Dynamic Slicing Techniques for Petri Nets

M. Llorens, J. Oliver, J. Silva, S. Tamarit, G. Vidal

Dep. of Information Systems and Computation (DSIC)
Technical University of Valencia (UPV)

4th International Workshop on Programming Language Interference and Dependence (PLID 2008)
1 Motivation
   • Program Slicing
   • Petri Nets
   • Static Slicing in PN
   • Dynamic Slicing in PN

2 Dynamic Slicing in PN from an initial marking
   • Motivation
   • Intuitive idea
   • Example
   • Comparison

3 Dynamic Slicing in PN from a firing sequence
   • Motivation
   • Intuitive idea
   • Example
   • Comparison

4 Conclusions and Future Work
Motivation

- Program Slicing
  - Petri Nets
  - Static Slicing in PN
  - Dynamic Slicing in PN

Dynamic Slicing in PN from an initial marking

- Motivation
- Intuitive idea
- Example
- Comparison

Dynamic Slicing in PN from a firing sequence

- Motivation
- Intuitive idea
- Example
- Comparison

Conclusions and Future Work
Program Slicing

- Method for decomposing programs in order to extract parts of them, called program *slices*, which are of interest.
- 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.
Motivation
Dynamic Slicing in PN from an initial marking
Dynamic Slicing in PN from a firing sequence
Conclusions and Future Work

Program Slicing

Dynamic Slicing in PN

Example

(a) Example program.

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

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

1. Program Slicing
2. Petri Nets
   - Static Slicing in PN
   - Dynamic Slicing in PN

Dynamic Slicing in PN from an initial marking

1. Motivation
2. Intuitive idea
3. Example
4. Comparison

Dynamic Slicing in PN from a firing sequence

1. Motivation
2. Intuitive idea
3. Example
4. Comparison

Conclusions and Future Work

M. Llorens, J. Oliver, J. Silva, S. Tamarit, G. Vidal
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 ⇒ Methods explore the state space, as the reachability graph.
- State explosion problem ⇒ various approaches have been proposed to minimize the number of system states to be studied.
1 Motivation

- Program Slicing
- Petri Nets
- **Static Slicing in PN**
- Dynamic Slicing in PN

2 Dynamic Slicing in PN from an initial marking

- Motivation
- Intuitive idea
- Example
- Comparison

3 Dynamic Slicing in PN from a firing sequence

- Motivation
- Intuitive idea
- Example
- Comparison

4 Conclusions and Future Work
Static Slicing in PN


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.
Motivation

Program Slicing
Petri Nets
Static Slicing in PN
Dynamic Slicing in PN

Dynamic Slicing in PN from an initial marking
Motivation
Intuitive idea
Example
Comparison

Dynamic Slicing in PN from a firing sequence
Motivation
Intuitive idea
Example
Comparison

Conclusions and Future Work
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
- Program Slicing
- Petri Nets
- Static Slicing in PN
- Dynamic Slicing in PN

Dynamic Slicing in PN from an initial marking
- Motivation
- Intuitive idea
- Example
- Comparison

Dynamic Slicing in PN from a firing sequence
- Motivation
- Intuitive idea
- Example
- Comparison

Conclusions and Future Work
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.
1. Motivation
   - Program Slicing
   - Petri Nets
   - Static Slicing in PN
   - Dynamic Slicing in PN

2. Dynamic Slicing in PN from an initial marking
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

3. Dynamic Slicing in PN from a firing sequence
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

4. Conclusions and Future Work
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.
1. Motivation
   - Program Slicing
   - Petri Nets
   - Static Slicing in PN
   - Dynamic Slicing in PN

2. Dynamic Slicing in PN from an initial marking
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

3. Dynamic Slicing in PN from a firing sequence
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

4. Conclusions and Future Work

M. Llorens, J. Oliver, J. Silva, S. Tamarit, G. Vidal

Dynamic Slicing Techniques for Petri Nets
Initial PN \((\mathcal{N}, M_0)\) and slicing criterion \(\langle M_0, \{p_5, p_7, p_8\} \rangle\)
Motivation

Dynamic Slicing in PN from an initial marking
Dynamic Slicing in PN from a firing sequence
Conclusions and Future Work

- Backward slice \((N_1, M_0|P_1)\)
**Forward slice** \( (\mathcal{N}_2, M_0|_{P_2}) \)
**Intersection: Final result of Algorithm 1**
Motivation

Intuitive idea

Example

Comparison

Dynamic Slicing in PN from an initial marking

Motivation

Intuitive idea

Example

Comparison

Dynamic Slicing in PN from a firing sequence

Motivation

Intuitive idea

Example

Comparison

Conclusions and Future Work
Comparison

- Rakow’s slice
  \[ \langle \{p_5, p_7, p_8\} \rangle \]

- Our slice
  \[ \langle M_0, \{p_5, p_7, p_8\} \rangle \]
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, $O(2T)$. 
1 Motivation
- Program Slicing
- Petri Nets
- Static Slicing in PN
- Dynamic Slicing in PN

2 Dynamic Slicing in PN from an initial marking
- Motivation
- Intuitive idea
- Example
- Comparison

3 Dynamic Slicing in PN from a firing sequence
- Motivation
- Intuitive idea
- Example
- Comparison

4 Conclusions and Future Work
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.
Motivation

1. Program Slicing
2. Petri Nets
3. Static Slicing in PN
4. Dynamic Slicing in PN

Dynamic Slicing in PN from an initial marking

1. Motivation
2. Intuitive idea
3. Example
4. Comparison

Dynamic Slicing in PN from a firing sequence

1. Motivation
2. Intuitive idea
3. Example
4. Comparison

Conclusions and Future Work
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 $\sigma = t_1 t_2 \ldots t_n$

$\langle M_0 \xrightarrow{t_1} M_1 \xrightarrow{t_2} \ldots M_{i-1} \xrightarrow{t_i} M_i \ldots \xrightarrow{t_n} M_n \rangle$.

How?

- Function $\text{slice}(M_n, Q)$ is called, where $M_n$ is a marking reachable from $M_0$ through $\sigma$.
- $\text{slice}(M_i, W) =$

$$\begin{cases} 
W & \text{if } i = 0 \\
\text{slice}(M_{i-1}, W) & \text{if } \forall p \in W. M_{i-1}(p) \geq M_i(p), \ i > 0 \\
\{t_i\} \cup \text{slice}(M_{i-1}, W \cup \bullet t_i) & \text{if } \exists p \in W. M_{i-1}(p) < M_i(p), \ i > 0
\end{cases}$$
1. **Motivation**
   - Program Slicing
   - Petri Nets
   - Static Slicing in PN
   - Dynamic Slicing in PN

2. **Dynamic Slicing in PN from an initial marking**
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

3. **Dynamic Slicing in PN from a firing sequence**
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

4. **Conclusions and Future Work**
Slicing criterion $\langle M_0, \sigma = t_5 t_2 t_3 t_0 t_2 t_3, \{p_5, p_7, p_8\}\rangle$

\[
M_0 = \begin{bmatrix}
1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

- $t_5$
- $t_2$
- $t_3$
- $t_0$
- $t_2$
- $t_3$

M. Llorens, J. Oliver, J. Silva, S. Tamarit, G. Vidal

Dynamic Slicing Techniques for Petri Nets
Slice result of Algorithm 2
1. **Motivation**
   - Program Slicing
   - Petri Nets
   - Static Slicing in PN
   - Dynamic Slicing in PN

2. **Dynamic Slicing in PN from an initial marking**
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

3. **Dynamic Slicing in PN from a firing sequence**
   - Motivation
   - Intuitive idea
   - Example
   - Comparison

4. **Conclusions and Future Work**
### Comparison

- **First slice**
  \[ \langle M_0, \{p_5, p_7, p_8\} \rangle \]

- **Second slice**
  \[ \langle M_0, \sigma = t_5 t_2 t_3 t_0 t_2 t_3, \{p_5, p_7, p_8\} \rangle \]
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]).