drift:** even if started at the same time, values eventually differ

Distributed systems are prone to both **transient faults** and **permanent faults**

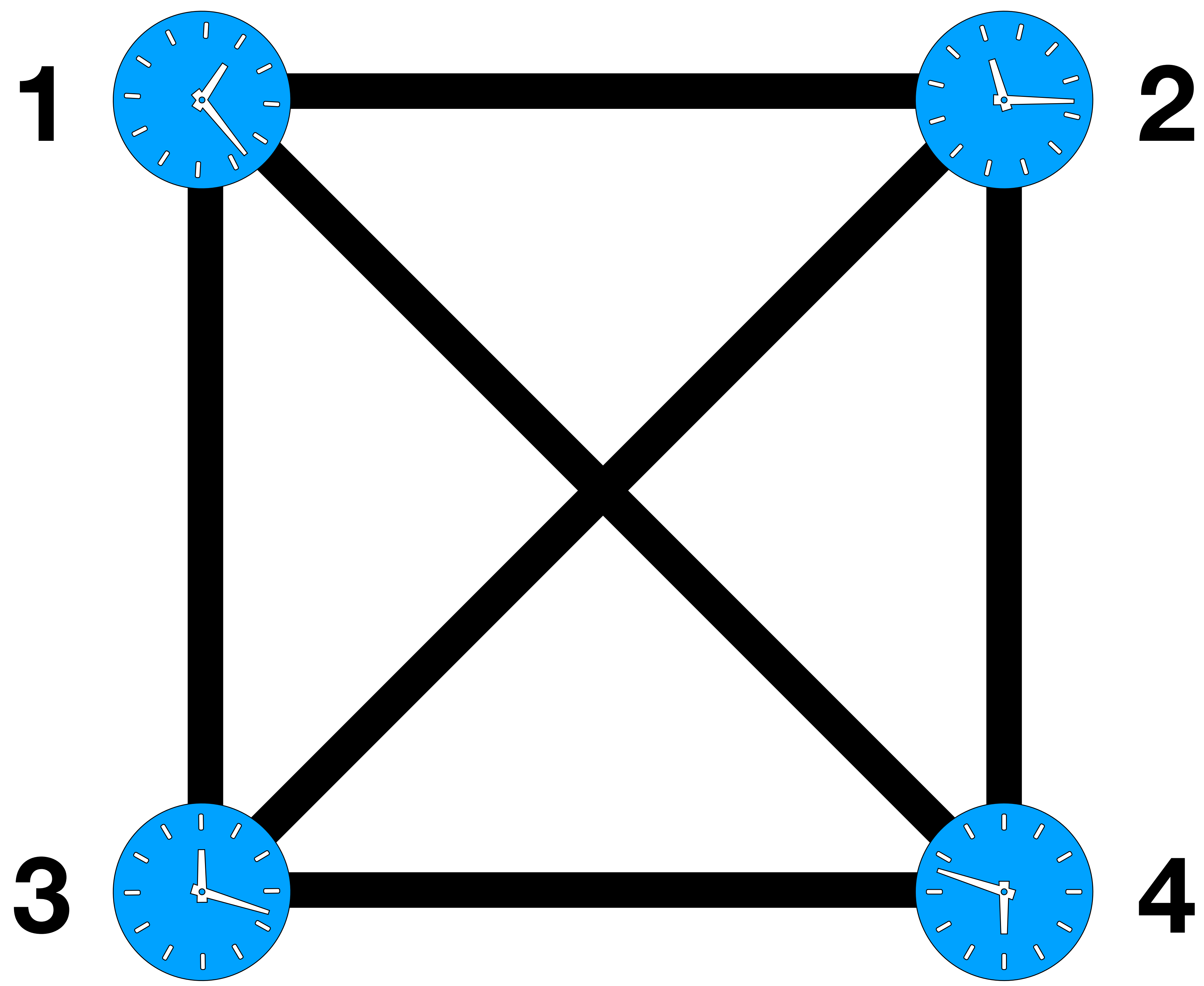
Model of computation



- n nodes with **local clocks**

Bounded clock drift:
fastest clock progresses
at most factor $\vartheta > 1$ faster
than the slowest clock

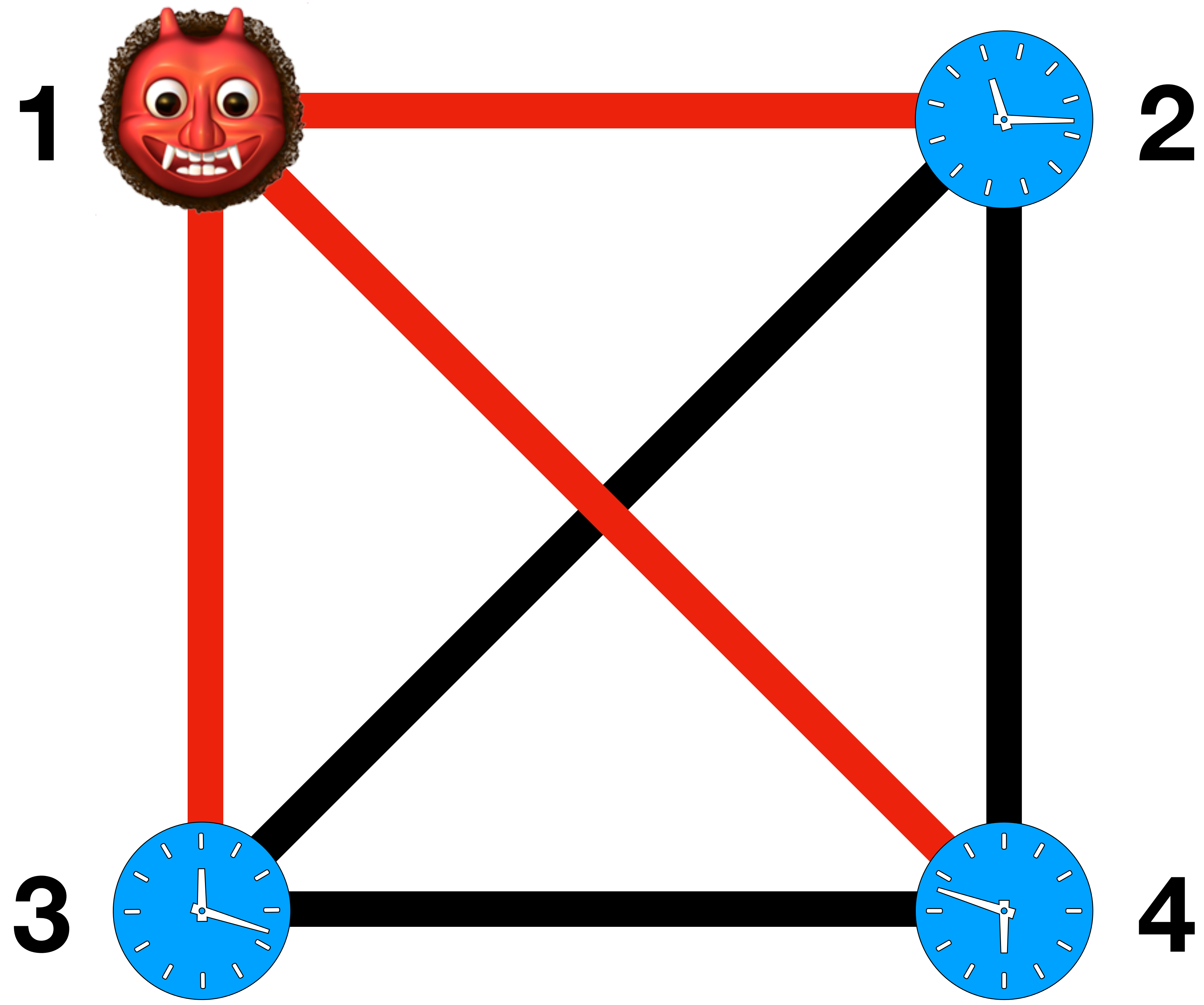
Model of computation



- *n* nodes with **local clocks**
- arbitrary initial state

Self-stabilisation:
Initial clock values and local state are arbitrary

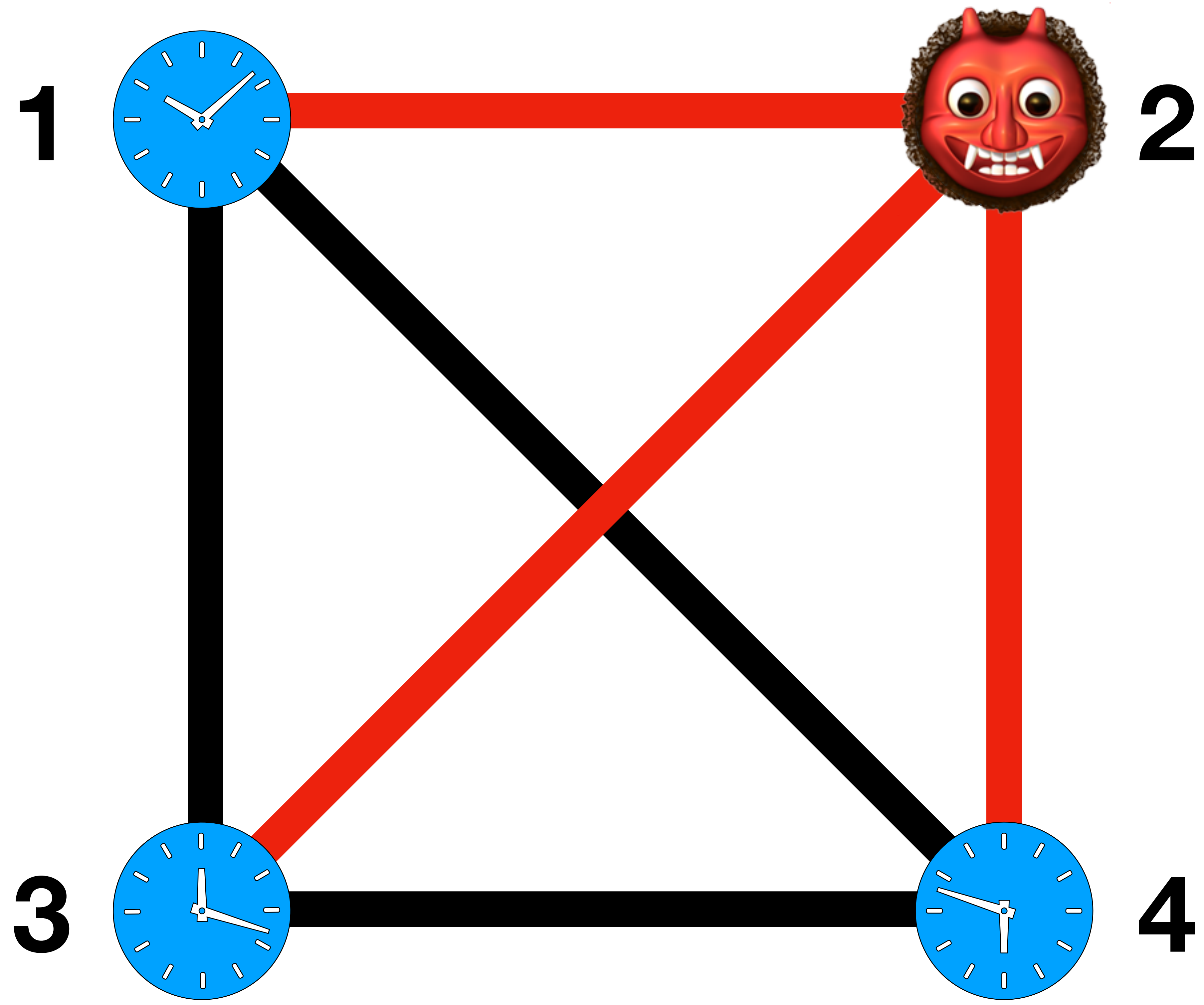
Model of computation



- n nodes with **local clocks**
- arbitrary initial state
- $f < n/3$ **Byzantine faulty** nodes

Arbitrary misbehaviour:
can crash, lose messages,
send different misinformation
to correct nodes, etc.

Model of computation



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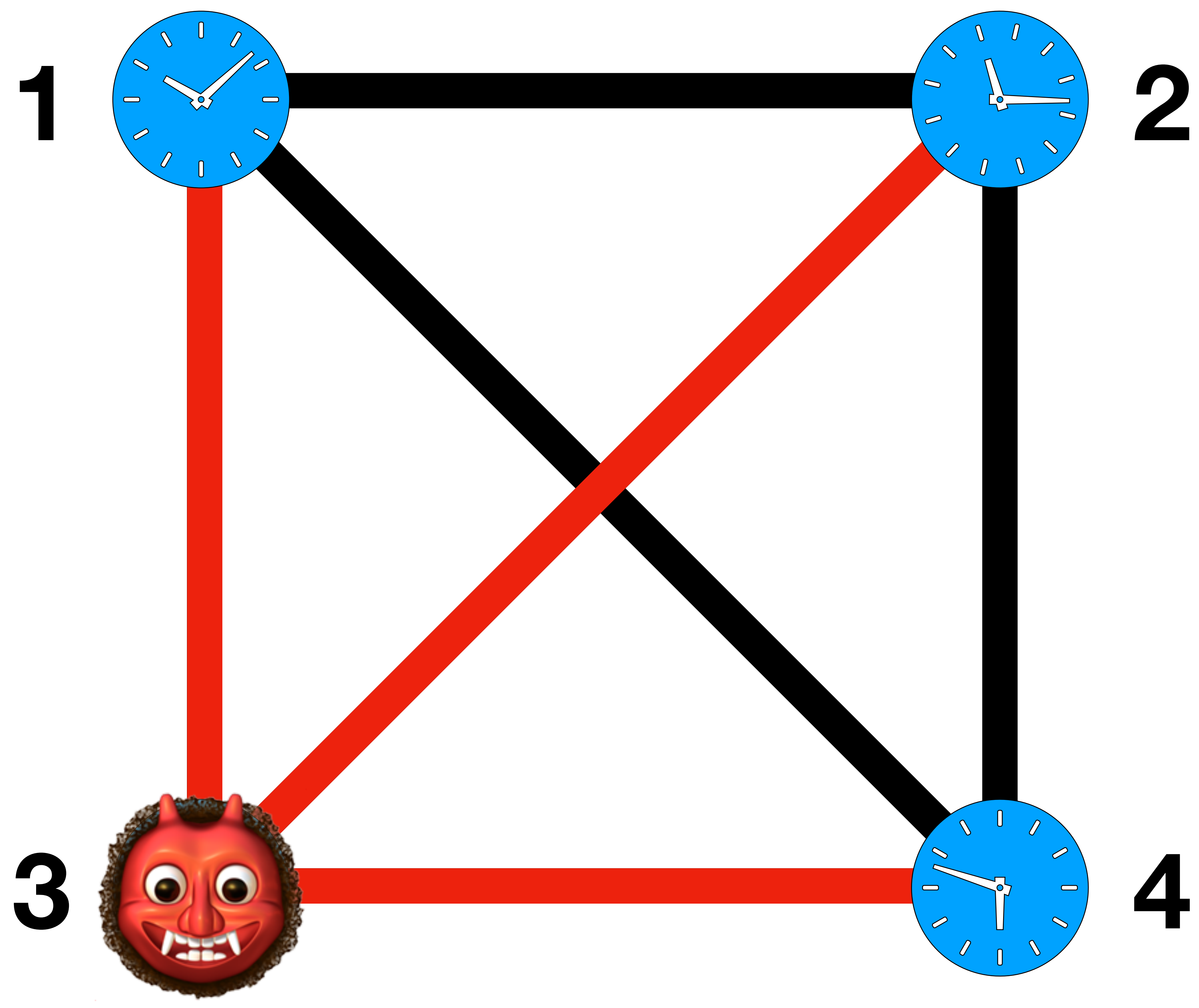

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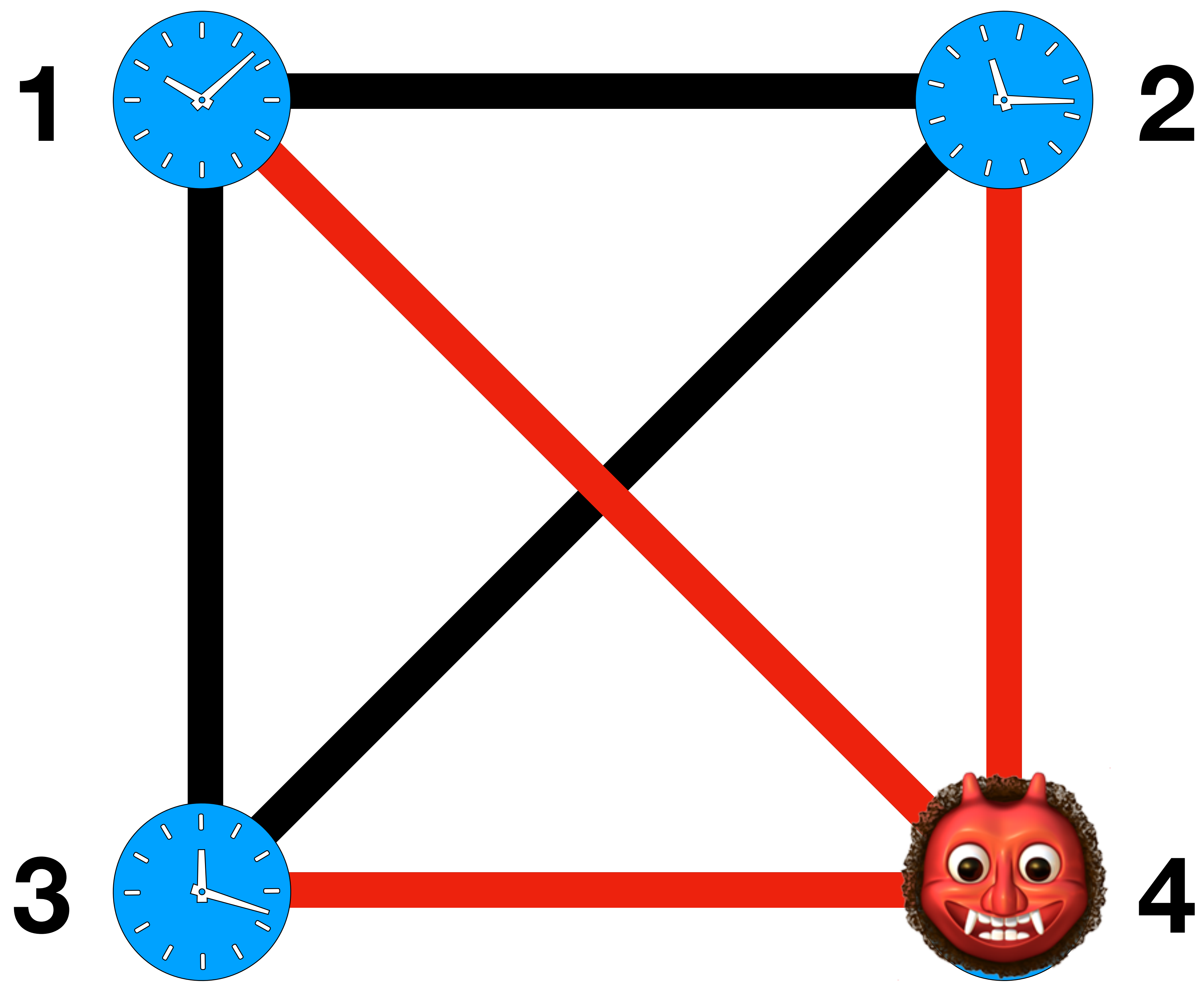

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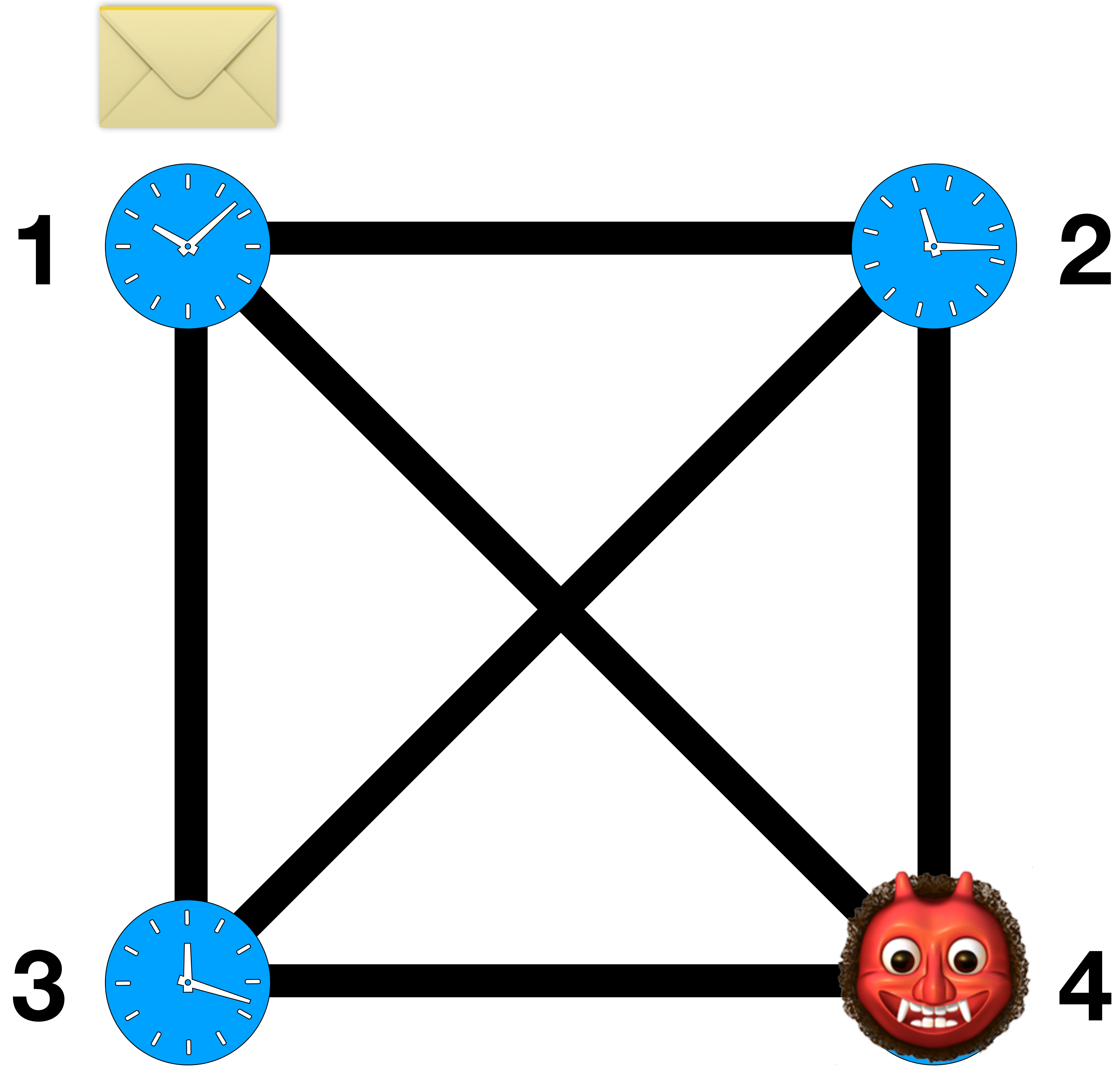

- n nodes with **local clocks**
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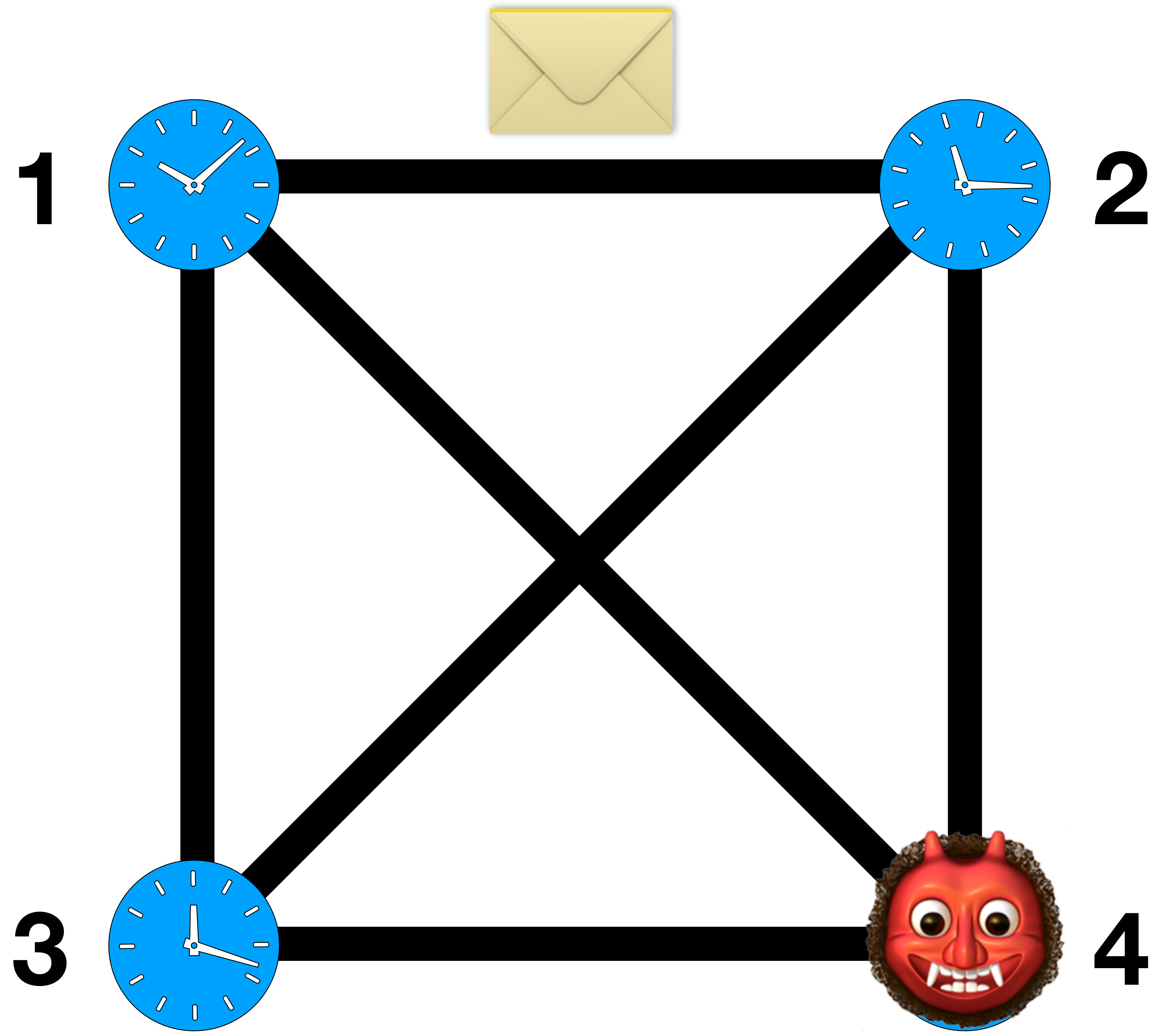
- $f < n/3$ **Byzantine faulty** nodes
- bounded delay communication

Message delay:
transmitting a messages takes
between 0 and d time units

Model of computation



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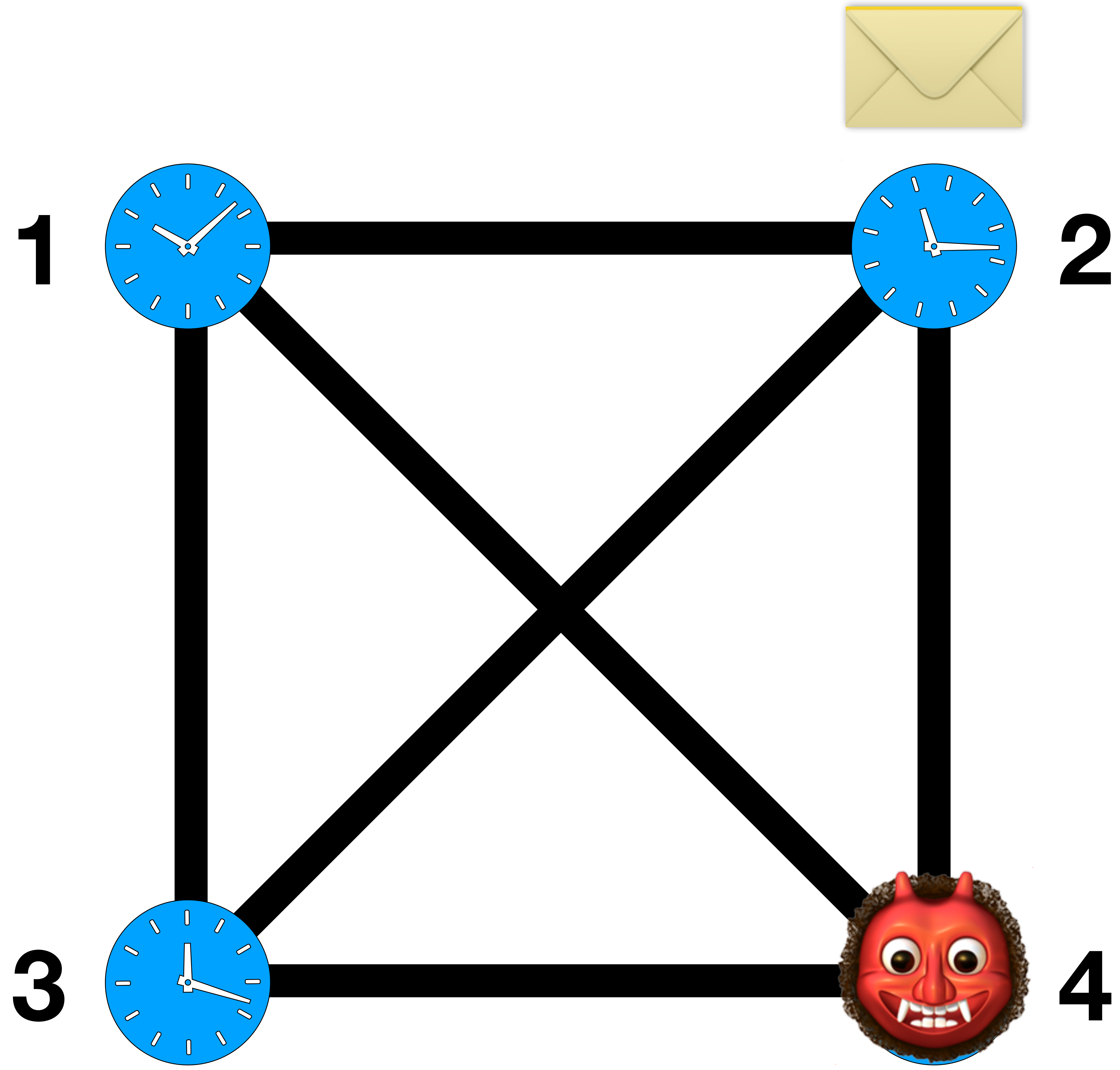

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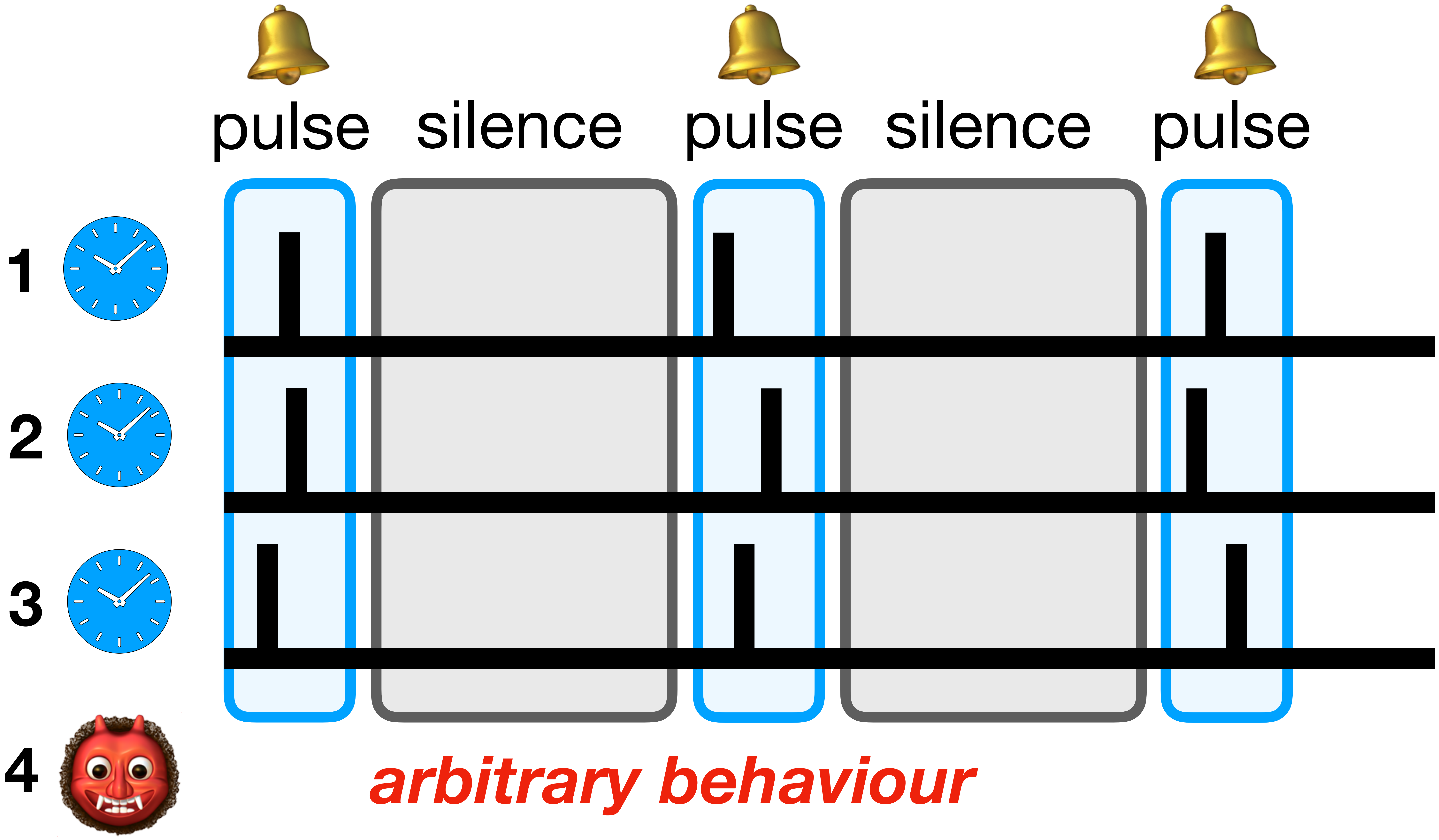
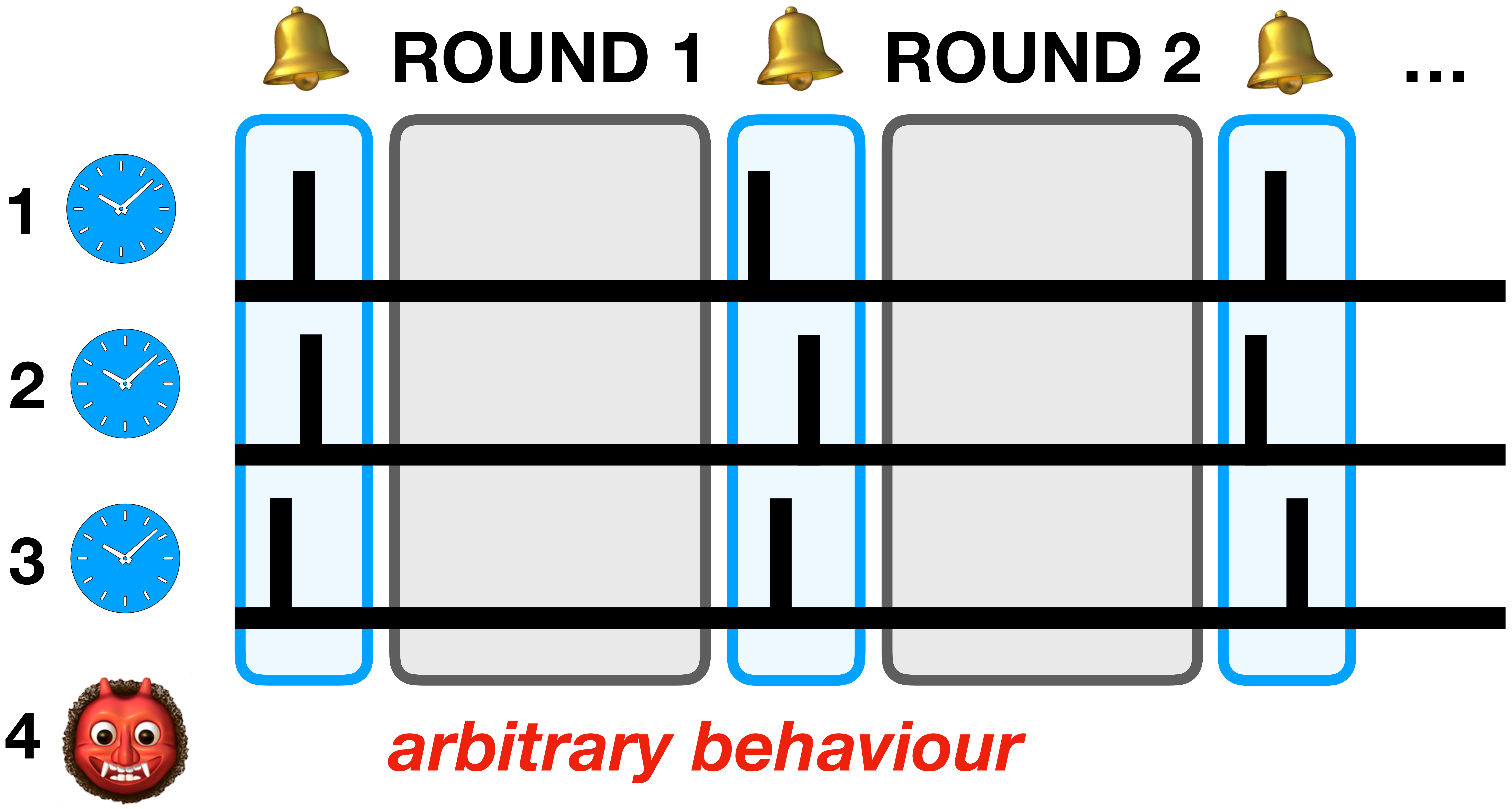
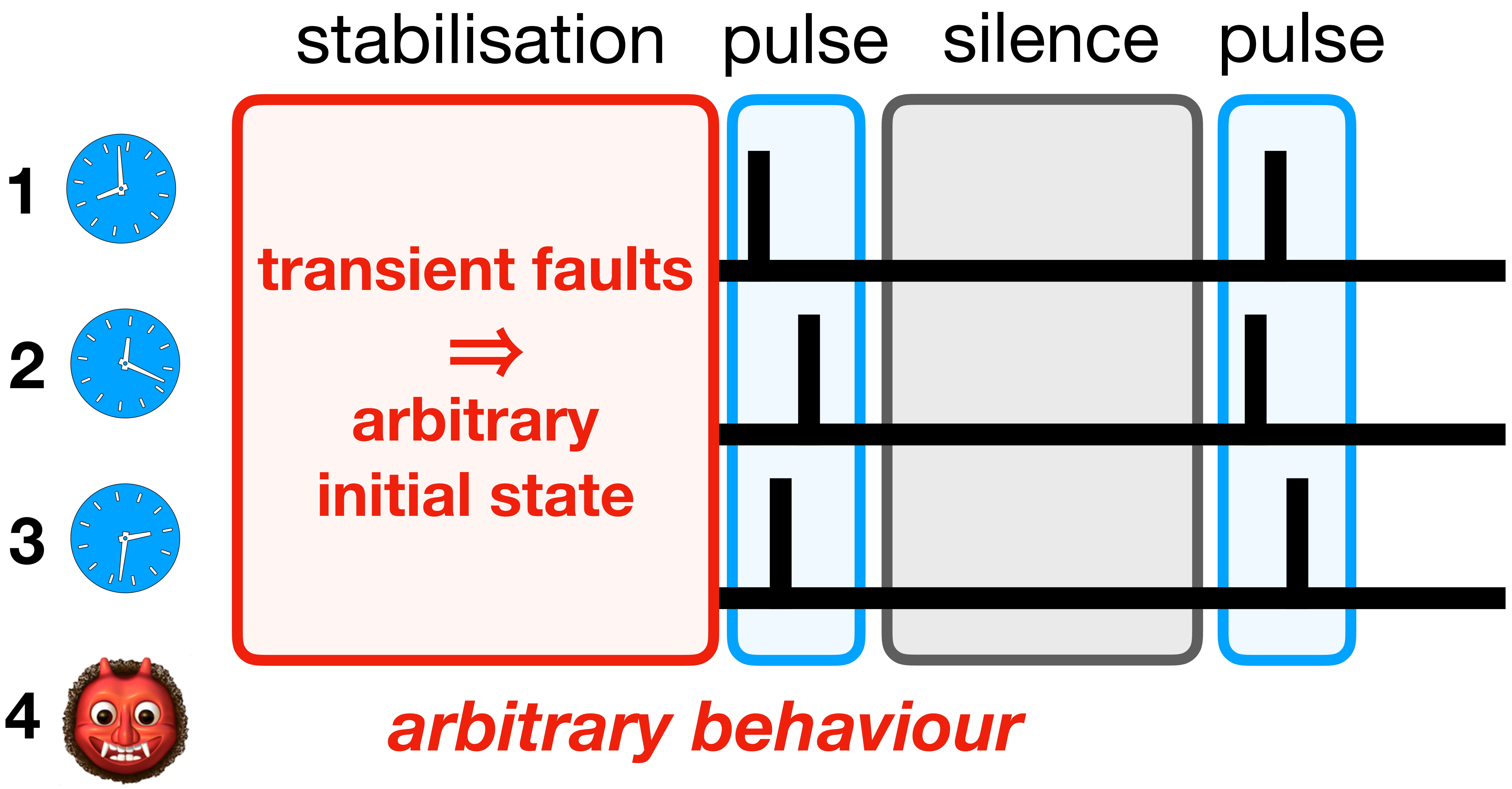
Pulse synchronisation



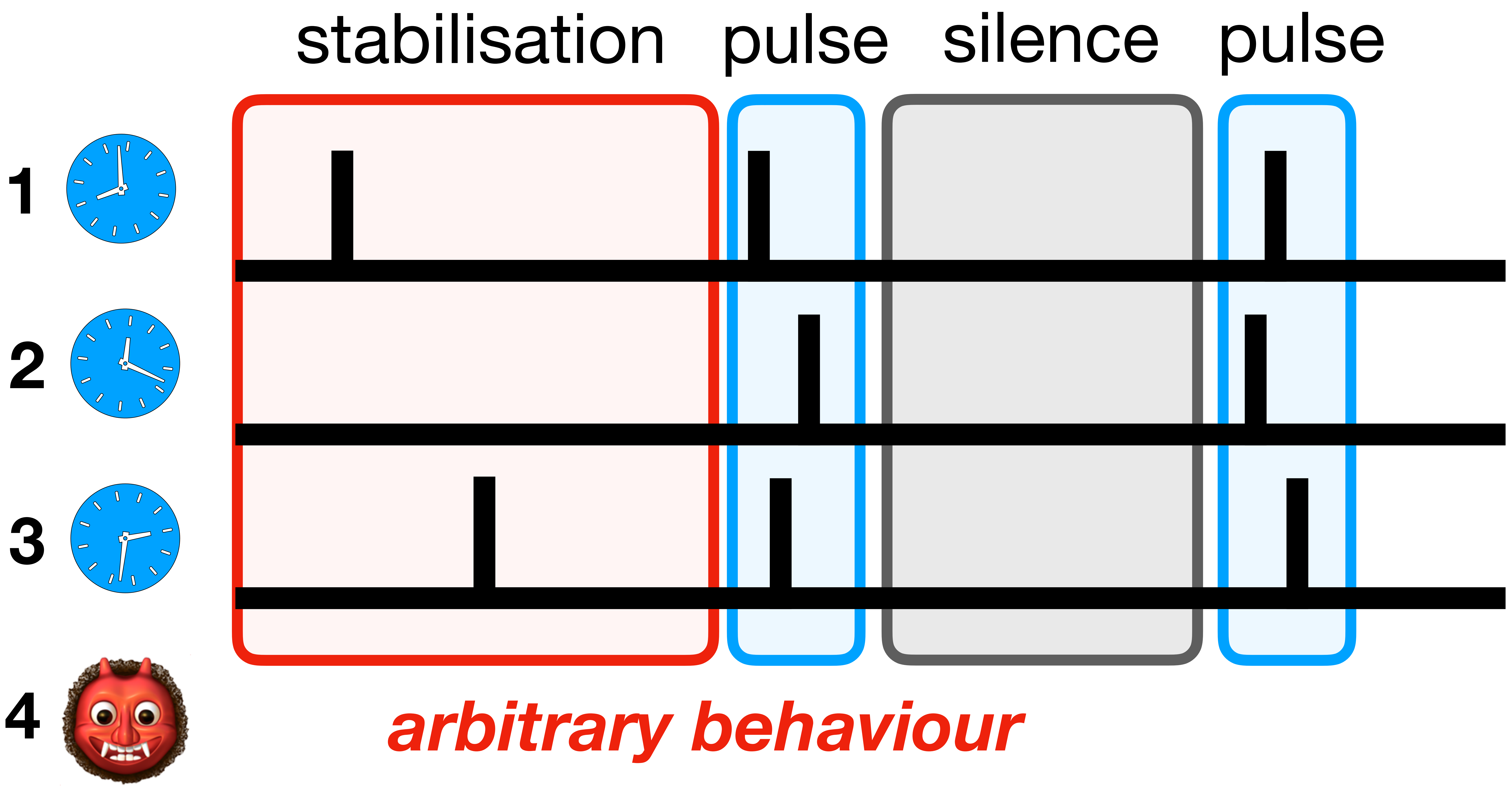
Gives the synchronous model



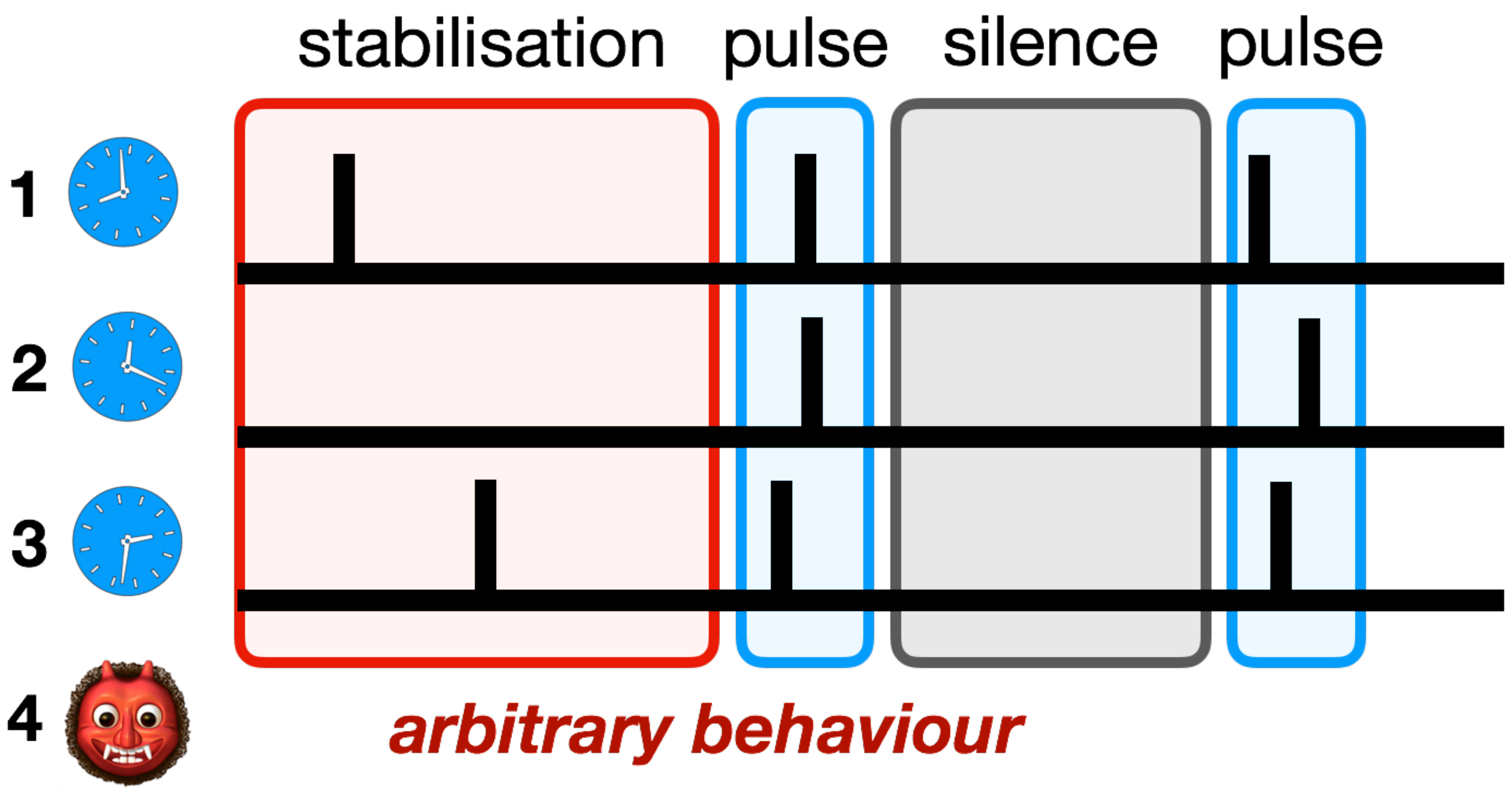
Self-stabilising pulse synchronisation



Self-stabilising pulse synchronisation



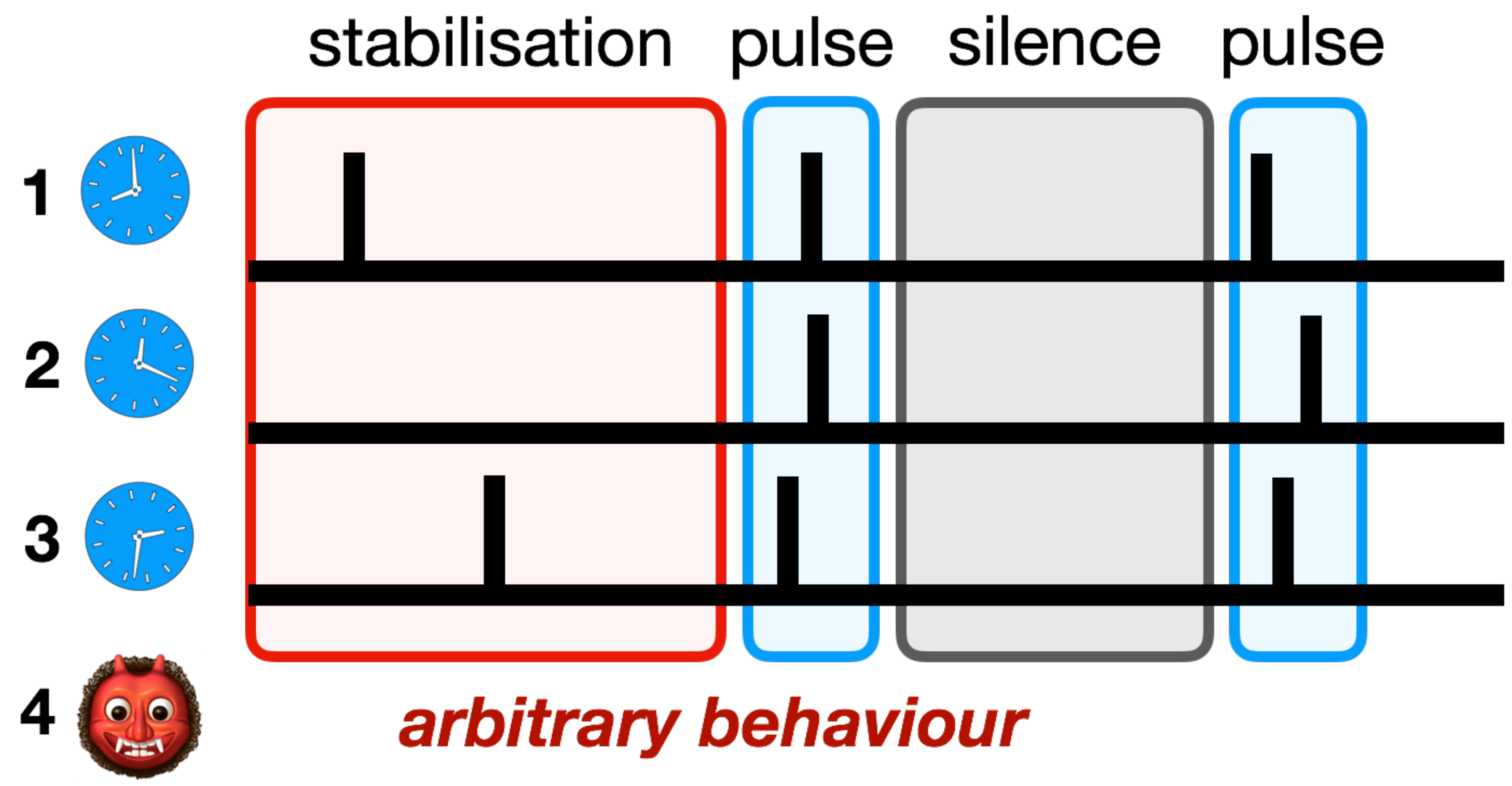
Complexity measures



Stabilisation time:
how many time units it takes before the correct nodes start pulsing synchronously

- n nodes
- $f < n/3$ faults
- drift parameter $\vartheta = O(1)$
- message delay $d = O(1)$

Complexity measures



- n nodes
- $f < n/3$ faults
- drift parameter $\vartheta = O(1)$
- message delay $d = O(1)$

Stabilisation time:
how many time units it takes before the correct nodes start pulsing synchronously

Bandwidth (per node):
how many bits per time unit a node broadcasts

Pulse synchronisation: status

authors	appears in		stabilisation time	bandwidth
S. Dolev & Welch	JACM 2004		exp(O(f))	**O(1)**
Daliot, D. Dolev & Parnas	SSS 2003		O(f^3)	**O(log f)**
D. Dolev & Hoch	SSS 2007		**O(f)**	O(f log f)
D. Dolev, Függer, Lenzen & Schmid	JACM 2014		O(f)	**O(1)**
this work		 	**polylog f** **O(log f)** **O(f)**	**polylog f** poly f **O(log f)**

Our result

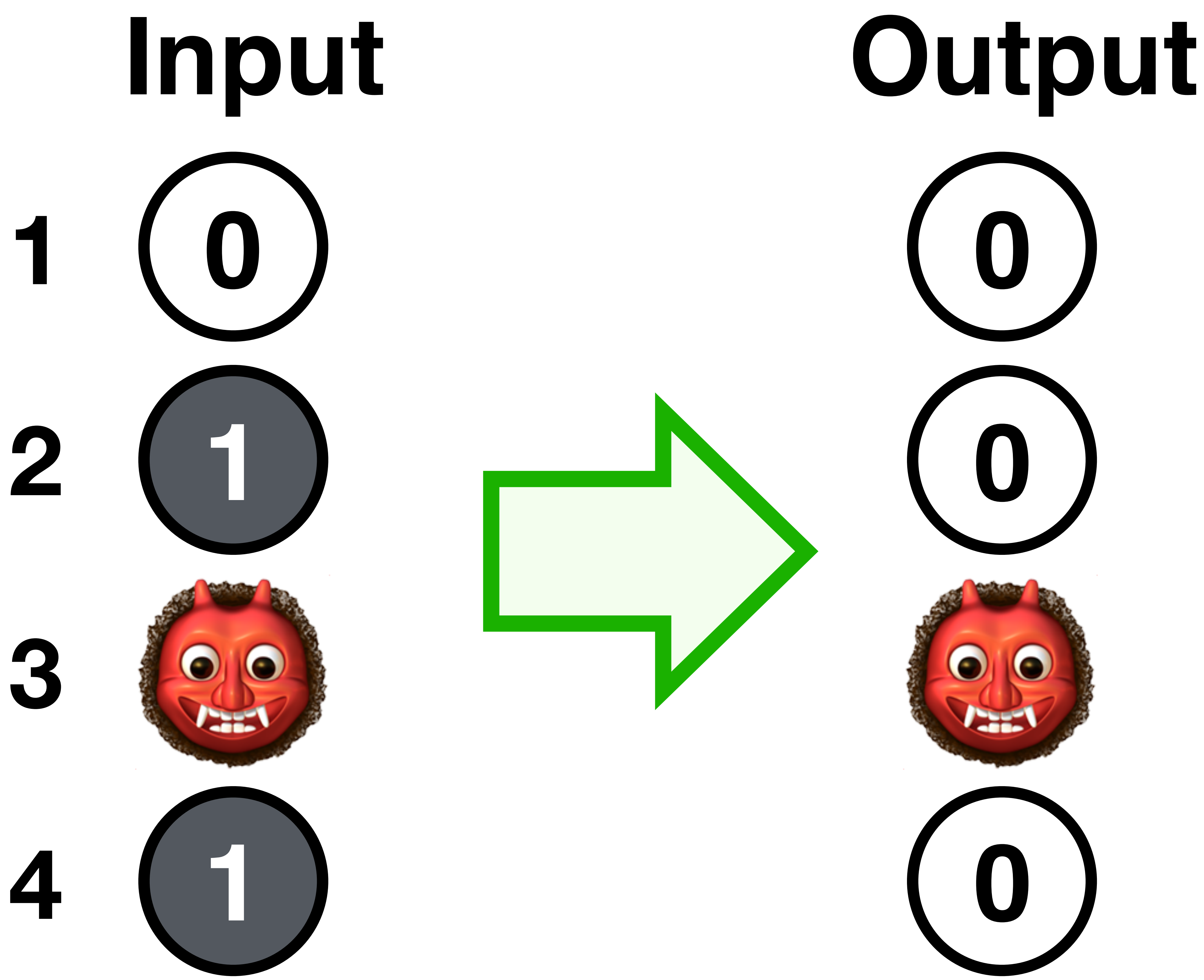
Synchronous BF consensus

$\Downarrow^*$

SS + BF pulse synchronisation
in the bounded delay model

(*) At most **logarithmic** overheads.

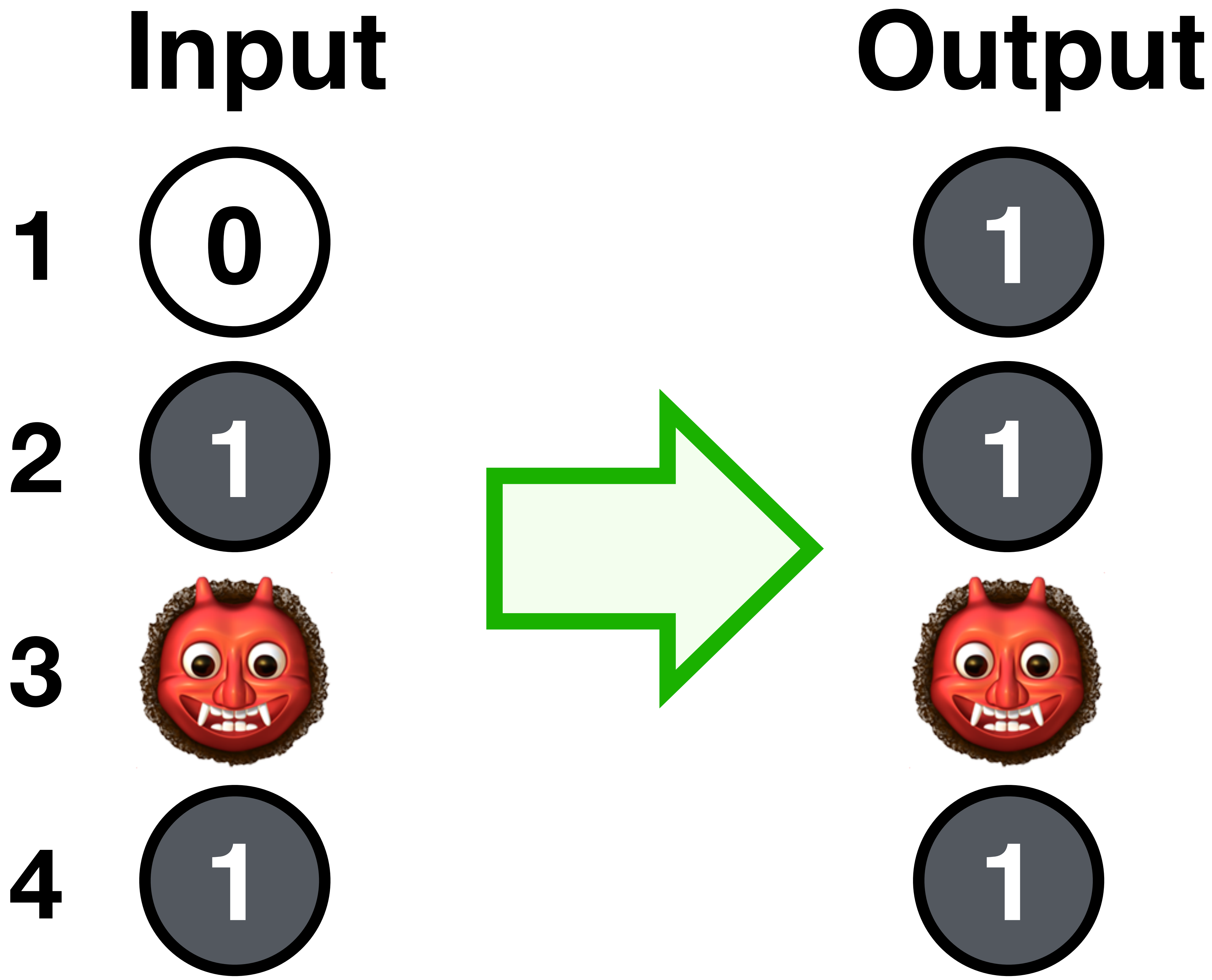
Synchronous binary consensus



Properties:

1. **Agreement**
2. Validity
3. Termination

Synchronous binary consensus



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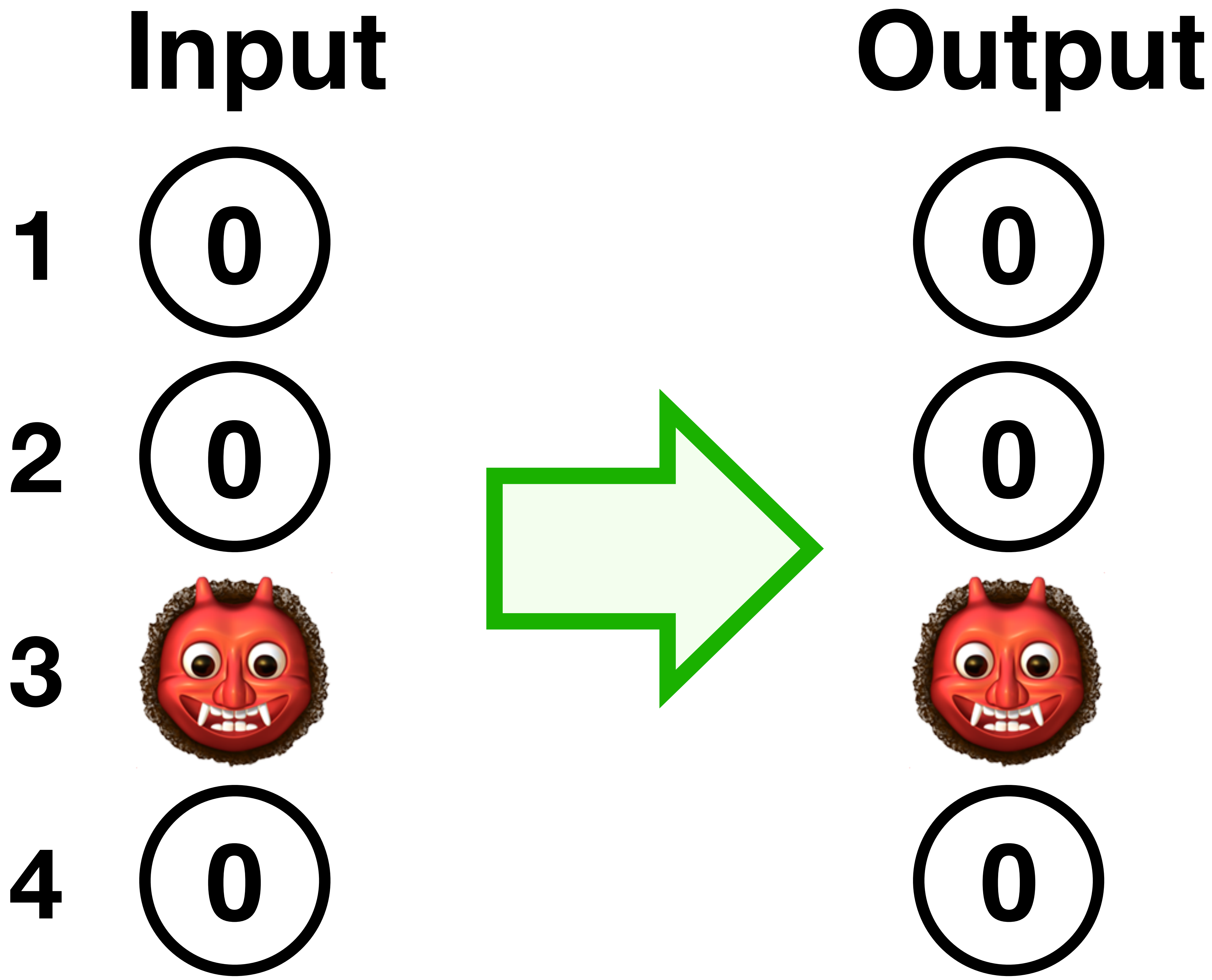

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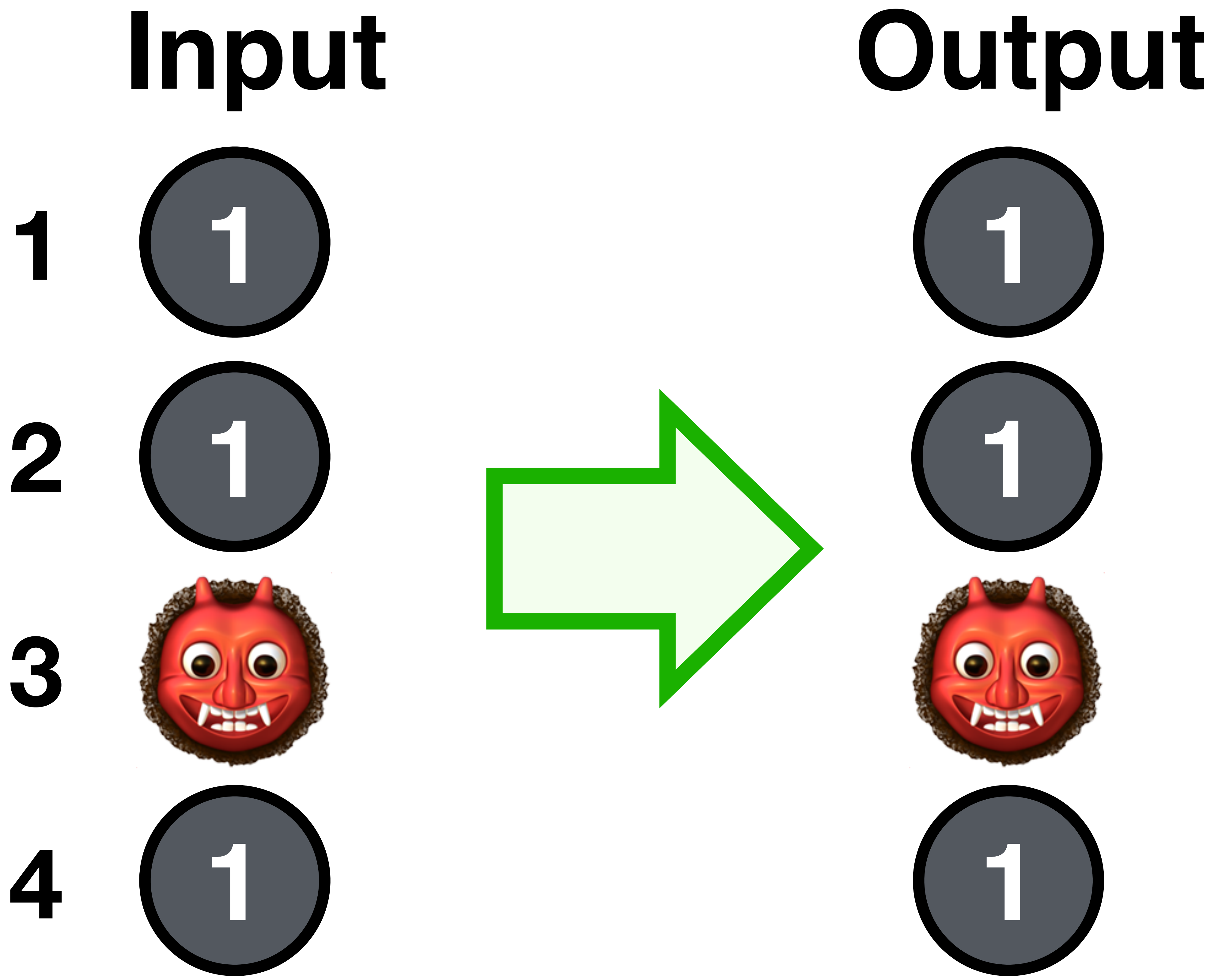

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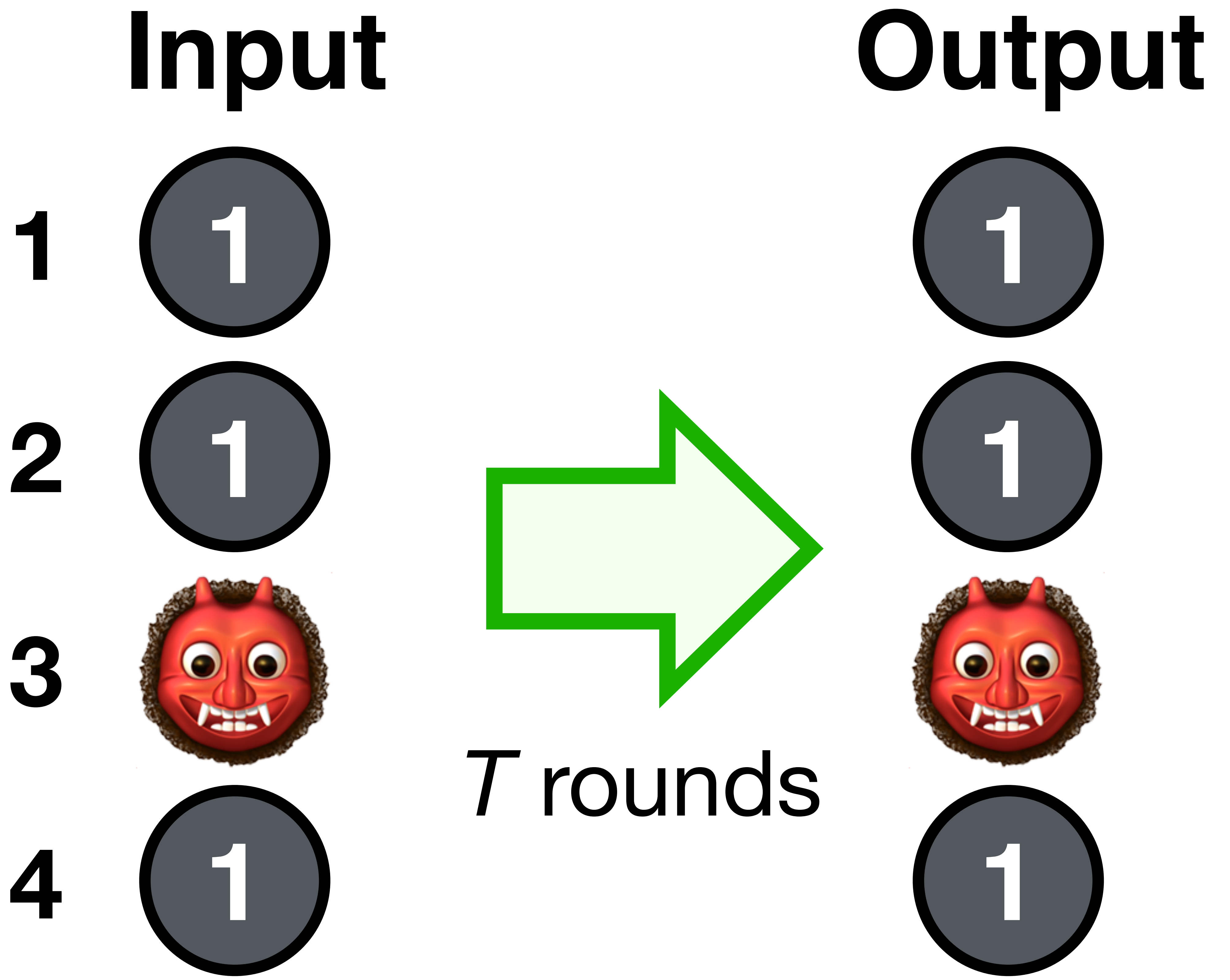

Properties:

1. Agreement
2. Validity
3. **Termination**

Synchronous consensus:

- **no** self-stabilisation
- **synchronous** communication
- terminates in *T* rounds

Our result

Synchronous BF consensus

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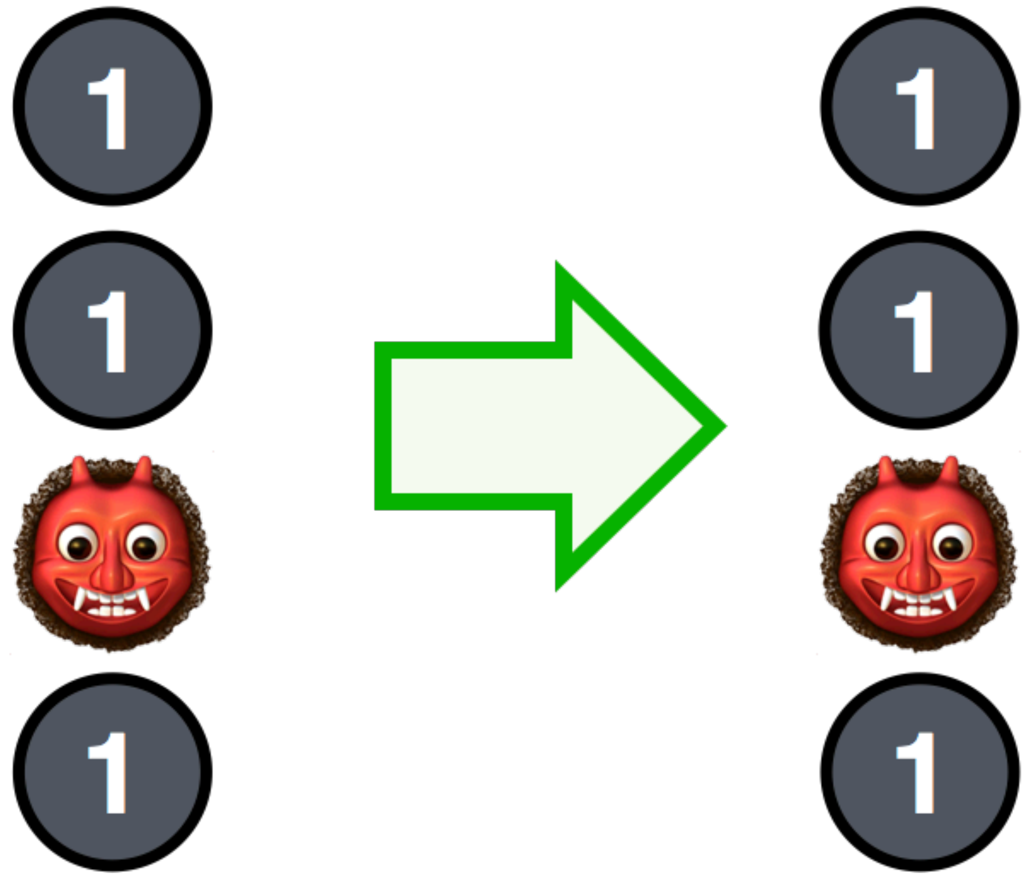
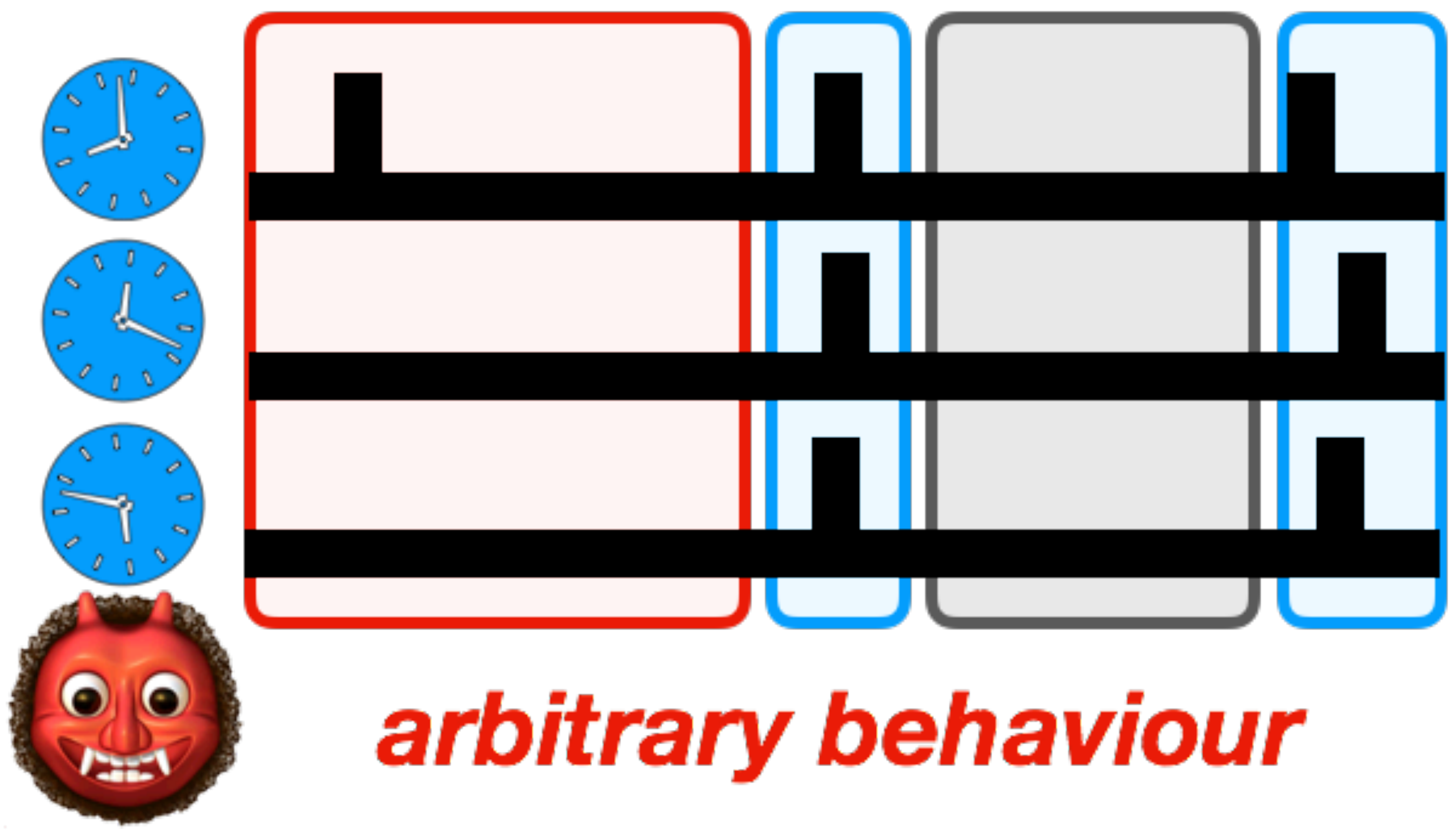
SS + BF pulse synchronisation in the bounded delay model

(*) At most **logarithmic** overheads.





Consensus ➡ pulse sync.

		consensus		pulse sync	
source		rounds	bits/round	stabilisation	bandwidth
Berman, Garay & Perry '1992		O(*f*)	O(1)	O(*f*)	O(log *f*)
King & Saia '2011		polylog(*f*)	polylog(*f*) *	polylog(*f*)	polylog(*f*)
Feldman & Micali '1988		O(1)	poly(*f*)	O(log *f*)	poly(*f*)

Approach: resilience boosting

Adapt ideas and techniques from prior work on *synchronous counting* (digital clock synchronisation)*:*

— Lenzen & R. (SSS 2016)
— Lenzen, R. & Suomela (SICOMP 2017)

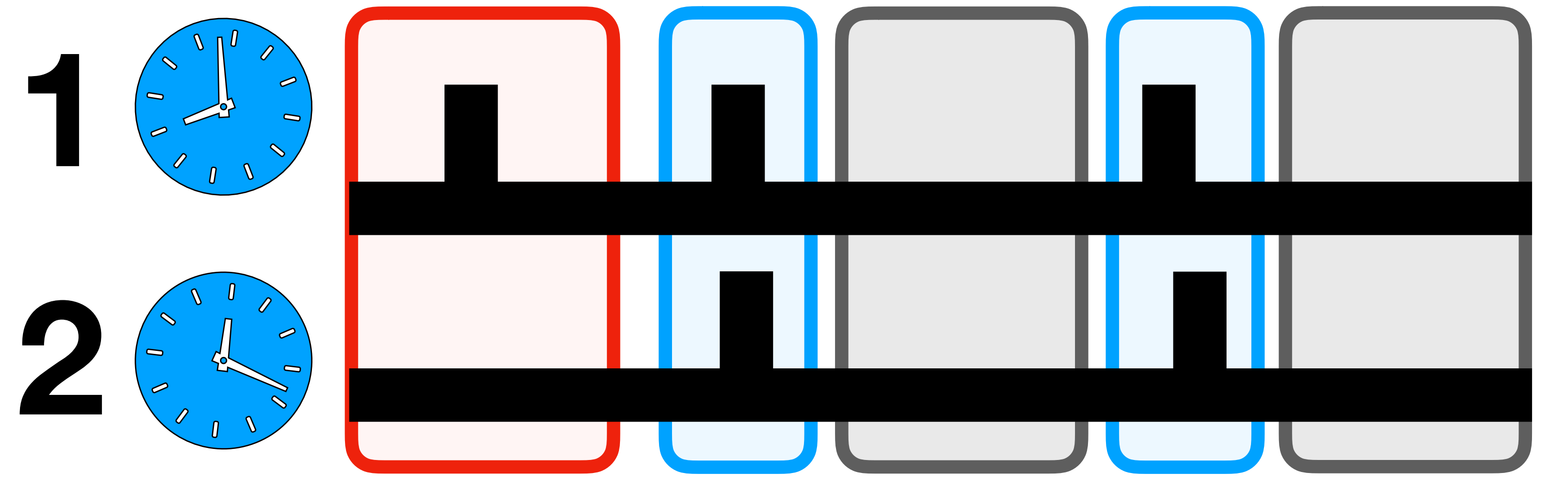
Difficulty: translating techniques from the synchronous model to bounded-delay model with clock drift

Resilience boosting: idea

Given:

Pulser **A**$_0$

- n_0 = 2 nodes
- f_0 = **0** resilience



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Pulser **A**$_1$

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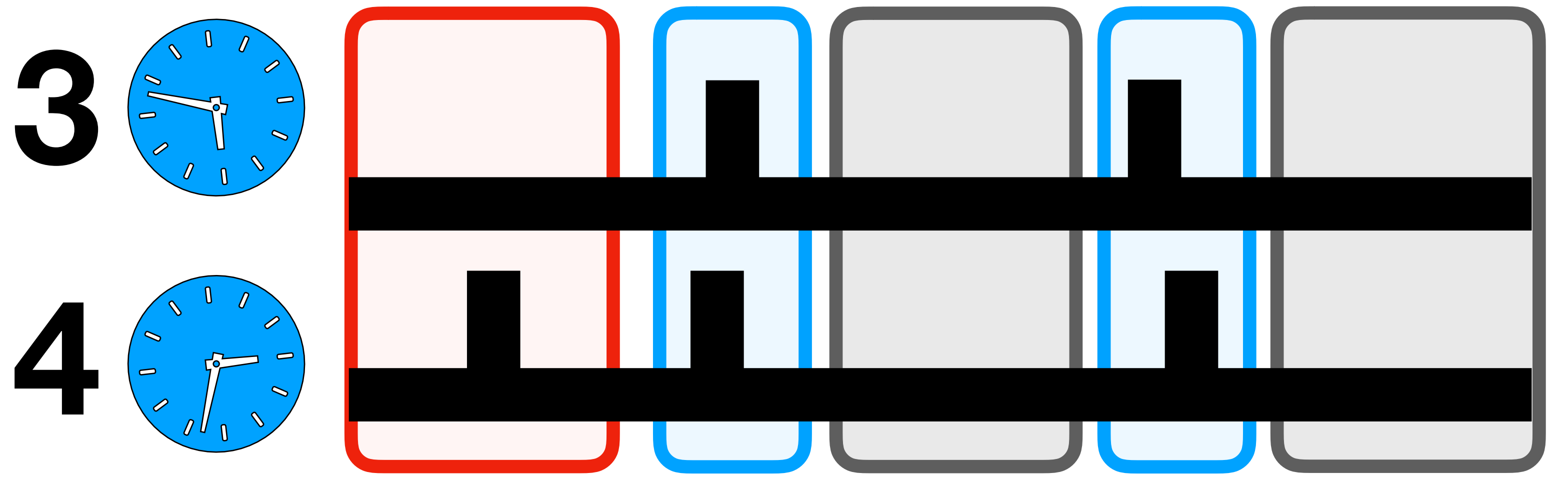

Resilience boosting: idea

Given:

Pulser $\mathbf{A_0}$
- $n_0 = 2$ nodes
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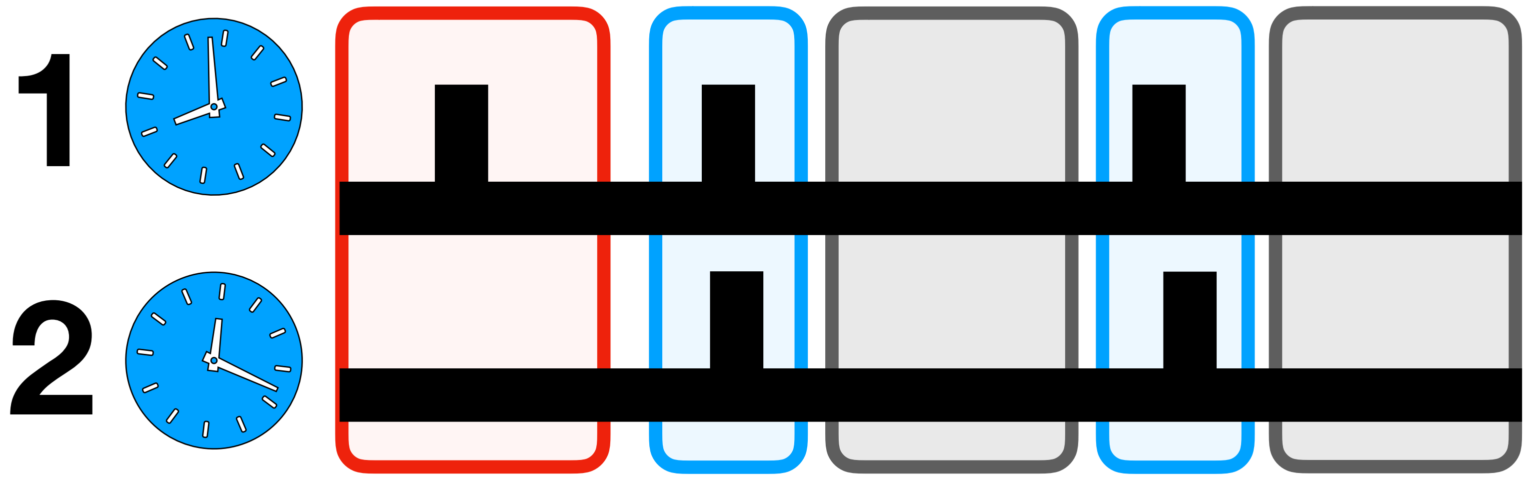

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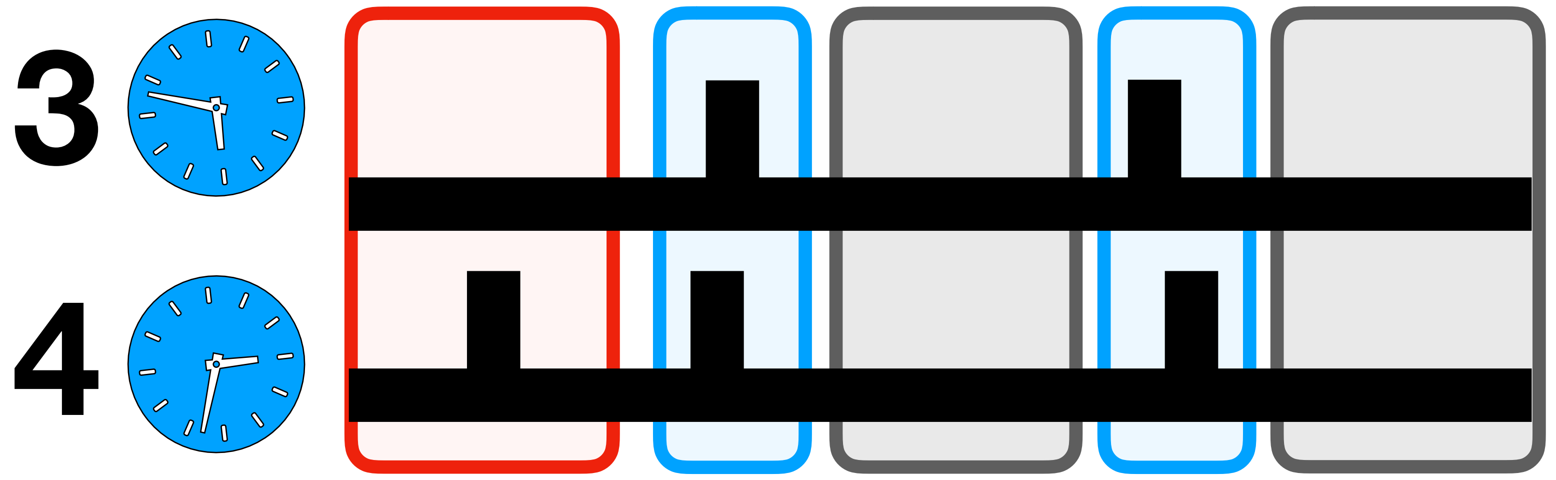
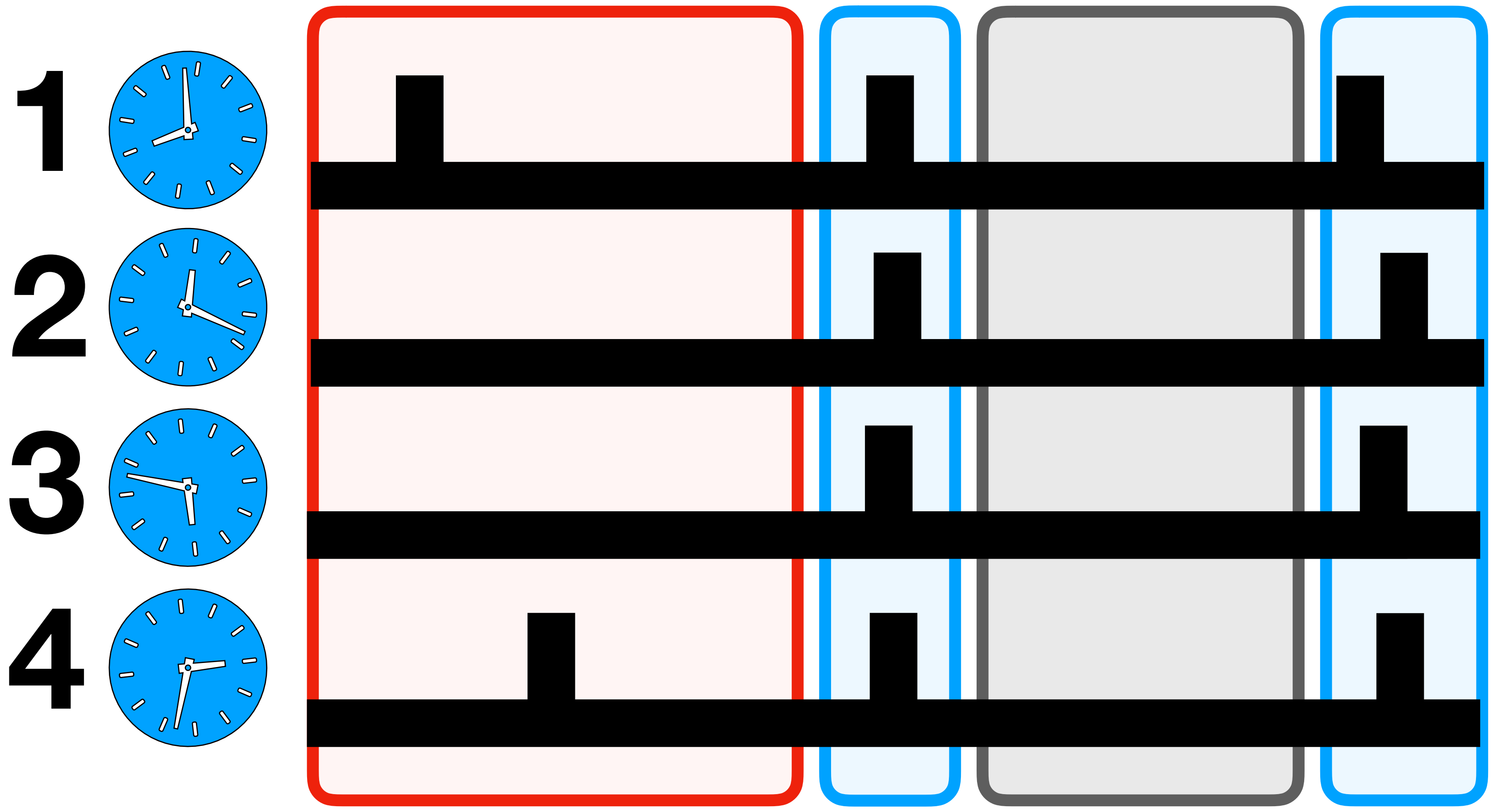


Result:

Pulser $\mathbf{A}$
- $n = n_0 + n_1$ nodes
- $f = f_0 + f_1 + \mathbf{1}$ resilience



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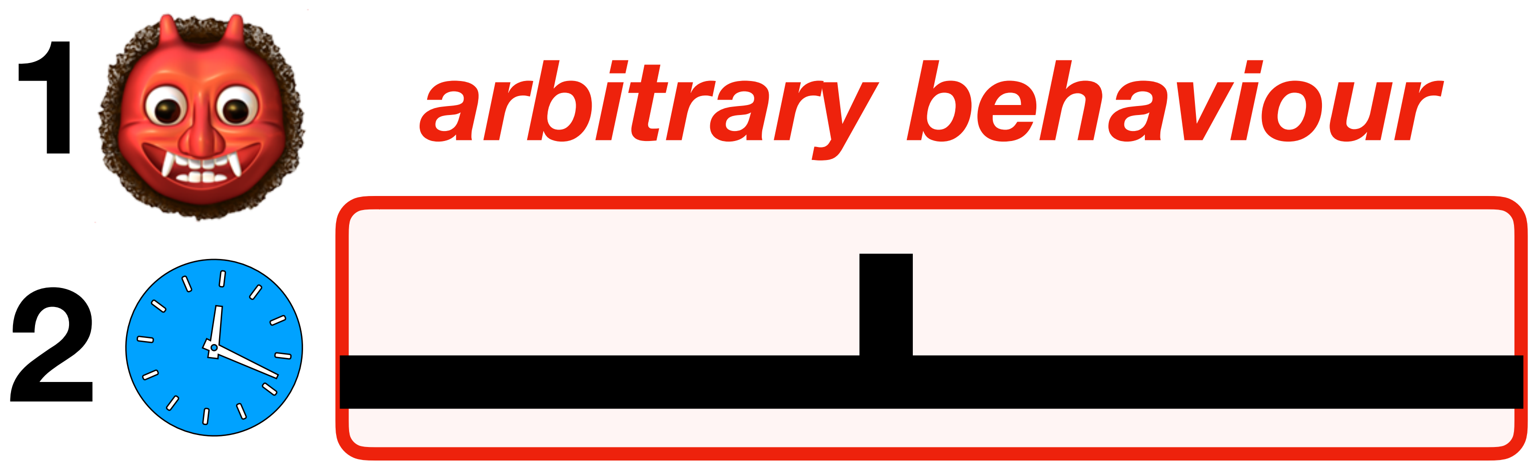

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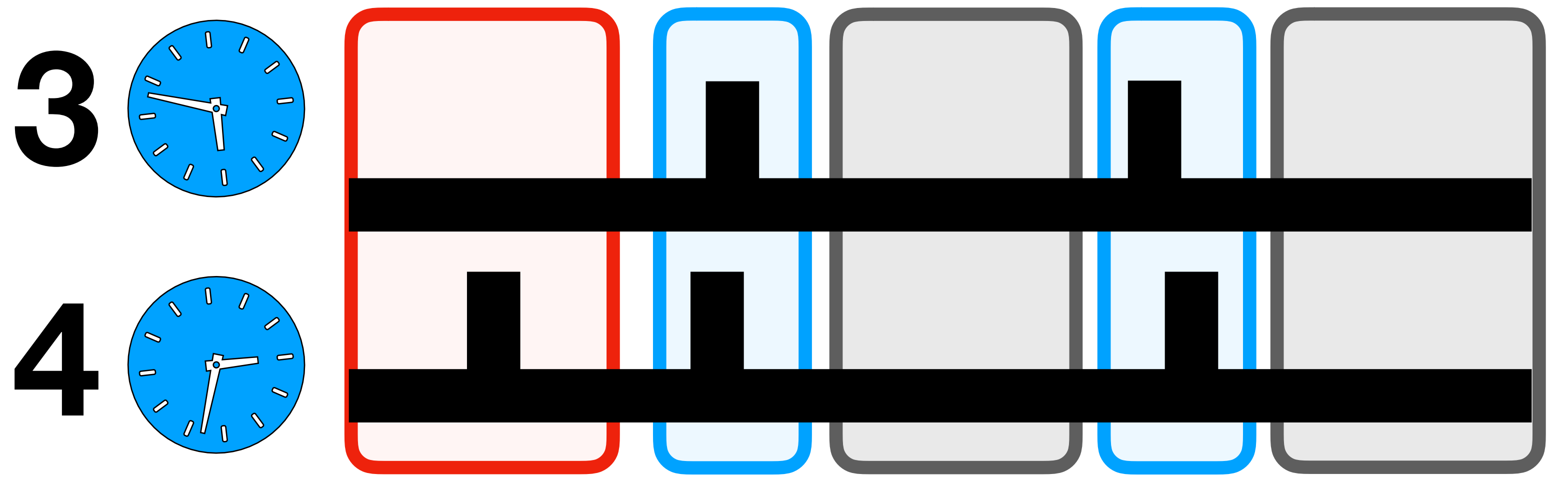

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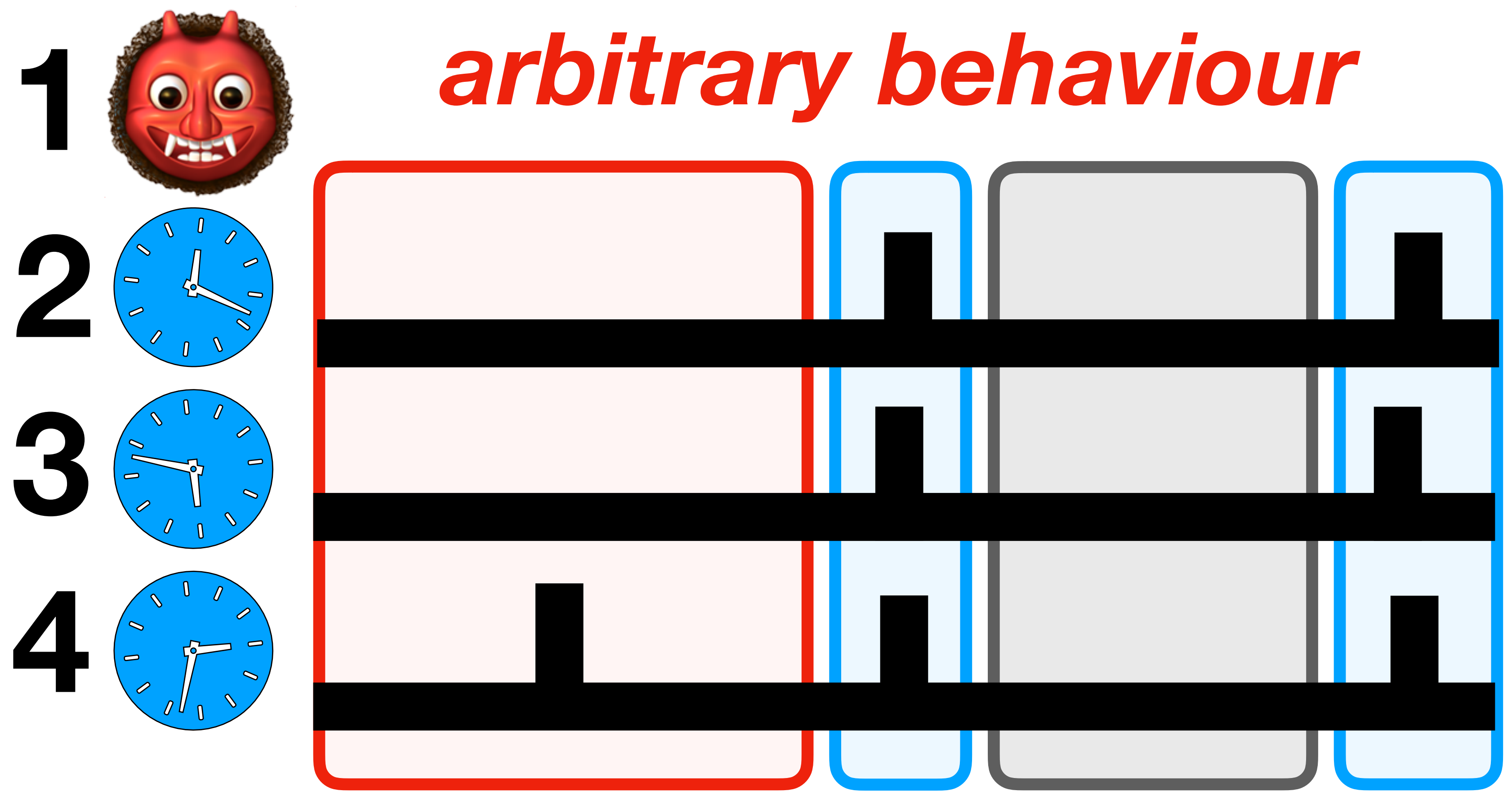

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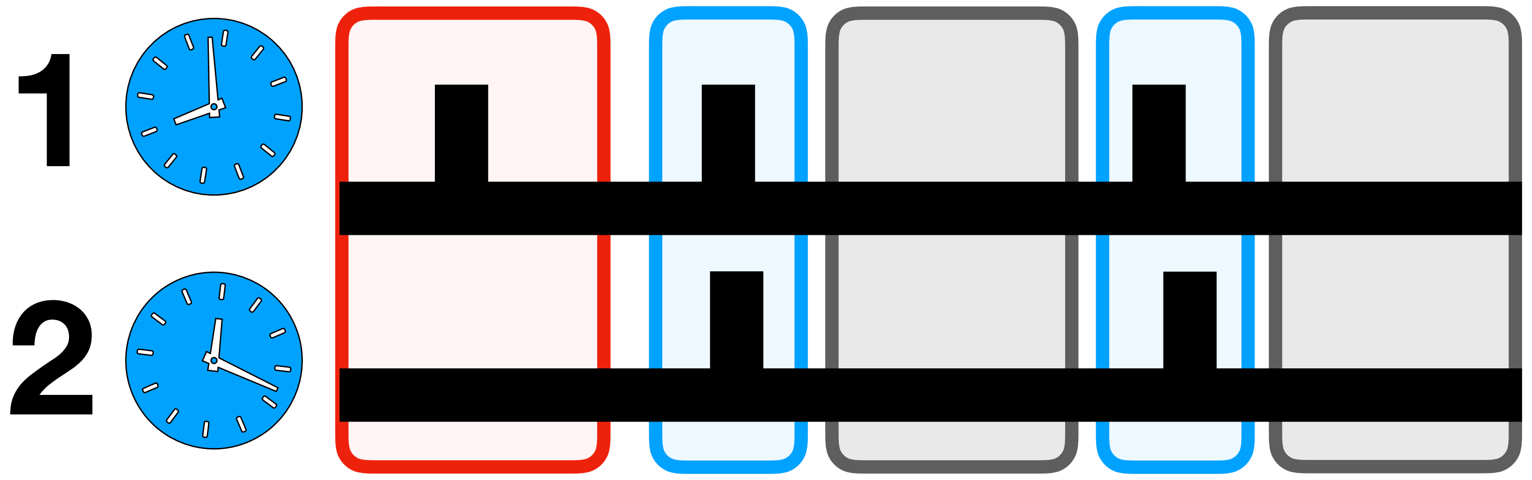

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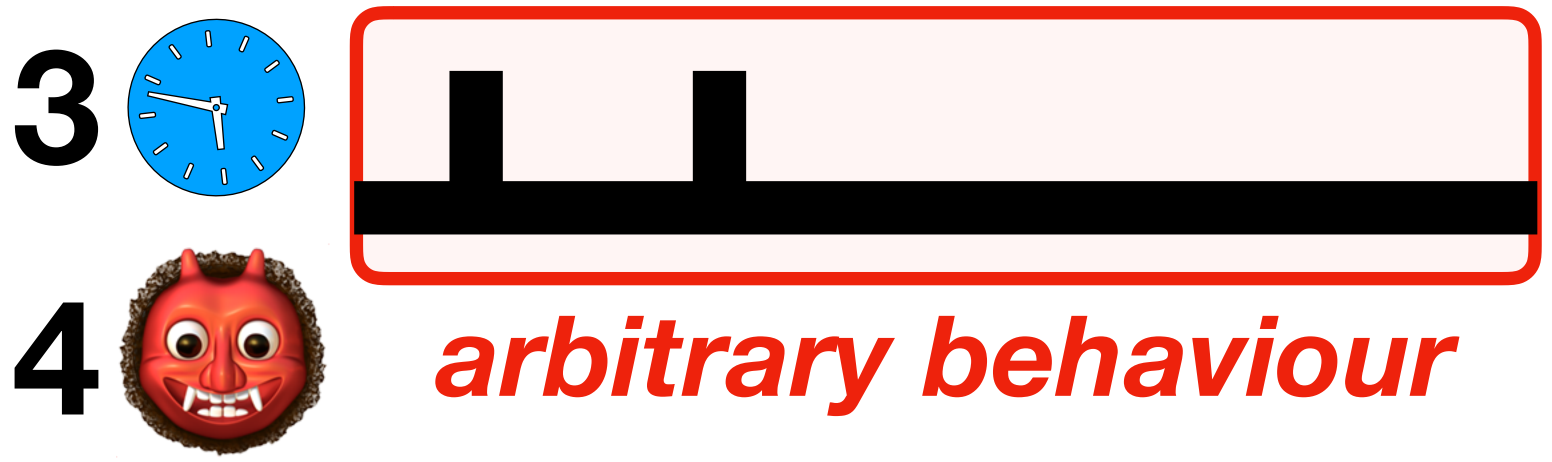

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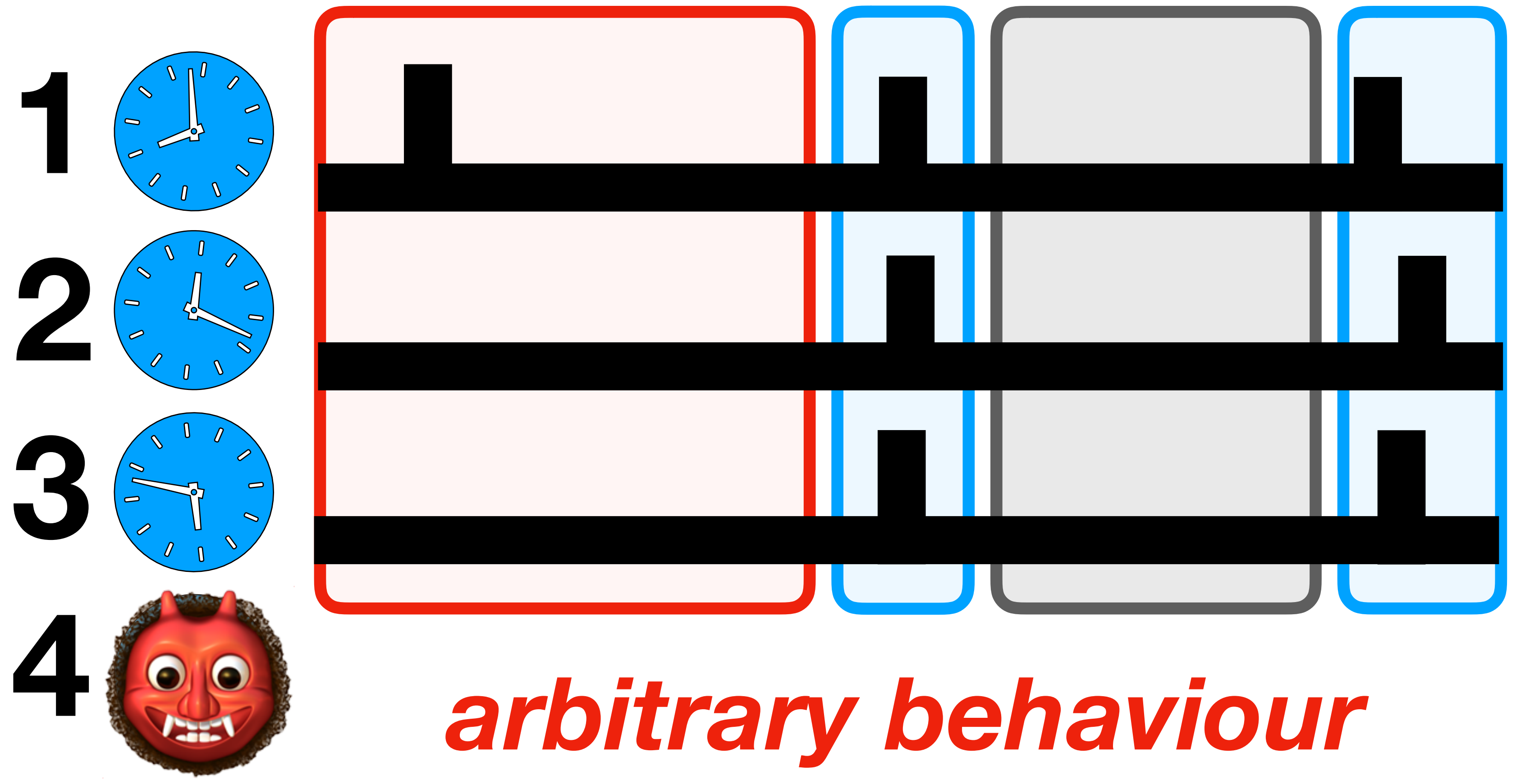
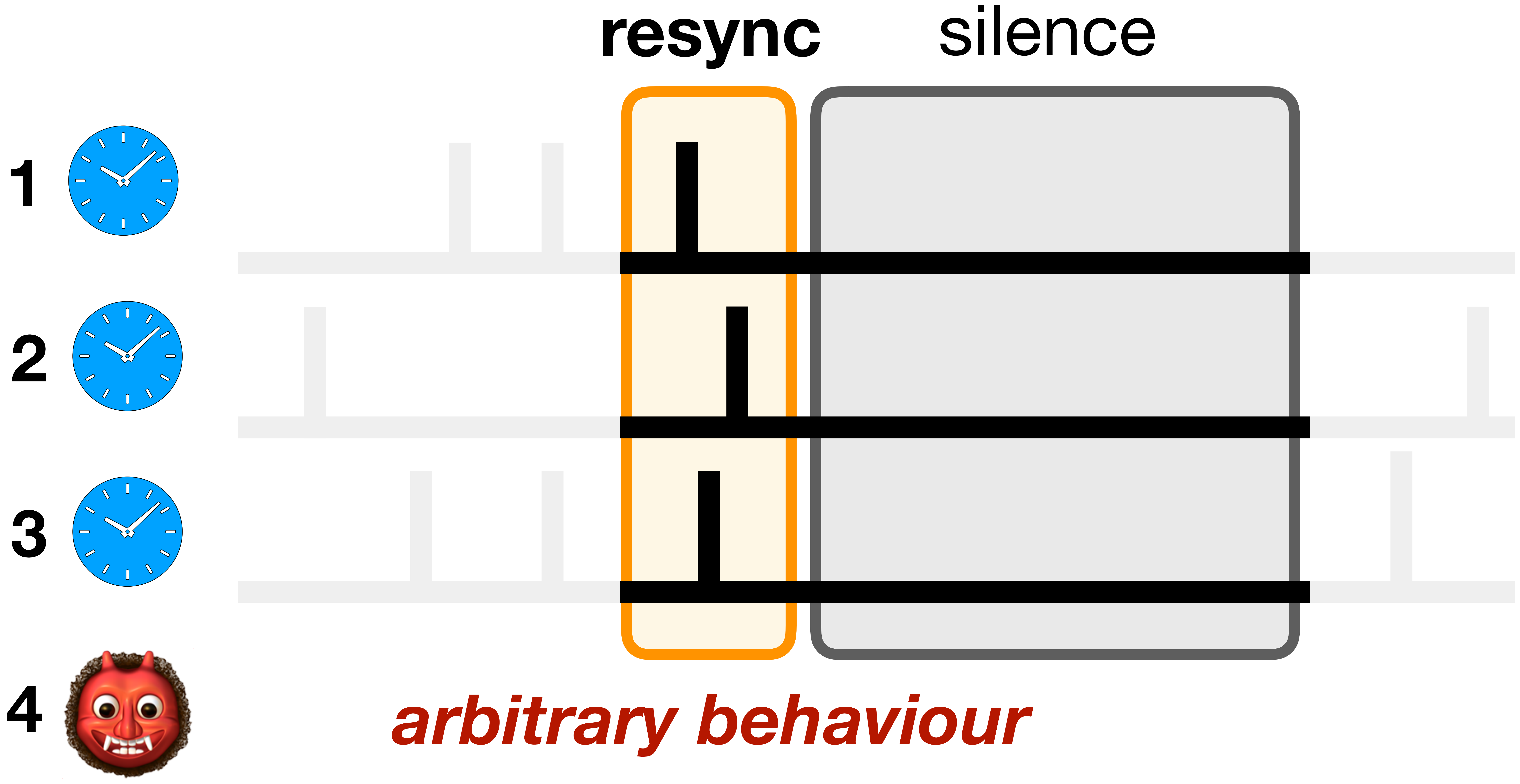


Ingredient: resynchronisation pulse



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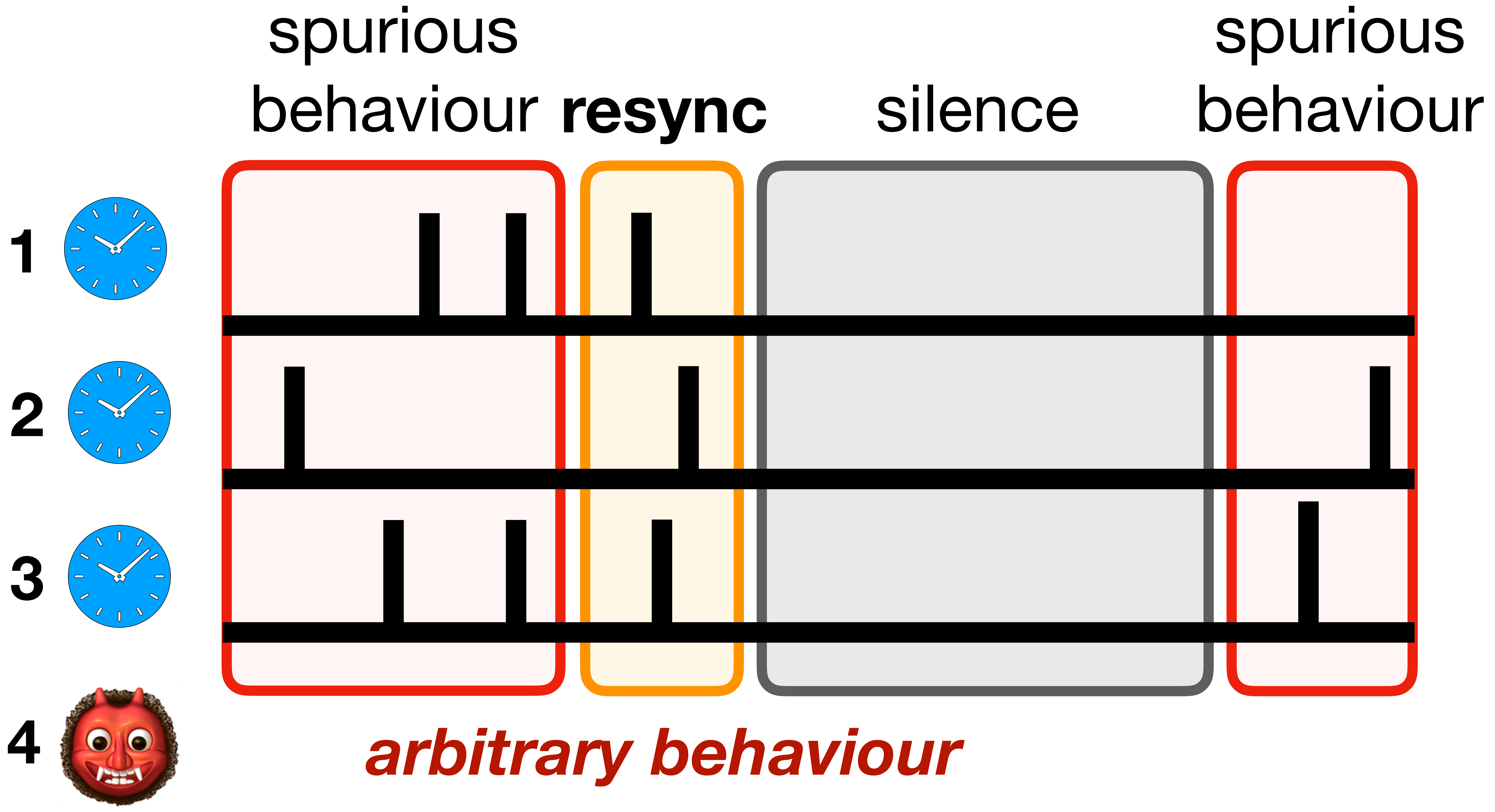

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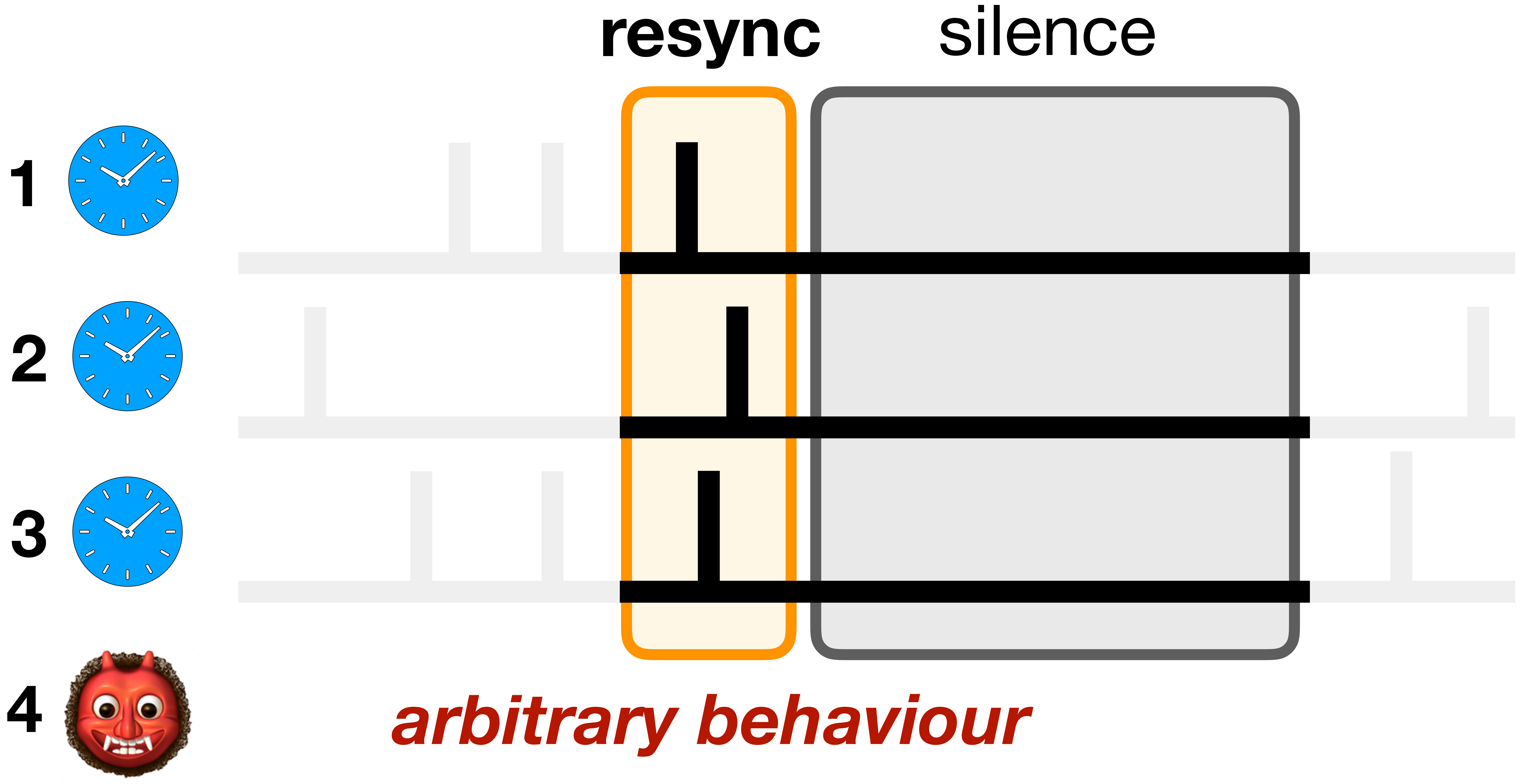
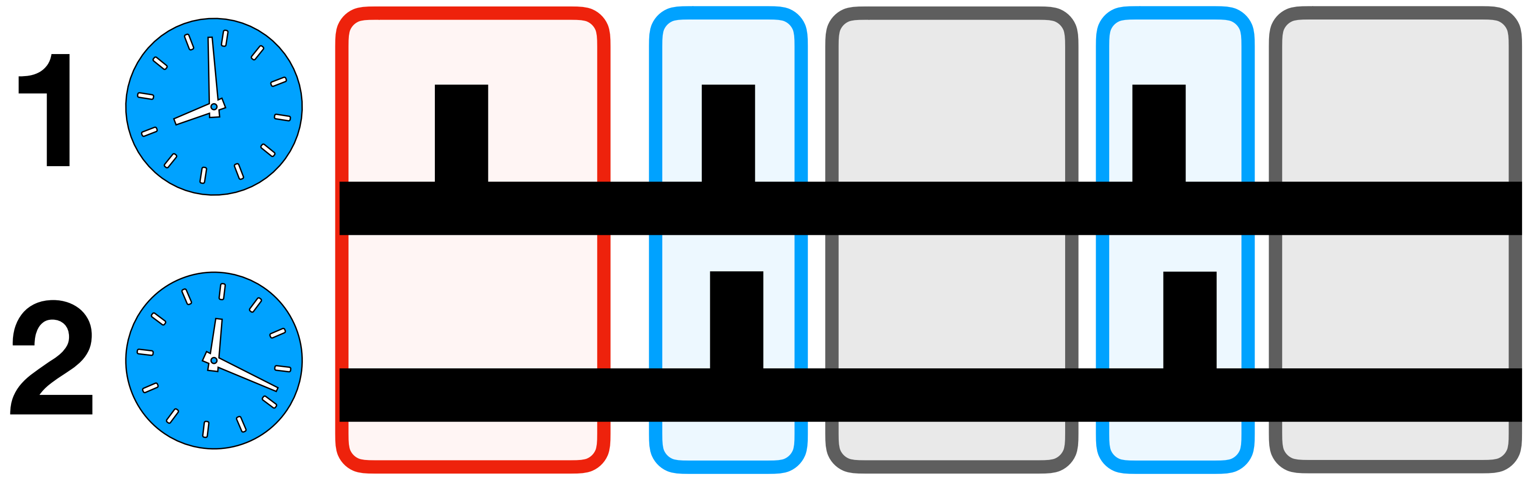


Constructing resync. algorithms

Given:

Pulser A$_0$

- n_0 = 2 nodes
- f_0 = 0 resilience



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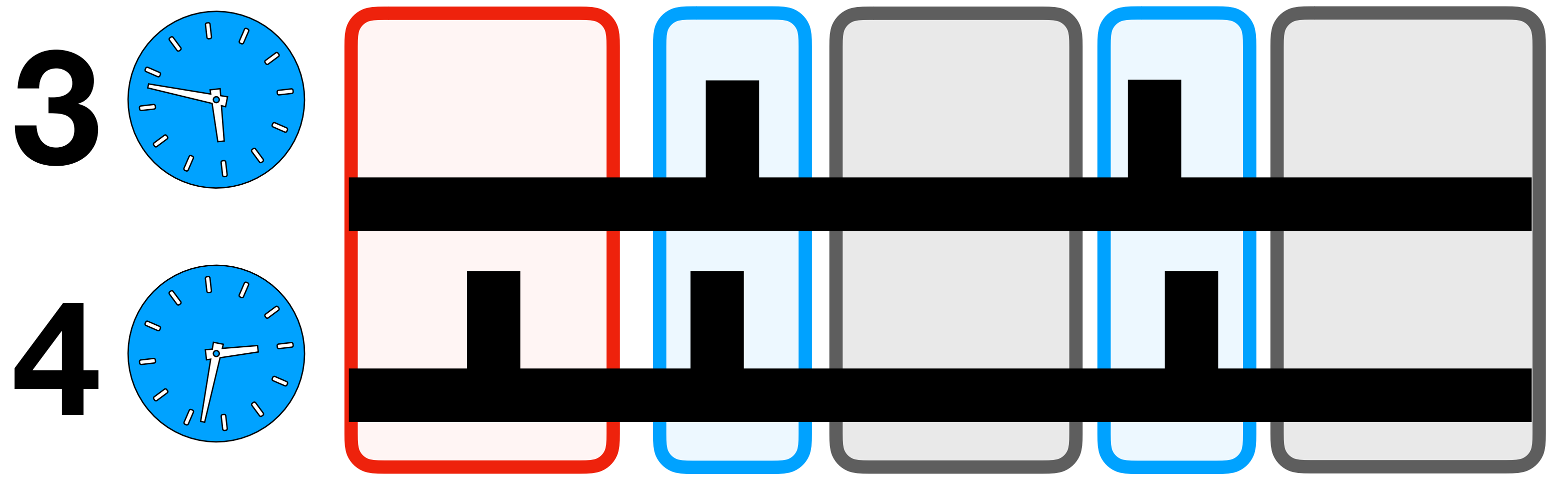
Pulser A$_1$

- n_1 = 2 nodes
- f_1 = 0 resilience

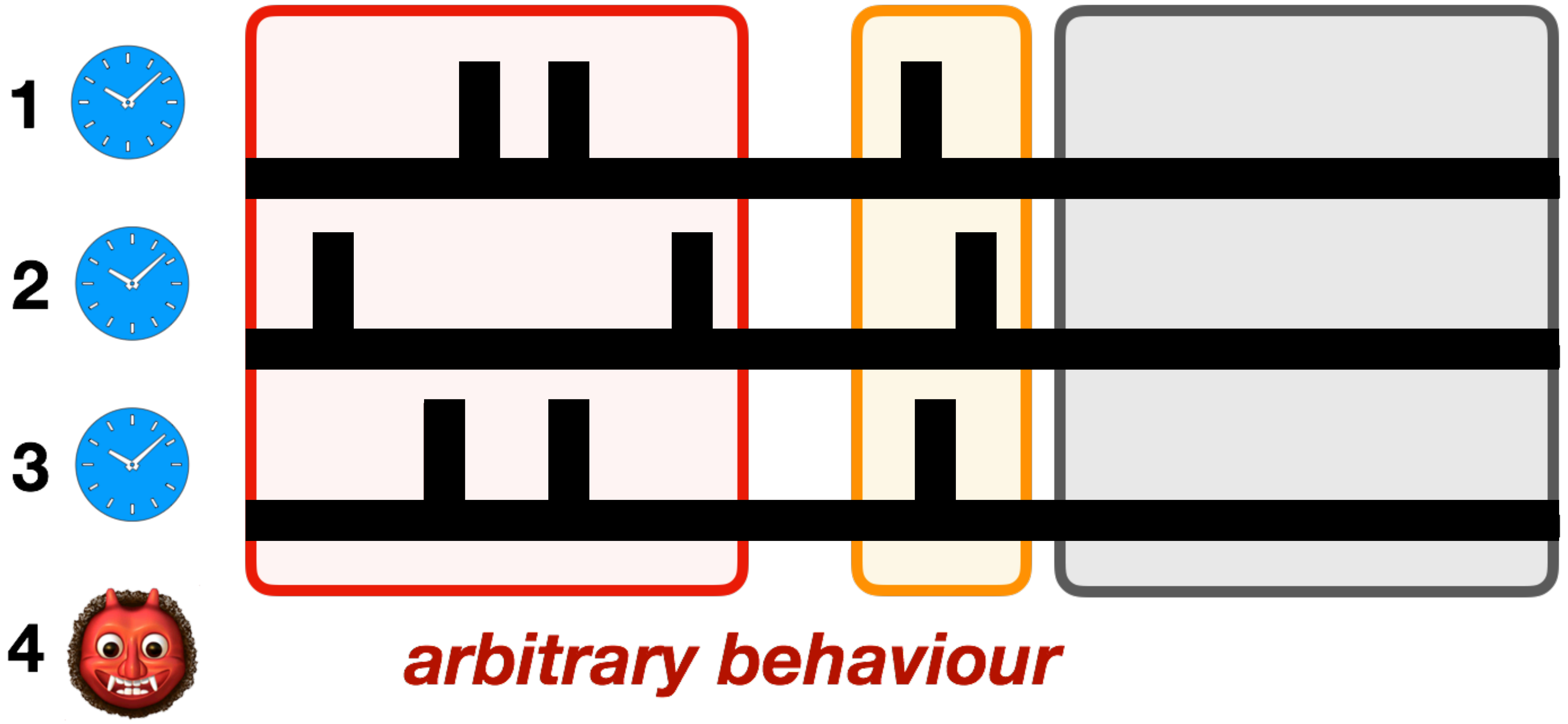


Result:

Resynchroniser B

- $n = n_0 + n_1$
- $f = f_0 + f_1 + 1$

Pulser A$_0$ Pulser A$_1$



Resilience boosting: details

Given:

Resynchroniser B

- $n = n_0 + n_1$
- $f = f_0 + f_1 + 1$

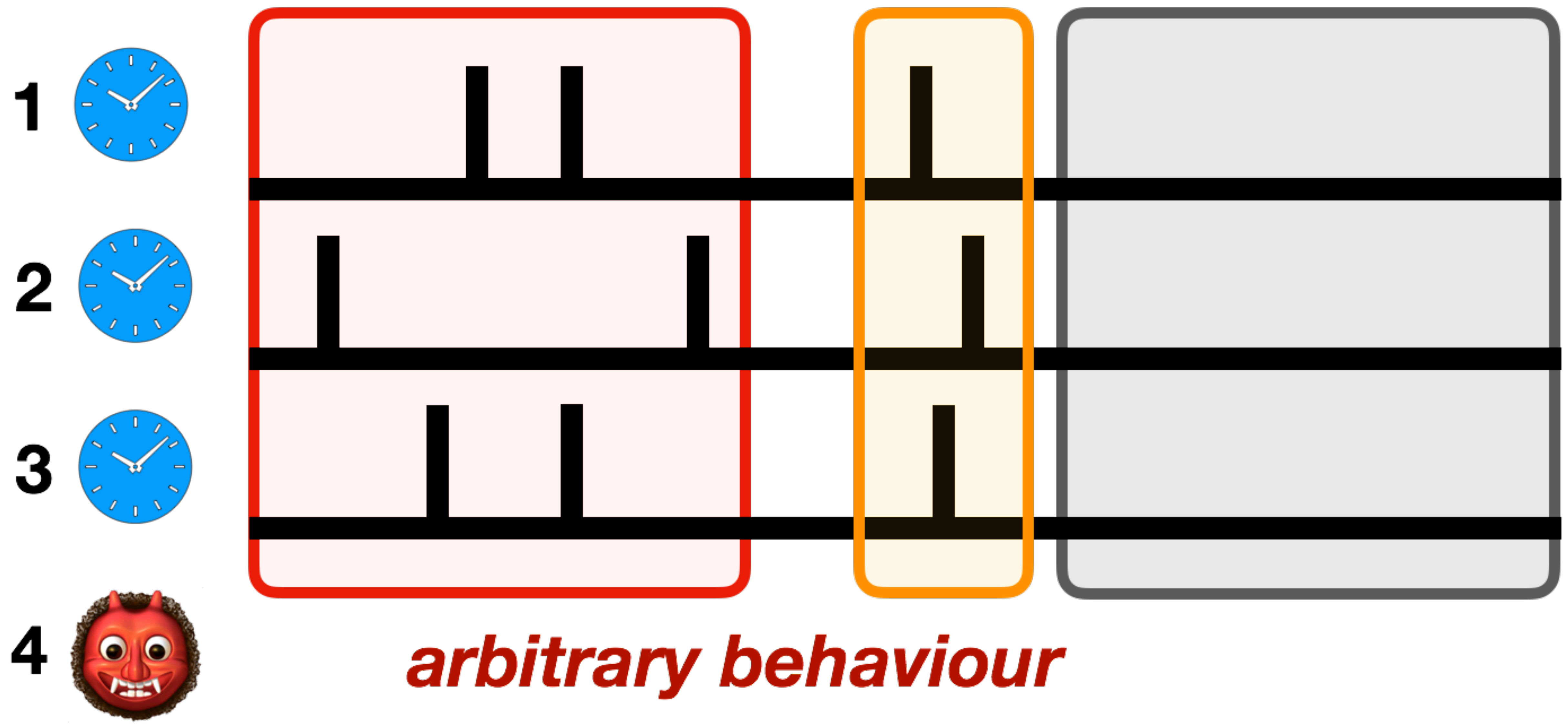
Pulser $\mathbf{A_0}$ | Pulser $\mathbf{A_1}$

\+

Wrapper W

Consensus C

- $n = n_0 + n_1$
- $f = f_0 + f_1$
- synchronous



Resilience boosting: details

Given:

Resynchroniser B

- $n = n_0 + n_1$
- $f = f_0 + f_1 + 1$

Pulser $\mathbf{A_0}$ Pulser $\mathbf{A_1}$

+

Wrapper W

Consensus C

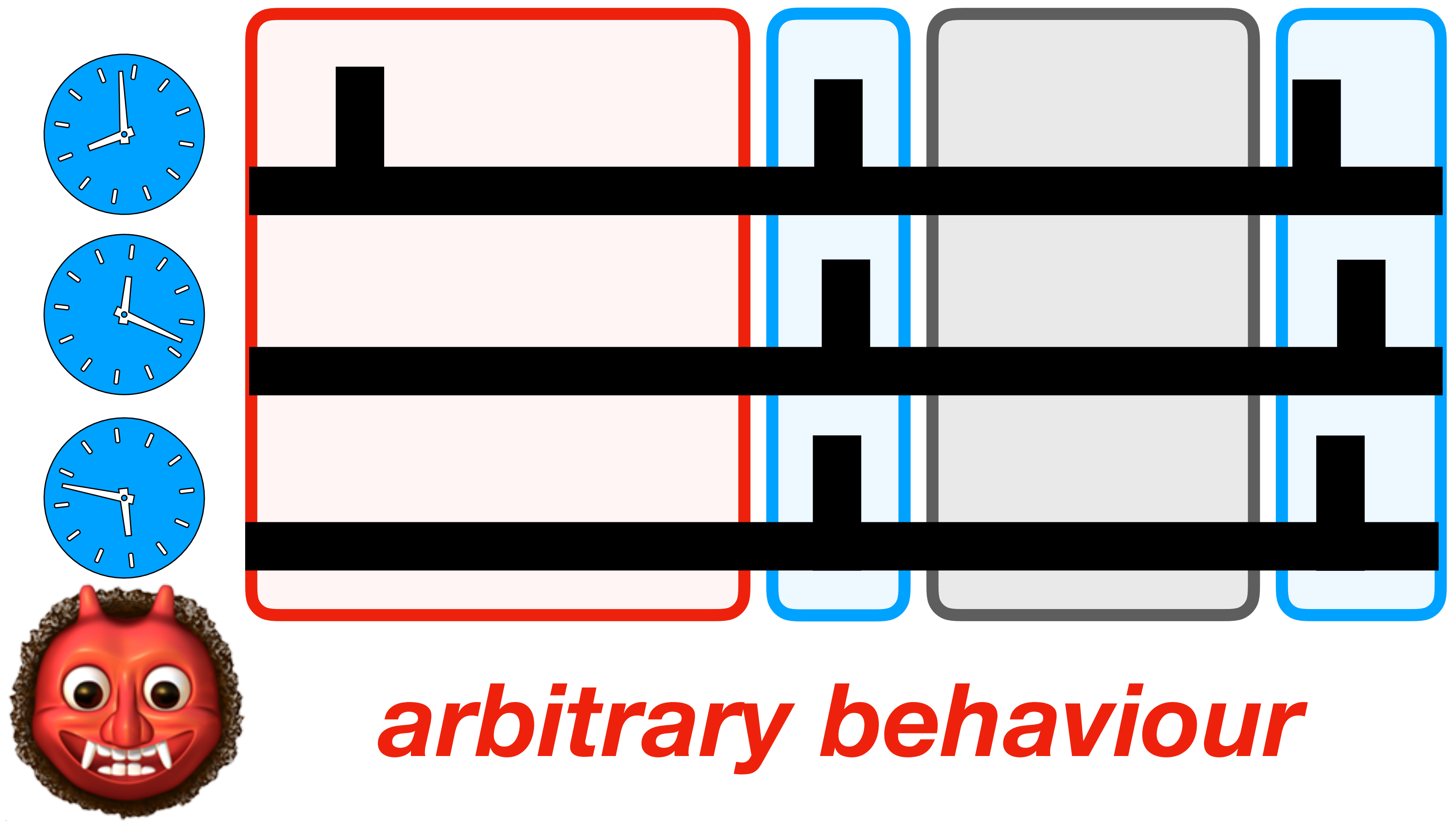
- $n = n_0 + n_1$
- $f = f_0 + f_1$
- synchronous

Result:

Pulser A

- $n = n_0 + n_1$ nodes
- $f = f_0 + f_1$ **+ 1** resilience

B: $\mathbf{A_0}$ $\mathbf{A_1}$ — **C**



Hardness of pulse synchronisation

Synchronous BF consensus

$\Downarrow^*$

SS + BF pulse synchronisation in the bounded delay model

(almost)
as easy as
consensus

Hardness of pulse synchronisation

Synchronous BF consensus

$\Uparrow$ **???**

SS + BF pulse synchronisation in the bounded delay model

but is it **as hard as** consensus?

Conclusions

Upper bounds:

	stabilisation time	bandwidth
	**polylog *f***	**polylog *f***
	**O(log *f*)**	poly *f*
	O(*f*)	**O(log *f*)**

Lower bounds:

No lower bounds known!

Conclusions

Upper bounds:

	stabilisation time	bandwidth
	polylog f	polylog f
	O(log f)	poly f
	O(f)	O(log f)

Lower bounds:

No lower bounds known!

Thanks!

arXiv:1705.06173