The complexity of soundness in workflow nets

Philip Offtermatt

Joint work with
Michael Blondin and Filip Mazowiecki

MAX PLANCK INSTITUTE
FOR SOFTWARE SYSTEMS

UNIVERSITAS VARSOVIENSIS

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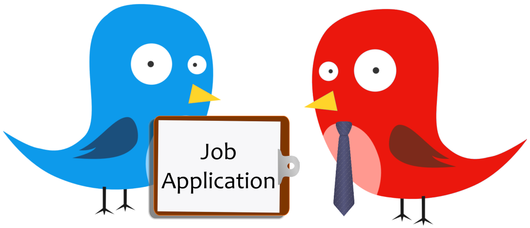
Processes are everywhere!



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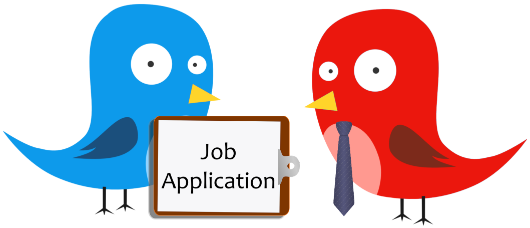

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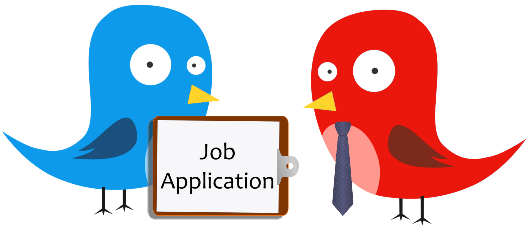
  - Check legal requirements
  - Check applicant suitability
- Decide: Accept/Reject/ Recheck application

Formally modeling processes: Workflow nets



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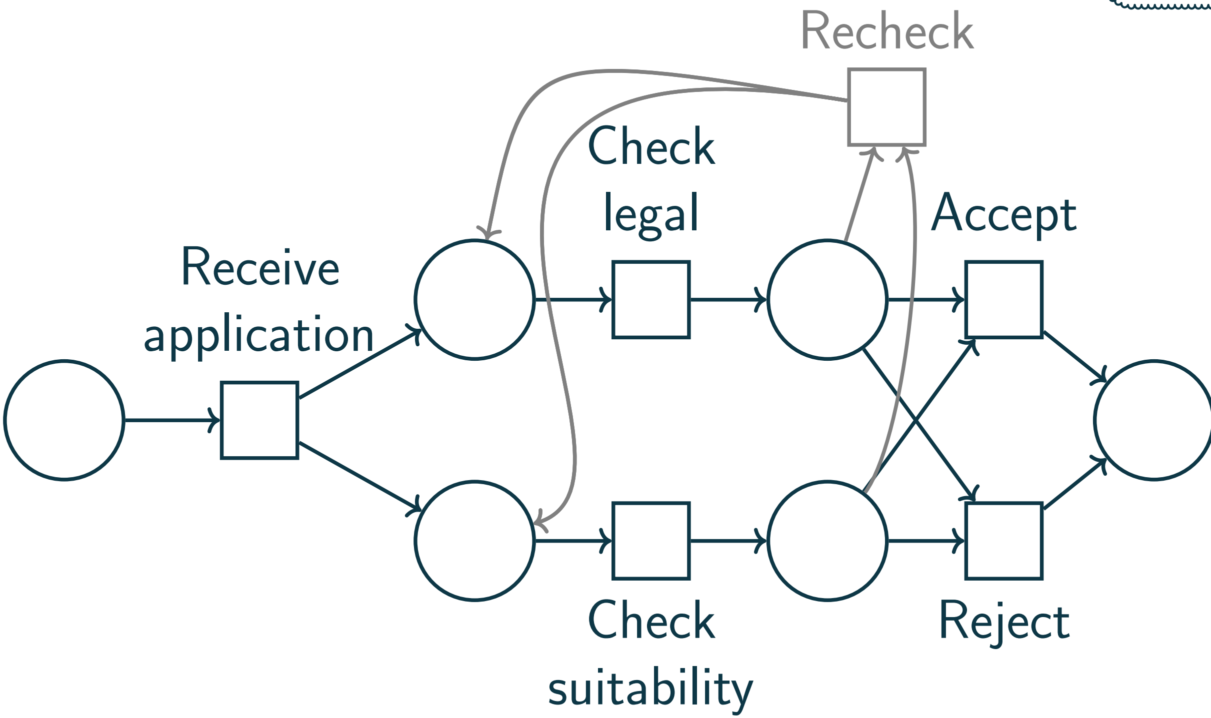

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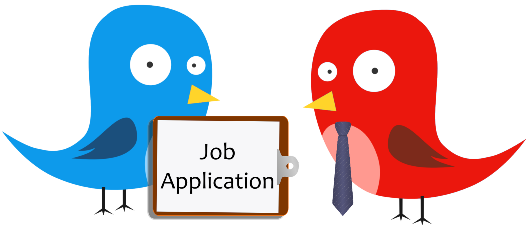

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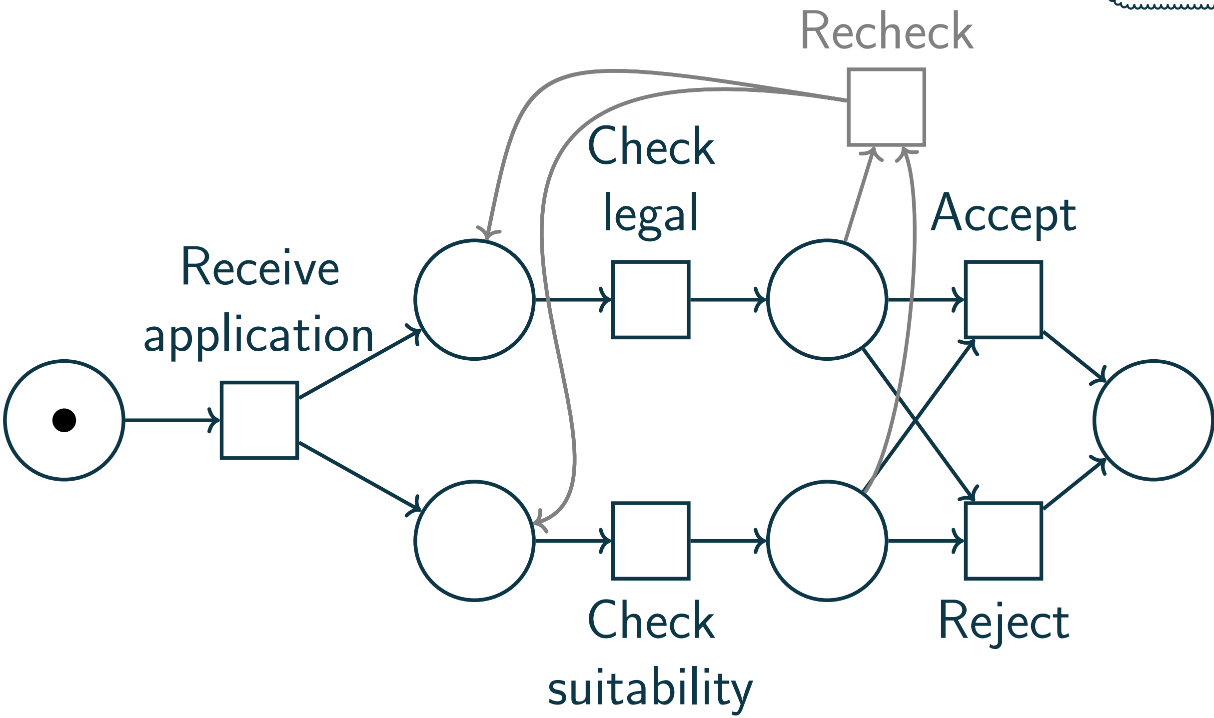

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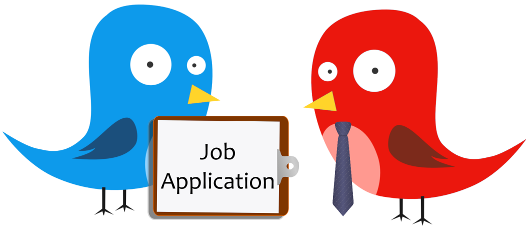

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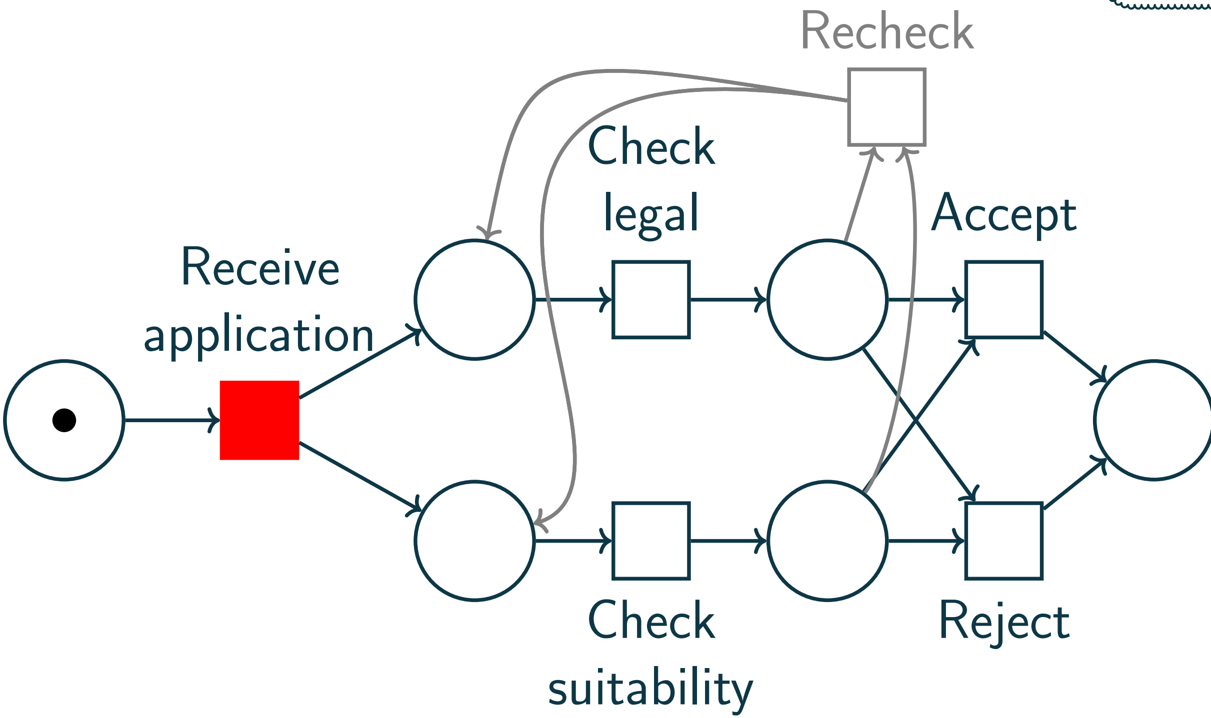

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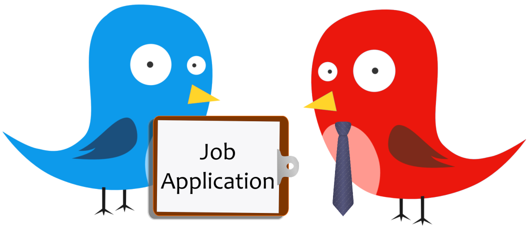

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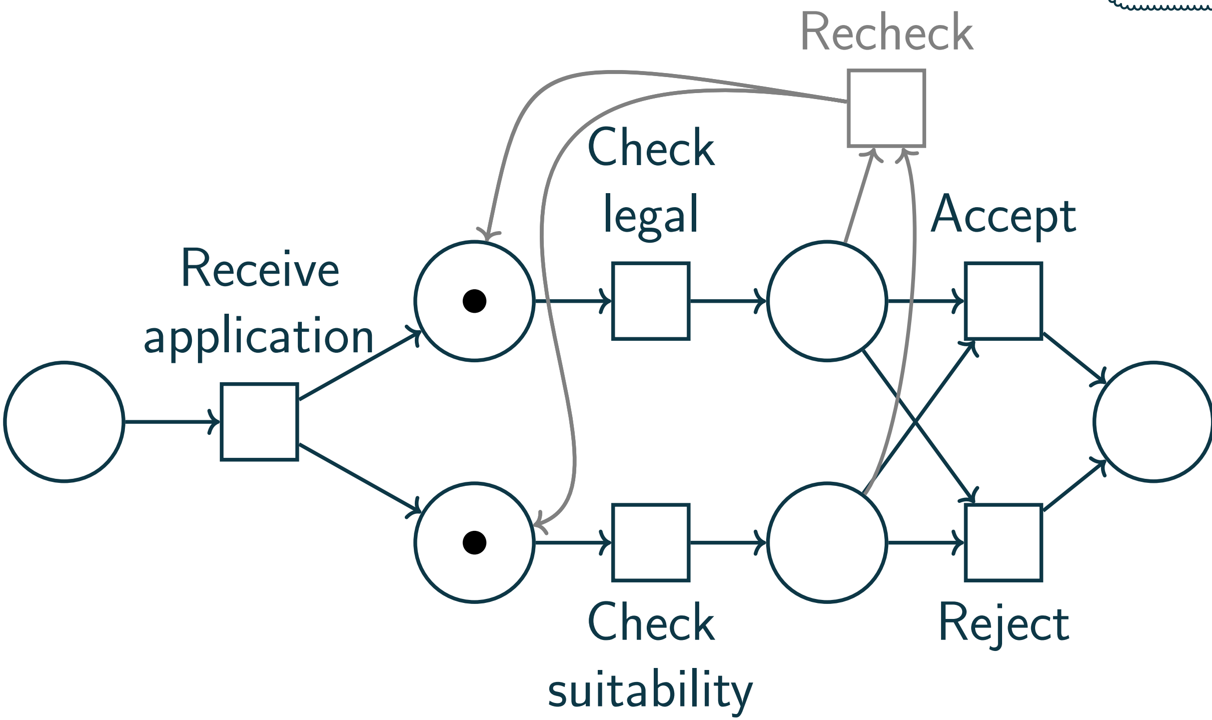
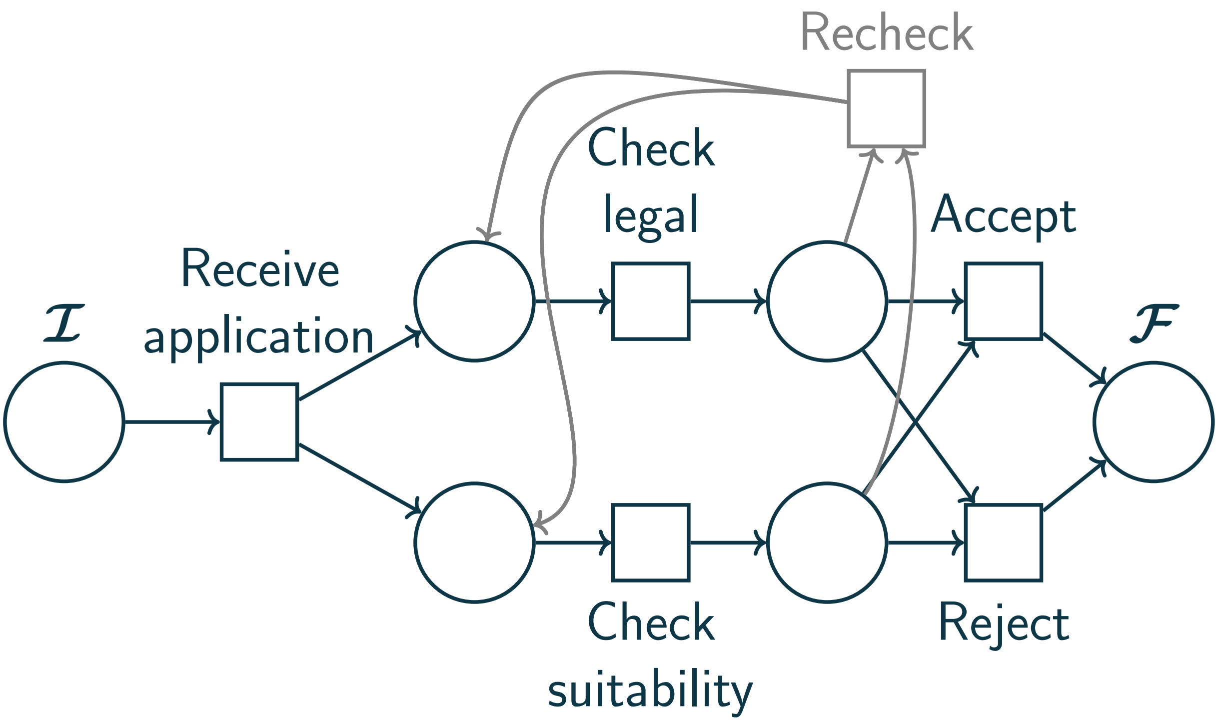
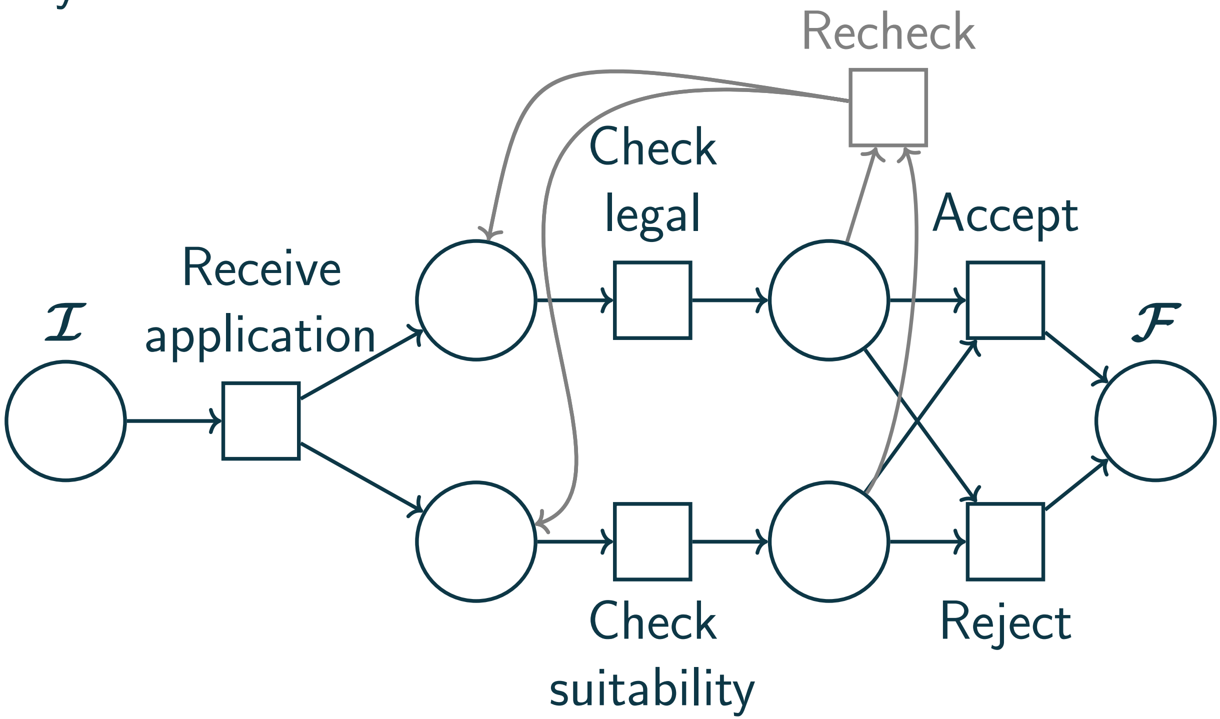


Correctness conditions for processes



Correctness conditions for processes

Option to complete:
We should be able to reach a
a marking that has tokens
only in $\mathcal{F}$



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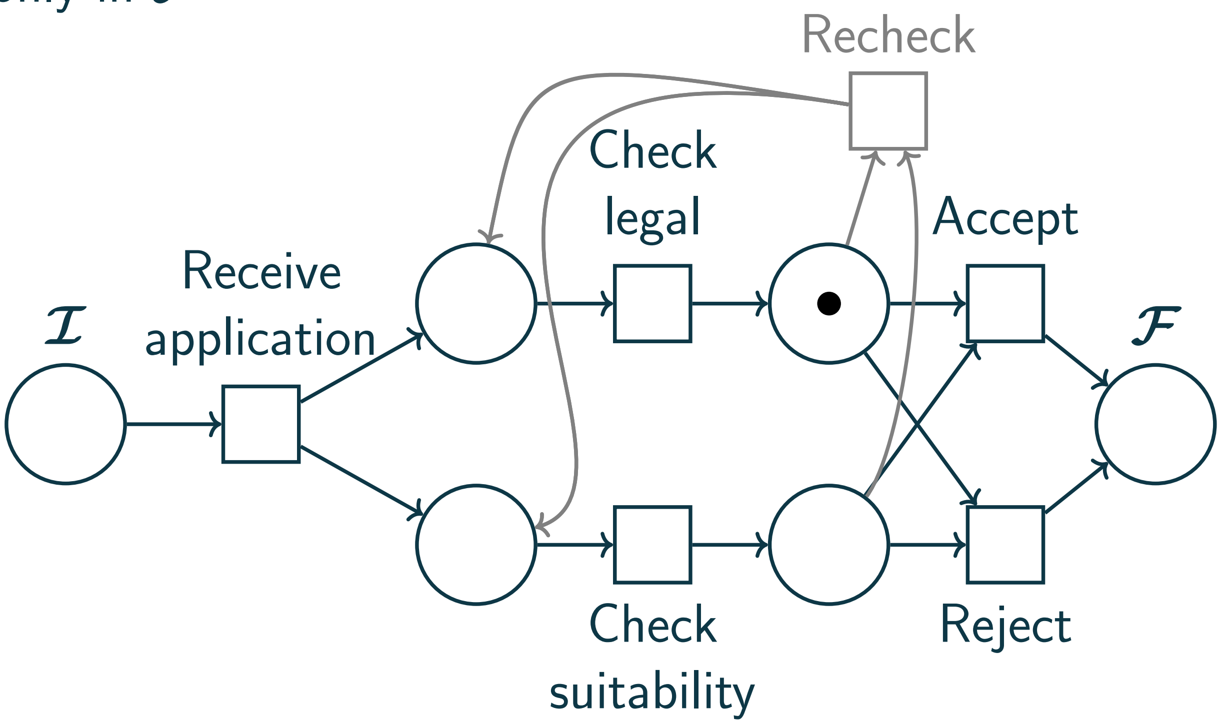

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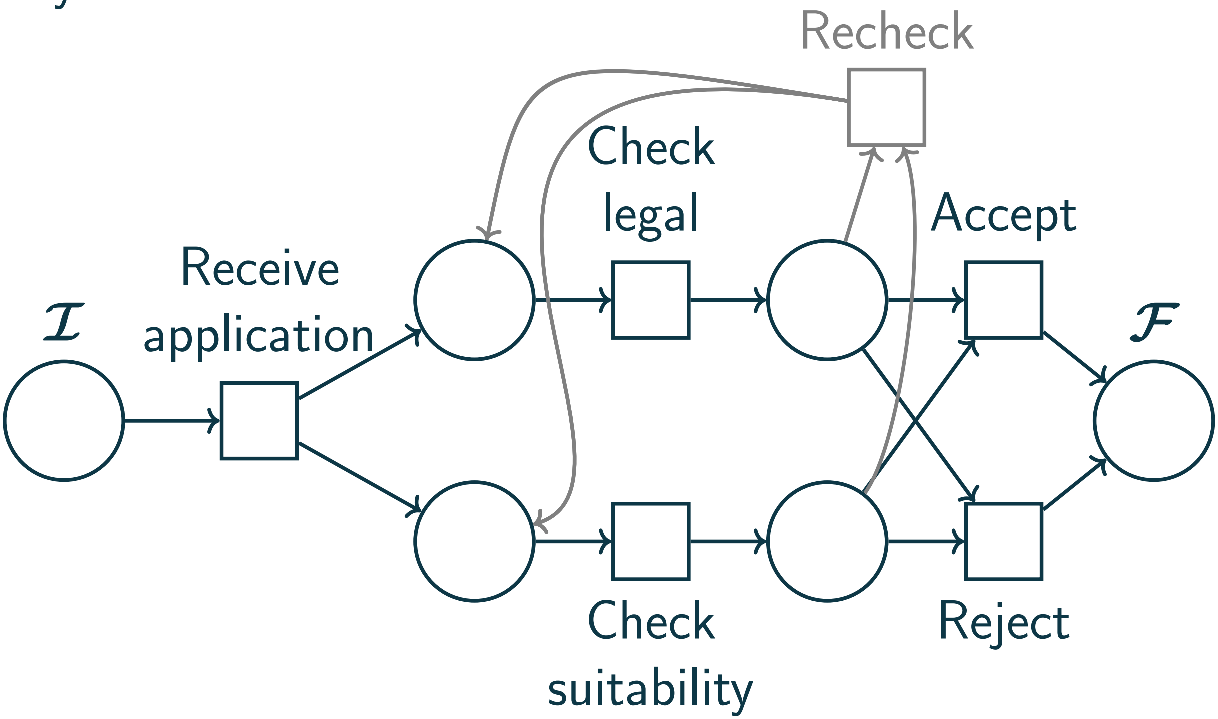

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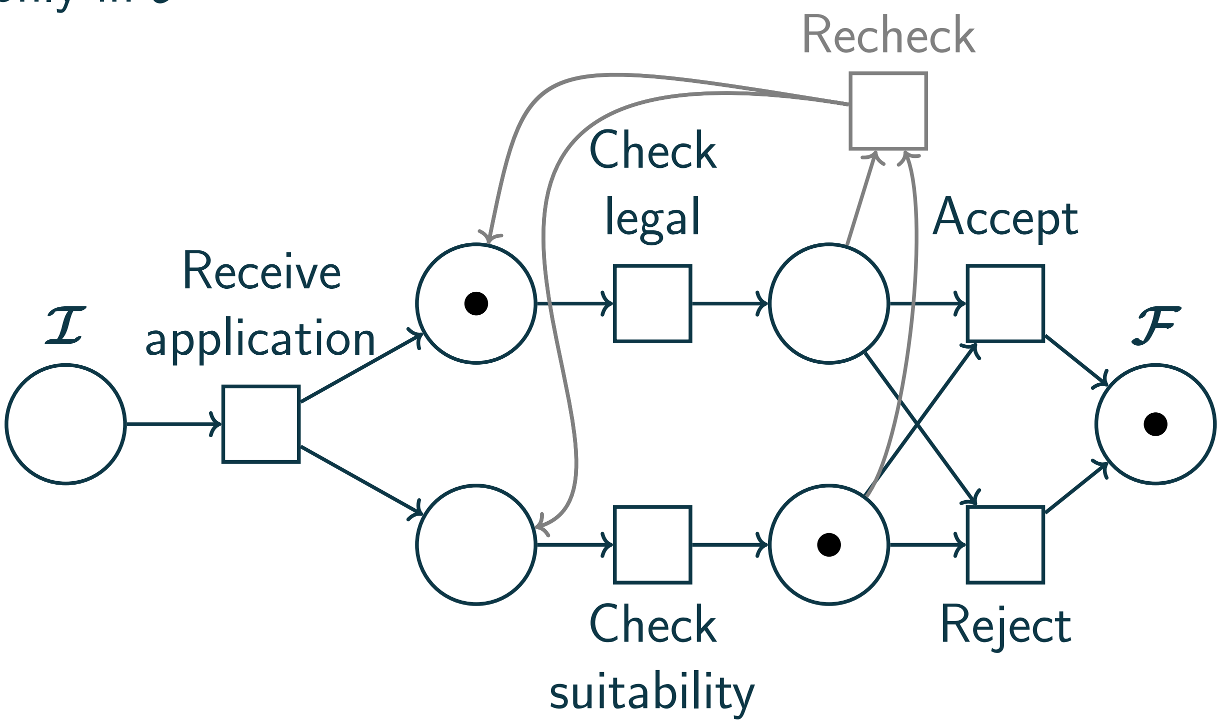

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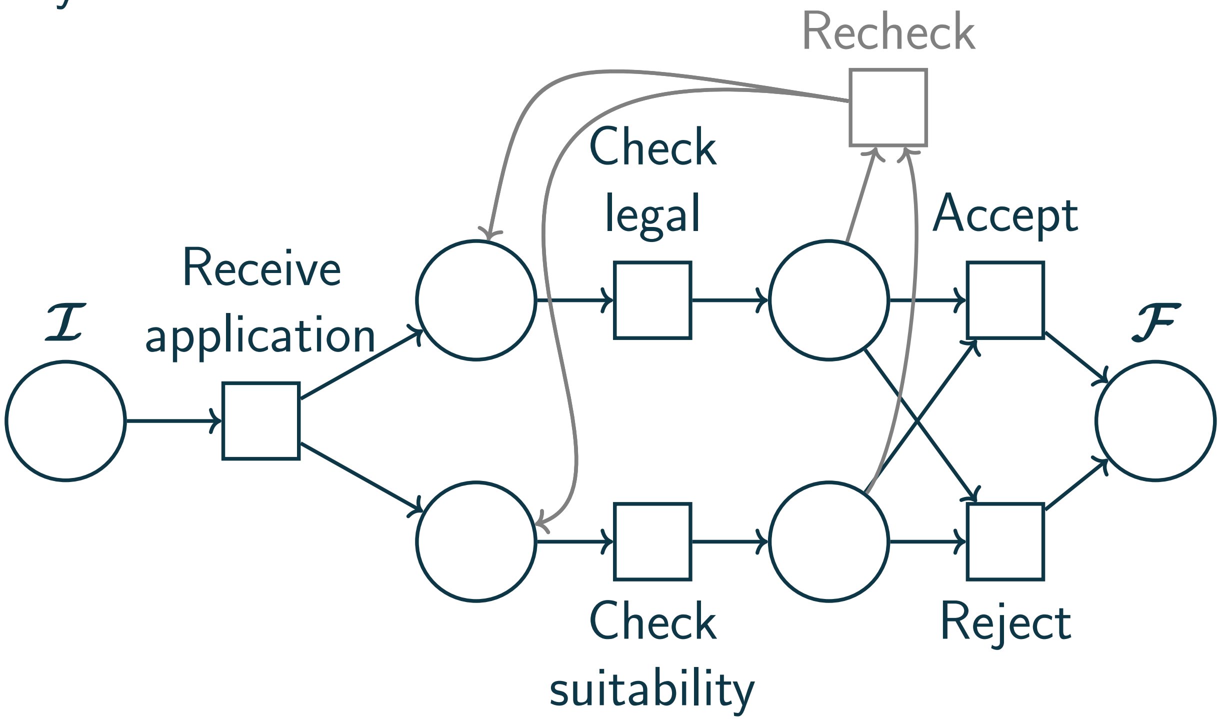
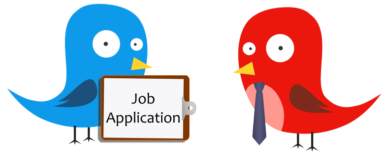


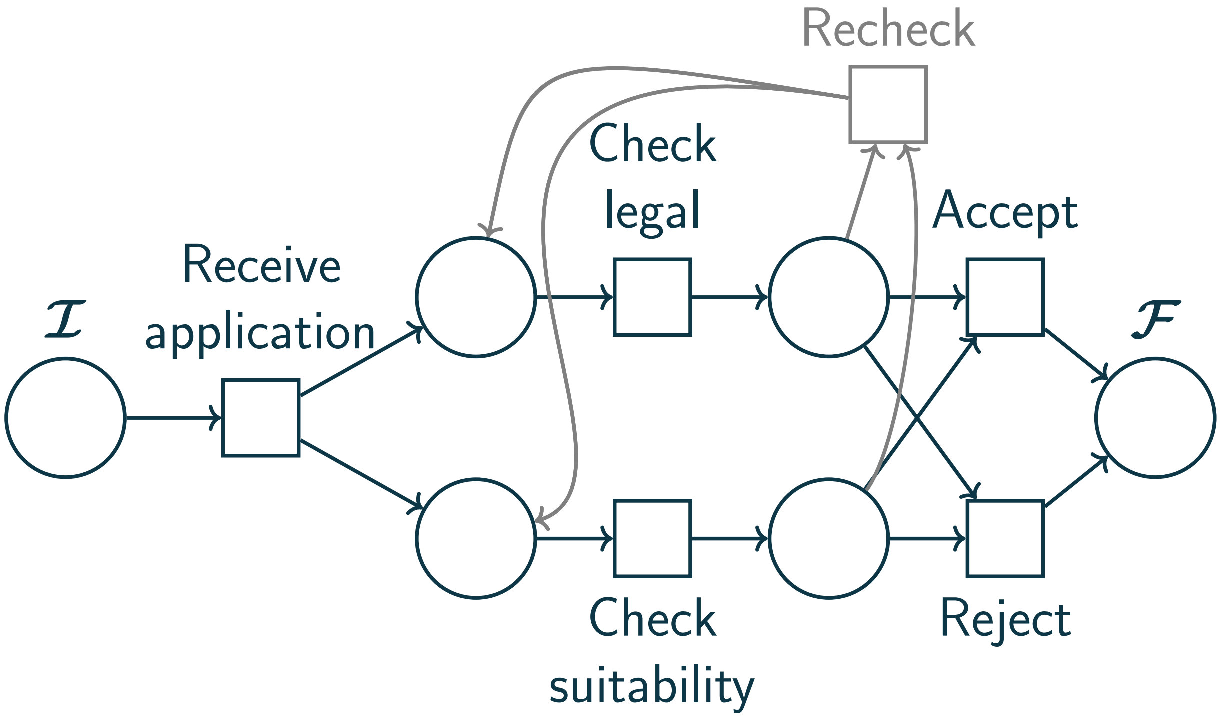
Can we condense these into a single condition?

A concise correctness condition

Soundness:
From any marking reachable from $\{\mathcal{I}: 1\}$, the final marking $\{\mathcal{F}: 1\}$ can be reached



$\forall$ runs π $\exists$ run π' : $\{\mathcal{I}: 1\} \xrightarrow{\pi\pi'} \{\mathcal{F}: 1\}$



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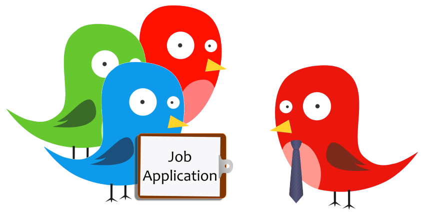
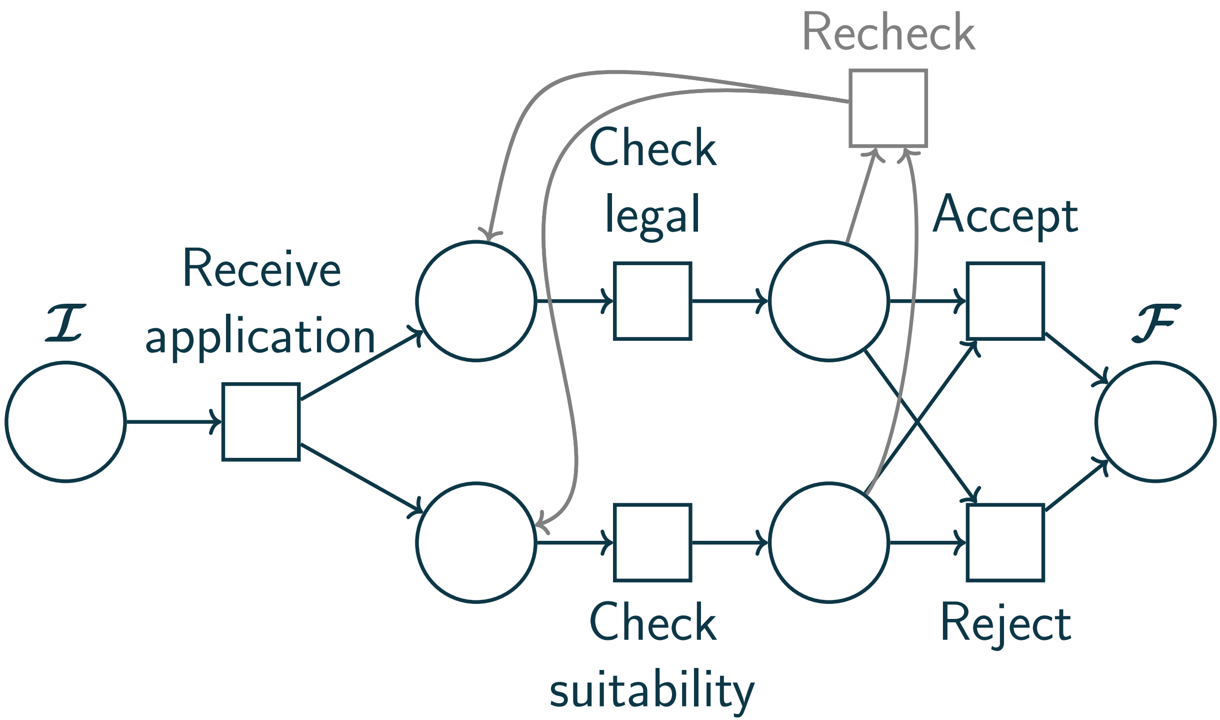
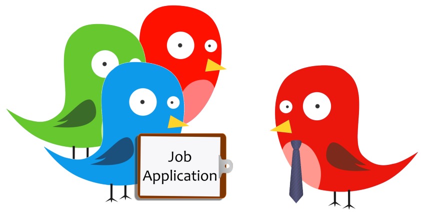
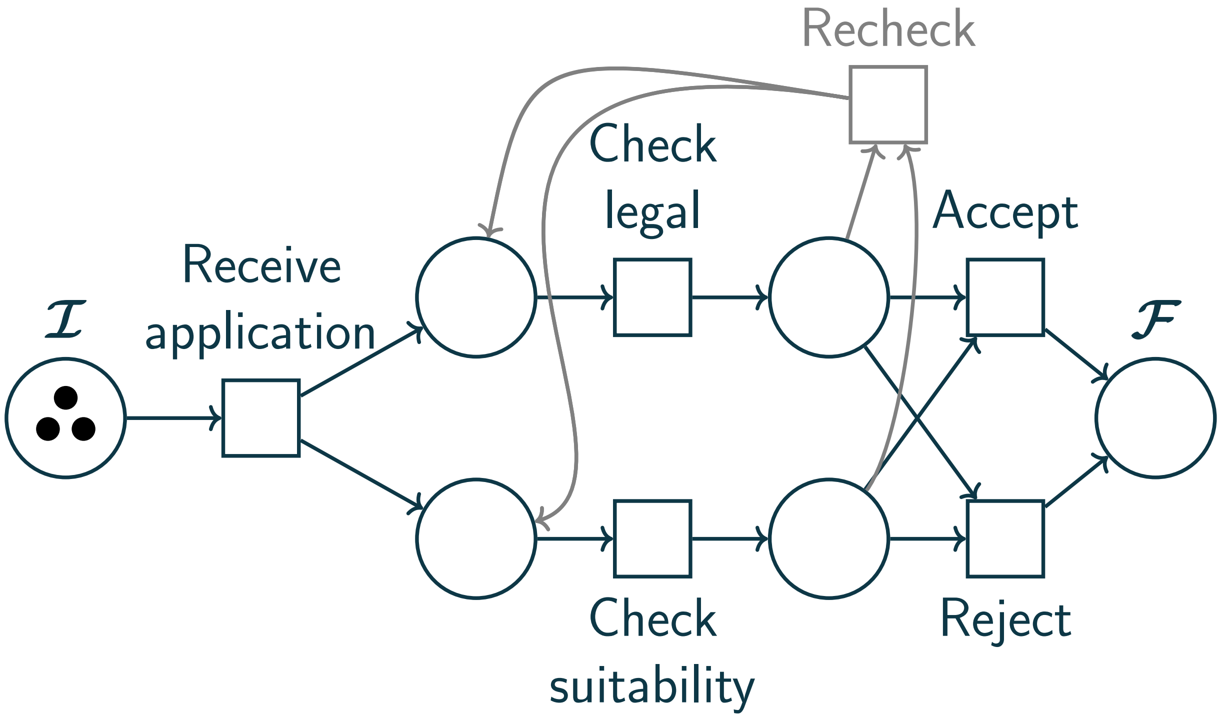




Extending soundness

k-soundness:
From any marking reachable from $\{\mathcal{I}: k\}$, the final marking $\{\mathcal{F}: k\}$ can be reached





Variants of soundness

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Variants of soundness

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Generalised soundness:	**Structural soundness:**
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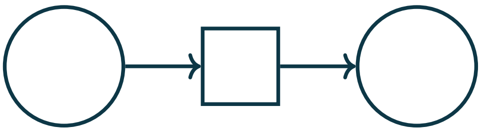
$\mathcal{I}$  $\mathcal{F}$

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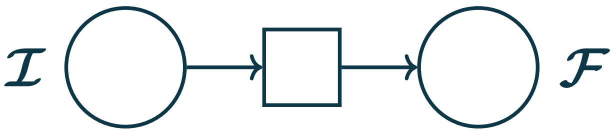	✓	

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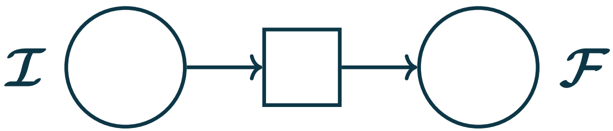	✓	✓

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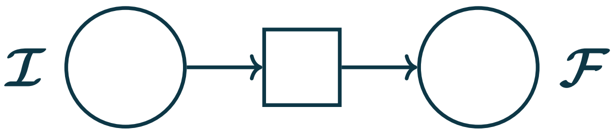
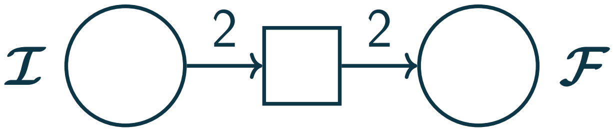
	✓	✓
		

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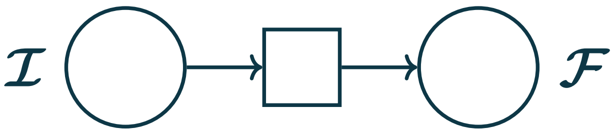
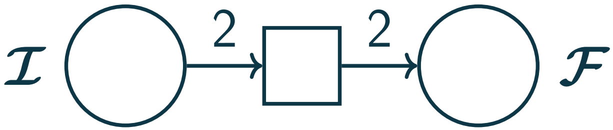
	✓	✓
	X Not 1-sound	

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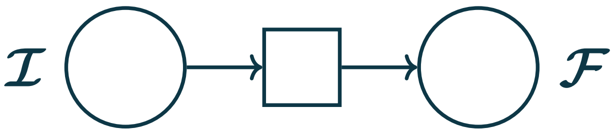
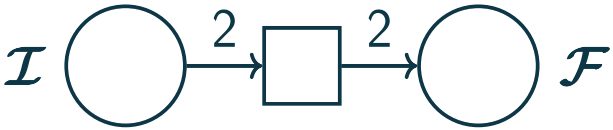
	✓	✓
	X Not 1-sound	✓ 2-sound

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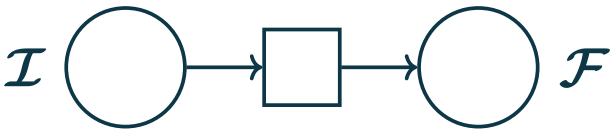

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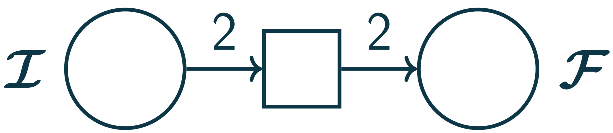

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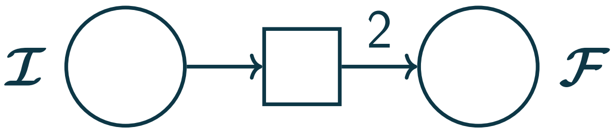

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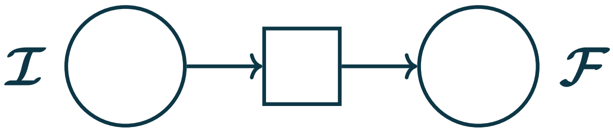
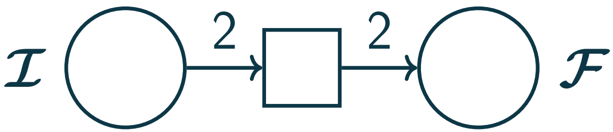
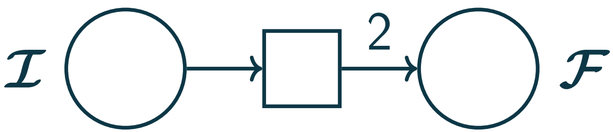
	✓	✓
	X Not 1-sound	✓ 2-sound
	X	

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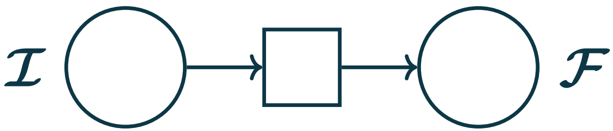
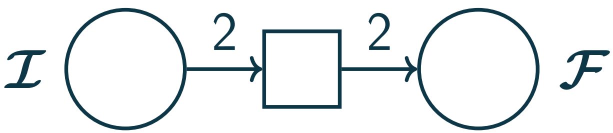
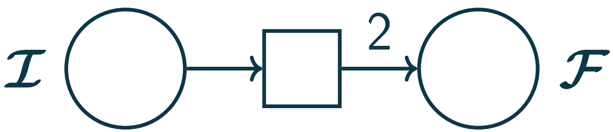
	✓	✓
	X Not 1-sound	✓ 2-sound
	X	X

Checking soundness - complexity?

	known results	our work
k-soundness		
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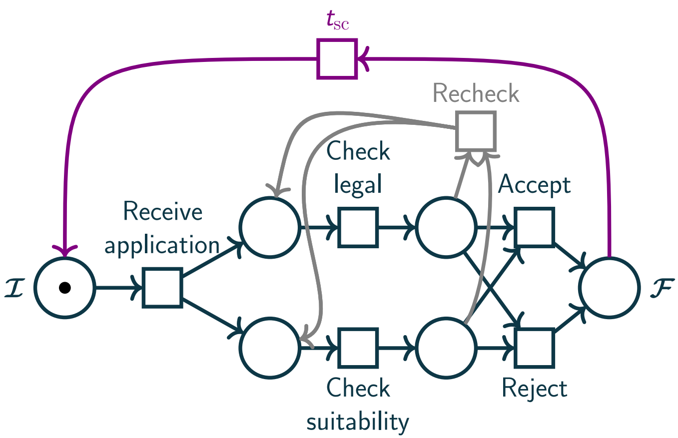

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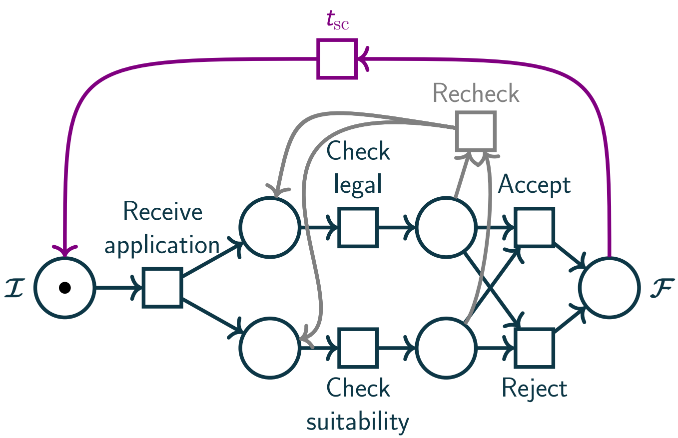

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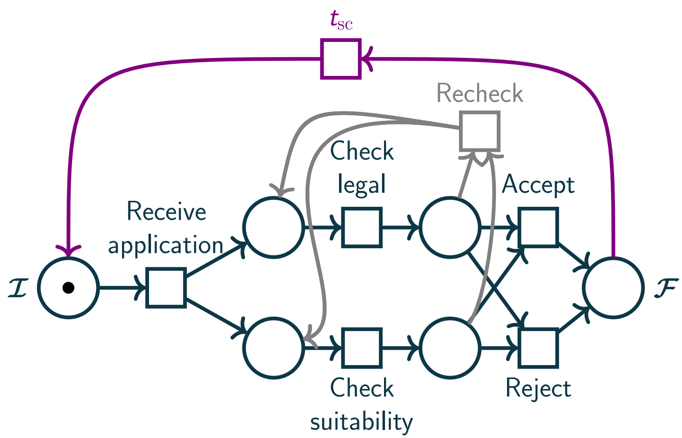

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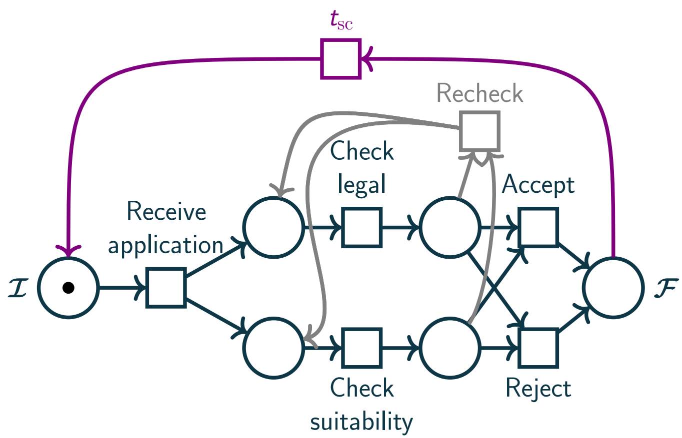

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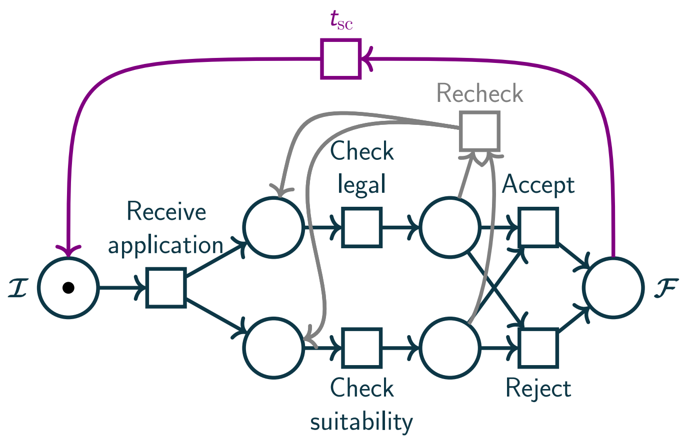

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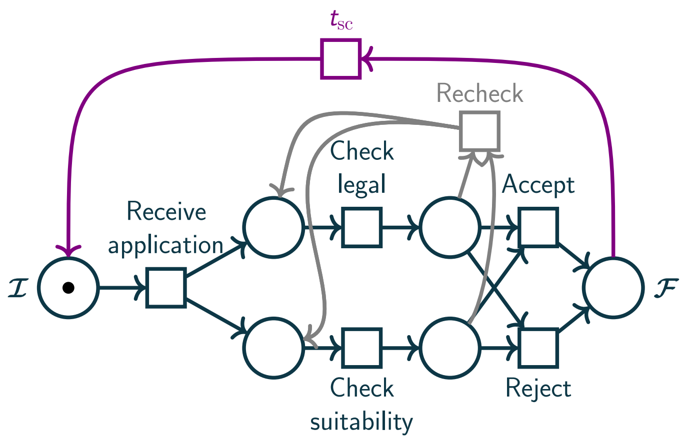

$(N_{\mathrm{SC}}, \{\mathcal{I}\colon 1\})$ **is**

N **is** 1-**sound** $\Leftarrow$ **cyclic** $+$ **bounded**

Any reachable marking can reach $\{\mathcal{F}\colon 1\}$

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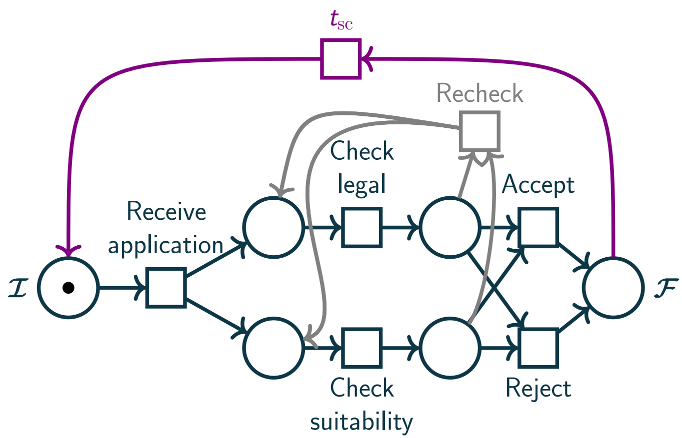
$\{\mathcal{I}\colon 1\}$ reaches m implies m reaches $\{\mathcal{I}\colon 1\}$



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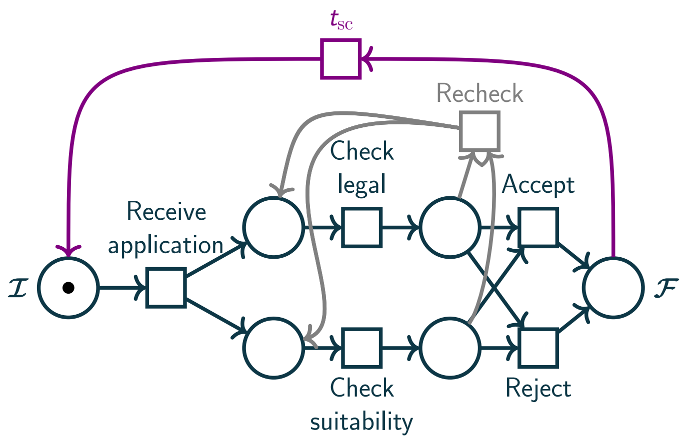
$\downarrow$

m reaches m$'$ which marks $\mathcal{F}$



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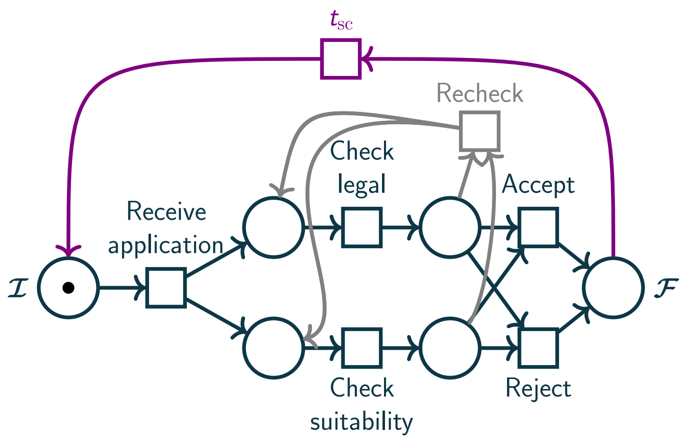

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m reaches m$'$ which marks $\mathcal{F}$

$\downarrow$

m$' = \{\mathcal{F}\colon 1\}$
otherwise N_{SC} is unbounded

$(N_{\mathrm{SC}}, \{\mathcal{I}: 1\})$ **is**

N **is** 1**-sound** $\Leftarrow$ **cyclic** + **bounded**

Any reachable marking can reach $\{\mathcal{F}: 1\}$

Any reachable marking can reach $\{\mathcal{I}: 1\}$

Unbounded: $\{\mathcal{I}: 1\}$ can reach m which can reach m′ with m < m′

$\{\mathcal{I}: 1\}$ reaches m implies m reaches $\{\mathcal{I}: 1\}$

↓

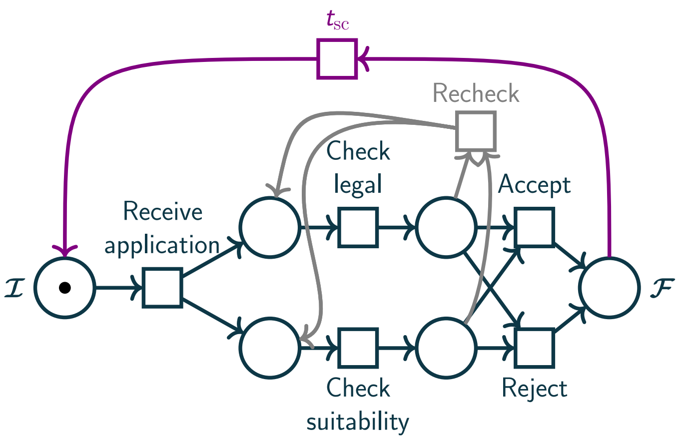
m reaches m′ which marks $\mathcal{F}$

↓

m′ = $\{\mathcal{F}: 1\}$
otherwise N_{SC} is unbounded

↓

Any reachable marking can reach $\{\mathcal{F}: 1\}$



$$(N_{\mathrm{SC}}, \{\mathcal{I}\colon 1\})\ \textbf{is}$$

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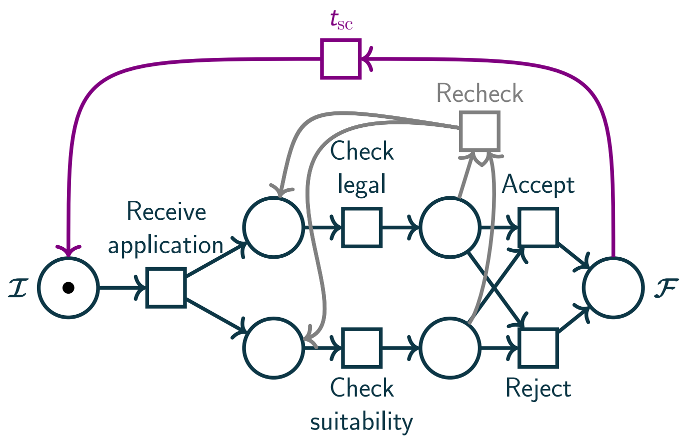

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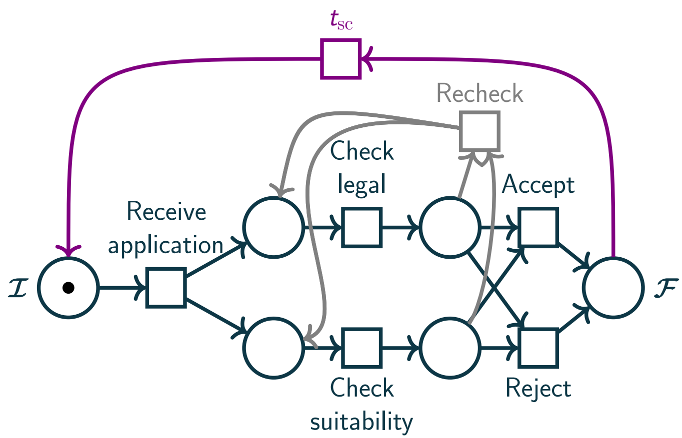

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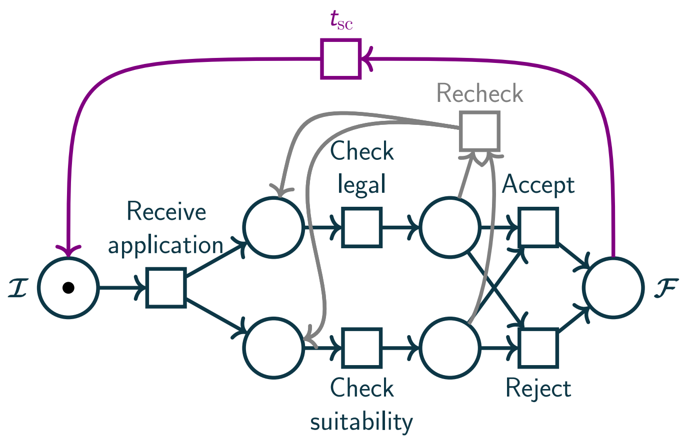
$\{\mathcal{F} \colon 1\}$ can reach $\{\mathcal{I} \colon 1\}$



N **is** 1**-sound** $\Rightarrow$ $(N_{\mathrm{SC}}, \{\mathcal{I}\colon 1\})$ **is cyclic** $+$ **bounded**

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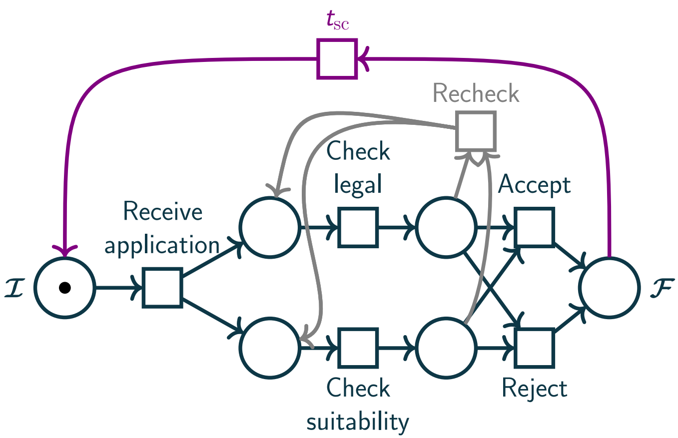

$$N \text{ is 1-sound} \Rightarrow (N_{\mathrm{SC}}, \{\mathcal{I}: 1\}) \text{ is cyclic} + \text{bounded}$$

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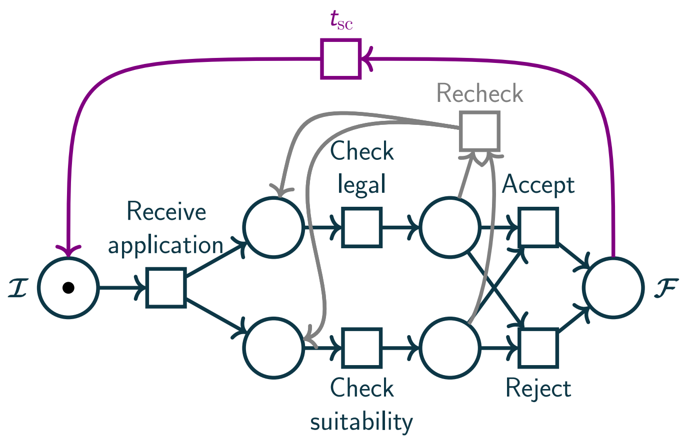
Assume N_{SC} is unbounded but N is 1-sound



$(N_{\text{SC}}, \{\mathcal{I}: 1\})$ **is**

N is 1-sound $\Rightarrow$ **cyclic** + **bounded**

Any reachable marking can reach $\{\mathcal{F}: 1\}$

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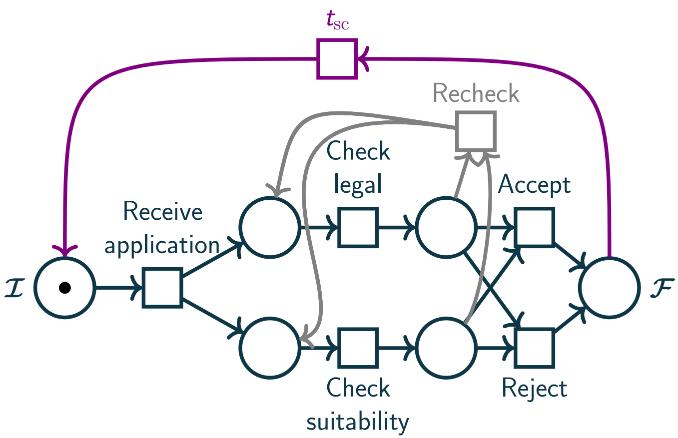
Assume N_{SC} is unbounded but N is 1-sound

↓

$\{\mathcal{I}: 1\}$ can reach m which can reach m′ $>$ m: m′ $=$ m $+$ n



N **is** 1**-sound** $\Rightarrow$ $(N_{\mathrm{SC}}, \{\mathcal{I}\colon 1\})$ **is cyclic** $+$ **bounded**

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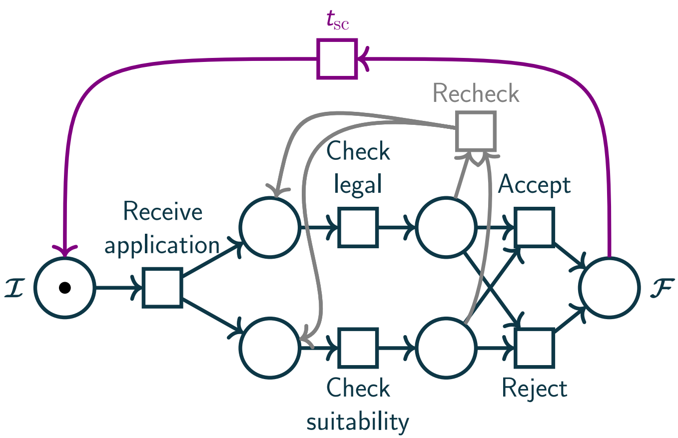

Assume N_{SC} is unbounded but N is 1-sound

$\downarrow$

$\{\mathcal{I}\colon 1\}$ can reach m which can reach $m' > m$: $m' = m + n$

$\downarrow$

m can reach $\{\mathcal{F}\colon 1\}$

$m + n$ can reach $\{\mathcal{F}\colon 1\} + n$

N **is 1-sound** $\Rightarrow$ $(N_{\text{SC}}, \{\mathcal{I}: 1\})$ **is cyclic** + **bounded**

Any reachable marking can reach $\{\mathcal{F}: 1\}$

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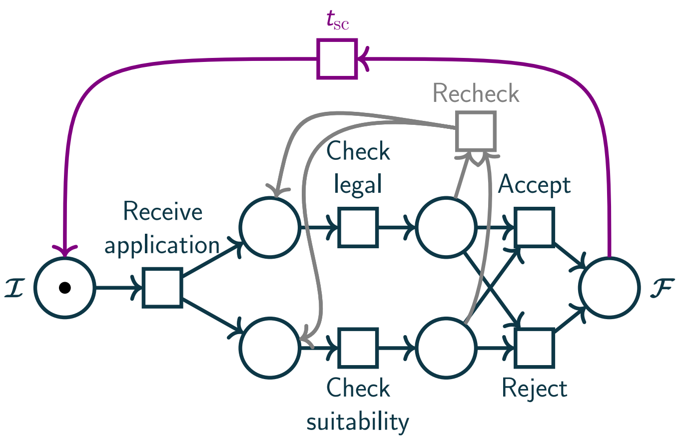

Assume N_{SC} is unbounded but N is 1-sound

↓

$\{\mathcal{I}: 1\}$ can reach m which can reach $\mathrm{m}' > \mathrm{m}$: $\mathrm{m}' = \mathrm{m} + \mathrm{n}$

↓

m can reach $\{\mathcal{F}: 1\}$
$\mathrm{m} + \mathrm{n}$ can reach $\{\mathcal{F}: 1\} + \mathrm{n}$

↓

$\{\mathcal{F}: 1\} + \mathrm{n}$ cannot reach $\{\mathcal{F}: 1\}$
$\Rightarrow N$ is not 1-sound!

$(N_{\mathrm{SC}}, \{\mathcal{I} : 1\})$ **is**

N **is** 1**-sound** $\Leftrightarrow$ **cyclic** $+$ **bounded**

$(N_{\mathrm{SC}}, \{\mathcal{I} \colon 1\})$ **is**

N **is** 1**-sound** $\Leftrightarrow$ **cyclic** $+$ **bounded**

In EXPSPACE
[Bouziane & Finkel, '97]

$(N_{\mathrm{SC}}, \{\mathcal{I}: 1\})$ **is**

N **is** 1**-sound** $\Leftrightarrow$ **cyclic** $+$ **bounded**

In EXPSPACE [Bouziane & Finkel, '97]

In EXPSPACE [Rackoff, '78]

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In EXPSPACE!

In EXPSPACE [Bouziane & Finkel, '97]

In EXPSPACE [Rackoff, '78]

Checking soundness - complexity?

	known results	our work	
***k*-soundness**	Decidable EXPSPACE-hard? [van der Aalst;'96, '97]	EXPSPACE-complete	1.
Generalised soundness	Decidable [van Hee et al.;'04]	PSPACE-complete	2.
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Generalised soundness

N is **generalised sound:**
$\forall k$: N is k-sound

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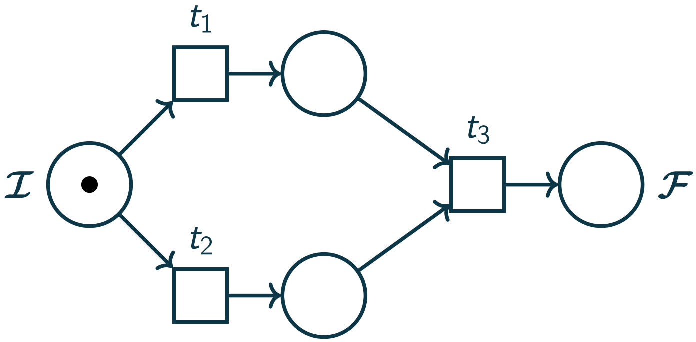

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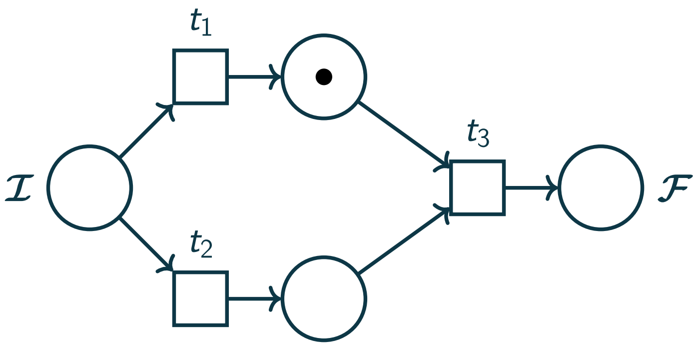

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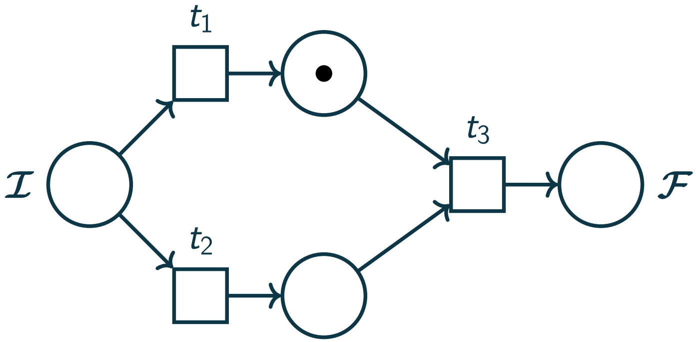

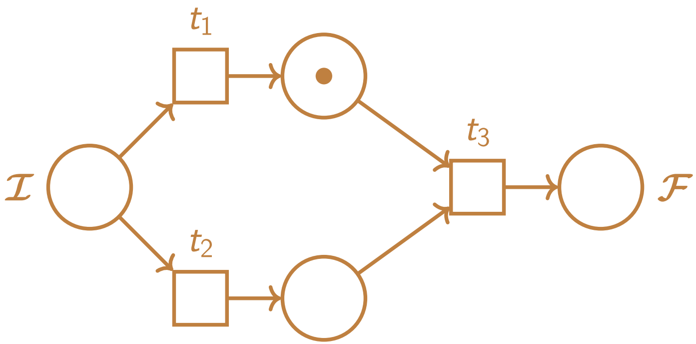

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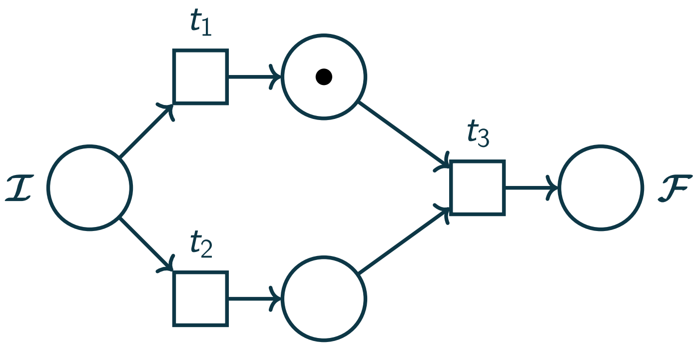

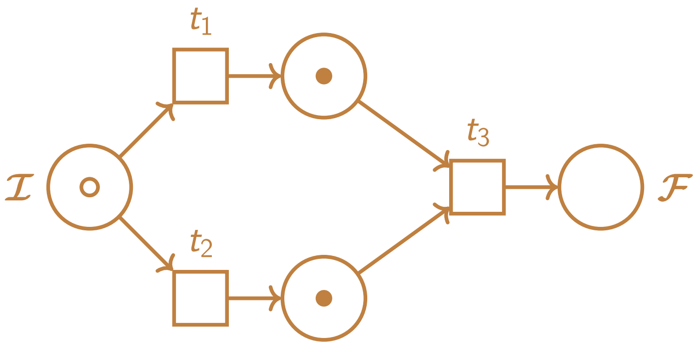

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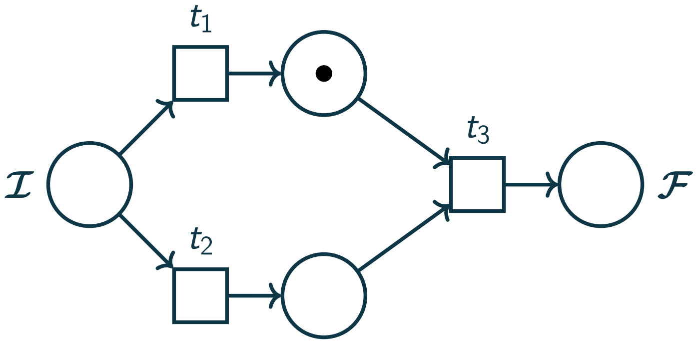

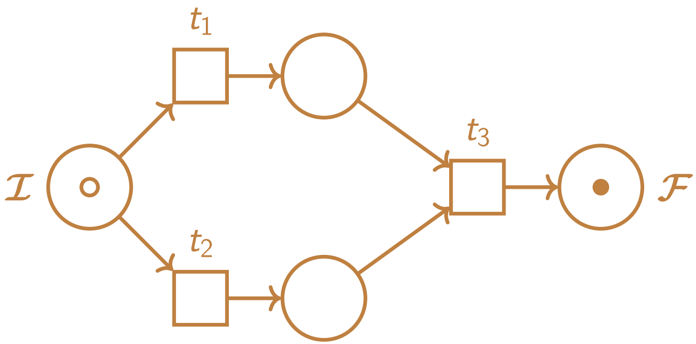

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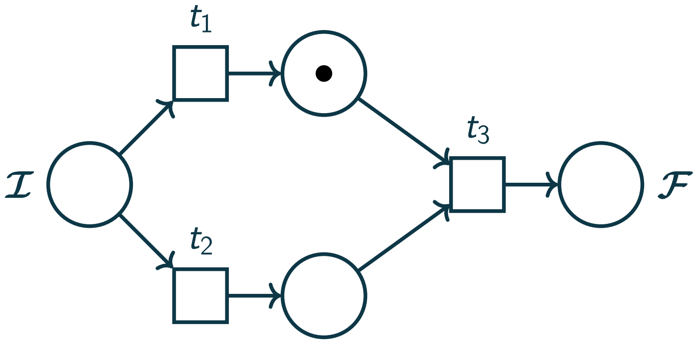

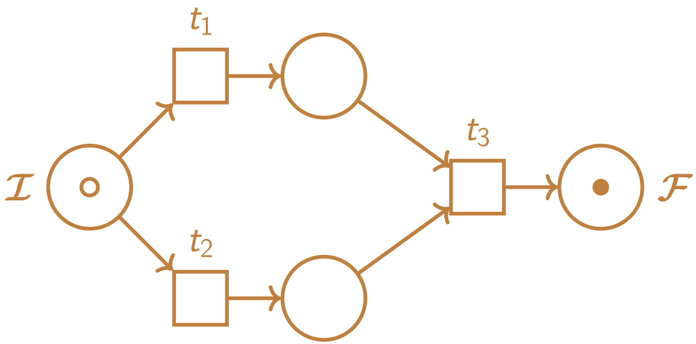

$\mathbb{Z}$-reachability

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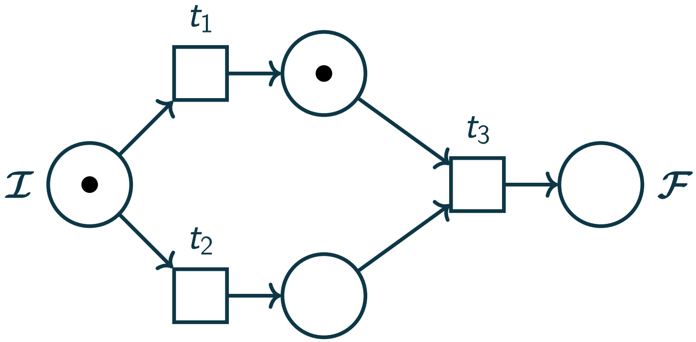

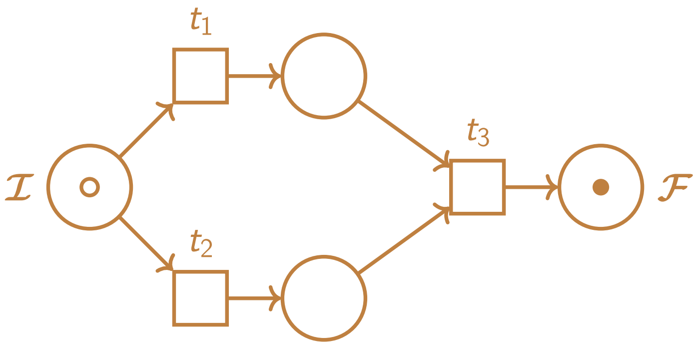

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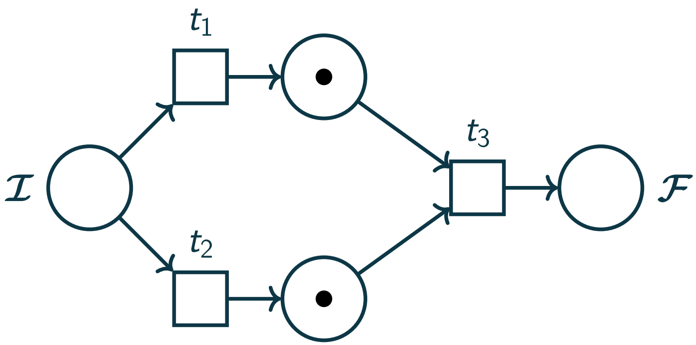

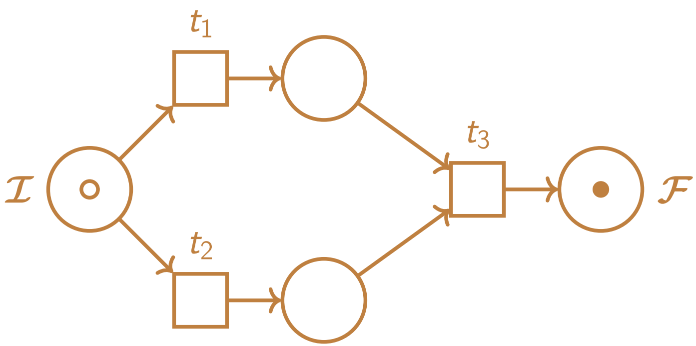

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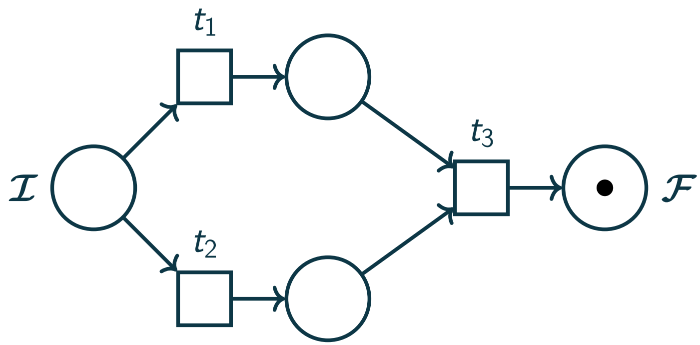

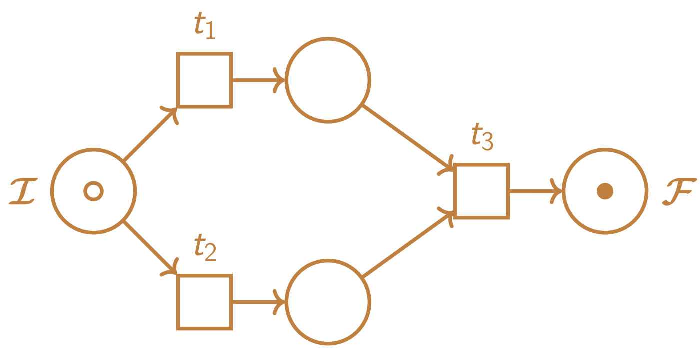

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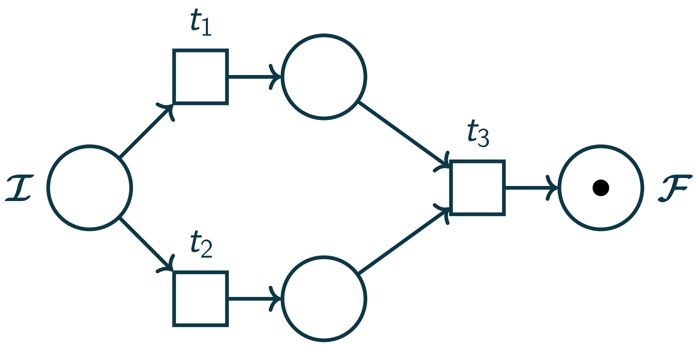
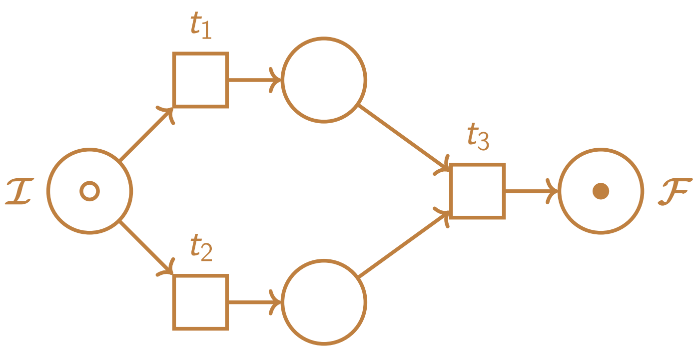


Reachability with many initial tokens



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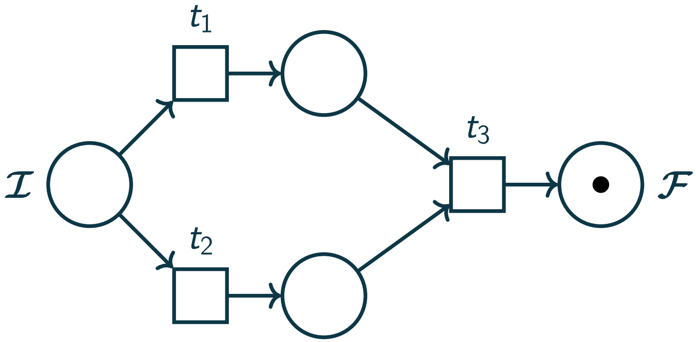

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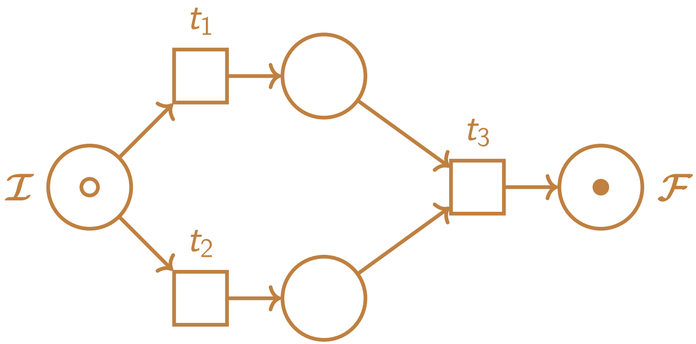
$\Uparrow$



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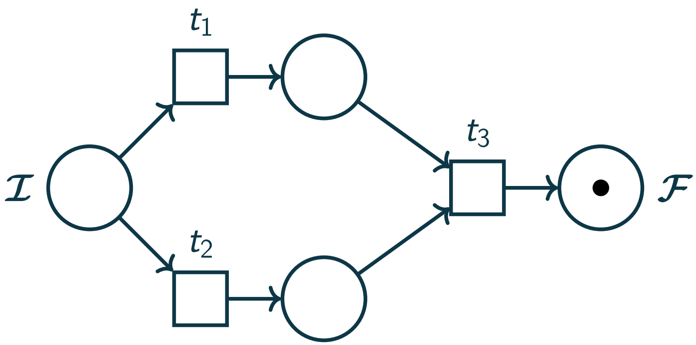

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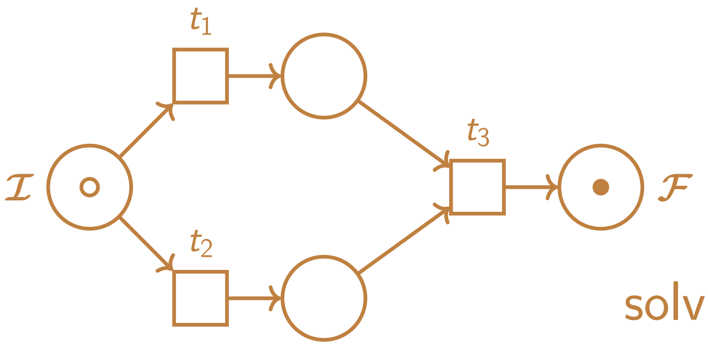

$\mathbb{Z}$-**reachability**

Reduces to
solving integer linear programs

Bounds on solutions to integer linear programs

Reachability with many initial tokens

$\Uparrow$

$\mathbb{Z}$-**reachability**

Reduces to solving integer linear programs

Bounds on solutions to integer linear programs

Reachability with many initial tokens

$\Uparrow$

Big solutions can be split into **small** solutions

[v.z.Gathen & Sieveking, 1978]

$\mathbb{Z}$-**reachability**

Reduces to solving integer linear programs

Bounds on solutions to integer linear programs

Big reachable markings can be split into **small** reachable markings

$\Uparrow$

Big solutions can be split into **small** solutions

[v.z.Gathen & Sieveking, 1978]

Reachability with many initial tokens

$\Uparrow$

$\mathbb{Z}$-**reachability**

Reduces to solving integer linear programs

Bounds on solutions to integer linear programs

Idea: For all $\mathbb{Z}$-reachable **small** markings
check reachability to **respective final marking**

Big reachable markings can be split into **small** reachable markings

$\Uparrow$

Big solutions can be split into **small** solutions
[v.z.Gathen & Sieveking, 1978]

Reachability with many initial tokens

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Conclusion

Workflow nets formally model **processes**

Soundness is an intuitive correctness condition

Current work: soundness for non-workflow-nets?