

Removing Implicit Places Using Regions for Process Discovery

Seminar - Selected Topics in Process Mining

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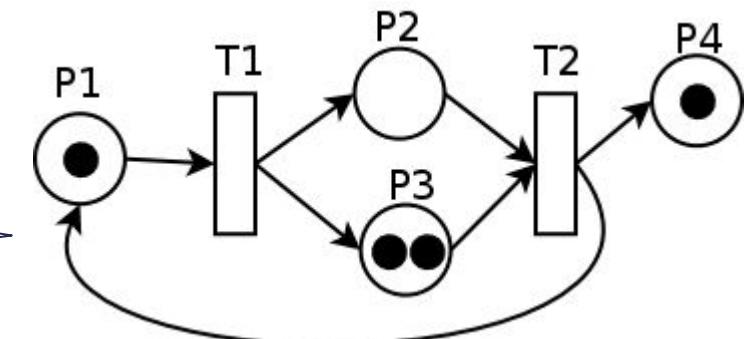
Introduction

Input: Event Log



Process Discovery

Output: Process model





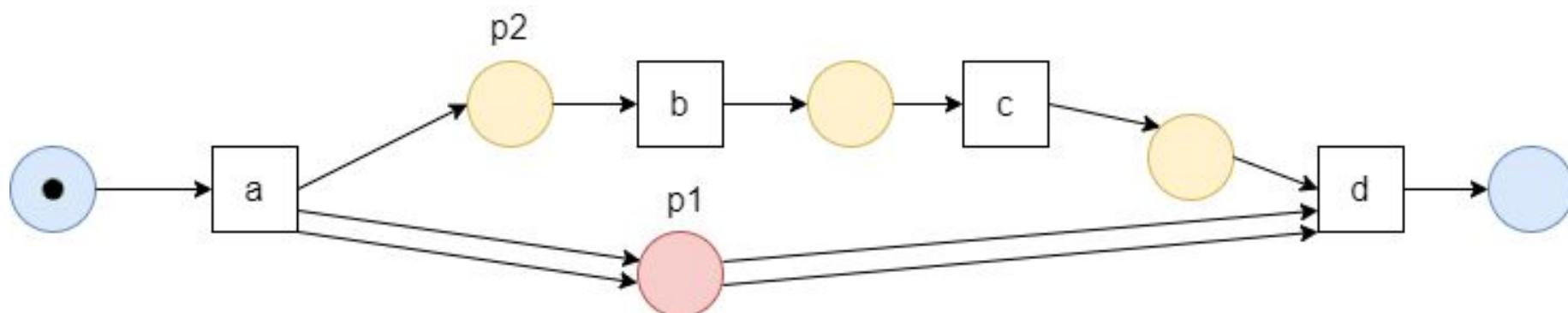
Motivation

- Process discovery aims to discover simple Petri nets
- Petri nets may contain several *implicit* places
- Implicit places increase model complexity
- A novel technique to identify and remove implicit places
- Integrating the approach with the eST-Miner

- An activity is simply **work** performed in a business process
- A trace is a sequence of activities
- An event log is a multiset of traces
- A marked Petri net (P, T, F, m_0) is a process model composed of places P , transitions T and a multiset of arcs $F \rightarrow \mathbb{N}_0$

- An implicit place p does not contribute to a Petri net's behaviour

$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



Preliminaries

$\langle a \rangle$
$\langle a, b \rangle$
$\langle a, b, c \rangle$
$\langle a, b, c, d \rangle$

The language L is every
possible firing sequence
in the Petri net

	ϵ	a	b	c	d
x_{p_2}	0	1	0	0	0

The token count function x_{pi}
defines the number of tokens
in place p_i

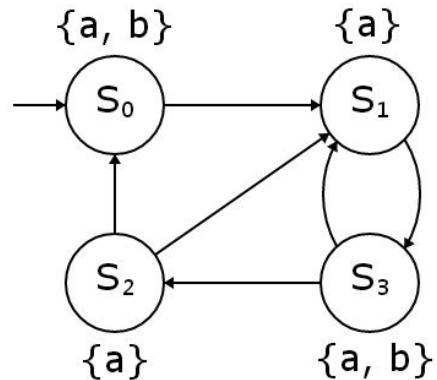
Preliminaries: Region Theory



Preliminaries: Region Theory

- Identifying *regions* in the event log
- Each region corresponds to a feasible place in the resulting Petri net

State-based region theory makes
use of a *transition system*



Language-based region theory makes
use of a *prefix-closed language*

$\langle a \rangle$
$\langle a, b \rangle$
$\langle a, b, c \rangle$
$\langle a, b, c, d \rangle$

Main Idea

➤ Given an event log and the corresponding Petri net N :

- $p_1, p_2 \in P$ are two individual places in N ,
- Comparing p_1 and p_2 , we verify the conditions:

$$\forall \sigma \in L(N) : x_{p_1}(\sigma) \geq x_{p_2}(\sigma) \quad (1)$$

$$\exists \sigma \in L(N) : x_{p_1}(\sigma) > x_{p_2}(\sigma) \quad (2)$$

Main Idea

- If $x_{p_1} > x_{p_2}$ for the prefix-closed language of N , then

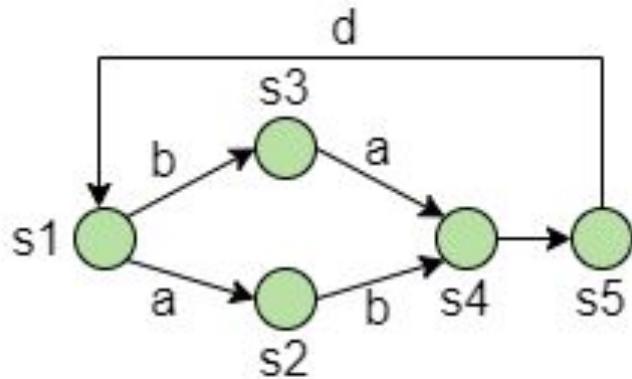
$$\boxed{x_{p_3}} = x_{p_1} - x_{p_2} \quad (3)$$

is a region and p_1 can be regarded as *implicit* if p_3 exists

- Incoming arc added for increase in the token count of place p_3
- Outgoing arc added for decrease in the token count of place p_3

Main Idea

- Minimal regions method avoids adding implicit places to a model

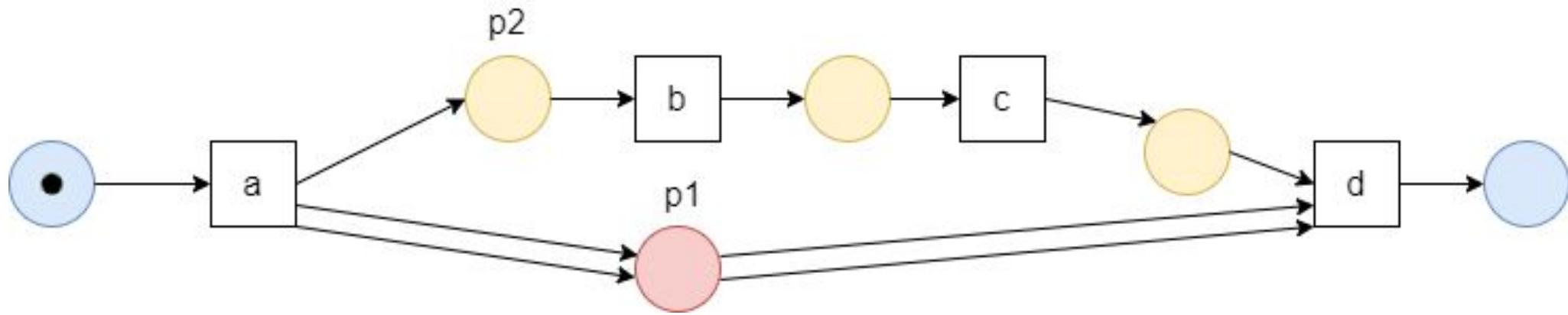


$$\begin{aligned}r_1 &= \{s1, s2\} \\r_2 &= \{s1, s3\} \\r_3 &= \{s2, s4\} \\r_4 &= \{s3, s4\} \\r_5 &= \{s5\}\end{aligned}$$

- Transitioning directly from the event log to the resulting model
- The goal is to remove implicit places from a discovered set of places

Running Example: Simple Case

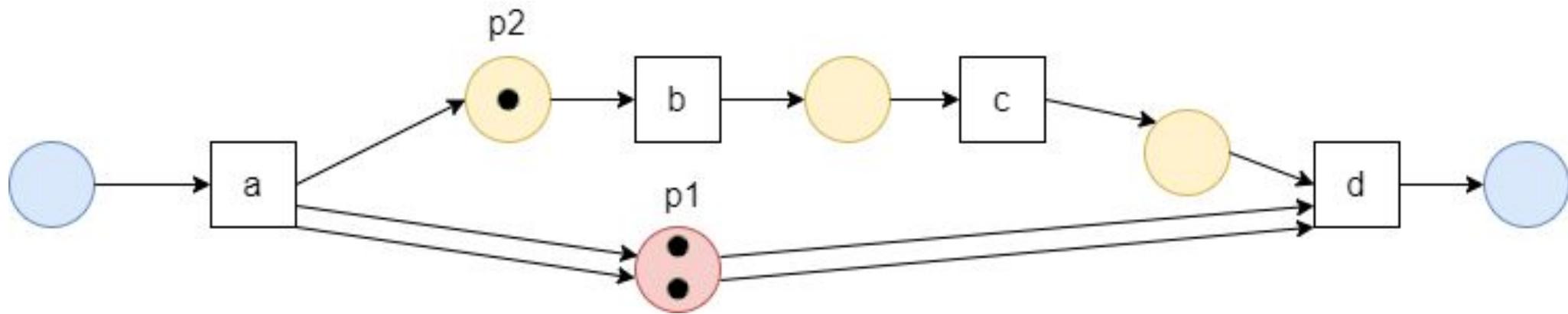
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0				
x_{p_2}	0				
x_{p_3}					

Running Example: Simple Case

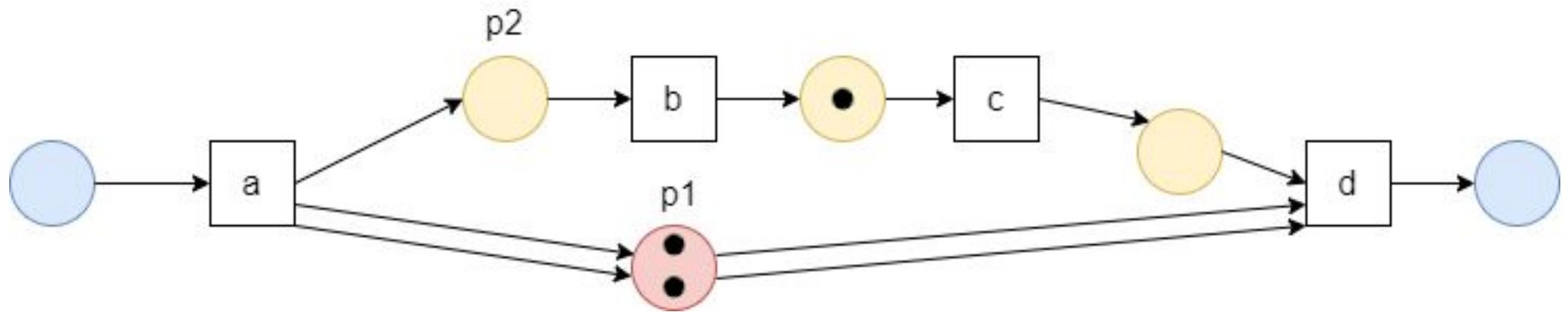
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0	2			
x_{p_2}	0	1			
x_{p_3}					

Running Example: Simple Case

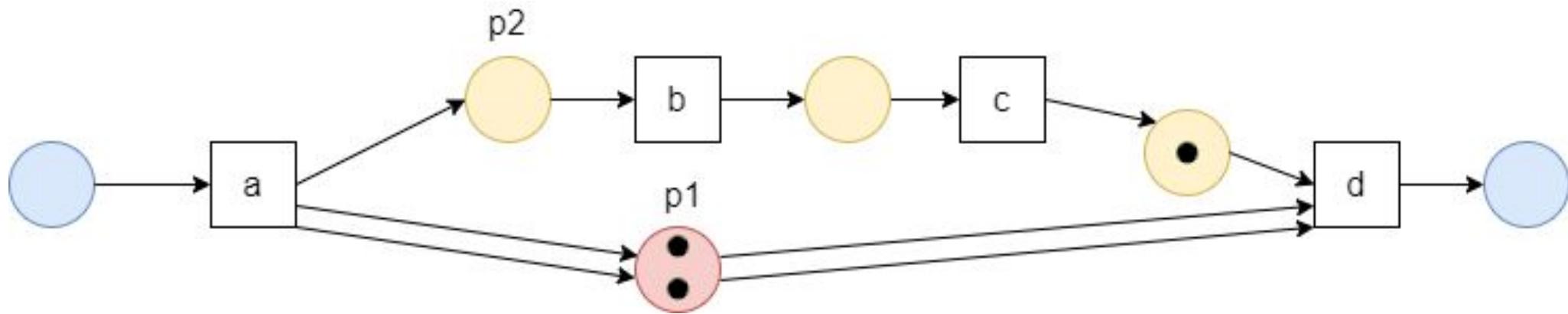
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0	2	2		
x_{p_2}	0	1	0		
x_{p_3}					

Running Example: Simple Case

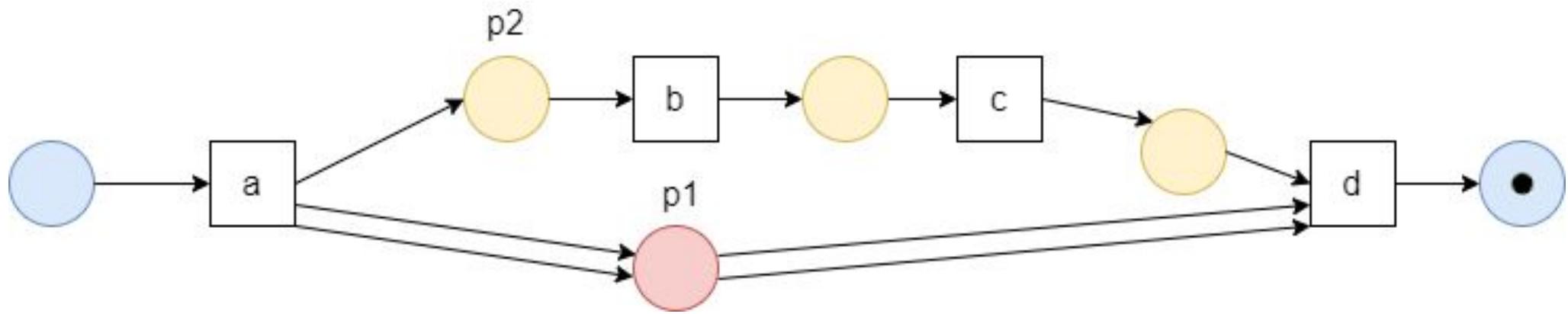
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0	2	2	2	
x_{p_2}	0	1	0	0	
x_{p_3}					

Running Example: Simple Case

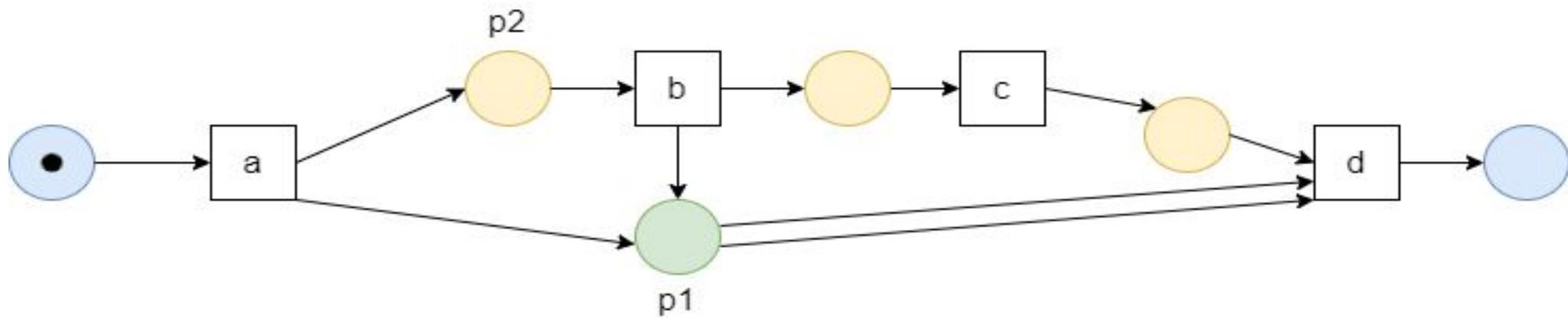
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0	2	2	2	0
x_{p_2}	0	1	0	0	0
x_{p_3}					

Running Example: Simple Case

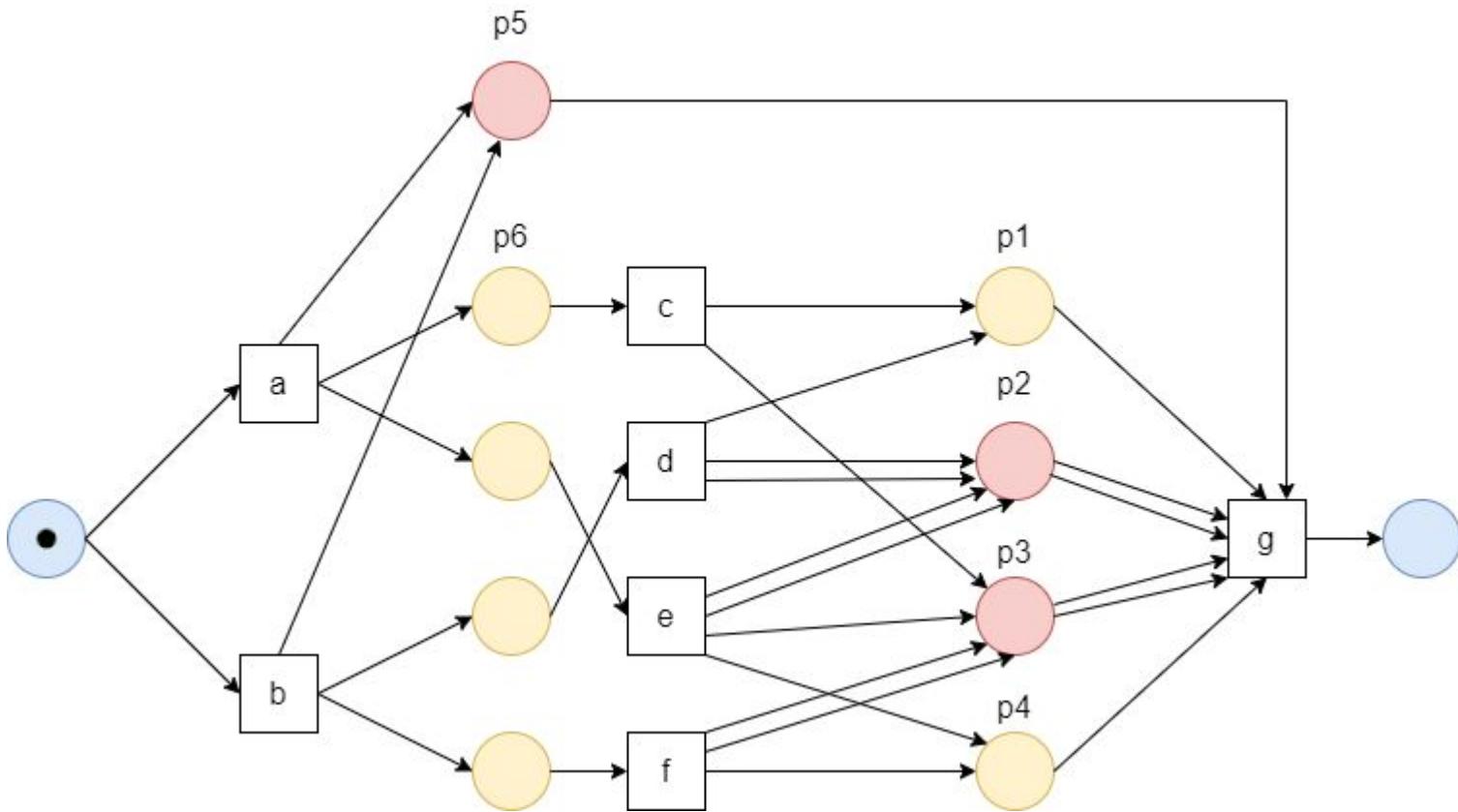
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	ϵ	a	b	c	d
x_{p_1}	0	2	2	2	0
x_{p_2}	0	1	0	0	0
x_{p_3}	0	1	2	2	0

Running Example: Intermediate Case

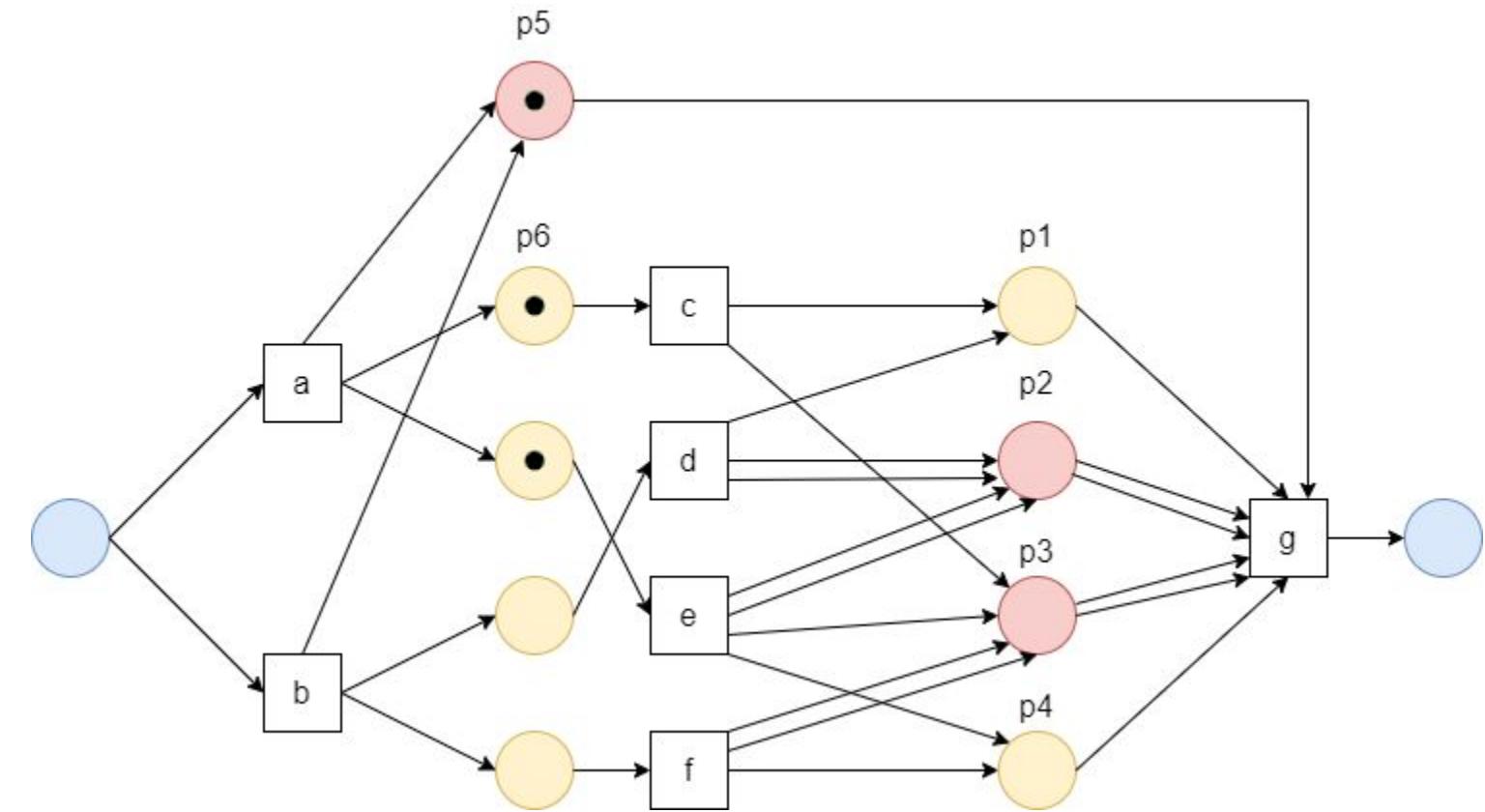
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_5}	0				
x_{p_6}	0				
x_{p_7}					

Running Example: Intermediate Case

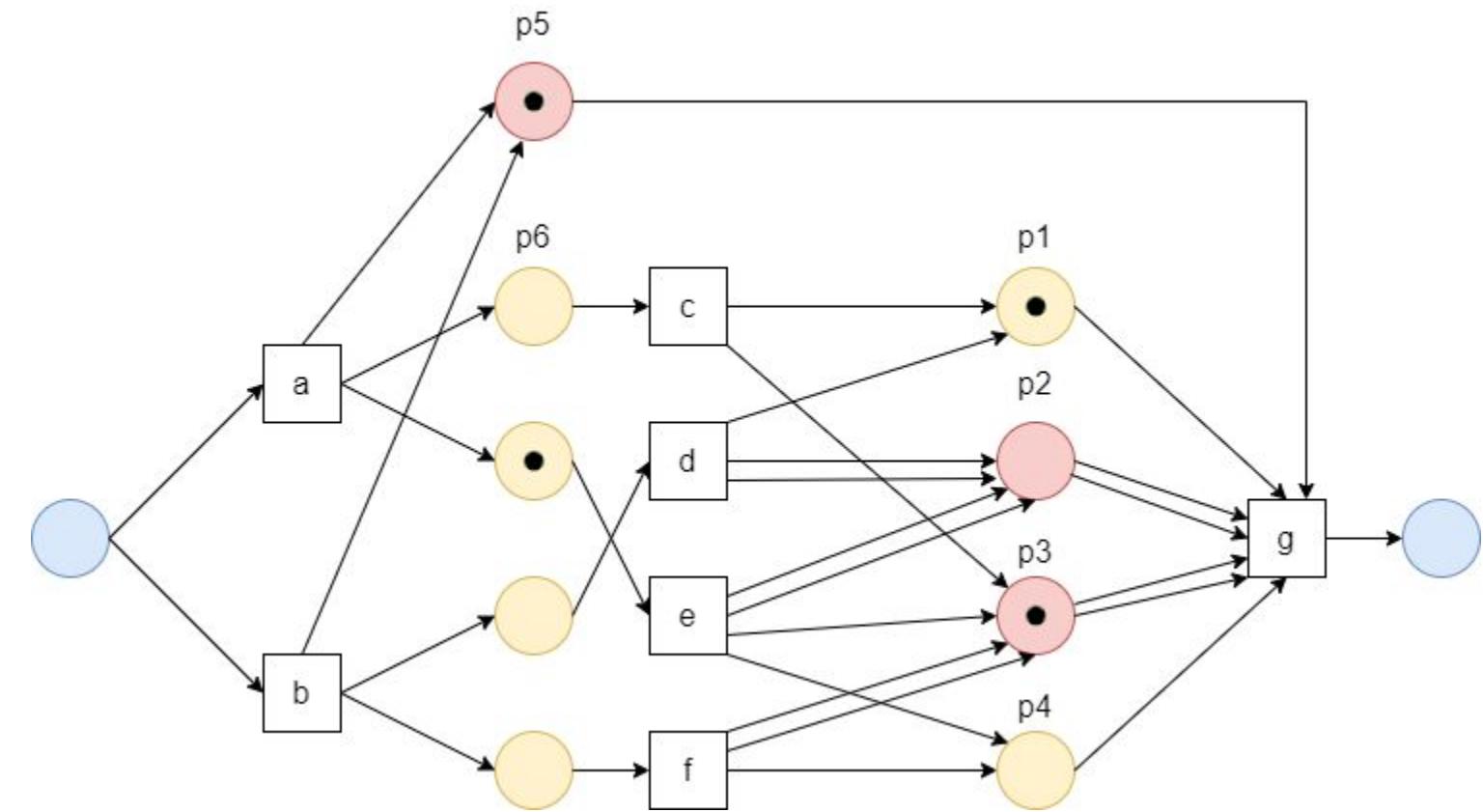
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_5}	0	1			
x_{p_6}	0	1			
x_{p_7}					

Running Example: Intermediate Case

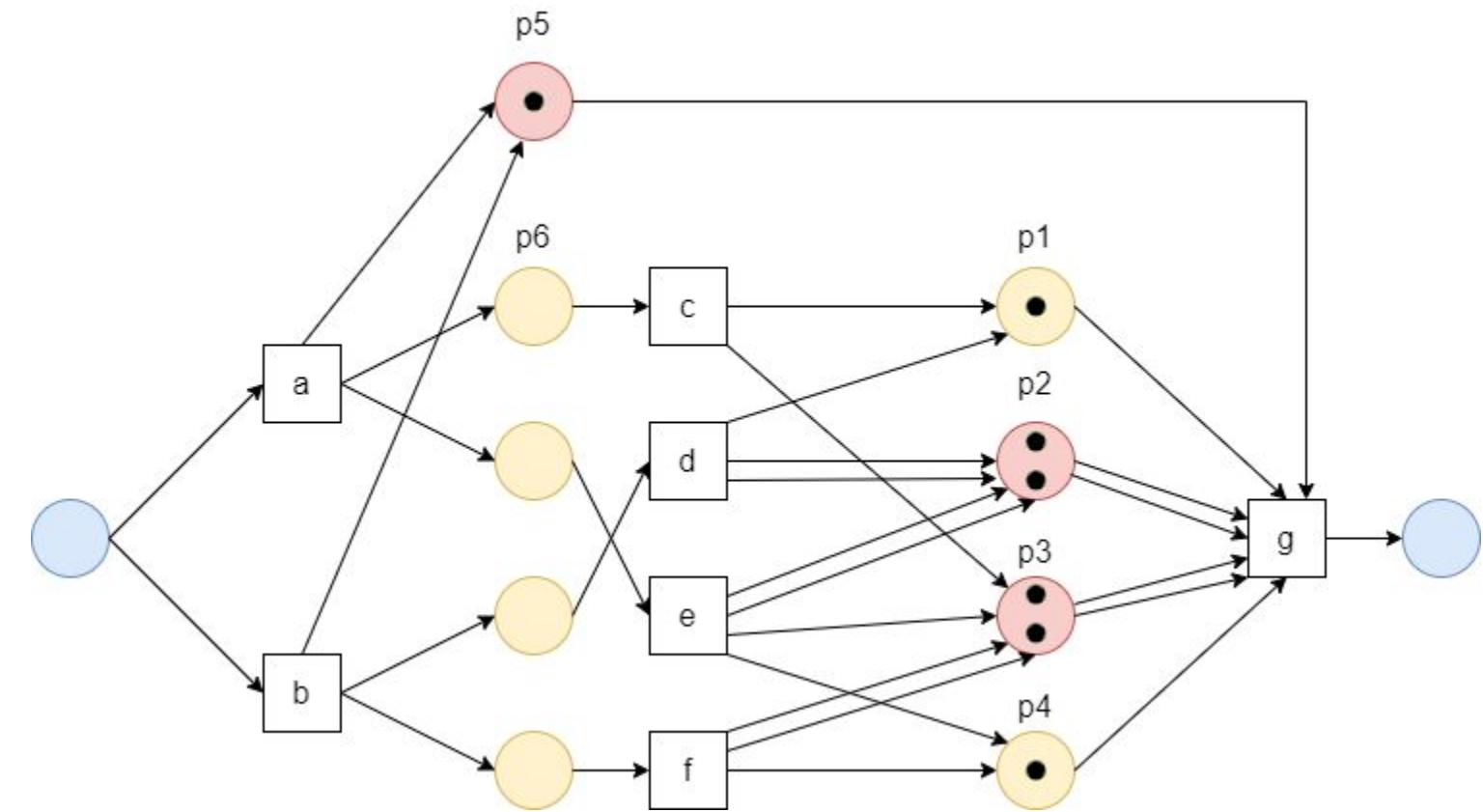
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	ε	a	c	e	g
x_{p_5}	0	1	1		
x_{p_6}	0	1	0		
x_{p_7}					

Running Example: Intermediate Case

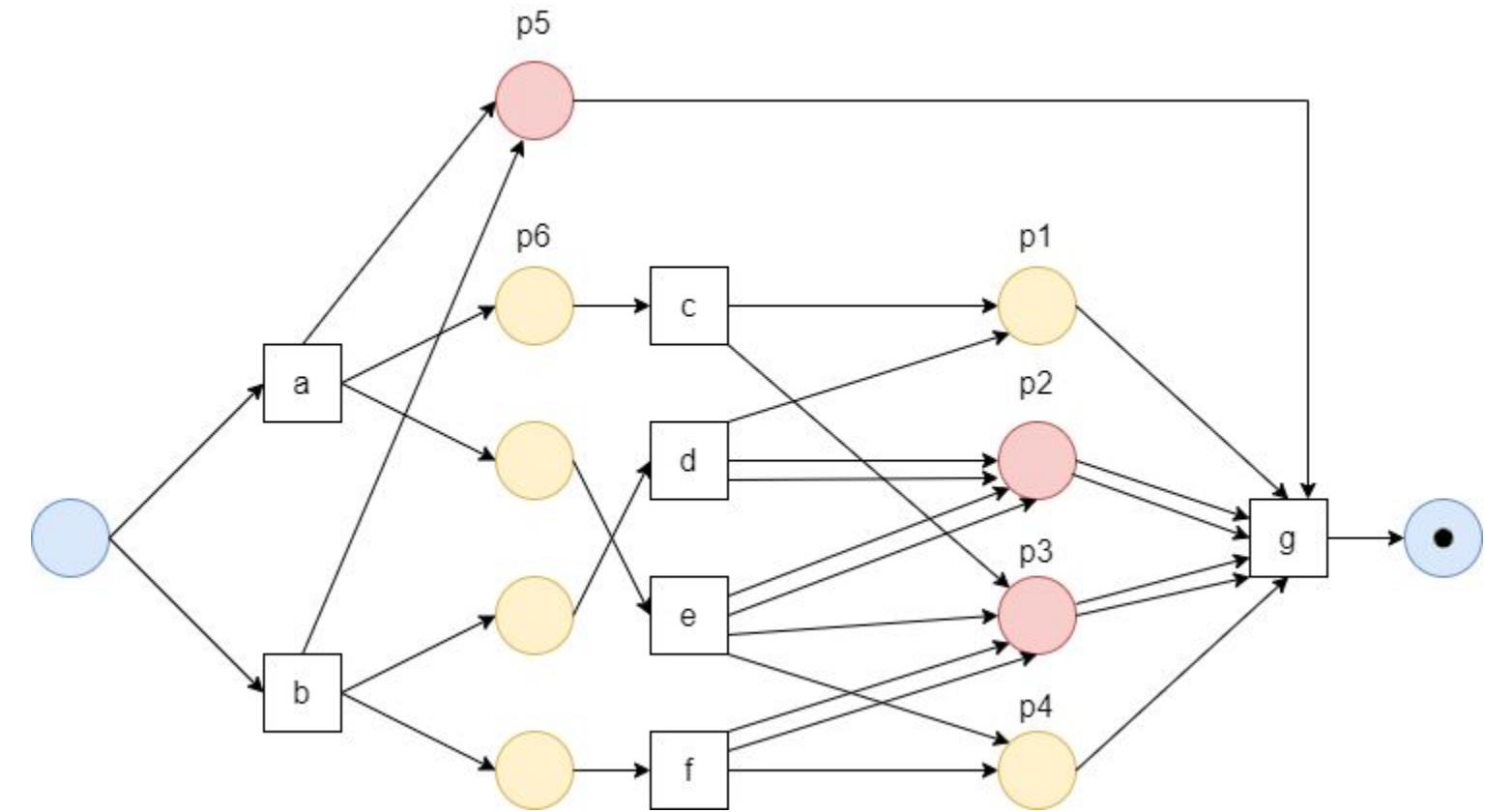
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_5}	0	1	1	1	
x_{p_6}	0	1	0	0	
x_{p_7}					

Running Example: Intermediate Case

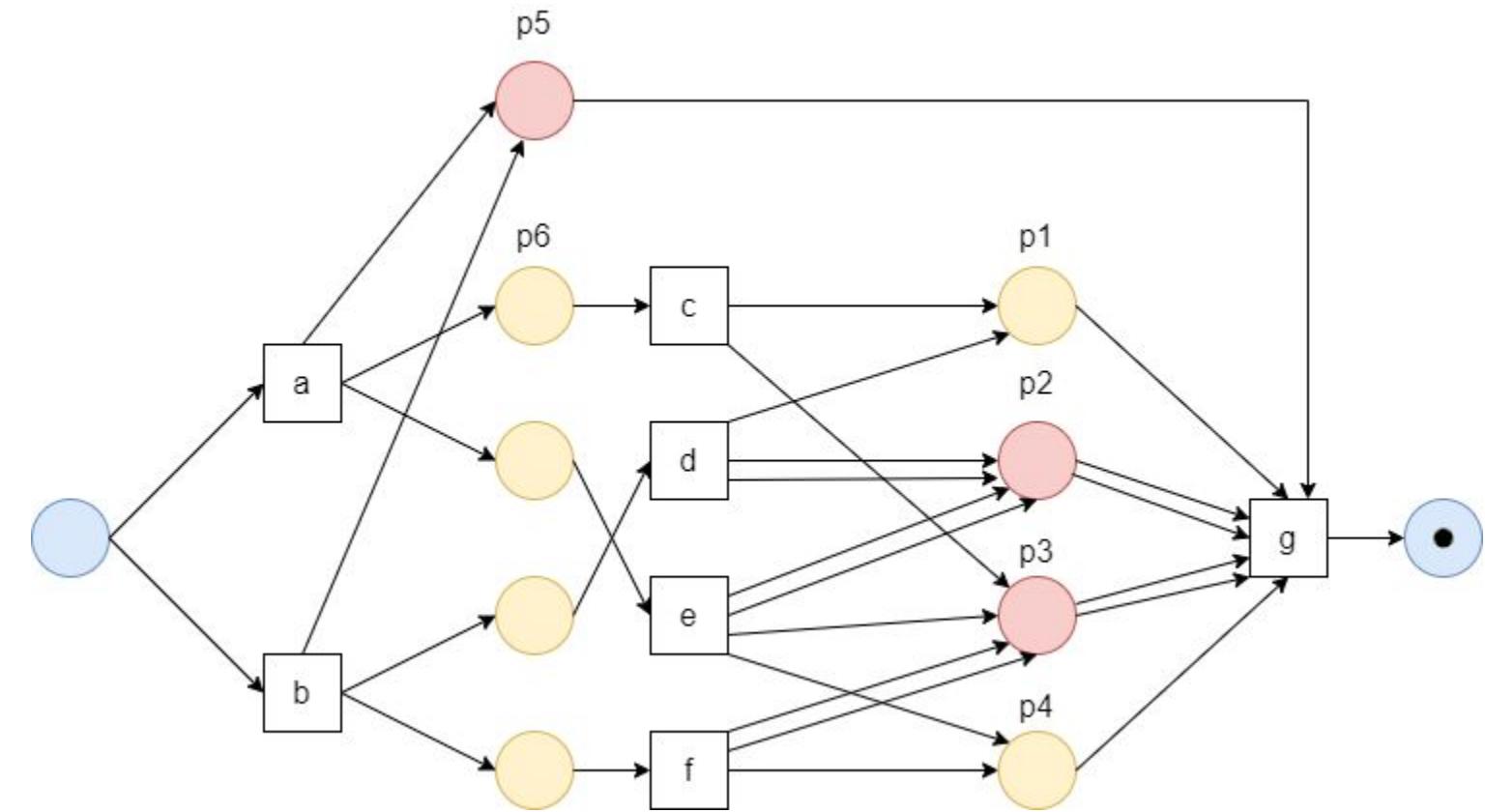
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	1	0	0	0
x_{p_7}					

Running Example: Intermediate Case

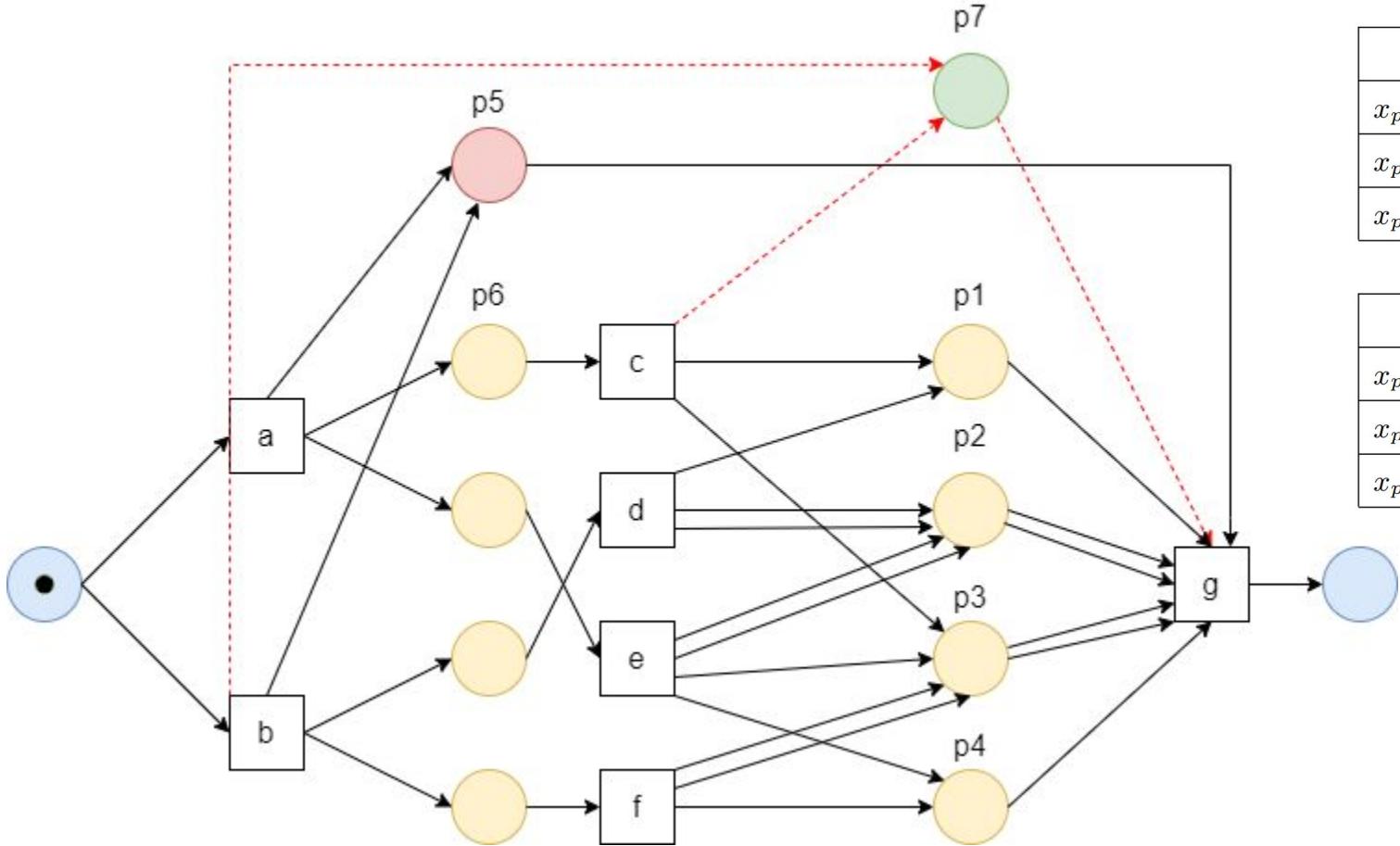
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	1	0	0	0
x_{p_7}	0	0	1	1	0

Running Example: Intermediate Case

$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	1	0	0	0
x_{p_7}	0	0	1	1	0

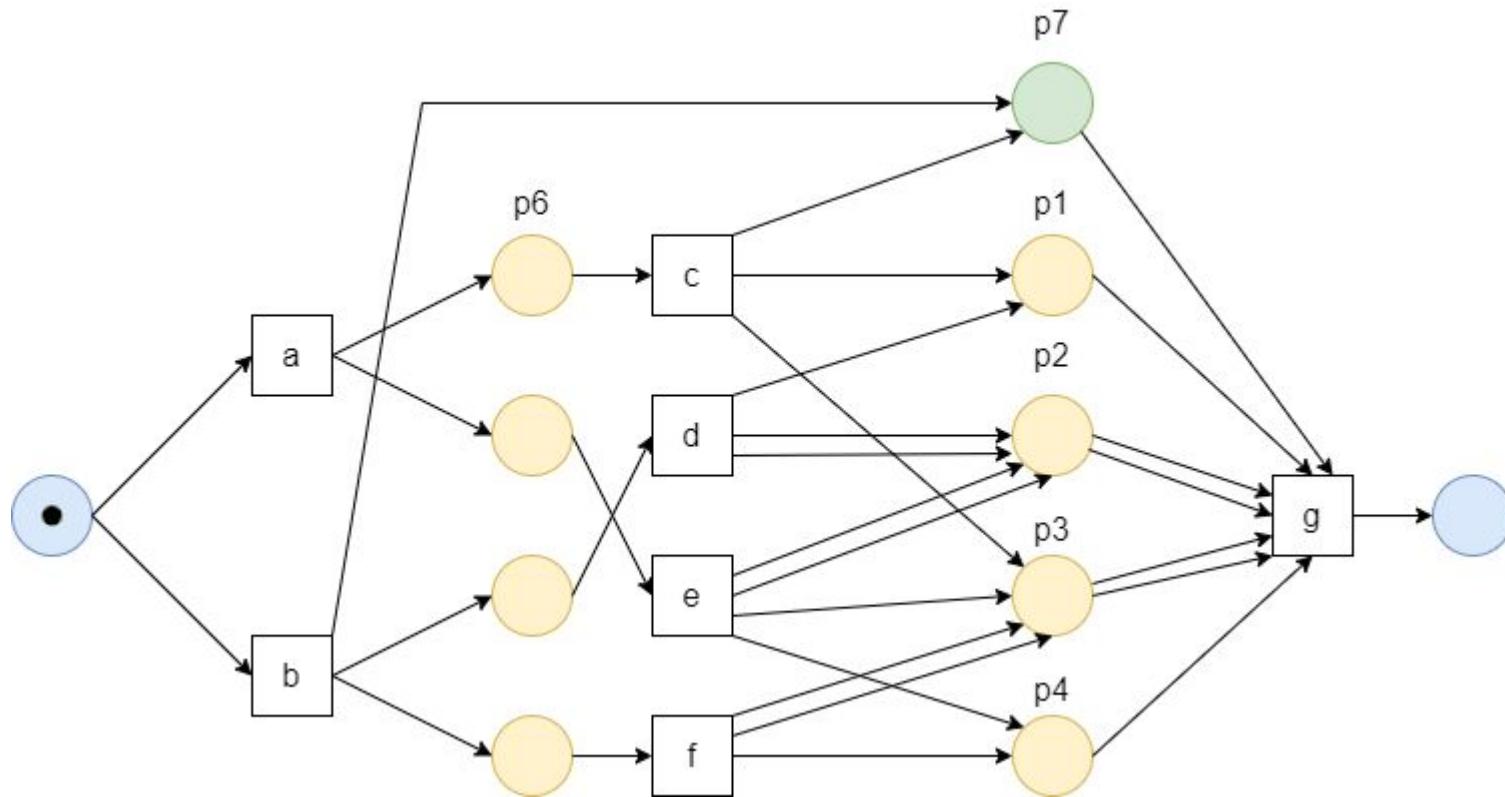
	ϵ	b	d	f	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	0	0	0	0
x_{p_7}	0	1	1	1	0

	ϵ	a	e	c	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	1	1	0	0
x_{p_7}	0	0	0	1	0

	ϵ	b	f	d	g
x_{p_5}	0	1	1	1	0
x_{p_6}	0	0	0	0	0
x_{p_7}	0	1	1	1	0

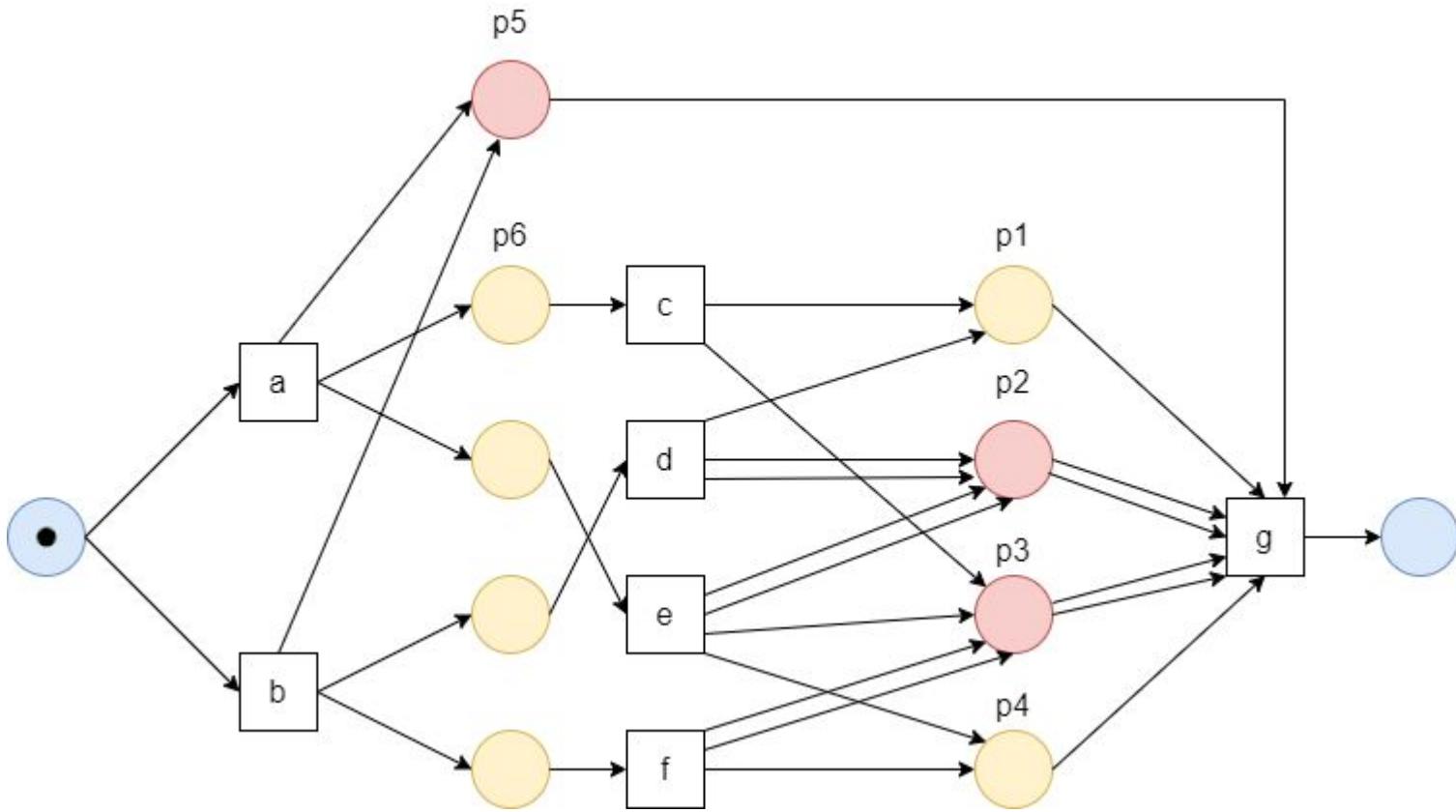
Running Example: Intermediate Case

$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



Running Example: Extended Case

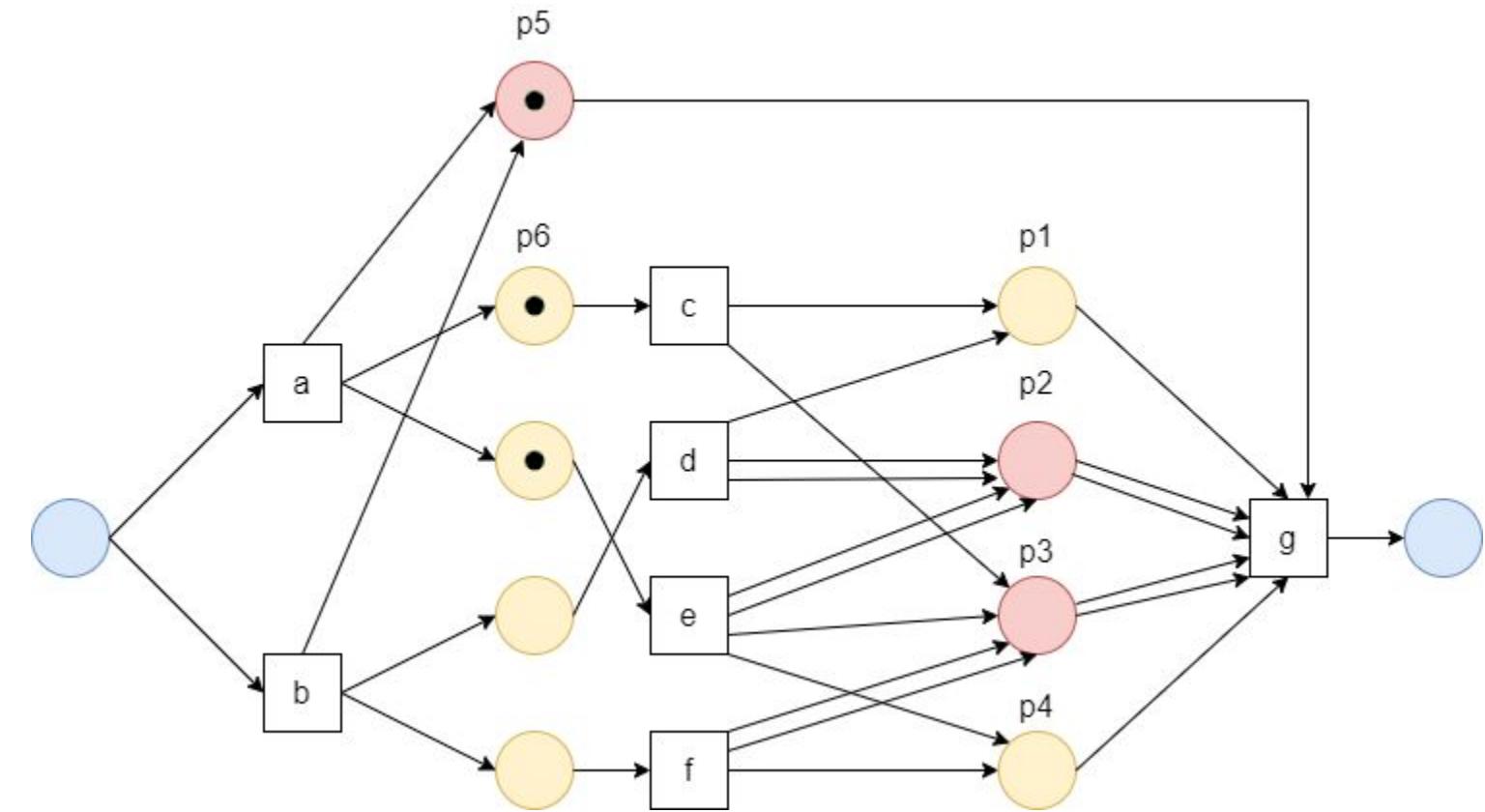
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_3}	0				
x_{p_4}	0				
x_{p_8}					

Running Example: Extended Case

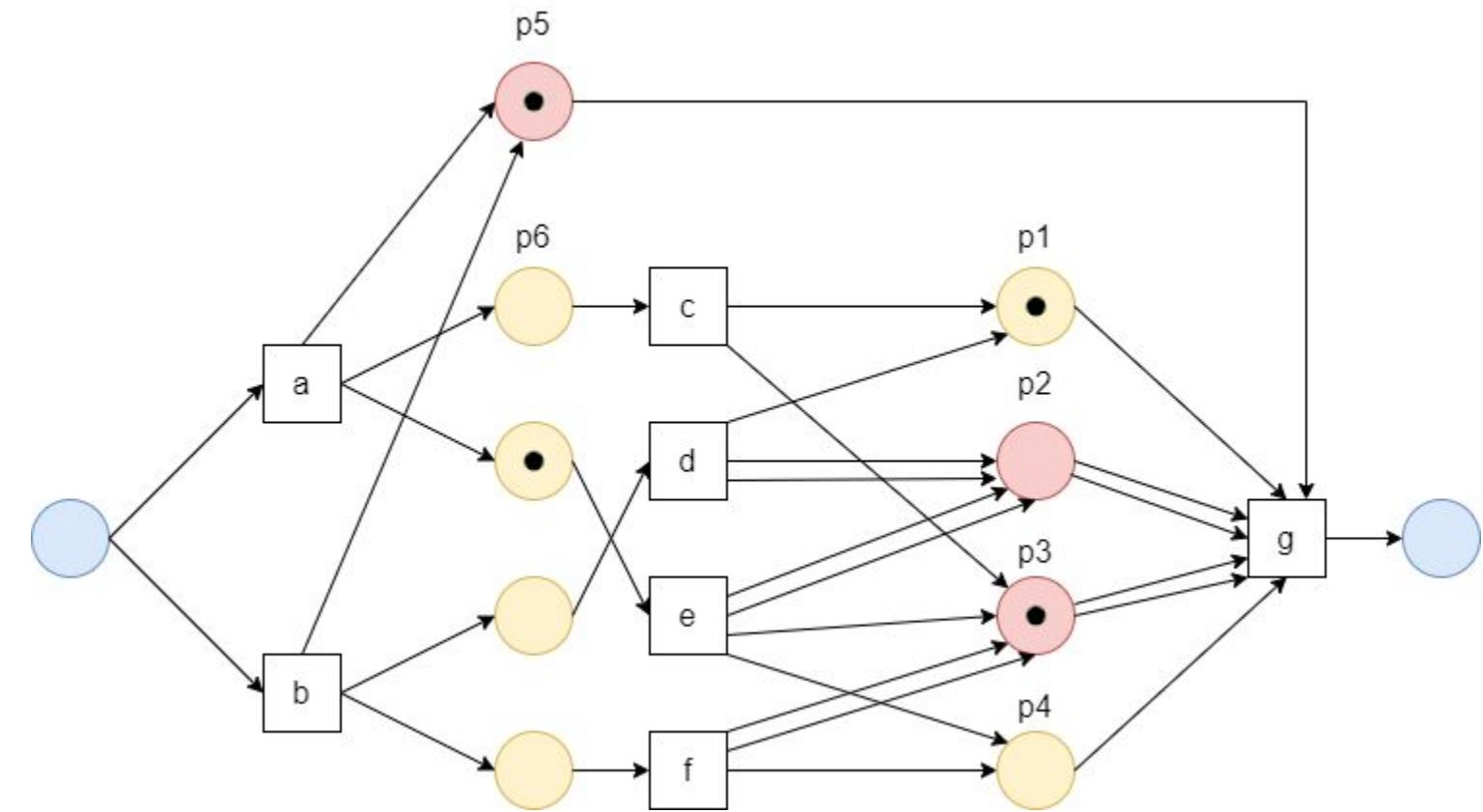
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_3}	0	0			
x_{p_4}	0	0			
x_{p_8}					

Running Example: Extended Case

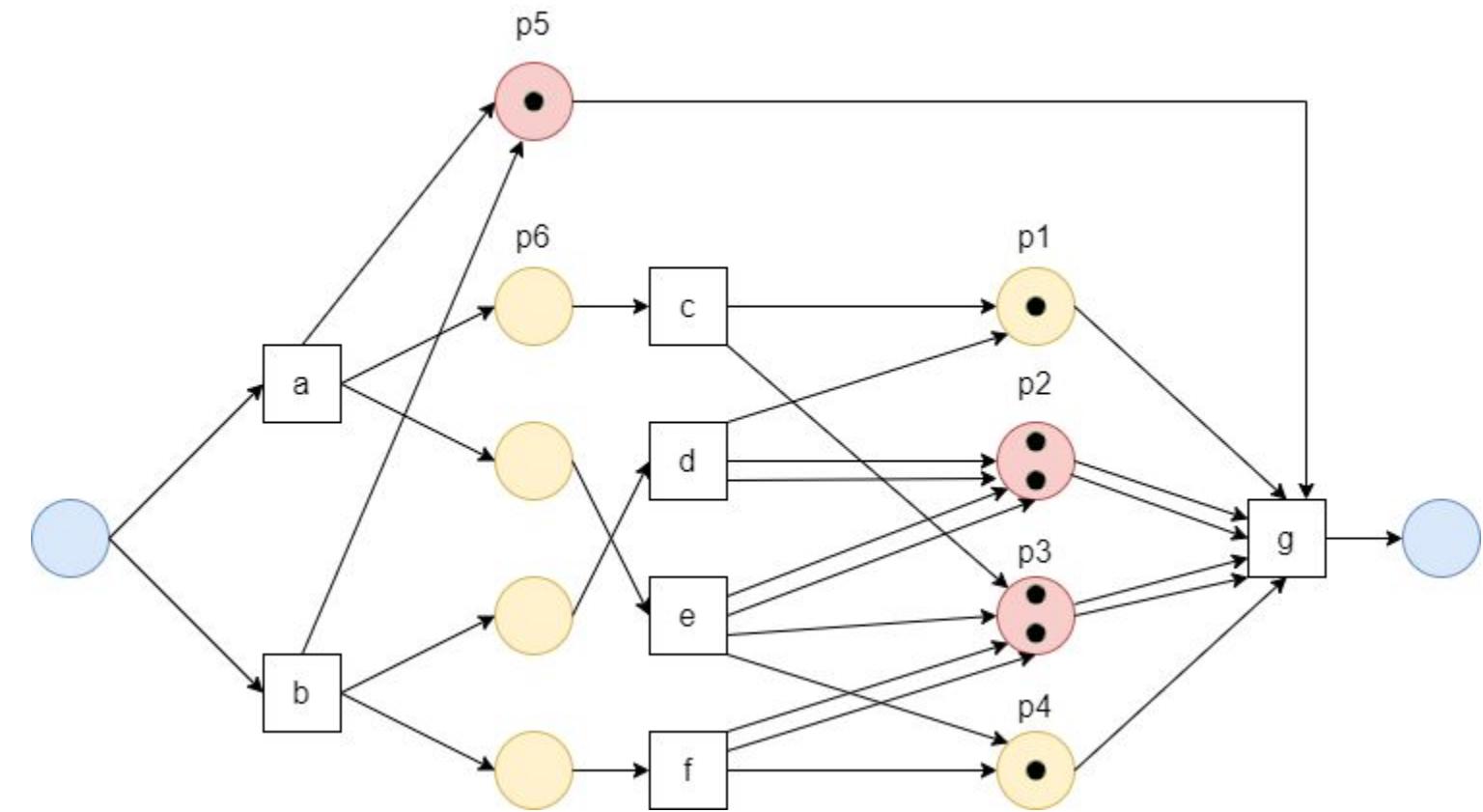
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_3}	0	0	1		
x_{p_4}	0	0	0		
x_{p_8}					

Running Example: Extended Case

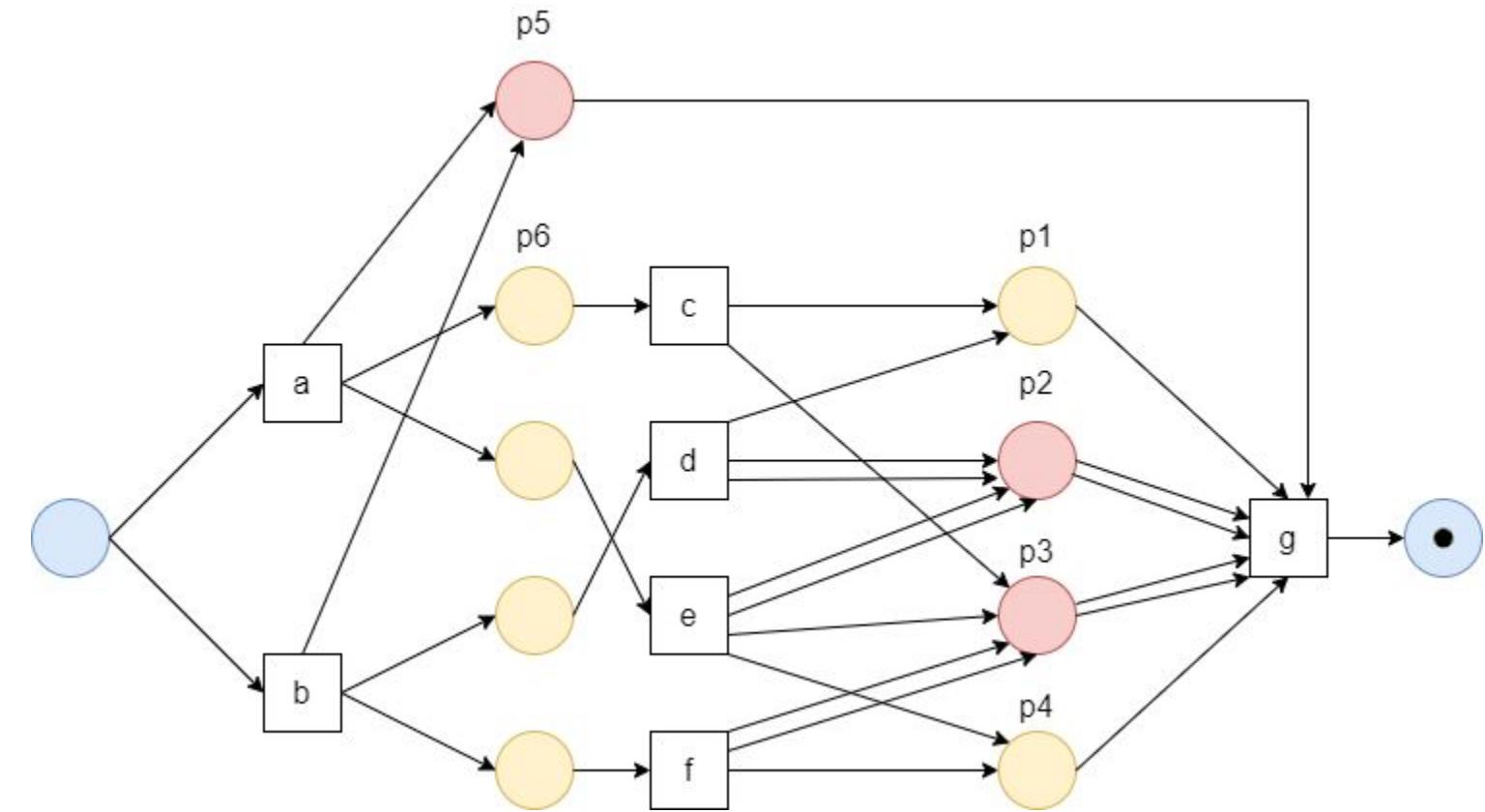
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_3}	0	0	1	2	
x_{p_4}	0	0	0	1	
x_{p_8}					

Running Example: Extended Case

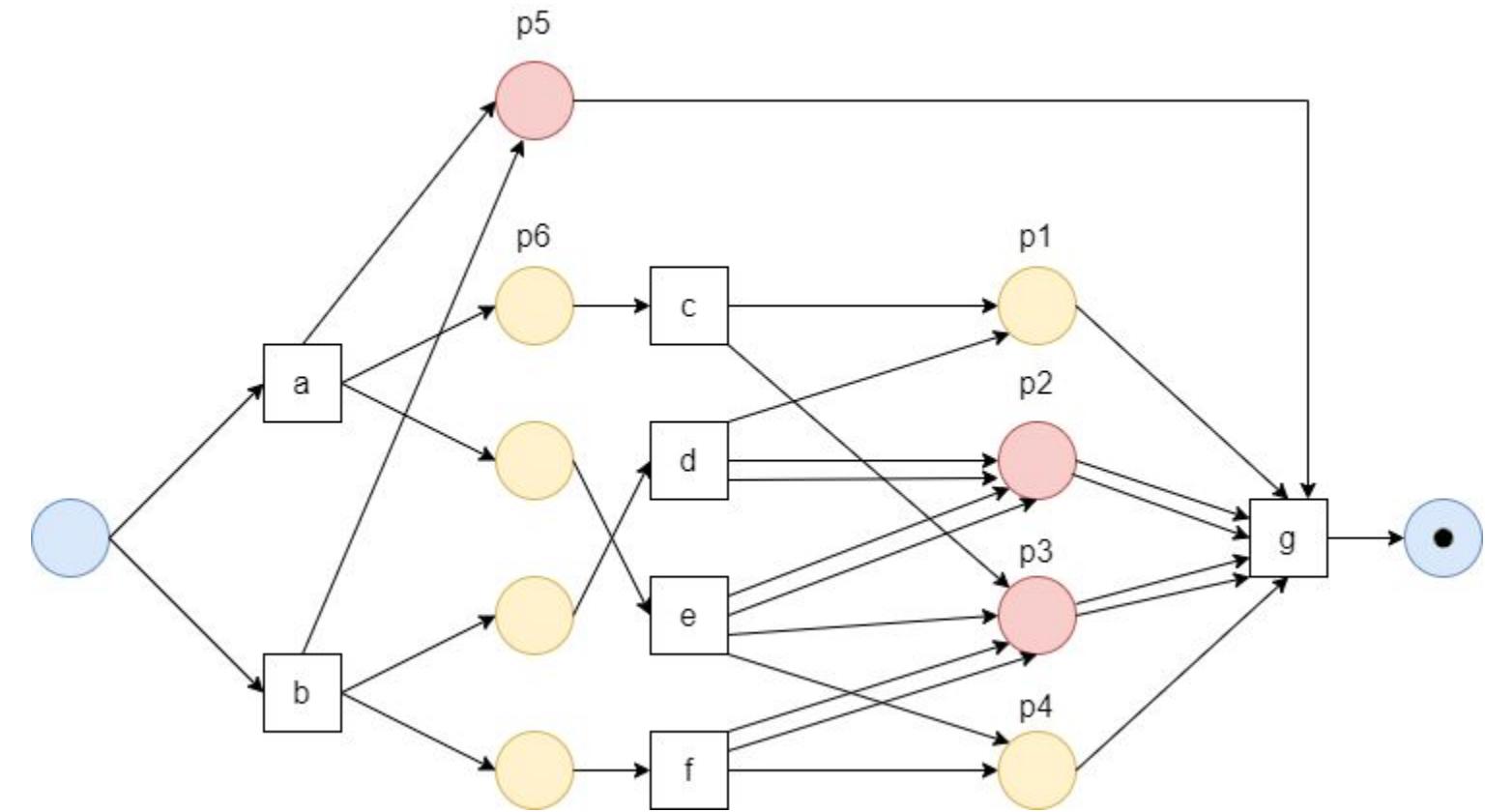
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ε	a	c	e	g
x_{p_3}	0	0	1	2	0
x_{p_4}	0	0	0	1	0
x_{p_8}					

Running Example: Extended Case

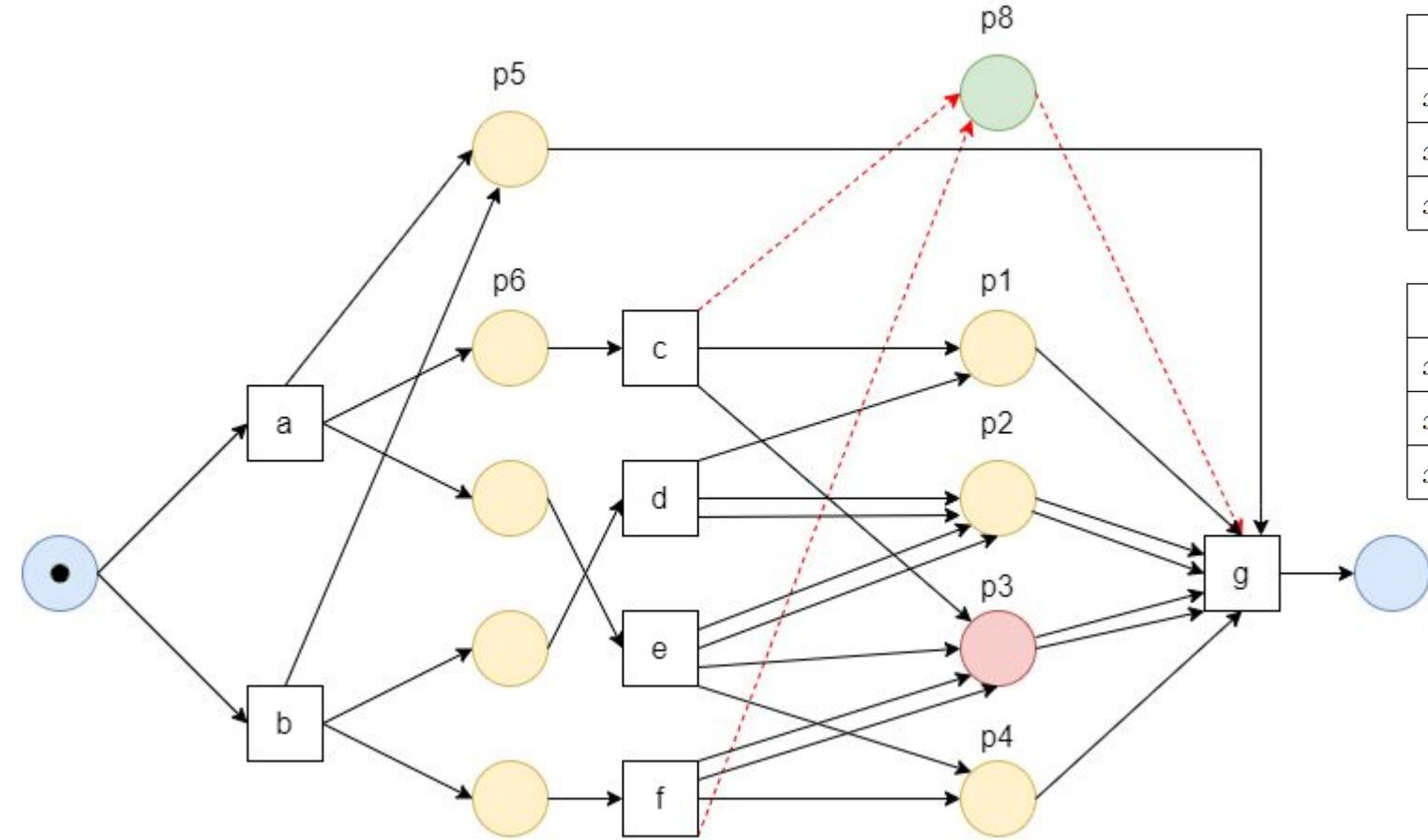
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_3}	0	0	1	2	0
x_{p_4}	0	0	0	1	0
x_{p_8}	0	0	1	1	0

Running Example: Extended Case

$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_3}	0	0	1	2	0
x_{p_4}	0	0	0	1	0
x_{p_8}	0	0	1	1	0

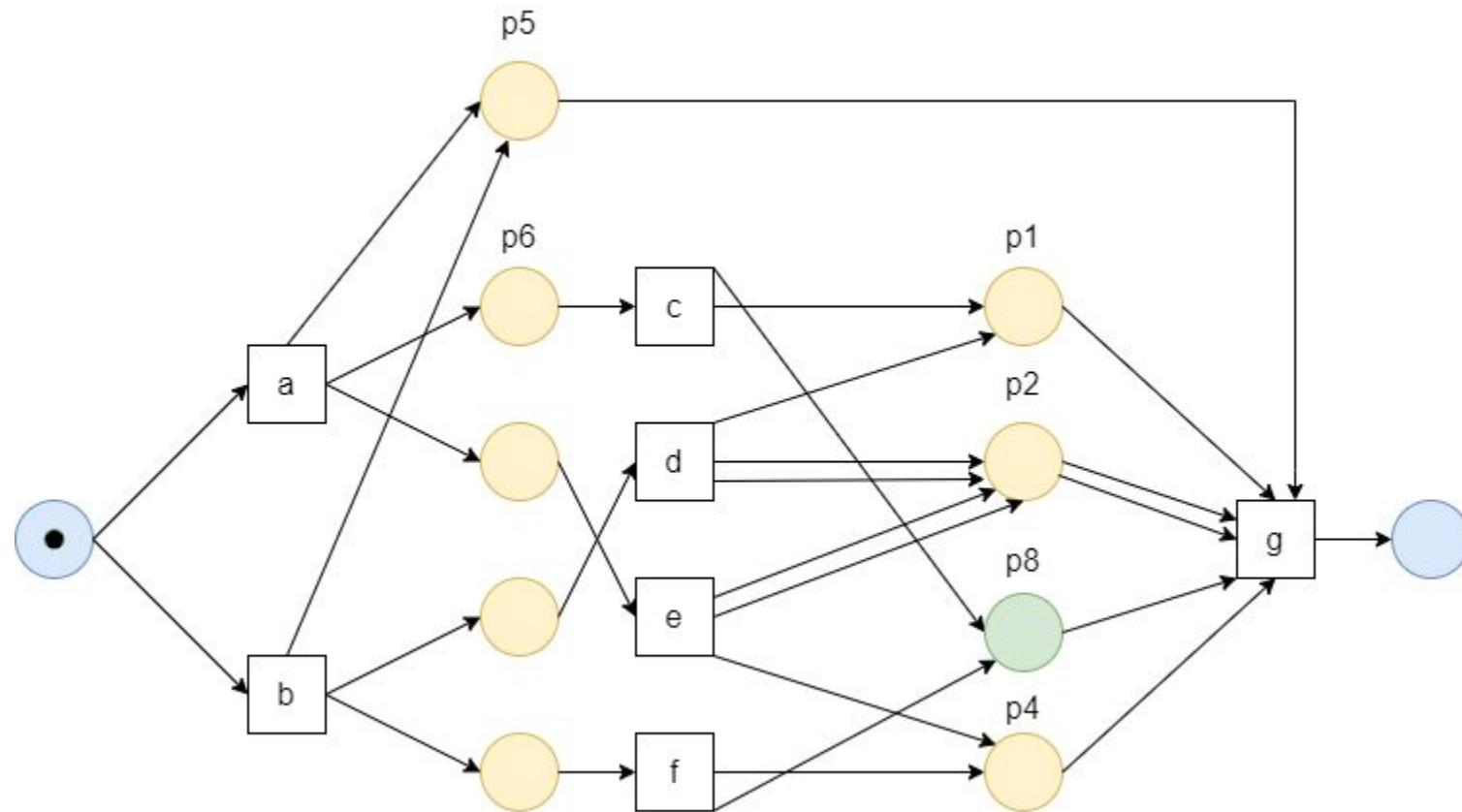
	ϵ	b	d	f	g
x_{p_3}	0	0	0	2	0
x_{p_4}	0	0	0	1	0
x_{p_8}	0	0	0	1	0

	ϵ	a	e	c	g
x_{p_3}	0	0	1	2	0
x_{p_4}	0	0	1	1	0
x_{p_8}	0	0	0	1	0

	ϵ	b	f	d	g
x_{p_3}	0	0	2	2	0
x_{p_4}	0	0	1	1	0
x_{p_8}	0	0	1	1	0

Running Example: Extended Case

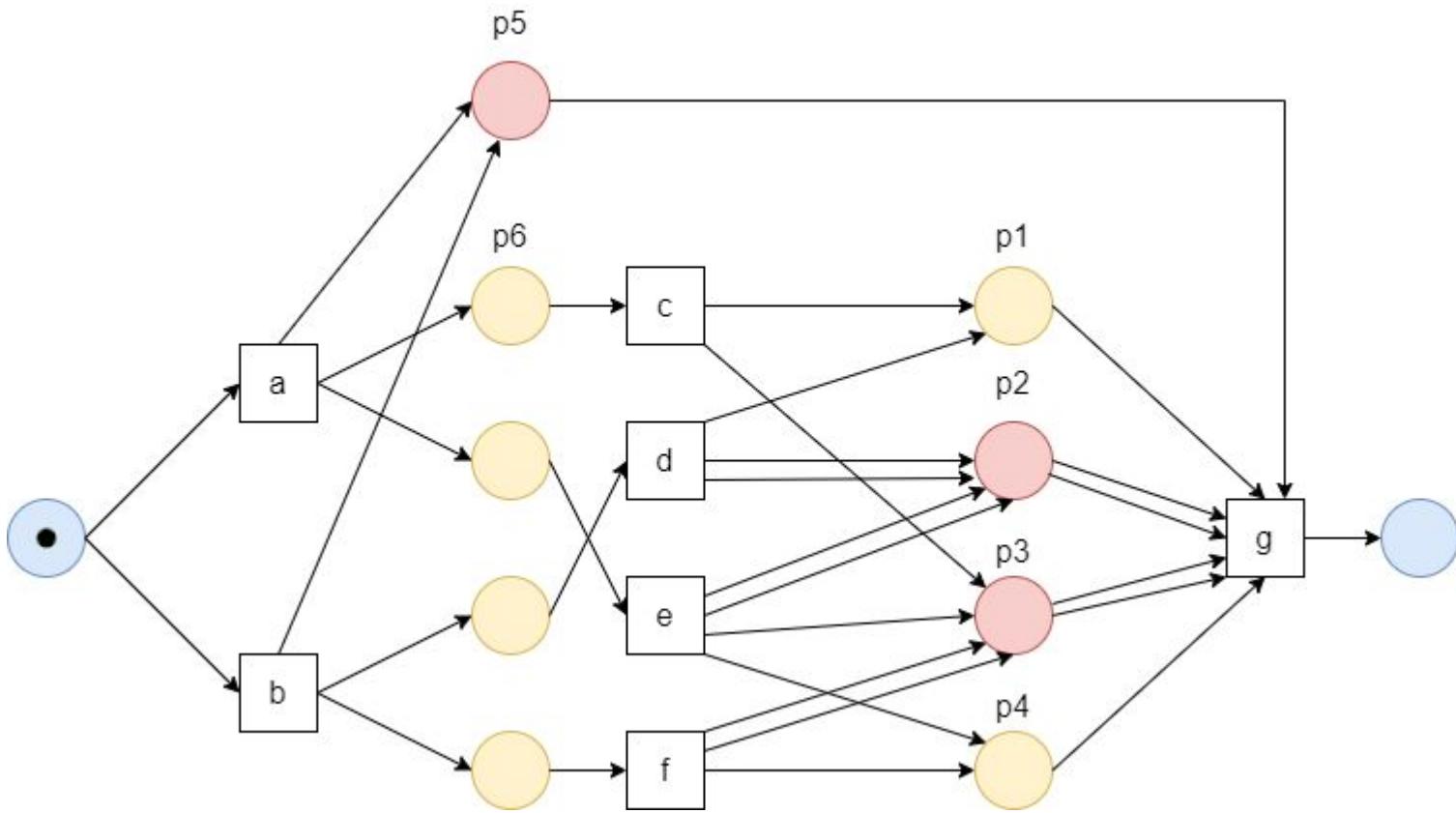
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- Realized the algorithm via its simple, intermediate and extended cases
- However, can all implicit places be discovered using this method?
- Uncovering the limitations of our implicit place removal technique

Limitations

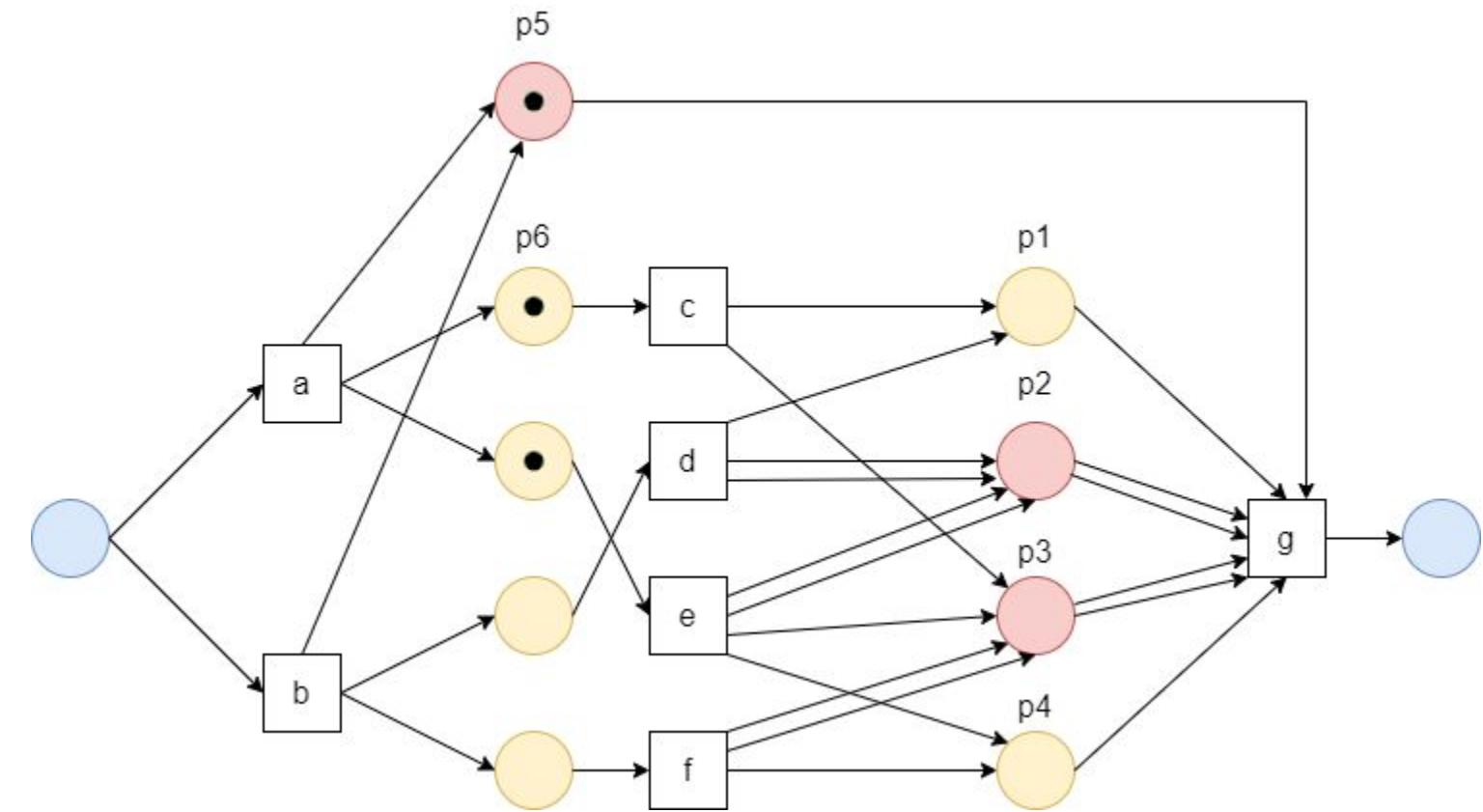
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_2}	0				
x_{p_1}	0				
x_{p_9}					

Limitations

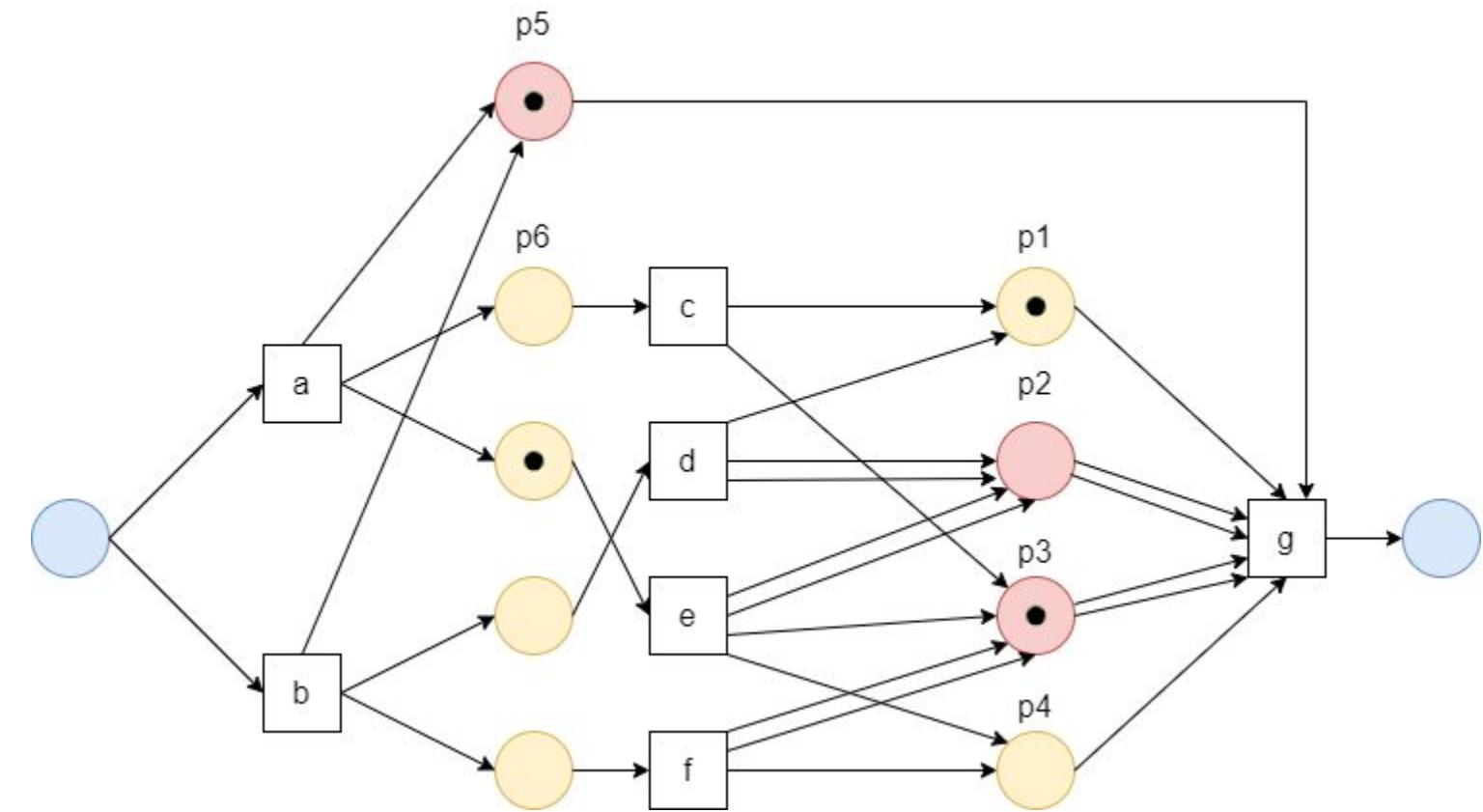
$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_2}	0	0			
x_{p_1}	0	0			
x_{p_9}					

Limitations

$$L = [\epsilon, \langle a, c, e, g \rangle^2, \langle a, e, c, g \rangle^3, \langle b, d, f, g \rangle^2, \langle b, f, d, g \rangle^4]$$



	ϵ	a	c	e	g
x_{p_2}	0	0	0		
x_{p_1}	0	0	1		
x_{p_9}	0	0	-1		

$x_{p_2} > x_{p_i}$ does not hold for any i

- Understood the motivation behind removing implicit places
- Examined the main idea of our method
- Witnessed running examples of the algorithm
- Recognized limitations of our technique



Next Steps

- When and where is this algorithm actually beneficial?
- Diving into the application to the eST-Miner
- Are there any associated implementation challenges?

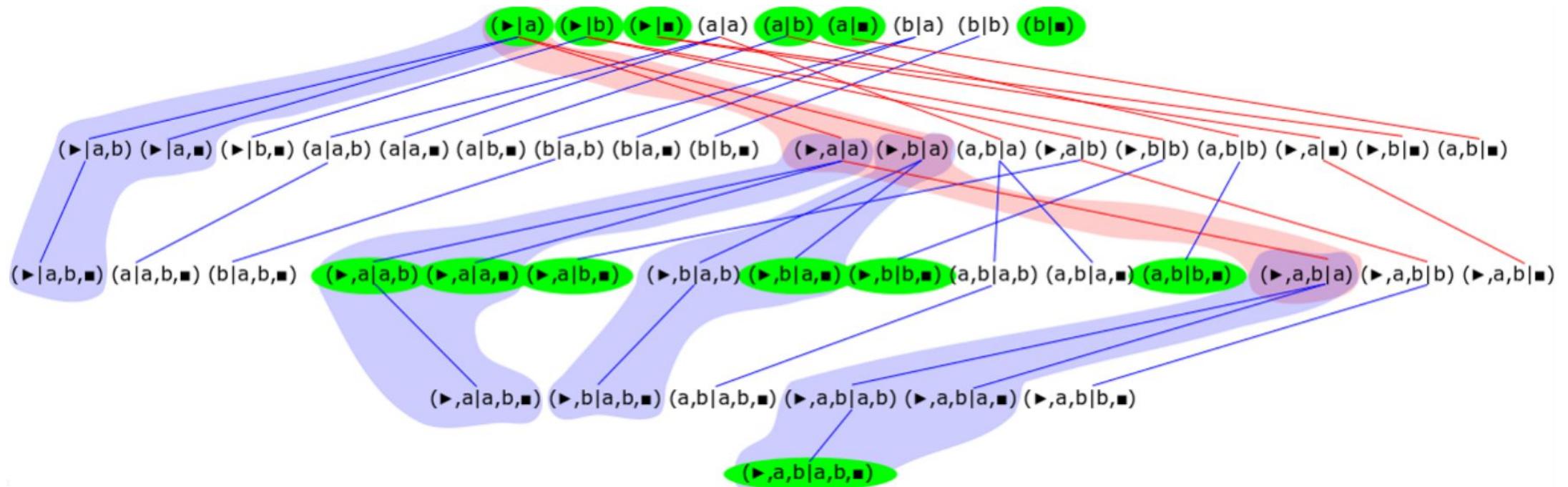


Application

- **Using the eST-Miner as a process discovery algorithm**
- **Only the event log is used**
- **Candidate places are traversed and evaluated using token replay**
- **Replaying the event log is crucial to removing implicit places**

Application

➤ A clever way to enumerate places using a *tree* like structure





Application

- The discovery of a set of all *fitting* places is guaranteed
- A significant number of implicit places are also discovered
- Removed by solving an Integer Linear Programming Problem
- Immense time and space complexity
- Reason for applying our implicit place removal technique



Application: Variants

Final Place Removal (FPR)

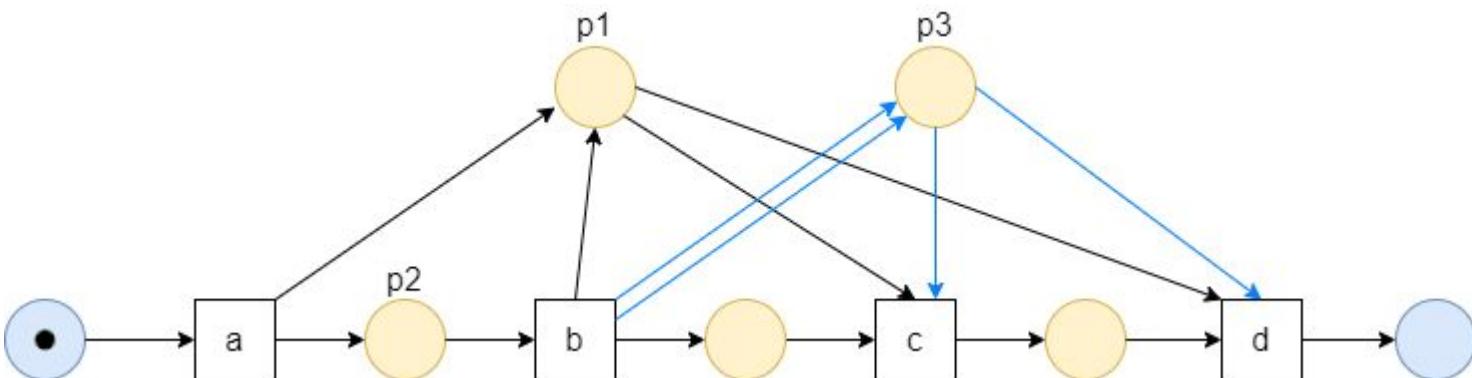
- The final set of places is computed first
- Then, all places are compared and implicit places are removed

Concurrent Place Removal (CPR)

- Every discovered place is directly compared to existing places
- Removed immediately if found to be implicit

Challenges

- The eST-Miner returns a Petri net without arc weights
- However, arc weights are required



	ϵ	a	b	c	d
x_{p_1}	0	1	2	1	0
x_{p_2}	0	1	0	0	0
x_{p_3}	0	0	2	1	0



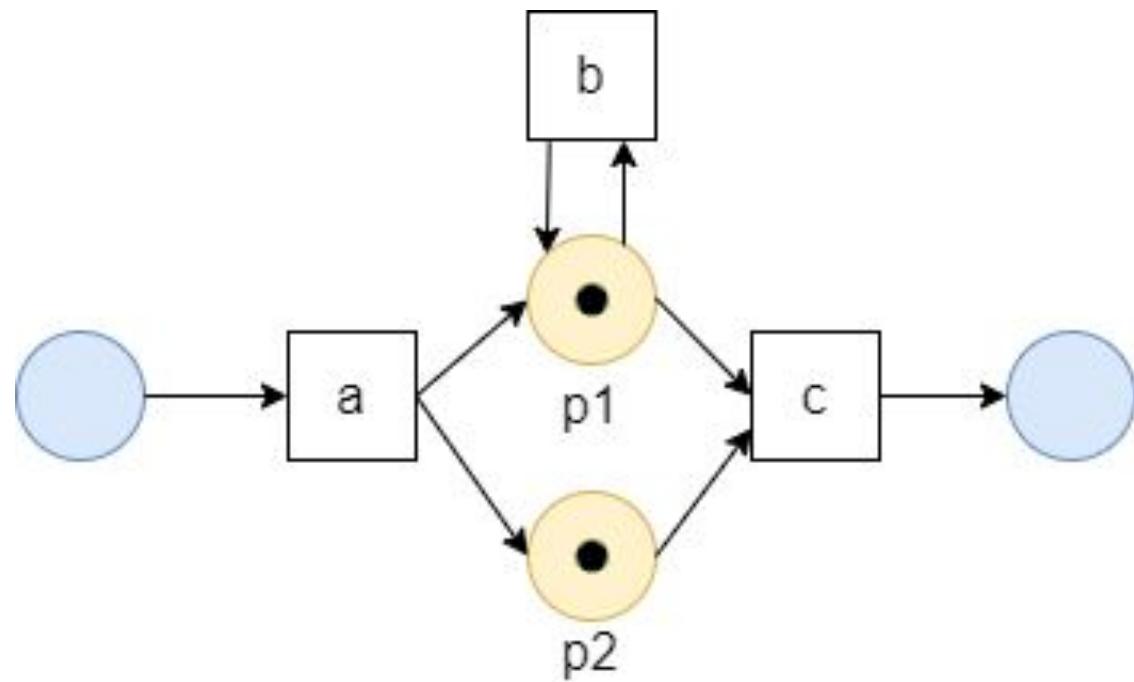
Challenges

- The eST-Miner discovers only fitting places
- Places empty at the beginning and end of token replay
- Place emptiness is guaranteed by construction

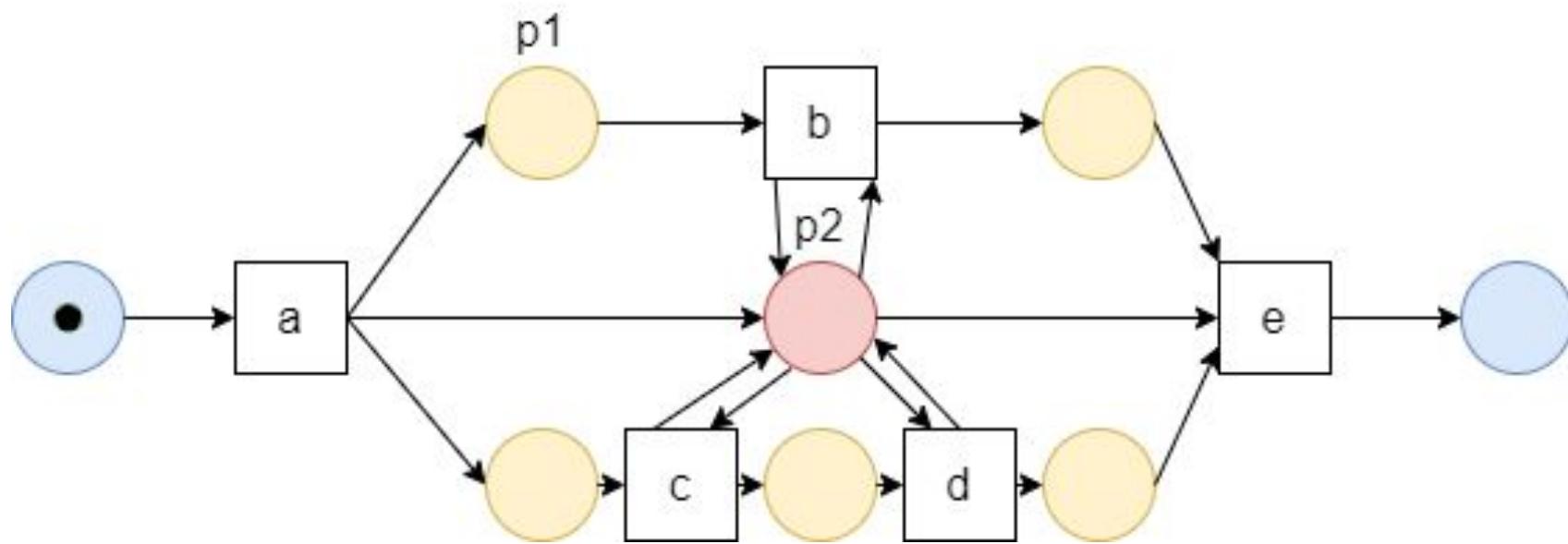
$$x_{p_1} = x_{p_2} = 0 \quad (4)$$

$$x_{p_3} = 0 \quad (5)$$

eST-Miner allows for Petri nets with self-loops

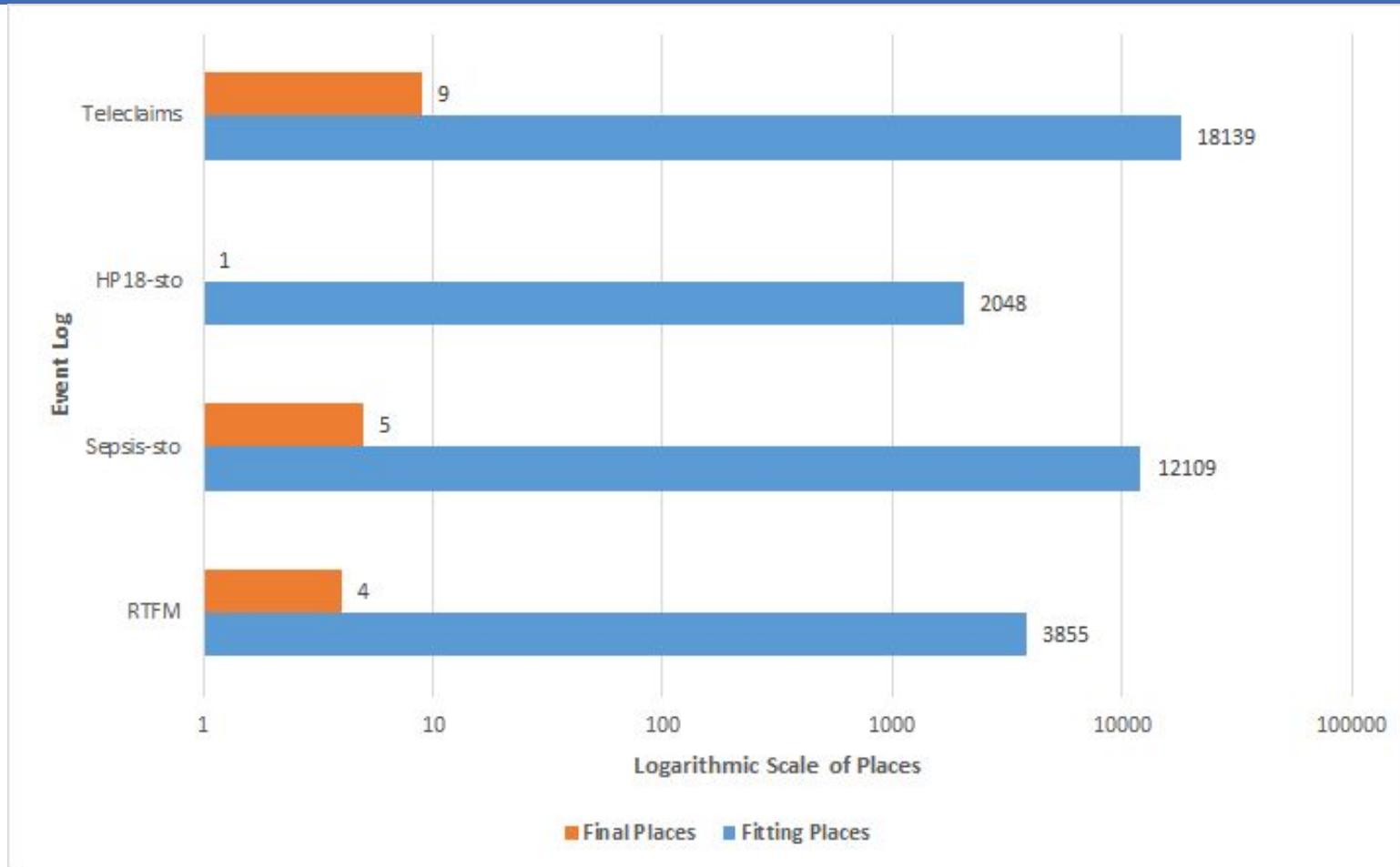


Special case of places with self-loops in parallel constructs



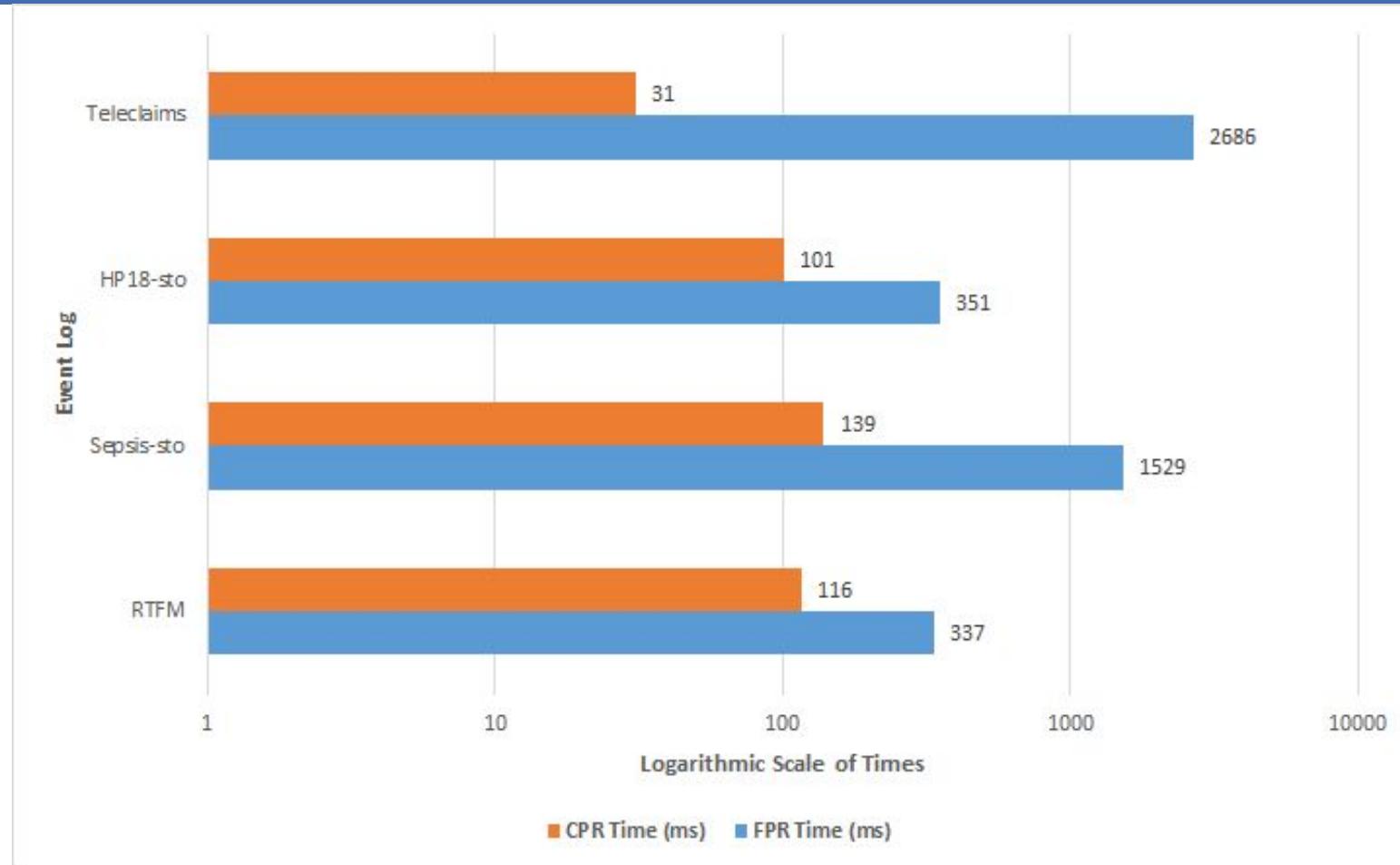
Evaluation: Space Efficiency

Remaining final places are significantly less than total fitting places



Evaluation: Time Efficiency

CPR is always significantly faster than FPR





Conclusion

- An approach to identify and remove implicit places from Petri nets
- Combination with the eST-Miner process discovery algorithm
- Sequential and concurrent application schemes
- Robust time and space efficiency of the CPR variant



Future Work

- **Further investigations with the eST-Miner**
 - **Increasing the efficiency of the candidate traversal step**
 - **Returning results after a certain running time**
- **Choosing the order of place comparisons**
- **Solving the problem of self-loop places in parallel constructs**
- **Application to the Inductive-Miner process discovery algorithm**

Thank you!

Questions?



References

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- [2] W. Aalst and A. Ter. Verification of workflow task structures: A petri-net-based approach. *Information Systems*, 25:43–69, 03 2000.
- [3] R. Bergenthal, J. Desel, R. Lorenz, and S. Mauser. Process mining based on regions of languages. In G. Alonso, P. Dadam, and M. Rosemann, editors, *Business Process Management*, pages 375–383, Berlin, Heidelberg, 2007. Springer Berlin Heidelberg.
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