NOVA SCHOOL OF SCIENCE & TECHNOLOGY
COMPUTER SCIENCE DEPARTMENT

Assigning Semantics to Concurrent Programs

lecture 15 (2021-05-10)

Master in Computer Science and Engineering

— Concurrency and Parallelism / 2020-21 —

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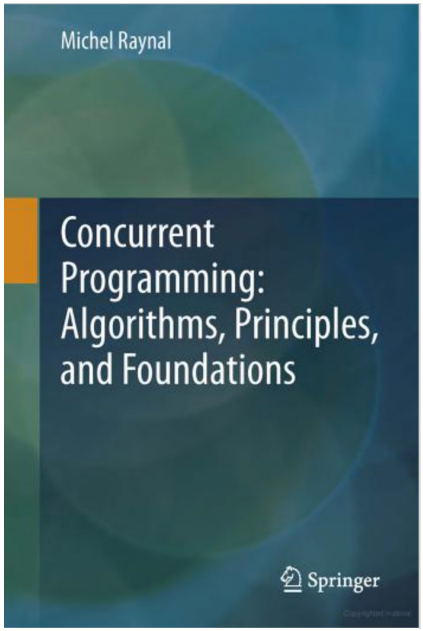
Summary

- Assigning Semantics to Concurrent Programs
  - Atomicity/Linearizability; Sequential consistency Serializability
- Runs
  - Program state as a N-dimensional lattice
  - Consistent and Inconsistent runs
- **Reading list:**
  - **Chapter 4** of the book Raynal M.; **Concurrent Programming: Algorithms, Principles, and Foundations;** Springer-Verlag Berlin Heidelberg (2013); ISBN: 978-3-642-32026-2



Assigning Semantics to Concurrent Programs

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X = Y = 0

X, Y => Global Vars
a, b => Local Vars

X = 1 Y = 2	a = Y b = X

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- What are the final values for 'X', 'Y', 'a' and 'b'?
  - X = 1, Y = 2, a = ?, b = ?
- Depends on the interleavings of the statements
  - Sequential Consistency [Lamport'79]
  - Program behavior = set of interleavings

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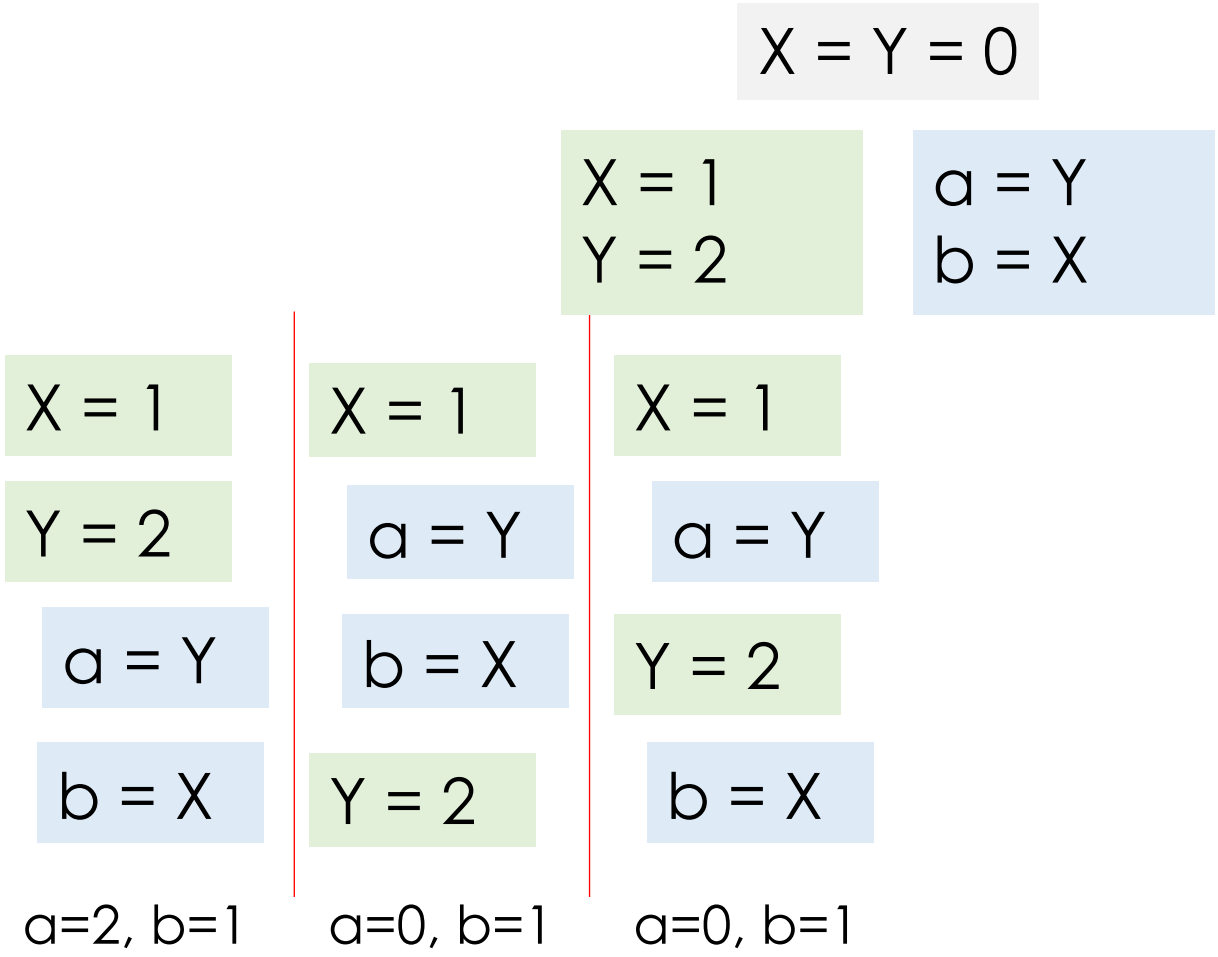
b = X	Y = 2
a=2, b=1	a=0, b=1

Assigning Semantics to Concurrent Programs



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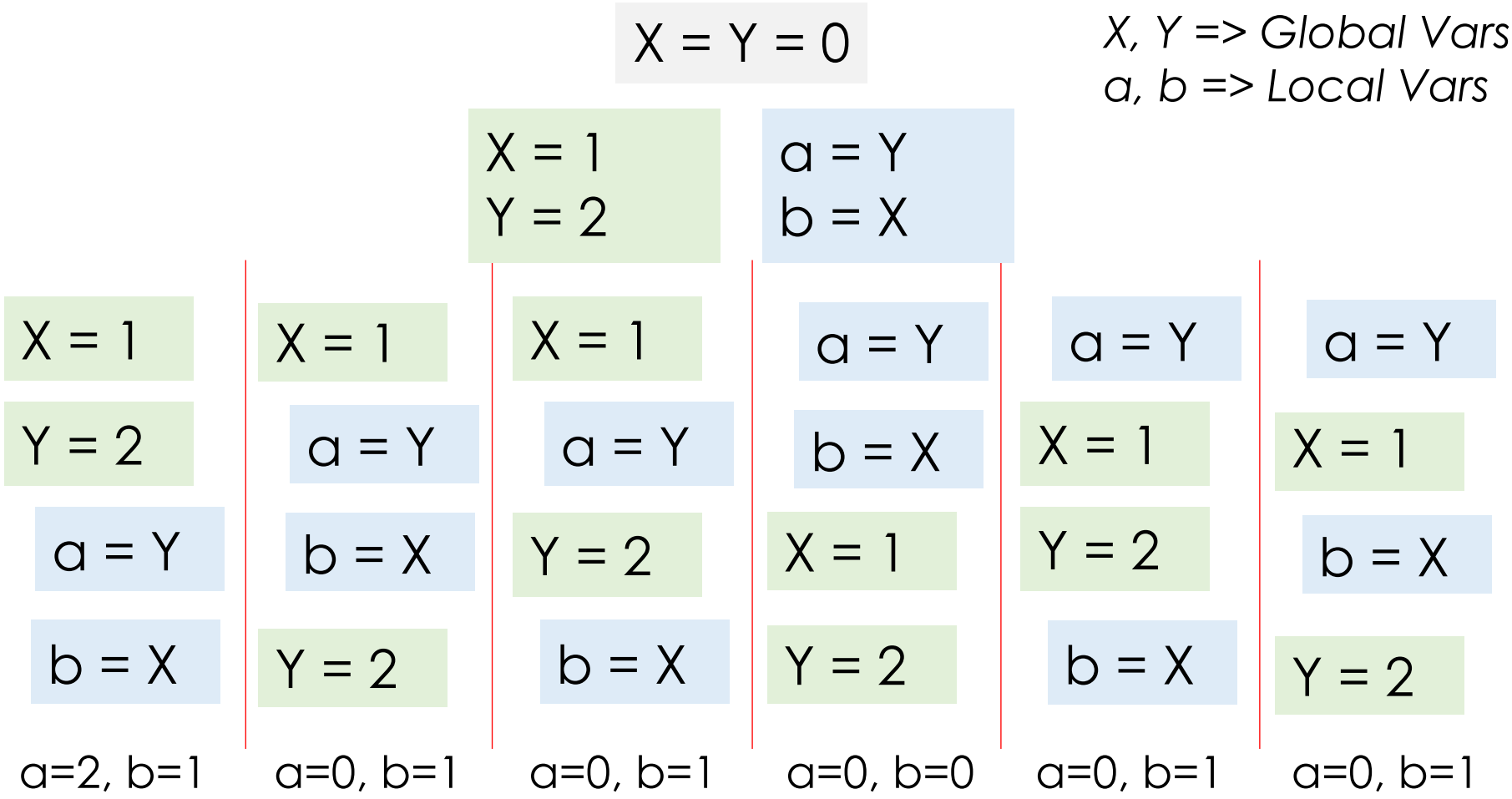
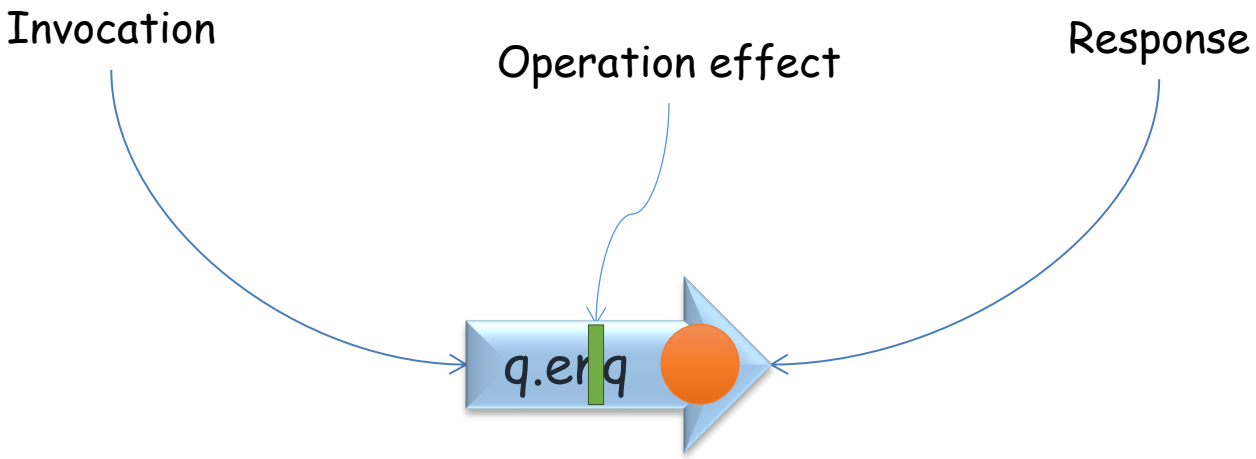


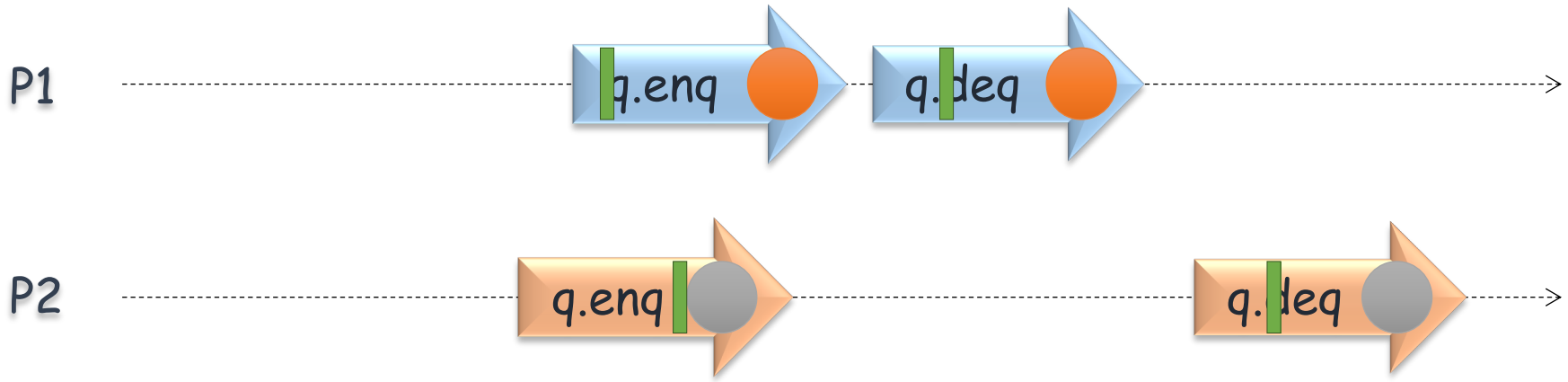
Sequential Consistency and Linearizability

- Each operation should appear to "take effect" instantaneously at some moment between its invocation and response



Sequential Consistency and Linearizability

- Each operation should appear to "take effect" instantaneously at some moment between its invocation and response
- Object is correct if its behaviour can be explained by a sequential execution of the (concurrent) operations



Sequential Consistency

- Instructions are executed by the order they appear in the program
- Memory behaves as a shared array
  - Reads and writes are effective immediately

- Be aware that:
  - This is naturally true for sequential programs…
  - But it is not true for concurrent programs!

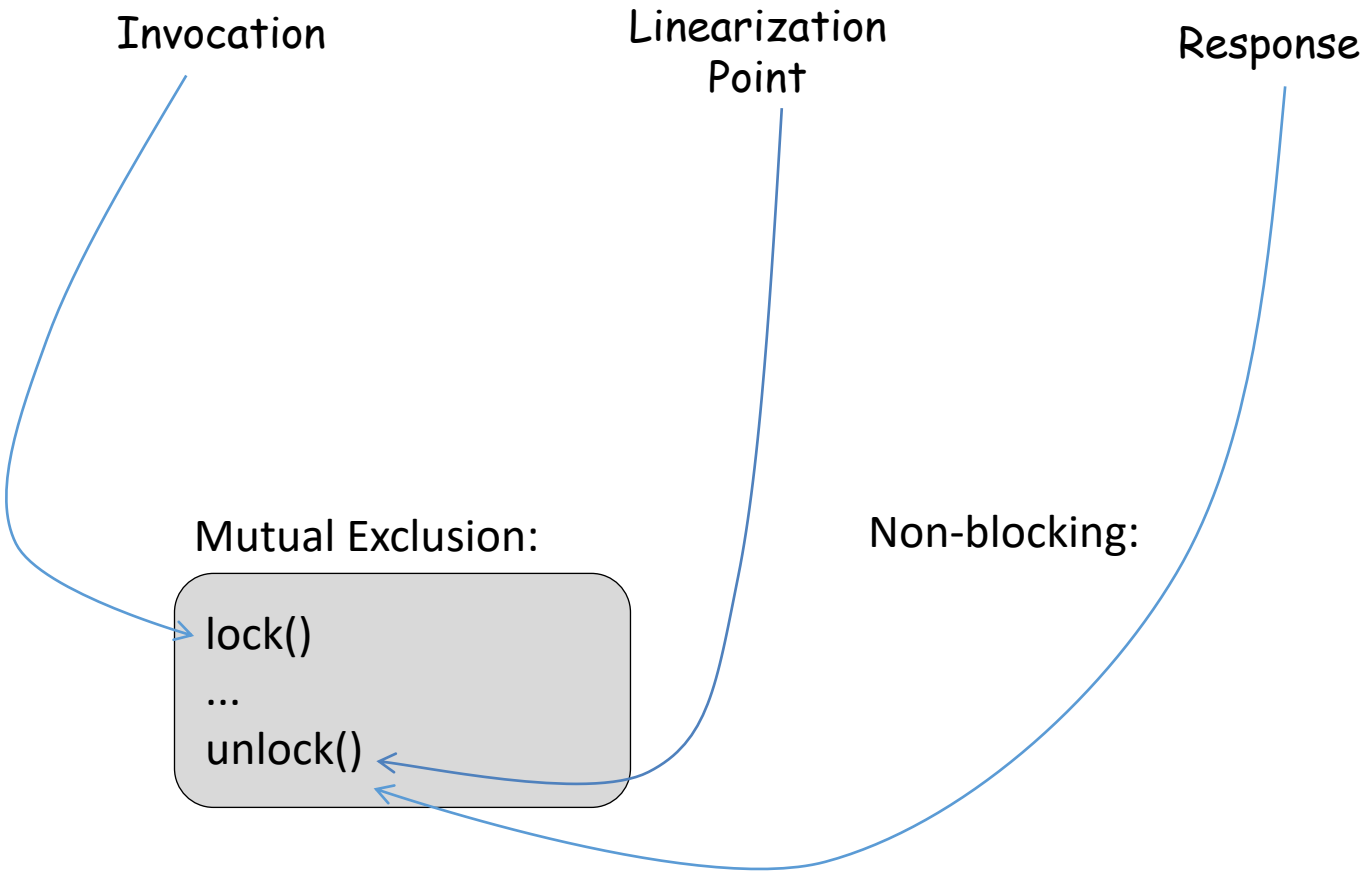
Linearizability

- Instructions are executed by the order they appear in the program
- Memory behaves as a shared array
  - Reads and writes are effective immediately
- Need to preserve real time order
- Be aware that:
  - This is naturally true for sequential programs…
  - But it is not true for concurrent programs!

Linearizability

- Permits programmers to specify and reason about concurrent objects using known techniques from the sequential domain
- Provides the illusion that each operation applied by concurrent processes takes effect instantaneously between its invocation and its response

Terminology



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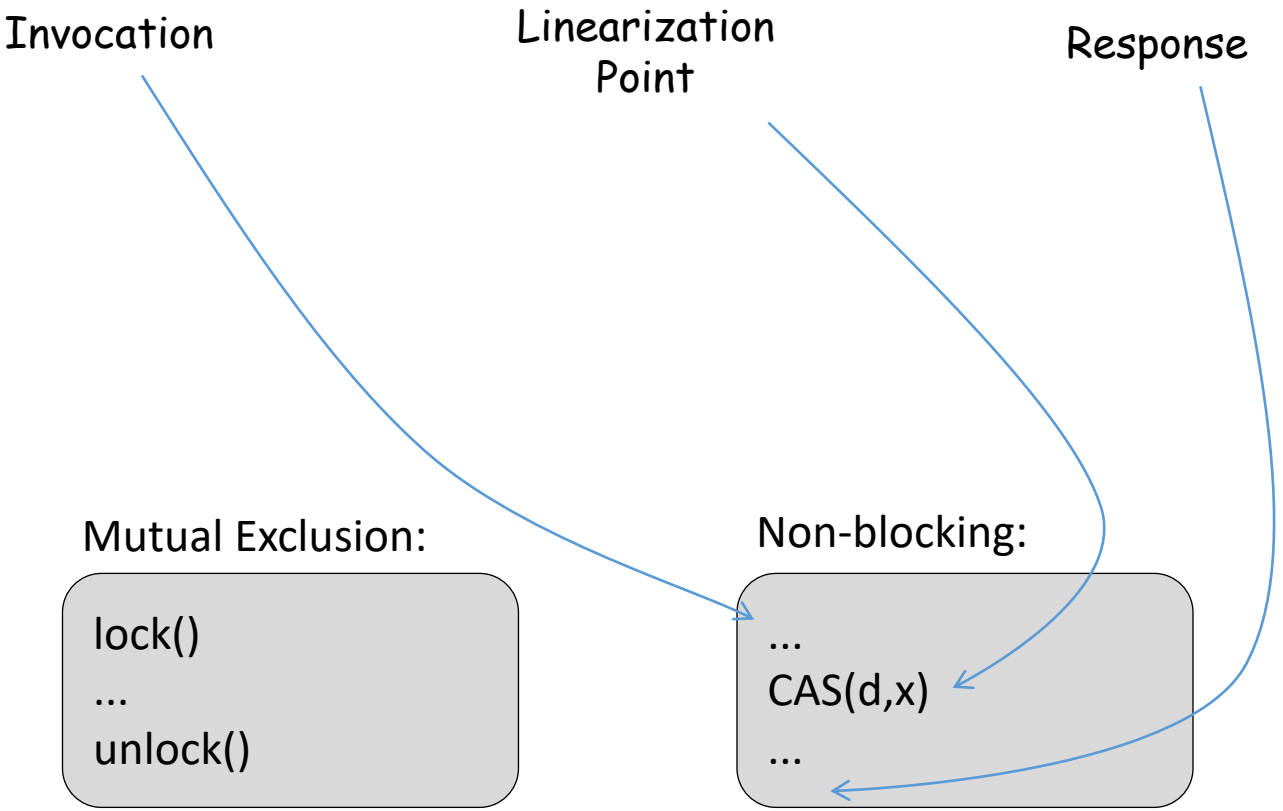
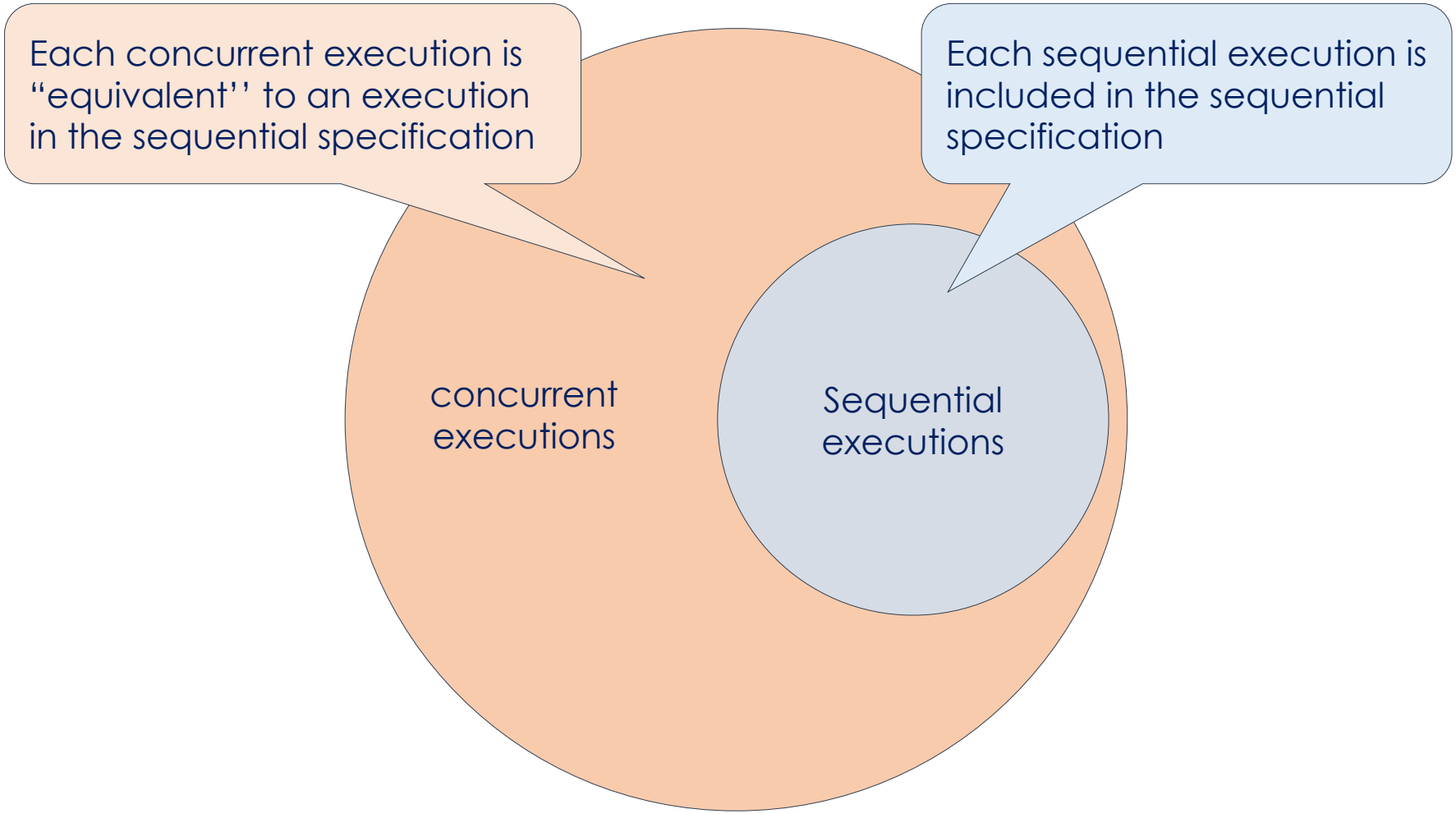


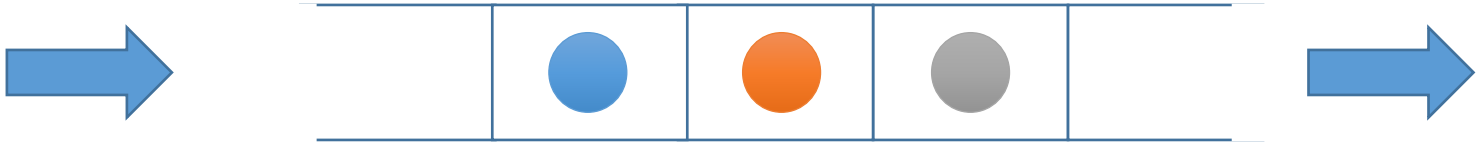
Sequential Specification of an object

- **Queue:** In sequential executions, the enqueue operation inserts a value to the queue and the dequeue operation returns and deletes the oldest value in the queue

Linearizability for an object



Example: Concurrent Queue

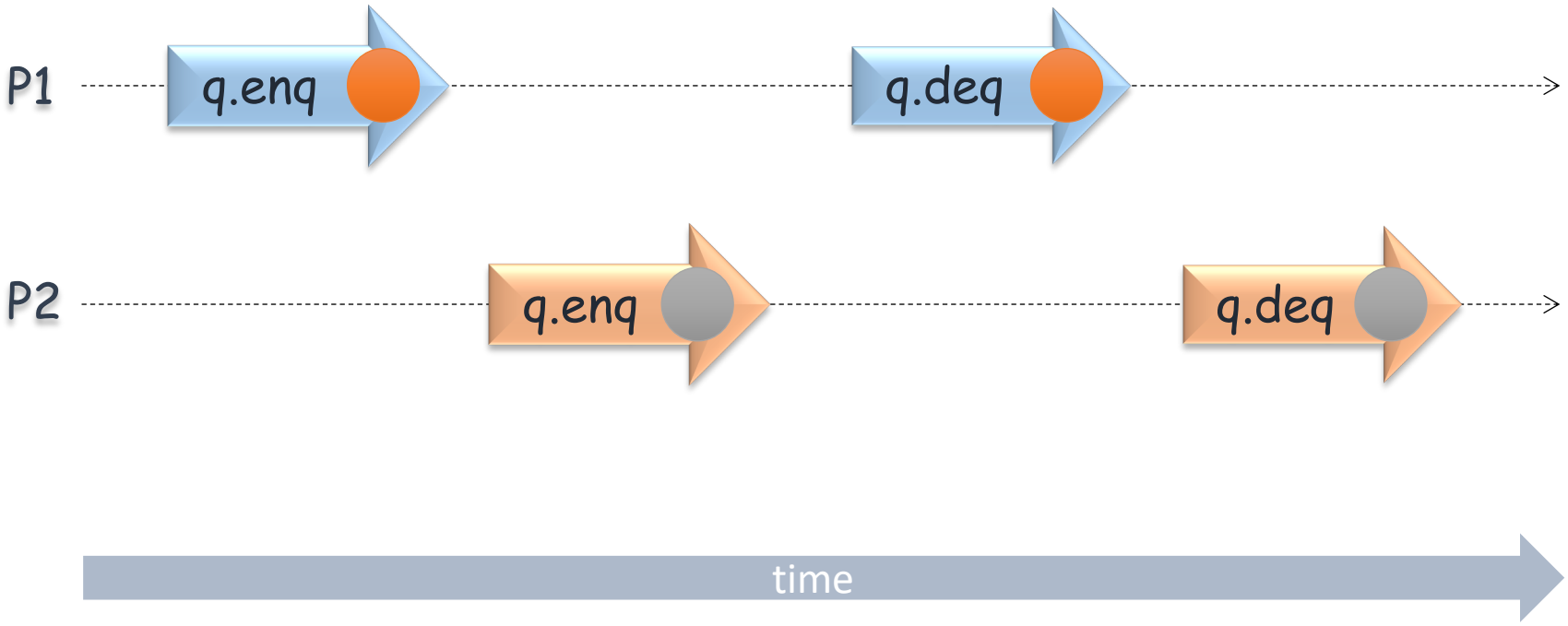


q.enq( )

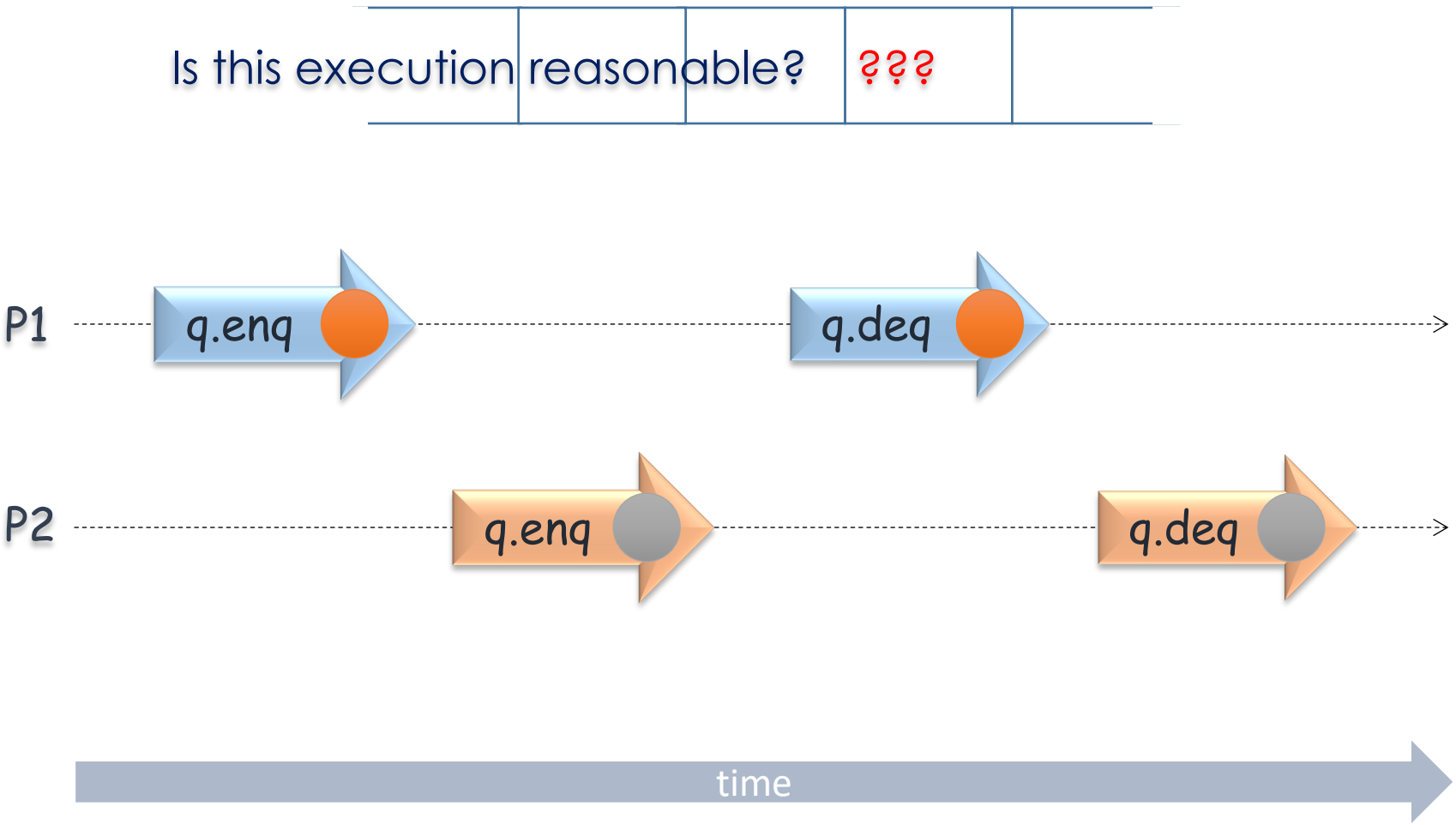
q.deq( )

Sequential Execution

Is this execution reasonable? Yes



Concurrent Execution



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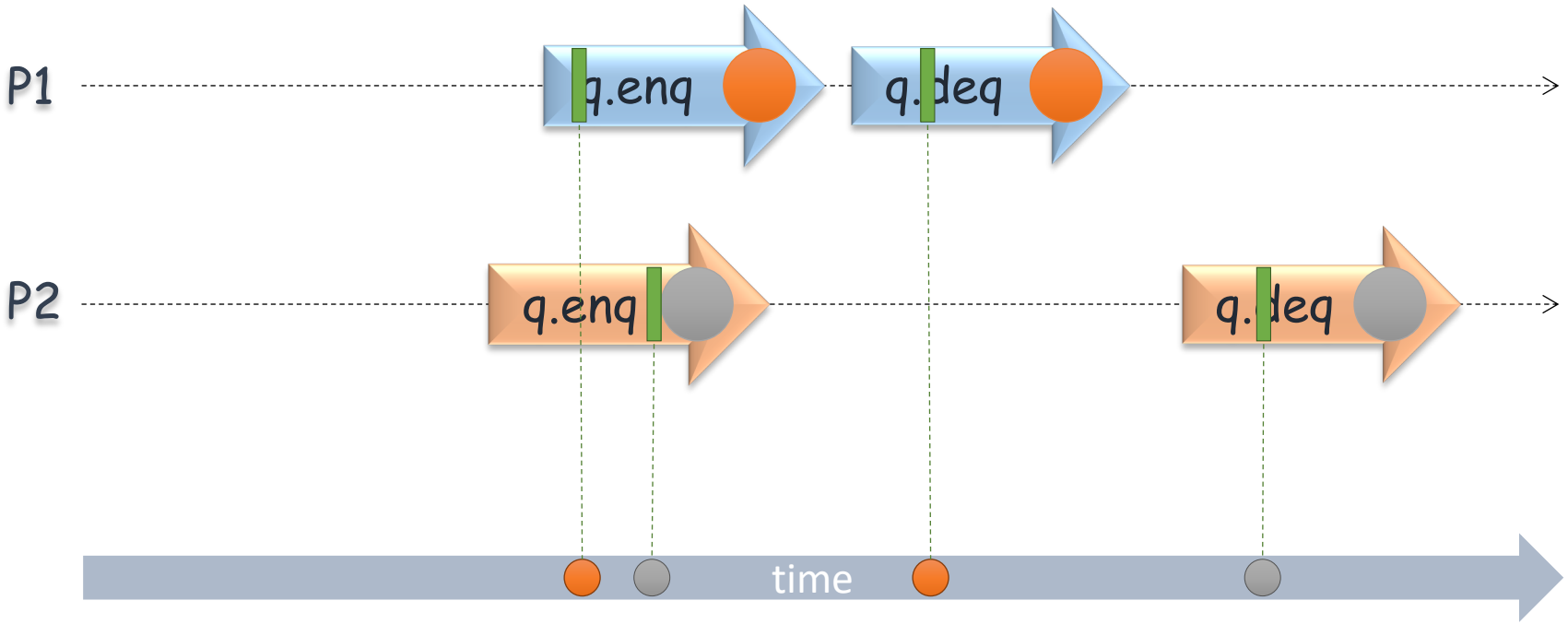

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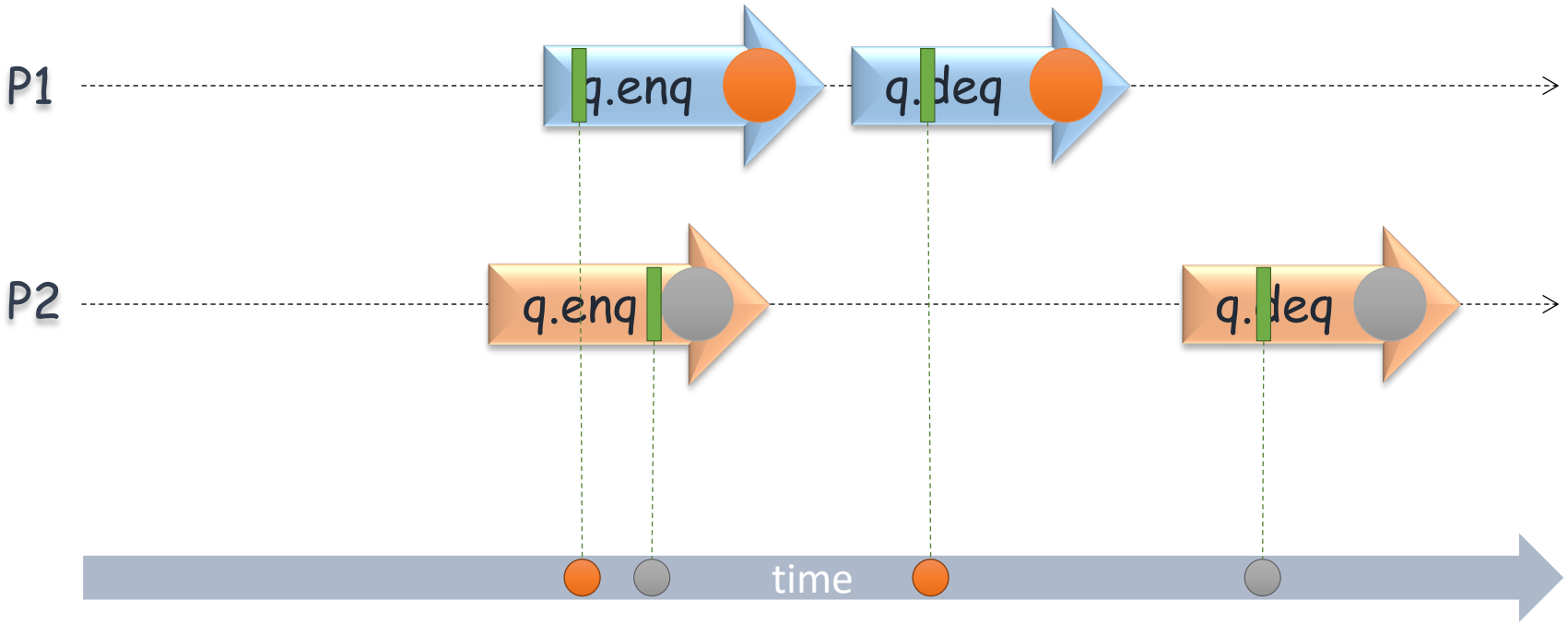

Linearizability

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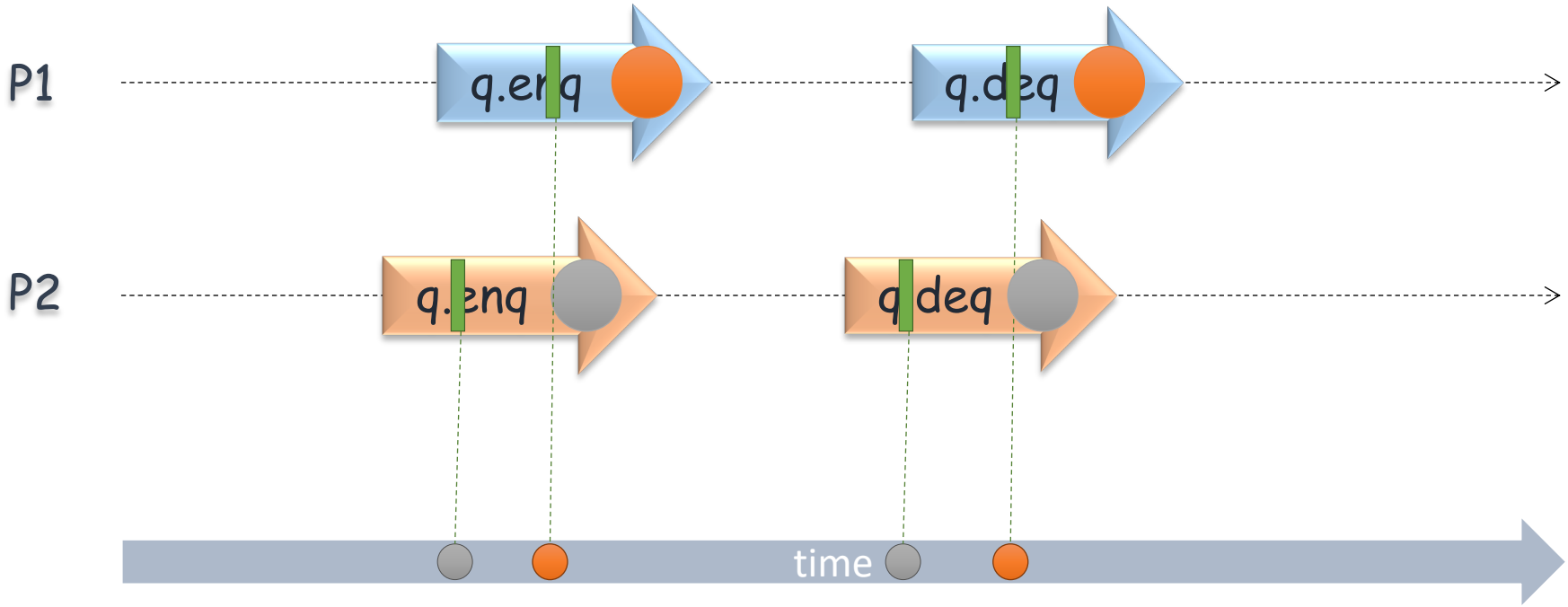

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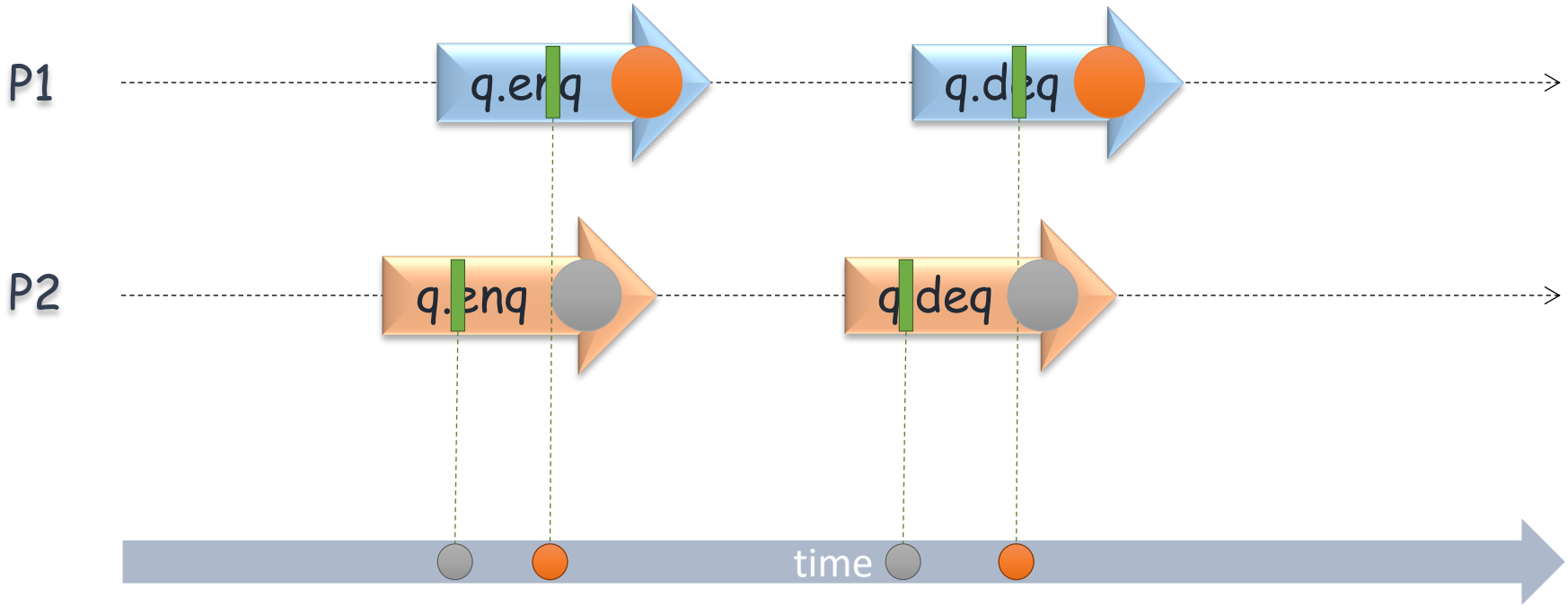
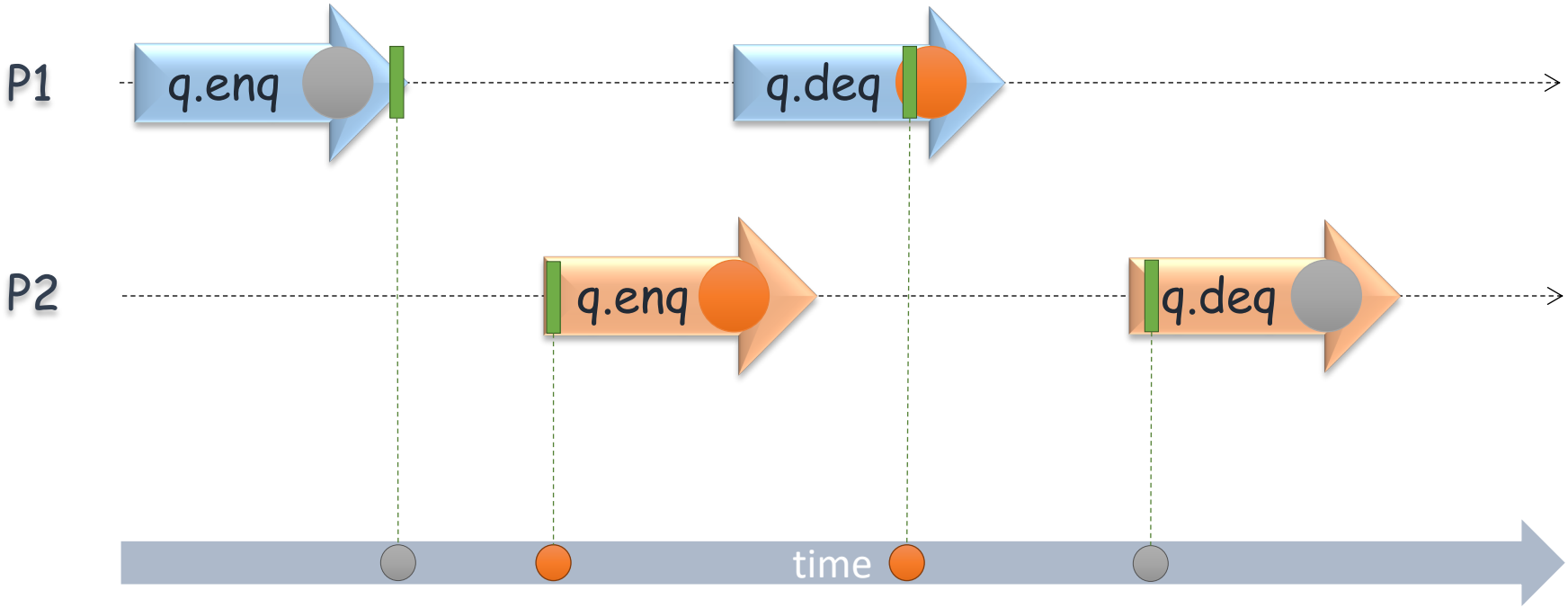


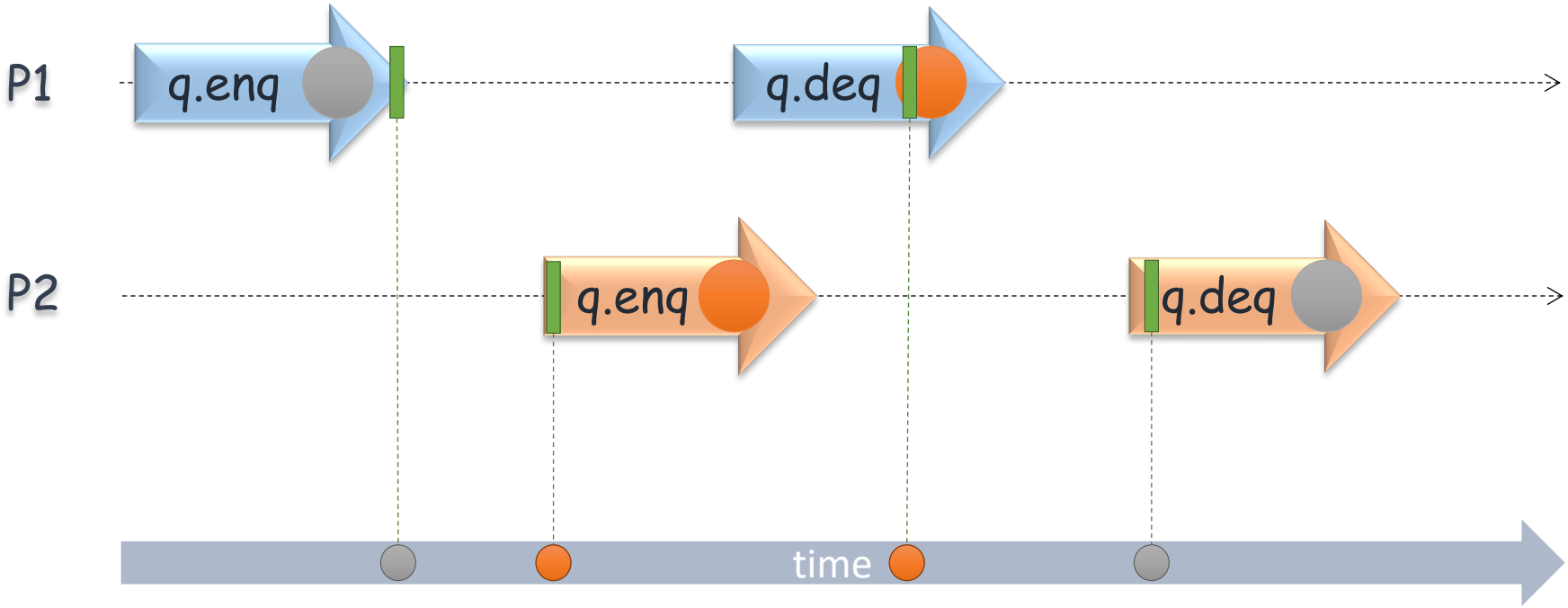
Linearizability

Is this execution **linearizable**? No, BUT …



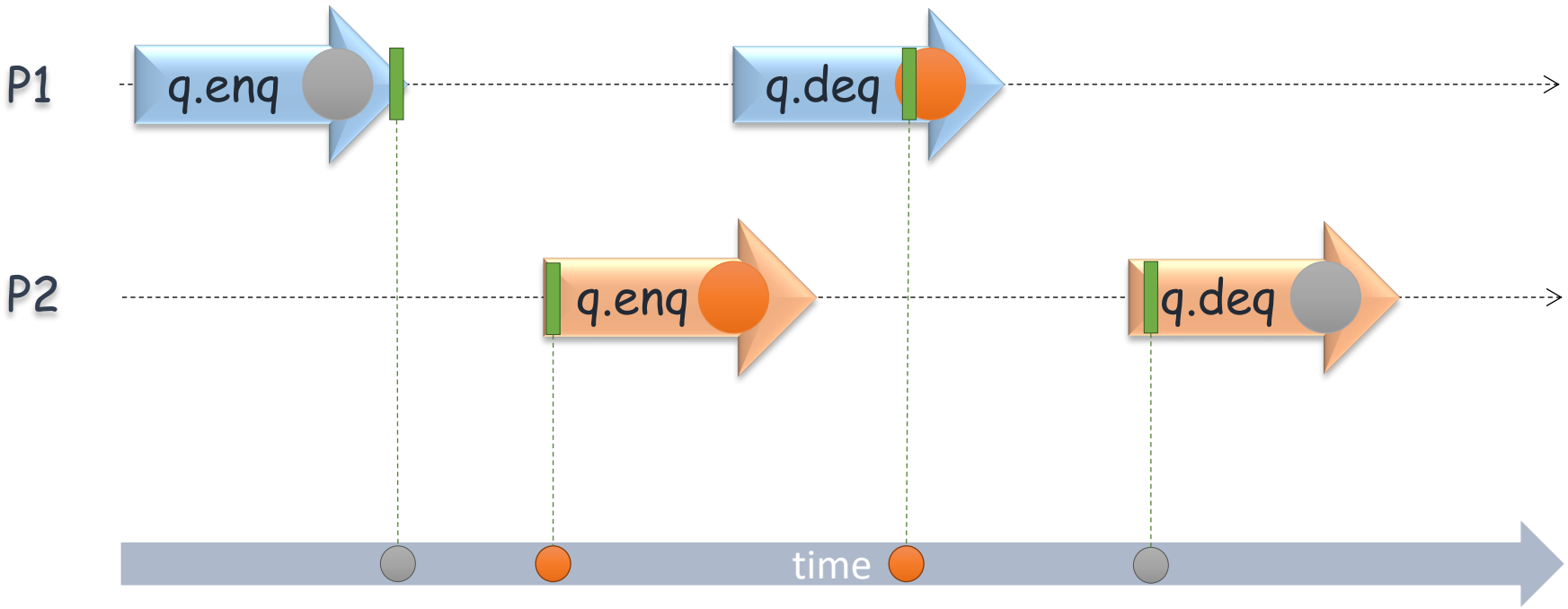
Linearizability

Is this execution **linearizable**? No, BUT …



~~Linearizability~~ Sequential Consistency

Is this execution **linearizable**? No, BUT …

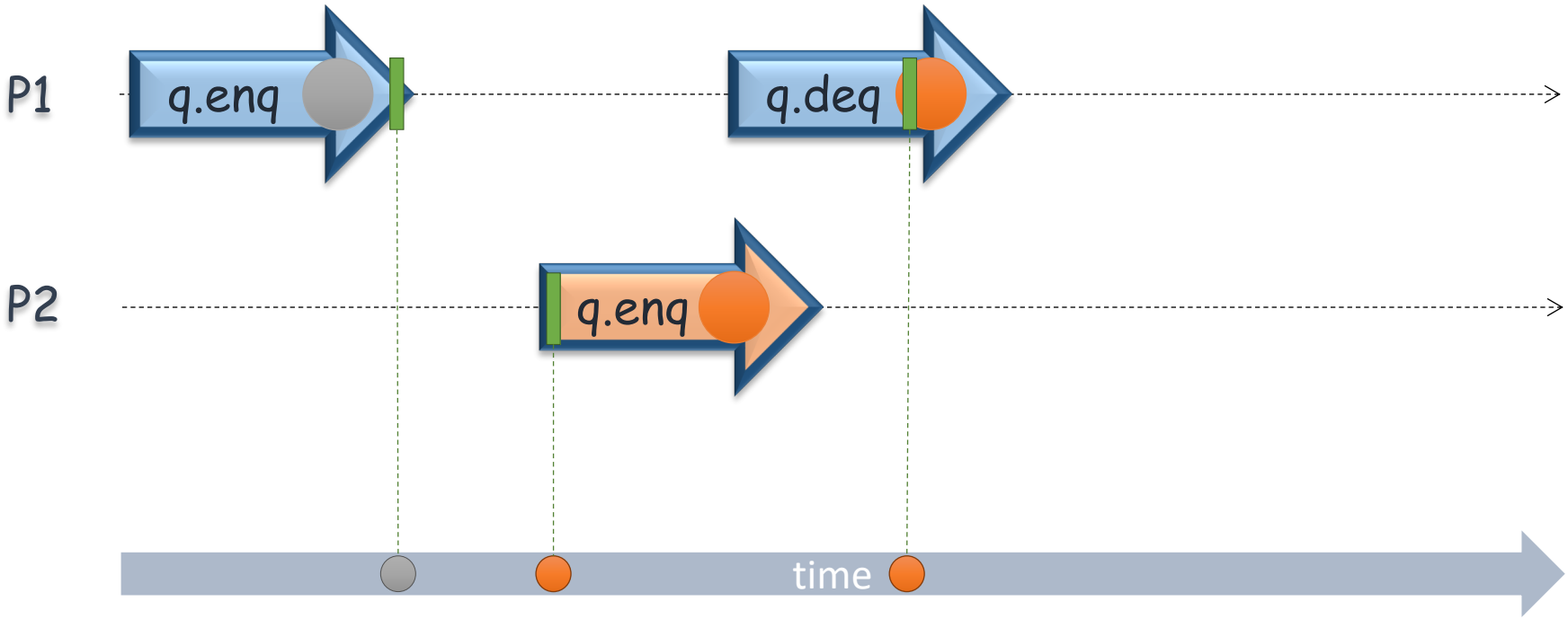


Sequential Consistency

- No need to preserve real time order
  - Operations can "slide" within the same thread but not be reordered
  - Parallel operations can be reordered as convenient
- Each operation should "take effect" instantaneously
- The result of the concurrent execution of a program P must be equivalent to some sequential execution of the same program P

Sequential Consistency

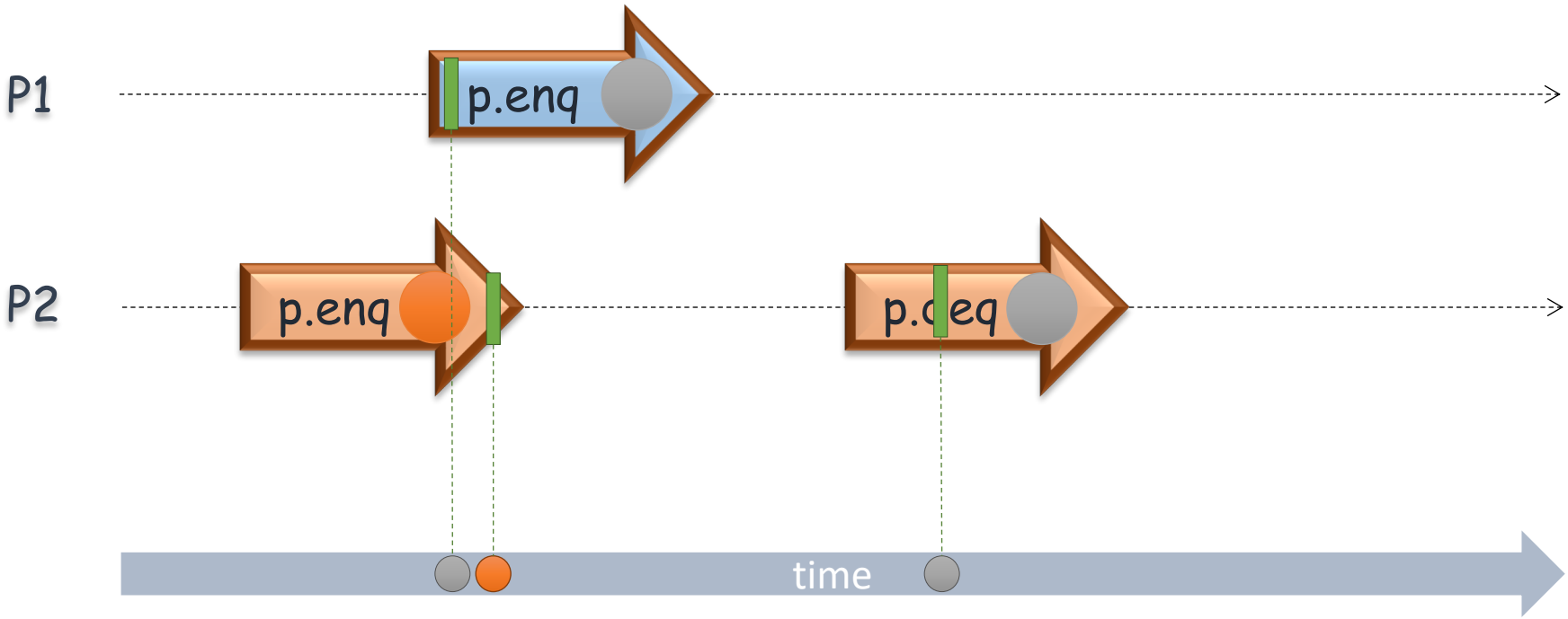
Is this execution sequentially consistent? Yes



Sequential Consistency

Is this execution sequentially consistent? Yes

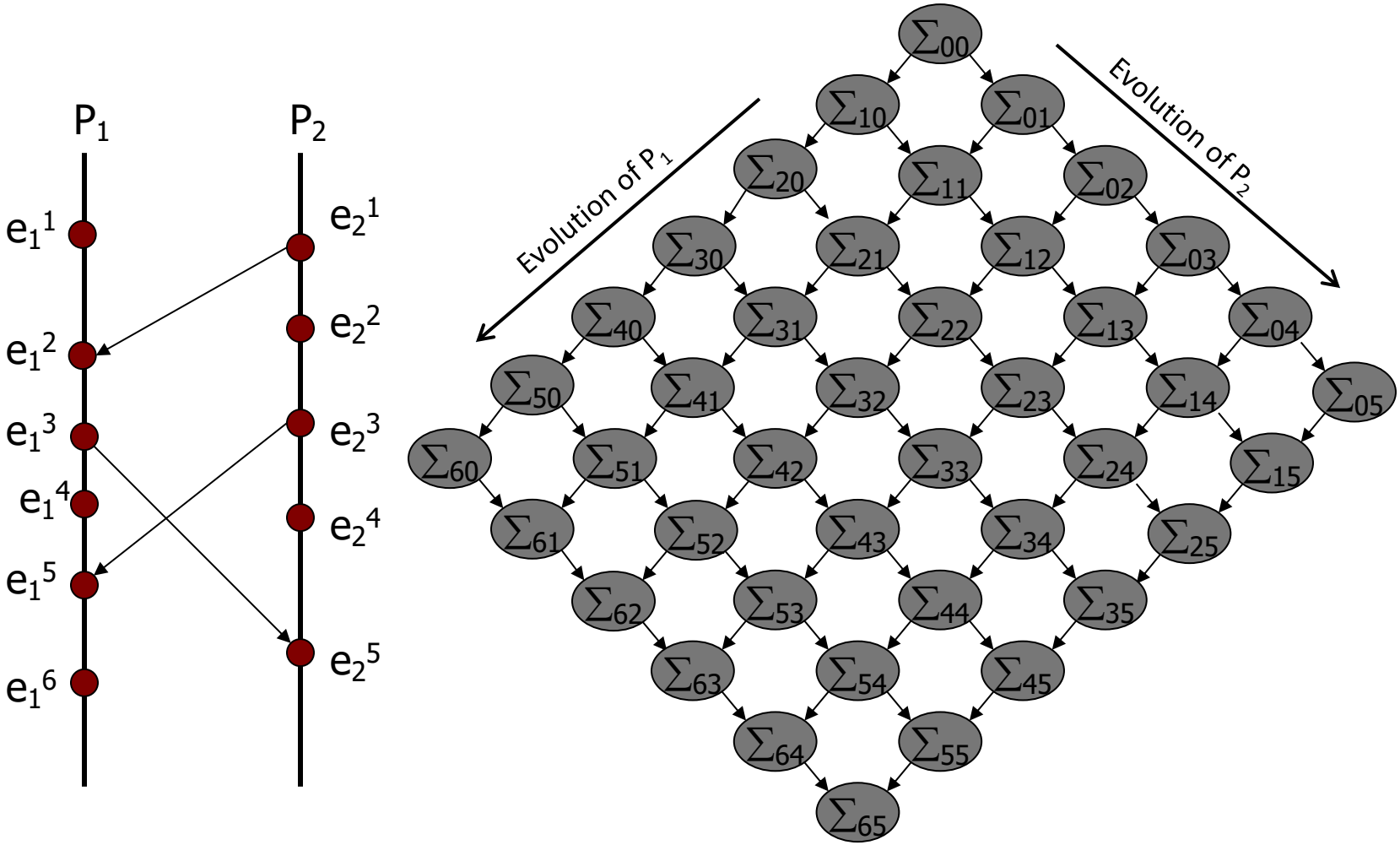
It is also linearizable!



Program State and Runs

- Program state as a N-dimensional lattice
- Runs
  - Consistent
  - Inconsistent

State explosion in concurrent programs



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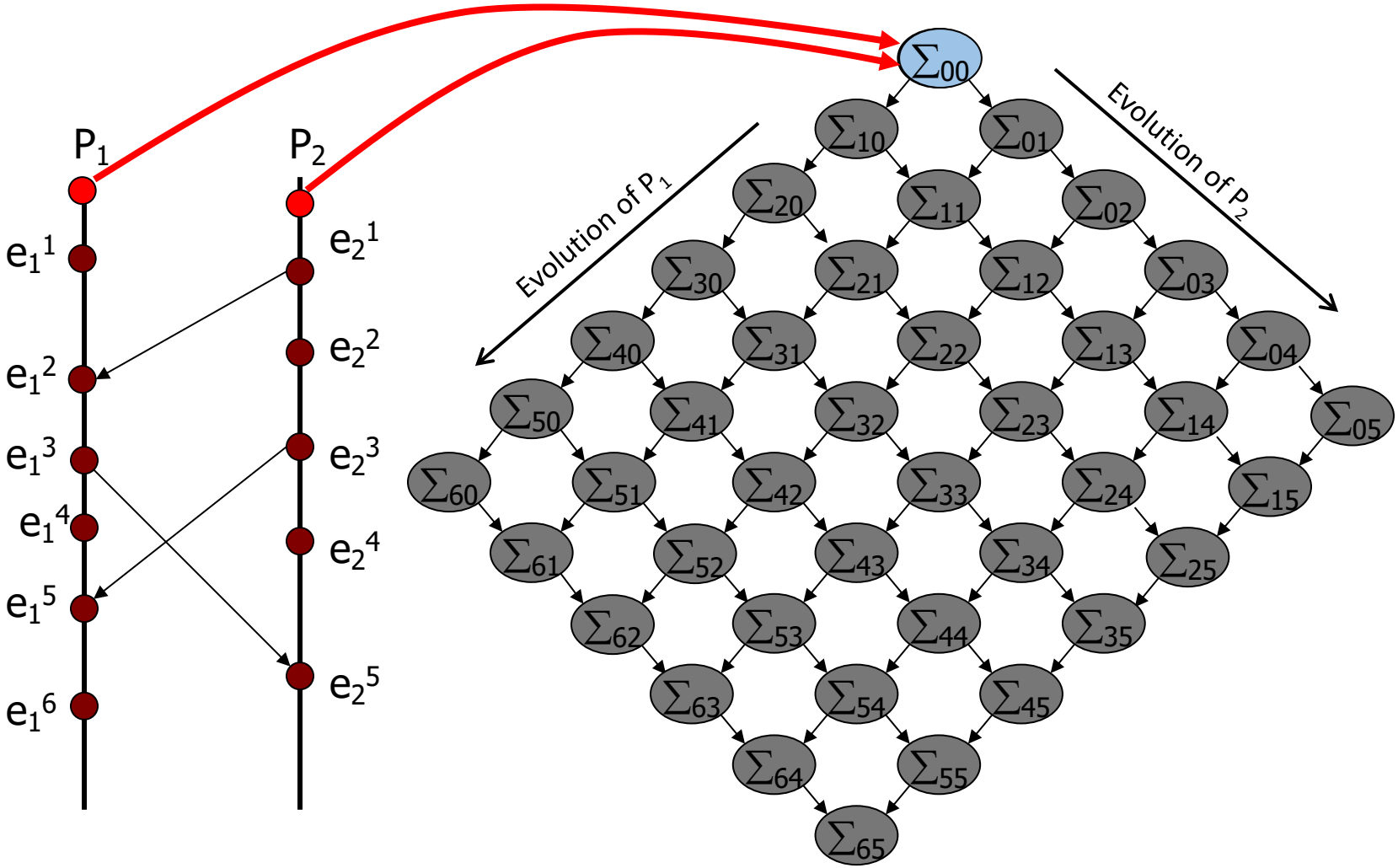

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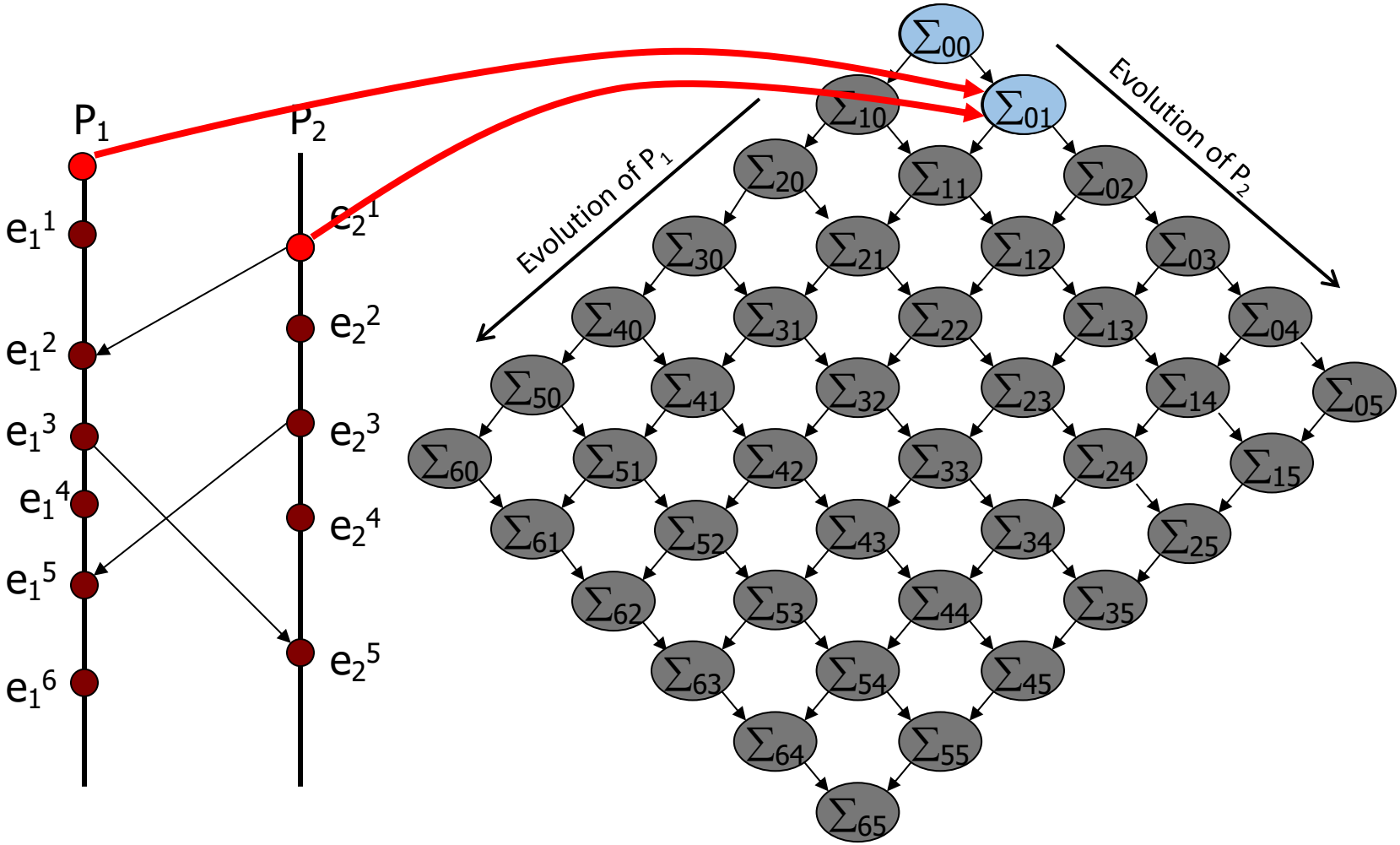

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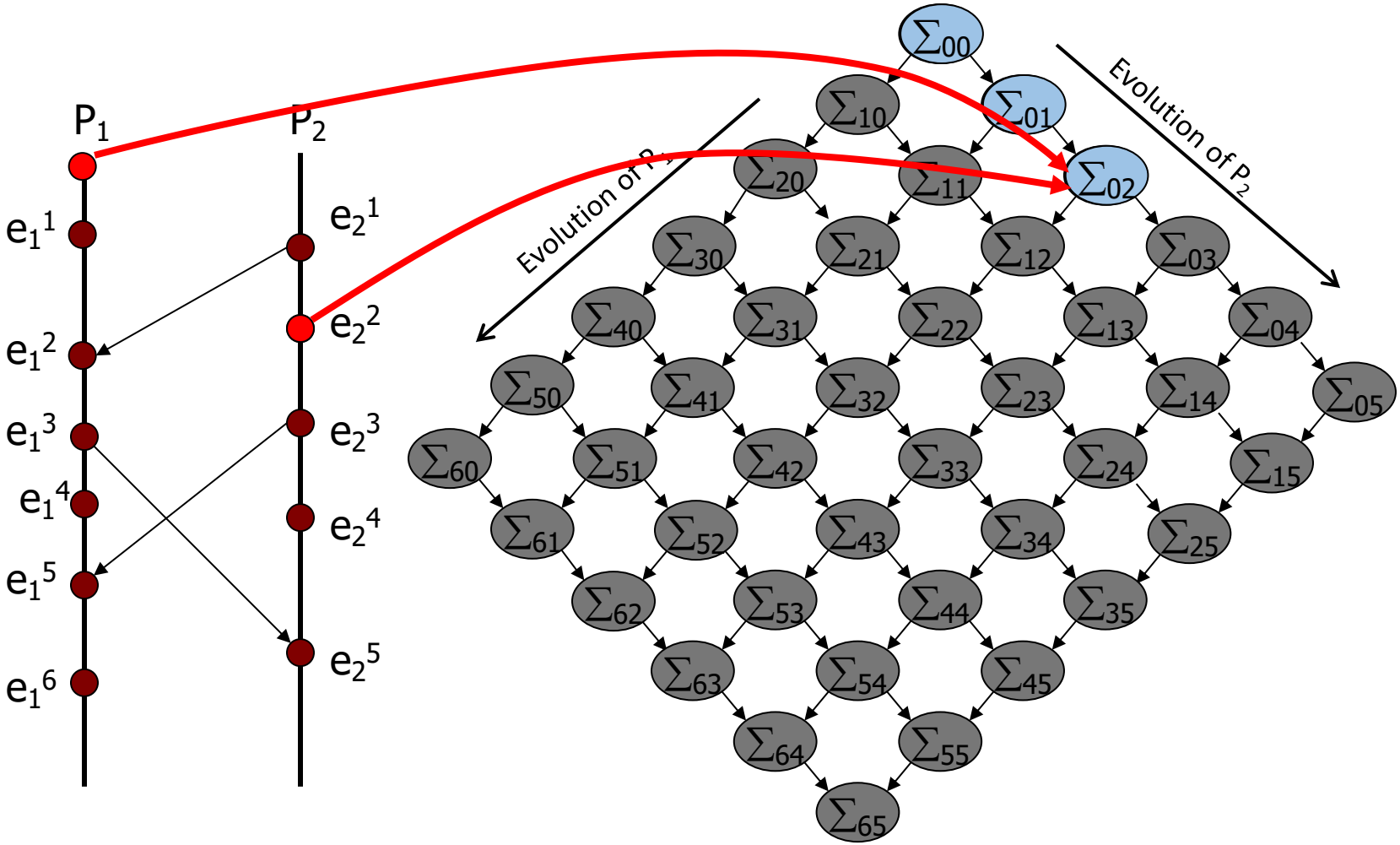

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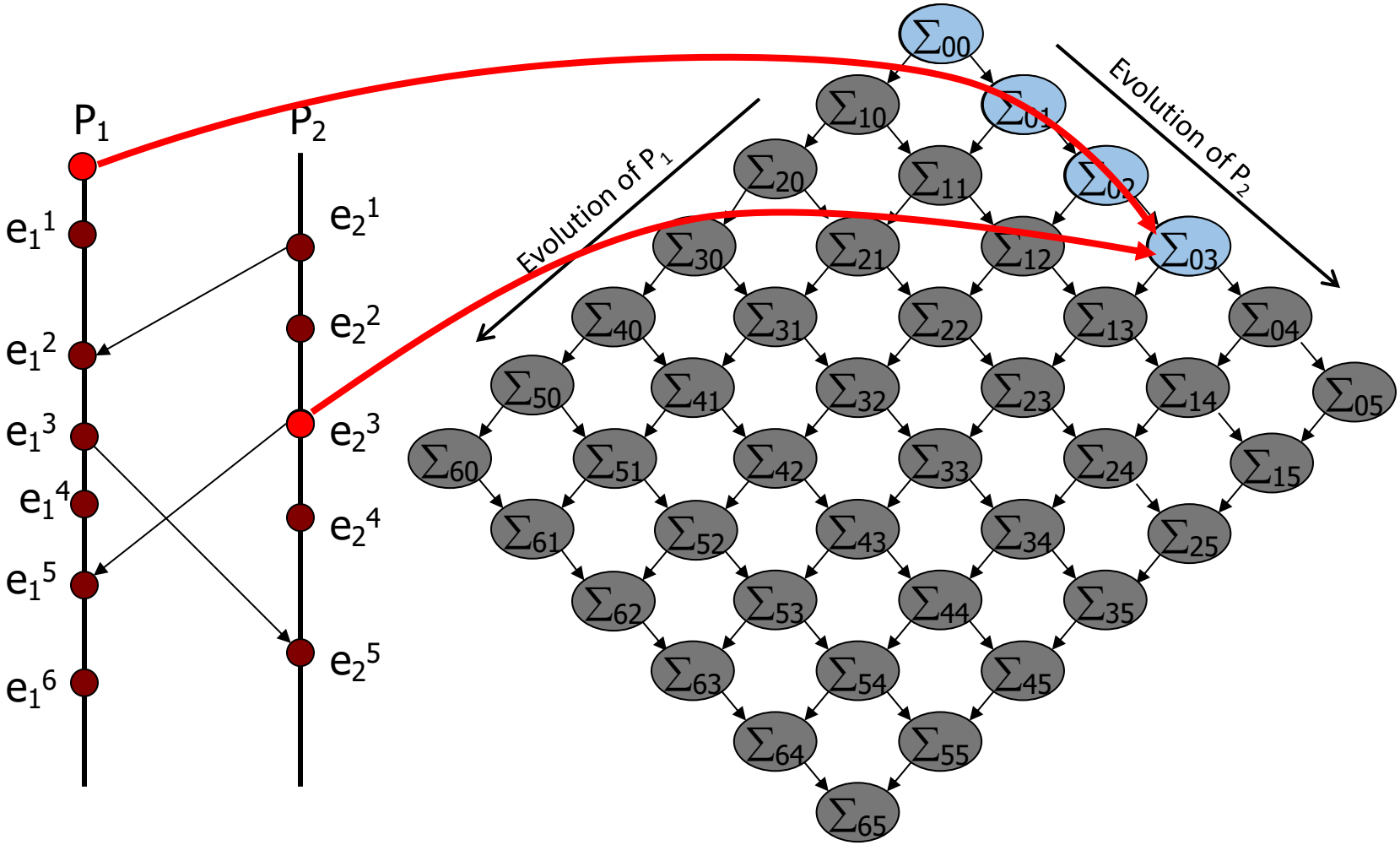

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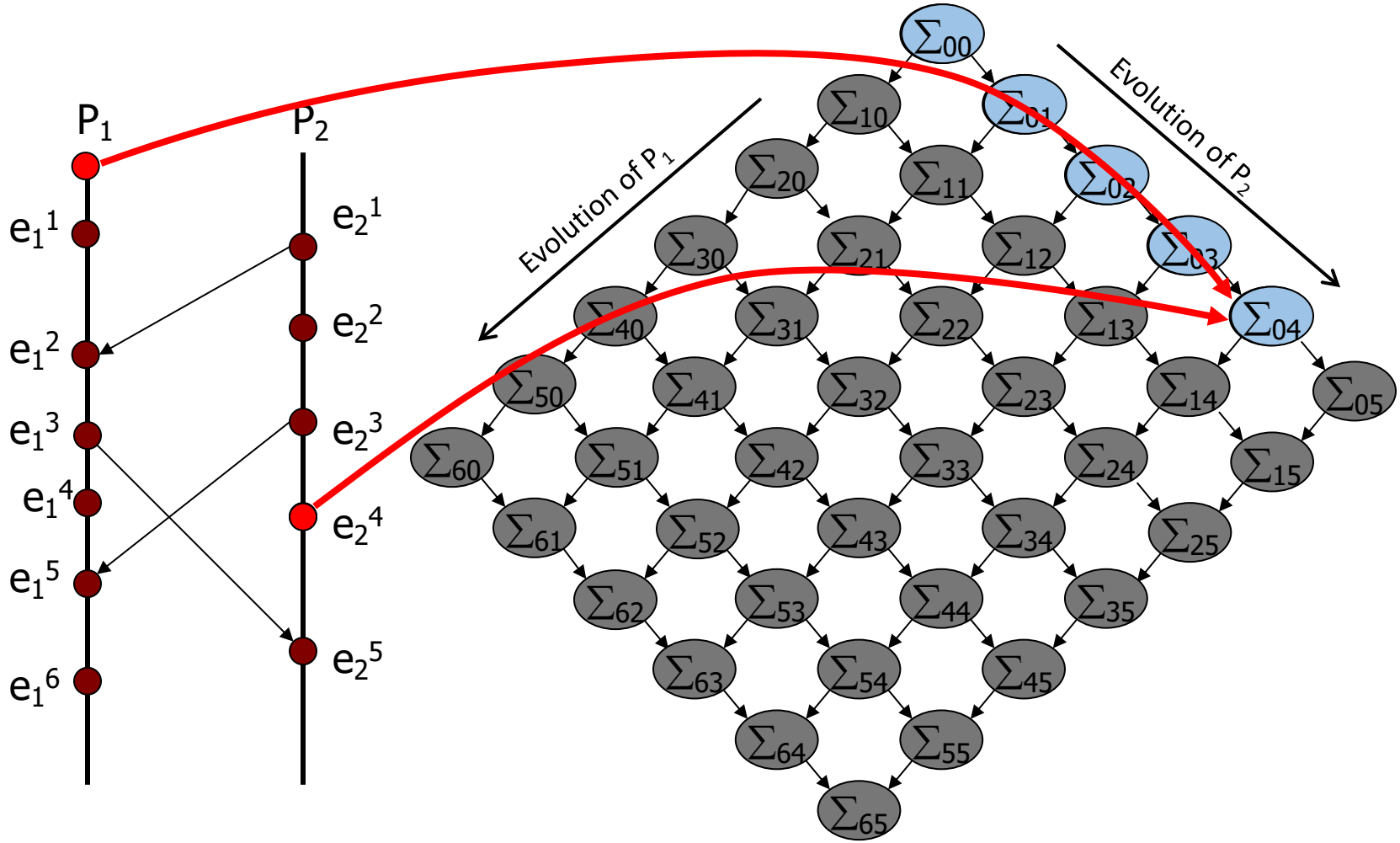

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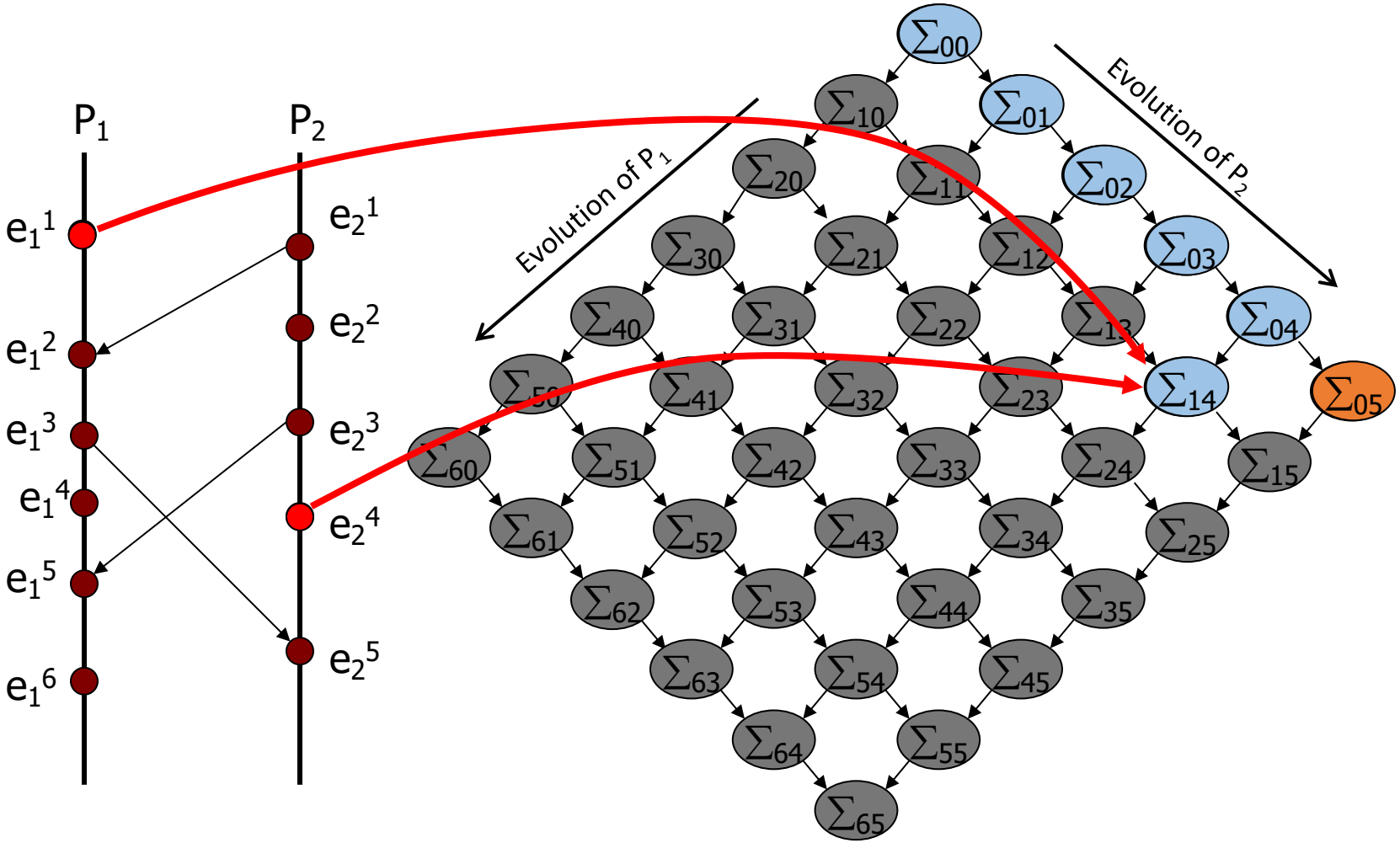

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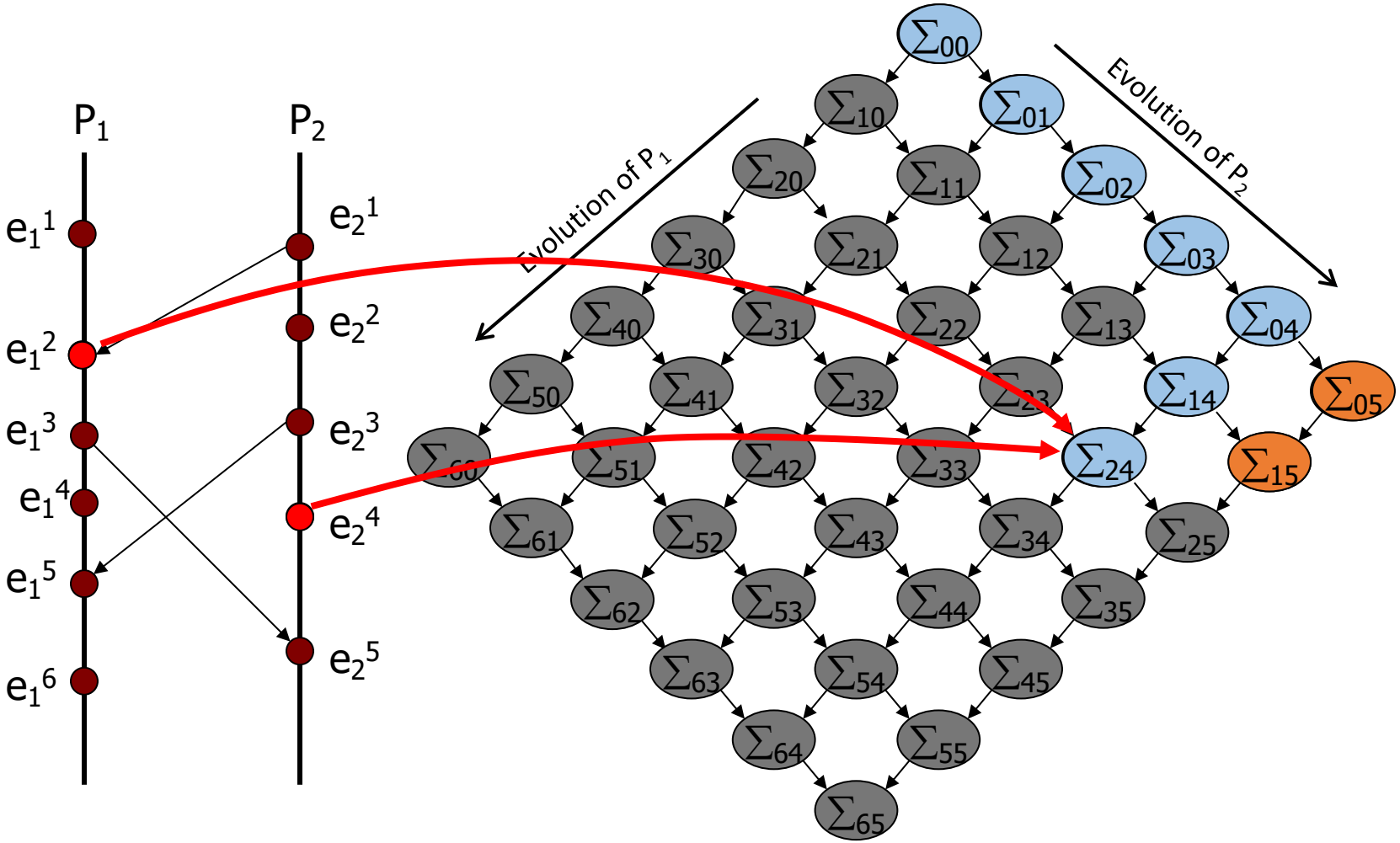

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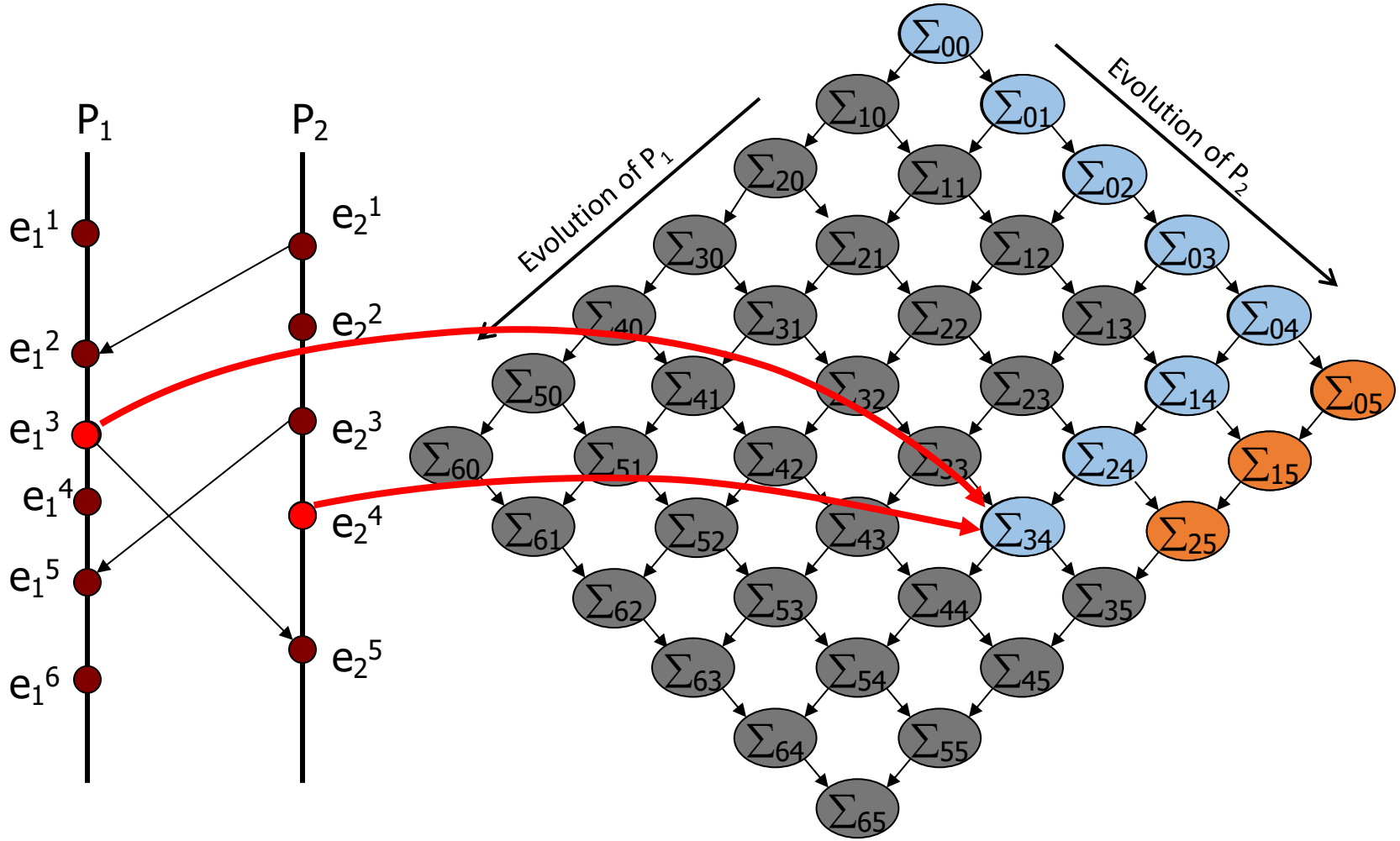

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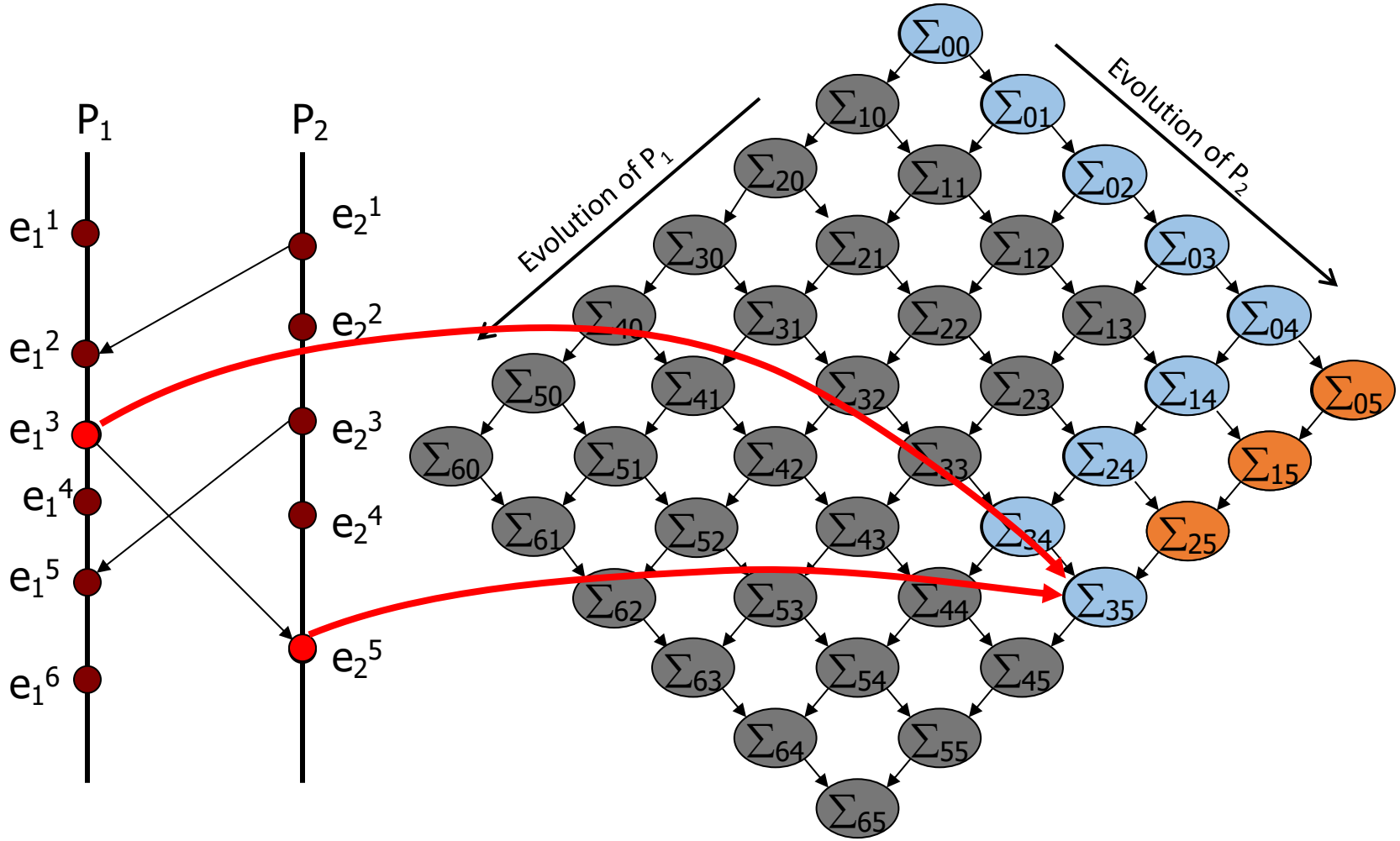

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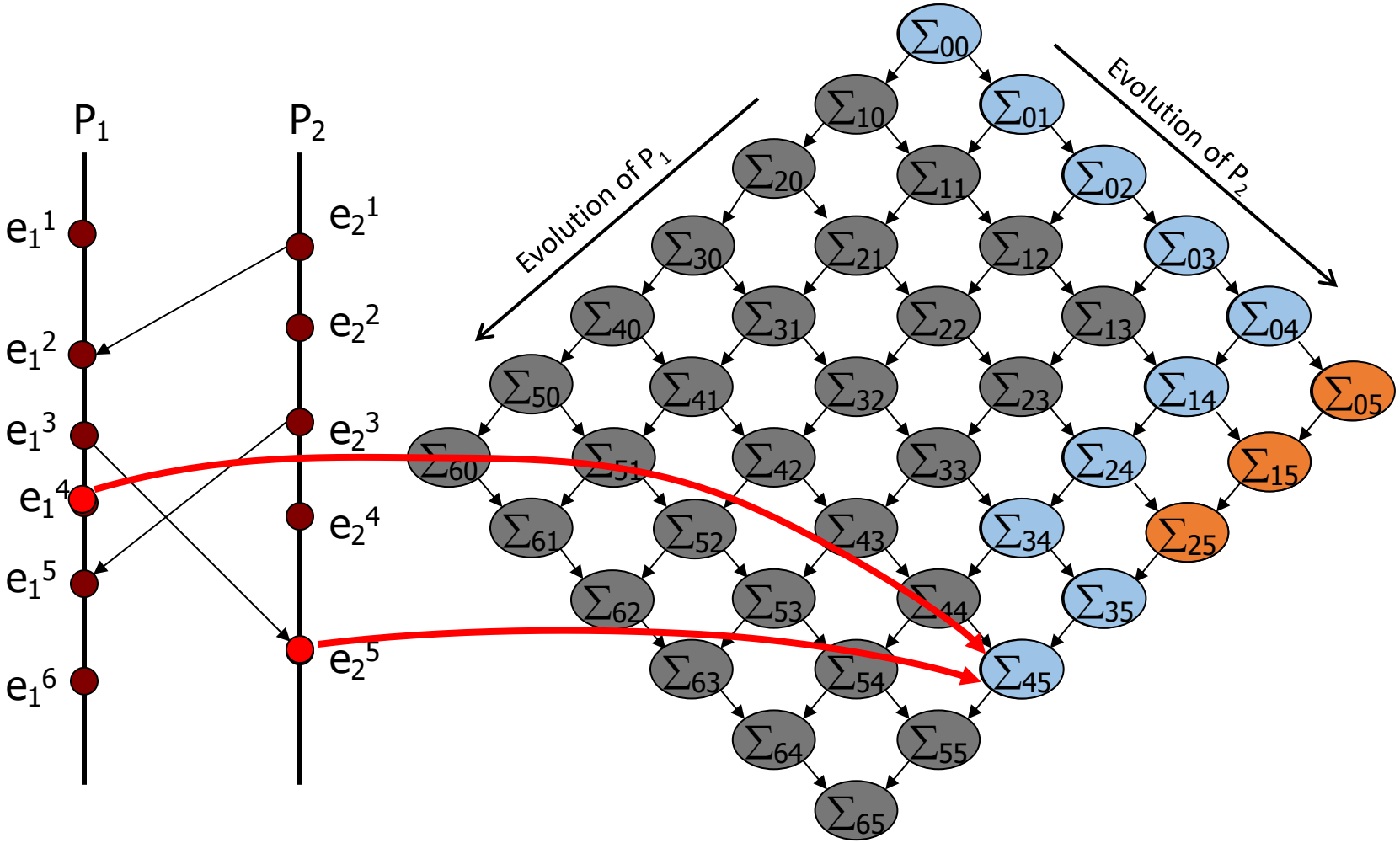

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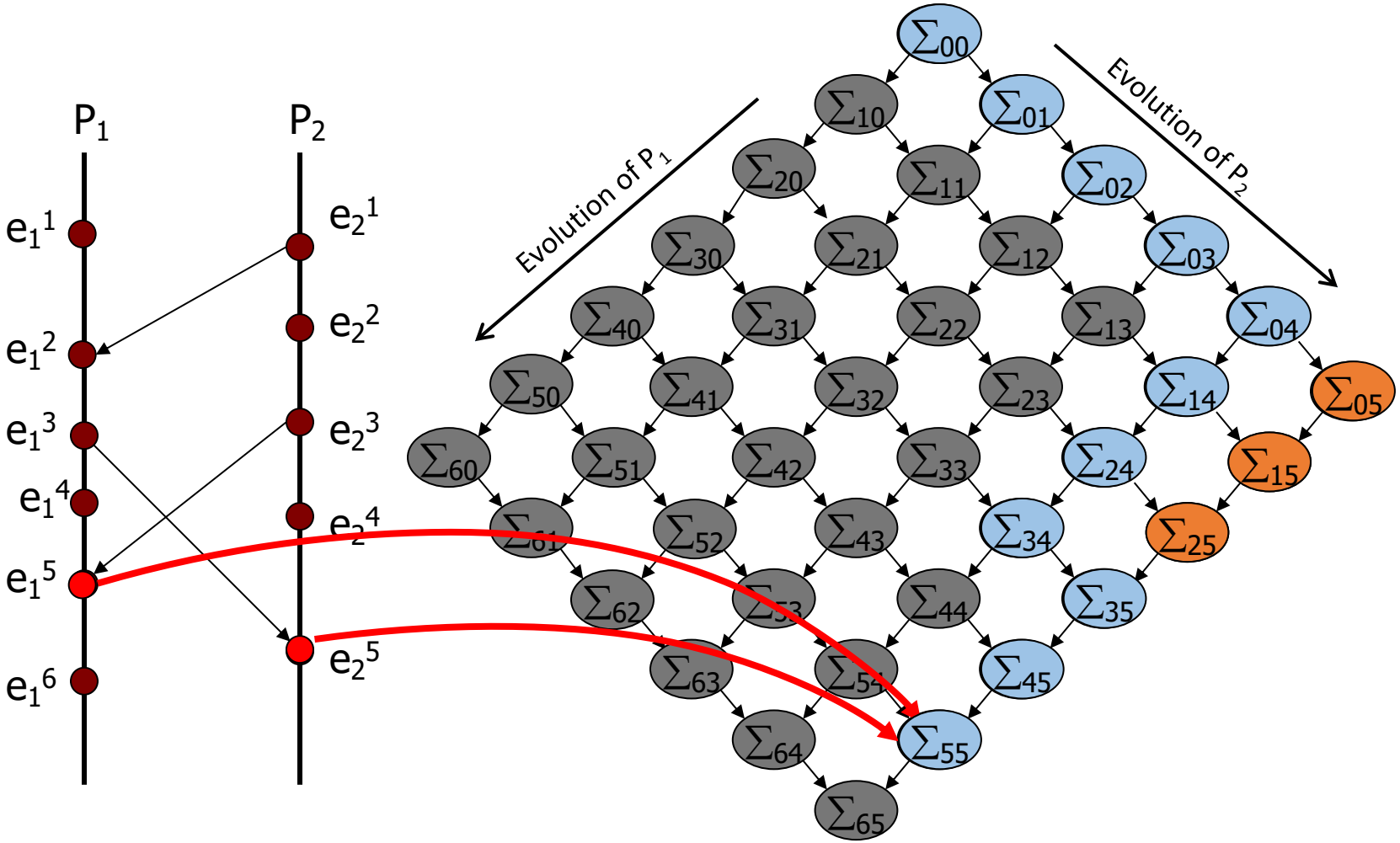

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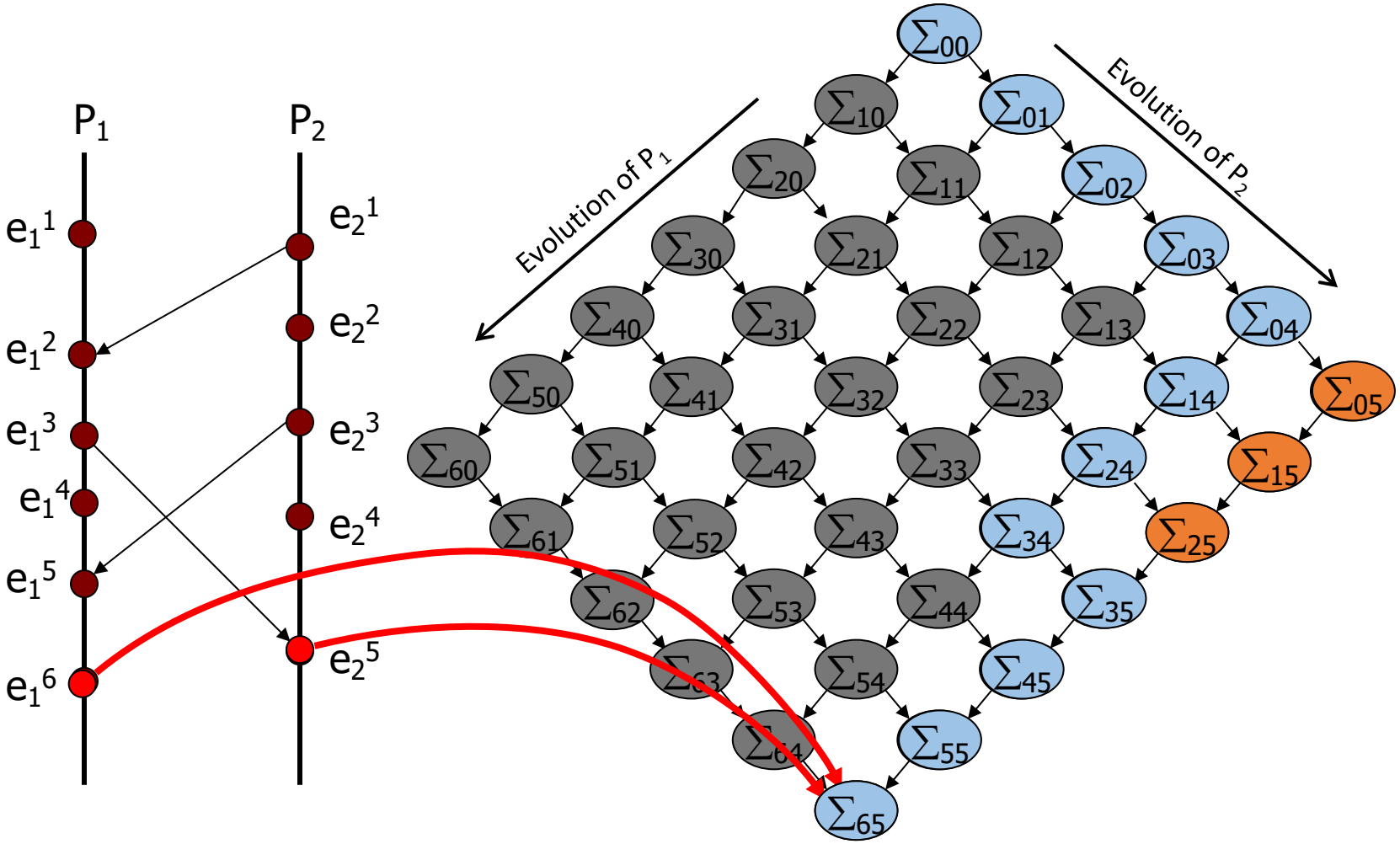

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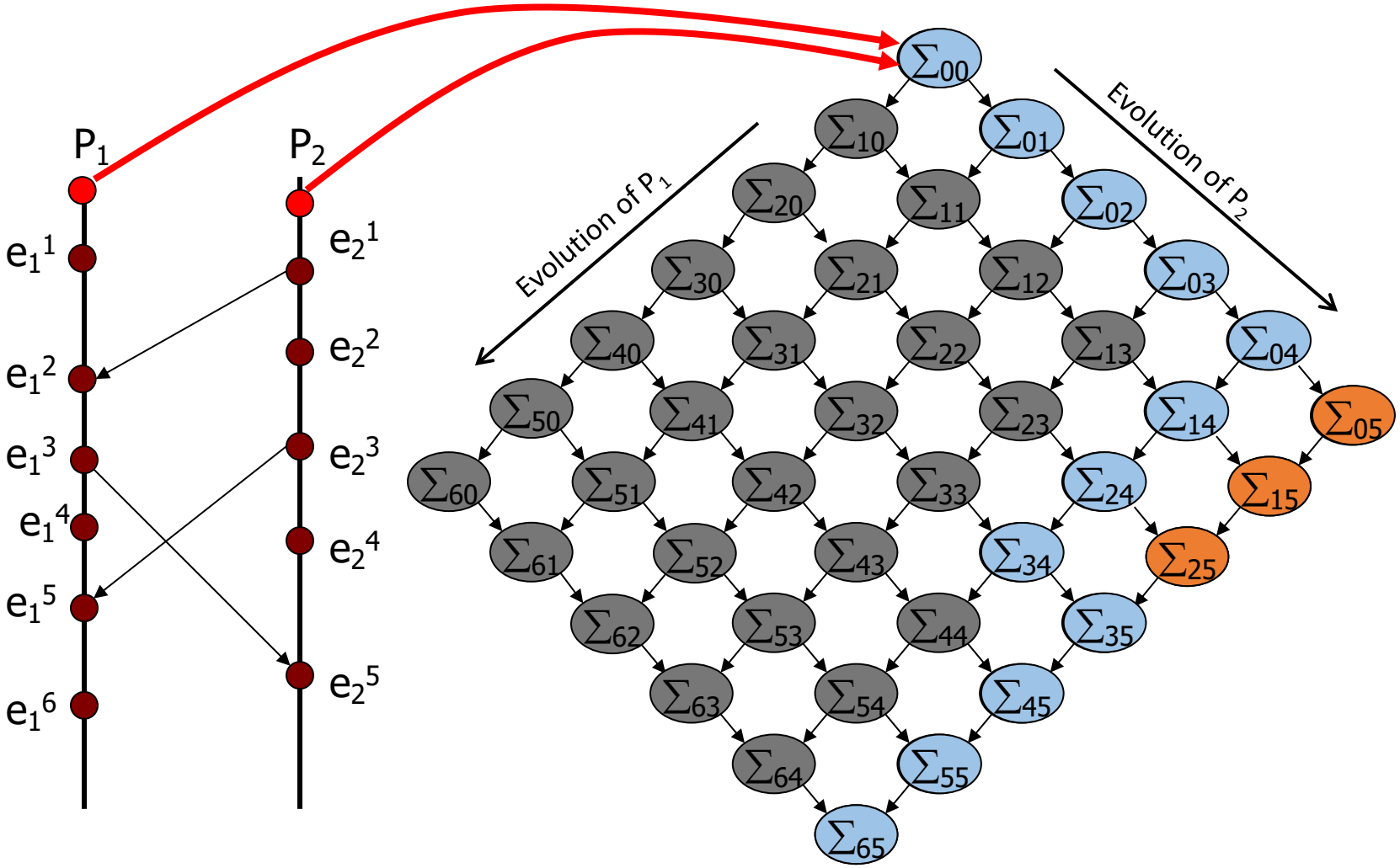

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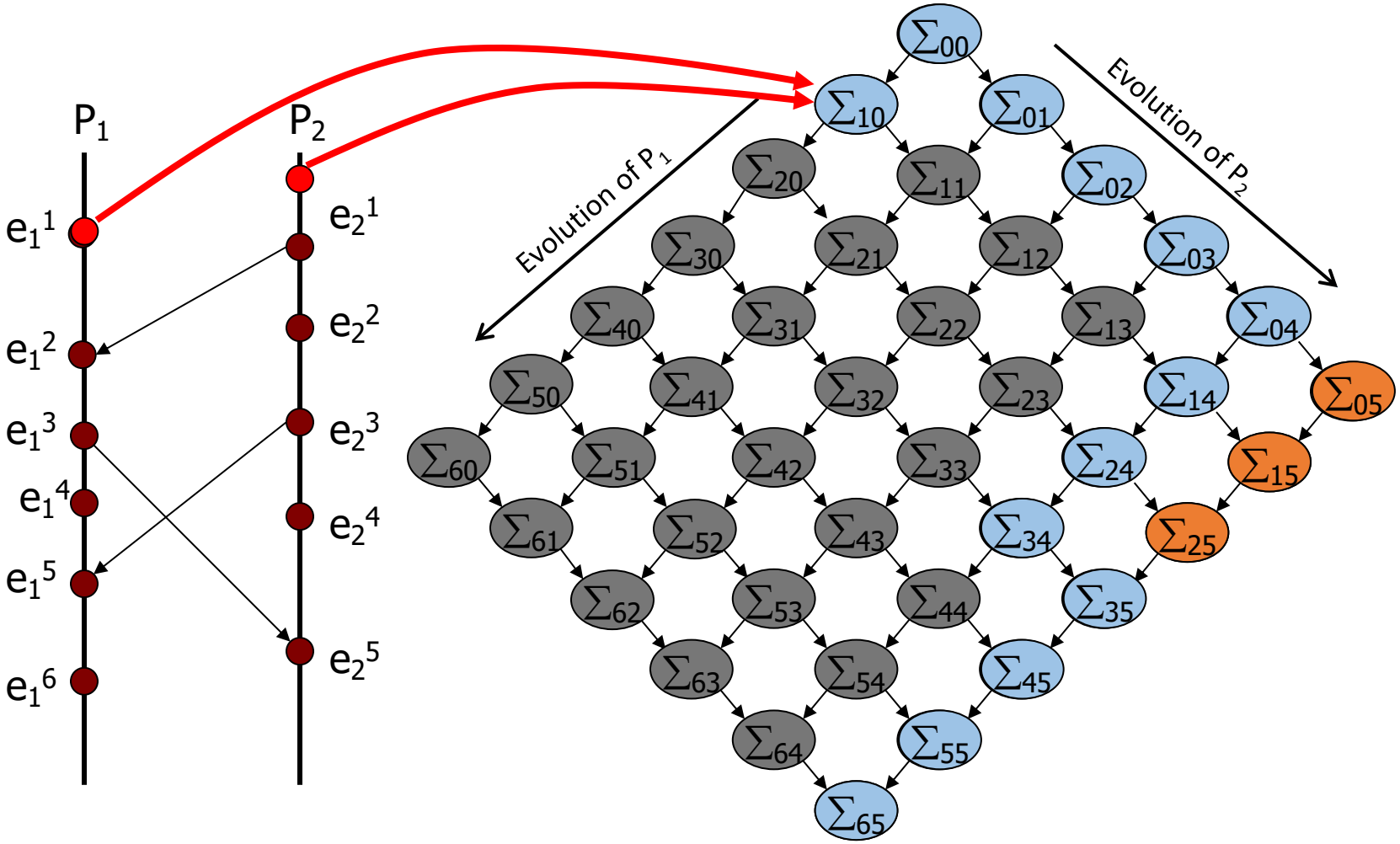

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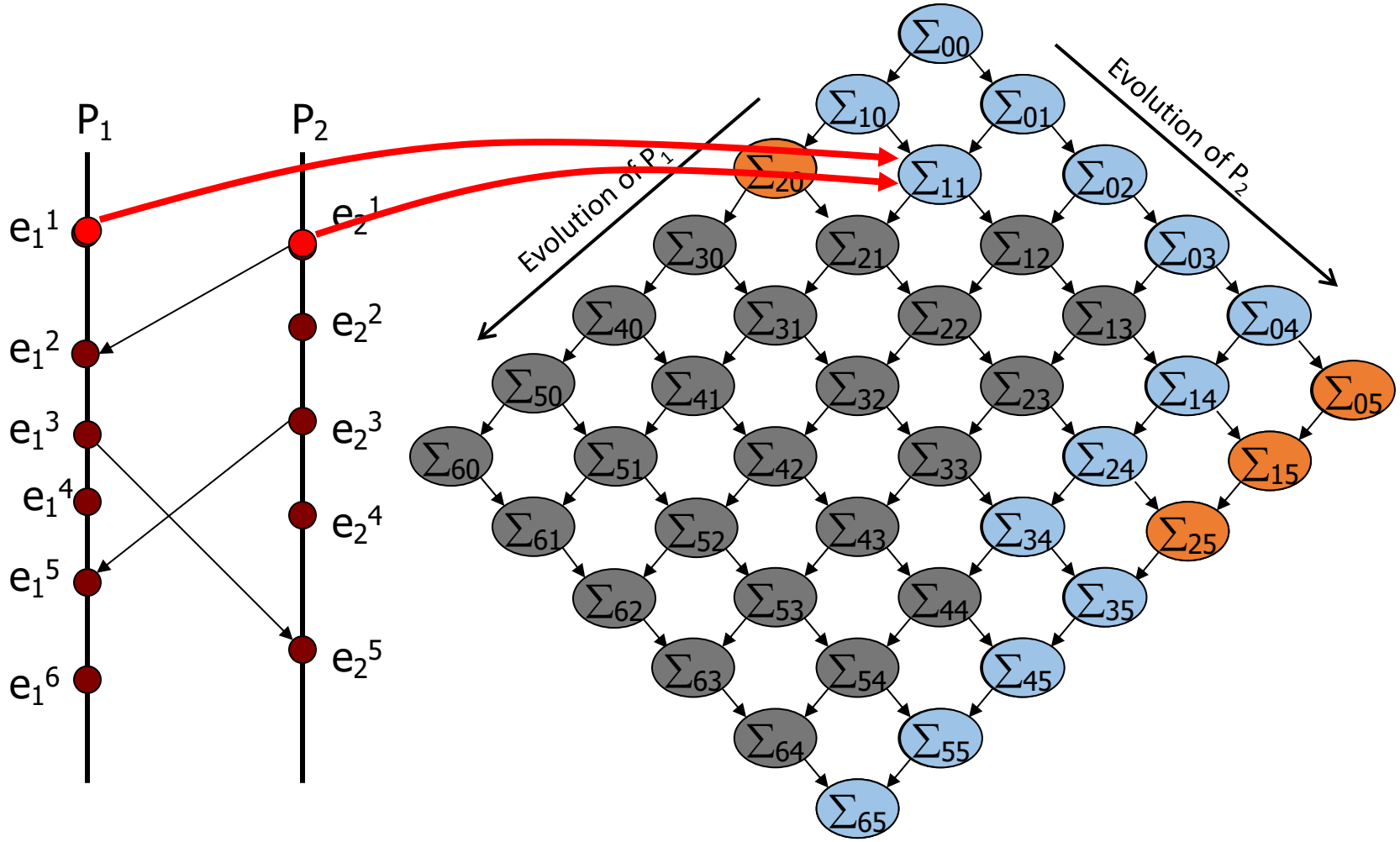

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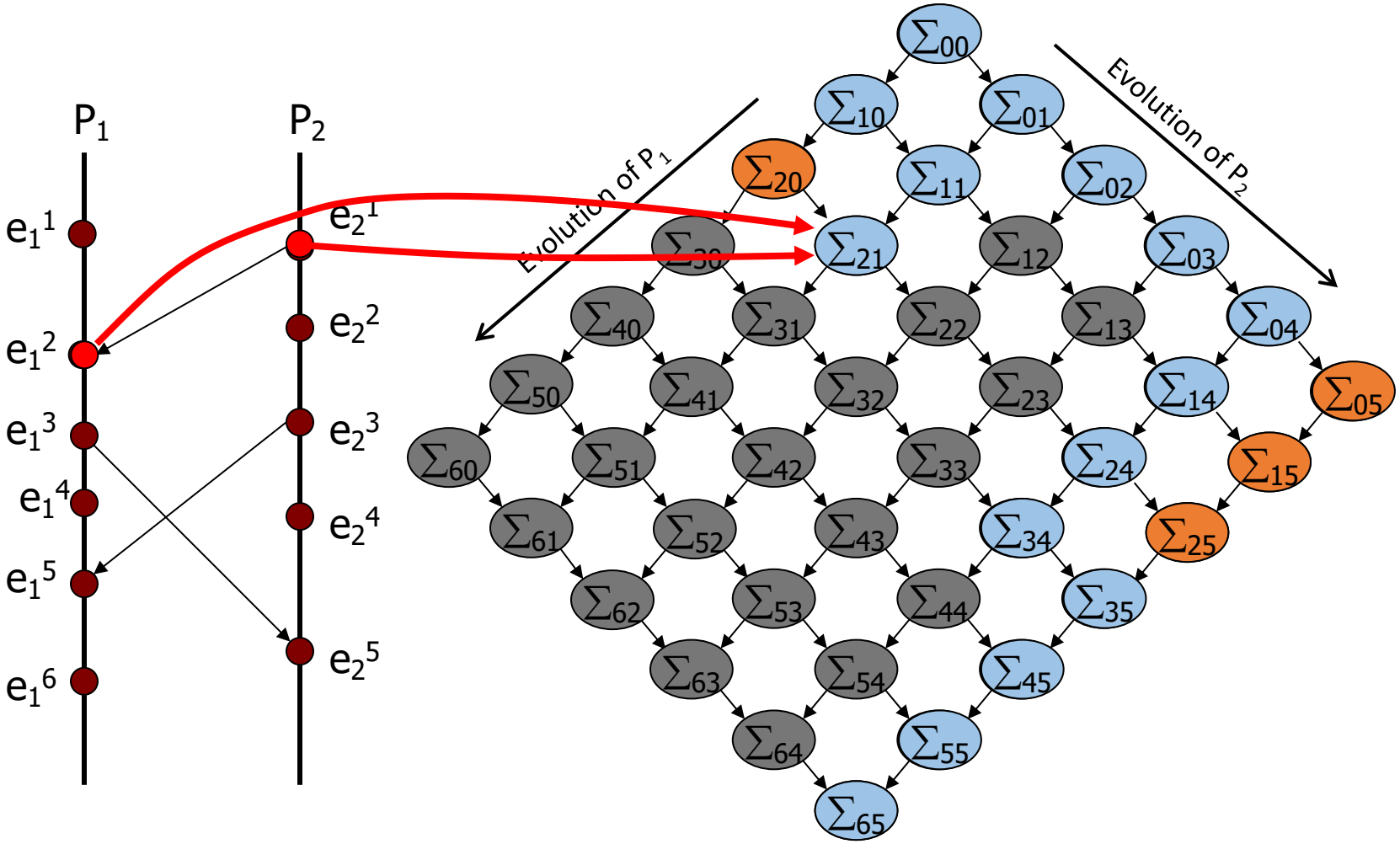

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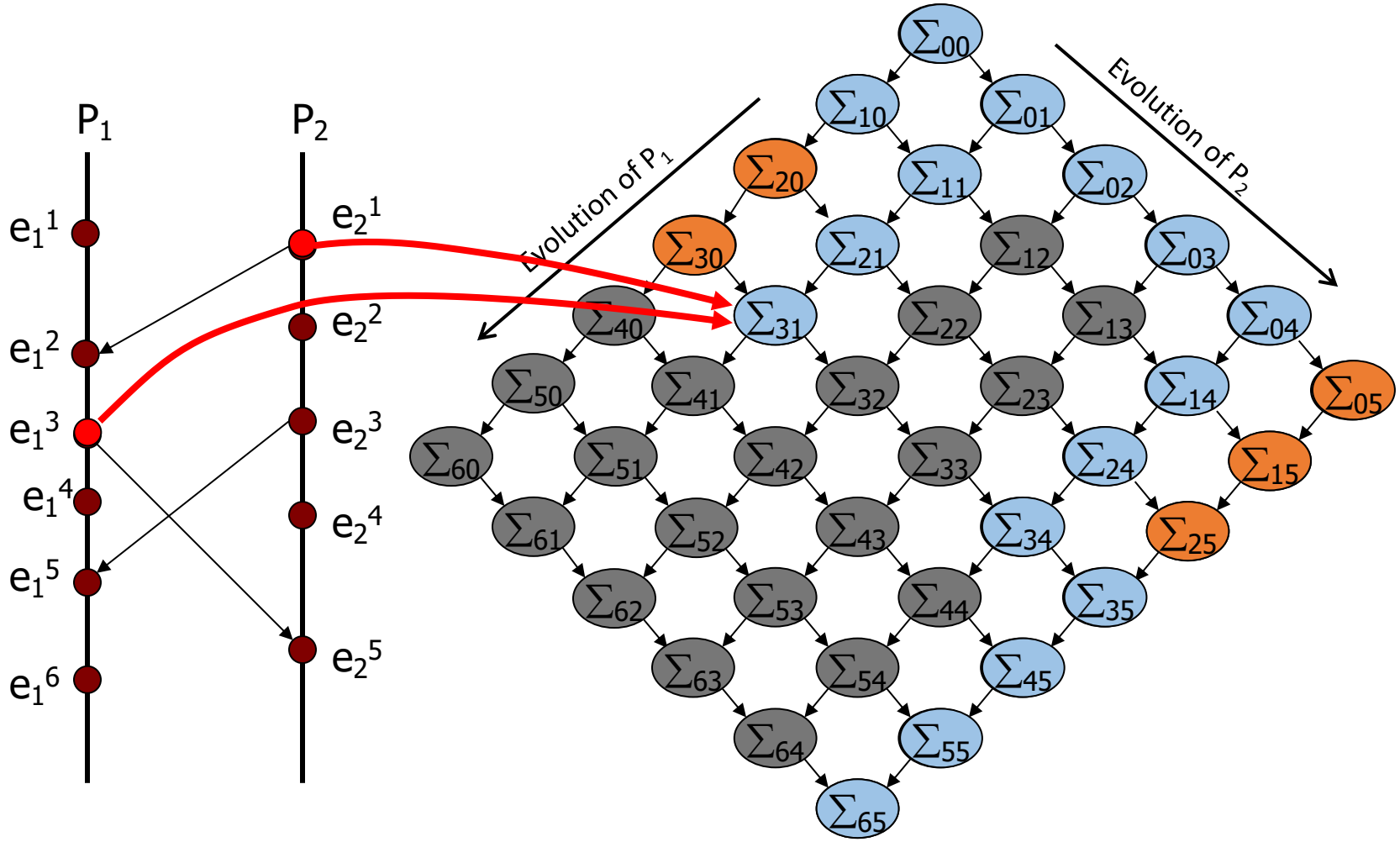

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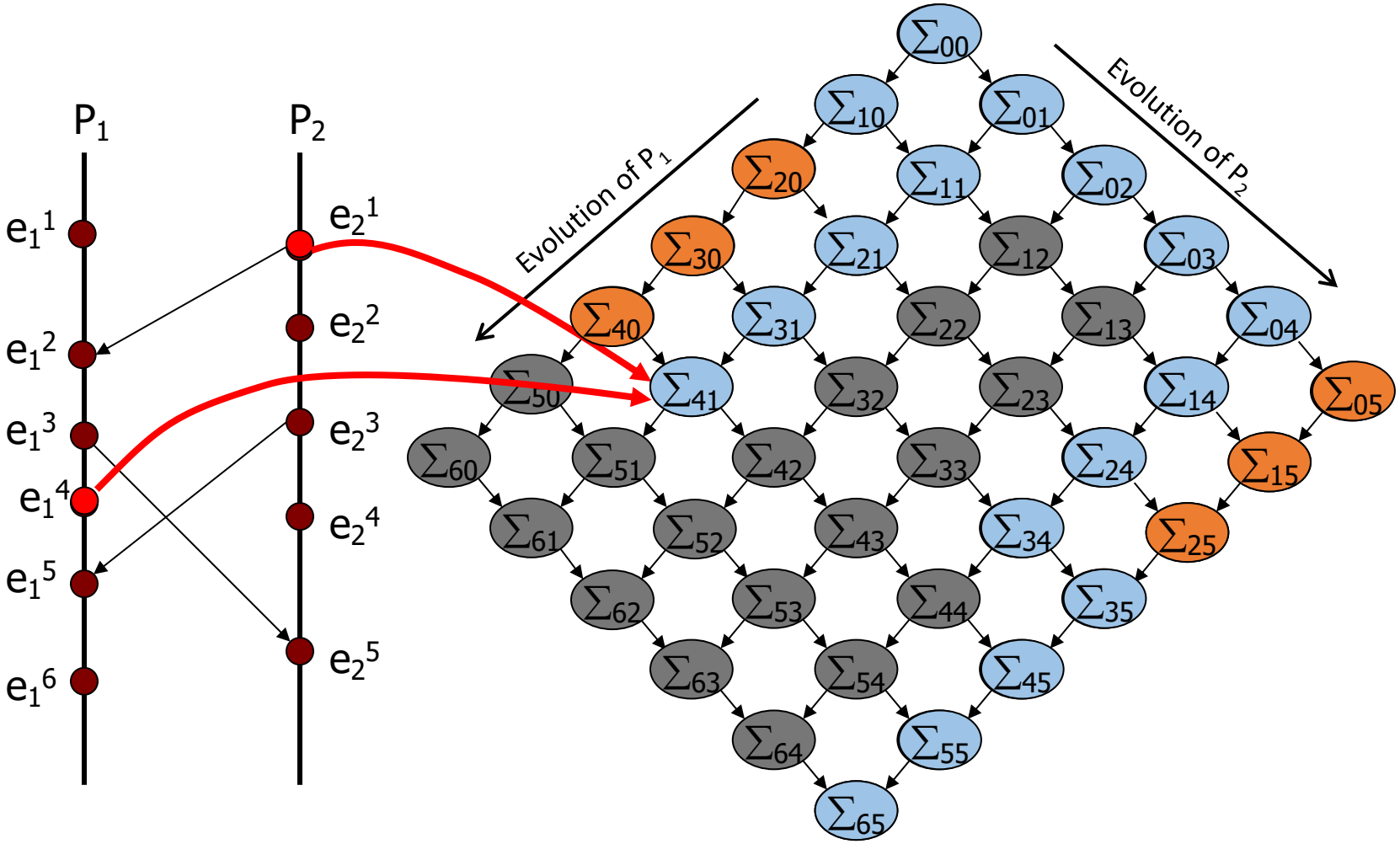

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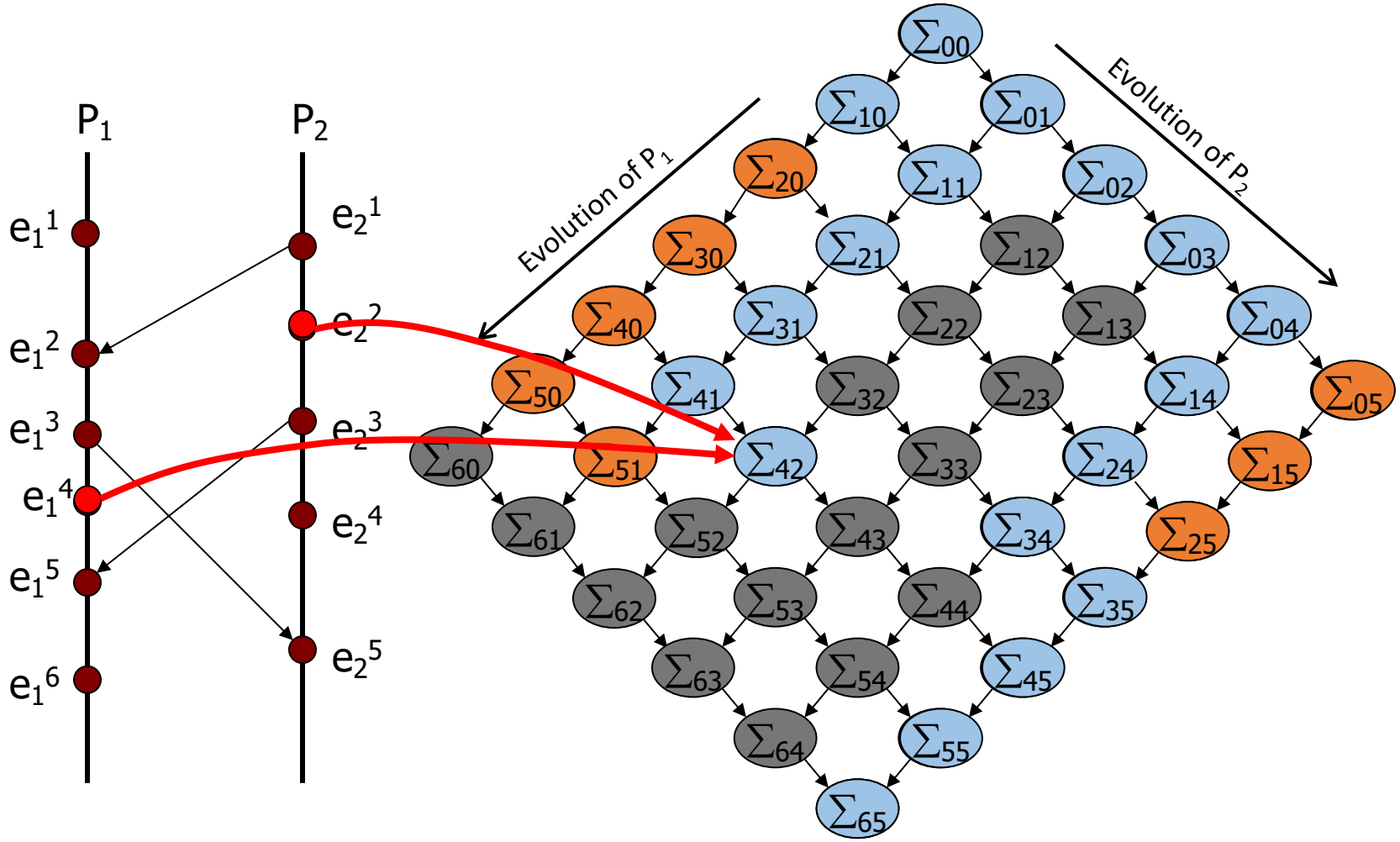

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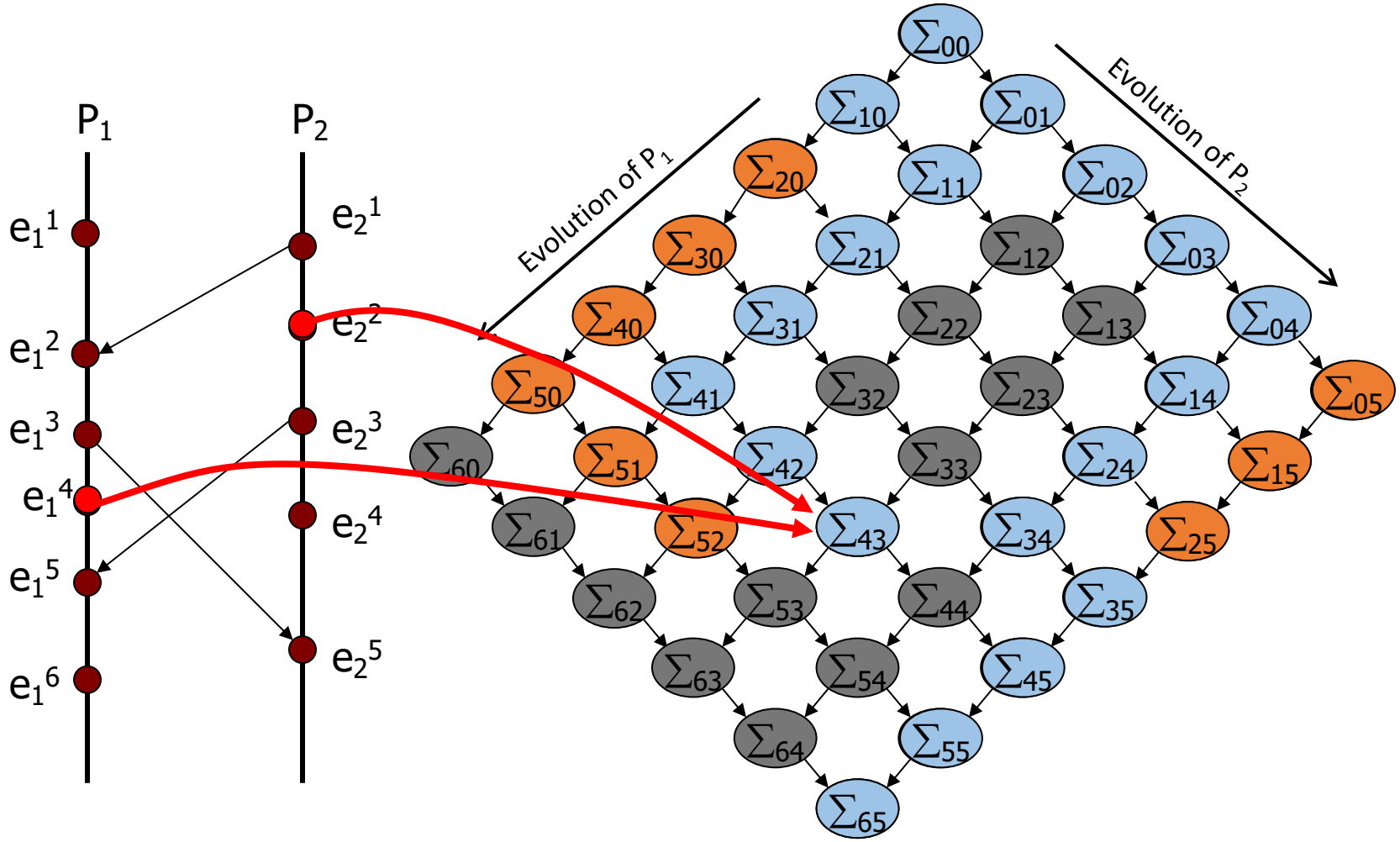

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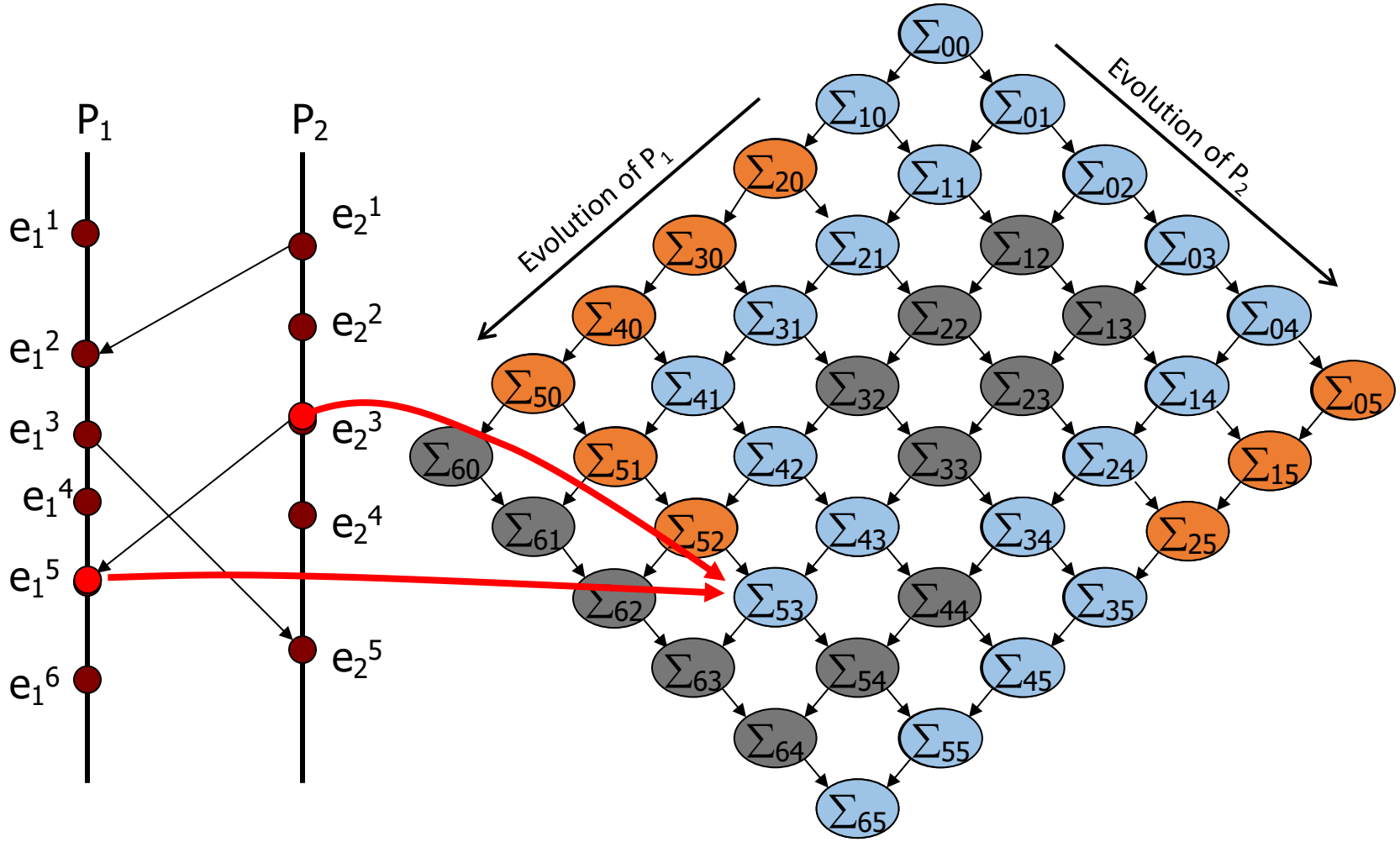

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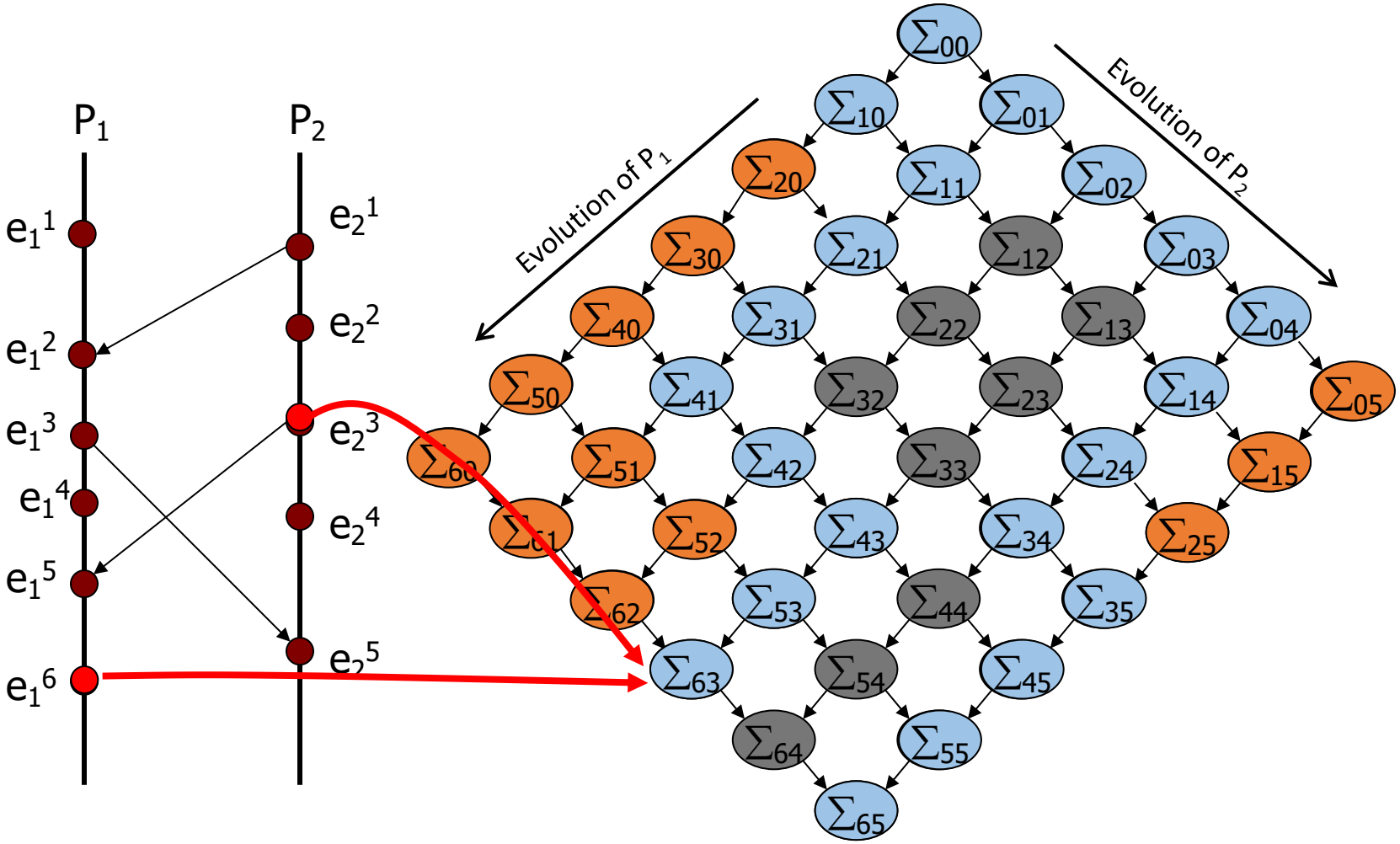

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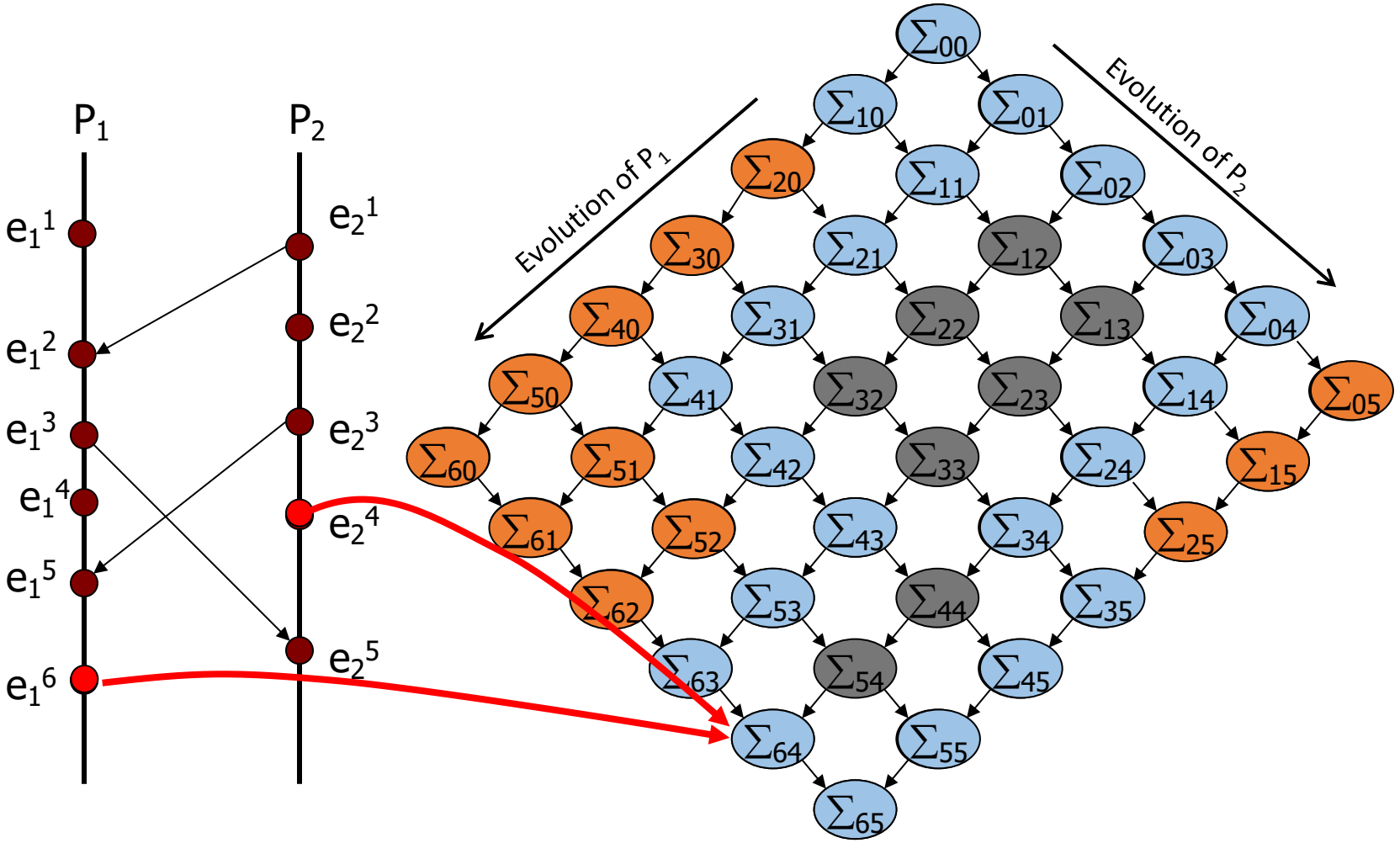

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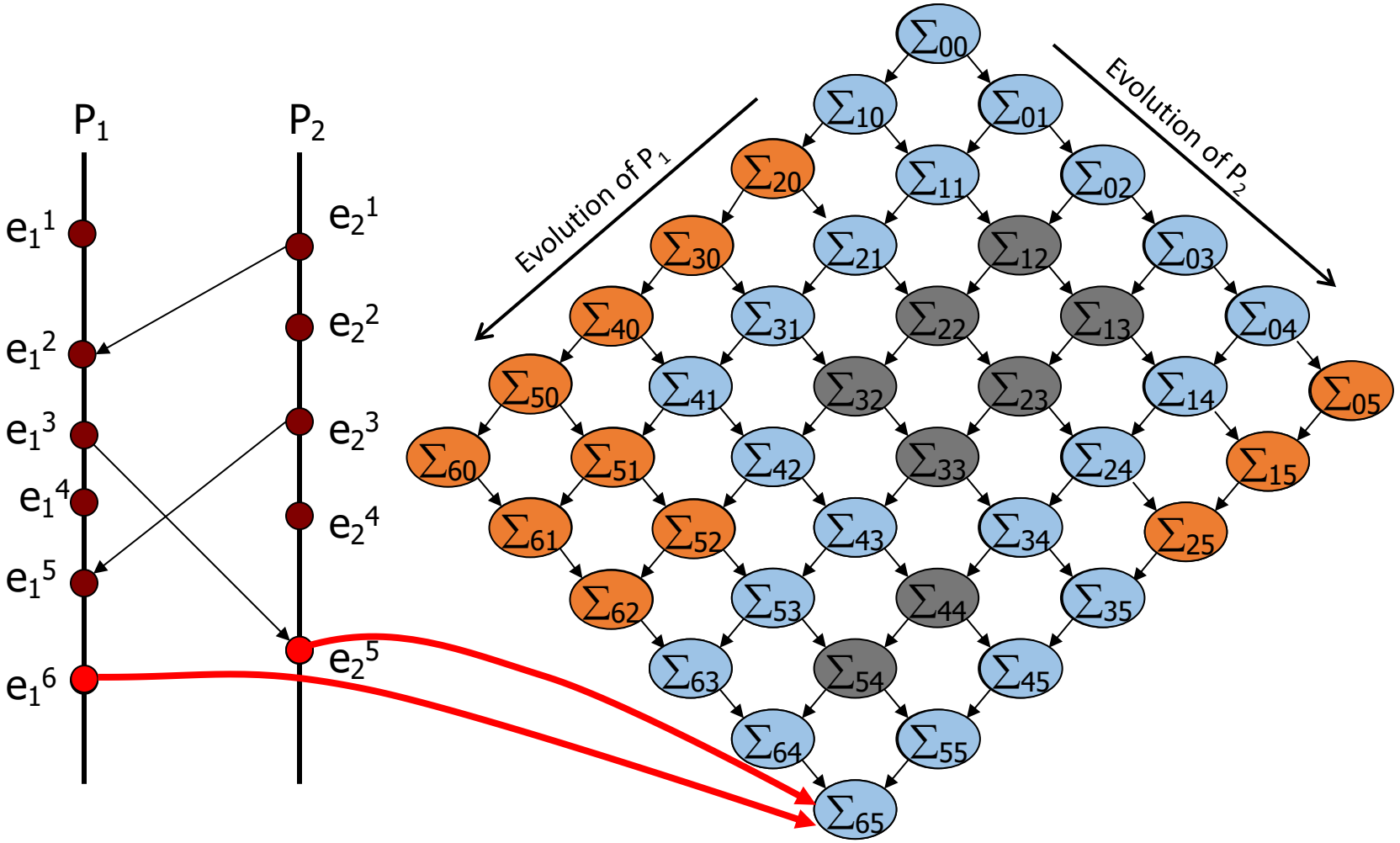

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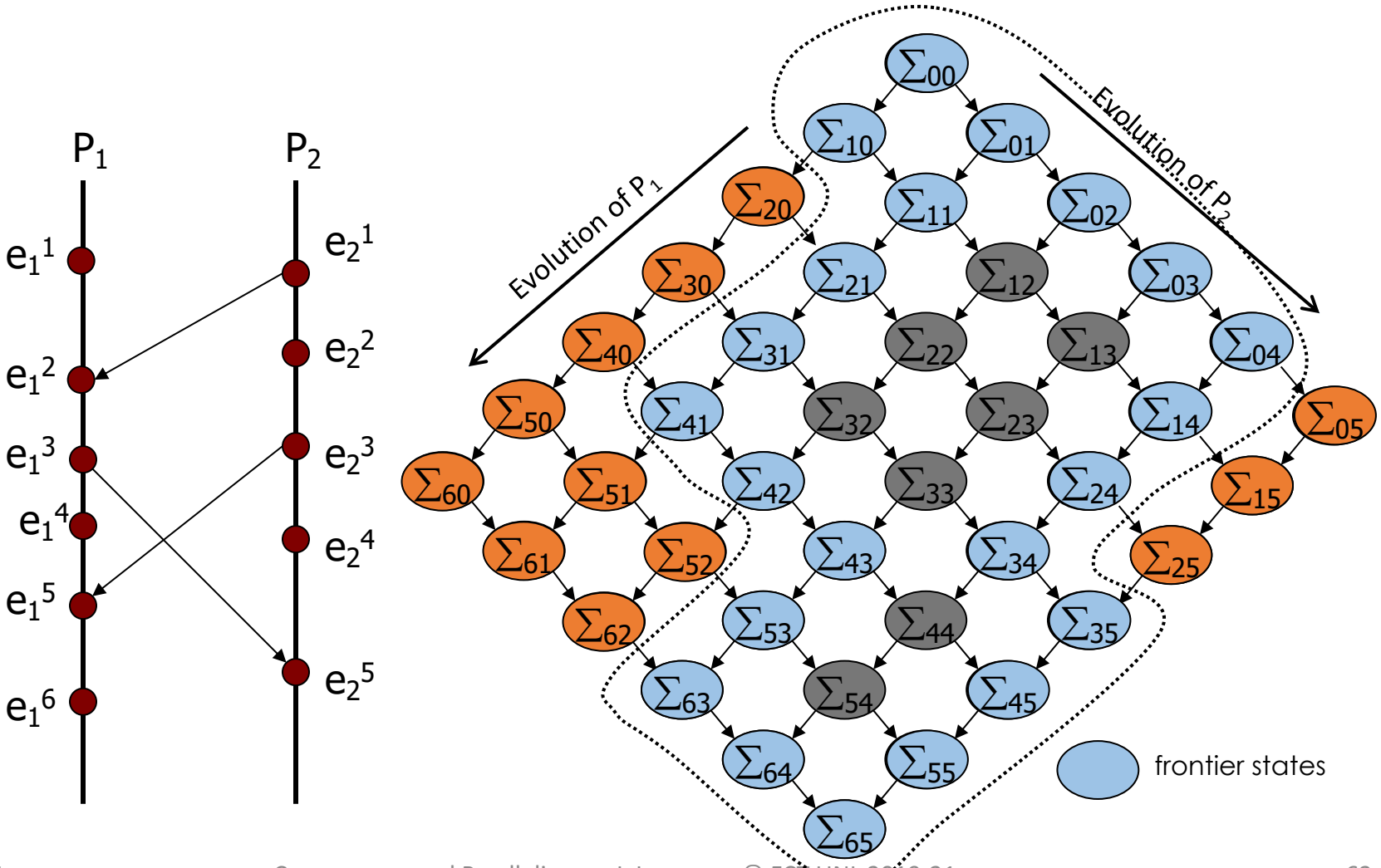

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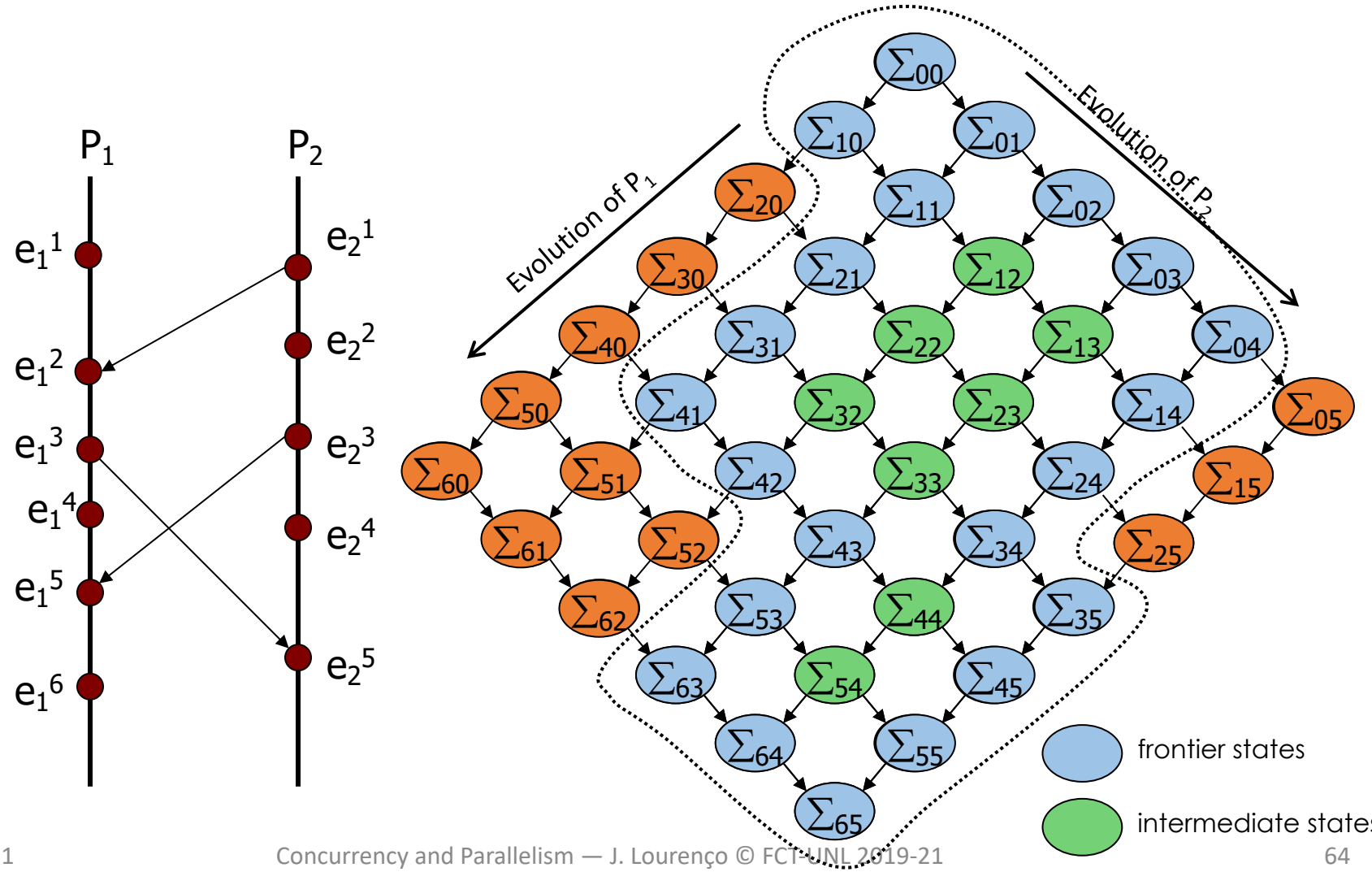

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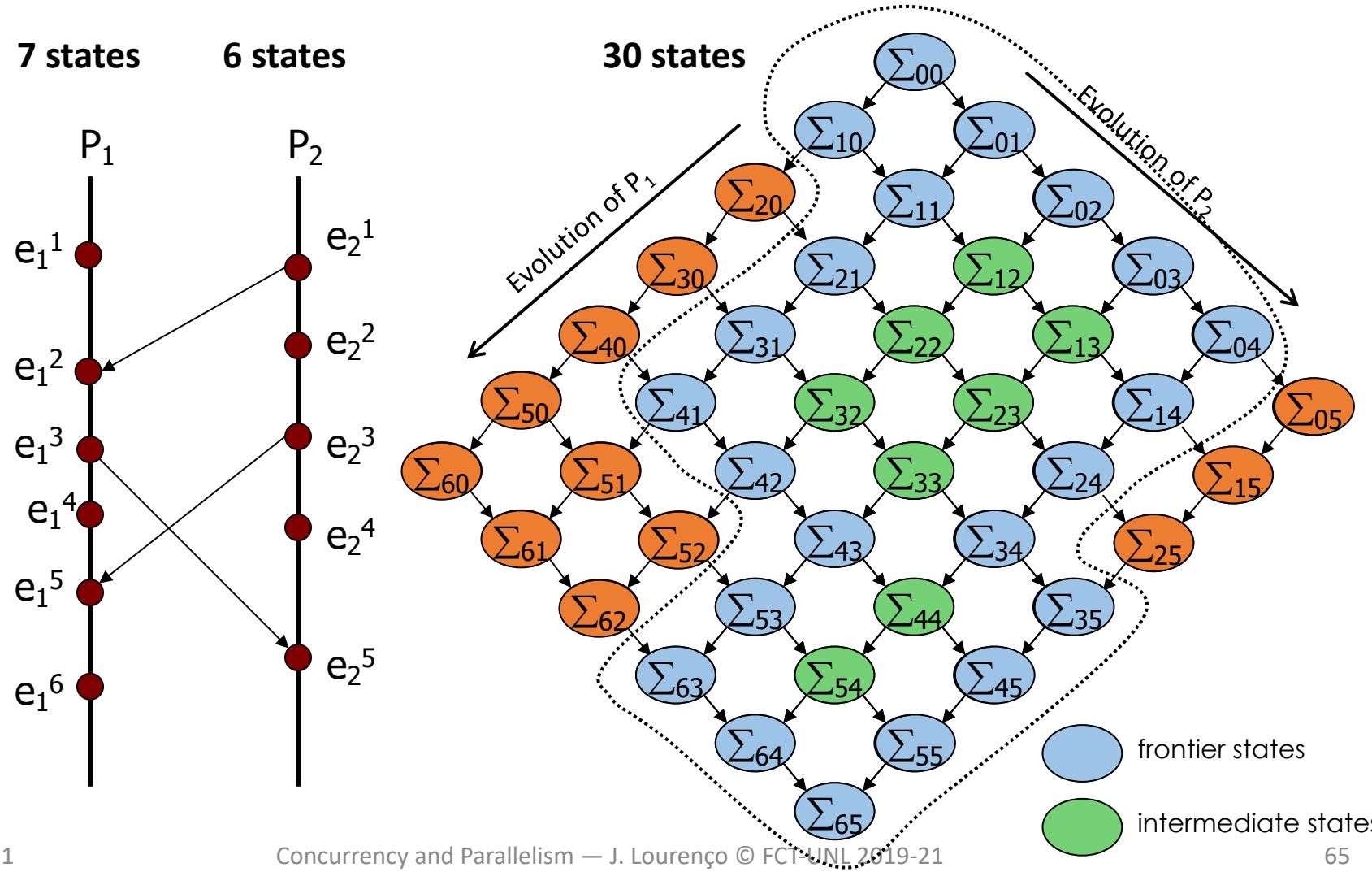
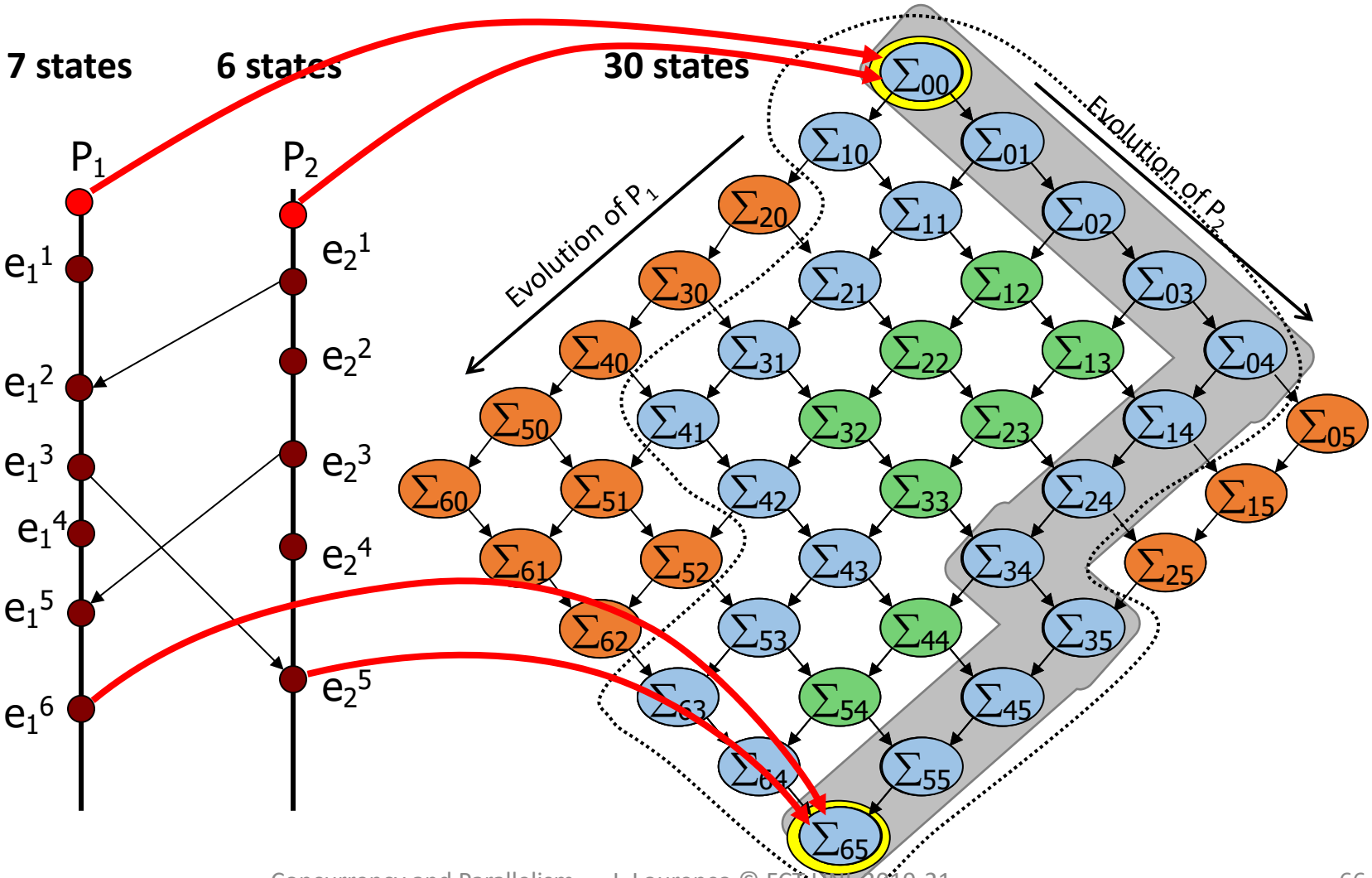
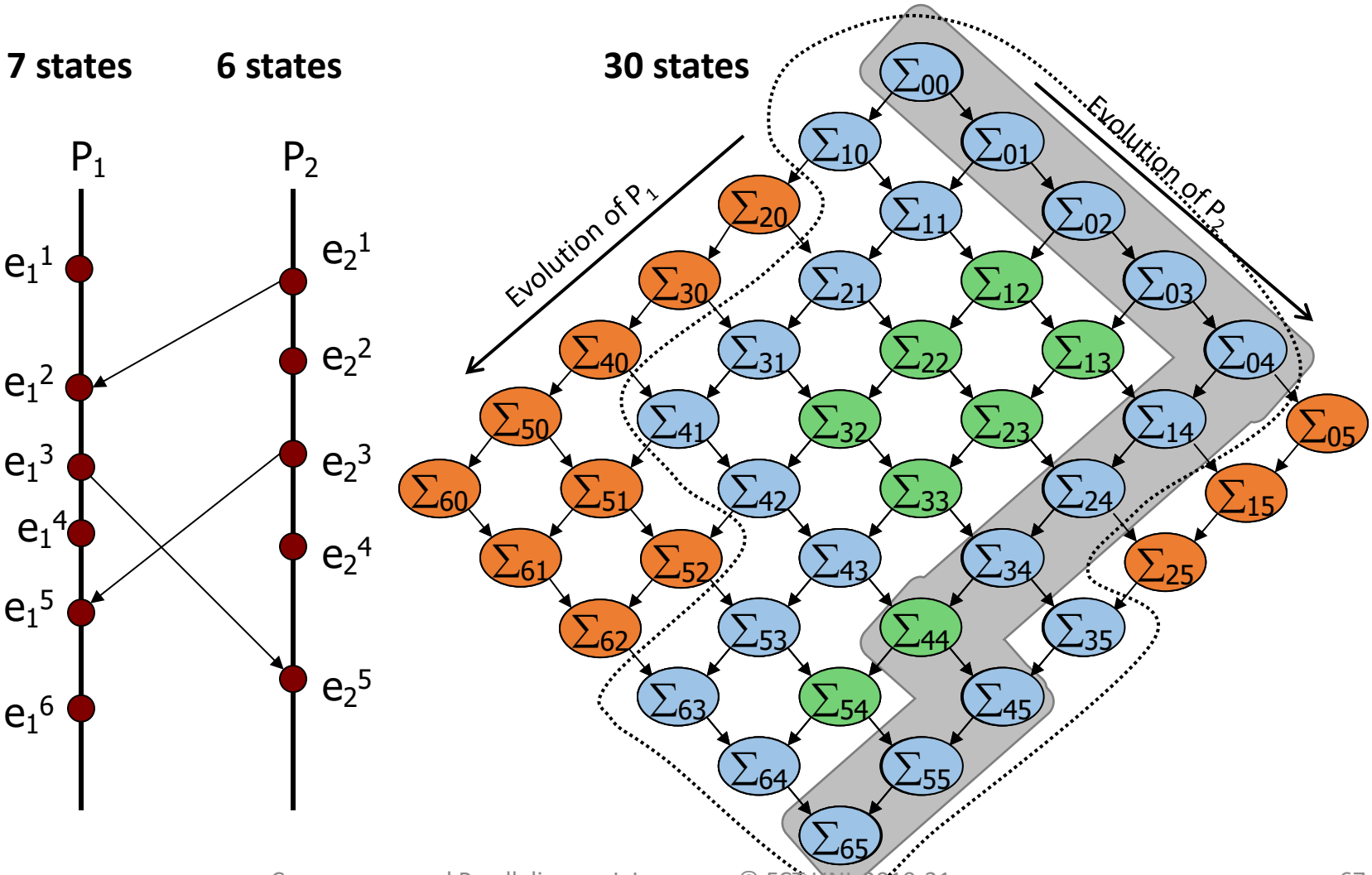


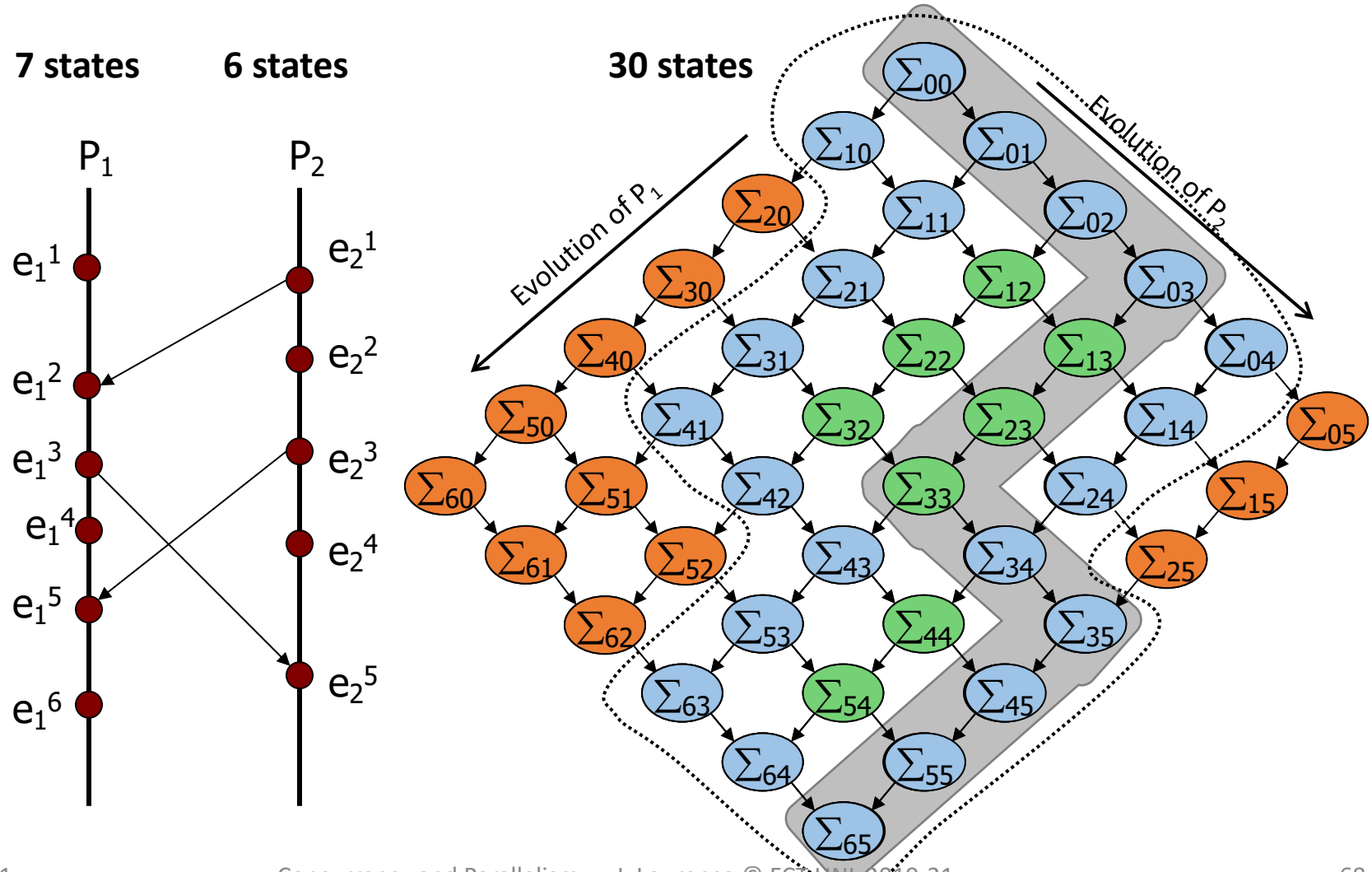
Consistent run: valid path Σ_{00} to Σ_{65}



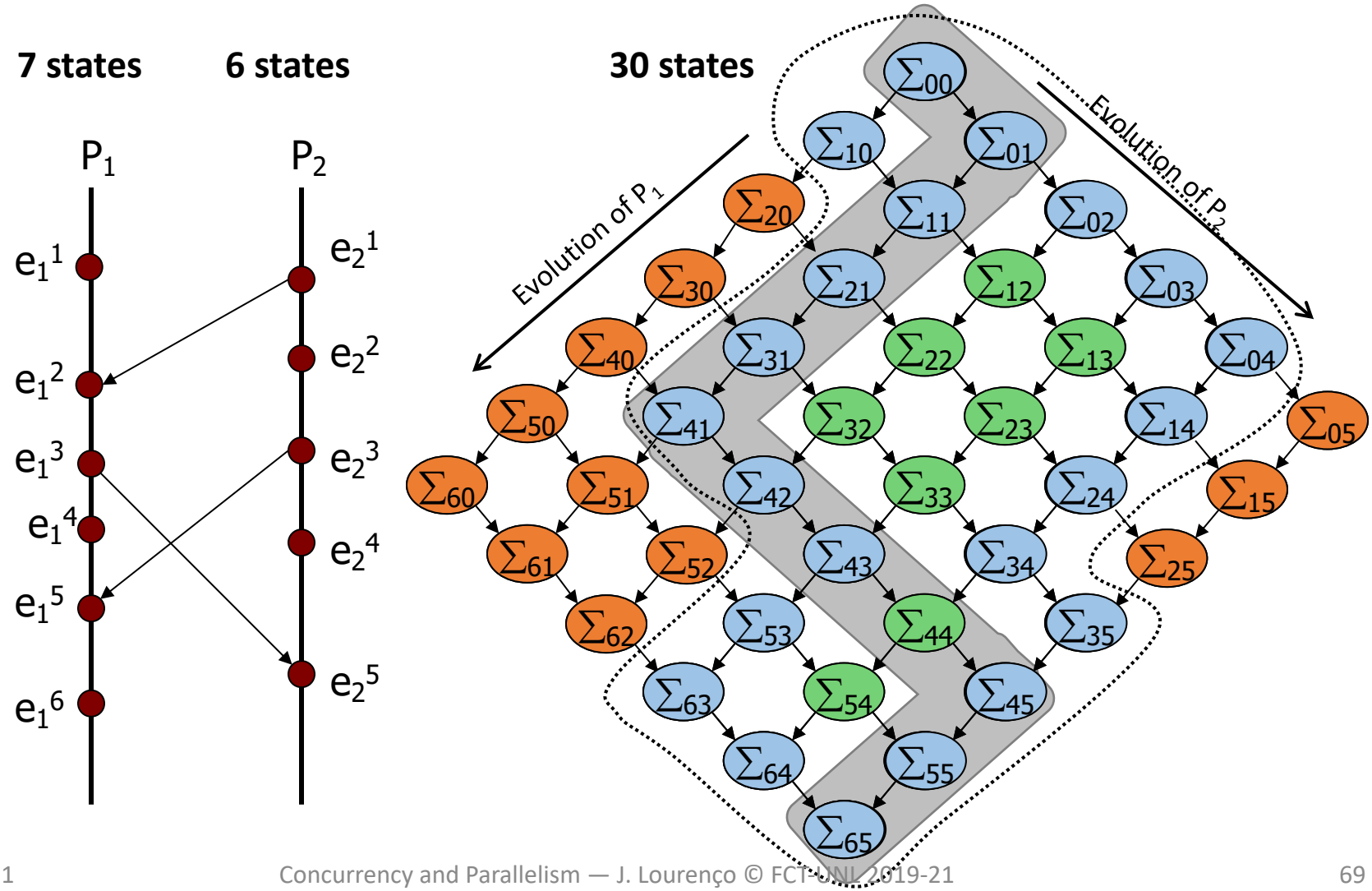
Consistent run



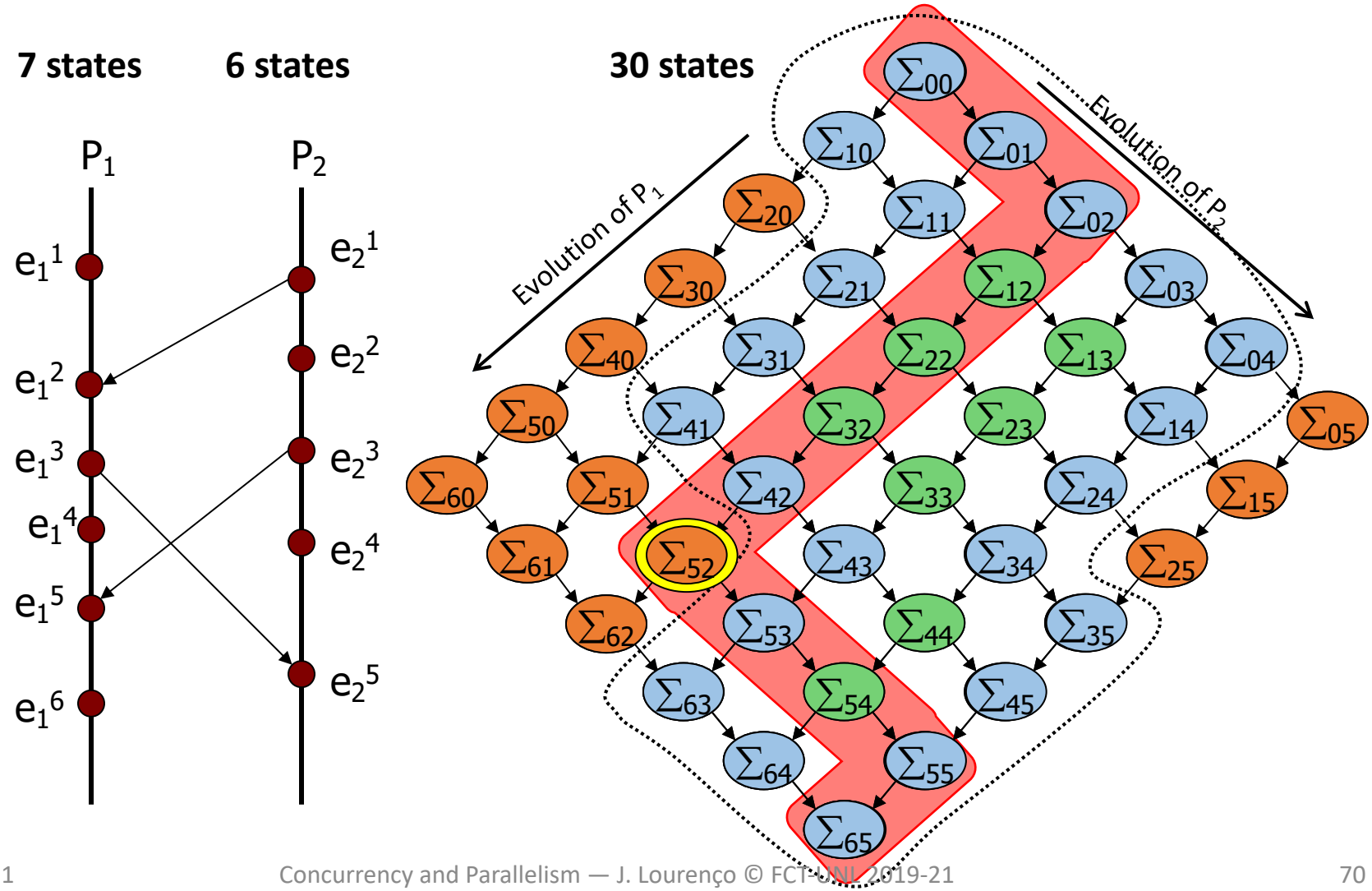
Consistent run



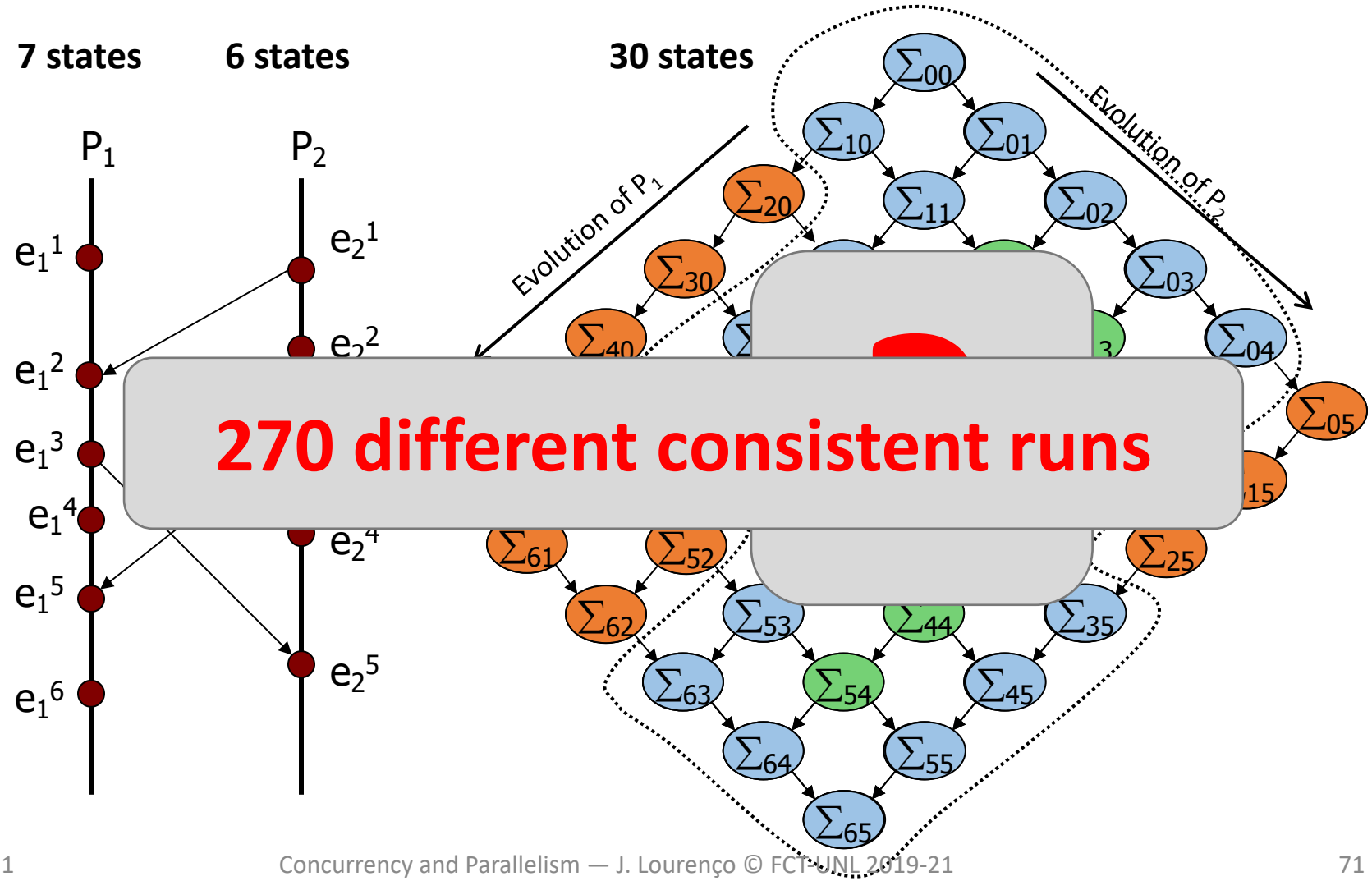
Consistent run



Inconsistent run – program error



Consistent runs – How many?



The END