Transformation of BPMN models for Behaviour Analysis

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Abstract. In industry, many business processes are modelled and stored in Enterprise Information Systems (EIS). Tools supporting the verification and validation of business processes can help to improve the quality of these business processes. However, existing tools can not directly be applied to models used in industry.
In this paper, we present our approach for model verification and validation: translating industrial models to Petri nets and mCRL2, and subsequently applying existing tools on the models derived from the initial industrial models. The following translations are described: BPMN models to Petri nets and Petri nets to mCRL2. It is shown what the analysis on the derived models can reveal about the original models.

1 Introduction

New laws, standards and technologies have given the use of Enterprise Information Systems (EIS) an enormous boost. For mayor firms, the knowledge about business processes is a mayor asset and is stored in EIS. Different firms define their business processes using different formalisms and tools. The data in the EIS is maintained and used by different persons within a firm and the correctness of the business processes should be validated and verified.
A particular check that can be performed is whether processes are sound. This applies in particular when a process describes a workflow. A workflow process is a process having one entry point and one exit point. A process is sound if for each state that can be reached from the initial state, a firing sequence exists that leads the system to the final state. In a process model with formal execution semantics, these types of properties can be defined precisely, and verified automatically by tools.
Although numerous editors for creating models are used in industry, their analysis facilities often have shortcomings. Business processes are typically specified using other formalisms than the ones required by most existing verification tools. Moreover, most scientific tools operate on models based on modeling languages not often used in industry.

Model transformations provide a wider range for applying model analysis on business processes used in industry. The original models are transformed to 'as-equivalent-as-possible' models, specified in other formalisms, enabling the use of analysis tools for these formalisms. This can result in better insight in, and additional information about, the quality of the original model.

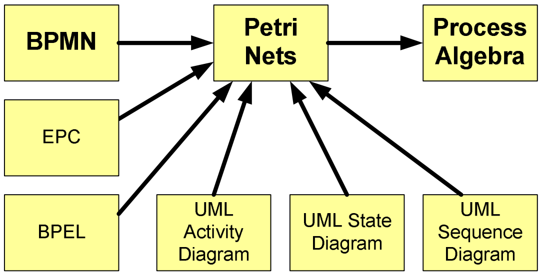


Figure 1. Model transformations

Our analysis approach is presented in Figure 1. First, the original models are automatically transformed to Petri nets [15]. Subsequently, the Petri net models can be used as input for Petri net-based analysis tools. The Petri nets can also automatically be transformed to mCRL2 [8], a process algebraic language [4], after which the mCRL2 toolset can be used.

The Business Process Modeling Notation, BPMN, [23] is a graphical notation designed for both business process design and business process implementation. BPMN presents a good case for our approach: translating BPMN models to formal standards supported by analysis facilities.

The same approach can also be followed for other industry standards, such as BPEL [7] EPC [11] or UML diagrams [6]. Transformations to Petri nets are described in [18] [12] for BPEL, in [20] for EPC and in [3] for UML.

Petri nets are well-suited for modeling, analyzing and describing concurrent systems with a complex process flow. There are many Petri net-based tools like Yasper [9], Woflan [19], INA [16], LoLA [17] and CPN Tools [14] that can be used for model checking and simulation. Different tools perform different types of analysis and some tools are limited to a subset of Petri nets that can be analyzed. Therefore, it is valuable to be able to use more tools. The range of analysis possibilities is extended by translating Petri nets to mCRL2, a process algebraic formalism. This enables automatic verification by the mCRL2 toolset.

The transformation from BPMN to Petri nets is implemented in XSLT. The transformation from Petri nets to mCRL2 is implemented in C++. As both transformations are integrated in our software framework [13] along with analysis tools, our approach can be carried out via a web browser.

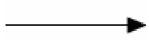
This paper is organized as follows. First the formalisms involved, BPMN, Petri Nets and mCRL2 are explained in section 2. The transformation of BPMN models to Petri nets is described in section 3. The Petri net-based analyses are explained in section 4. The transformation of Petri nets to mCRL2 is described in section 5. Section 6 shows how our analysis approach has been used in practice and what the Petri net based analysis has revealed about the original BPMN models.

2 The formalisms involved

2.1 Business Process Modeling Notation

The Business Process Modeling Notation (BPMN) [23] is a graphical notation for business process modeling. It describes processes in terms of order dependencies between subprocesses and atomic tasks. The notation is supported by a variety of business process modeling applications, and companies start to use it as their standard modeling technique. The BPMN standard was recently adopted by OMG [10].
Process steps are combined to processes, expressing control logic such as sequences, choice, parallel execution and iteration. BPMN models consist of a set of nodes connected by sequence flows or other types of flows. The main symbols are shown in Table 2. An example BPMN model is shown in Figure 3.

Table 2. BPMN elements.

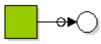
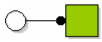
BPMN element	Description
 Start Event Interm. Event End Event	The Start Event indicates where a particular process will start. Intermediate Events occur between a Start Event and an End Event and will affect the flow of the process. The End Event indicates where a process will end.
 Task	A task is an atomic activity within the process. It represents work to be performed. A task will be activated when one of its incoming sequence flows is triggered and will trigger all its outgoing sequence flows when it is finished.
 AND Gateway	An AND Gateway will trigger all outgoing flows, when all incoming flows are triggered.
 XOR Gateway	An XOR Gateway will trigger one of its outgoing flows when one of its incoming flows is triggered.
 Subprocess	Subprocesses are used to support hierarchy. A Subprocess contains its own Start and End Event.
 Sequence Flow	The Sequence Flow shows the order in which activities will be performed in a Process.

2.2. Petri Nets

Petri nets provide a formal method to describe behaviour. A Petri net consists of places and transitions, connected by directed arcs. A place can only be connected to a transition and vice versa. In classical Petri nets, these are the only allowed elements.

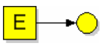
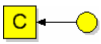
The formal definition of Petri nets can be found in [14]. Petri nets can be extended to be able to express more behaviour. The Petri nets used here, further referred to as extended Petri nets, are extended with inhibitor [1] and reset arcs [2]. In Table 3, the Petri net elements are explained.

Table 3. Petri net elements.

Element	Description
 Transition	A transition is a modeling unit representing a process step.
 Place  Place with tokens	A place can contain tokens that define a part of the state of the net. A distribution of tokens over the places is called a marking, representing the state of the net.
 Inflow Arc	An inflow arc is the arrow from a (incoming) place to a transition. If all incoming places connected to a transition have enough tokens according to the firing rules, the transition is enabled and can fire.
 Outflow Arc	An outflow arc is the arrow from a transition to a (outgoing) place. If a transition fires, it consumes tokens from its incoming places, and produces tokens in its outgoing places according to the firing rules.
 Reset Arc	When a place is connected to a transition with a reset arc, all tokens are removed from it when the transition fires.
 Inhibitor Arc	When a place connected to a transition via an inhibitor arc contains a token, the transition cannot be enabled.

Yasper [9] is a Petri net modeller and simulator extending Petri nets with various notions. The most important ones are shown in Table 4. Transitions are also extended with properties dealing with timing, costs, and resources for simulation purposes.

Table 4. Yasper specific elements.

Element	Description
 Case sensitivity (yellow)	Yasper distinguishes between different workflow cases in a process. This is done with case sensitive places. Transitions having multiple case sensitive input places can only fire if enough tokens of the same case are present. If a transition fires, tokens produced in the case sensitive output places have the same case identity as tokens consumed from the case sensitive input places.
 Emitter	A transition, with outflow arcs to case sensitive places but without inflow arcs from case sensitive places, is drawn differently and is called *emitter*.
 Collector	A transition, with no outflow arcs to case sensitive places but with inflow arcs from case sensitive places, is drawn differently and is called *collector*.
 XOR	This element requires and consumes one token from one of the places connected with an inflow arc. When the XOR fires, one token is produced in one of the places (chosen non-deterministically) connected with an outflow arc.
 Subnet	This element is used to support hierarchy.

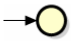
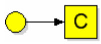
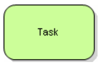
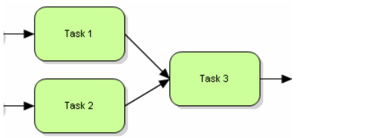
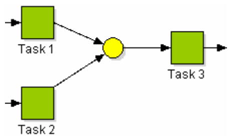
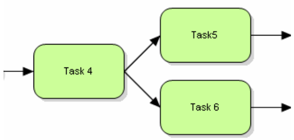
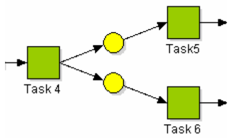
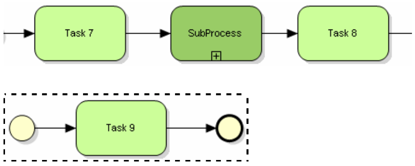
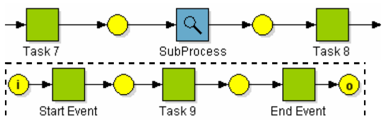
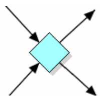
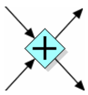
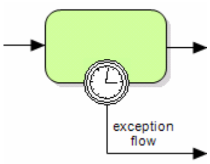
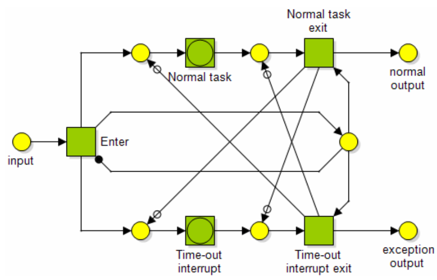
2.3 mCRL2

The language mCRL2 [8] offers a uniform framework for the specification of *data* and *processes*. Data is specified by *equational* specifications: one can declare types and functions working upon these types, and describe the meaning of these functions by equational axioms. Processes are described in process algebraic style, where the particular process syntax stems from ACP [4], extended with data-parametric ingredients. Infinite processes are specified by means of (finite systems of) *recursive equations*, which can also be data-parametric. As an example, for action *a,* each solution for the equation $X=a.X$ specifies the process that can only repeatedly execute *a*. Here, *X* is a process name and "." is the *sequential composition* operator. The Process *Y(23)*, where *Y(n)* is defined by the data-parametric equation $Y(n)=a.Y(n+1)$, can do the same as *X*.
mCRL2 makes use of *multiactions*. A multiaction is a collection of ordinary actions that happen simultaneously as one atomic step. A few examples of multiactions are $a|b$, $a|b|c$ and $a|a|b$. The multiactions are convenient for representing Petri nets because several actions may be performed synchronously when a transition is being fired, like removing a token from an input place and adding a token to an output place. These actions are combined to a multiaction and then hidden in a way that only the transition name is left visible.
In mCRL2 parallel composition does not communicate. Instead, it introduces multiactions, e.g. the *parallel* composition $a||b$ of actions *a* and *b* is equal to $a.b+b.a+a|b$, where + is the *alternative composition* operator. As a result, the number of multiactions can increase exponentially with the number of parallel compositions. Hence, operators need to restrict this behaviour. The *blocking operator block*(*H,p*) blocks all multiactions *a* part of which occurs in the action set *H*, on the process *p*. For example: $block(\{a\}, a+b.(a\,|\,c)) = \delta + b.\delta = b.\delta$ where δ is a *deadlock* process that cannot execute any action.
Communication of actions is also defined using the concept of multiactions. The local *communication operator comm*(*C,p*) realizes communication of multiactions with equal data arguments. For instance, $comm(\{\_a|a \rightarrow \_\_a\},\ a|\_a|c|d) = \_\_a|c|d$.

3. Transforming BPMN models to Petri nets

The mapping rules for the translation of BPMN to Petri nets are shown in Table 5. If the resulting Petri nets do not contain reset or inhibitor arcs, most Petri net tools can be used to analyze the translated BPMN models. The last translation rule in the table illustrates how a time-out exception is translated. An example of the mapping is shown in Figure 3. The translation is described in detail in [21].

Table 5. The mapping between BPMN and Petri nets.

BPMN elements	Petri net elements
 Start Event	 Emitter connected to place
 End Event	 Place connected to Collector
 Task	 Transition
 Task with two incoming sequence flows	 Merge-like behaviour
 Task with two outgoing sequence flows	 Fork-like behaviour
 A connected Subprocess	 A connected Subnet
 XOR Gateway	 XOR
 AND Gateway	 Transition
 Time-out interruptible task	 The translation result of the time-out interruptible task

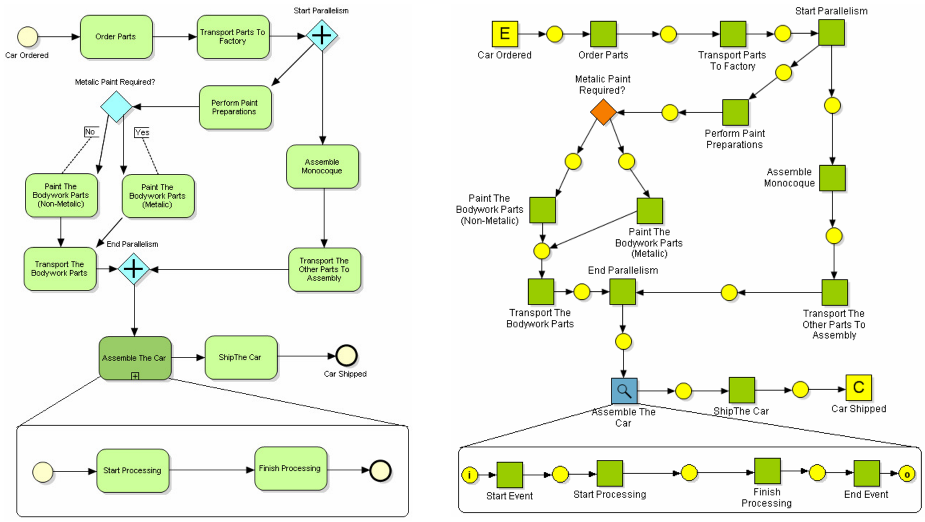


Fig. 3. An example BPMN model and the derived Petri net.

4. Analyzing industrial models using Petri net-based tools

Figure 4 depicts the Petri net analyzers and transformations from, to, and between Petri nets we use.

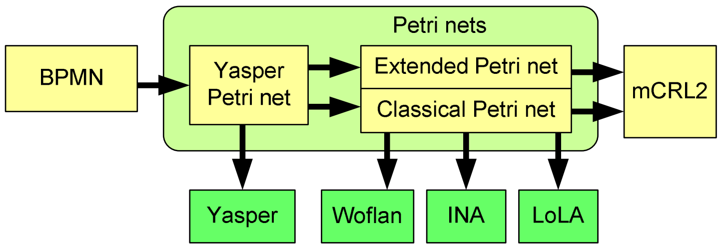


Fig. 4. Petri net analysis tools and related transformations.

4.1 Yasper

After the transformation of a BPMN model to a Yasper Petri net, Yasper simulations on the derived Petri net can be used to validate the original model.
Yasper supports *automatic simulation*, where the transitions to execute are randomly chosen. Transitions can have a mean execution time and deviation and both fixed costs and costs per time unit. The automatic simulation uses this information to provide performance analysis by simulation.

Another facility is the stepwise execution of a net. At each step, the user can select one of the enabled transitions to execute, after which the state (i.e. the distribution of tokens) is updated accordingly. This *manual simulation* helps users to validate their models by enabling them to quickly explore many different process execution paths and discover that unexpected or incorrect states are reachable.
The Yasper Petri net editor and analysis tool [9] can assist with soundness verification in several ways. Yasper provides *reduction* techniques [22] preserving properties like soundness and liveness. These reductions result in a smaller model which is easier to analyse.

4.2 Woflan, INA, and LoLA

In order to invoke automatic verification tools, like Woflan, INA, and LoLA, the Yasper Petri nets are transformed to classical Petri nets. This can only be done if the net does not contain reset arcs or inhibitors.
Woflan [19], the Workflow Analyzer, is a software tool with the specific purpose of analyzing workflow Petri nets for soundness. Applied to a net it reports whether the net is a valid workflow net, and if so, whether it is *sound*; if not, it lists one or more specific problems with the net.
INA [16], the Integrated Net Analyzer, provides traditional Petri net analysis on classical Petri nets: it can check a number of Petri net properties and show the invariants, the reachability and the coverability graphs of a Petri net. INA also offers model checking with temporal logic on Petri nets to verify properties of the system.
LoLA [17] is a model checking tool which tackles the state space explosion by using reduction techniques. Therefore, INA is first used to check the Petri net, and then LoLA is used to verify properties on the system.

5. Petri nets to mCRL2

If the Petri net contains reset arcs or inhibitor arcs, most Petri net tools cannot be used. In this case, our solution is transforming the extended Petri net to mCRL2, to enable automatic verification.
Petri nets are input to the transformation to mCRL2 specifications. Petri nets consist of a finite set of places $\{P_1,...,P_n\}$, transitions $\{T_1,...,T_m\}$, and arcs $\{a_1,...,a_k, a'_1,\ldots,a'_l\}$ that connect places to transitions (inflow arcs), and vice versa (outflow arcs). The arcs may be ordinary, inhibitor or reset arcs. Besides the Petri net itself, also the initial marking of the Petri net is used for the translation to mCRL2.

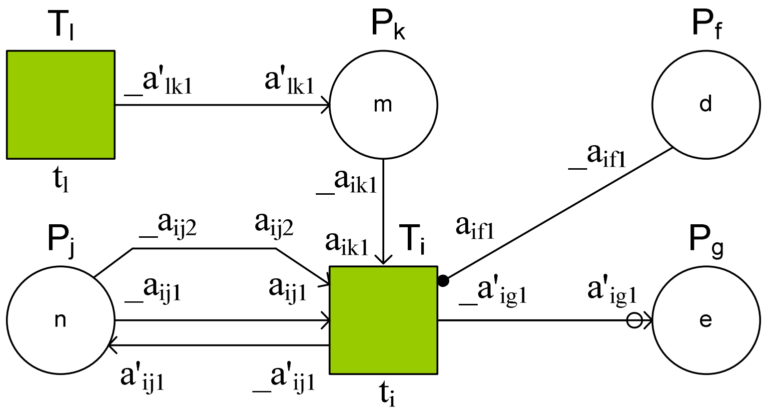


Fig. 5. mCRL2 actions mapped to the arcs and transitions of a Petri net.

As illustrated in Figure 5 the result of the transformation, a mCRL2 specification, is constructed in the following way:
Each arc is represented by three actions in mCRL2: *a* and *_a* represent the outflow actions and the inflow actions associated with the arc, and *__a* represents their synchronization where $\_\_a = a|\_a$.
Each transition T_i is represented by the process

$$T_i = a_{i11} \mid \ldots \mid \_a_{ipx} \mid a'_{i11} \mid \ldots \mid a'_{ipx} \mid t_i$$

where $a_{i11},...,a_{ipx}$ are the inflow arcs that enter T_i and $\_a'_{i11},...,\_a'_{ipx'}$ are the outflow arcs that depart from T_i. Action t_i is used to indicate that transition T_i has fired.
Each place P_j is represented by the process equation

$$P_j(n:Nat) = \sum_{i \in \{1,\ldots,q\}} (n \geq p(i,j)) \rightarrow \_a_{ij1} \mid \ldots \mid \_a_{ijp(i,j)} \mid a'_{ij1} \mid \ldots \mid a'_{ijp'(i,j)} . P_j(n - p(i,j) + p'(i,j))$$

where q is the number of different transitions connected to P_j by an arc, and the actions $\_a_{ijx}$ and a'_{ijx} are the inflow and the outflow actions corresponding to the inflow and outflow arcs connecting place P_j and transition T_i, respectively. The parameter n represents the amount of tokens P_j contains, p(i,j) is the number of inflow arcs from P_j to T_i, and $p'(i,j)$ is the number of outflow arcs from T_i to P_j.
In case of inhibitor arcs we check if the adjacent place is empty using the condition $n=0$ in the above process equation. In case of reset arcs we set the number of tokens to be the number of incoming arcs by changing the recursive call to $P_j(p'(i,j))$ in the above process equation.
All transitions are combined in one process $T = (T_1+...+T_m).T$ which represents that the transitions must be interleaved, and do not happen simultaneously.
The whole system is represented by the parallel composition of all processes representing places, where the actions representing arcs are forced to synchronize:

$$S = hide(\{\_\_a\}, block(\{a, \_a\}, comm(\{a|\_a \rightarrow \_\_a\}, P_1 \| \ldots \| P_n \| T)))$$

The arc firing actions are hidden, which only leaves the t_i actions visible. This shows when a particular transition fires.

5.1 Analyzing Petri nets using the mCRL2 toolset

The mCRL2 toolset allows to generate a transition system (state space) corresponding to the generated mCRL2 specification derived from the Petri net. The labels of this transition system represent the firings of the transitions of the Petri net. Each path in the generated transition system can be simulated with Petri net simulation tools. The mCRL2 toolset can automatically find deadlock traces starting from the system's initial state and resulting in a state from where no transitions are enabled.

Furthermore, the mCRL2 toolset can visualize the state spaces. This can be used to find livelock-states from which it is possible to keep repeating the same set of activities, but from which it is impossible to perform a sequence of activities that lead the system to the desired final state.

6. Case study

One of our clients is maintaining business processes related to various sectors. Education is one of these sectors and its processes are stored as BPMN models. We received six BPMN models and performed automated error detection on these models.

We translated the BPMN models to Petri nets and subsequently invoked Woflan on the Petri nets to perform automatic verification. The results are shown in Table 6.

Table 6. The results of the analysis of the BPMN models

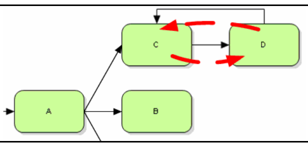
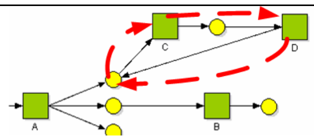
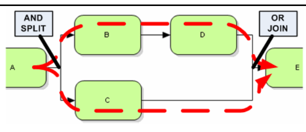
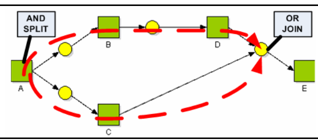
Model number	Number of BPMN elements	Number of Petri net elements	Woflan result
1	14	26	1 AND-OR mismatch
2	41	79	No workflow (unrelated nodes)
3	17	33	Sound workflow process definition
4	73	143	2 AND-OR mismatches
5	93	176	5 AND-OR mismatches
6	62	114	No workflow (no unique start condition)

The column 'Woflan result' contains the summarized conclusion of Woflan.

After retrieving the results, we had to translate them back in terms of the BPMN models to locate the errors. In the reports, Woflan printed the names of the Petri net transitions involved in the error. Since the transition names are identical to the BPMN task names and as the translation uses the BPMN lay-out to generate the Petri net lay-out, it was relatively easy to locate the BPMN tasks involved.

Two of the analyzed models are no workflows and eight AND-OR mismatches were found in the four remaining models. The AND-OR mismatches reported by Woflan indicate that a parallel split is not matched by a parallel join, while it should be joined by a parallel join. The unrelated nodes, indicated by Woflan in Table 6, turned out to be a livelock. A livelock state is a state from which it is possible to proceed, but from which it is impossible to reach the desired final state. Table 7 shows how the livelock and an AND-OR mismatch found in the Petri net relate to errors in the BPMN model.

Table 7. Interpreting the analysis results

The Livelock in the BPMN model	The Livelock in the Petri net
	
The AND-OR mismatch in the BPMN model	AND-OR mismatch in the Petri net
	

Once task A from the shown livelock is triggered, the process will reach a livelock state. Most AND-OR mismatches were similar to the one that is shown. Two sequence flows leaving task A means that both task B and C will be triggered, but the two sequence flows entering task E, result in task E being triggered twice. These errors can be prevented by forbidding modellers to model tasks which have multiple incoming and outgoing sequence flows. Instead gateways should be used.

7. Conclusions and future work

We now have an operational tool to perform BPMN model translations that we can further extend with more advanced BPMN constructs. We have employed it on pre-existing BPMN models in actual use, and found many actual inconsistencies with the models, clearly pointing out the need for the modellers to improve their models before they can be used as exact specifications.

Our next goal is to be able to automatically present the Petri net and mCRL2 analysis results in terms of the original model. For example, we want to parse deadlock traces, which can be sequences of the elements of a Petri net model, and subsequently automatically back-translate these to deadlock traces in terms of the original BPMN models. This should fasten the interpretation of analysis results to original models.

References

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