On the suitability of correctness criteria for business process models

Juliane Dehnert[1] and Armin Zimmermann[2]

[1] Fraunhofer ISST Berlin, juliane.dehnert@isst.fhg.de
[2] Technische Universität Berlin, azi@cs.tu-berlin.de

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Abstract. A popular requirement for the validation of workflow models is soundness. As soundness can not be easily seen on the model level, different correctness criteria have been proposed in the literature to bridge the gap between the modeling process and a executable workflow model. Well-structuredness and relaxed soundness are investigated in the paper. Relationships between the properties are derived.

1 Introduction

An increasing number of companies have adopted process-aware information systems during the past years. By doing so, complex and distributed business processes can be managed and improved easier. Standard ERP software tools have been enhanced by a workflow module, while other examples like Staffware are dedicated workflow management systems (WfMS).

The basis of any of these systems is a model of the company's business processes in a machine-readable manner: the workflow definition. Modeling workflow requires a deep inside into the application context. Domain experts are often put in charge of the modeling, although they do not necessarily are modeling experts. The models describe the processes with the modelers view, and thus do not necessarily adhere strictly to sound models.

Soundness [Aal98] guarantees that there are no faulty executions at runtime, like deadlocks or processes that leave dangling documents when terminating. The soundness of a workflow definition can be checked, but is not easy to see on the model level. To bridge that gap, different properties have been proposed in the literature to assist non-expert modelers in creating sound business process models. Maybe the most commonly used property in this context is well-structuredness [Aal98,CWBH+03,Ver04]. The advantage of this property is that it can be checked easily on the structural level of the model. Well-structured process descriptions are guaranteed to be sound if they are live. However, well-structuredness is quite restrictive, and does not support all workflow patterns.

Relaxed soundness [DR01] has been proposed as a property which is claimed to be better suited for this task. It is a weaker property than soundness, thus allowing more workflow structures. However, an additional step is required to achieve a sound WF-net. It has been shown recently how methods from Petri net controller synthesis can be adopted to automatically generate a sound model from a relaxed sound one [DZ04,DvdA04]. The question for workflow modelers as well as WfMS tool designers is now which one of the existing criteria — soundness, well-structuredness or relaxed soundness — should be used to guide the modeler in creating a sound workflow definition. This discussion is the main motivation for this paper. The main contribution is the theoretical background for the comparison. Proofs are provided that put the criteria in relation to each other. Based on these considerations, the usability of the properties is briefly compared from the modeler's point of view.

2 Soundness - Well-Structuredness - Relaxed Soundness

For the modeling of business processes we refer to WF-nets, cf. [Aal98]. WF-nets are a special class of Petri nets characterized by a source place ($^{\bullet}i = \emptyset$) and a sink place o ($o^{\bullet} = \emptyset$). Furthermore, short-circuiting the net by an additional transition t' the resulting net is strongly connected.

Figure 1 shows a WF-net modeling the business process initiated by incoming goods. The process is assigned to two departments, the accountancy and the storage, which may work in parallel. The thread of control is split accordingly in the beginning. In the accountancy (c.f. upper thread in the figure) the receipt of the goods is recorded. The incoming goods are checked and stored in the other department (lower thread). In case the check is negative, a notification is sent to the accountancy. Finally, the threads are joined again.

In the following we introduce some relevant process properties.

Well-structuredness is a property that has been proposed in the literature (e.g. [Aal98,Ver04]) to assist non-expert modelers in formalizing their business processes. Well-structuredness is a property requiring a strict block structuring of a process description. It is satisfied if every split (OR, AND etc.) is followed be a corresponding join of the same type. The restriction to well-structuredness is also present in UML v1.4 [UML02] activity diagrams, BPEL4WS [BEA03] and ADEPT [RD98][3]. In terms of Petri-net theory, well-structuredness is characterized by the absence of handles[4] [ES90].

Definition 1 (Well-structured). *A WF-net PN is well-structured if the short-circuited net $\overline{PN}$ does not contain any handles, i.e. $\overline{PN}$ is well-handled.*

The WF-net of Figure 1 is not well-structured. Examples for existing handles are the transition-place pair (`t1`, `p5`) and the place-transition pair (`p2`, `t10`).

Soundness has been introduced in [Aal98]. A WF-net is sound if termination is always possible and once terminated there are no residual tokens outside o. Furthermore, there are no dead transitions and neither deadlocks nor livelocks.

[3] In the latter two, the strict block structuring conditions are relaxed by allowing control links (resp. synchronization edges) to synchronize tasks belonging to different parallel control flow paths.

[4] A handle is a pair of two different nodes (a place and a transition) that are connected via two elementary paths sharing only these two nodes.

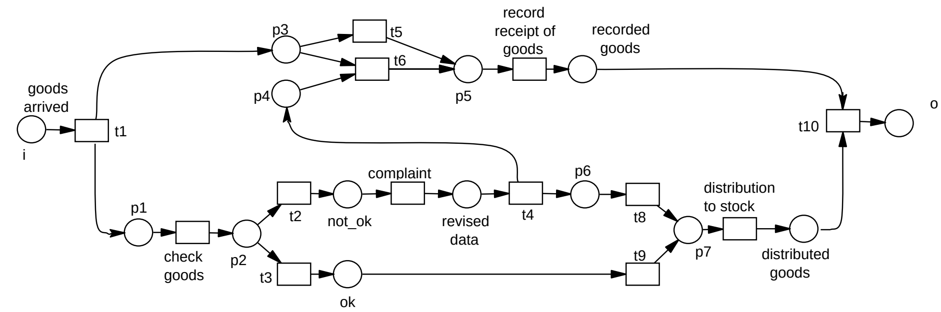

Fig. 1. WF-net "Processing of incoming goods"

Definition 2 (Soundness). *A WF-system (PN, i) is sound iff:*

(i) For every state M reachable from state i, there is a firing sequence leading from state M to state o: $\forall M : (i \xrightarrow{*} M) \Rightarrow (M \xrightarrow{*} o)$.

(ii) State o is the only state reachable from state i with at least one token in place o (proper termination)[5]: $\forall M : (i \xrightarrow{*} M \wedge M \geq o) \Rightarrow (M = o)$

(iii) There are no dead transitions in PN: $\forall t \in T\ \exists M, M' : (i \xrightarrow{*} M \xrightarrow{t} M')$

The WF-net "Processing of incoming goods" (c.f. Figure 1) is not sound. There are firing sequences that do not terminate properly.

Relaxed soundness was introduced with the intention to represent a more pragmatic view of correctness. Relaxed soundness does not require the absence of residual tokens, livelocks or deadlocks. A process is relaxed sound if each task of the business process is part of a properly terminating sequence.

Definition 3 (Relaxed soundness). *A workflow system (PN, i) is relaxed sound iff each transition t of PN appears in some sound firing sequence σ: $\forall t \in T \quad \exists \sigma : i \xrightarrow{\sigma} o \quad with \quad t \in \sigma$*

The process specification shown in Figure 1 is relaxed sound. There are enough sound firing sequences, i.e. all transitions are covered.

3 Relations between the properties

Clearly, soundness implies relaxed soundness. This can be derived directly from the definitions. Another proposition relates all three properties. We will show that a process description is sound if it is well-structured and relaxed sound.

Proposition 1. *Let PN be a WF-net with input place i. If PN is well-structured and (PN, i) is relaxed sound, then (PN, i) is sound.*

[5] Note that this statement from the original definition already follows from requirement (i) [HSV04].

The proof of this claim is provided in two steps. It is first proved for free-choice[6] WF-nets. The result is then applied to the unrestricted class of WF-nets.

Proof 1 (PN is free-choice): Because PN is well-structured, the short-circuited net $\overline{PN}$ is well-handled and strongly connected. With [ES90] (Theorem 3.1 & 3.2) we can conclude that $\overline{PN}$ is well-formed, i.e. structurally bounded and structurally live. Soundness of (PN, i) coincides with liveness and boundedness of $(\overline{PN}, i)$ [Aal98]. Boundedness of $(\overline{PN}, i)$ follows directly from the fact that $(\overline{PN}, i)$ is structurally bounded. It thus remains to prove that $(\overline{PN}, i)$ is live.

As (PN, i) is relaxed sound, there is an infinite firing sequence σ of $(\overline{PN}, i)$ which supports each transition. σ can be constructed, linking the set of sound firing sequences in (PN, i) via firing of transition t^*. This is done infinitely often: $\sigma = \sigma_1 t^* \sigma_2 t^* ... t^* \sigma_n t^* \sigma_1 t^* \sigma_2 t^* ... t^* \sigma_n ....$ With [ES90] (Theorem 3.2) we know that $\overline{PN}$ is covered by S-components[7]. The infinite firing sequence σ is enabled in i and contains all transitions. Since $\overline{PN}$ is strongly connected, every place and therefore every trap is marked during the occurrence of σ. Since marked traps remain marked, every trap and therefore every S-component is marked in i. With [DE95] (Theorem 5.8), it can be concluded that $\overline{PN}$ is live. □

In order to transfer the result to the class of non-free-choice WF-nets we first establish some prerequisites. We recall a transformation rule ([DE95]) that transforms a non-free choice net PN into a free-choice net PN'. According to this rule, every arc $(p, t) \in F$ in PN is replaced by a sequence $(p, t')(t', p')(p', t) \in F'$. The sets P and T are extended appropriately. Note that this transformation preserves well-structuredness (I) and relaxed soundness (II), whereas it does not hold for liveness. However, the properties liveness and boundedness are preserved during the backward direction of the considered transformation (III).

Proof 2 (PN is not free-choice): We apply the free-choice transformation rule to PN and obtain a well-structured (I) and relaxed sound (II) WF-net (PN', i), which is additionally free-choice. We short-circuit PN' and obtain the strongly connected, well-handled and free-choice net $\overline{PN'}$. Using again [ES90], we can conclude that $\overline{PN'}$ is well-formed. Exploiting the result of the first proof, we can infer that $(\overline{PN'}, i)$ is live and bounded. As the reverse direction of the free-choice transformation preserves these properties (III), we can conclude that $(\overline{PN}, i)$ is also live and bounded. Therefore, PN is sound. □

Figure 2 shows an Euler diagram depicting the established relations between Petri net classes considered in workflow modeling.

4 Usability of the properties

Supporting the modeler, meaningful but possibly loose modeling restrictions should be posed, such that a wide range of process descriptions can be defined

[6] A Petri net $PN = (P, T, F)$ is a free-choice net (basically extended free-choice) iff $\forall t, t' \in T : {}^\bullet t \cap {}^\bullet t' = \emptyset \vee {}^\bullet t = {}^\bullet t'$.

[7] A Subnet $PN' = (P', T', F')$ is an S-component of the net $PN = (P, T, F)$ iff PN' is a strongly connected state machine and $\forall p \in P' : {}^\bullet p \cup p^\bullet \subseteq T'$.

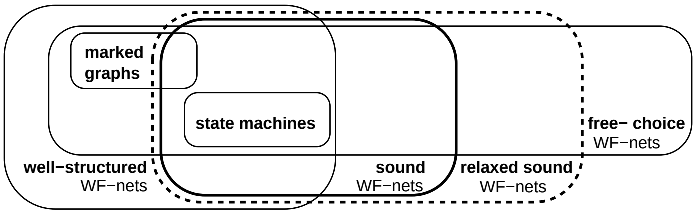

Fig. 2. Relations between different Petri net-properties

having a sensible/useful interpretation. However, this means especially that all process descriptions which are sound (c.f. [Aal98]) should satisfy the used criterion. On the other hand, all process descriptions not satisfying the property should clearly contain design faults.

Soundness is now widely accepted as a necessary requirement for any executable workflow model. However, soundness is not easily seen on the model level. The reason for this is that soundness requires complete knowledge of all possible behavior. As a consequence, the modeler is required to think about the "how" of the execution. This contradicts the argument that the specification of business processes should be as abstract as possible.

Demanding a strict hierarchical design, as done using **well-structuredness**, seems to be a valuable help in the modeling process. The modeler must only follow simple structural rules to get a correct process description. However, some business processes can hardly be matched by a well-structured process description. The demand for a strict hierarchical design ignores the need to assign the tasks according to their organizational assignment. Modeling in a well-structured manner requires overview of the whole process. This can hardly be assumed if the process to be described is spanning different organizational units of the company, involving various modelers. The mentioned shortcoming can be characterized also as follows: When modeling in a well-structured manner, some useful process descriptions are disregarded right from the beginning. Figure 2 shows that there are processes which are sound but not well-structured.

In previous publications (e.g. [DZ04]), it is argued that **relaxed soundness** meets the modeling capabilities of modelers, as it does not require high modeling knowledge but acknowledges the process view of domain experts. The main reason for that is that relaxed soundness does not impose operational semantics. Whereas the users point of view should be reflected, it is clear that formally correct process descriptions, such as described by the soundness criterion, should as well assessed to be correct. This holds for relaxed soundness. All sound process descriptions are relaxed sound by definition, c.f. Figure 2. Therefore, no sound process description is disregarded already at design time. On the other hand, WF-nets which are not relaxed sound are not sound either. Such process descriptions contain transitions which are not contained in any sound firing sequence. Such redundant transitions clearly constitute a design flaw. They relate to tasks that have been modeled but do not contribute to any proper terminating execution. It is hardly imaginable that such modeling is intended. Such WF-nets clearly needs revision.

5 Conclusion

In this paper the main criteria for Petri net workflow models have been put into relation. The formal part relates soundness, well-structuredness and relaxed soundness. It is shown that relaxed soundness and well-structuredness together imply soundness. The shown relations are briefly interpreted from the modeler's point of view.

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