Removing Implicit Places Using Regions for Process Discovery

Seminar - Selected Topics in Process Mining

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Outline

- Introduction
- Motivation
- Preliminaries
- Main Idea
- Running Example
- Limitations
- Application
- Evaluation
- Conclusion
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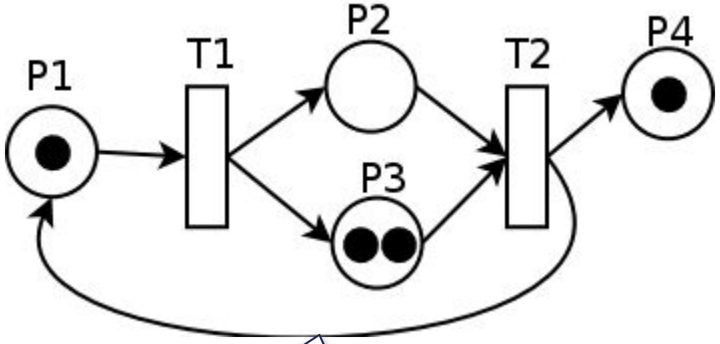
Introduction

Input: Event Log

Output: Process model

Process Discovery



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

Preliminaries

- 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

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

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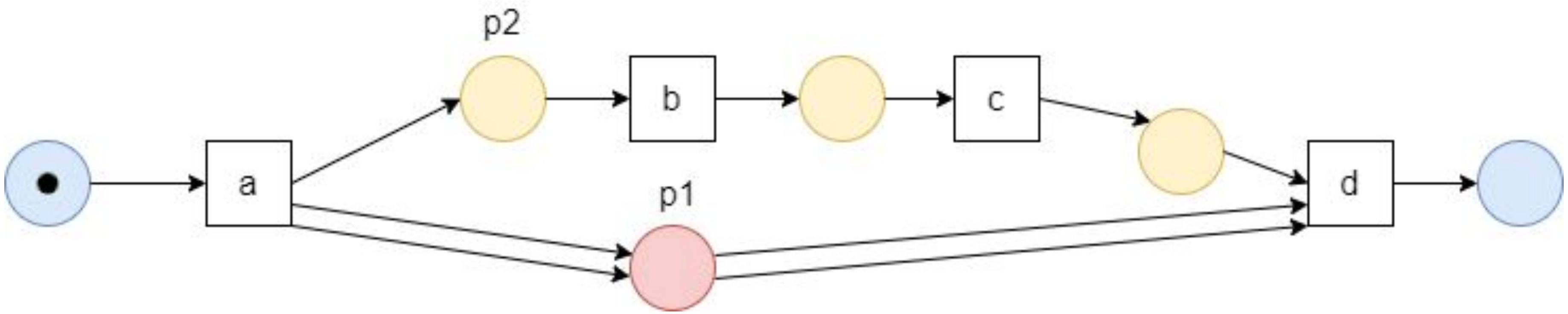
Preliminaries

- 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 -> $\mathbb{N}_0$
- An implicit place p does not contribute to a Petri net's behaviour



Preliminaries

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

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

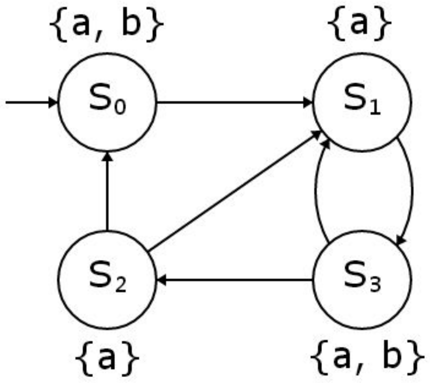
	ε	a	b	c	d
x_{p_2}	0	1	0	0	0

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

Preliminaries: Region Theory

- 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 $x_{p1} > x_{p2}$ for the prefix-closed language of N, then

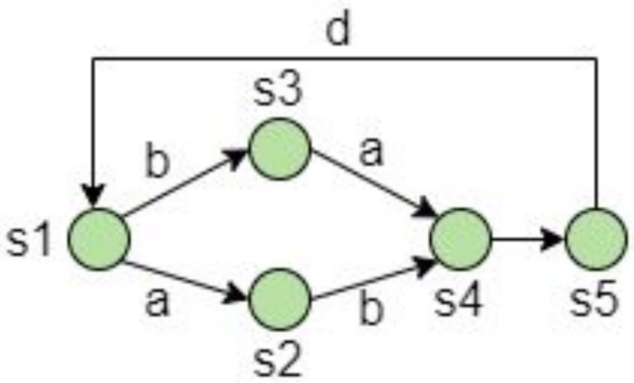
$$x_{p_3} = x_{p_1} - x_{p_2} \quad (3)$$

  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



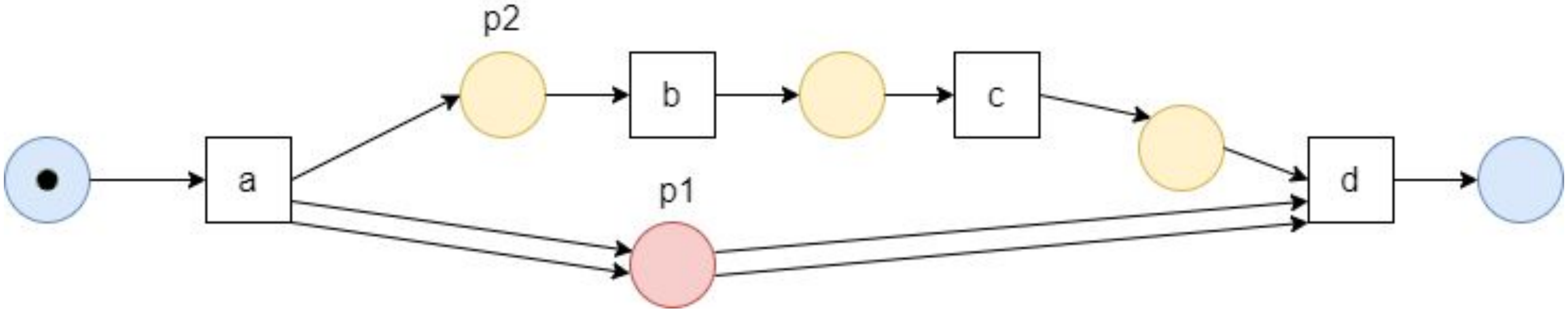
$r_1 = \{s1, s2\}$
$r_2 = \{s1, s3\}$
$r_3 = \{s2, s4\}$
$r_4 = \{s3, s4\}$
$r_5 = \{s5\}$

- 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

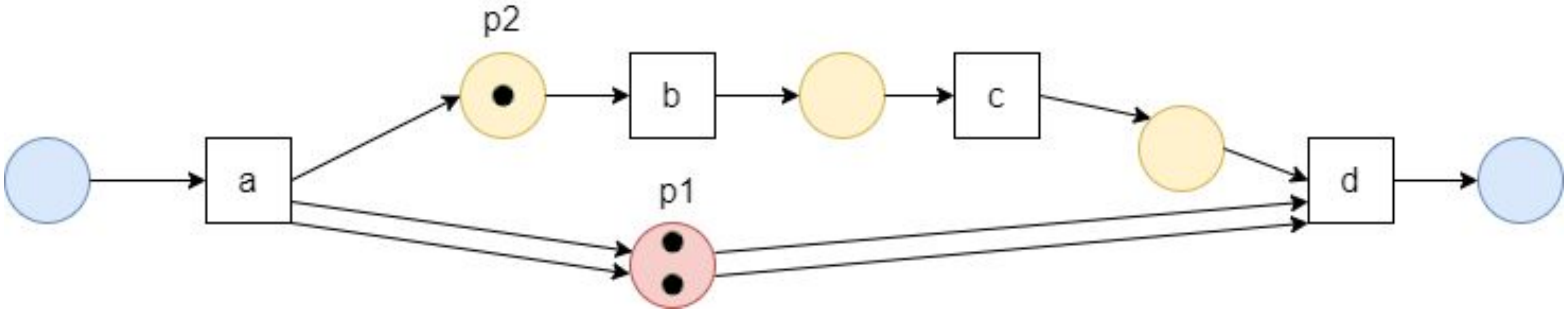
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



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

Running Example: Simple Case

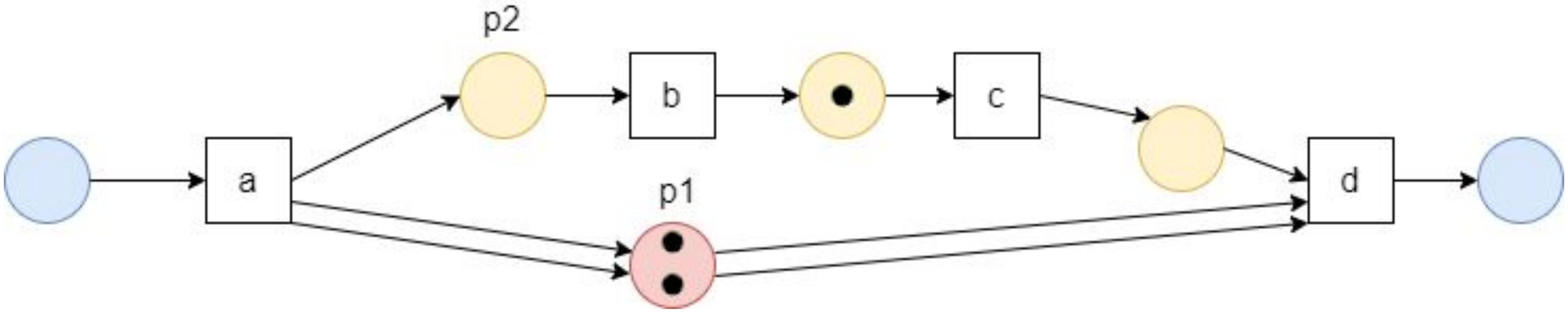
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



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

Running Example: Simple Case

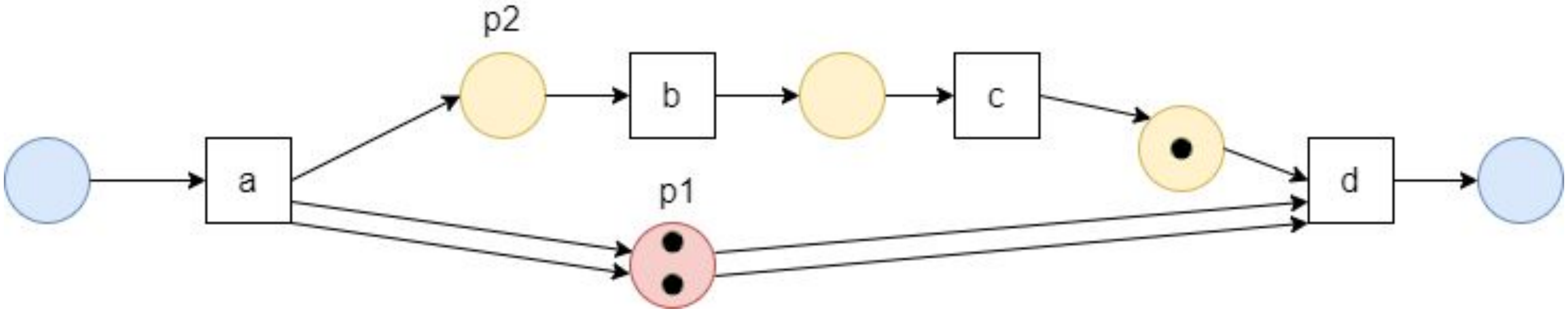
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



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

Running Example: Simple Case

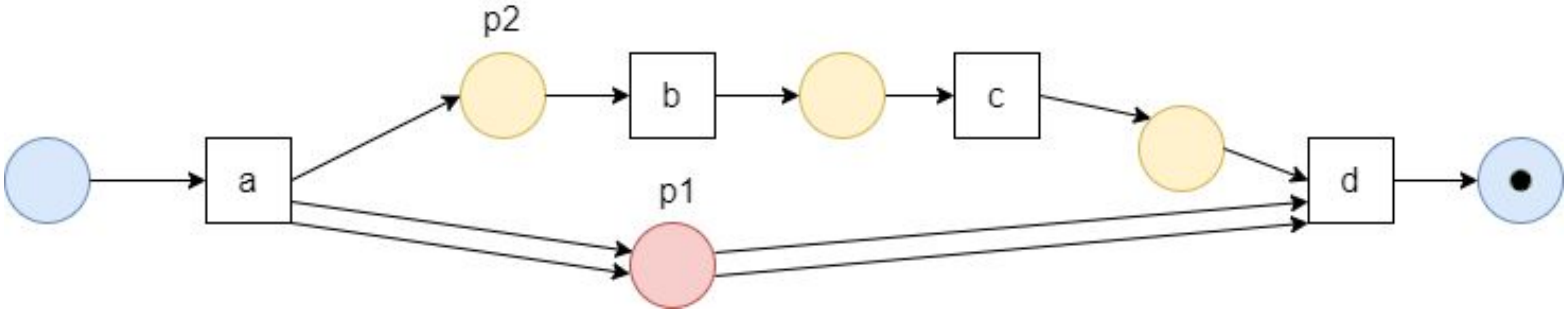
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	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

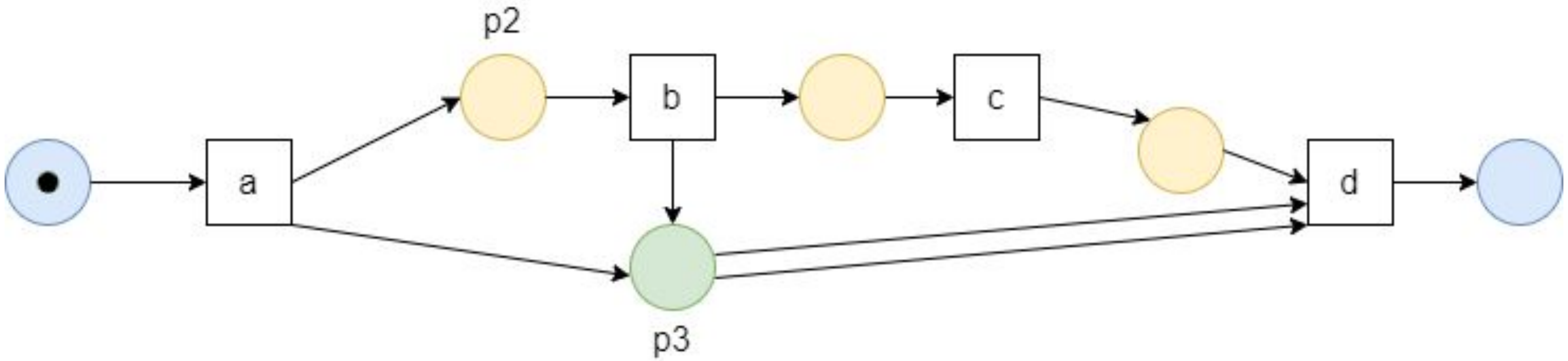
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	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

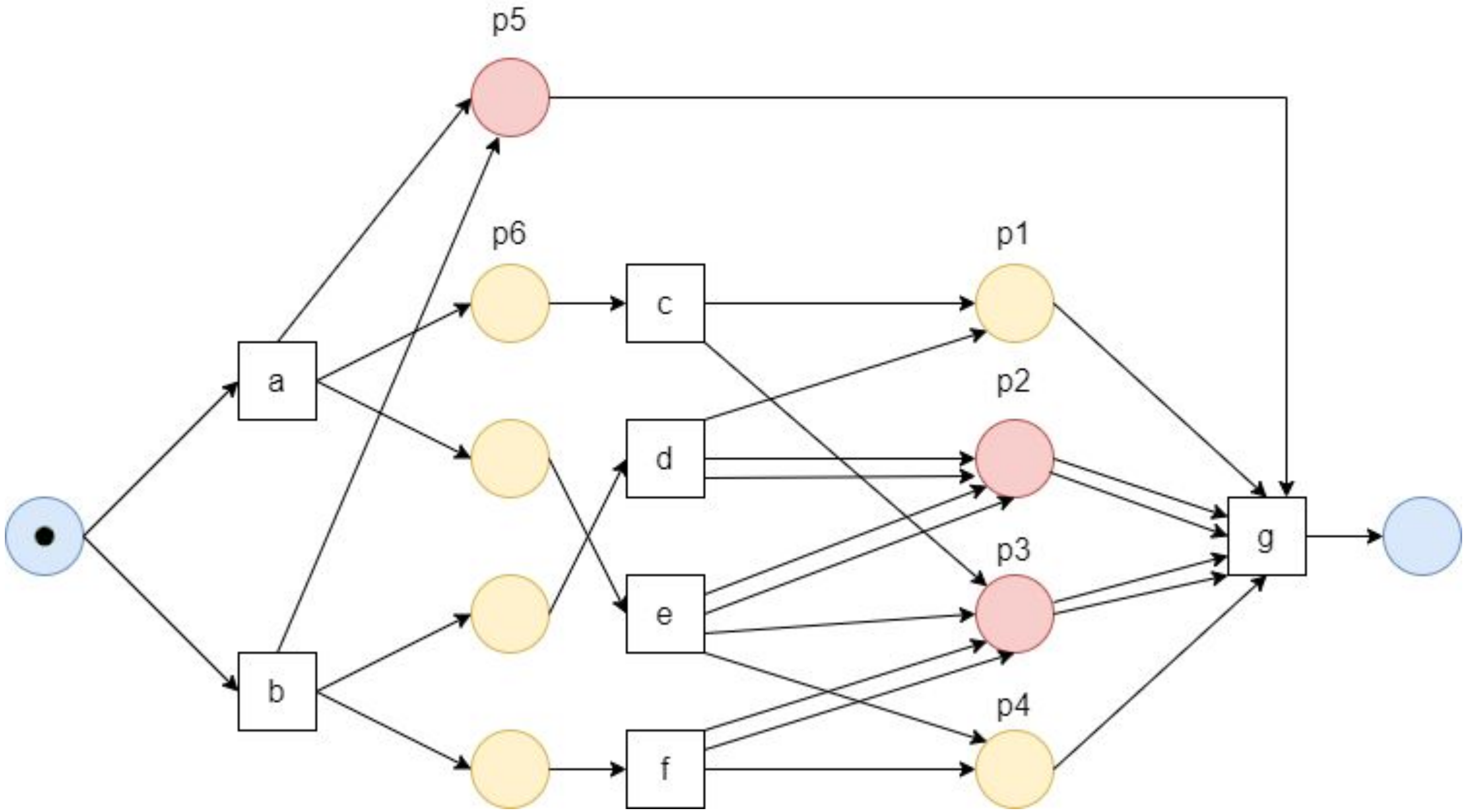
$$L = [\epsilon, \langle a, b, c, d \rangle^4]$$



	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

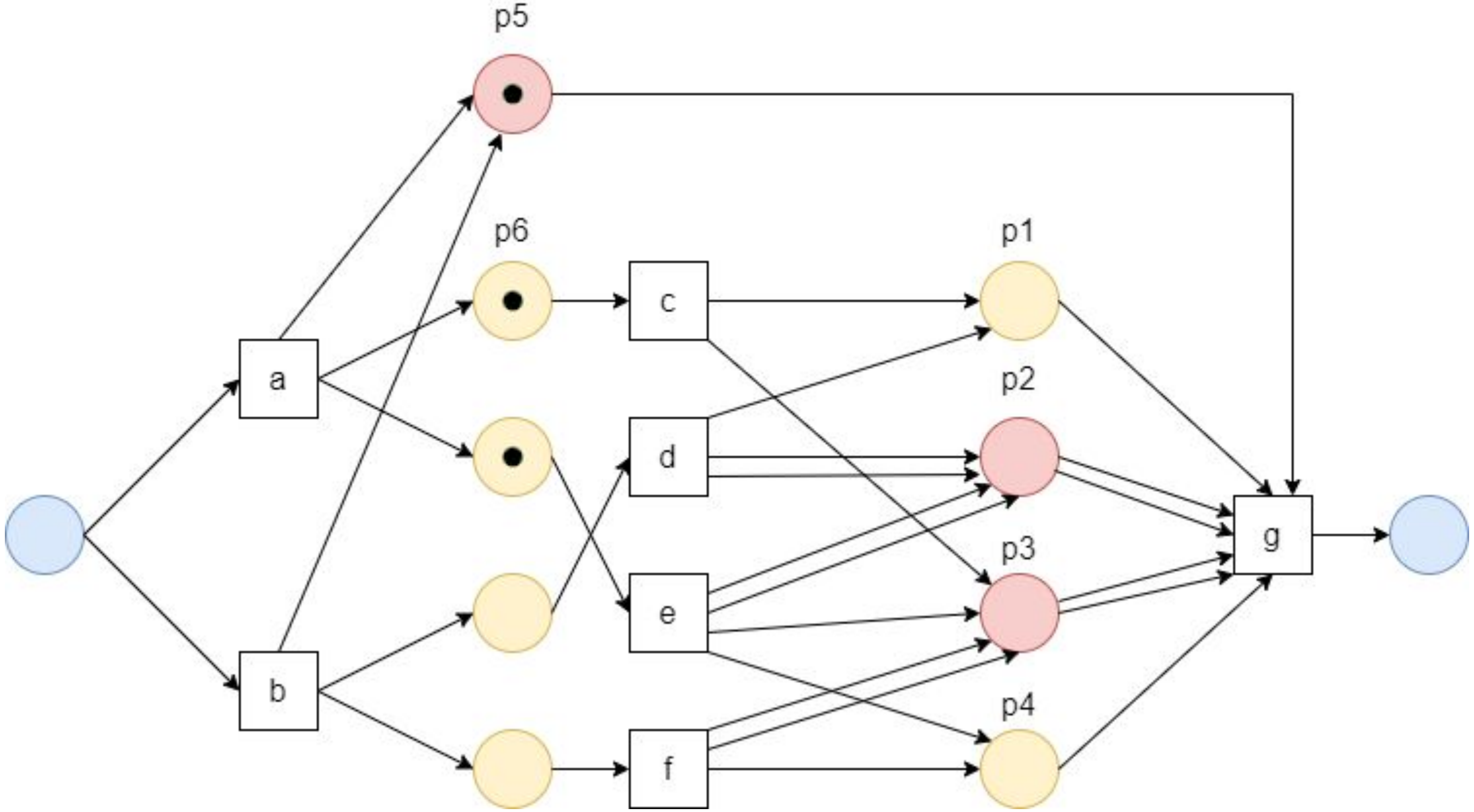
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	a	c	e	g
x_{p5}	0				
x_{p6}	0				
x_{p7}					

Running Example: Intermediate Case

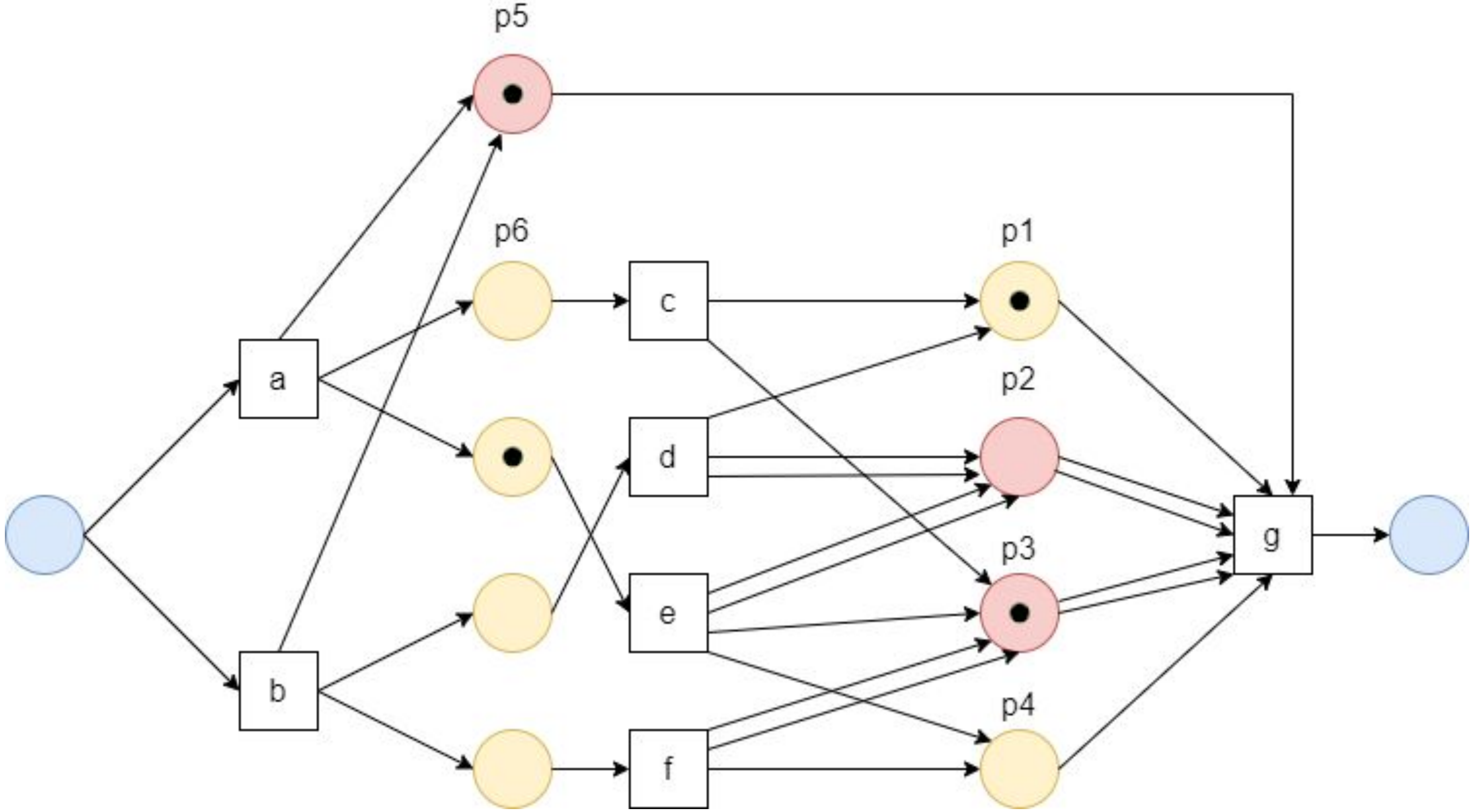
$$L = [\epsilon, \langle a, c, e, g\rangle^2, \langle a, e, c, g\rangle^3, \langle b, d, f, g\rangle^2, \langle b, f, d, g\rangle^4]$$



	ε	a	c	e	g
x_{p5}	0	1			
x_{p6}	0	1			
x_{p7}					

Running Example: Intermediate Case

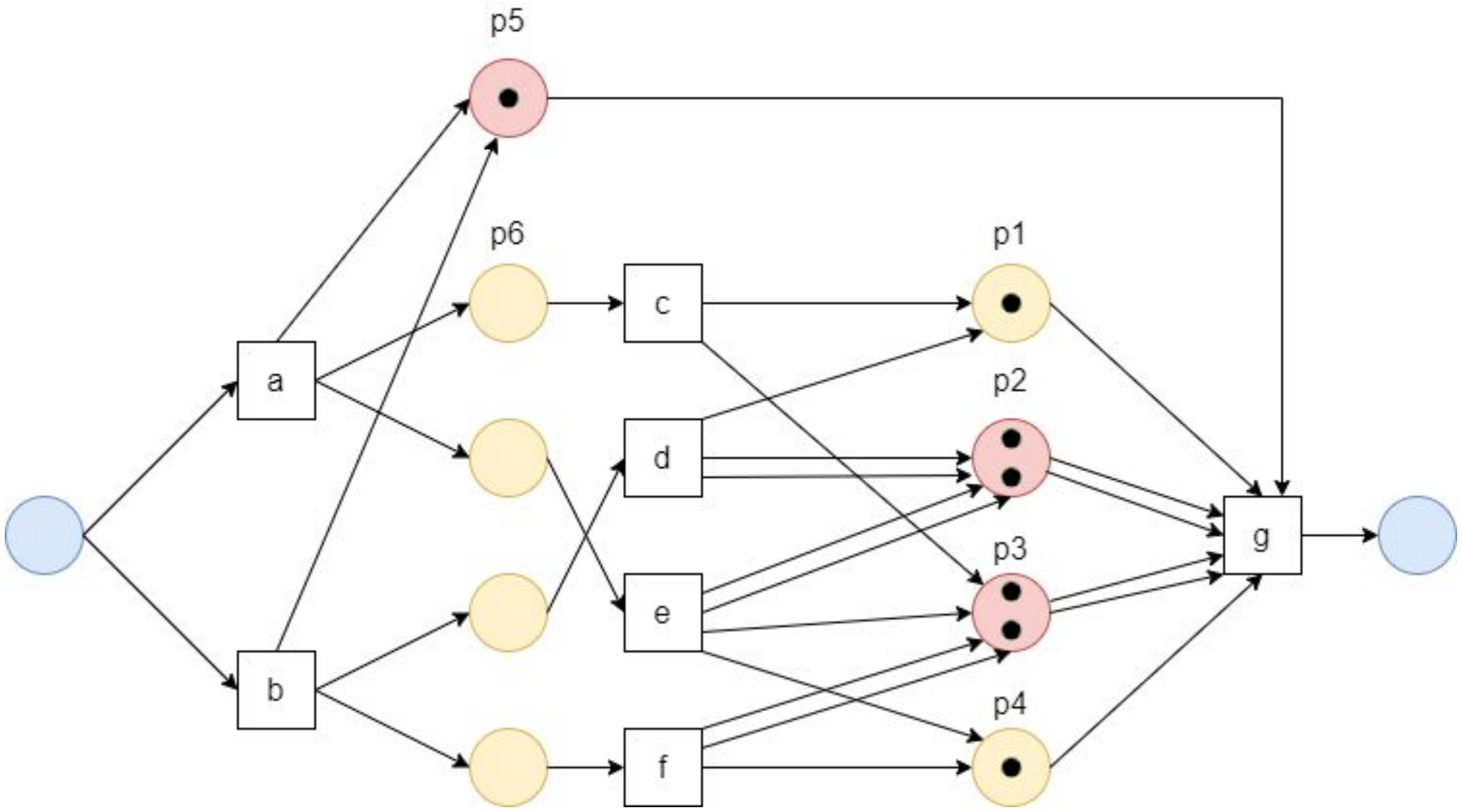
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



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

Running Example: Intermediate Case

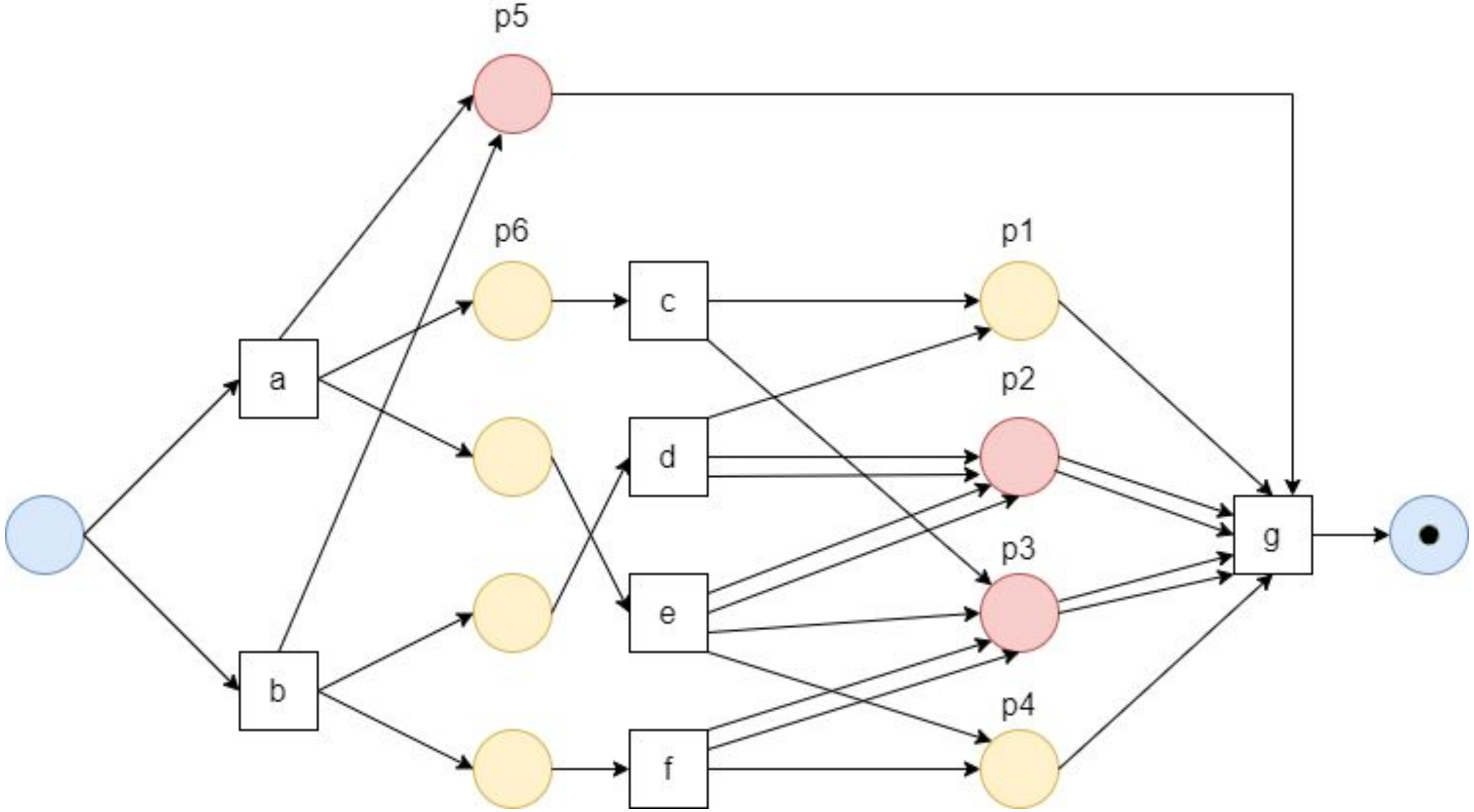
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	**a**	**c**	**e**	**g**
x_{p5}	0	1	1	1	
x_{p6}	0	1	0	0	
x_{p7}					

Running Example: Intermediate Case

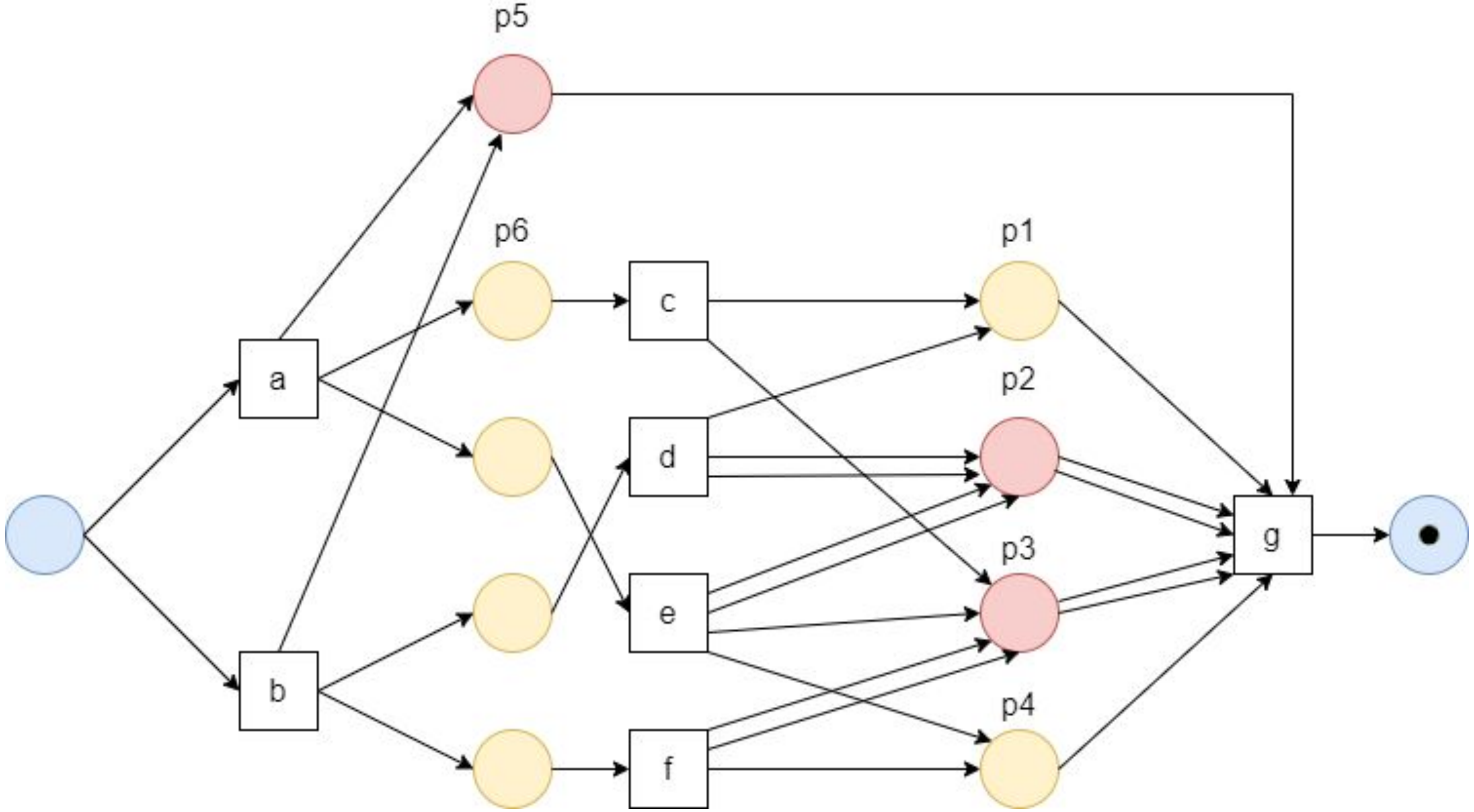
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	**a**	**c**	**e**	**g**
x_{p5}	0	1	1	1	0
x_{p6}	0	1	0	0	0
x_{p7}					

Running Example: Intermediate Case

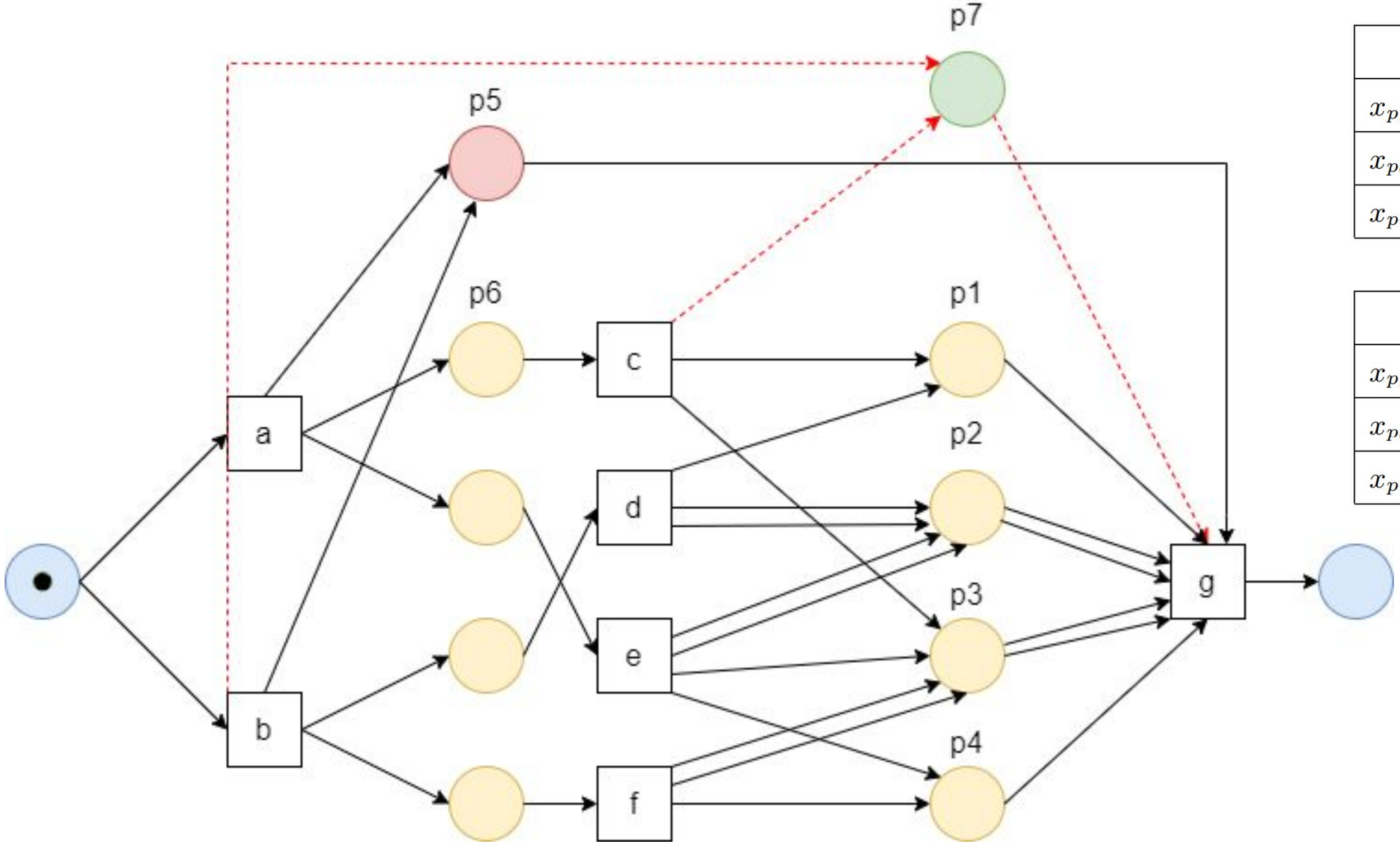
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	a	c	e	g
x_{p5}	0	1	1	1	0
x_{p6}	0	1	0	0	0
x_{p7}	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_{p5}	0	1	1	1	0
x_{p6}	0	1	0	0	0
x_{p7}	0	0	1	1	0

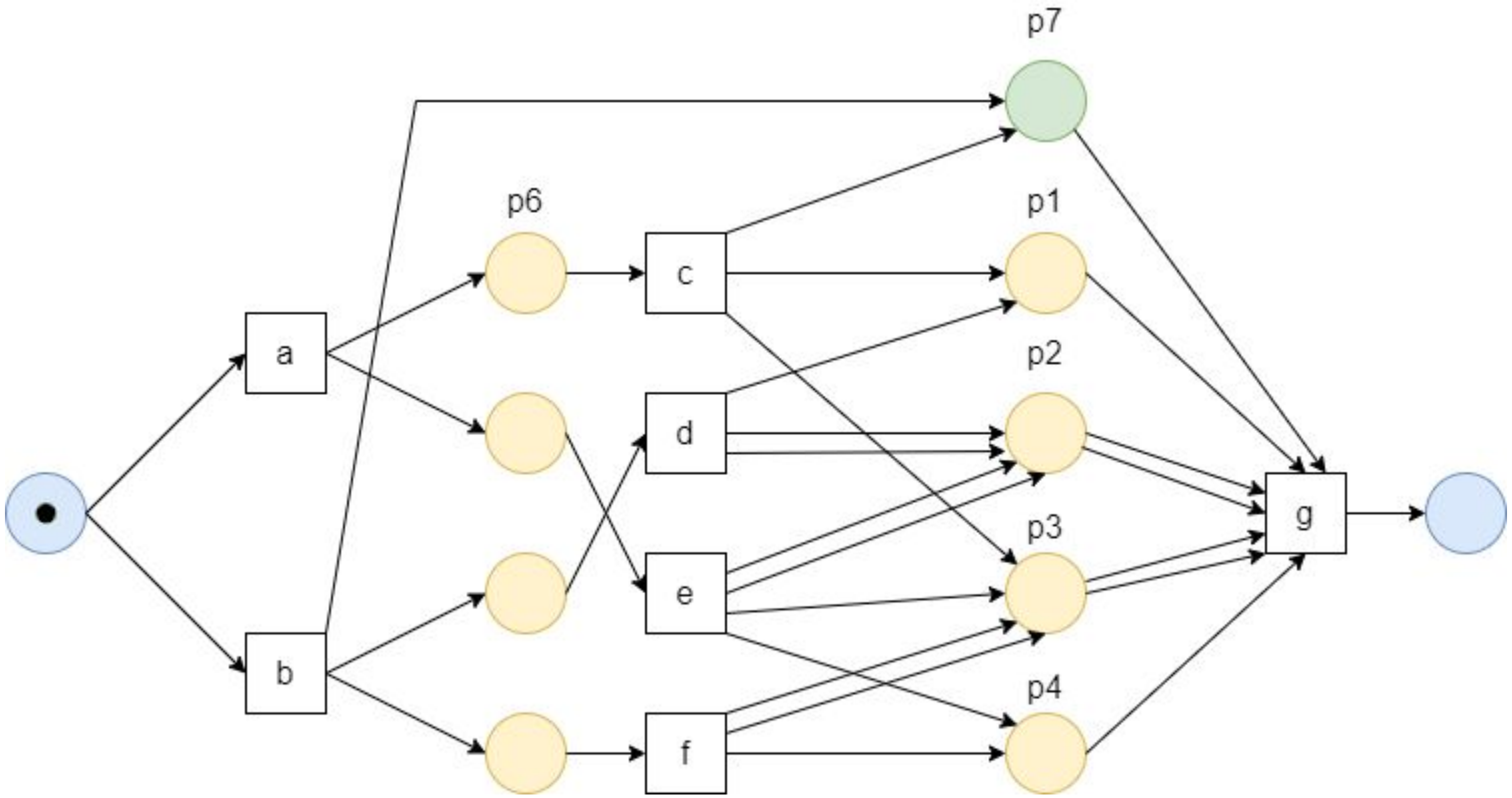
	ε	a	e	c	g
x_{p5}	0	1	1	1	0
x_{p6}	0	1	1	0	0
x_{p7}	0	0	0	1	0

	ε	b	d	f	g
x_{p5}	0	1	1	1	0
x_{p6}	0	0	0	0	0
x_{p7}	0	1	1	1	0

	ε	b	f	d	g
x_{p5}	0	1	1	1	0
x_{p6}	0	0	0	0	0
x_{p7}	0	1	1	1	0

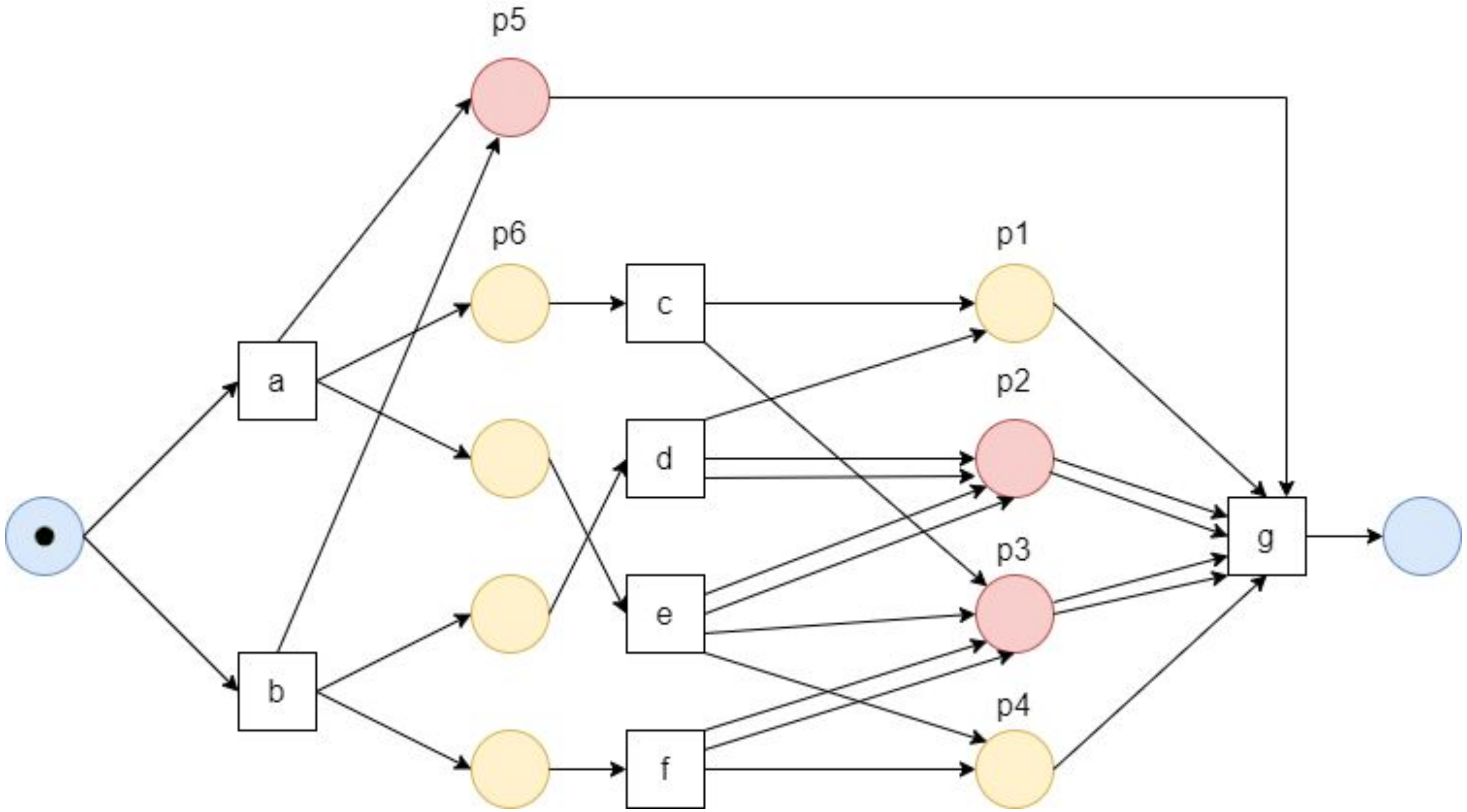
Running Example: Intermediate Case

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



Running Example: Extended Case

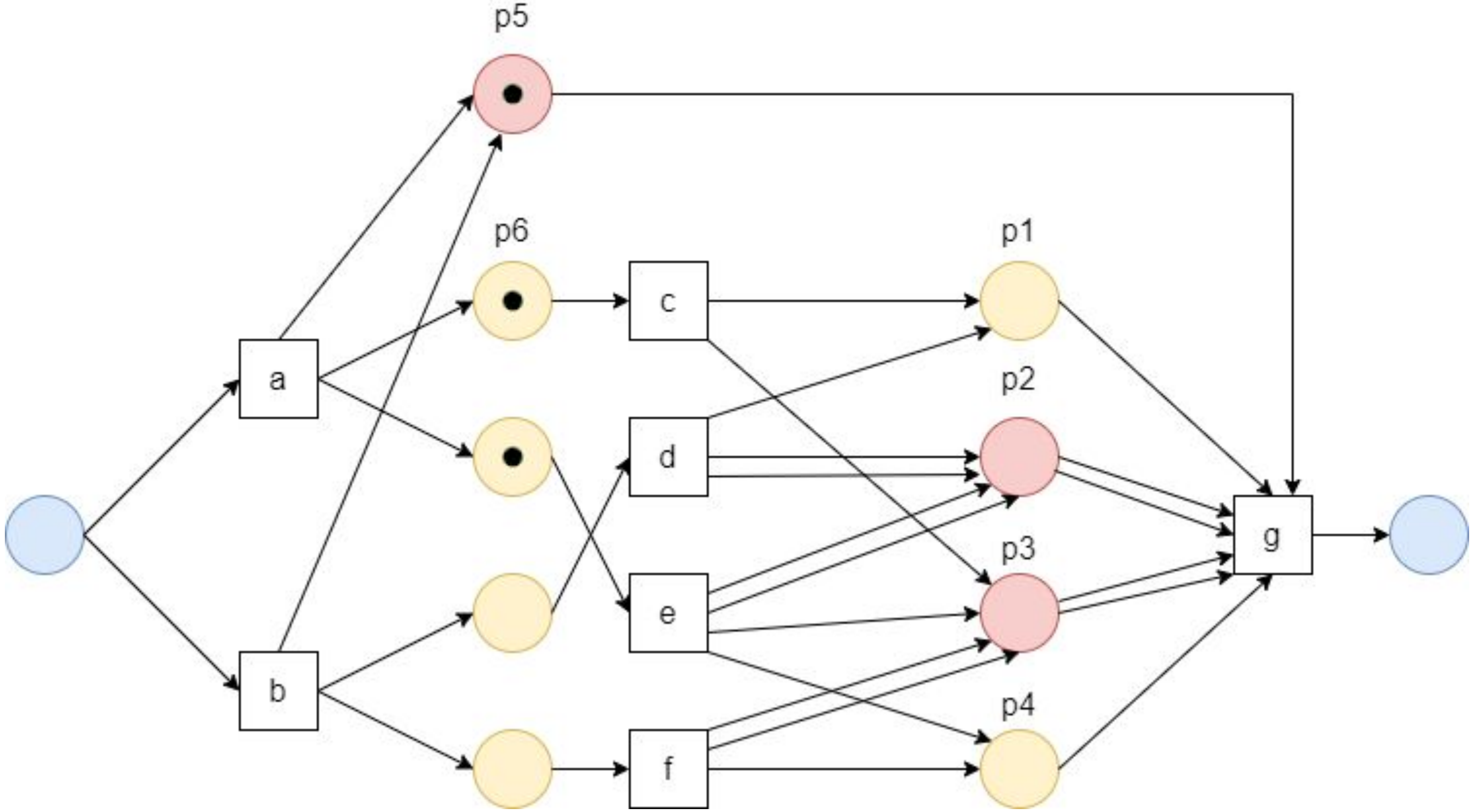
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



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

Running Example: Extended Case

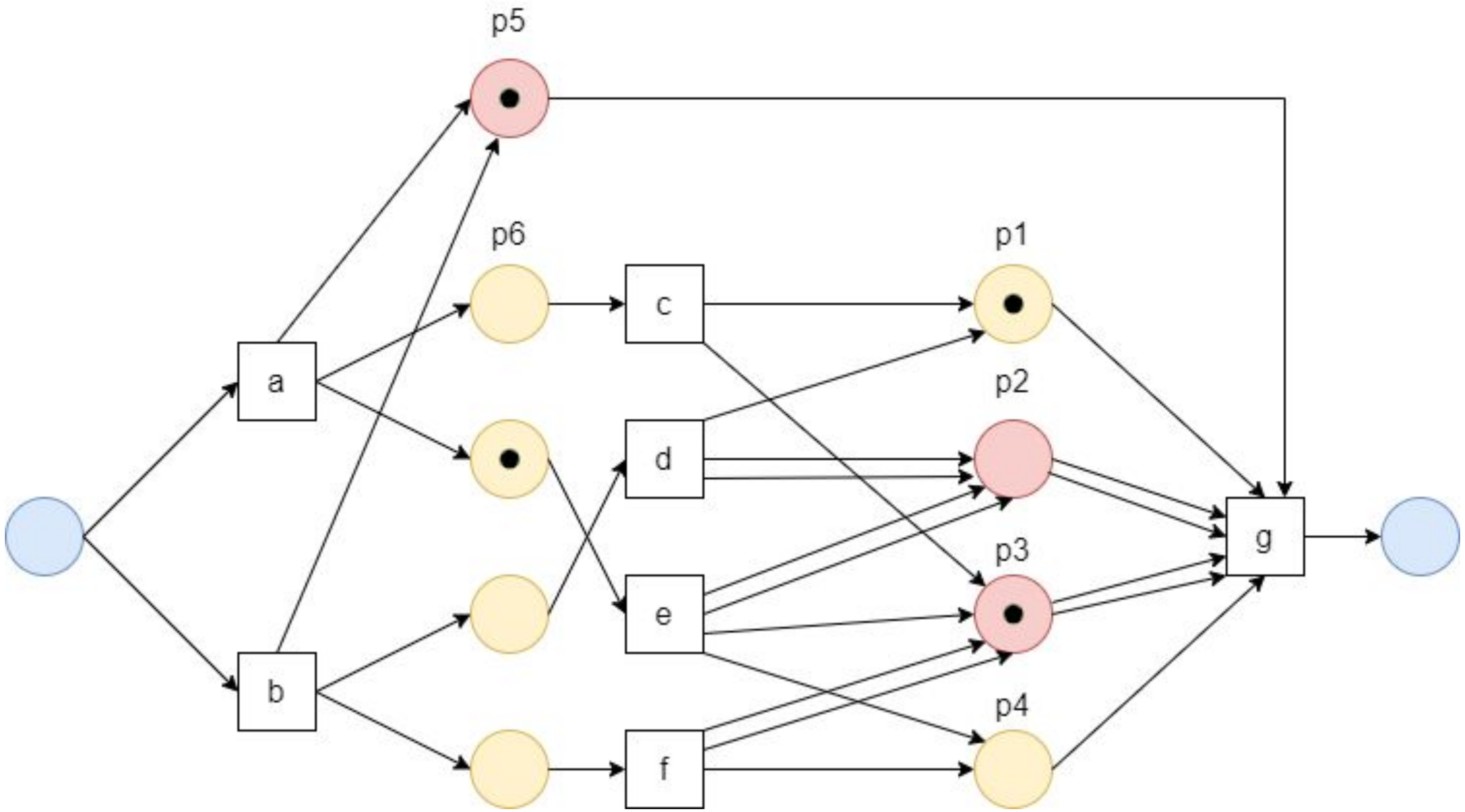
$$L = [\epsilon, \langle a, c, e, g\rangle^2, \langle a, e, c, g\rangle^3, \langle b, d, f, g\rangle^2, \langle b, f, d, g\rangle^4]$$



	ε	a	c	e	g
x_{p3}	0	0			
x_{p4}	0	0			
x_{p8}					

Running Example: Extended Case

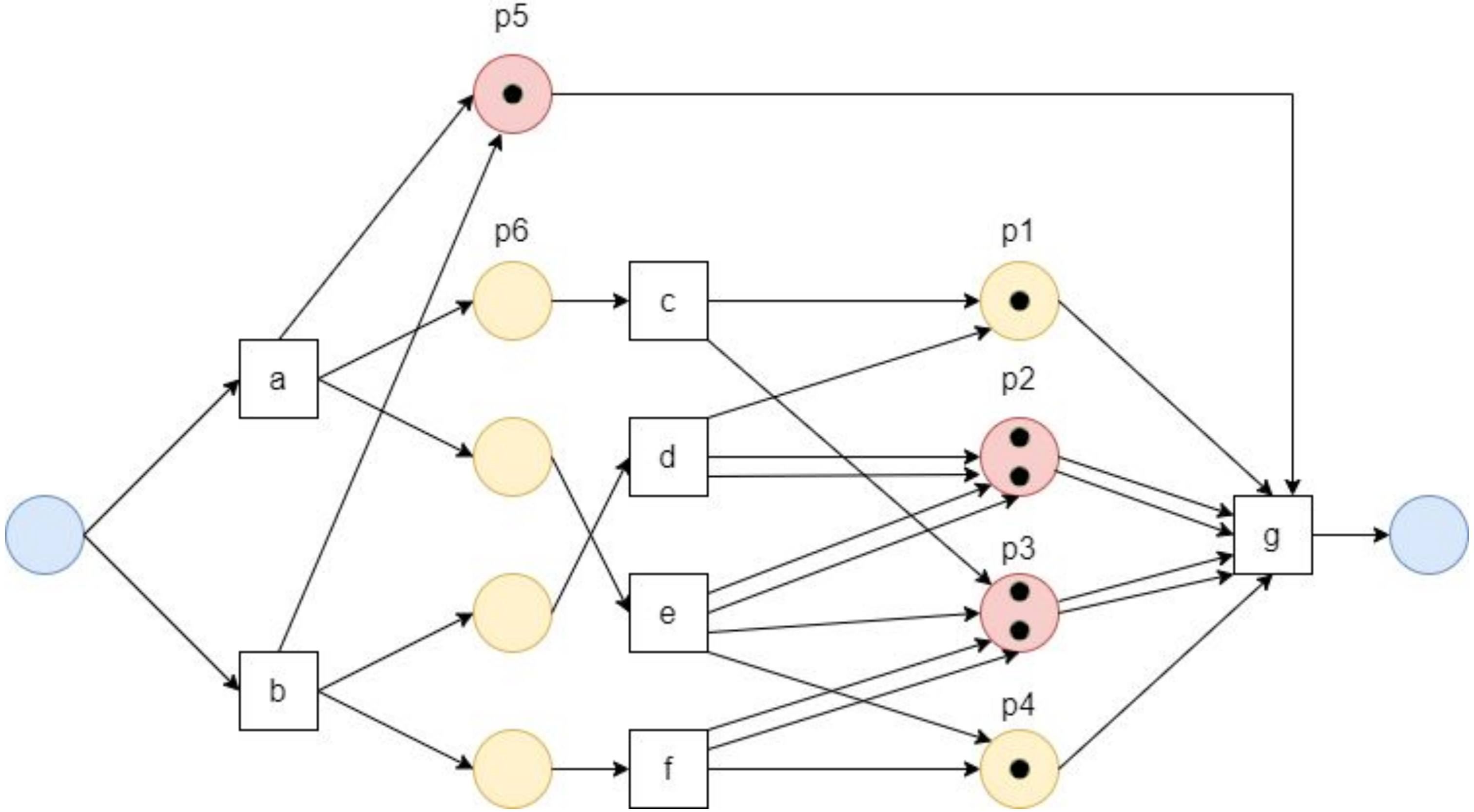
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	a	c	e	g
x_{p3}	0	0	1		
x_{p4}	0	0	0		
x_{p8}					

Running Example: Extended Case

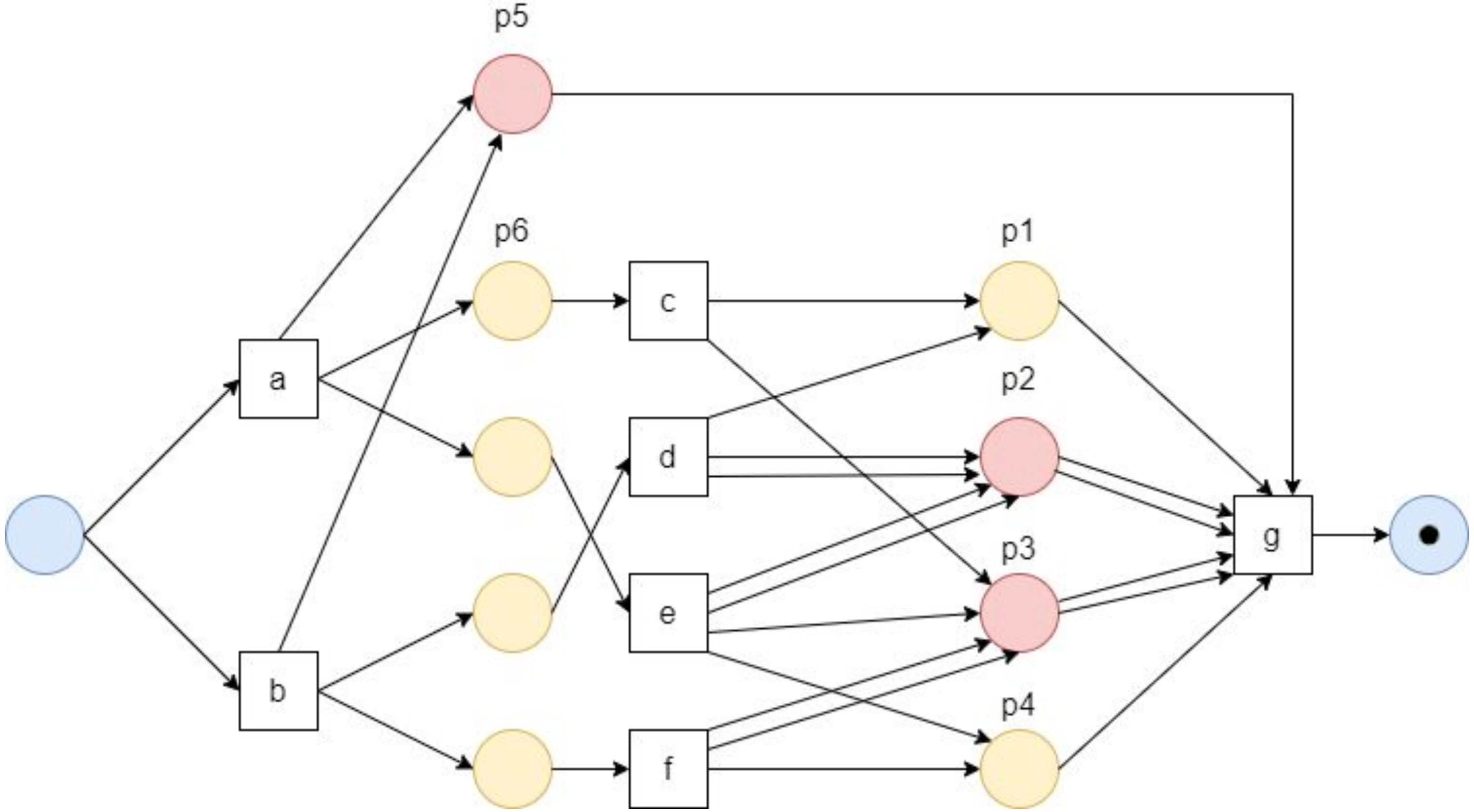
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	a	c	e	g
x_{p3}	0	0	1	2	
x_{p4}	0	0	0	1	
x_{p8}					

Running Example: Extended Case

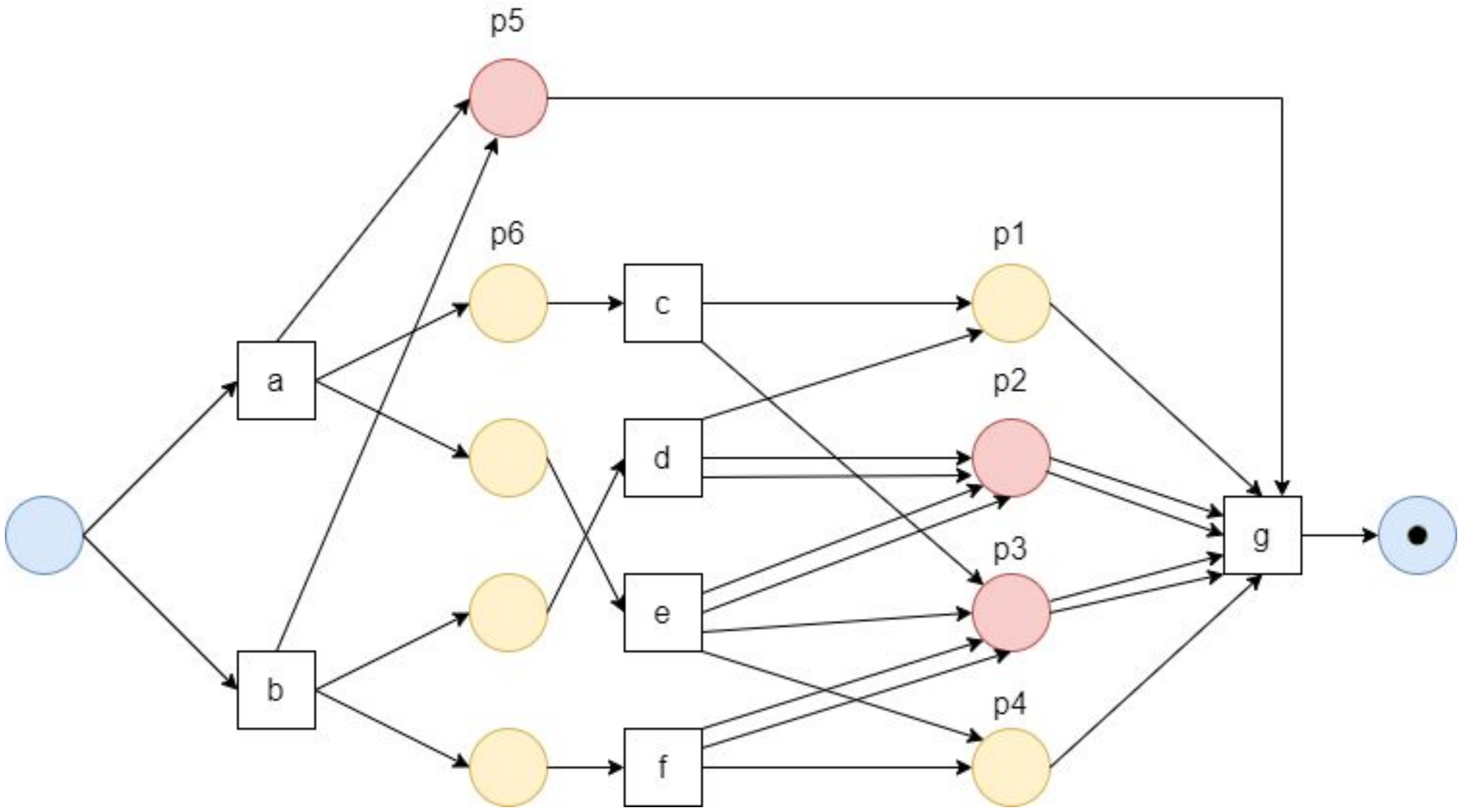
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



	ε	a	c	e	g
x_{p3}	0	0	1	2	0
x_{p4}	0	0	0	1	0
x_{p8}					

Running Example: Extended Case

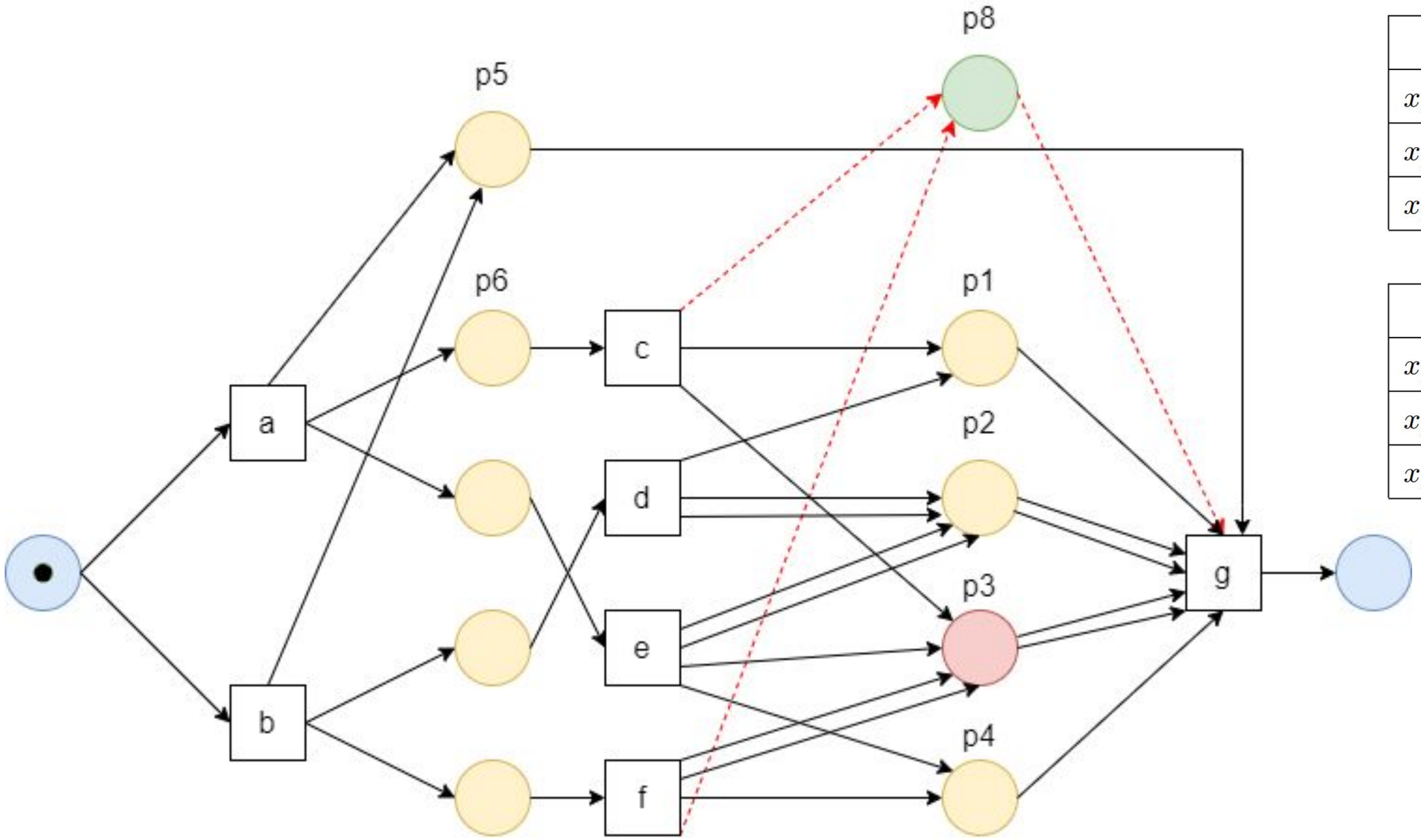
$$L = [\epsilon, \langle a, c, e, g\rangle^2, \langle a, e, c, g\rangle^3, \langle b, d, f, g\rangle^2, \langle b, f, d, g\rangle^4]$$



	ε	a	c	e	g
x_{p3}	0	0	1	2	0
x_{p4}	0	0	0	1	0
x_{p8}	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_{p3}	0	0	1	2	0
x_{p4}	0	0	0	1	0
x_{p8}	0	0	1	1	0

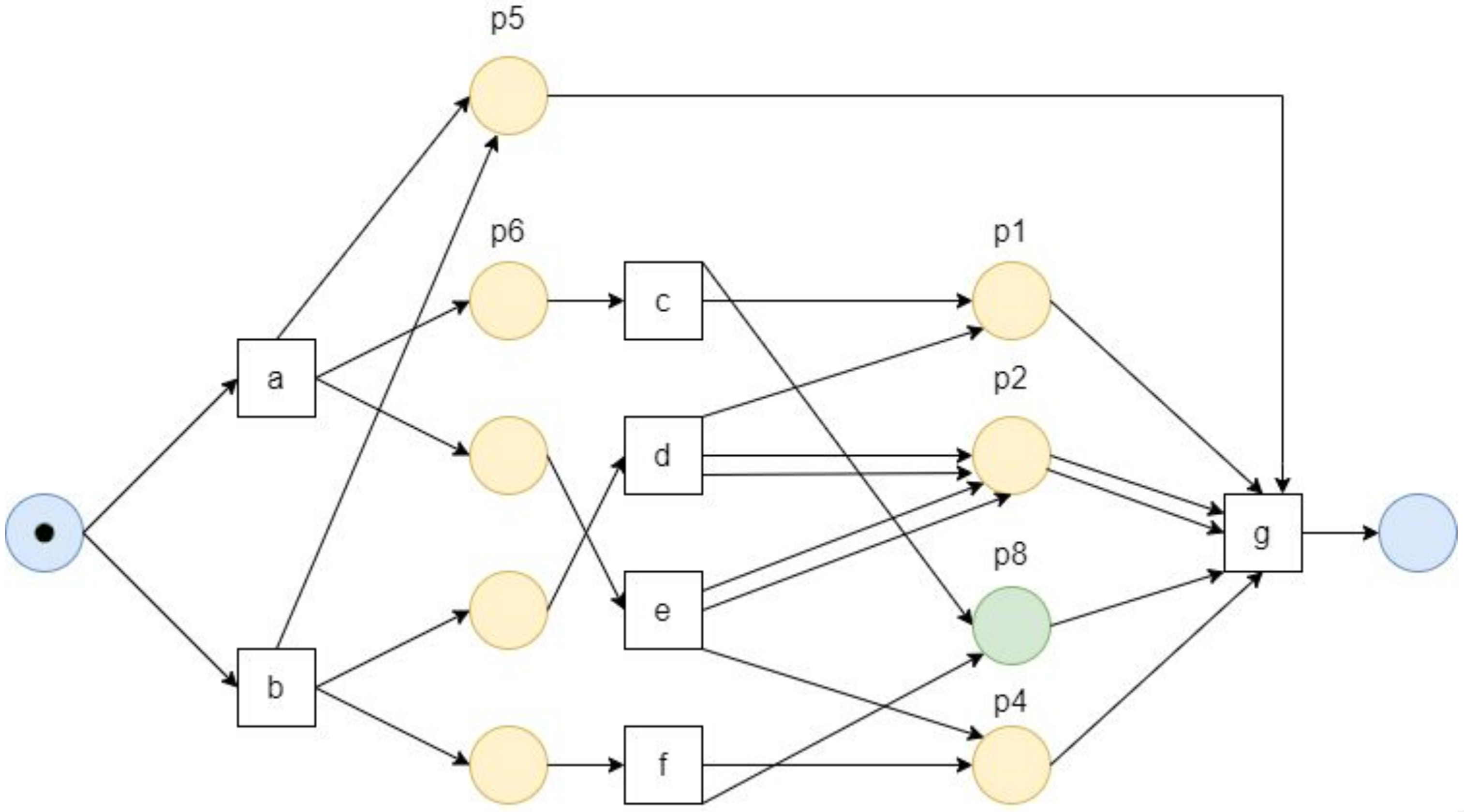
	ε	a	e	c	g
x_{p3}	0	0	1	2	0
x_{p4}	0	0	1	1	0
x_{p8}	0	0	0	1	0

	ε	b	d	f	g
x_{p3}	0	0	0	2	0
x_{p4}	0	0	0	1	0
x_{p8}	0	0	0	1	0

	ε	b	f	d	g
x_{p3}	0	0	2	2	0
x_{p4}	0	0	1	1	0
x_{p8}	0	0	1	1	0

Running Example: Extended Case

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

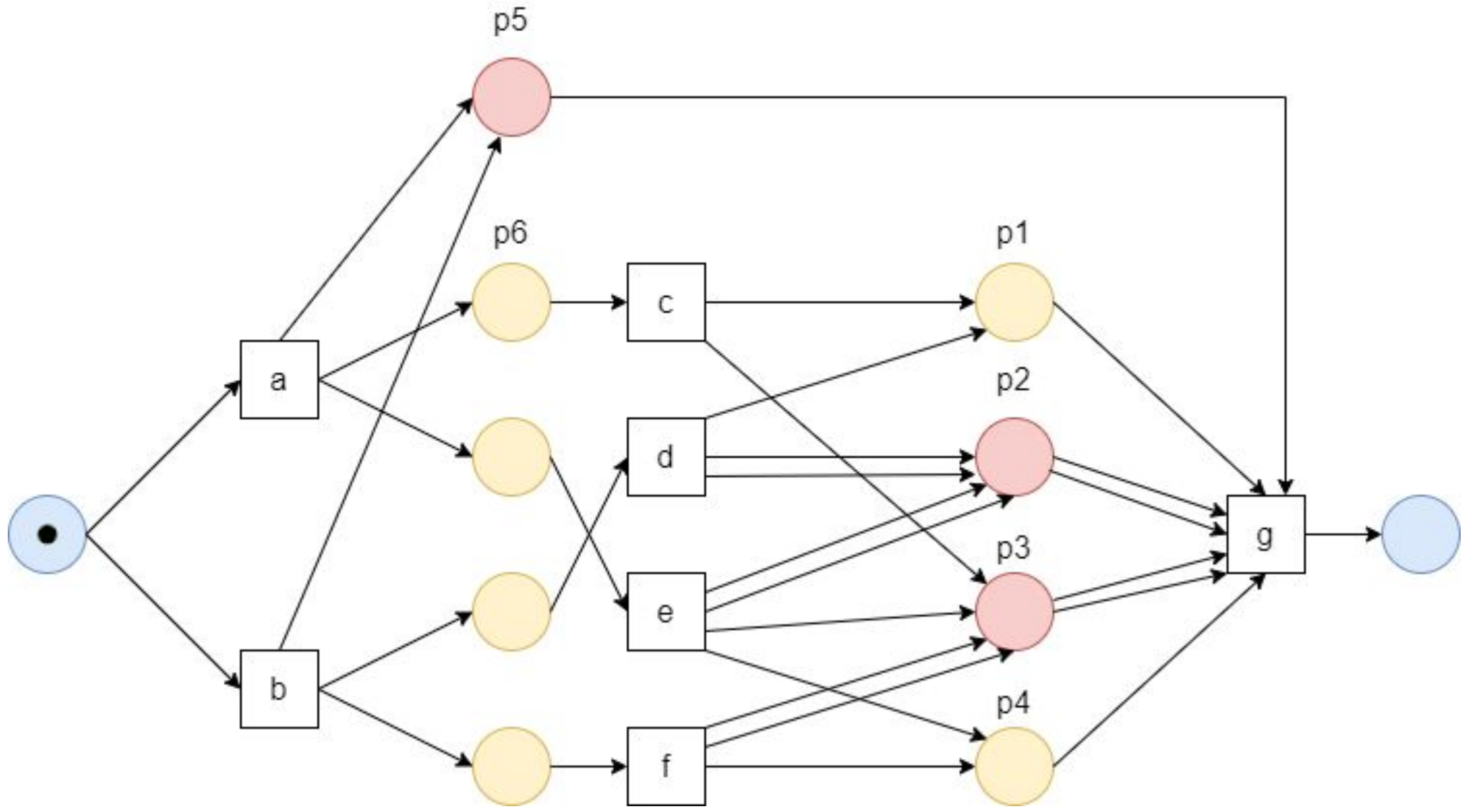


Review

- 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

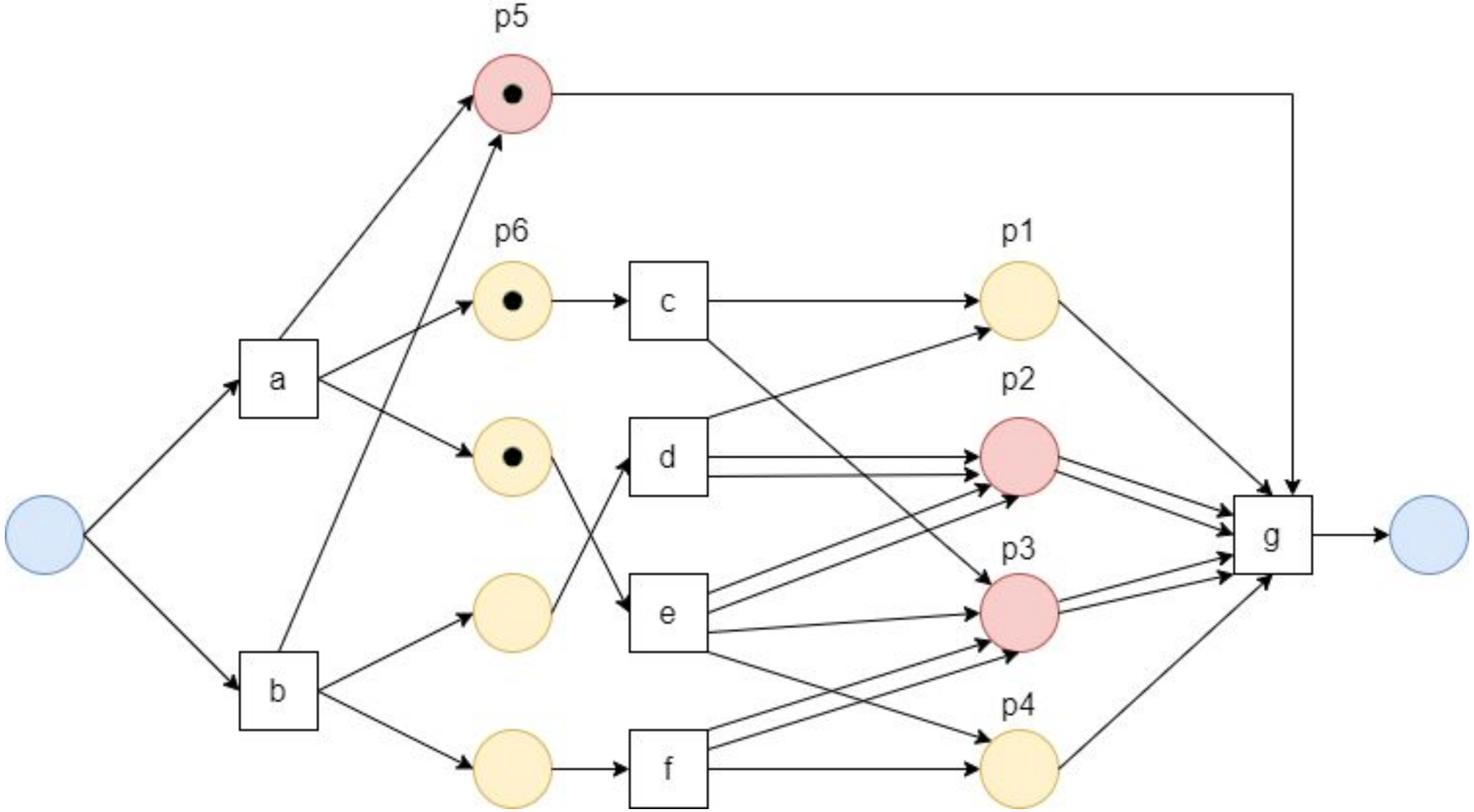
$$L = [\epsilon, \langle a,c,e,g\rangle^2, \langle a,e,c,g\rangle^3, \langle b,d,f,g\rangle^2, \langle b,f,d,g\rangle^4]$$



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

Limitations

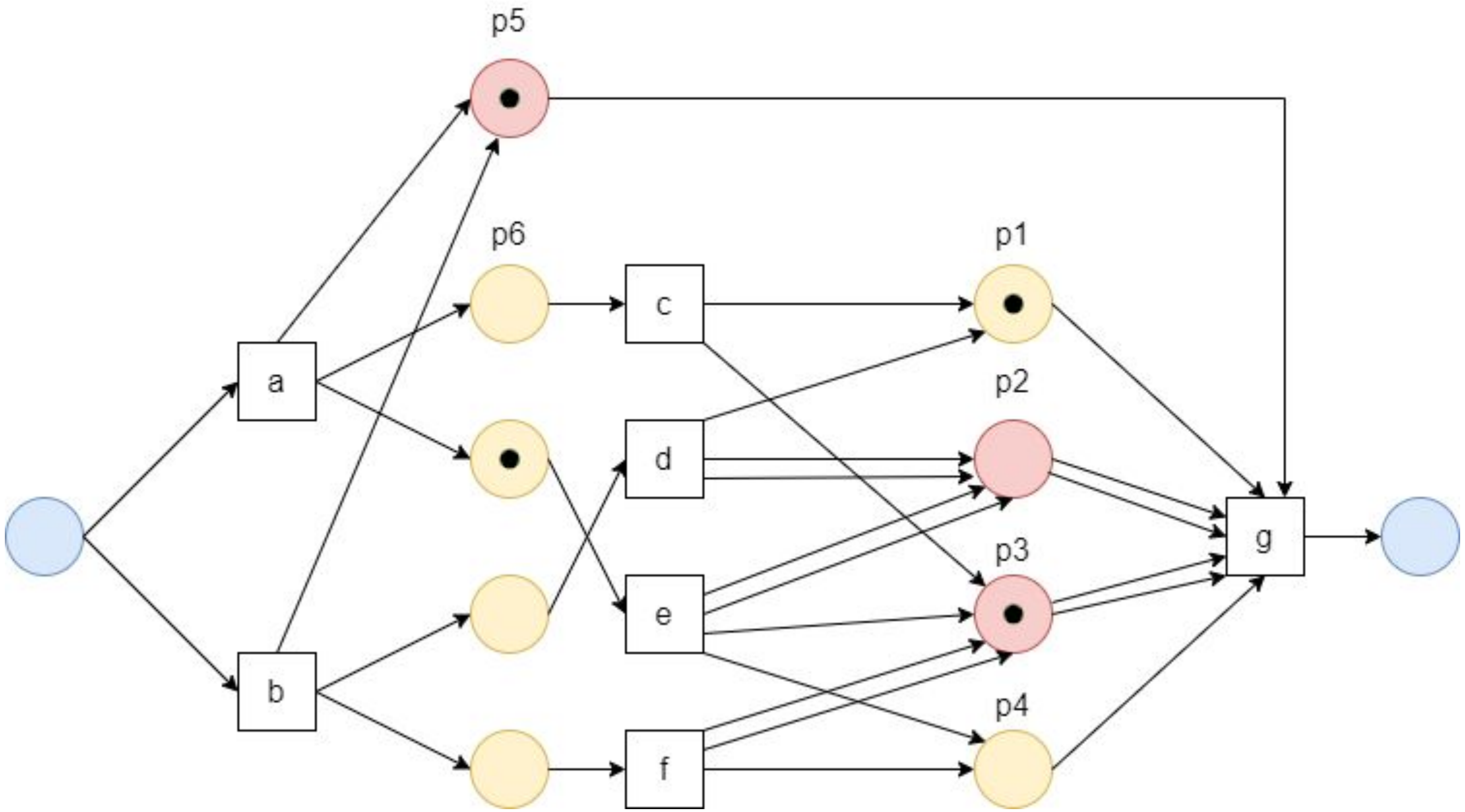
$$L = [\epsilon, \langle a, c, e, g\rangle^2, \langle a, e, c, g\rangle^3, \langle b, d, f, g\rangle^2, \langle b, f, d, g\rangle^4]$$



	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		

$x_{p2} > x_{pi}$ **does not hold for any** i

Review

- 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

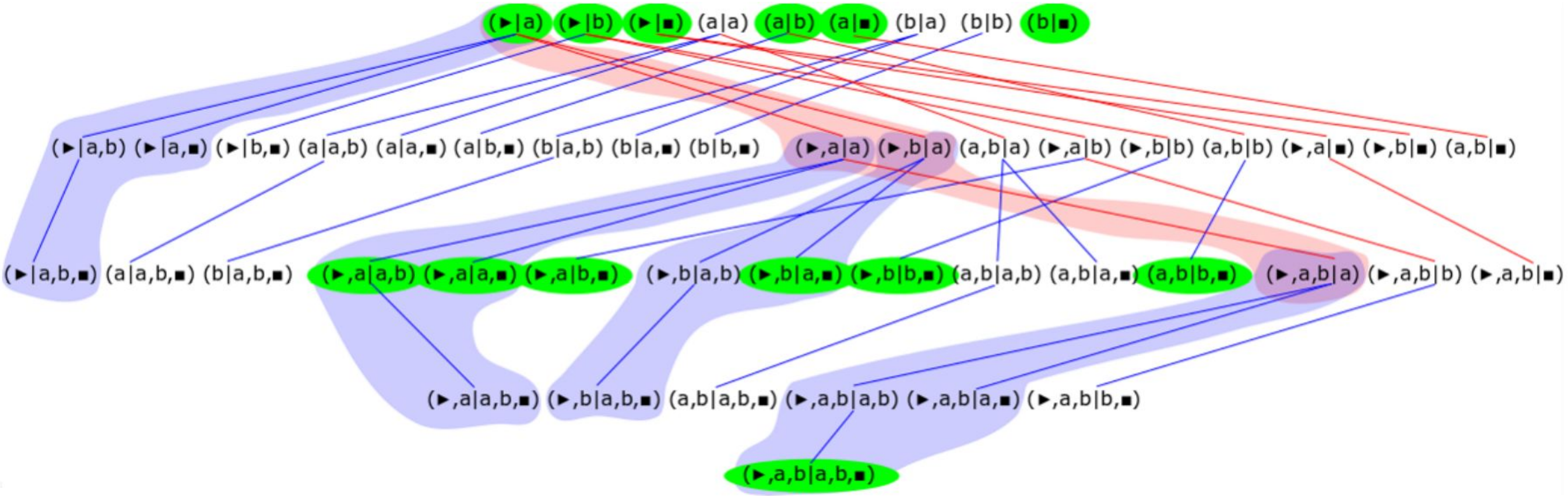
- When and where is this algorithm actually beneficial?
- Diving into the application to the eST-Miner
- Are there any associated implementation challenges?

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

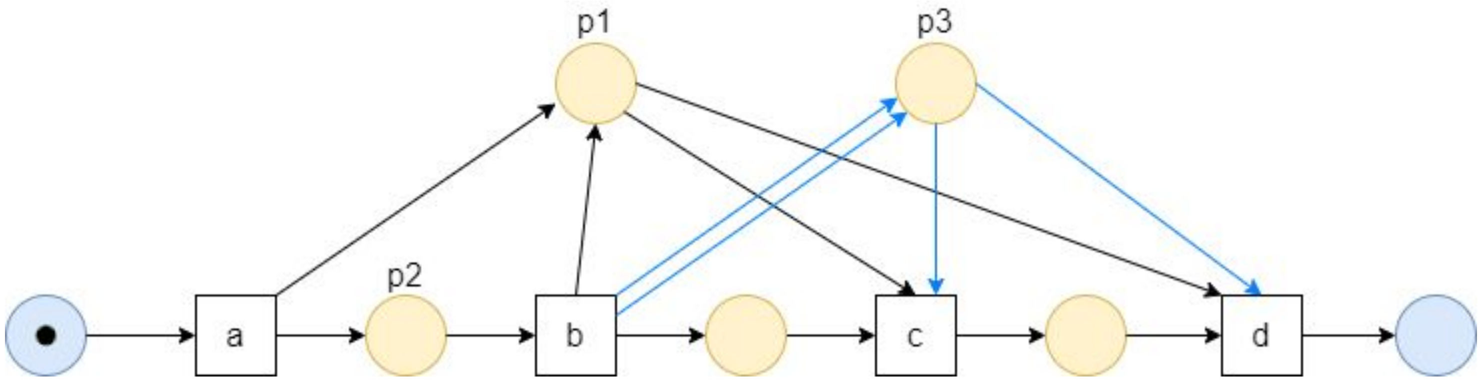
Concurrent Place Removal (CPR)

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

Application: 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

Application: Challenges

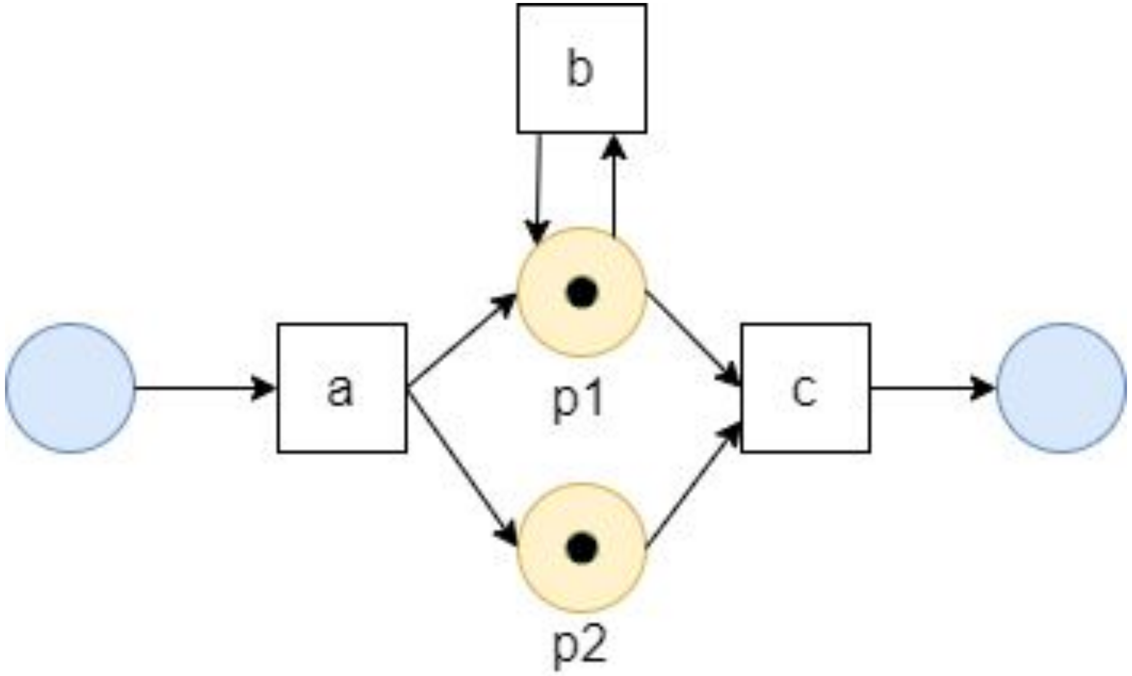
- The eST-Miner discovers only fitting places
- Places empty at the beginning and end of token replay
- Place emptiness is guaranteed by construction

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

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

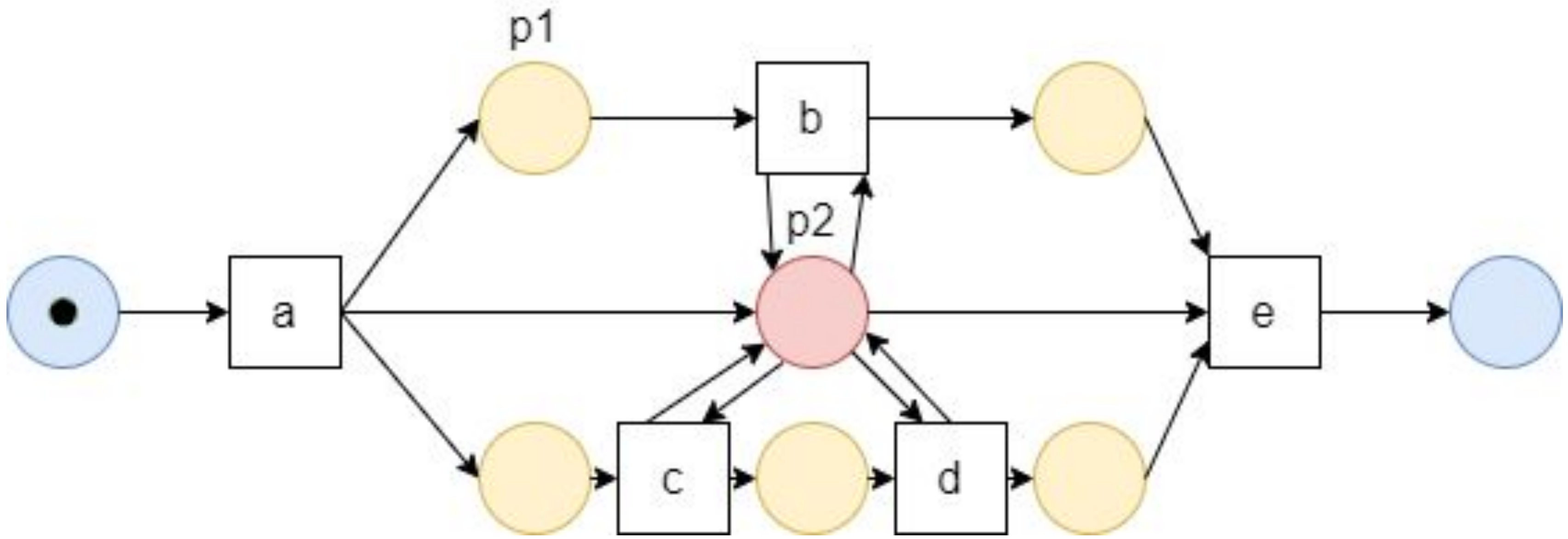
Application: Challenges

eST-Miner allows for Petri nets with self-loops



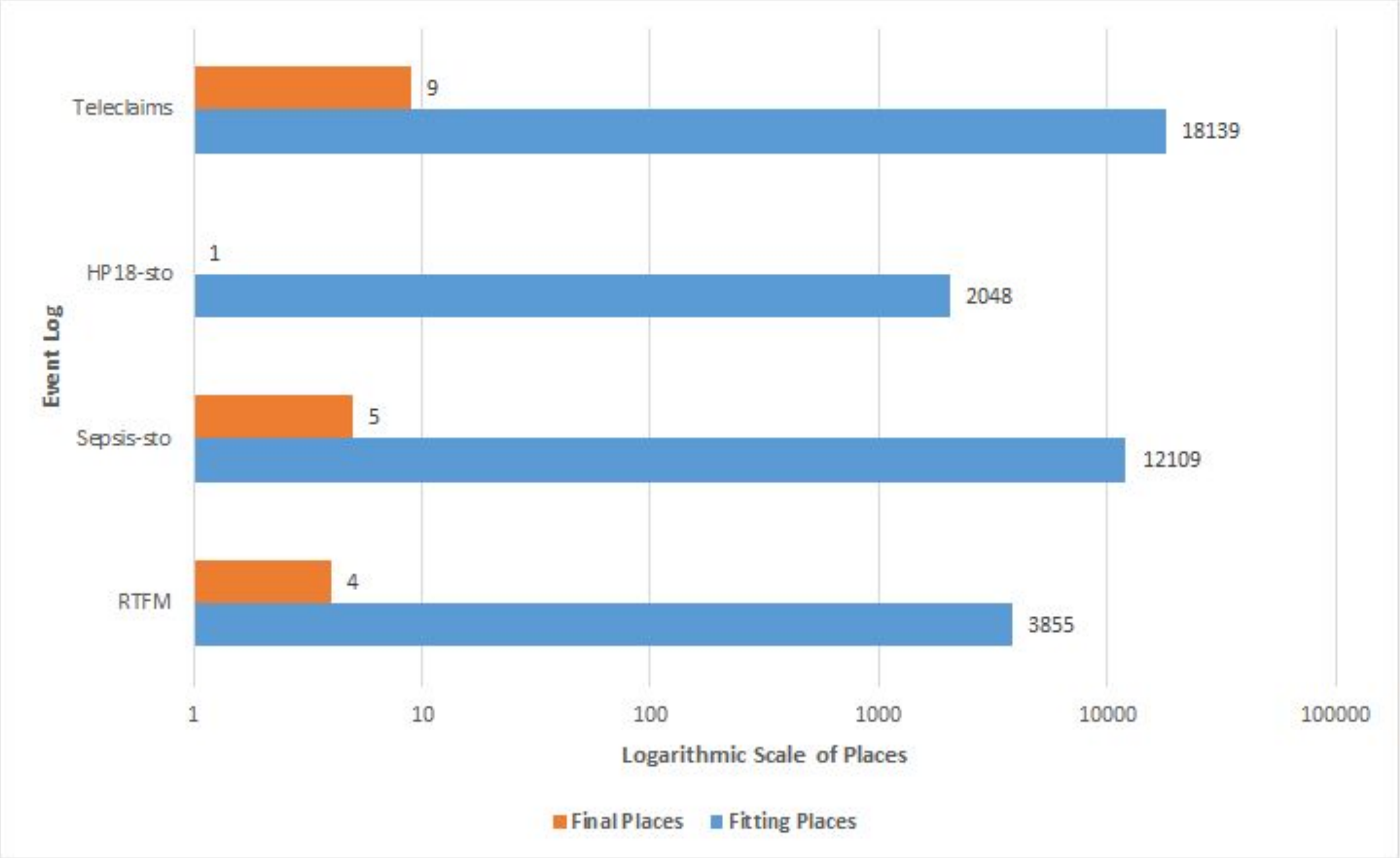
Application: Challenges

Special case of places with self-loops in parallel constructs



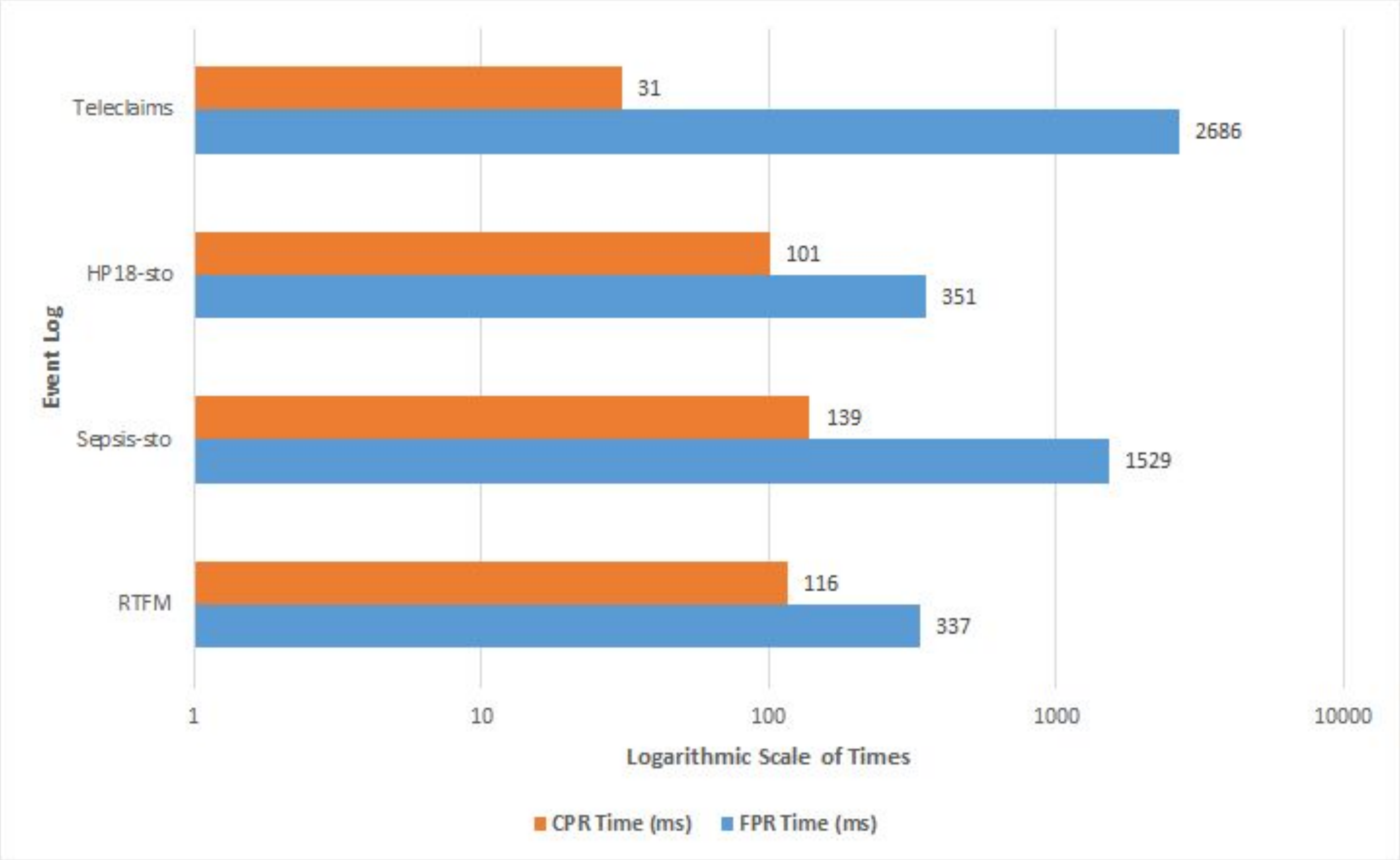
Evaluation: Space Efficiency

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?

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