An NMF solution to the State Elimination case at the TTC 2017

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Abstract

This paper presents a solution to the State Elimination case at the Transformation Tool Contest (TTC) 2017 using the .NET Modeling Framework (NMF). The goal of this case was to investigate, to which degree model transformation technology may help to make the specification of state elimination more declarative and faster than the reference implementation in JFLAP for smaller models.

1 Introduction

State elimination is a well known technique in theoretical computer science to extract the regular expression represented by a given state machine.

In the scope of the Transformation Tool Contest 2017, this problem has been reified as a model transformation problem[1] in order to reason on the understandability, but also on the scalability of modern model transformation systems.

In this paper, we present a solution for the state elimination case using the .NET Modeling Framework (NMF, [Hin16]). However, the state elimination case does not fit either of the model transformation languages NTL [Hin13] or NMF Synchronizations [Hin15]. Both of these language share the common assumption that it is a characterizing element of a model transformation that there is correspondence between elements of the source model and elements of some target model. Based on this simple assumption, NTL offers unidirectional, imperative model transformations meanwhile NMF Synchronizations is more declarative and supports also bidirectional and incremental transformations.

As both of these languages do not fit, we still have NMF Expressions[2], the incrementalization system used in NMF. This incrementalization system supports the incremental execution of *arbitrary* analyses, but rests on the assumption that the analysis is essentially referential transparent, in particular does not make side-effects beyond object creations.

Therefore, we present a solution using standard C# based on the model API generated for the given Ecore model using NMF. However, we tried to demonstrate the usage of declarative C#-parts that also reach a good degree of declarativeness.

Our solution is publicly available online[3] but not on SHARE because the used version of NMF requires at least Windows Vista which is not available in SHARE.

The remainder of this paper is structured as follows: Section 2 presents our solution. Section 3 evaluates our solution with regard to performance and conciseness. Section 4 concludes the paper.

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[1] `http://www.transformation-tool-contest.eu/TTC_2017_paper_4.pdf`

[2] There is no dedicated publication yet, but usage examples can be found in [HH15].

[3] `https://github.com/georghinkel/state-elimination-mt`

2 Solution

Our proposed solution is completely standard general-purpose code. However, the language features of C# make this code already very concise such that we believe there is no further language necessary to further reduce the size of the code.

As the very first step, the our solution has to load the input model. For this, we need to transform the Ecore metamodel to the NMeta format used within NMF and generate code for it. Both steps can be done together using the tool `Ecore2Code` that ships with the NMF Nuget Package `NMF-Basics`. However, we manually refined the generated NMeta metamodel to set lower bounds of the involved attributes to 1. As a reason, NMF generates nullable types for attributes with lower bound 0 and they are much more cumbersome to use.

The actual deserialization of the input model is as straight forward as shown in Listing 1. We need to create a new repository and load the model into that repository.

```
1 var repository = new ModelRepository();
2 var transitionGraph = repository.Resolve(path).RootElements[0] as TransitionGraph;
```

Listing 1: Loading the input model

Our solution only solves the main task and extension task 1. In the solution, we first select the initial state and create a new one, if the selected initial state has incoming edges. The implementation is depicted in Listing 2.

```
1  var initial = transitionGraph.States.FirstOrDefault(s => s.IsInitial);
2  if (initial.Incoming.Count > 0)
3  {
4    var newInitial = new State { IsInitial = true };
5    transitionGraph.Transitions.Add(new Transition
6    {
7      Source = newInitial,
8      Target = initial
9    });
10   initial = newInitial;
11 }
```

Listing 2: Creating a new initial state, if the initial state has an incoming state

The solution makes intensive use of the ability of C# to initialize objects inline. This syntax feature is also supported by NMF, at least for single-valued features. We also make use of the fact that NMF respects bidirectional references. Therfore, the assignments in Lines 7 and 8 of Listing 2 do not only set the `Source` and `Target` property of the newly created transition object, they also implicitly add the new transition to the `Incoming` and `Outgoing` collection for the respective states. For this to work, NMF generates special collection implementations for these two collections. This simplifies the manually written code.

Next, we select a final state. Because the logic for this slightly more complex, we extracted it into a method whose implementation is depicted in Listing 3. At first, we obtain a list of all states that are currently set as final states. If this list only contains a single element, there is no need to change anything and we simply select the state as the new final state. If there are multiple states, we create a new final state and add transitions from the existing final states to that new state. Adding those transitions is done exactly in the same way as in Listing 2.

```
1  var finalStates = transitionGraph.States.Where(s => s.IsFinal).ToList();
2  if (finalStates.Count == 1 && finalStates[0].Outgoing.Count == 0)
3  {
4    return finalStates[0];
5  }
6  else
7  {
8    var newFinal = new State();
9    foreach (var s in finalStates)
10   {
11     transitionGraph.Transitions.Add(new Transition
12     {
13       Source = s,
14       Target = newFinal
15     });
16   }
17   transitionGraph.States.Add(newFinal);
18   return newFinal;
19 }
```

Listing 3: Creating a new final state, if multiple final states exist

The next part of the solution already is the removal of states. The implementation of this step is depicted in Listing 4. We first check whether there are any self-transitions for the state to be removed and join them. To make this joining more readable, we picked the C# query syntax to select the labels of all self-edges. If there is a self-edge with a non-empty label, we directly star it for the regular expression.

```
foreach (var s in transitionGraph.States.ToArray())
{
  if (s == initial || s == final) continue;

  var selfEdge = string.Join("+", from edge in s.Outgoing
                                  where edge.Target == s
                                  select edge.Label);

  if (!string.IsNullOrEmpty(selfEdge)) selfEdge = $"({selfEdge})*";

  foreach (var incoming in s.Incoming.Where(t => t.Source != s))
  {
    if (incoming.Source == null) continue;
    foreach (var outgoing in s.Outgoing.Where(t => t.Target != s))
    {
      if (outgoing.Target == null) continue;
      var transition = incoming.Source.Outgoing.FirstOrDefault(t => t.Target == outgoing.Target);
      if (transition == null)
      {
        transitionGraph.Transitions.Add(new Transition
        {
          Source = incoming.Source,
          Target = outgoing.Target,
          Label = incoming.Label + selfEdge + outgoing.Label
        });
      }
      else
      {
        transition.Label = $"({transition.Label}+{incoming.Label␣+␣selfEdge␣+␣outgoing.Label})";
      }
    }
  }

  s.Delete();
}
```

Listing 4: Removing states

Before we actually remove the state, we iterate through all of its incoming and outgoing transitions. For each pair of incoming and outgoing transition, we create a new transition that avoids the state to be deleted. The label of that new transition is the same as following the `incoming` edge to the state marked for deletion, then making cycles in that state (only in case there actually are cycles) and then following the `outgoing` edge to the target state.

Finally, we delete the state that we previously picked from the list of all states. This will remove the state from the collection it is contained in, i.e. the collection of states in the transition graph. Further, it resets all references to that state. Because transitions are independent of states in the metamodel, the incoming and outgoing transitions will still exist after the state has been deleted. However, after the deletion operation, they are no longer connected to the deleted state, but the `Source` and `Target` reference are simply empty, i.e. point to `null`.

We could go on and delete those transitions as they are no longer valid. However, in our experiments, we came to the conclusion that it is better to leave these transitions in there because the effort to delete them (removing an element from an ordered collection is an $O(n)$-operation!) is larger than the effort not to delete them.

Finally, we return the possible paths from the initial state to the target state. This can be done similarly as above. The implementation, this time as a one-liner, is depicted in Listing 5.

```
return string.Join("+", from edge in initial.Outgoing where edge.Target == final select edge.Label);
```

Listing 5: Calculating the overall regular expression

3 Evaluation

Our solution is very concise. Besides generated code for the metamodel and one line of metamodel registration, the entire solution consists of 102 lines, of which 31 lines are either blank or only contain braces.

Model	Execution time
example	235ms
leader3_2	241ms
leader4_2	233ms
leader3_3	236ms
leader5_2	263ms
leader3_4	247ms
leader4_3	990ms
leader3_5	271ms
leader6_2	582ms
leader3_6	352ms

Table 1: Execution times for the example input models

The execution times for the test models are depicted in Table 1. The execution times have been recorded on an Intel i7-4710MQ clocked at 2.50Ghz on a system with 16GB RAM. All measurements have been repeated five times and Table 1 report the mean values. The `example` model refers to the example state machine that is depicted in the paper. The 235ms execution time for this model essentially represent the overhead that NMF requires to initialize and load the metamodels.

For the larger models, both for the main task and the extension task 1, the solution runs out of memory. This is somehow surprising, because the smaller models complete in a very short time.

4 Conclusion

In this paper, we discussed how the .NET Modeling Framework can be used to solve state elimination reified as model transformation task. Because the transformation languages in NMF are not well suited for this problem, our solution is essentially using general-purpose code, although the implementation of bidirectional references and automatically resetting references for deleted model elements makes the implementation more concise.

The performance results for the smaller models are good, however the solutions runs into memory problems for larger models.

References

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