Dynamic Slicing Techniques for Petri Nets

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Program Slicing

- Method for decomposing programs in order to extract parts of them, called program *slices*, which are of interest.
- Mark Weiser (1979).
- Program debugging $\Rightarrow$ For isolating the program statements that may contain a bug.
- In general, slicing extracts the statements that may affect some point of interest, referred to as *slicing criterion*.
- Classified into two classes:
  - *Static*: if the input of the program is unknown.
  - *Dynamic*: if a particular input for the program is provided.

Program Slicing

Example

```
(1)   read(n) ;
(2)   i := 1 ;
(3)   sum := 0 ;
(4)   product := 1 ;
(5)   while i <= n do
         begin
(6)         sum := sum + i ;
(7)         product := product * i ;
(8)         i := i + 1 ;
         end ;
(9)   write (sum) ;
(10)  write (product) ;
```

(a) Example program.

```
read(n) ;
i := 1 ;

product := 1 ;
while i <= n do
   begin

      product := product * i ;
      i := i + 1 ;
   end ;

write (product) ;
```

(b) Slice of this program w.r.t. the slicing criterion (10,product).

Petri Net

- Graphic, mathematical tool used to model and verify the behavior of systems that are concurrent, asynchronous, distributed, parallel, non-deterministic and/or stochastic.
- Verification $\Rightarrow$ Methods explore the state space, as the *reachability graph*.
- State explosion problem $\Rightarrow$ various approaches have been proposed to minimize the number of system states to be studied.

Static Slicing in PN

- C.K. Chang and H. Wang. A slicing algorithm of concurrency modelling based on Petri nets. In *Proc. of the 1986 Int. Conf. on Parallel Processing*, IEEE Computer Society Press, pp. 789-792, 1987.
- W.J. Lee, S.D. Cha, Y.R. Kwon, and H.N. Kim. A Slicing-based Approach to Enhance Petri Net Reachability Analysis. In *Journal of Research and Practice in Information Technology*, vol. 32(2), pp. 131-143, 2000.
- A. Rakow. Slicing Petri Nets. Technical Report, Department für Informatik, Carl von Ossietzky Universität, Oldenburg, 2007.
- A. Rakow. Slicing Petri Nets with an Application to Workflow Verification. In *Proc. of the 34th Conf. on Current Trends in Theory and Practice of Computer Science (SOFSEM 2008)* , Springer LNCS 4910, pp. 436-447, 2008.

Algorithm of Rakow'07

- The slicing criterion for $\mathcal{N} = (P, T, F)$ is $\langle Q \rangle$ where $Q \subseteq P$ is a set of places.
- It computes all the parts of the Petri net which could transmit tokens to the slicing criterion Q.
  1. The marking of a place p depends on its input and output transitions,
  2. a transition may only be fired if it is enabled, and
  3. the enabling of a transition depends on the marking of its input places.
- The slice $\mathcal{N}' = (P', T', F')$ is a subnet of $\mathcal{N}$ that includes all input places of all transitions connected to any place p in P', starting with $Q \subseteq P'$.
- Limitation $\Rightarrow$ Big slices due to no initial marking nor firing sequence were considered.

Dynamic Slicing in PN

- *Proposal 1*: It extends the slicing criterion in Rakow'07 in order to also consider an initial marking.
- *Proposal 2*: It reduces the size of the computed slice by only considering a particular execution, a sequence of transition firings.

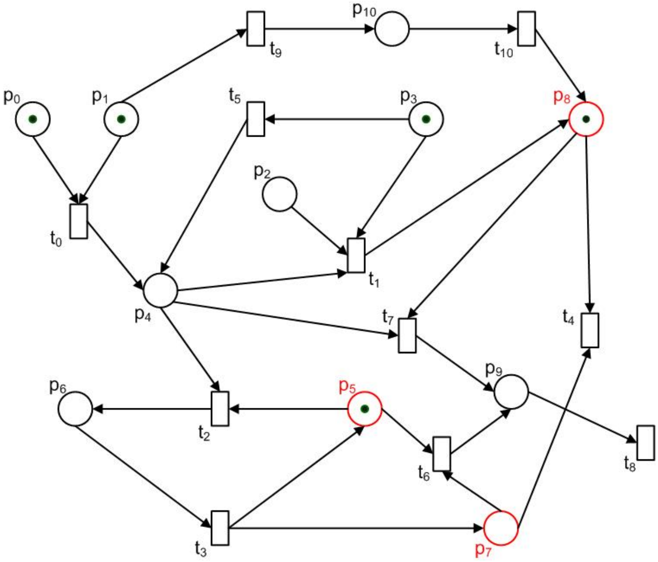
Motivation

- Dynamic $\Rightarrow$ Initial marking $\Rightarrow$ Debugging
- In a particular trace of a marked Petri net, an erroneous state is reached.
- Extracting the set of places and transitions that may erroneously contribute tokens to the places of interest.

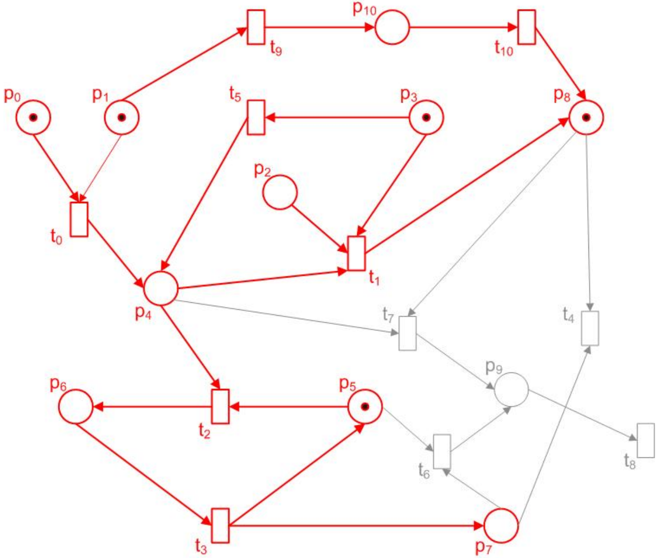
Intuitive idea

- The slicing criterion for $\mathcal{N} = (P, T, F)$ is a pair $\langle M_0, Q \rangle$ where M_0 is an initial marking for $\mathcal{N}$ and $Q \subseteq P$ is a set of places.
- The slice $\mathcal{N}' = (P', T', F')$ is a subnet with those places and transitions of $\mathcal{N}$ which can contribute to change the marking of Q in any execution starting in M_0.
- How?
  1. We first compute the possible paths which lead to the slicing criterion (*backward slice*).
  2. We also compute the paths that may be followed by the tokens of the initial marking (*forward slice*).
  3. The result is the intersection of backward and forward slices.

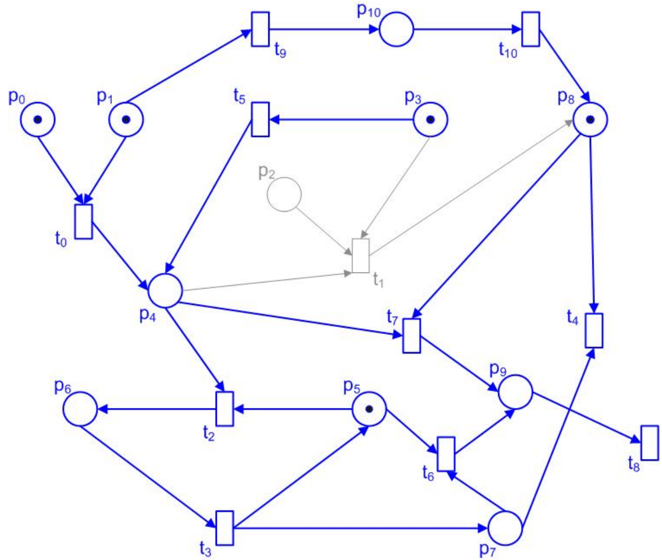
- Initial PN $(\mathcal{N}, M_0)$ and slicing criterion $\langle M_0, \{p_5, p_7, p_8\}\rangle$



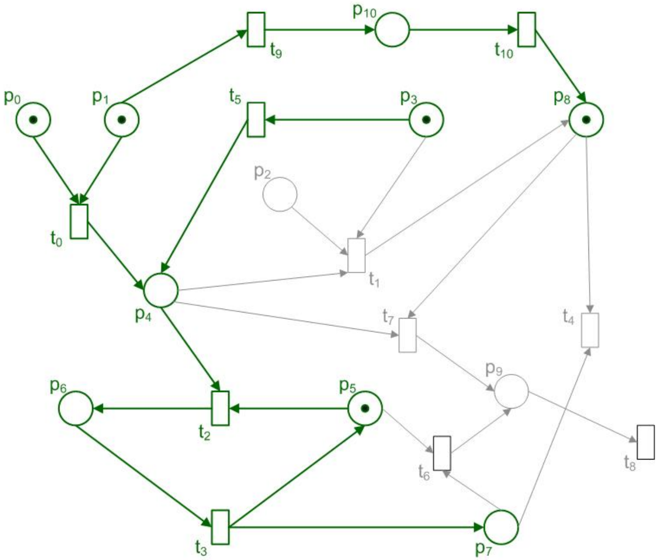
- Backward slice $(\mathcal{N}_1, M_0|_{P_1})$



- Forward slice $(\mathcal{N}_2, M_0|_{P_2})$

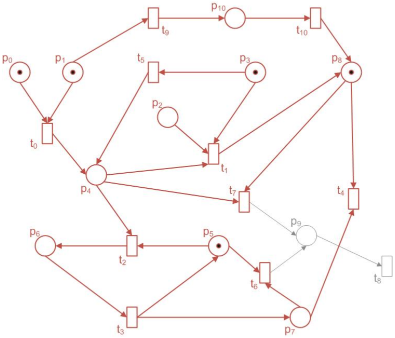


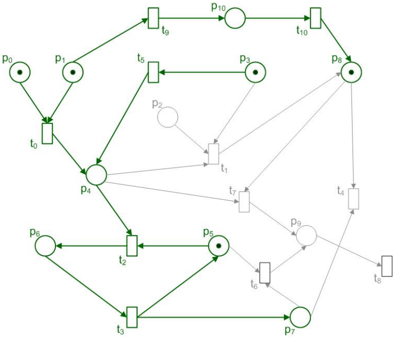
- Intersection: Final result of Algorithm 1



Comparison

- Rakow's slice — Our slice
- $\langle \{p_5, p_7, p_8\} \rangle$ — $\langle M_0, \{p_5, p_7, p_8\} \rangle$





Comparison

- Rakow's algorithm computes all the parts of the Petri net which could transmit tokens to $\langle Q \rangle$.
- We compute all the parts of the Petri net which could transmit tokens to Q from M_0.
- Our technique is more general than Rakow's technique $\Rightarrow$ the Rakow's slice w.r.t. $\langle Q \rangle$ is the same as our slice w.r.t. $\langle M_0, Q \rangle$ if $M_0(p) > 0$ for all $p \in P$.
- But it keeps its simplicity and efficiency.
- Its cost is bounded by the number of transitions T of the original Petri net, $\mathcal{O}(2T)$.

Motivation

- We refine the notion of slicing criterion including the firing sequence that represents the erroneous simulation.
- The slice is more precise than the one produced by previous proposal.

Intuitive idea

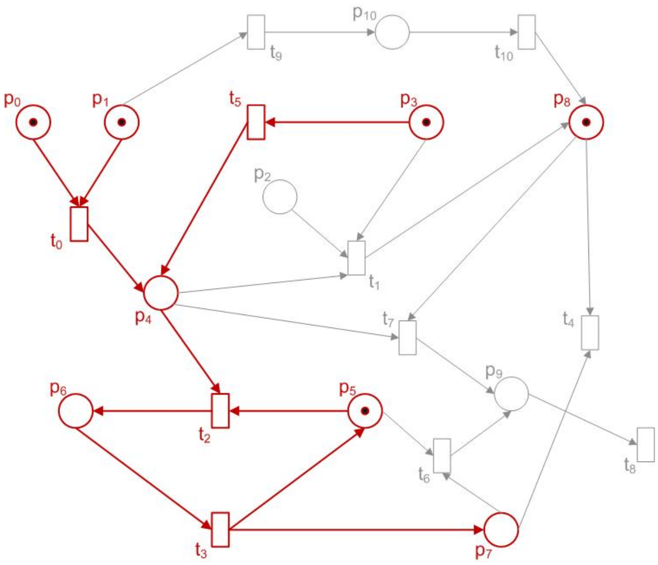
- The slicing criterion for $\mathcal{N} = (P, T, F)$ is $\langle M_0, \sigma, Q \rangle$.
- The slice $\mathcal{N}' = (P', T', F')$ is a subnet with those places and transitions of $\mathcal{N}$ which are necessary to move tokens to the places in Q, following $\sigma = t_1 t_2 \ldots t_n$ $(M_0 \xrightarrow{t_1} M_1 \xrightarrow{t_2} \ldots M_{i-1} \xrightarrow{t_i} M_i \ldots \xrightarrow{t_n} M_n)$.
- How?
  - Function slice(M_n, Q) is called, where M_n is a marking reachable from M_0 through σ.
  - $\mathrm{slice}(M_i, W) =$

$$\begin{cases} W & \text{if } i = 0 \\ \mathrm{slice}(M_{i-1}, W) & \text{if } \forall p \in W.\ M_{i-1}(p) \geq M_i(p),\ i > 0 \\ \{t_i\} \cup \mathrm{slice}(M_{i-1}, W \cup {}^{\bullet}t_i) & \text{if } \exists p \in W.\ M_{i-1}(p) < M_i(p),\ i > 0 \end{cases}$$

- Slicing criterion $\langle M_0, \sigma = t_5 t_2 t_3 t_0 t_2 t_3, \{p_5, p_7, p_8\}\rangle$

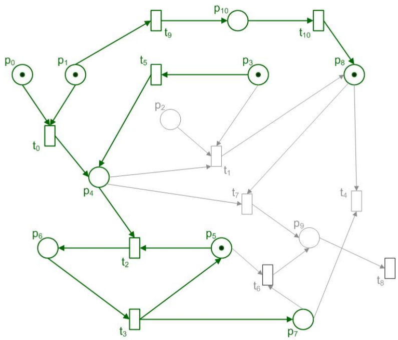
	p_0	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}
M_0	1	1	0	1	0	1	0	0	1	0	0
t_5	1	1	0	0	1	1	0	0	1	0	0
t_2	1	1	0	0	0	0	1	0	1	0	0
t_3	1	1	0	0	0	1	0	1	1	0	0
t_0	0	0	0	0	1	1	0	1	1	0	0
t_2	0	0	0	0	0	0	1	1	1	0	0
t_3	0	0	0	0	0	1	0	2	1	0	0

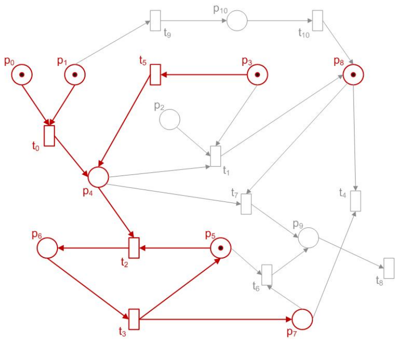
- Slice result of Algorithm 2



Comparison

- First slice — Second slice
- $\langle M_0, \{p_5, p_7, p_8\}\rangle$ — $\langle M_0, \sigma = t_5 t_2 t_3 t_0 t_2 t_3, \{p_5, p_7, p_8\}\rangle$





Conclusions

- We have introduced two different techniques for dynamic slicing of Petri nets.
- To the best of our knowledge, this is the first approach to dynamic slicing for Petri nets.
- The first proposal takes into account the Petri net and an initial marking, but produces a slice w.r.t. any possibly firing sequence.
- The second proposal further reduces the computed slice by fixing a particular firing sequence.
- In general, our slices are smaller than previous (static) approaches where no initial marking nor firing sequence were considered.

Future work

- We plan to carry on an experimental evaluation of our slicing techniques in order to test its viability in practice.
- We also find it useful to extend our slicing techniques to other kind of Petri nets (e.g., coloured Petri nets [Jensen97] and marked-controlled reconfigurable nets [Llorens and Oliver04]).