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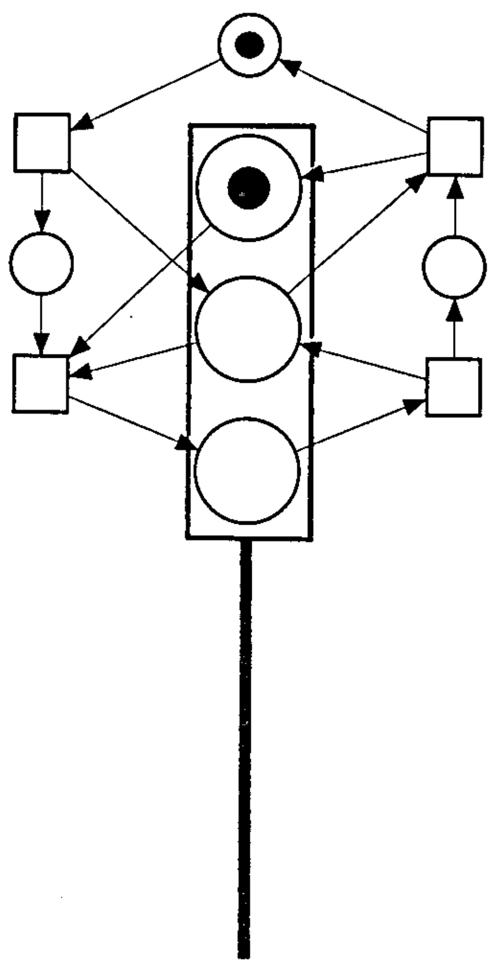

Contents

... from the editors:

This time it was quite hard to get input for the newsletter. Finally, people from the very active Hamburg group provided three interesting contributions, and I had to write a cover picture again. Remember that the newsletter is not a regular journal but also publishes ideas, jokes, questions, examples etc. Please contribute to it!

The newsletter is still an important medium for conference and workshop announcements and reports, even if email and www is faster. For such announcements it is important that you send me an A4 postscript file (or A4 with regular mail) in time. This issue contains programs of EKA'99, PN'99, PNPM'99, SABPM'99 and other events.

Jörg Desel, Karlsruhe, April 1999

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The Petri Net Newsletter is an information service of the Special Interest Group FG 0.0.1 "Petri Nets and Related System Models" of Gesellschaft für Informatik (GI), Bonn, Germany. Two issues per year are being published. The editors are Jörg Desel, Peter Starke und Rüdiger Valk. Their addresses are listed at the bottom of this page.

Scope of concern: The Petri Net Newsletter serves as a medium for the rapid distribution of any information about Petri Nets and related system models all over the world. Topics include:

- technical contributions
- surveys and state-of-the-art-reports
- problems and puzzles
- conference announcements, programs and reports
- reports on departments, institutes, companies, projects, local activities
- abstracts of recent publications
- new books and PhD thesis

Subscription: Members in FG 0.0.1 of the GI receive one copy of the Newsletter free of charge. The membership causes no further obligations or charges. Page 73 of this issue is an application form containing the address of the GI. Additional and former issues can also be obtained from the GI.

Contributions: They should be sent to one of the editors, preferably to Jörg Desel. Any contributions to the field are welcome. They are not refereed. As they will be printed as submitted, make sure that no space is wasted.

Conference Announcements and Conference Reports: Conference announcements such as Call for Papers and Call for Registration should be sent to Jörg Desel. They should be formatted according to the layout of the Newsletter and take at most 2 pages (exceptionally more, if the scientific program is included).

Recent Publications: Since we can only print abstracts of papers we are aware of, please send information about recent publications to one of the editors, preferably to Rüdiger Valk.

Deadlines: There are two issues per year. Deadlines are the end of March and the end of September.

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Cover Picture Story

How to Model Traffic Lights

Jörg Desel
Katholische Universität Eichstätt

One of my favorite exercises in elementary courses on modeling with Petri nets is the traffic light example: The students are asked to model the dynamic behavior of a single German traffic light by a one-safe Petri net. This net should have at least three places, called *red*, *yellow*, and *green*. The subsequent markings of these places should exactly reflect the change of colors of a German traffic light. Surprisingly, many students claim that they do not know the subsequent colors of traffic lights by heart. Well, here they are:

$$m_0\colon red,\ m_1\colon red \text{ and } yellow,\ m_2\colon green,\ m_3\colon yellow,\ m_0\colon red,\ \ldots$$

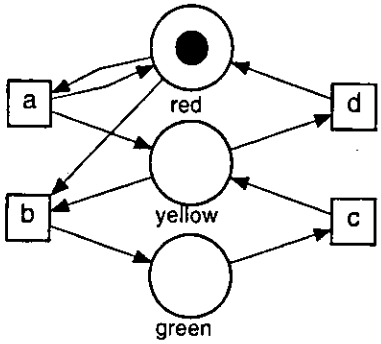
(actually, some traffic lights in east Germany still have an additional combination *yellow* and *green* before *yellow*, but I do not consider this exception here).

When using this exercise the first time, I strongly believed that for such a simple example there would be a single obvious and canonical solution. However, it turned out that students came up with quite different models. I will only mention some of the correct ones among them in the sequel. Not only was the outcome quite different but also the approach chosen for constructing the model.

Before presenting the first model, the class of considered Petri nets should be defined more precisely. A one-safe Petri net is a marked Petri net without arc weights, capacity restrictions, priorities etc., with the standard occurrence rule [2]. One-safety requires that, for no reachable marking, any place carries more than one token. However, in contrast to elementary net systems, a transition with a self-loop (i.e. arcs from and to the same place) can occur if all its input places are marked.

The first approach begins with a representation of the behavior. The model should have four reachable markings, m_0 to m_3, entered in a circular manner. This behavior is easily modeled using a circle of four places and four transitions such that exactly one of the places carries a token initially (see the outer circle of the cover picture). The *green* light burns in exactly one reachable marking, namely m_2. So its corresponding place coincides with a place of the circle. Finally, the two other places representing lights have to be added, as shown in the cover picture. The *red* light burns in m_0 and in m_1 whereas the *yellow* light burns in m_1 and m_3, hence the respective input and output arcs.

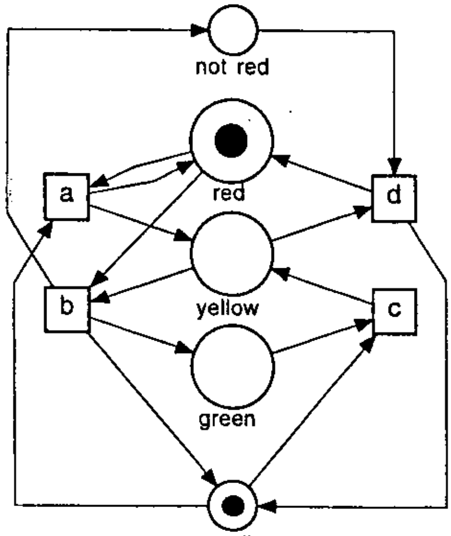
The second approach begins with the required places *red*, *yellow* and *green* and the required transformations. They are represented by a Petri net in the following figure.



This model is not correct because transition a can occur arbitrarily often at m_0, spoiling the one-safety of place *red*. In other words, a can occur at m_1 (*red* and *green*) but should only be enabled at m_0. Moreover, transition d can occur at m_1, adding a second token to *red*. An obvious way to repair the net is to enforce one-safety by adding complement places.

Recall that a complement place for a place s is a new place $\overline{s}$ satisfying ${}^\bullet\overline{s} = s^\bullet \setminus {}^\bullet\overline{s}$, $\overline{s}^\bullet = {}^\bullet s \setminus s^\bullet$, and $m_0(\overline{s}) = 1 - m_0(s)$, where m_0 is the initial marking [2].

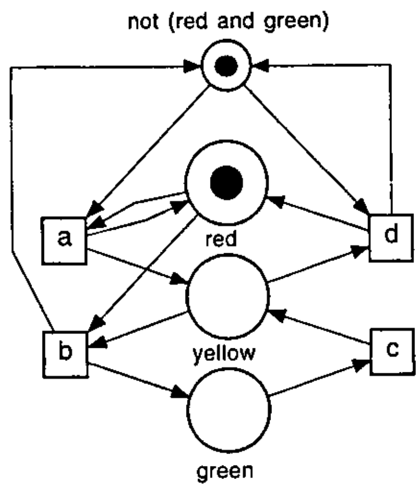
Since the place *green* is already one-safe, we only add complements to the places *red* and *yellow*:



This net has less elements than the cover picture net. In the first approach, every reachable marking is represented by a place (which leads to huge nets in general). The second approach might seem more natural because we start with the possible local behavior and only add complement places where necessary. However, this net is not the minimal net satisfying the requirement, as shown next.

The third approach is again based on global marking properties. One can observe that the faulty behavior of the net without complements only occurs at the reachable marking m_1. This marking enables transitions a, b and d but only b should be allowed to occur. Thus, it suffices to add a place that is unmarked at m_1 and that is an input place to transitions a and d. This place should be marked at every other reachable marking. So it is marked if and only if not both places *red* and *green* are marked.

This additional place is marked initially. It is an input place of transition a because a leads to m_1. Similarly, it is an output place of transition b. A self-loop to transition d ensures that d cannot occur at m_1 and that the occurrence of d does not change the marking of the place. The resulting net is shown below.



There exist many papers devoted to the so-called "synthesis problem", i.e. the problem of systematic construction of a Petri net from a given sequential behavior [1]. In a beginner's course, however, we should provide intuitive rules to come from a systems description to a suitable net. This note presented three different such approaches. After all, I consider none of them canonical. The readers of the Petri net newsletter are invited to think about different simple approaches, and perhaps to validate them by modeling the traffic lights of their respective countries.

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A Petri Net View on Synchronous Channels

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Abstract

Synchronous channels as proposed by Christensen in [1] provide a powerful abstraction mechanism for Petri nets. In this article we try to establish a Petri net based theory of synchronous channels that is more abstract as well as more general than previous formalisms.

1 Introduction

Synchronous channels were first considered for coloured Petri nets by Christensen and Damgaard Hansen in [1]. A net is augmented by a set of channels. The channels are accessed via the operators `?!` and `!?` that can be inscribed to any transition. A step is only enabled when each channel receives the same number of accesses via `?!` and `!?` and if the argument values of the accesses match, too.

In [1] a procedure is suggested that converts a net with channels to an ordinary coloured net. It is also characterized in which cases this conversion preserves the finiteness of the net, assuming that each transition has at most one channel inscription of each type. Most Petri net models with channels satisfy this restriction, e.g., the work of Lakos in the context of substitution places [5] or several message passing schemes in object-oriented net formalisms that can be viewed as channels, e.g. [6].

Nevertheless, formalisms like the one presented in [3] require an unrestricted approach with more modelling freedom. In the following we will provide the required propositions and characterizations. Although we state our proofs in a very simplistic setting, they are directly applicable to the formalisms discussed above.

2 Definitions

A channel is a means to communicate information between two transitions that fire simultaneously. The two transitions have to agree on the data value that may be passed through the channel. In our definitions, we abstract from these data values that may be passed through a channel, because the data values usually originate from a Turing-complete inscription, which would introduce irrecoverable undecidability problems.

We also neglect the effect of the occurring transition, which would usually consist of some tokens being moved. This irrelevant here, because we are only interested in the patterns of communication and synchronization that occur due to the channels.

Definition 1 A *channel system* is a tuple $K = (C, T, F, W)$ where (C, T, F) is a net and $W : (C \times T) \cup (T \times C) \to \mathbb{N}^+$ is a function such that $\forall (x, y) \in \text{dom}(W) : W(x, y) > 0 \Leftrightarrow (x, y) \in F$. ◊

Hence, channel systems are defined exactly like P/T-nets, but we interpret the net's places as channels.

We must be aware that, as in [1], the direction of F does not indicate a direction of information transfer. We merely separate two distinct modes of access, such that a synchronization can only take place if every access of the one mode is matched by an access of the other mode. An access $t\ F\ c$ corresponds to an inscription `?!c` and $c\ F\ t$ corresponds to `!?c`.

In Fig. 1 you can see a simple net that accesses two synchronous channels `a` and `b` on the left hand side. The net can be converted into a channel system by representing the channels

A CONCISE PROOF OF THE COVERABILITY THEOREM FOR LIVE AND BOUNDED EXTENDED FREE CHOICE NETS

Andrei Kovalyov
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The known proofs of the well-known coverability theorem for free-choice nets consider system behavior, (firing sequences or processes [BD,DE]) and thus seem a bit long. Here a concise proof based only on structural properties of nets is given. All basic notations and notions of Petri nets: liveness, boundedness, subnets, deadlocks, traps, clusters, invariants. They can be found in [DE]. An *S-allocation* is the set $\alpha \subseteq S$ such that for every cluster $a \in \mathcal{A}$ $|a \cap \alpha| = 1$. A set $X \subseteq S$ is an *S-component* iff $(X, {}^\bullet X)$ is a strongly connected subnet satisfying the following three conditons:

(A) $\forall t \in X^\bullet \quad |{}^\bullet t \cap X| = 1$
(B) $X^\bullet = {}^\bullet X$
(C) $\forall t \in {}^\bullet X \quad |t^\bullet \cap X| = 1$

Let $N = (S, T, F)$ be a net. Then $N^{-d} = (T, S, F^{-1})$ is *reverse-dual* net of net N. The notions of *T-allocation*, *T-component*, *absorber* and *generator* are reverse-dual to the notions of S-allocation, S-component, deadlock and trap respectively. A net is *S-(T-)covered* iff it is covered by S-(T-)components.

Lemma.

(1) [Ha] (Deadlock-trap property) An EFC-net has a live marking iff every deadlock contains a trap.

(2) (A necessary condition of liveness) Let N be an EFC-net having a live marking. Then every T-allocation of N contains a generator.

(3) [K] (Coverability by minimal deadlocks) Let N be a strongly connected EFC-net. Then the places of N are covered by minimal deadlocks.

(4) [KL] Let N be a strongly connected EFC-net and D be a minimal deadlock. Then there exists an S-allocation α such that $(\alpha, \alpha^\bullet)$ is a connected subnet of N, and D is only deadlock with $D \subseteq \alpha$.

(5) [EBS] Let D be a minimal deadlock of an EFC-net. Then $(D, {}^\bullet D)$ is a strongly connected subnet satisfying (A).

(6) [MR] If J is a semi-positive $S-(T-)$invariant then the support $S(J)$ is the set of nodes satisfying (B)

(7) [MR] Let N be a net satisfying

(D) $\exists J > 0 \quad C \cdot J \leq 0$

Then $\forall X$ if $X \cdot C \geq 0$ then $X \cdot C = 0$.

(8) [B] If N has a live and bounded marking then it is strongly connected.

(9) [R] If N has a live and bounded marking then it has a positive T-invariant.

(10) Let N be a net with (4) and Q be a trap satisfying (A) then $\chi(Q)$ is an S-invariant and (B), (C) hold for Q.

Proof. (2) Let $T_1 \subseteq T$ be a T-allocation, and M^0 be a live marking of N. Then the system $(S, T_1, F \cap ((S \times T_1) \cup (T_1 \times S), M^0)$ has non-empty set of live transitions $T_2 \subseteq T_1$. It is obvious that T_2 is a generator.

(10) *Claim.* Let $Q \subseteq S \quad \forall t \in Q^\bullet \quad |{}^\bullet t \cap Q| = 1$. Then Q is a trap iff $\chi(Q) \cdot C \geq 0$. Proof of the Claim is trivial. Let $Q \subseteq S$ be a trap satisfying (A). Then by Claim $\chi(Q) \cdot C \geq 0$. By Lemma 7, $\chi(Q)$ is an S-invariant. Since (A) holds and $\chi(Q)$ is an S-invariant, it is easy to see that (C) holds. By Lemma 6, (B) holds. □

Theorem. [BD,DE] (Coverability Theorem) Let N be an EFC-net having a live and bounded marking. Then it is S-covered and T-covered.

Proof. By Lemmata 8 and 9, N is strongly connected and has a positive T-invariant. Hence N satisfies (D). Since N has a live marking, by Lemma 1, every every minimal deadlock D contains a trap $Q \subseteq D$. Then by Lemma 5, $(Q, {}^\bullet Q)$ satisfies (A). By Lemma 10, Q satisfies (B) and (C). Hence Q is a deadlock. By minimality of D, $Q = D$. Hence (B), (C) hold for D, and D is an S-component. By Lemma 3, N is S-covered.

By Lemma 8, N is strongly connected. Since N is S-covered, the sum of characteristic vectors of all S-components of a cover is a positive S-invariant. Let A be a minimal absorber of N. By reverse-dual version of Lemma 4, there exists a T-allocation α such that $A \subseteq \alpha$ and for every other absorber A', $A' \not\subseteq \alpha$. Since N has a live marking, by Lemma 2, every T-allocation contains a generator. Hence there exists a generator $G \subseteq \alpha$ and $\forall s \in {}^\bullet G \quad |s^\bullet \cap G| = 1$. By reverse-dual version of Lemma 10, G satisfies (B) and $\forall s \in {}^\bullet G \quad |{}^\bullet s \cap G| = 1$. Hence G is an absorber. By minimality of A, $A = G$. Hence A is a T-component. By reverse-dual version of Lemma 3, N is T-covered. □

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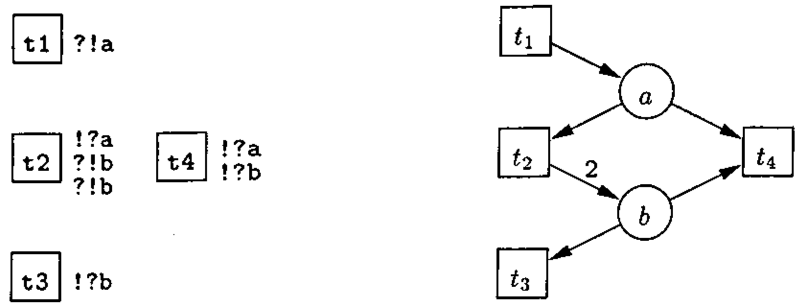

Figure 1: A net with channel inscriptions and the associated channel system

as places. A transition may have an arbitrary number of channels and may access the same channel multiple times. Note the arc weight 2 between t_2 and b.

We denote the preset of a net element x by $F^{-1}[x]$ and the postset by $F[x]$. $x\ F\ y$ denotes that $(x, y) \in F$.

Definition 2 A *weak channel pattern* is a labelled synchronization graph $M = (C, T, F, \varrho)$ such that $\forall c \in C : |F[c]| = 1 = |F^{-1}[c]|$ and ϱ is a function with $\text{dom}(\varrho) = C \cup T$).
A *channel pattern* is a weak channel pattern such that $(C \cup T)^2 = (F \cup F^{-1})^+$. ◊

In a channel pattern every transition can communicate information to every other transition, because it is weakly connected. A weak channel pattern could be replaced by a collection of channel patterns in such a way that the combined effect matches the effect of the original pattern.

Definition 3 A weak channel pattern (C, T, F, ϱ) *matches* a channel system (C', T', F', W'), if $\varrho(C) \subseteq C'$, $\varrho(T) \subseteq T'$, $\forall t \in T : \forall c' \in C' : |\{c \in C \mid t\ F\ c \wedge \varrho(c) = c'\}| = W'(\varrho(t), c')$, and $\forall t \in T : \forall c' \in C' : |\{c \in C \mid c\ F\ t \wedge \varrho(c) = c'\}| = W'(c', \varrho(t))$. ◊

Note that this is exactly the way in which Petri net processes are matched with P/T-nets. However, we do not require that the unfolding is acyclic, but rather that no place (or here: channel) has an empty preset or postset.

Such a concept might be useful to define cyclic processes, which have been investigated by the author jointly with Mark-Oliver Stehr, but here we do not consider any temporal relationship at all. Rather, we assume that all transitions in a channel pattern occur simultaneously and atomically.

In Fig. 2 you can see an example channel pattern for the channel system from Fig. 1. Note that there are two distinct transitions labelled t_1 and that the weight of the output arc of t_2 results in two places labelled b. There are of course other possible patterns. While in this example the channel pattern is indeed acyclic, this is a mere coincidence.

The definition of a channel pattern corresponds roughly to the definition of a *transition group* from [1], but because of our generalizations it has to be more complex.

Definition 4 A channel system $K = (C, T, F, W)$ is called *weakly well-formed*, if for every element $x \in C \cup T$ there is a matching channel pattern $M' = (C', T', F', \varrho')$ such that $x \in \varrho'(C' \cup T')$.
A channel system $K = (C, T, F, W)$ is called *well-formed*, if every transition and every channel occurs in a *finite* channel pattern M'. ◊

A channel system that is not even weakly well-formed makes no sense, because we can remove the elements that do not occur without changing the set of possible channel patterns.

Definition 5 A channel system K is called *finitary*, if for every matching channel pattern $M = (C, T, F, \varrho)$ the set $C \cup T$ is finite.
A channel system K is called *bounded*, if there is some $n \in \mathbb{N}$ such that for every matching finite channel pattern $M = (C, T, F, \varrho)$ we have $|C \cup T| \leq n$. ◊

Note that the second item of the last definition makes only assumptions for the finite case. We need both finitary and bounded channel systems to make sure that *all* matching channel pattern have a maximum size.

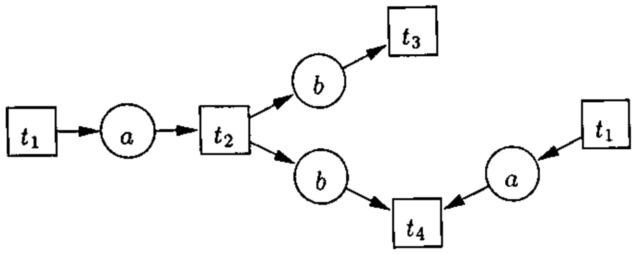

Figure 2: A matching channel pattern

Non-finitary channel systems pose a problem, because an infinite number of elements in a channel pattern indicates a modelling problem for the system in question: An atomic action should be performable in finite time and hence with finite resources.

Unbounded channel systems are difficult to convert to a formalism without channels, because they introduce infinities when we try to represent each channel pattern by a separate transition.

3 Propositions

The formulation of synchronous channels presented above has much in common with ordinary Petri nets. There are also similarities in the theorems, e.g., invariants have a meaning for channel systems.

Prop. 6 Let $K = (C', T', F', W')$ be a finite channel system and $M = (C, T, F, \varrho)$ a matching finite weak channel pattern. Then $i : T' \to \mathbb{N}$ with $i(t') = |\varrho^{-1}(t')|$ is a T-invariant of K. □

As always in this overview article we omit the proof. Most proofs are quite technical and would occupy a excessive amount of space.

Prop. 7 Let $K = (C', T', F', W')$ be a finite channel system and $i \neq \hat{0}$ a T-invariant of K. Then there is a finite weak channel pattern $M = (C, T, F, \varrho)$ that matches K, such that $i(t') = |\varrho^{-1}(t')|$. □

We can also see that the well-formedness properties have an easy characterization.

Prop. 8 Let $K = (C, T, F, W)$ be a finite channel system. It is well-formed, if and only if it is covered by a positive T-invariant. □

Prop. 9 Let $K = (C, T, F, W)$ be a channel system. It is weakly well-formed, if and only if $\forall c \in C : F[c] \neq \emptyset \wedge F^{-1}[c] \neq \emptyset$. □

The next definition intends to define cycles through a channel pattern that do not cross the same net element twice and do not change their direction at channels, although it is allowed to change the direction at transitions.

Definition 10 Let $M = (C, T, F, \varrho)$ be a weak channel pattern. A sequence $(t_0, c_0, t_1, c_1, \ldots, c_{n-1}, t_n)$ without repeated elements is called a *channel cycle* of M, if $t_0 = t_n$ and $\forall 0 \leq i < n : t_i \; F \; c_i \; F \; t_{i+1} \vee t_{i+1} \; F \; c_i \; F \; t_i$.
A channel system $M = (C, T, F, \varrho)$ is called *weakly acyclic*, if no matching finite channel pattern contains a channel cycle.
A channel system $M = (C, T, F, \varrho)$ is called *acyclic*, if no matching channel pattern contains a channel cycle. ◊

The presence of a channel cycle is an indicator of deeper problems.

Prop. 11 Let K be a channel system. If K is finitary, then K is acyclic. □

Prop. 12 Let K be a finite channel system. If K is acyclic, then K is finitary. □

Prop. 13 Let K be a channel system. If K is bounded, then K is weakly acyclic. □

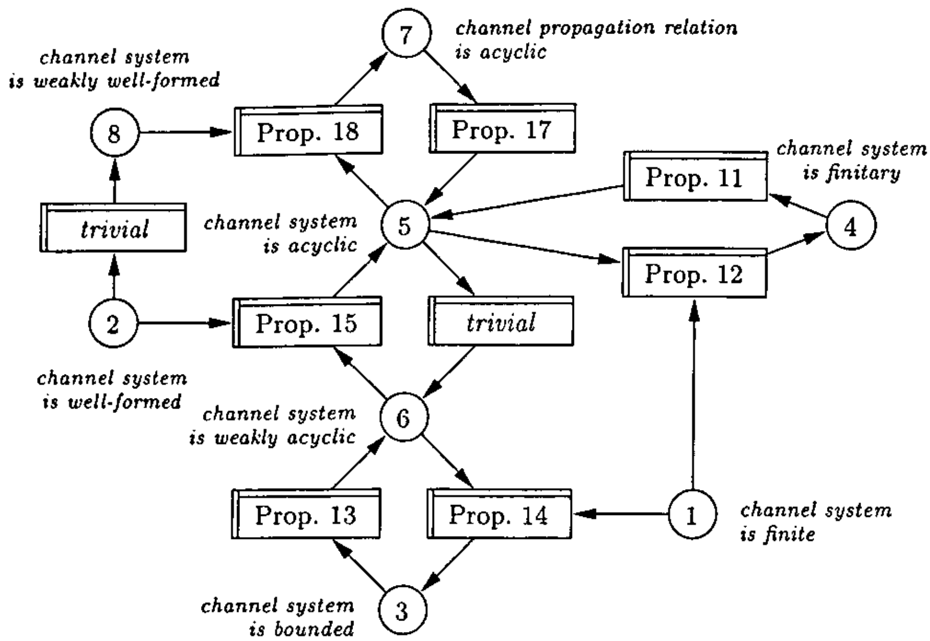

Figure 3: Fact net on properties of channel systems

Prop. 14 Let K be a finite channel system. If K is weakly acyclic, then K is bounded. □

The assertion that the channel systems are finite cannot be dropped for Prop. 12 and Prop. 14. Now the relation of acyclic and weakly acyclic systems remains to be discussed.

Prop. 15 Let K be a well-formed channel system. If K is weakly acyclic, then K is acyclic. □

The previous propositions do not yet give a decision procedure to check if a channel system has the desirable property of being bounded.

Construction 16 Let $K = (C, T, F, W)$ be a channel system. We construct a relation on the base set $X = \{(c, x) \mid c \in C \wedge x \in \{0,1\}\}$. Here $(c, 0)$ means that an access of the channel c with the operator ?! has to be satisfied, while an access with the operator !? would be denoted by $(c, 1)$.
We say that t *propagates* from (c, x) to (k, y), if

- $c = k \wedge x = 0 \wedge y = 1 \wedge (c, t) \in F \wedge W(c, t) \geq 2$ or
- $c = k \wedge x = 1 \wedge y = 0 \wedge (t, c) \in F \wedge W(t, c) \geq 2$ or
- $c = k \wedge x = y \wedge (c, t) \in F \wedge (t, c) \in F$ or
- $c \neq k \wedge (x = 0 \Rightarrow c\ F\ t) \wedge (x = 1 \Rightarrow t\ F\ c) \wedge (y = 0 \Rightarrow t\ F\ k) \wedge (y = 1 \Rightarrow k\ F\ t)$.

Let $R = \{((c, x), (k, y)) \mid \exists t \in T : t$ propagates from (c, x) to $(k, y)\}$ be the *channel propagation relation* of K. We say that R is acyclic, if $R^+ \cap id_X = \emptyset$, where id_X is the identity relation on X. ◊

The channel propagation relation is computable in polynomial time, given the channel system. We can then trivially check acyclicity.

Prop. 17 Let K be a channel system and R the channel propagation relation of K. If R is acyclic, then K is acyclic. □

Prop. 18 Let K be a weakly well-formed channel system and R the channel propagation relation of K. If K is acyclic, then R is acyclic. □

Now we have prepared all results for the main theorem.

Theorem 19 Let K be a finite (1) and well-formed (2) channel system and R the channel propagation relation of K, then the following conditions are equivalent.

- K is bounded (3).
- K is finitary (4).
- K is acyclic (5).
- K is weakly acyclic (6).
- R is acyclic (7).

Proof In Fig. 3 you can see a fact net that summarizes the previous results. In a fact net, places represent system properties and transitions represent relations of the properties. A transition states that, if the conditions of its preset are fulfilled, then at least one condition of its postset is also fulfilled. For details see [2]. □

4 Conclusion

We have shown that under sensible assumptions all defined finiteness properties and acyclicity properties of channel systems are equivalent. This might be of considerable value when the theory of channels is adapted to concrete other formalisms, because only a single concept needs to be transferred and checked. Nevertheless, the specific prerequisites of the propositions like well-formedness or finiteness shed light on the subtle differences between the various properties.

We have suggested a decision procedure that allows to check models with synchronous channels for potential problems. At the moment, the algorithm is not implemented, but it is an interesting extension that might be used in our own tool Renew [4] or with other channel-based tools.

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Renew – the Reference Net Workshop

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Abstract

We present an overview of Renew, the Reference Net Workshop. Reference nets are a special high-level Petri net formalism that uses Java as an inscription language and extends Petri nets by dynamic net instances, net references, and dynamic transition synchronisation through synchronous channels. Renew itself is implemented in Java and is freely available. It offers an intuitive GUI for building net models and viewing simulation runs.

1 Introduction

On the following pages, a short overview of Renew, the Reference Net Workshop, is presented. The most important topics are the reference net formalism (section 2), on which the tool is based, and a short summary of Renew's GUI (section 3). Both reference nets and their supporting tools are based on the programming language Java. To be able to use them to their full capacity, some knowledge of Java is required.

To download the tool and gain practical experience with it, visit our web page at `www.renew.de`. There, you can also make suggestions for improvements or request an update notification.

The main strength of Renew lies in its openness and versatility.

- Renew has been written in Java, so it will run on all major modern operating systems
- Renew comes complete with source, so its algorithms may be freely extended and improved. It is in fact possible to add special net inscriptions quickly. It is even possible to implement completely new net formalisms without changing the basic structure of Renew.
- Renew can make use of any Java class. Today there exist Java classes that cover almost all aspects of programming. Reference nets are themselves Java objects. Making calls from Java code to nets is just as easy as to make calls from nets to Java code.
- Renew supports bidirectional synchronous channels. Channels are a powerful communication mechanism and they can be used as a reliable abstraction concept.
- Net instances allow object-oriented modelling with Petri nets. While a few other net formalisms provide net instances, it is their consistent integration with the other features that makes them useful.
- Reference nets were specifically designed with garbage collection of net instances in mind.

There are, however, a few points to be aware of.

- There are currently no analysis tools for Renew. However, for many applications, analysis does not play a prominent role. Petri nets are often used only because of their intuitive graphical representation, their expressiveness, and their precise semantics.

- During simulation, the user cannot influence decisions where non-determinism is involved, but the simulation engine takes care of solving these conflicts randomly. Interactive parts have to be explicitly implemented using Java inscriptions. In our formalism, there is also no notion of simulation time or firing probabilities.

Since Renew is provided with source code, you can do many changes on your own. And your feature requests have a high probability to be satisfied if you can already provide an implementation.

2 Reference Nets

First, we are going to take a look at Petri nets with Java as an inscription language. Then we look at synchronous channels and net references, two extensions that greatly add to the expressiveness of Petri nets as described in [3].

2.1 Net Elements

Reference nets consist of *places*, *transitions*, and *arcs*. There are, in essence, three types of arcs. Firstly, ordinary *input* or *output arcs* that come with a single arrow head. These behave just like in ordinary Petri nets, removing or depositing tokens at a place. Secondly, there are *reserve arcs*, which are simply a shorthand notation for one input and one output arc. Effectively, these arcs reserve a token during the firing of a transition. Thirdly, there are *test arcs*, which have no arrowheads at all. A single token may be accessed, i.e. tested, by several test arcs at once.

Each place or transition may be assigned a *name*. Currently, this name is used only for the output of trace messages. By default, names are displayed in bold type.

Every net element can carry semantic inscriptions. Places can have an optional *place type* and an arbitrary number of *initialisation expressions*. The initialisation expressions are evaluated and the resulting values serve as initial markings of the places. By default, a place is initially unmarked. Arcs can have an optional *arc inscription*. When a transition fires, its arc expressions are evaluated and tokens are moved according to the result. Transitions can be equipped with a variety of inscriptions. *Expression inscriptions* are ordinary expression that are evaluated while the net simulator searches for a binding of the transition. The result of this evaluation is discarded, but in such expressions you can use the equality operator `=` to influence the binding of variables that are used elsewhere. *Guard inscriptions* are expressions that are prefixed with the reserved word `guard`. A transition may only fire if all of its guard inscriptions evaluate to `true`.

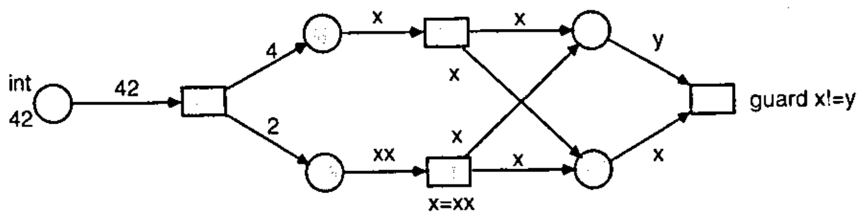

Figure 1: The net `coloured`

With these additions we cover the basic coloured Petri net formalism. In Fig. 1 we find a net that uses the basic place and arc inscriptions. At the left, we have a place that is typed `int`, which means that it can only take integers as tokens. In this case, it has an initial marking of one integer `42` token. The other places are untyped and initially unmarked. The leftmost transition will take `42` out of the place and deposit one `4` and one `2` into the respective places. The upper middle transition takes some x, which happens to be 4 in this case, out of its input places and copies it into its two output places. The lower middle transition is similar, but here the equality of input and output arc variables is established by the transition inscription `x=xx`. The rightmost transition has a guard that ensures that $x \neq y$, written `guard x!=y`. Therefore it can only take a 2 out of the upper place and a 4 out of the lower place or vice versa.

Action inscriptions are expression inscriptions preceded with the keyword `action`. Contrary to expression inscriptions, action inscriptions are guaranteed to be evaluated exactly once during the firing of a transition. Action inscriptions cannot be used to calculate the bindings of variables that are used on input arcs, because input arc expressions must be fully evaluated before a transition can fire. However, action inscriptions can help to calculate output tokens and they are required for expressions with side effects.

Then there are *creation inscriptions* that deal with the creation of net instances (see Section 2.3) and *synchronous channels* (see Section 2.4).

2.2 The Inscription Language

The possible kinds of tokens are Java values or references. By default, an arc will transport a black token, denoted by `[]`. But if you add an *arc inscription* to an arc, that inscription will be evaluated and the result will determine which kind of token is moved.

Arc inscriptions are simply Java expressions, but there are a few differences. The first difference concerns the operators that are used in expressions. The binary operators `&&` (short-circuit logical and) and `||` (short-circuit logical or) and the ternary selection operator `?:` are not implemented. Possibly, these three operators might still occur in later releases of Renew.

In Java variables receive their value by *assignment*. After a second assignment, the value from the first assignment is lost. This flavour of variables is not well-suited for high-level Petri nets. Instead variables are supposed to be bound to one single value during the firing of a transition and that value must not change. However, during the next firing of the same transition, the variables may be bound to completely different values. This is quite similar to the way variables are used in logical programming, e.g. in Prolog.

If variables are declared in a *declaration node*, they can only take values of their associated type.

Reference nets also support method invocations. E.g., `x.meth("a")` invokes the method `meth` of the object referenced by `x` with the parameter string `"a"`. All Java methods can be used in reference nets, but it is preferable if the invoked methods do not produce any side effects.

The inscription language of reference nets has been extended to include *tuples*. A tuple is denoted by a comma-separated list of expressions that is enclosed in square brackets. Tuples are useful for storing a whole group of related values inside a single token and hence in a single place.

We already know that the black token is denoted by `[]`. Therefore a black token is simply a tuple without components (a zero-tuple).

2.3 Net Instances and Net References

A net that is drawn in the editor is a static structure. However, an instance of the net has a marking that can change over time. Whenever a simulation is started, a new *net instance* is created. Every net has to be given a *name*. New net instances are created by transitions that carry *creation inscriptions*, which consist of a variable name, a colon (`:`), the reserved word `new`, and the name of the net. In Figs. 2 and 3 you can see a simple example.

The top transition of `creator` can fire and creates two new net instances of `othernet`. References to the two nets are deposited in the middle place. Now *three* transition instances are

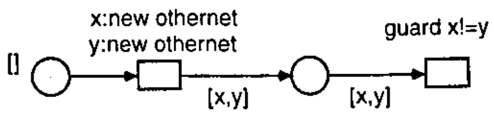

Figure 2: The net **creator**

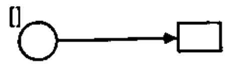

Figure 3: The net **othernet**

activated, namely the two transitions in the two instances of **othernet** and the bottom transition of **creator**. The guard is satisfied, because two different creation inscriptions are guaranteed to create different net instances. You never create the same instance twice.

Now the order of execution is undefined. It might be possible that the bottom transition of **creator** fires first. Even in that case, the two transitions instances of **othernet** remain activated. A net does not disappear simply because it is no longer referenced. On the other hand, if a net instance is no longer referenced and none of its transition instances can possibly become enabled, then it is subject to garbage collection.

2.4 Synchronous Channels

In this section we establish a means of communication for net instances, *synchronous channels*, which were fist considered for coloured Petri nets by Christensen and Damgaard Hansen in [1]. They synchronise two transitions which both fire atomically at the same time. Both transitions must agree on the name of the channel and on a set of parameters before they can synchronise.

Here we generalise this concept by allowing transitions in different net instances to synchronise. In association with classical object-oriented languages we require that the initiator of a synchronisation knows the other net instance.

The initiating transition must have a special inscription, the so-called *downlink*. A downlink makes a request at a designated subordinate net. A downlink consists of an expression that must evaluate to a net reference, a colon (:), the name of the channel, and an optional list of arguments.

On the other side, the transition must be inscribed with a so-called *uplink*. An uplink serves requests for everyone. Therefore the expression that designates the other net instance is missing for downlinks.

In Fig. 4 you can see an example net with local channels. In reference nets, **this** denotes the net instance in which a transition fires. The input place of the left transition is marked and the transition's downlink specification can be met by synchronising with the right transition in the same net instance. Both transitions fire synchronously, such that one token is removed from the left place and one token is added to the right place in a single step. Now no more transitions are enabled. The left transition lacks a token on its input place, the right transition has an uplink that is not invoked by another transition.

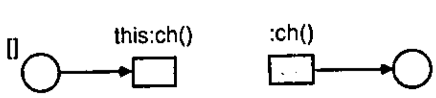

Figure 4: The net **synchro**

Generally, transitions with an uplink cannot fire without being requested explicitly by another transition with a matching downlink. It is allowed that a transition has multiple downlinks. It is also allowed that a transition has both an uplink and downlinks.

Channels can also take a list of parameters. Although there is a direction of invocation, this direction need not coincide with the direction of information transfer. Indeed it is possible that a single synchronisation transfers information in both directions. Fig. 5 shows a possible application where the left transition consults a lookup table that is managed by the right net instance. The parameter lists (x,y) and (a,b) match if x=a and y=b. After binding x from the left place the variable a is determined and only one token of the right place matches the tuple of the arc inscription. This allows to bind b and hence y.

Figure 5: The net param

In the previous examples we only encountered local synchronisations within one net, but of course it is possible to specify synchronisation between different net instances.

3 Renew's Graphical User Interface

A reference net model usually consists of quite a lot small nets, of which several instances are created that interact with each other. This kind of model requires a specifically adapted graphical user interface. Therefore, a user interface has been implemented that groups all global functions in a single application window, but provides a window for each net that is used in the current net system. Each window can be accessed from the application window by a menu containing the nets' names. During simulation, every single instance is treated as a first-class object and displayed in its own window, so that the model developer can concentrate on the relevant information.

The second requirement is that it is easy to construct and edit the Petri nets themselves. This requirement is met by the special graph editing capabilities Renew inherits from the JHotDraw framework [2]. Connectors move together with their corresponding nodes. Additionally, a special Petri net construction mode has been added that allows rapid drawing of nets from scratch. Inscriptions move together with the nodes they are connected to and can be edited on the fly.

Renew also provides basic drawing functions, so that for illustration or documentation purposes, net models can be complemented by graphical elements like text, different shapes, or bitmap graphics. Complete models can be exported as PostScript graphics.

Acknowledgements

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Characterizing Security in Synchronization Graphs

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Abstract: Synchronization graphs, marked graphs, or more precisely T-systems, constitute an important class of Petri nets well suited for the description and analysis of concurrent but deterministic synchronization schemes. T-systems are a well investigated model of net theory with a rich collection of theoretical results.

Nevertheless it has recently been found by the author that a fundamental problem concerning the nature of concurrency and causality has not been addressed so far, namely the question if there exists another binary relation between net elements not covered by concurrency and causality in safe and live T-systems. Here we will give a negative answer by proving that every two elements are either concurrent or causally dependent (tertium non datur).

Another issue that has not received much attention so far is the notion of security introduced by C. A. Petri with the motivation that it provides a more adequate abstraction of technical safety than the usual notion of safety in net theory. As an application of the first result on the nature of concurrency and causality we will prove that a surprisingly simple structural criterion for security proposed by C. A. Petri and C. Y. Yuan actually provides a characterization of security in safe and live T-systems.

Keywords: Petri nets, synchronization graphs, marked graphs, T-systems, causality, concurrency, safety, security

1 Introduction

Abstract notions of concurrency and causality have been studied by C. A. Petri in the context of concurrency theory [9] [10] [11]. Following [11] its structures are triples (X,li,co) where li and co are irreflexive, symmetric binary relations over a set X. The basic axioms include $co \cap li = \emptyset$ and $co \cup li \cup \mathrm{id}_X = X \times X$. The standard interpretations for li and co are (undirected) causality and concurrency, respectively, although further interpretations are suggested in [9].

Since the introduction of the first ideas of concurrency theory in [7] and [8] different sets of axioms, interactions between them, extensions and refinements of the theory have been studied [9] [2] [16] [10] [11] [1] [13] [6]. A general motivation was to provide a foundation for the theory of Petri nets and their processes in terms of more elementary concepts. In addition to the investigation of partial-order-based models [1] [2] where li is generated from a partial order by $li = (<) \cup (<)^{-1}$ there are also some results on models which do not rely on the assumption of an underlying partial order [17] [5] [6] [18]. As an example for the latter class we have studied concurrency structures associated with T-systems as models of concurrency theory [6].

Although definitions of causality and concurrency directly on T-systems instead of on their processes were originally motivated by our interest in T-system models of concurrency theory, they will play a different role in the present work: The binary relations of concurrency and causality will be used as a means to express important aspects of arbitrary safe and live T-systems.

The notion of security has been introduced for elementary net systems in [12], since safety has been found to be not an appropriate abstraction of technical safety if the objects modeled by tokens exhibit a spatial or temporal extension (as it is usually the case). Whereas safety is defined as the absence of *contacts*, security requires additionally the absence of *transjunctions*. Intuitively, a transjunction is a situation where "successive" tokens are not separated by an empty place. So security ensures that a well-defined separation between tokens is maintained explicitly in the net model. There are different ways to achieve security, either by net transformation or, more economically, by choosing an appropriate synchronization scheme as a basis of the system design. For the latter possibility a parameterized class of security structures, called cycloids, has been proposed in [14].

The present work is organized as follows: After some preliminaries fixing terminology and recapitulating folklore results about T-systems, we provide some facts about flow reversal in Section 3 that will be important for the proof of our main result. Next we provide definitions of causality (li) and concurrency (co) which are appropriate for safe and live T-systems. Formally, we will define irreflexive, symmetric relations $li,co \subseteq X \times X$, where X is the set of net elements. In Section 5 we prove the main result, namely that co and li do not only satisfy the equation $co \cap li = \emptyset$ but also $co \cup li \cup \mathrm{id}_X = X \times X$. Finally, in Section 6 this result is applied to prove a structural characterization of security in T-systems which is of remarkable simplicity.

2 Preliminaries

A possibly infinite *sequence* w is a function such that $\mathrm{dom}(w)$ is a subset of the integers and $i,k \in \mathrm{dom}(w) \wedge i < j < k \Rightarrow j \in \mathrm{dom}(w)$. The elements of $\mathrm{dom}(w)$ are called *indices* of w. We will use sequences together with the obvious definition of *concatenation* denoted by juxtaposition. Elements are conceived as singleton sequences.

As in [14] a *net* N is a triple (S,T,F) with $S \cap T = \emptyset$, $F \subseteq (S \times T) \cup (T \times S)$, $F \cap F^{-1} = \emptyset$, $\mathrm{dom}(F) \cup \mathrm{ran}(F) = S \cup T$. S, T, and F are the set of *places*, the set of *transitions*, and the *flow relation*, respectively. $X := S \cup T$ is also called the set of *net elements*. For a net element $x \in X$ the *preset* and *postset* of x are ${}^\bullet x := F^{-1}[x]$ and $x^\bullet := F[x]$, respectively. Two distinct transitions $t,t' \in T$ are said to be independent iff $({}^\bullet t \cup t^\bullet) \cap ({}^\bullet t' \cup t'^\bullet) = \emptyset$. Notice that the definition of a net excludes side-conditions, i.e. places in ${}^\bullet t \cap t^\bullet$, and isolated net elements, i.e. elements $x \in X$ with ${}^\bullet x \cup x^\bullet = \emptyset$.

A set $M \in \mathcal{P}(S)$ is called a *marking* of N. An element $x \in M$ is said to be *marked* at M. The occurrence relation $(\xrightarrow{t}) \subseteq \mathcal{P}(S) \times \mathcal{P}(S)$ for $t \in T$ is the smallest relation satisfying $M \cup {}^\bullet t \xrightarrow{t} M \cup t^\bullet$ for some marking M disjoint from ${}^\bullet t$ and $t^\bullet$. In case of $M \xrightarrow{t} M'$ we say that t is *(forward) enabled* at M, t is *backward enabled* at M' and M' is reachable from M by the occurrence of t. We also write $M \xrightarrow{w} M'$ for a sequence $w = (w_0 \ldots w_{n-1})$ iff there is a sequence $m = (m_0 \ldots m_n) = (M \ldots M')$ with $m_i \xrightarrow{w_i} m_{i+1}$ for all indices $i \in \{0 \ldots n{-}1\}$. Moreover, we define a relation $(\rightarrow) \subseteq \mathcal{P}(S) \times \mathcal{P}(S)$ by $M \rightarrow M' \Leftrightarrow \exists\, t \in T : M \xrightarrow{t} M'$ and an equivalence relation $(\leftrightarrow^*) := (\rightarrow \cup \rightarrow^{-1})^*$. For a marking M the set $\{M' \mid M \rightarrow^* M'\}$ is called the *forward case class* generated by M and $\{M' \mid M \leftrightarrow^* M'\}$ is the *full case class* generated by M.

T-nets are nets without branching places, i.e. $|{}^\bullet s|, |s^\bullet| \leq 1$ for all $s \in S$. An *(elementary) T-system* (N,C_0) is a T-net equipped with a marking C_0. The forward case class of (N,C_0) is the forward case class generated by C_0 and is denoted by $\mathcal{C}$.

Let N be a net and $\mathcal{M}$ be a set of markings. $\mathcal{M}$ is *(forward) safe* iff there is no marking $M \in \mathcal{M}$ and transition $t \in T$ such that t has a *(forward) contact* at M, i.e. ${}^\bullet t \subseteq M$ and $t^\bullet \cap M \neq \emptyset$. $\mathcal{M}$ is *backward safe* iff there is no marking $M \in \mathcal{M}$ and transition $t \in T$ such that t has a *backward contact* at M, i.e. $t^\bullet \subseteq M$ and ${}^\bullet t \cap M \neq \emptyset$. $\mathcal{M}$ is *(forward) live* iff for every marking $M \in \mathcal{M}$ and transition $t \in T$ there is a marking $M' \in \mathcal{M}$ with $M \rightarrow^* M'$ such that t is enabled at M'. $\mathcal{M}$ is *backward live* iff for every marking $M \in \mathcal{M}$ and transition $t \in T$ there is a marking $M' \in \mathcal{M}$ with $M' \rightarrow^* M$ such that t is backward enabled at M'. $\mathcal{M}$ has a *(forward) deadlock* iff there is a marking $M \in \mathcal{M}$ such that no transition is enabled at M.

Throughout this work we assume that (N,C_0) is a T-system with a net $N = (S,T,F)$ that has the following properties: $S \cup T$ is non-empty and finite, N is connected, i.e. $(F \cup F^{-1})^* = X \times X$.

A sequence w is said to be a *chain* iff $w_i \; F \; w_{i+1}$ for all indices i, $i{+}1 \in \mathrm{dom}(w)$. A chain w is *simple* iff $w_i \neq w_j$ for all indices $i \neq j$ of w. A finite chain $w = (w_0 \ldots w_{n-1})$ is a *cycle* iff it is nonempty and $w_{n-1} \; F \; w_0$. A *circuit* is a simple cycle. A sequence w *carries* $|\{i \in \mathrm{dom}(w) \mid w_i \in M\}|$ *tokens* at a marking M. Since N is a T-net, the number of tokens carried by a cycle/circuit is invariant under occurrence of transitions. We say that a sequence w is *marked* at M iff it carries at least one token at M. A cycle/circuit w is a *basic cycle/basic circuit* iff it carries exactly one token at C_0.

We will implicitly use the following folklore results, which can be adapted to our terminology e.g. from [3] or [4]: If $\mathcal{C}$ is safe and live then N is strongly connected. $\mathcal{C}$ is safe and live iff every circuit carries at least one token and every net element is contained in a basic circuit. If $\mathcal{C}$ is safe but not live then $\mathcal{C}$ has a deadlock.

The concept of basic cycle is usually not considered in the context of safe and live T-systems, since it is equivalent to the notion of basic circuit. This fact will be exploited in the proof of our main result.

Remark 2.1 If $\mathcal{C}$ is live then w is a basic circuit iff w is a basic cycle.

Proof Clearly every basic circuit is a basic cycle. It remains to prove the converse. Let w be a basic cycle. Assume w is not a circuit. Then there is a net element x occurring at least twice in w. W.l.o.g. we can assume that x is a transition, because N is a T-net. Now w has the form $(w'\ x\ w''\ x\ w''')$ and carries a single token. Hence, it can be decomposed into two cycles $(x\ w'')$ and $(x\ w'''\ w')$, but at most one of them can be marked, contradicting liveness. □

3 Flow Reversal

Flow reversal is a simple operation associating to each net $N = (S,T,F)$ the reverse net $N^{-1} := (S,T,F^{-1})$. In general, flow reversal can destroy important properties, however, it is rather well-behaved for safe and live T-systems, as demonstrated subsequently. This will enable us to use flow reversal as a technical means in the proof of our main result. Since the effect of flow reversal has not been treated in the Petri net literature, we have included the proofs. Remember that $\mathcal{C}$ is the forward case class of (N,C_0).

Remark 3.1 If $\mathcal{C}$ is live and (forward) safe then $\mathcal{C}$ is backward safe.

Proof Assume $t \in T$ has a backward contact at some case $C \in \mathcal{C}$. Since N is strongly connected (due to safety and liveness) we have $t^\bullet \subseteq C$ and there is some $s \in {}^\bullet t \cap C$. Again due to safety and liveness, s must be contained in a basic circuit w, but then w contains some $s' \in t^\bullet$. Now we have $s \neq s$, since N has no side-conditions, and $s,s' \in C$ contradicting the fact that w is a basic circuit. □

The next lemma states that backward occurrence can be simulated by forward occurrence in safe and live T-systems.

Lemma 3.2 Let $\mathcal{C}$ be safe and live and assume a marking $C \in \mathcal{C}$ and an arbitrary marking M.
Then $M \xrightarrow{t} C$ implies $C \rightarrow^* M$ for each $t \in T$.

Proof There is a finite sequence w of transitions such that $C \xrightarrow{w} C$ and w

contains each transition exactly once (see e.g. [3]). So we have $C \overset{(u\ t\ v)}{\rightarrow} C$ with finite sequences u and v. From $M \overset{t}{\rightarrow} C$ we obtain ${}^\bullet t \subseteq M$ and $t^\bullet \subseteq C$. We will first prove the claim that t and t' are independent for all t' occurring in v. Assume there is a transition t' in v such that t and t' are not independent. It follows that there is a place $s \in S$ such that $s \in {}^\bullet t \cap t'^\bullet$ or $s \in t^\bullet \cap {}^\bullet t'$. In the first case s is marked after the occurrence of t' and, since $s \in {}^\bullet t$ and t is not contained in v, s remains marked in final marking C. But then t would have a backward contact at C contradicting safety and liveness (see previous remark). In the second case s is marked after the occurrence of t. Then the token is removed by t' in v. Hence s is unmarked at C. But this contradicts $s \in t^\bullet \subseteq C$. So the claim about independence holds, and we can reshuffle $C \overset{(u\ t\ v)}{\rightarrow} C$ to obtain $C \overset{(u\ v\ t)}{\rightarrow} C$ by exchanging independent neighbors of the transition sequence. Due to $M \overset{t}{\rightarrow} C$ the last relation can be decomposed into $C \overset{(u\ v)}{\rightarrow} M \overset{t}{\rightarrow} C$. □

Remark 3.3 The forward case class $\mathcal{C}$ is equal to the full case class generated by C and is invariant under flow reversal.

Proof Equality follows from the previous lemma. Invariance under flow reversal is obvious from the definition of the full case class. □

By the previous remark the forward case class and full case class generated by C coincide. *Hence we will refer to them simply as the case class $\mathcal{C}$ in the remainder of this work.*

Lemma 3.4 If $\mathcal{C}$ is safe and live then for all $C,C' \in \mathcal{C}$ we have $C \rightarrow^* C'$.

Proof $C,C' \in \mathcal{C}$ implies $C_0 \rightarrow^* C$ and $C_0 \rightarrow^* C'$. By Lemma 3.2 we obtain $C \rightarrow^* C'$. □

Finally we observe that safety and liveness *together* are preserved by flow reversal.

Remark 3.5 If $\mathcal{C}$ is safe and live w.r.t. N then $\mathcal{C}$ is also safe and live w.r.t. N^{-1}.

Proof Safety of $\mathcal{C}$ w.r.t. N^{-1} follows from backward safety w.r.t. N which holds by Remark 3.1. Liveness of $\mathcal{C}$ w.r.t. N^{-1} follows from backward liveness w.r.t. N, which can be proved as follows: Due to liveness of $\mathcal{C}$ w.r.t. N for every marking $C \in \mathcal{C}$ and transition $t \in T$ there is a marking C' with $C \rightarrow^* C'$ such that t is enabled at C'. Let C'' be a marking with $C' \overset{t}{\rightarrow} C''$. Clearly, t is backward enabled at C''. Moreover, $C'' \rightarrow^* C$ because of $C,C'' \in \mathcal{C}$ and Lemma 3.4. □

For the remainder of this work we restrict our attention to *safe and live T-systems* (N,C_0), i.e. T-systems with a safe and live case class $\mathcal{C}$ generated by C_0.

4 Causality and Concurrency

In this section we will define causality and concurrency for T-systems using a simple technical device, namely T-splitting. In [14] T-splitting has been used to obtain security from safety. Here T-splitting allows us consider the original net N together with a refined version $\tilde{N}$ where the activity of transitions can be observed from the state. It may be helpful to think of N as a net where transitions can be marked (cf. [6]). Technically, the refined net will enable us to speak about net elements in a uniform way.

The *refined net* $\tilde{N} := (\tilde{S},\tilde{T},\tilde{F})$ obtained by *T-splitting* from N. It is defined by $\tilde{S} := \{\tilde{x} \mid x \in X\}$, $\tilde{T} := \{\acute{t}, \grave{t} \mid t \in T\}$ and $\tilde{F}$ being the smallest relation satisfying (a) $\acute{t}\ \tilde{F}\ \tilde{t}\ \tilde{F}\ \grave{t}$, (b) $\tilde{s}\ \tilde{F}\ \acute{t}$ if $s\ F\ t$, (c) $\grave{t}\ \tilde{F}\ \tilde{s}$ if $t\ F\ s$ for $s \in S$ and $t \in T$. This refinement induces a net morphism $\phi : \tilde{N} \to N$ mapping $\acute{x}$, $\tilde{x}$, $\grave{x}$ to x in the sense of [14]. For convenience we identify x and $\tilde{x}$ for all $x \in X$ throughout the work.

Observe that T-splitting does not change the behavior of a T-system essentially. More precisely, the *refined T-system* $(\tilde{N},\tilde{C}_0)$ has a safe and live case class $\tilde{\mathcal{C}}$ generated by $\tilde{C}_0$ which satisfies $\tilde{\mathcal{C}} \cap \mathcal{P}(S) = \mathcal{C}$. $\tilde{\mathcal{C}}$ is also called the *refined case class* of (N,C_0).

Now it is easy to introduce appropriate notions of causality and concurrency for T-systems: Let x and y be different net elements of N. x and y are *causally dependent* ($x\ li\ y$) iff there is a basic circuit of N containing both x and y. x and y are *concurrent* ($x\ co\ y$) iff there is a marking in the refined case class $\tilde{\mathcal{C}}$ containing both x and y. Intuitively, two net elements x and y are concurrent iff they *can* be active/marked concurrently. x and y are causally dependent on the other hand iff they *must* be active/marked in strict alternation.

Remark 4.1 *li* and *co* are invariant under flow reversal.

Proof Holds by definition for *li* and follows from Remark 3.3 for *co*. □

Actually, the relation *li* is the binary aspect of a more general view of T-systems as cyclic orders [19] but as demonstrated in [17] already a single binary relation, either *li* or *co*, is sufficient to determine the structure and dynamics of a rather general class of T-systems uniquely up to flow reversal.

5 The Main Result

We will first give a technical lemma prepared by the following proposition, which is of independent interest, since it conveys a fundamental aspect of the topological nature of safe and live T-systems: We can always reach one net element from another one via the flow relation such that there is a marking in the refined case class that has not to be passed.

Proposition 5.1 Let x and y be distinct net elements of N. Then there is a marking $\tilde{D} \in \tilde{\mathcal{C}}$ containing x and a simple chain $v = (x\ v'\ y)$ such that v' is unmarked at $\tilde{D}$.

Proof Due to liveness and strong connectedness there is a marking $\tilde{C} \in \tilde{\mathcal{C}}$ containing x. Let w be a basic circuit containing x. Consider the marking $\tilde{C}' := \tilde{C} - \{x\}$ and the refined case class $\tilde{\mathcal{C}}'$ generated by it. As w carries no token at $\tilde{C}'$, $\tilde{\mathcal{C}}'$ is not live. Hence, from $\tilde{C}'$ we can reach a deadlock at some marking $\tilde{D}' \in \tilde{\mathcal{C}}'$. Due to safety every transition has at least one empty input place at $\tilde{D}'$. Starting from y and proceeding along F^{-1} we can construct a backward-infinite chain $(u\ y)$ such that u carries no token at $\tilde{D}'$. Due to finiteness of X the infinite chain u must contain a circuit w.r.t. $\tilde{\mathcal{C}}'$. This unmarked circuit was impossible w.r.t. $\tilde{\mathcal{C}}$, because $\tilde{\mathcal{C}}$ is live. It follows that x must be contained in this circuit and consequently it is contained in u. Hence, $(u\ y)$ is of the form $(u'\ x\ v'\ y\ u'')$ and w.l.o.g. we can assume that the length of v' is minimal. Observe that $v = (x\ v'\ y)$ is a chain with v' being unmarked at $\tilde{D}'$. Due to minimality of v' and $x \neq y$ the chain v is simple, in particular x is not contained in v'. So v' is also unmarked at $\tilde{D} := \tilde{D}' \cup \{x\}$, which is a marking of $\tilde{\mathcal{C}}$. □

For the proof of the main result we will need a modification of the previous proposition. It is given by the following lemma.

Lemma 5.2 Let x and y be distinct net elements of N such that $\neg\ (x\ co\ y)$. Let $u = (x\ u'\ y)$ be a chain such that x is not contained in u' and let $\tilde{C} \in \tilde{\mathcal{C}}$ such that x and u' are marked at $\tilde{C}$. Then there is a marking $\tilde{D} \in \tilde{\mathcal{C}}$ containing x and a simple chain $v = (x\ v'\ y)$ such that v' is unmarked and u' is marked at $\tilde{D}$.

Proof Extend the previous proof as follows: Proceed as above using the supplied marking $\tilde{C} \in \tilde{\mathcal{C}}$. Clearly, u' is marked at $\tilde{C}' := \tilde{C} - \{x\}$. Observe that we cannot have an intermediate marking $\tilde{C}''$ containing y and reachable from $\tilde{C}'$ (in particular y is not marked at the deadlock $\tilde{D}'$). Otherwise $\tilde{C}'' \cup \{x\}$ would be a marking of $\tilde{\mathcal{C}}$ violating $\neg\ (x\ co\ y)$. Consequently, the number of tokens in u' cannot decrease while going from $\tilde{C}'$ to $\tilde{D}'$, as this is only possible via y. Hence u' remains marked at $\tilde{D}'$ and also at $\tilde{D} := \tilde{D}' \cup \{x\}$. □

Theorem 5.3 For net elements $x \neq y$ we have either $x\ li\ y$ or $x\ co\ y$ but not both.

Proof The fact that $x\ li\ y$ implies $\neg\ (x\ co\ y)$ follows immediately from the definitions of li and co. It remains to prove that $\neg\ (x\ co\ y)$ implies $x\ li\ y$. So assume $\neg\ (x\ co\ y)$. Due to strong connectedness x and y are contained in at least one cycle w. Let $u = (x\ u'\ y\ u'')$ be a cycle containing x and y carrying a minimum number of tokens. By liveness u carries at least one token. If u carries exactly one token then it is a basic cycle and also a basic circuit (see Remark 2.1) proving $x\ li\ y$. Otherwise u carries at least two tokens. Consider a marking $\tilde{C} \in \tilde{\mathcal{C}}$ containing x. As x and y cannot be marked simultaneously (here we use $\neg\ (x\ co\ y)$), u' or u'' is marked. First we consider the case where u' is marked: Observe that x is not contained in u', otherwise a cycle containing x and y carrying fewer tokens could be constructed. Now the preceding lemma provides a marking $\tilde{D} \in \tilde{\mathcal{C}}$ and a simple chain $(x\ v'\ y)$ such that v' is unmarked and u' remains marked at $\tilde{D}$. So we can construct a new cycle $(x\ v'\ y\ u'')$ which carries fewer tokens than u at $\tilde{D}$, contradicting the minimality assumption. Finally, we deal with the case where u'' is marked by considering the reverse T-system (N^{-1},C_0) instead of (N,C_0). This can be justified by the following facts: $\mathcal{C}$ is also the case class generated by C_0 w.r.t. N^{-1} (by Remark 3.3). $\mathcal{C}$ is safe and live (by Remark 3.5) w.r.t. N^{-1}. *co* is invariant under flow reversal (by Remark 4.1). The number of tokens carried by cycles is invariant under flow reversal. Exploiting these facts we can apply the same argument as in the previous case (replacing F by F^{-1} and exchanging u' and u'') to derive a contradiction. □

6 Characterizing Security

As an easy application of the previous theorem we obtain a security characterization that has already been proposed in [15] as a security criterion but without proving that it actually characterizes security in safe and live T-systems.

For a net N a set $\mathcal{M}$ of markings is said to be *secure* iff $\mathcal{M}$ is (forward) safe and backward safe and there is no marking $M \in \mathcal{M}$ and transition $t \in T$ such that t is in transjunction at M. Here a transition t is said to be in *transjunction* at M iff ${}^\bullet t \cap M \neq \emptyset \wedge t^\bullet \cap M \neq \emptyset$. In contrast to the definitions of contact the notion of transjunction is invariant under flow reversal.

Remember that $\mathcal{C}$ has been assumed to be safe and live and it coincides with the full case class. Indeed it is the full case class which has been used in the original definition of security in [12] and [14] for $\mathcal{M}$.

Corollary 6.1 $\mathcal{C}$ is secure iff for every $t \in T$ every pair $x \in {}^\bullet t$, $y \in t^\bullet$ is contained in a basic circuit.

Proof ($\Leftarrow$) Backward safety follows from safety by Remark 3.1. Moreover, $\mathcal{C}$ is obviously free of transjunctions due to the structural condition. ($\Rightarrow$) Let $t \in T$ and $x \in {}^\bullet t$, $y \in t^\bullet$. We have $x \neq y$, since N has no side-conditions. From security it follows that there is no marking $C \in \mathcal{C}$ with $x,y \in C$. By definition of *co* we obtain $\neg\ (x\ co\ y)$ and using Theorem 5.3 we conclude $x\ li\ y$. Now x and y are contained in some basic circuit according to the definition of *li*. □

From the non-trivial part of this corollary it follows that there is only one way to achieve security, namely by structural means of a very special kind.

7 Final Remarks

The main theorem about the structure of concurrency and causality presented in Section 5 has been derived as a by-product while investigating the close relationship between cyclic orders and T-systems [18]. Nevertheless we believe that this result is of independent interest due to its generality and its close connection to the notion of security. From the results of this work we conclude that security can be characterized structurally in terms of a single binary relation, either causality *or* concurrency.

From a foundational point of view these results shed new light on the local axioms of concurrency theory (cf. [17]), stating that the immediate neighborhood of each element consists of two *co*-equivalence classes related by *li*. Interpreting the two *co*-equivalence classes as the immediate past and the immediate future of an element, respectively, the local axioms require that the immediate past and immediate future of a single element are causally dependent. From this perspective security is just a reformulation of this natural assumption on the level of net systems.

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New Books

Wolfgang Reisig and Grzegorz Rozenberg, Editors

Lectures on Petri Nets I: Basic Models and Lectures on Petri Nets II: Applications

Volumes 1491 and 1492 of Lecture Notes in Computer Science, Springer-Verlag, 1998.

The two volumes are based on the Advanced Course on Petri Nets, held in Dagstuhl (Germany) in September 1996. Some material not presented in Dagstuhl is also included, in order to get a more balanced presentation of the area of Petri Nets. The two volumes address those who are

- interested in systems design and would like to learn to use Petri Nets,
- familiar with subareas of the theory or the applications of nets and wish to become acquainted with the whole area,
- interested in learning about recent results presented within a unified framework,
- going to learn about successfully applying Petri Nets in various practical situations,
- interested in the relationship of Petri Nets to other models of concurrent systems.

M. Uzam

Petri-Net-Based Supervisory Control of Discrete Event Systems and Their Ladder Logic Diagram Implementations

PhD-thesis, University of Salford, M5 4WT, UK, 1998.

As Discrete Event Systems (DESs) become more complex, the need for an effective design tool and its implementation becomes more important. Supervisory control theory, based on finite state machines (FSM) and formal languages, is a well established framework for the study of DESs. In supervisory control, given a model of the system and the desired system behaviour specifications, the objective is to find a supervisor (controller) such that the controlled behaviour of the system does not contradict the specifications given and does not unnecessarily constrain the behaviour of the system. In general, the classes of specifications that have been considered within the supervisory control fall into two categories: the forbidden state problem, in which the control specifications are expressed as forbidden conditions that must be avoided, and the desired string problem, in which the control specifications are expressed as sequence of activities that must be provided. The thesis investigates the use of Petri nets in supervisory control. Both the forbidden state problem and the desired string problem are solved. In other words, this work presents systematic approaches to the synthesis of Petri-nets-based supervisors (controllers) for both the forbidden state problem and the desired string problem and introduces the details of supervisory design procedures. The supervisors obtained are the form of a net structure as oppose to supervisors given as a feedback function. This means that

a controlled model of the system can be constructed and analysed using the techniques regarding to Petri net models.
An approach to the conversion from the supervisors to ladder logic diagrams (LLDs) for implementation on a programmable logic controller (PLC) is proposed. A discrete manufacturing system example is then considered. The aim of this is to illustrate the applicability, strengths and drawbacks of the design techniques proposed.

Boudewijn R. Haverkort

Performance of Computer-Communication Systems

John Wiley and Sons, 1998 (515 pages).

Its 18 chapters comprise a very wide overview of modern performance evaluation techniques and shows their applicability for the evaluation of computer and communication systems. The emphasis in the book is on the problem-solving capabilities of the models, rather than on the mathematical aspects; the models are used to understand the operation of systems. This fact plus the about 100 exercises make the book very well suited for courses on performance evaluation.
Among the techniques covered are: Little's law, stochastic processes, birth-death queueing systems, M—G—1, G—M—1, G—G—1 and PH—PH—1 queueing models, cyclic server models, open and closed queueing network models with and without load-dependent service rates (including the MVA and convolution method), BCMP networks and the QNA method, stochastic Petri nets, numerical analysis of Markov chains (steady-state and transient) and stochastic Petri nets with matrix-geometric solution, simulation techniques and the statistical evaluation of simulations.
Among the applications covered are: multiprogramming systems, ATM multiplexers with complex schedulers, central server systems, token ring systems (IBM and FDDI), connection management systems in ATM, packet-switched communication networks, reliability studies.

Twan Basten

In Terms of Nets – System Design with Petri Nets and Process Algebra

PhD-thesis, Eindhoven University of Technology, NL, 1998 (237 pages).

Two of the most widely used formalisms for analyzing and describing concurrent systems are Petri nets and process algebra. The main motivation of this thesis is to study topics combining these two formalisms. The first goal is to learn more about the strengths and the weaknesses of both Petri nets and process algebra. The second goal is to stimulate the use and acceptance of formal methods in design practice.
The first part of the thesis gives an introduction to basic concurrency theory, including labeled transition systems, labeled P/T-nets and an ACP-style process algebra. The second part combines Petri nets and process algebra in a method supporting the compositional design of concurrent systems, including the activities of behavioral specification, Petri-net modeling, simulation and algebraic verification. The third part describes an approach to inheritance of dynamic behavior both in a process-algebraic setting and in a Petri-net framework.

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EKA '99

Hiermit melde ich mich verbindlich an für (bitte ankreuzen)

- ❑ Tutorium, 26. Mai 1999
- ❑ Fachtagung, 27. und 28. Mai 1999

TU Braunschweig
Institut für Regelungs- und Automatisierungstechnik
Langer Kamp 8

D-38106 Braunschweig

Faxantwort: +49 (0) 531 391 - 5197

Nach Eingang der Anmeldung erhalte ich eine Anmeldebestätigung sowie Informationen über Unterbringungsmöglichkeiten. Die Tagungsgebühr wird in Rechnung gestellt. In den Tagungsgebühren sind Tagungsband, Tagungsunterlagen, Mittagessen, Pausengetränke und Abendempfang enthalten.

Tagungsgebühr	Tutorium, 26.5.1999	Fachtagung, 27.+28.5.1999
Normalzahler	290,- DM	870,- / 770,- DM *)
Hochschulangehörige	240,- DM	670,- / 570,- DM *)

*) Bei Anmeldung zur Fachtagung vor dem 1. April und Überweisung der Tagungsgebühr vor dem 15. April werden 100,- DM Frühzahler-Rabatt gewährt.

Bitte in Blockschrift ausfüllen:

Firma / Institution

Abteilung

Teilnehmer (Nachname, Vorname, Titel, Anrede m/w)

Straße, PLZ, Wohnort

Telefon, Fax, E-Mail

Ort, Datum, Unterschrift

utorium „Technisches Marketing“ Iittwoch, 26. Mai 1999

arketing: Schlüsselpunkt im Lebenszyklus ttechnischer Anlagen

Zeichen zusammenwachsender Märkte soll das Tutorium Grundlagen Anforderungen eines modernen Marketings für die Entwicklung leit-nischer Anlagen vermitteln. Es werden folgende Themen behandelt:

Übersicht über den globalen Markt der Leittechnik – Informationsmodell „Markt Leittechnik“ mit seinen Elementen rsteller, Produkte, Anwender, Aufgaben, Lösungen) in objektorientierter arstellung – Branchen, Regionen, Kompetenzen, Zielmärkte – Produkt-nd Produktionsphilosophie – Management, Akquisition, Engineering – Kompetente Erstellung und Umsetzung von Lastenheften – Entwicklungstendenzen des Leittechnik-Marktes

erent: **Prof. Dr. M. Polke** (Köln). Beginn: 11.00 Uhr

Informationsstrukturierung am Beispiel der Kunstgeschichte

erentin: **Dr. S. Rauprich** (Köln). Beginn: 18.00 Uhr

chließend Transfer zum Domplatz mit Erläuterungen vor Ort, ach gemeinsames Abendessen.

achtagung EKA onnerstag, 27. Mai 1999

rüßung durch den Präsidenten der TU Braunschweig und durch wissenschaftlichen Leiter der Tagung, Prof. Dr. E. Schnieder

ffnungsvortrag
lution von Entwicklungswerkzeugen der Automatisierungstechnik
Schnieder (TU Braunschweig)

narsitzung 1

nomical Construction of Petri Net Simulation Models for the Design of nplex Automation Systems
v. Uthmann (Uni Münster)

tigungssysteme Modellieren, Bewerten und Steuern mit TimeNET$_{MS}$
Zimmermann, J. Freiheit, G. Hommel (TU Berlin)

narsitzung 2

ndardisierter Produktdatenaustausch im Umfeld der Automatisierungs-nik verfahrenstechnischer Anlagen: dringender denn je
Ahrens, H. Buchner (Bayer AG, Leverkusen)

Verhaltenssteuerung in reaktiven Systemen: Konstruktion von Master-Slave-Hierarchien in CIP Modellen
H. Fierz (ETH Zürich, Schweiz),
H. Müller (CIP System AG, Zürich, Schweiz)

The Explication Problem: Achille's Heel of Formal Methods
S. Parthasarathy, E. Schnieder (TU Braunschweig)

Engineering-Werkzeuge 1

Engineering großer Leitsysteme
R. Vahldieck (Elsag Bailey Hartmann & Braun, Minden)

REDISE – Remote and Distributed Software Engineering
K. Jopke (Aerodata Flugmesstechnik GmbH, Braunschweig),
M. Lother (DLR, Braunschweig)

Advant Objects – Basis für ein integriertes Anlagenmanagement über den gesamten Lebenszyklus
K. Auer (ABB Industrietechnik GmbH, Mannheim)

Engineering-Werkzeuge 2

Objektorientierter Entwurf verteilter eingebetteter Echtzeitsysteme auf Basis höherer Petri-Netze
J. Nützel, W. Fengler, T. Böhme (TU Ilmenau)

Technologisches Projektieren von SPS mit verifiziertem AWL-Generator
J. Alder, A. Pretschner, L. Klein, U. Petermann, M. Wittek (HTWK Leipzig)

Hybridnetzbeschreibung und Simulation mit der erweiterten Sprache APNN
A. Schleußinger (Uni Erlangen)

Analyse & Synthese 1

Kooperierende Roboter – eine Fallstudie zu hybriden Resourcenzuweisungs-problemen
D. Franke, K. Frick, T. Moor (Uni der Bundeswehr, Hamburg),
H. Holm (Uni Aalborg)

Approximative Erreichbarkeitsanalyse für gesteuerte kontinuierliche Systeme
J. Preußig, O. Stursberg, S. Kowalewski (Uni Dortmund)

Modellbildung und Analyse hybrider Systeme mit Petri-Netzen und geschal-teten Differentialgleichungen
Ch. Müller, H. Rake (RWTH Aachen)

Analyse & Synthese 2

Modelling and Analyzing PLC with Petri Nets
M. Heiner, T. Menzel (Uni Cottbus)

Synthese asynchroner Steuerwerksverbünde aus der Petrinetz-Spezifikation des Sollverhaltens – ein Überblick
R. Wollowski, J. Beister (Uni Kaiserslautern)

Beschreibung und Anwendung von Bäumen zur Lösung von Steuerungs-aufgaben ereignisdiskreter Systeme
H.-J. Albrecht (TU Dresden)

Fachtagung EKA Freitag, 28. Mai 1999

Modellbildung 1: Fertigungssysteme

Simulation der Fertigungs- und Prüfsicherheit via Petrinetz-Modellierung
T. Pfeifer, K. P. Pieper, M. Merget (RWTH Aachen)

Automatische Modellierung Flexibler Fertigungssysteme zur Synthese von Überwachersteuerungen
M. Seidl, G. Schmidt (TU München)

UML-Basierte Beschreibungssprache zur hybriden Maschinenmodellierung
K. Bender, J. Albert (TU München)

Engineering-Methodik

Neue Vorgehensweise im Entwicklungsprozess durch den interdisziplinären, prozessorientierten Entwurf intelligenter technischer Systeme
B. Weisshaupt (Technologie Management Gruppe TMG AG, Frauenfeld, Schweiz)

Engineering verteilter Automatisierungssysteme mit neuen Informations-technologien und -methoden
J. Hörger (Siemens AG, Karlsruhe),
R. Simon (Inst. f. Automation und Kommunikation e. V., Magdeburg)

YAnCC – Entwicklung und Umsetzung einer methodischen Vorgehensweise für hochsicherheitskritische Entwicklungen im spurgebundenen Verkehr – ein Erfahrungsbericht
M. Krone (Siemens AG, München),
H.-J. Reder (Siemens AG, Braunschweig)

Fuzzy-Petrinetz-Anwendungen 1

Fuzzybewertete Petri-Netze als Grundlage für den Entwurf von hardware-realisierten Fuzzy-Systemen
J. Bogoljubow, W. Fengler (TU Ilmenau)

Planning and Scheduling of Complex Activities Characterized by Fuzzy Properties
A. Pagnoni (Università di Milano, Italien)

Fuzzy-Regelbasierte Exploration von Erreichbarkeitsgraphen zur Entschei-dungsunterstützung der Ablaufplanung in flexiblen Fertigungssystemen
D. Sackmann, H. Ey (FH Braunschweig/Wolfenbüttel)

Modellbildung 2: Hybride Systeme

Synthese einer Anfahrregelung für eine Destillationskolonne auf der Grundlage einer ereignisdiskreten Approximation der kontinuierlichen Dynamik
E. Klein, H. Wehlan (Uni Stuttgart), **A. Kienle, J. Raisch** (Max-Planck-Institut für Dynamik komplexer technischer Systeme, Magdeburg)

Hybride Datenflußgraphen – Ein systemtheoretischer Ansatz zur homo-genen, graphbasierten Darstellung hybrider Systeme
Ch. Grimm, K. Waldschmidt (Uni Frankfurt a. M.)

Modellbildung 3: Informationsmodelle

Ein erweitertes Informationsmodell auf Petrinetzbasis als Spezifizierungs-werkzeug
U. Becker, B. Erdmann (TU Braunschweig)

Komponentenbasierte Funktionsbausteintechnik
U. Enste, U. Epple (RWTH Aachen)

Peripherie/Interoperabilität

Einsatz eines Prozeßmodells zur Analyse und Spezifikation von Bussystemen
U. Bock, G. Bikker, J.-U. Varchmin, E. Schnieder (TU Braunschweig)

Interoperabilitätsprüfung offener intelligenter Feldbusgeräte
T. Huang, K. Bender (Forschungszentrum Informatik Karlsruhe)

Formal Models

The Dynamic Models of UML: Towards a Semantics and its Application in the Development Process
T. Gehrke, U. Goltz (TU Braunschweig), **H. Wehrheim** (Uni Oldenburg)

Capturing the Logical Structure of Requirements for the Automatic Generation of Test Specifications
M. R. Donat (Intrepid Critical Software Inc., Vancouver, Canada),
K. M. L. Cooper, M. R. Ito (University of British Columbia, Vancouver, Canada)

Advanced Software Process Automation with MSC/SDL: a case study
M. Van Limberghen (S.A. Intellect-Prodata N. V., Zaventem, Belgien)

Fuzzy-Petrinetz-Anwendungen 2

Stoffstrombilanzierung und -management durch Anwendung der Fuzzy-Petri-Netz-Simulation
A. Tuma (Uni Bremen)

Ein Fuzzy-Petrinetz-Konzept als Modellbasis für komplexe Automatisie-rungsaufgaben
H.-P. Lipp, S. Bachmann (FH Schmalkalden)

Grenzen der Wissensrepräsentation mit Fuzzy-Petrinetzen
A. Fay (ABB Forschungszentrum, Heidelberg)

Schlußsitzung

Schlußvortrag
Referent: **Prof. Dr. W. Ch. Zimmerli** (Uni Marburg) – angefragt

Verabschiedung

Preliminary Program and Call for Participation

SABPM '99

Software Architectures for Business Process Management

Workshop at the CAiSE'99

Heidelberg, Germany, June 14th. and 15th.

The process paradigm has changed the way organizations work. Organizational structures as well as IT-infrastructures are effected by this paradigm shift. New types of software systems, such as enterprise resource planning (ERP) systems, workflow management (WFM) systems and computer supported cooperative work (CSCW) systems, offer some support for the management of business processes. Unfortunately, these systems offer only limited support for specific aspects, impose all kinds of constraints. Moreover, software components for business process modeling, simulation, enactment, communication, monitoring, and quality control are poorly integrated and have problems dealing with the business changing dynamically. New metaphors, and robust but flexible software architectures implementing them are needed to establish satisfactory long-term solutions to these problems.

The workshop will feature keynote talks by Amit Sheth and Stefan Jablonski. Further talks on various aspects of the workshop topic are being held by specialists from different branches of business process related disciplines to initiate an intensive discussion.

The workshop will take place at the European Media Lab, Villa Bosch, Heidelberg. Please find registration information on CaiSE'99 at the URL: http://www-i5.informatik.rwth-aachen.de/caise99/
To register for SABPM'99 use http://lwi2.wiwi.uni-frankfurt.de/caise99/form.htm

The workshop is organized by

Wil van der Aalst, Technische Universiteit Eindhoven, The Netherlands, wsinwa@win.tue.nl
Jörg Desel, Katholische Universität Eichstätt, Germany, desel@aifb.uni-karlsruhe.de
Roland Kaschek, Universität Klagenfurt, Austria, roland.kaschek@ifit.uni-klu.ac.at

All of them can be consulted for further information.

Monday, June 14th, 1999

14.00	**opening** Jörg Desel: Extending the Workflow Reference Architecture for Business Process Management
14.40	Kees van Hee, Robert van der Toorn, Peter Verkoulen: A Framework for Component Based Software Architecture
15.20	Sergio Daniel Mabres: The Need for new Ways of Developing Application, the Dissatisfaction Gap
16.00	*coffee*

16.30	**keynote talk** Amit Sheth: Processes Driving the Networked Economy: ProcessPortals, ProcessVortex and Dynamically Trading Processes
17.30	Joachim Wehler: Towards an Interaction Theory of Business Modeling
18.10	discussion
19.00	*workshop dinner*

Tuesday, June 15th, 1999

9.00	Roland Kaschek: Requirements for Software Architectures Supporting Dynamic Business
9.40	Anatol W. Holt: Software Architecture in Support of Organized Activity
10.20	*coffee*
10.50	Elvira Kuhn: Support for the Reaction to Changing Business Contexts within Robust Enterprises
11.30	Paolo Predozani, Giancarlo Succi, Tullio Vernazzi: Support for the Reaction to Changing Business Contexts within Robust Enterprises
12.10	*bus transfer to lunch in Heidelberg*
14.10	Wil van der Aalst: Workflow Management: Three Problems: One Solution?
14.50	Christoph Bussler: Workflow Class Inheritance and Dynamic Workflow Class Binding
15.30	*coffee*
16.00	**keynote talk** Stefan Jablonski: Experiences in Applying Workflow Technology in Industrial Projects
17.00	Shazia W. Sadiq & Maria E. Orlowska: Dynamic Workflow Modification
17.40	discussion
18.00	**closing**

Petri Nets '99

20th International Conference on
›plication and Theory of Petri Nets

University Center
College of William and Mary
Williamsburg, Virginia, USA
21 – 25 June 1999

Sponsored by:
Department of Computer Science
College of William and Mary

http://www.cs.wm.edu/pn99/
Email: pn99@cs.wm.edu

◈ OVERVIEW ◈

Introductory Tutorials
›esel, S. Donatelli, K. Jensen, W. Reisig, G. Rozenberg, M. Silva
Monday, June 21 and Tuesday, June 22

Advanced Tutorials
Performance Analysis (G. Balbo)
Monday, June 21

Distributed Algorithms (W. Reisig)
Tuesday, June 22

Workshops
Hardware design and Petri nets
Organizers: Alex Yakovlev, Luciano Lavagno
Monday, June 21, 1999

Applications of Petri nets to intelligent system development
Organizers: Luigi Portinale, Robert Valette, Du Zhang
Tuesday, June 22, 1999

Tool Presentations
Wednesday, June 23, 1999

Tool Demonstrations
Monday, June 21 to Friday, June 25

Work-In-Progress Session
Wednesday, June 23, 1999

◈ PROGRAM COMMITTEE CO-CHAIRS ◈

Susanna Donatelli, Università di Torino, Italy
H.C.M. Kleijn, Leiden University, The Netherlands

◈ PROGRAM COMMITTEE ◈

W. van der Aalst, The Netherlands
P. Azema, France
W. Brauer, Germany
S. Christensen, Denmark
A. Desrochers, U.S.A.
C. Girault, France
L. Gomes, Portugal
J. Hillston, United Kingdom
E. Kindler, Germany
S. Kumagai, Japan
C. Lakos, Australia
A. Levis, U.S.A.
J. Lilius, Finland
T. Murata, U.S.A.
G. Nutt, U.S.A.
K. Onaga, Japan
W. Penczek, Poland
L. Pomello, Italy
W. Sanders, U.S.A.
M. Silva, Spain
D. Simpson, United Kingdom
P.S. Thiagarajan, India
K. Trivedi, U.S.A.
R. Valette, France
R. Valk, Germany
A. Yakovlev, United Kingdom
W. Zuberek, Canada

◈ ORGANIZING COMMITTEE CHAIR ◈

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◈ ORGANIZING COMMITTEE ◈

Evgenia Smirni (Tools Demonstrations)
College of William and Mary, Department of Computer Science
Deborah S. Noonan (Finance)
College of William and Mary, Department of Computer Science
Mariellyn D. Maurer (Logistics)
College of William and Mary, Conference Services

◈ STEERING COMMITTEE ◈

G. Balbo, Italy
J. Billington, Australia
C. Girault, France
K. Jensen, Denmark
S. Kumagai, Japan
G. De Michelis, Italy
T. Murata, USA
C. A. Petri, Germany (honorary member)
W. Reisig, Germany
G. Roucairol, France
G. Rozenberg, The Netherlands (chair)
M. Silva, Spain

◈ TUTORIAL PROGRAM ◈

Introductory tutorials, Monday, June 21, 1999

09:00 - 09:30 *Informal Introduction to Petri Nets* (W. Reisig)
09:30 - 11:00 *Elementary Net Systems I* (G. Rozenberg)
11:00 - 11:30 Coffee break
11:30 - 12:15 *Place/Transition Nets I* (J. Desel)
12:15 - 14:15 Lunch
14:15 - 15:00 *Place/Transition Nets I, cont.* (J. Desel)
15:00 - 16:30 *High Level Nets I* (K. Jensen)
16:30 - 17:00 Coffee break
17:00 - 18:00 *Timed and Stochastic Nets* (S. Donatelli)

Introductory tutorials, Tuesday, June 22, 1999

09:00 - 10:30 *Elementary Net Systems II* (G. Rozenberg)
10:30 - 11:00 Coffee break
11:00 - 12:00 *Place/Transition Nets II* (M. Silva)
12:00 - 14:00 Lunch
14:00 - 15:00 *Introduction to GSPNs* (S. Donatelli)
15:00 - 16:30 *High Level Nets II* (K. Jensen)
16:30 - 17:00 Coffee break

Advanced tutorial, Monday, June 21, 1999

09:00 - 11:00 *Performance Analysis, part 1* (G. Balbo)
11:00 - 11:30 Coffee break
11:30 - 12:15 *Performance Analysis, part 2* (G. Balbo)
12:15 - 14:15 Lunch
14:15 - 16:30 *Performance Analysis, part 3* (G. Balbo)
16:30 - 17:00 Coffee break
17:00 - 18:00 *Performance Analysis, part 4* (G. Balbo)

Advanced tutorial, Tuesday, June 22, 1999

09:00 - 10:30 *Distributed Algorithms, part 1* (W. Reisig)
10:30 - 11:00 Coffee break
11:00 - 12:00 *Distributed Algorithms, part 2* (W. Reisig)
12:00 - 14:00 Lunch
14:00 - 16:30 *Distributed Algorithms, part 3* (W. Reisig)
16:30 - 17:00 Coffee break
17:00 - 18:00 *Distributed Algorithms, part 4* (W. Reisig)

◈ WORKSHOP PROGRAM ◈

Monday, June 21, 1999

Hardware design and Petri nets
Organized by: Alex Yakovlev, Luciano Lavagno
Sessions: TBD

Tuesday, June 21, 1999

Applications of Petri nets to intelligent system development
Organized by: Luigi Portinale, Robert Valette, Du Zhang
Sessions: TBD

◈ CONFERENCE PROGRAM ◈

Wednesday, June 23, 1999

09:00 - 09:30 Opening Session
09:30 - 10:30 Invited Talk: *Design, simulation, and implementation of hybrid systems*
P. Varaiya (Univ. of California, Berkeley)
10:30 - 11:00 Coffee break
11:00 - 12:30 *Efficient reachability set generation and storage using decision diagrams*
A.S. Miner, G. Ciardo
Structural methods to improve the symbolic analysis of Petri nets
E. Pastor, J. Cortadella, M.A. Pena
Stubborn sets for standard properties
K. Schmidt
12:30 - 14:00 Lunch break
14:00 - 15:00 *Petri net based behavioural specification of CORBA systems*
R. Bastide, P. Palanque, O. Sy, Duc-Hoa Le, D. Navarre
Symmetric communication between coloured Petri net simulations and Java-processes
O. Kummer, D. Moldt, F. Wienberg
15:00 - 15:30 Coffee break
15.30 - 16:50 Tool Presentations
Polymorphism and model-reuse mechanisms for algebraic Petri nets in CoopnTools
M. Buffo, D. Buchs
The Petri Net Kernel: An infrastructure for building Petri net tools
E. Kindler, M. Weber
PetShop: a CASE tool for Petri net based specification and prototyping of CORBA systems
O. Sy, R. Bastide, P. Palanque, Duc-Hoa Le, D. Navarre
Federation of tools in CPN-Ami, with the support of the FrameKit Platform for the analysis of telecommunication systems
F. Kordon, E. Paviot-Adet
17:00 - 18:00 Work-In-Progress Session

Thursday, June 24, 1999

09:00 - 10:00 Invited Talk: *Recent developments in modeling and analysis of hybrid dynamic systems*
B. Krogh (Carnegie Mellon Univ.)
10:00 - 10:30 *Autonomous continuous P/T systems*
L. Recalde, E. Teruel, M. Silva
10:30 - 11:00 Coffee break
11:00 - 12:30 *An approach to the analysis of interworking traders*
A. Tokmakoff, J. Billington
Parallel approaches to the numerical transient analysis of stochastic reward nets
S. Allmaier, D. Kreische
SWN nets as a framework for the specification and the analysis of FT techniques adopted in electric plant automation
L. Capra, R. Gaeta, O. Botti
12:30 - 14:00 Lunch break
14:00 - 15:00 *Monitoring discrete event systems using Petri net embeddings*
C. N. Hadjicostis, G.C. Verghese
Quasi-static scheduling of embedded software using free-choice Petri Nets
M. Sgroi, L. Lavagno, Y. Watanabe, A. Sangiovanni-Vincentelli
15:00 - 15:30 Coffee break
15:30 - 17:00 *Theoretical aspects of recursive Petri nets*
S. Haddad, D. Poitrenaud
Petri net theory - Problems solved by commutative algebra
C. Schneider, J. Wehler
Testing undecidability of the reachability in Petri nets with the help of 10th Hilbert problem
P. Chrzastowski-Wachtel
19:00 - 22:00 Banquet

Friday, June 25, 1999

09:00 - 10:00 Invited Talk: *Net theory and workflow models*
G. De Michelis (University of Milano)
10:00 - 10:30 *Concurrent implementation of asynchronous transition systems*
W. Vogler
10:30 - 11:00 Coffee break
11:00 - 12:30 *Reasoning about algebraic generalisation of Petri nets*
J. Fanchon
Trace channel nets
G. Juhas
The box algebra - A model of nets and process expressions
E. Best, R. Devillers, M. Koutny
12:30 - 14:00 Lunch break
14:00 - 15:30 *Detection of illegal behaviors based on unfoldings*
J.-M. Couvreur, D. Poitrenaud
Five classes of invariant-preserving transformations on colored Petri nets
T.-Y. Cheung, Y. Lu
Verifying intuition - ILF checks DAWN proofs
T. Baar, E. Kindler, H. Voelzer
15:30 - 16:00 Coffee break
16:00 - 17:00 Closing Session

✧ ACCOMODATIONS ✧

A block of rooms has been reserved at the Williamsburg Hospitality House, the Official Conference Hotel, for the attendees of Petri Nets '99. This hotel is located downtown, a two-minute walk from the University campus and the conference site. The address is:

Williamsburg Hospitality House
415 Richmond Rd.
Williamsburg, VA 23185-3536
USA

A special conference rate of $95.00 (+ 9.5% tax) per night, for single or double occupancy, is available to attendees that book their reservation by May 20, 1999.

Be sure to mention Petri Nets '99 when you make your reservation, in order to receive the conference rate.

For reservations:
Tel. (international) +1-757-229-4020
Tel. (toll free, US only) 800-932-9192
Fax. +1-757-229-0731

Note:s

- The special room rate is available from Saturday, June 19, 1999, to Sunday, June 27, 1999.
- All reservation must be accompanied by one night's deposit for room and tax. Deposits are refundable, provided notice of cancellation is received by the Williamsburg Hospitality House at least 72 hours prior to arrival
- Changes in arrival date must be made by 5:00pm, 72 hours prior to arrival, or a charge for the first night lodging wil apply. Also, any change affecting the length of the stay must be made by 5:00pm, 72 hours prior to arrival, or a charge of $35.00 will apply.
- Advance reservation may also be guaranteed by VISA, MasterCard, Diners Club, American Express, and Discover Card.

As June is in the height of the touristic season, we strongly recommend that you make your reservations as early as possible.

Inexpensive accommodations are also available in one of the College's dormitories. These are student-style accommodations, with a sink in the room and a shared bathroom in the corridor.

The cost is $29 per night for a single room and $52 per night for a double (with two single beds).

To reserve a dormitory room, please fill the reservation form, and send it with your payment, by surface mail or courier, to

Conference Services Office
P.O. Box 3542
Williamsburg, VA, 23187-3542
USA

If you are paying by credit card, you can alternatively fax the form to +1-757-221-2090

If you have questions, please contact the Conference Services Office at +1-757-221-4084, or send email to wmconf@mail.wm.edu.

Petri Nets '99 Dormitory Reservation Form

Use this form only to reserve dormitory rooms, not to reserve hotel rooms.

Please use one form per room.

Last Name: ____________________
First Name: ____________________
Full postal mailing address: ____________________
____
____
____
____
____
Phone: ____________________
Fax: ____________________
Email: ____________________

If you are reserving a double room (with two single beds), please provide the same information for your roommate (only one form is needed):

Last Name: ____________________
First Name: ____________________
Full postal mailing address: ____________________
____
____
____
____
____
Phone: ____________________
Fax: ____________________
Email: ____________________

Arrival date/time: ____________________
Departure date/time: ____________________
Number of days: ________ at $29/day ☐ $52/day ☐ (check one).
Total payment: $ ☐

Form of payment:

☐ Check payable to The College of William and Mary in U.S. funds drawn on a U.S. bank

☐ International or U.S. Postal order to The College of William and Mary

☐ Credit card (fill information below)

Type of credit card: ☐ VISA or ☐ MasterCard
Name as it appears on the card: ____________________
Credit card number: ____________________
Expiration date: ☐ /
Amount to be charged: $ ____________________
Cardholder's Signature: ____________________

✧ REGISTRATION ✧

The registration fees are as follows:

MEMBERS*		NON-MEMBERS		STUDENTS
By May 21	After May 21	By May 21	After May 21	
Tutorial or Workshop (per day)				
$85	$85	$85	$85	$70
Conference only (3 days)				
$380	$430	$430	$480	$180
Tutorials or Workshops and Conference (5 days)				
$500	$550	$550	$600	$290
Additional banquet ticket (per person)				
$80	$80	$80	$80	$80

Registration fee for Members(*) and Non-Members includes proceedings, welcome reception, coffee breaks, conference banquet and lunches (Wednesday, Thursday, and Friday).

Registration fee for Students includes proceedings, coffee breaks, and lunches (Wednesday, Thursday, and Friday), but it does not include welcome reception and conference banquet. Student registrations must be endorsed by a faculty member at their institution.

(*) Members of AFCET SIG "Systemes Paralleles et Distribues" and CNRS-PRS, AICA, BCS SIG "Formal Aspects of Computing Science", EATCS and GI SIG "Petri Nets and Related System Models".

Payment

Payment in full must be received for your registration to be complete. Participants may pay by credit card (VISA or MasterCard), check in U.S. funds drawn on a U.S. bank or International or U.S. Postal order. Checks should be made payable to: The College of William and Mary

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Petri Nets '99 Registration Form

Last Name: ______________________

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Name on badge (if different): ______________________

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I am registering as "Member", here is my membership information:
Organization ______________________
Membership number ______________________

I am registering as "Student", here is my faculty sponsor information:
Faculty name ______________________
Faculty signature ______________________

I am sending a total payment of $ ☐ for:

Monday June 21, 1999 (check at most one)

- ☐ Introductory Tutorial I
- ☐ Advanced Tutorial I: Performance Analysis
- ☐ Workshop: Hardware Design and Petri Nets

Tuesday June 22, 1999 (check at most one)

- ☐ Introductory Tutorial II
- ☐ Advanced Tutorial II: Distributed Algorithms
- ☐ Workshop: Applications of PNs to Intelligent System Development

Wednesday June 23 - Friday June 25, 1999 (check if attending)

- ☐ Conference

Additional banquet tickets ($80 each): ☐

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To help us provide attendees and their families with a range of entertainment options, please provide the number of tickets you plan purchase (this does not imply a committment on your part):

- ☐ tickets for Colonial Williamsburg (valid your entire stay)
- ☐ tickets for Busch Gardens (each valid for one day)
- ☐ tickets for Water Country USA (each valid for one day)

Accepted Paper for the 8th International Workshop on Petri Nets and Performance Models

(PNPM'99)

to be held in Centro Politécnico Superior, Universidad de Zaragoza Zaragoza, Spain,
September 8 to 10, 1999

For further information please see http://www4.cs.uni-dortmund.de/pnpm99/pnpm_title.html

1. Scenario durations charaterization of t-timed Petri nets using linear logic
   B. Pradin-Chezalviel, R. Valette, L.A. Kunzle
   LAAS-CNRS, France

2. Analysis of Timed-Arc Petri Nets
   V. Valero Ruiz, D. de Frutos Escrig, F. Cuartero Gomez
   Universidad de Castilla-La Mancha, Spain

3. GSPN Analysis of Dual-Band Mobile Telephony Networks
   M. Meo, M. Ajmone Marsan, M. Sereno
   Politecnico di Torino, Italy

4. Clearing up the priority specification in GSPN
   E. Teruel, G. Franceschinis, M. De Pierro
   Univ. Zaragoza, Spain

5. An Asymptotically Optimal Well-Specified Check
   D. Deavours, W. Sanders
   University of Illinois, USA

6. Checking Time Petri Nets for Linear Duration Properties
   X. Li, J. Lilius
   Turku Centre for Computer Science, Finland

7. Implicit Places in Net Systems
   F. G. Valles, J. M. Colom
   Universidad de Zaragoza, Spain

8. Stepwise Refinements of Net Models and Their Place Invariants
   W. Zuberek
   Memorial University of Nfld, Canada

9. On the Efficient Sequential and Distributed Evaluation of Very Large Stochastic Petri Nets
   B. Haverkort, Bohnenkamp, Bell
   RWTH Aachen, Germany

10. Non equivalence between Time Petri Nets and Time Stream Petri Nets
    M. Boyer, M. Diaz
    LAAS/CNRS, France

11. Fluid Stochastic Petri Nets: An Extended Formalism to Include non-Markovian Models
    M. Gribaudo, M. Sereno, A. Bobbio
    Universita' di Torino, Italy

12. A mapping of autonomous net condition event systems to GSPNs
    P. Kemper
    Universitaet Dortmund, Germany

13. On state space decomposition for the numerical analysis of stochastic Petri nets
    C. J. Perez-Jimenez, J. Campos
    Universidad de Zaragoza, Spain

14. Exploiting Petri Nets to support Fault Tree based dependability analysis
    R. Gaeta, A. Bobbio, G. Franceschinis, L. Portinale
    Universita' di Torino, Italy

15. A data structure for the efficient Kronecker solution of GSPNs
    G. Ciardo, A. Miner
    College of William and Mary, USA

16. Performance Evaluation of IEEE 802.11 Wireless LANs with Stochastic Petri Nets
    R. German, A. Heindl
    TU Berlin, Germany

17. Towards a Foundation of the Analysis of Markov Regenerative Stochastic Petri Nets
    R. German, M. Telek
    TU Berlin, Germany

18. Modeling Software Systems with Rejuvenation, Restoration and Checkpointing through Fluid Stochastic Petri Nets
    A, Bobbio, S. Garg, M. Gribaudo, A. Horvarth, M. Sereno, M. Telek
    Universita' di Torino, Italy

(only the location of the first author is printed in the list!)

Einladung und Call for Papers
zum 6. Workshop
ALGORITHMEN UND WERKZEUGE FÜR PETRINETZE
Frankfurt am Main, 11. - 12. Oktober 1999

veranstaltet von der Fachgruppe 0.0.1 "Petrinetze und verwandte Systemmodelle" der Gesellschaft für Informatik.
Der Workshop konzentriert sich auf Fragestellungen zur Analyse und Simulation von Petrinetz-Modellen sowie auf Erfahrungen mit der Implementierung von Analyse-, Simulations- und Visualisierungswerkzeugen. Aktuelle Ergebnisse, Werkzeuge und auch Überblicke können vorgestellt werden. Einen Schwerpunkt des Treffens bilden der Erfahrungsaustausch und die Diskussion.

Veranstaltungsort:
J.W. Goethe-Universität, Hauptgebäude, Mertonstraße 17, Frankfurt/Main

Organisation:
Jörg Desel, Universität Karlsruhe
Ekkart Kindler, Humboldt-Universität zu Berlin
Andreas Oberweis, J.W. Goethe-Universität Frankfurt

Themen (mit Bezug zu Petrinetzen):
- Entscheidungsalgorithmen für dynamische Eigenschaften
- Zustandsraumreduktion
- Temporale Logik und Model-Checking
- Analyse mit algebraischen und linear-algebraischen Methoden
- Simulationsverfahren
- Datenstrukturen und Algorithmen in Werkzeugen
- Benutzungsschnittstellen und Visualisierung
- Schnittstellen und Austauschformate für Petrinetzwerkzeuge
- Fallstudien zur Validierung von Modellierungstechniken
- Software-Engineering- und Workflow-Managementwerkzeuge
- Mit Petrinetzen verwandte Modelle und Methoden

Beiträge:
Ergebnisse können in Form von Vorträgen und Werkzeugdemonstrationen präsentiert werden. Ein Auswahlverfahren findet nicht statt, die eingegangenen Beiträge werden lediglich auf thematische Eignung hin überprüft. Schriftliche Ausarbeitungen (höchstens 6 Seiten) können bis zum 31. August 1999 an

Prof. Dr. Andreas Oberweis
J.W. Goethe-Universität, Lehrstuhl für Wirtschaftsinformatik II
Postfach 111932, D-60054 Frankfurt/Main
Fax: 069-798-25073, E-mail: oberweis@wiwi.uni-frankfurt.de

geschickt werden. Die Beiträge werden in einem Forschungsbericht des Instituts für Wirtschaftsinformatik veröffentlicht, den alle Teilnehmer erhalten. Beiträge können in englischer oder deutscher Sprache verfaßt sein.
Werkzeugpräsentationen können ebenfalls bis zum 31. August 1999 bei A. Oberweis angemeldet werden.

Anmeldung:
Eine Anmeldung zum Workshop ist bis zum 30. September 1999 bei A. Oberweis möglich. Die Teilnahme am Workshop ist kostenlos.

Weitere Informationen:
Informationen im WWW unter der URL http://lwi2.wiwi.uni-frankfurt.de/AWPN99/

The DFG research group "Petri Net Technology" announces:

Petrinetz-Technologie

Colloquium on Petri Net Technologies for Modelling Communication Based Systems

Berlin, October 21st and 22nd, 1999

Technische Universität Berlin — Humboldt-Universität zu Berlin

Prof. Dr. H. Weber — Prof. Dr. H. Ehrig — Prof. Dr. W. Reisig

The research group "Petri Net Technology" successfully completed its first project phase. At the colloquium, we present the main results to a broad interested audience from both universities and industry.[1]

Scope of the colloquium:

Many of todays business data processing systems and embedded data processing systems will be turned into communication based systems: They are expected to support the communication between people to enable their coordinated interworking, the communication between software systems to enable their interoperation, and the communication between computers to enable both the interoperation of systems and the interworking of people. Communication has hence become an issue of critical importance in domains like

- Computer Based Business Process Management
- Man Machine Dialog Management
- Systems Integration and Interoperation
- Communication Protocols
- etc.

[1] see `http://www.informatik.hu-berlin.de/PNT/Coll/` for registration details

Petri Nets have gained a wide acceptance in many of these work areas, and are now a research topic in different communities like the Petri Net Community, the Systems and Software Engineering Community and the Specification Techniques Community. As a consequence, Petri Nets are applied now in the modelling and specification of communication based systems in various forms and variants.

The colloquium is intended to join renowned experts from the areas indicated above to discuss matters as

- Classification of Petri Net variants for different purposes
- Development of modelling guidelines that help practitioners
- Tool support for validation and verification of models and specifications
- Integration of different modelling and specification techniques
- Distributed algorithms
- Specification and semantics of processes

Programme:

The research group will present its main result, i. e. the conception of a Petri net construction kit for the development of Petri net based communication systems. The presentations will be accompanied by 12 talks of invited experts:

- Wil van der Aalst (Eindhoven University of Technology):
  Inheritance of Interorganizational Workflows to Enable Business-to-Business E-commerce
- Jörg Becker (Westfälische Wilhelms-Universität Münster):
  Petri Nets for Modeling Business Processes - Potentials, Deficits and Recommendations
- Andrea Corradini (University of Pisa):
  On the process semantics of graph and net based systems
- Jörg Desel (Universität Eichstätt):
  Partial-Order Based Simulation of Petri Nets
- Volker Gruhn (Universität Dortmund):
  Process Landscaping - A Petri Net based Method for Structuring Complex Processes
- Hans-Michael Hanisch (Otto-von-Guericke-Universität Magdeburg):
  Modular Modeling of Closed Loop Systems
- Günter Hommel (Technical University Berlin):
  Non-Markovian Stochastic Petri Nets for the Quantitative Analysis of Communication-Based Systems

- Ugo Montanari (Università di Pisa):
  Zero-Safe Nets: Composing Nets via Transition Synchronization
- Grzegorz Rozenberg (Leiden University):
  Team Automata for Groupware Systems
- Bernhard Steffen (University of Dortmund):
  The Electronic Tool Integration Platform (ETI)
- Rüdiger Valk (Universität Hamburg):
  Comparing Reference and Value Semantics for Object Petri Nets
- Martin Wirsing (Ludwig-Maximilians-Universität München):
  Debugging ROOM Designs using High-Level-Petri-Nets

Further information and contact:

Colloquium homepage: `http://www.informatik.hu-berlin.de/PNT/Coll/`
Project homepage: `http://www.informatik.hu-berlin.de/PNT/`
email: `pnt-leitung@.informatik.hu-berlin.de`

Application of Petri Nets in Workflow and Controling Technique

- Petri Nets and Information Systems in practical use -

Peter Langner, **innobis** GmbH

The 10th meeting of the working group "Petri Nets and Informations Systems in practical use" took place in Magdeburg on October 26th. It was organized by the **innobis** GmbH assisted by the "Otto-von-Guericke-Univeristät" and "Softlab AG". The interdisciplinary working group comes together twice a year for the purpose of exchanging experiences. The working group is organized by both special interest groups "Petri Nets and Related System Models" (FG 0.01) and "Development Methods and its Application" (EMISA, FG 2.5.3) of the Gesellschaft für Informatik (GI).

In the first lecture, Mr. Arndt Lüder, Universität Magdeburg, NCES represented the Condition/Event-Systems and some other applications. Concerning Condition/Event-Systems (CES) it is a question of model forms for the modelling of sensible systems with a continous time axis. They are composed of moduls and signal connections and are used by control technicians to model e. g. reactor units or transport systems or plants. NCES models the function of the basic elements by Petri Nets and thus the methods of net theory to analyse and simulate structure and function of the whole system are available.

In a second lecture, Mr. Ulrich Christmann, talked about the use of *BatchMon*. *BatchMon* is a simulation system for operative ressource planning based on NCES. This study has been worked out by the department for trade company and showed how NCES can be supported by a tool. With the help of the results it was easy to improve the extant plant and therefore they could turn away new investments.

Mr. Ramakers and Mr. Neckebroek, Ley GmbH, presented applications of the product family COSA. COSA is a workflow system which uses Petri Nets to define workflows and which is used in the new BaaN Software. Furthermore it is also capable to work standalone. As a result of the partnership with IDS Prof. Scheer Mr. Ramakers and Mr. Neckebroek presented COSARIS an interface from ARIS to COSA which converts event-driven processchains into Petri Nets.

After these talks the 19 participants discussed in two smaller groups the topics "Petri Nets as basis for production planning" and "Demands for an implement set to create Petri Net implements".

All persons using (or intending to use) Petri Nets in connection with information systems (i. e. in order to analyse business processes, to describe interactive user-orientated systems, to model and to document information systems, to create administrational routines, etc.) are invited to join the next meeting.

Information regarding the past meetings can be obtained form www.innobis.de.

Registrations, request for further information and details should be sent to the address given below:

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Bericht über den Workshop der Gesellschaft für Informatik

Modellierung'99

Karlsruhe, März 1999

Bei der Entwicklung von Software- und Informationssystemen werden verschiedene Aspekte von Struktur und Verhalten eines Systems modelliert. Dazu stehen unterschiedliche Modellierungssprachen zur Verfügung. Das Fachgebiet Modellierung befaßt sich mit derartigen Modellen sowie mit ihren Beziehungen untereinander und auch mit dem Prozeß der Modellerstellung. Der Workshop Modellierung wurde 1999 zum zweiten Mal von sieben Fachgruppen der Gesellschaft für Informatik ausgetragen, darunter die Fachgruppe 0.0.1 (Petrinetze). Er fand statt im Fasanenschlößchen in Karlsruhe, ein idyllisches kleines Tagungshaus der staatlichen Forstschule, direkt auf dem Campus der Universität gelegen.

Die Tagung war neben interessanten Vorträgen geprägt von intensiven Diskussionen und Arbeitsgemeinschaften. Dabei standen die Themen "Grundlagen der Modellierung" und "Modellierung in der Lehre" im Vordergrund. Die Beiträge und Diskussionspapiere sind in einem Tagungsband erschienen, der im Teubner-Verlag erschienen ist:

> Jörg Desel, Klaus Pohl, Andy Schürr (Herausgeber): Modellierung'99, Teubner-Reihe Wirtschaftsinformatik. B.G.Teubner, Stuttgart und Leipzig 1999 (198 Seiten).

Inhalt:

Recent Publications

[1] Abdallah, I.B.; ElMaraghy, H.A.: *Deadlock prevention and avoidance in FMS – a Petri net based approach.* In: International Journal of Advanced Manufacturing Technology, Vol. 14, No. 10, pages 704–715. 1998.

The use of structure theory of Petri nets to develop efficient deadlock prevention and deadlock avoidance methods for flexible manufacturing systems (FMSs) modeled by (SR)-R-4 nets is demonstrated. Major synchronization patterns, such as generalized parallel and sequential mutual exclusion, frequently observed in FMS contexts can be represented by this class. The liveness property of a given (SR)-R-4 net (deadlock-freeness in the context of FMSs) is characterized in terms of structural Petri net properties. The performance of the proposed approaches is illustrated using several examples.

[2] Ajmone Marsan, M.; Bobbio, A.; Donatelli, S.: *Petri Nets in Performance Analysis: An Introduction.* In Reisig, W.; Rozenberg, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 211–256. Springer-Verlag, 1998.

In this tutorial paper, the authors discuss the motivations that led to the adoption of Petri nets for performance evaluation, define the class of Petri nets that is most frequently used for performance analysis, and present the subclasses that allow a simpler derivation of performance metrics. Definitions and discussions are paralleled with examples, thus visualizing the strong and weak points of the different alternatives.

[3] Amer-Yahia, C.; Zarhouni, N.; El Moudni, A.; Ferney, M.: *Some subclasses of Petri nets and the analysis of their structural properties: a new approach.* In: IEEE Trans. on Systems, Man, and Cybernetics – A, Vol. 29, No. 2, pages 164–172. 1999.

The purpose of this paper is to consider some special types of Petri nets, introduced by Lien, and propose a complete and unified approach for the study of their structural properties by using techniques of linear algebra of matrices. Four subclasses of nets are distinguished: forward conflict-free, backward conflict-free, forward concurrent-free, and backward concurrent-free nets. A modification of the classical incidence matrix results in a square matrix, named a modified incidence matrix, with nonpositive (nonnegative) off-diagonal elements when backward (forward) conflict-free or concurrent-free Petri nets are considered. The modified incidence matrix eigenvalues are computed and theorems on matrices of this type are used to prove several sufficient and/or necessary conditions for structural boundedness, liveness, repetitiveness, conservativeness, and consistency of these four subclasses of Petri nets.

[4] Badouel, E.; Darondeau, P.: *Theory of Regions.* In Reisig, W.; Rozenberg, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 529–586. Springer-Verlag, 1998.

The synthesis problem for nets consists in deciding whether a given graph is isomorphic to the marking graph of some net and then constructing it. This problem has been solved in the literature for various types of nets ranging from elementary nets to Petri nets. The general principle for the synthesis is to inspect regions of graphs representing extensions of places of the likely generating nets. We follow in this survey the gradual development of the theory of regions from its foundation by Ehrenfeucht and Rozenberg, with a particular insistence on the abstract meaning of the theory, which is a general product decomposition of graphs into atomic components determined by a parameter called a type of nets, and on the derivation of efficient algorithms for net synthesis based on linear algebra.

[5] Baldan, P.; Corradini, A.; Montanari, U.: *An Event Structure Semantics for P/T Contextual Nets: Asymmetric Event Structures.* In Nivat, M.: Lecture Notes in Computer Science, Vol. 1378: Proceedings of 5th Intern. Conf. on Foundations of Software Science and Computation Structures (FOSSaCS'98) held as part of the Europ. Conf. on Theory and Practice of Software, ETAPS'98 in Lisbon, Portugal, pages 63–80. Springer, 1998.

We propose an event based semantics for contextual nets, i.e. an extension of Place/Transition Petri nets where transitions can also have context conditions, modelling resources that can be read without being consumed. The result is a generalization of Winskel's work on safe nets: the event based semantics is given at categorical level via a chain of coreflections leading from the category WS-CN of weakly safe contextual nets to the category Dom of finitary prime algebraic domains. A fundamental rôle is played by the notion of asymmetric event strutures that generalize Winskel's prime event structures, follwing an idea similar to that of 'possible flow' introduced by Pinna and Poigné. Asymmetric event structures have the usual causal relation of traditional prime event structures, but replace the symmetric conflict with a relation modelling asymmetric conflict of weak causality. Such relation allows oneto represent the new kind of dependency between events arising in contextual nets, as well as the usual symmetric conflict. Moreoverk it is used in a non-trivial way in the definition of the ordering of configurations, which is different from the standard set-inclusion.

[6] BARKAOUI, K.; PRADAT-PAYRE, J.-F.: *Verification in concurrent programming with Petri nets structural techniques.* In: Proc. 3-rd Int. IEEE High-Assurance Systems Engineering Symposium, 13-14 November 1998, Washington, DC, pages 124–133. 1998.

This paper deals with verification of flow control in concurrent programs. Ada language is used as a reference. After translation of Ada programs into Petri nets (named Ada nets for Ada programs), it is shown how one can fully exploit the relationship between the behavior of the concurrent program and the structure of the corresponding Petri net. Using the siphon structure, some structural conditions are refined for behavioral properties such as liveness and deadlock-freeness that correct concurrent programs must satisfy. These conditions can be proved or disproved using efficient algorithms. A formal justification of guidelines (such as client/server paradigm) that programmers observe traditionally in order to build correct concurrent programs is also provided. Several examples are presented to show the effectiveness of using structure theory of Petri nets for static analysis of concurrent programs.

[7] BECKER, M.; SZCZERBICKA, H.: *Modeling and optimization of kanban controlled manufacturing systems with GSPN including QN.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 570–575. 1998.

This paper investigates the kanban assignment problem for assembly kanban systems. REMO, a general purpose tool for optimization is used. For finding an optimal kanban assignment with respect to certain performance measures of the system, a fast performance analysis is a crucial factor for sensible and successful application of optimization algorithms. Petri nets including queueing nets (PNiQ) are introduced for this purpose, as a modeling formalism. At modeling level, PNiQs allow the use of both the concise description of queueing nets where possible and the notation of stochastic Petri nets where needed, e.g., to model fork./join needed for the matching of kanbans and parts. Approximate performance analysis is carried out by decomposition and aggregation of the queueing net parts. This technique provides a fast numerical solution even for large systems as important requirement for the application of optimization algorithms. The optimization not only yields optimal kanban assignments for various kanban systems but also a common pattern in the set of solutions can be recognized.

[8] BENAZZOUZ, D.; FARAH, A.: *The use of Petri nets in the performance evaluation of shuffle-exchange network under uniform traffic distribution.* In: Arabian Journal for Science and Engineering, Vol. 23, No. 2B, pages 253–263. 1998.

Many multistage interconnection networks (MINs) and single stage interconnection networks (SSINs) have been proposed for parallel computer systems and for fast packet switching in high speed networks. In this paper we evaluate the unbuffered shuffle-exchange network (SEN) topology of SSIN. The behavior of the SEN is modeled probabilistically as a stochastic Petri net (SPN) graph. We have minimized the number of places and transitions to find an efficient and reasonable combination state. We analyze the random delay experienced by a message traversing a SEN for a uniform traffic. Messages can have different sizes. The time between the generation of two consecutive requests is exponentially distributed. It is shown that the unbuffered strategy is suited to long data transfer times. The power of this approach is its simplicity to model the network and to compute the passing or blocking probabilities between states.

[9] BERIO, G.; DI LEVA, A.; GIOLITO, P.; VERNADAT, F.: *Process and data nets: the conceptual model of the M*-OBJECT methodology.* In: IEEE Trans. on Systems, Man, and Cybernetics – B, Vol. 29, No. 1, pages 104–114. 1999.

The paper describes a specification model, called the Process and Data Net (PDN) model, used as the modeling tool for the M*-OBJECT information system design methodology. The model integrates the representation of static, dynamic, and behavioral aspects of a database application. PDN consists of two components: an object-oriented data model that describes static and behavioral aspects of objects of the system under analysis, and a process model that specifies a way organization activities must be coordinated. The major features of the proposed approach are: 1) the system representation captures all relevant properties from the end-user viewpoint without unnecessary details concerning implementation, 2) complex data structures and data manipulations can be specified, and 3) specifications are executable for rapid prototyping.

[10] Best, E.; Devillers, R.; Koutny, M.: *Petri Nets, Process Algebras and Concurrent Programming Languages.* In Reisig, W.; Rozenberg, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

This paper discusses issues that arise when process algebras and Petri nets are linked; in particular, operators, compositionality, recursion, refinement and equivalences. It uses the box algebra in order to show how Petri nets can be manipulated algebraically. Also, the paper shows how other process algebras such as CCS, COSY and CSP can be treated in the same way, how Petri net semantics of concurrent programming languages can be given, and how Petri net methods can be applied to the verification of concurrent algorithms.

[11] Best, E.; Fraczak, W.; Hopkins, R.P.; Klaudel, H.; Pelz, E.: *M-nets: an algebra of high-level Petri nets with an applications to the semantics of concurrent programming languages.* In: Acta Informatica, Vol. 35, No. 10, pages 813–857. 1998.

This paper describes a high-level Petri net model called M-nets (for modular multilabeled nets). A distinctive feature of this model is that it allows both: unfolding, as do most other high-level net models; and composition – in particular, synchronization – in a process algebraic style, turning the set of M-nets into an algebraic domain. It turns out that the composition operations of this domain have various algebraic properties. Moreover, the model is such that composition operations are coherent with unfolding, in the sense that the unfolding of a composite high-level net is the composition of the unfoldings of its components. One of the motivations for M-nets is that they be a vehicle for giving semantics of concurrent programming languages. To illustrate their capability for that, the compositional semantics of $B(PN)^2$ – a simple, expressive concurrent programming language – is given. An associated low-level net semantics is described, and the coherence of these high-level and low-level semantics is proved.

[12] Bilinski, K.; Dagless, E.L.: *Efficient approach to symbolic state exploration of complex parallel controllers.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 132–142. 1998.

This paper presents a method based on the use of Zero-suppressed BDDs (0-Sup-BDD) applied to symbolic state space exploration of parallel controllers. Unlike traditional methods, the new approach is based on the implicit manipulation of sets of states instead of the manipulation of their characteristic functions. A formal specification of the parallel controller is given in a form of an interpreted petri net, Experimental results demonstrate that the proposed approach can successfully compete against the state of the art methods of state space exploration.

[13] Billington, J.: *Protocol Specification Using P-Graphs, a Technique Based on Coloured Petri Nets.* In Reisig, W.; Rozenberg, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications, pages 293–330. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

P-Graphs combine inhibitors Petri nets and abstract data types within the same algebraic framework. They are useful for the specification of concrete concurrent systems and in particular communication protocols. The inhibitor has been included to allow compact descriptions of systems by promoting the economy of data types. They are also necessary for the purging of resources; a common activity when modelling protocols or their services. This paper shows how to map P-Graphs to P-nets, which are Coloured Petri Nets (CP-nets) extended with place capacities and inhibitors. This is important for the analysis of P-Graph specifications, as P-nets can be transformed to CP-nets in almost all practical situations. Thus the analysis techniques of CP-nets can then be applied. Useful notation for capacities are introduced and their semantics defined in terms of the P-Graph. A notation for purging places of the tokens is also introduced. Two case studies, the Demon game and the M-Access Service of the Cambridge Fast Ring, are included to illustrate the formalism.

[14] Billington, J.; Du, B.B.; Farrington, M.: *Modelling and Analysis of Multi-Agent Communication Protocols using CP-nets.* In: Proc. 3rd Biennial Engineering Mathematics and Applications Conference (EMAC'98), Adelaide, Australia, 13-16 July 1998, pages 119–122. 1998.

[15] Bobbio, A.; Telek, M.: *Non-exponential stochastic Petri nets: an overview of methods and techniques.* In: Computer Systems Science and Engineering, Vol. 13, No. 6, pages 339–351. 1998.

The analysis of stochastic systems with non-exponential timing requires the development of suitable modeling tools. Recently, some effort has been devoted to generalize the concept of Stochastic Petri nets, by allowing the firing times to be generally distributed. The evolution of the Petri Net (PN) in time becomes a stochastic process, for which in general, no analytical solution is available. The paper surveys suitable restrictions of the PN model with generally distributed transition times, that have appeared in the literature, and compares these models from the point of view of the modeling power and the numerical complexity.

[16] Boccalatte, A.; Giglio, D.; Paolucci, M.: *An object-oriented modeling approach based on entity-relationship diagrams and Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 1347–1352. 1998.

Information systems (ISs) development process is usually characterized by several phases, among which a critical role is played by conceptual and logical design. To model static information structures, entity-relationship (ER) diagrams are probably the widespread formalism. To represent dynamic information, Petri nets are a flexible formalism as they are able to model processes from an aggregate point of view to a very detailed one. The purpose of this work is to try to integrate these two different formalisms in order to allow an automatic translation of conceptual models of process into a relational structure. Then, the functionality of an RDBMS could be extended by including in the relational database also a representation of dynamic information, and allowing the RDBMS to directly control the process execution.

[17] Boel, R.; Bordbar, B.; Stremersch, G.: *Controlled timed Petri nets: equivalence relations, model reduction.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 674–679. 1998.

This paper discusses controlled timed Petri net models for the formal synthesis of supervisory controllers for real time discrete event systems (e.g., communication protocols, supervisors for FMSs, control for batch processes). The standard Petri net formalism is extended with firing delays between the time a transition becomes state enabled, and the time it is executed. These firing delays are partly controllable between lower and upper bounds. The goal is to guarantee that certain forbidden distributions of tokens will never occur. The influencing net, corresponding to forbidden sets, is defined for this purpose. Deciding whether a maximally permissive controller exists, and if yes, constructing such a controller, requires solving large sets of linear inequalities over firing times in this influencing net. Hence, some equivalence relations between different subnets of a timed Petri net can be helpful in reducing this set. An example shows that replacing a subnet by a simpler equivalent subnet can significantly reduce the size of the sets of inequalities to be solved.

[18] Bolognesi, T.; Accordino, F.: *A layer on top of PROLOG for composing behavior constraints.* In: Software Practice and Experience, Vol. 28, No. 13, pages 1415–1435. 1998.

The paper proposes an enrichment of the Prolog language based on the introduction of explicit notions of state variables and, most notably, of actions. The extended language, called co-notation, supports the formal, executable description of a wide variety of systems in a so-called 'constraint-oriented style': system behaviors are described as hierarchical compositions of constraints on actions and state variables. Explicit action ordering constraints are represented as Petri nets. Constraint composition is also reminiscent of process composition in process algebra, but encompasses interaction both by rendezvous and by shared variables.

[19] Brat, G.P.; Garg, V.K.: *Analyzing nondeterministic real-time systems with (max,+) algebra.* In: Proc. Real-Time Systems Symposium, 2-4 December 1998, Mardid, Spain, pages 210–219. 1998.

The paper describes a hierarchical technique that allows a class of nondeterministic timed Petri nets to be analyzed using the (max,+) algebra of periodic signals. It is shown that the timing and controllability analysis of such systems is possible via the use of (sup- and) inf-convolution operations within the (max,+) framework. This technique is applied to the verification of timing constraints in an intelligent structural control system and the proposed approach is compared with other modeling tools for real-time systems.

[20] Chang, N.; Kwon, W.H.; Park, J.: *Hardware implementation of real-time Petri-net-based controllers.* In: Control Engineering Practice, Vol. 6, No. 7, pages 889–895. 1998.

This paper presents an implementation method for high-speed Petri-net-based controllers for time-critical control with parallelism, based on look-up tables. Unlike microprocessor-based software implementations, the method is based on hardware, and offers enough speed to control fast plants at low cost. The method is easily able to accommodate more complex control problems than hardwired implementations. The data structure and execution module are composed of common memory devices and simple logic gates. A modified matrix-based data structure, named the bi-column matrix-based data structure, is suggested. It has a regular form but retains the efficiency of list-based data structures. A sub-class of Petri nets is defined in order to fit Petri nets to the bi-column matrix-based data structure, and conversion to Petri nets of the sub-class is described. The matrix framework enables pipelined execution, which increases the performance in an efficient way. An event-driven evolution scheme is proposed as well, to enhance response time. This method is demonstrated by an implementation using a Xilinx 4000 series LCA. An example illustrates that the Petri-net-based controller is useful in a high-speed supervisor-control problem.

[21] Chen, H.X.: *Net structure and control logic synthesis of controlled Petri nets.* In: IEEE Trans. on Automatic Control, Vol. 43, No. 10, pages 1446–1450. 1998.

Control logic synthesis of discrete-event systems is considered in this paper in the setting of controlled Petri nets. The problem is to find a control policy that restricts the behavior of a controlled Petri net so that a collection of forbidden state conditions is satisfied. S-decreases are introduced as a tool for the control synthesis. The S-decreases are weight vectors defined on the places of a net such that the weighted sum of tokens in the net never increases with any transition firing. On the basis of S-decreases, the authors propose an efficient

method for the synthesis of the maximally permissive state feedback control policy for a class of controlled Petri nets whose uncontrolled subnets are forward and backward conflict-free nets. This method upgrades all integer linear programming-based methods for which the authors only require solving much simpler linear programming problems to determine maximally permissive controls.

[22] CHO, Y.C.; KWON, W.H.: *On forbidden state problems in a general class of non-ordinary controlled Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 90–95. 1998.

A new method is proposed for solving the forbidden state problem in a general class of non-ordinary controlled Petri nets (NCPNs). A concept of step-aligned subnets is introduced to handle the behavior of reachable markings in NSPNs. In addition, the step-alignment algorithm is developed to transform any loop-free subnets into step-aligned subnets. New procedures called the step-evaluation method and the forbidden condition reduction algorithm (FCRA) are developed to efficiently check admissible/boundary conditions given forbidden conditions and to reduce the computational complexity.

[23] CHO, Y.C.; MOON, H.J.; KWON, W.H.: *On state avoidance policies for nonordinary controlled Petri nets with uncontrollable transitions.* In: IEICE Trans. on Fundamentals of Electronics, Communications and Computer Science, Vol. E81-A, No. 11, pages 2426–2432. 1998.

In this paper, a new method is proposed for solving forbidden state problems in non-ordinary controlled Petri nets (NCPNs) with uncontrollable transitions. Using a precedence subnet and a boundary subnet with decision-free properties, the behavior of markings are analyzed structurally. An efficient algorithm is presented for calculating the number of total tokens in forbidden places reachable from a marking. This paper derives necessary and sufficient conditions for identifying admissible markings and boundary markings in terms of the precedence subnet and the boundary subnet.

[24] CHRISTENSEN, S.; PETRUCCI, L.: *How to determine and use place flows in colored Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 66–71. 1998.

The theory behind the notions of place invariants and place flows for colored Petri nets has been known since 1980, but the lack of tool support entails that the practical use of these results has been very limited. The aim of this paper is to help bridging the gaps between the theory and tool support related to place flows. There are three related problem areas to address: finding place flows from the structure and inscriptions of CP-nets, showing how the place flows determine place invariants, and finally finding properties of CP-nets from place invariants. The paper shows how checking that a set of weights determines a place flow can be formulated as a lambda-expression rewriting problem, allowing us to use the whole set of techniques developed inside the field of lambda calculus. It is also shown how these techniques can be used to prove properties such as deadlock freeness.

[25] CIARDO, G.; LI, G.: *Efficient approximate transient analysis for a class of deterministic and stochastic Petri nets.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 34–43. 1998.

Transient analysis of non-Markovian stochastic Petri nets is a theoretically interesting and practically important problem. The paper presents a new method to compute bounds and an approximation on the average state sojourn times for a special class of deterministic and stochastic Petri nets (DSPNs). In addition to the idea of the subordinated Markov chain traditionally used for the stationary solution of DSPNs, the proposed algorithm makes use of concepts from renewal theory. An application to a finite-capacity queue with a server subject to breakdowns is included.

[26] COLOMBO, A.W.: *Development and Implementation of Hierarchical Control Structures of Flexible Production Systems Using High-Level Petri Nets.* Pages 1–216. Dissertation. Fertigungstechnik / University Erlangen-Nürnberg — Bamberg: Meisenbach Verlag, 1998. ISBN 3-87525-109-1.

This work describes an H-L-PN-based approach for development of Flexible Production Systems (FPS) that comprises a new control- and monitoring-concept. Opposite to other solutions, a designed, modelled and validated FPS can be controlled directly through data exchange between H-L-PN-based model and production system, and through information exchange between H-L-PN-based model and overlapped control levels (real-time decisions and/or planning level). The usage of such complete platform-independent and -configurable models of the systems and their control structures makes possible important saves of time and costs.

[27] COOK, J.E.; WOLF, A.L.: *Event-based detection of concurrency.* In: Proc. ACM SIFSOFT 6-th Int. Symp. on the Foundations of Software Engineering, 3-5 November 1998, Lake Buena Vista, FL, Vol. 23, pages 35–45. 1998.

Petri nets are used in this paper as models of concurrent processes. A technique is presented to discover patterns of concurrent behavior from traces of system events. The techniques is based on a probabilistic analysis of the event traces. Using metrics for the number, frequency, and regularity of event occurrences, a determination is made of the likely behavior being manifested by the system. The technique is useful in a wide variety of software engineering tasks, including architecture discovery, reengineering, user interaction modeling, and software process improvements.

[28] COVES, C.; CRESTANI, D.; PRUNET, F.: *Design and analysis of workflow processes with Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 101–106. 1998.

This paper aims to model workflow processes and to analyze them. From an enterprise model, the workflow processes are automatically translated into an equivalent Petri net which allows the check properties of good behavior. Thus, it is possible to verify the models and to detect some process problems in the enterprise.

[29] COVES, C.; CRESTANI, D.; PRUNET, F.: *How to manage coverability graphs construction: an overview.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 541–546. 1998.

To analyze the behavior of Petri nets, the reachability graph permits to verify qualitative properties. However, even for small nets, the reachability graph can become infinite if the analyzed Petri net is unbounded. So, to deal with the state space explosion problem, the coverability graph must be used. This paper aims to expose the main ways of constructing coverability graphs and specifies how some qualitative properties can be checked using these different approaches.

[30] DARONDEAU, P.: *Deriving unbounded Petri nets from formal specifications.* In: Lecture Notes in Computer Science, Vol. 1466: Concurrency Theory (CONCUR'98), pages 533–548. Springer-Verlag, 1998.

The paper proposes procedures based on regions for two problems on pure unbounded Petri nets with injective labeling. One problem is to construct nets from incomplete specifications, given by pairs of regular languages that impose respectively upper and lower bounds on the expected behaviors. The second problem is to derive equivalent nets from deterministic pushdown automata, thus exhibiting their hidden concurrency.

[31] DE FARIAS, G.F.; TURNELL, M.F.Q.V.: *Modeling the user interface of an industrial system in colored Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 44–48. 1998.

Industrial systems human interfaces deal with high volumes of information on the plant, some of which with hard deadlines. This paper focuses on modeling the human interface component of industrial systems using colored Petri nets (CPNs). A set of objects and functions typical for the industrial user interfaces were selected to be part of the model. The resulting CPN industrial interface model should be easily expanded and integrated into an industrial plant's model.

[32] DE MICHELIS, G.; ELLIS, C.A.: *Computer Supported Cooperative Work and Petri Nets.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

This paper takes a look at the past, present, and potential future of workflow technology and of the role of Petri Nets in it. The authors reflect upon experiences building and deploying "office information systems" at Xerox PARC during the 1970s; progress on flexible groupware systems and models during the 1980s; and the state of the art in the 1990s. This document briefly discusses ongoing research, and work that needs to be done to prevent a repetition of the past failures.

[33] DE SOUSA, M.R.F.; TURNELL, M.F.Q.V.: *User interface evaluation based on colored Petri nets modeling and analysis.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 1127–1132. 1998.

This paper proposes the modeling and analysis of computer user interfaces using colored Petri nets (CPNs). It presents a case study in which a user interface is modeled and analyzed using a computational tool Design/CPN. The results of the analysis are discussed based upon the verification of the properties of the nets.

[34] DEAVOURS, D.D.; SANDERS, W.H.: *'On-the-fly' solution techniques for stochastic Petri nets and extensions.* In: IEEE Trans. on Software Engineering, Vol. 24, No. 10, pages 889–902. 1998.

High-level modeling representations, such as stochastic Petri nets, frequently generate very large state spaces and corresponding state-transition-rate matrices. This paper proposes a new steady-state solution approach that avoids explicit storing of the matrix in memory. This method does not impose any structural restrictions on the model, uses Gauss-Seidel and variants as the numerical solver, and uses less memory than current state-of-the-art solvers. An implementation of these ideas shows that one can realistically solve very large, general models in relatively little memory.

[35] DENG, Y.; WANG, J.; SINHA, R.: *Integrated architecture modeling of real-time concurrent systems with applications in FMS.* In: Proc. of the 10th Int. Conf. on Software Eng. and Knowledge Eng., June 18-20, 1998, pages 34–43. 1998.

A Real-time Architectural Specification (RAS) model and its application in the modeling of flexible manufacturing system (FMS) are presented. An FMS is a typical real-time concurrent system. The growing demand for higher performance and flexibility in these systems and the interlocking factors of concurrency, deadline-driven activities, and real-time decision making pose a significant challenge in FMS design, especially in terms of control and scheduling. A formal engineering approach that helps handle the complexity and dynamics of FMS modeling, design and analysis is needed. RAS combines mature Time Petri nets and Real-Time Computational Tree Logic to form an integrated system model for architectural specification and analysis of real-time concurrent systems such as FMS.

[36] DENG, Y.; YANG, C.-R.: *Architecture-driven modeling of real-time concurrent systems with applications in FMS.* In: Journal of Systems and Software, Vol. 45, No. 1, pages 61–78. 1998.

Petri nets have become increasingly popular for flexible manufacturing system (FMS) modeling and control because they accurately capture the concurrent, non-deterministic and time-dependent properties of the systems. While offering many advantages, conventional Petri net models suffer from some serious problems that limit their usability as design models for complex FMSs. Central to these problems is the lack of an engineering support for incremental design, refinement and analysis of large-scale systems. This paper presents and architecture-driven approach for the modeling and design of FMSs that effectively addresses the problems while leveraging the strengths of Petri nets. The approach has two major aspects. The first is the net-based and object-based architectural model (NOAM) that introduces a well-founded architectural framework into the Petri net notation and lays a foundation to support formal design. The second is a modeling method based on NOAM that uses architecture decomposition and refinement as the basis to reduce design complexity, to provide smooth transition from informal to formal design, and to support incremental refinement and analysis. A case study is provided.

[37] DESEL, J.: *Basic Linear Algebraic Techniques for Place/Transition Nets:* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 257–308. Springer-Verlag, 1998.

Linear algebraic techniques for place/transition nets are surveyed. In particular, place and transition invariant vectors and their application to verification, proof and analysis of behavioral properties of marked Petri nets are presented. The considered properties are the non-reachability of a marking and conditions that hold true for all reachable markings. In addition, it is shown how the rank of the incidence matrix implies sufficient criteria and necessary criteria for liveness of bounded marked Petri nets.

[38] DESEL, J.: *Petrinetze, lineare Algebra und lineare Programmierung: Analyse, Verifikation und Korrektheitsbeweise von Systemmodellen.* Pages 1–133. Teubner-Texte zur Informatik, Vol. 26 — Leipzig: B.G.Teubner Verlagsgesellschaft, 1998. In German.

This book explains a variety of state-of-the-art analysis methods for Petri nets, that are based on the incidence matrix of a net. It is shown in which ways net properties are related to integral or fractional solutions of linear equations or inequations.

[39] DESEL, J.; REISIG, W.: *Place/Transition Petri Nets.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 122–173. Springer-Verlag, 1998.

This contribution provides an introduction to the theory of place/transition Petri nets. Topics include the sequential and the concurrent behavior of place/transition Petri nets, marking graphs and coverability trees, and some analysis techniques that are based on the structure of place/transition Petri nets.

[40] DEUSSEN, P.: *Algorithmic Aspects of Concurrent Automata.* In: Workshop on Concurrency, Specification & Programming (CSP '98), Berlin, September 1998, pages 39–50. 1998. ISSN 0863-095.

Partial order semantics of Petri nets have a long history. In this paper, we describe a formalism which combines partial order semantics with the usual notion of markings of a Petri net. We call this formalism concurrent automata. We present a generation algorithm for concurrent automata. We show that our algorithm is correct in the sense of semi language equivalence: The generated automaton recognizes essentially the same set of semiwords as the associated Petri net.

[41] DEUSSEN, P.: *Concurrent Automata.* In 1998: Technical Report I-05. Brandenburg Technical Univ. at Cottbus, 1998.

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[42] DEVILLERS, R.; KOUTNY, M.: *Recursive nets in the box calculus.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 239–249. 1998.

This paper presents an approach to giving a formal meaning to petri nets defined using equations. It specifically addresses this problem for the box algebra, a model of concurrent computation which combines Petri nets and standard process algebra. The paper presents a detailed investigation of the solvability of recursive equations on nets in a setting which allows infinite number of possibly unguarded equations, each equation possibly involving infinitely many recursion variables. The main result is that by using a suitable partially ordered domain of nets, it is always possible to solve a system of equations by constructing the limit of a chain of successive approximations starting from a suitable, very simple net.

[43] DI MARZO SERUGENDO, G.; GUELFI, N.: *Formal development of Java based Web parallel applications.* In: Proc. 31-st Annual Hawaii Int. Conf. on System Sciences; Vol. 7: Software Technology Track, 6-9 January 1998, Kohala Coast, HI, pages 604–613. 1998.

The Java object-oriented programming language has been the subject of an important involvement from programmers and the industry, especially for applications related to the Web. The problem of a rapid penetration of Java into commercial products is related to the lack of a systematic methodology for developing parallel applications. This paper presents a formal development methodology based on the stepwise refinement of CO-OPN/2 formal specifications, using a real Web parallel application. Starting from a centralized view, the following refinement steps are presented: data distribution, behavior distribution, communication layer, and Java program. During the whole refinement process, the evolution and the verification of one specific property is studied.

[44] DI MARZO SERUGENDO, G.; GUELFI, N.: *Using objet-oriented algebraic nets for the reverse engineering of Java programs: a case study.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 166–176. 1998.

The problem addressed in this paper is the following: how to use high-level petri nets for the reverse engineering of implemented distributed algorithms. A reverse engineering methodology is presented that is applied to a real (simple) Java applet-based client/server application. First, starting from the Java program, several abstraction steps are described using the CO-OPN/2 formal specification language. Then, a brand new research is presented that studies properties preservations during a refinement process.

[45] DONATELLI, S.; FRANCESCHINIS, G.: *Modelling and Analysis of distributed Software Using GSPNs.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

This chapter discusses the role that Generalized Stochastic Petri Nets (GSPN) can play in the static analysis of distributed software. The material is organized along two main lines: the need and the advantages of studying both qualitative and quantitative aspects of a program, and the need for doing it in an automatic maimer. The role of performance evaluation in the analysis of distributed software is illustrated through a small example, classical in the qualitative approach (the dining philosophers). Although small this example allows to point out the need and the requirements of automatic translation and to discuss the main hypothesis behind program performance evaluation through GSPN models. A procedure for the automatic generation of GSPN models starting from a distributed program written in a CSP-like language, and for the definition of program performance indices in terms of GSPN ones is then given and illustrated by means of a realistic example.

[46] DONATELLI, S.; HADDAD, S.; MOREAUX, P.: *Structured characterization of the Markov chain of phase-type SPN.* In: Lecture Notes in Computer Science, Vol. 1469: Computer Performance Evaluation, pages 243–254. Springer-Verlag, 1998.

This paper presents a characterization of the Markovian state space of a stochastic Petri net with phase-type distributed transitions as a union of Cartesian products of a set of 'components' of the net. The method uses an abstract of the net based on the vectors of enabling degrees of phase-type transitions, as well as on the sets of 'interrupted clients'. Following the decomposition used for the state space characterization, a tensor algebra expression for the infinitesimal generator (actually for its rate matrix) is given, that allows the steady-state probability to be computed directly from a set of matrices of the size of the components, without the need of storing the whole infinitesimal generator.

[47] EBERT, C.: *Experiences with colored predicate/transition nets for specifying and prototyping embedded systems.* In: IEEE Trans. on Systems, Man and Cybernetics – Part B, Vol. 28, No. 5, pages 641–652. 1998.

Computer systems in today's society require an increasing amount of embedded software and hardware systems. Their application has introduced new problems for the software engineer combined with the complexity of such systems. Especially the early stages of the software development process are vital for the successful implementation of computer systems, High-order Petri nets are introduced and extended as a powerful formalism for the specification and analysis of concurrent systems. A tool called SystemSpecs has been applied that supports rapid system prototyping with such nets. This survey article provides techniques for early systems analysis that can be used as a real-time system prototype for customer presentations. Small examples are extracted from industrial applications to indicate how the described techniques can be used. While the major disadvantage of typical net descriptions is their visual complexity that makes them useless for large distributed systems, the paper also describes how to find overly complex structures, and describes selected methods of how to refine such structures.

[48] ENGELFRIET, J.; GELSEMA, T.: *Multisets and structural congruence of the pi-calculus with replication.* In: Theoretical Computer Science, Vol. 211, No. 1-2, pages 311–337. 1999.

In the pi-calculus with replication, two processes are multiset congruent if they have the same semantics in the associated multiset transition system. It is proved that (extended) structural congruence is the same as multiset congruence, and that it is decidable.

[49] ESPARZA, J.: *Decidability and Complexity of Petri Net Problems – An Introduction.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 374–428. Springer-Verlag, 1998.

A collection of 10 rules of thumb is presented that helps to determine the decidability and complexity of a large number of Petri net problems.

[50] FANNI, A.; GIUA, A.: *Discrete event representation of qualitative models using Petri nets.* In: IEEE Trans. on Systems, Man, and Cybernetics – Part B, Vol. 28, No. 6, pages 770–780. 1998.

The paper discusses how Petri nets may be used for the qualitative modeling of physical systems. The qualitative state of a system is represented by the marking of the net. The crossing of a landmark value corresponds to the firing of a transition. The paper gives a formal procedure to construct a Petri net model corresponding to a given set of qualitative equations. The approach can be used to study both autonomous systems and systems with forcing inputs. The dynamic behavior of the system can be studied as sequences of reachable markings of the net and can be computed with standard Petri net execution techniques. This approach also leads to a simple framework for the study of hybrid systems. Several examples, with applications to diagnostic and control, are fully discussed.

[51] FARRINGTON, M.; BILLINGTON, J.: *Analysing a Coloured Petri Net Model of an Assembly Line.* In: Proc. 3rd Biennial Engineering Mathematics and Applications Conference (EMAC'98), Adelaide, Australia, 13-16 July 1998, pages 193–196. 1998.

[52] FATKHI, V.A.; DOLGOPOLYI, A.V.: *Diagnostic modeling of discrete devices in the language of hierarchical Petri nets.* In: Automatic Control and Computer Sciences, Vol. 32, No. 5, pages 26–35. 1998.

The article considers procedures for modeling discrete devices in the language of hierarchical Petri nets and algorithms for controlling the technical state of discrete devices. It is based on a study of the properties of the model performed by means of cluster analysis.

[53] FELDMANN, K.; COLOMBO, A.W.: *Material Flow and Control Sequence Specification of Flexible Production Systems using Coloured Petri Nets.* In: International Journal of Advanced Manufacturing Technology, Vol. 14, No. 10: Special Issue on Petri Nets Applications in Advanced Manufacturing Systems, pages 760–774. Springer-Verlag, 1998.

Starting with the specification of each resource and the whole structure of a flexible production system, in this approach a special kind of coloured Petri nets is used for performing the modelling and the validation of the coordination control structure of the systems. In a second phase, it is proposed to modify the first models to synchronised Petri net schemas to facilitate the supervision and the interaction of the coordination model with the physical components of the system as well as the development and maintainability of the discrete-even control structures. The final result is a formal specification of coloured Petri net based coordination control of resources of the system, and logic control structures for control sequencing based on the use of synchronised sub-Petri net structures derived from the first one by refining transitions, i.e., their occurrence modes.

[54] FERRARINI, L.; MARONI, M.: *Deadlock-avoidance control for manufacturing systems with multiple capacity resources.* In: International Journal of Advanced Manufacturing Technology, Vol. 14, No. 10, pages 729–736. 1998.

his paper addresses the problem of designing a control scheme capable of avoiding deadlock conditions for a class of manufacturing systems. The considered model for the system under control is based on Petri nets, and is formulated according to well-known modeling rules. A deadlock avoidance policy is proposed which is an extension of a previously presented one. The proofs of its main properties are briefly sketched. Finally, an example of an automated manufacturing system for which such a deadlock avoidance policy has been applied is discussed.

[55] FERSCHA, A.: *Optimistic distributed execution of business process models.* In: Proc. 31-st Annual Hawaii Int. Conf. on System Sciences; Vol. 7: Software Technology Track, 6-9 January 1998, Kohala Coast, HI, pages 723–732. 1998.

For the modeling of large and complex systems of business processes, a flow oriented, graphical framework based on Petri nets has emerged, taping the potentials of a qualitative and a quantitative analysis based on one and the same model. For the qualitative analysis of business process models (BPMs), representing realistically sized enterprise organizations, traditional evaluation techniques (like discrete event simulation) tend to become practically intractable. To be able to cope with very complex models, a distributed execution mechanism based on the timed warp distributed simulation protocol has been developed. A corresponding software tool was implemented based on the MPI communication library, thus portable to almost any distributed or parallel computing platform. A whole new class of (complex) BPM simulations becomes practically tractable, and traditional simulations can be accelerated dramatically.

[56] FIORINO, H.; TESSIER, C.: *Agent cooperation: a Petri net based model.* In: Proc. 3-rd Int. Conference on Multi-Agent Systems (ICMAS'98), 3-7 July 1998, Paris, France, pages 425–426. 1998.

The purpose of this research is to devise an operating model for systems involving several naturally distributed physical entities designed to achieve a predefined collective task. Examples of such entities are surveillance robots organized in patrols, unarmed aerial vehicles (drones) supporting piloted aircraft for reconnaissance or attack missions, domain specialist involved in fault diagnosis aiding systems.

[57] FLEISCHHACK, H.; GRAHLMANN, B.: *Towards compositional verification of SDL systems.* In: Proc. 31-st Annual Hawaii Int. Conf. on System Sciences; Vol. 7: Software Technology Track, 6-9 January 1998, Kohala Coast, HI, pages 404–414. 1998.

A new method for proving qualitative properties of SDL-systems is presented in this paper. The method is based on compositional high-level Petri nets semantics for SDL. Since emphasis is laid on the modeling of dynamic creation and termination of processes and of procedures, the presented method is especially interesting for typical client-server systems. By using M-nets as the semantic model, 'state-of-the-art' verification techniques can be used. For instance, the verification component of the PEP tool may be applied. The benefit of the proposed method is shown by applying it to a typical client-server system. After describing how safety, liveness and progress properties can be checked fully automatically, examples are given to show how the compositional nature of the M-net semantics can be used to solve the 'state exploration' problem, and how interactive verification may extend the verification possibilities.

[58] FRANCESCHINIS, G.; FUMAGALLI, A.; GRASSO, R.: *Performance analysis of a WDM bus network based on GSPN models.* In: Lecture Notes in Computer Science, Vol. 1469: Computer Performance Evaluation, pages 207–218. Springer-Verlag, 1998.

Recent progress in optical technology makes it possible to design innovative high-speed network architectures. Oe possible architecture consists of a folded bus fiber in which parallel transmission channels are obtained using wavelength dividing multiplexing (WDM). Nodes connected to the bus exchange data using the channels in parallel. Signal are transmitted from the source to the destination node in an all-optical fashion, thus avoiding the bottleneck of electronic processing at the intermediate nodes. The aim of this paper is to study the performance of the WDM bus network controlled by a novel access protocol proposed in this paper. The analysis is based on two GSPN model that allow to determine the access delay of the proposed protocol and its fairness throughout the nodes. As a result, it is possible to quantitatively determine the effect that some design choices have on system fairness. The paper discusses the strength and limits of GreatSPN, the tool used to perform the analysis.

[59] FRANCESCHINIS, G.; RIBAUDO, M.: *Efficient Performance Analysis Techniques for Stochastic Well-formed Nets and Stochastic Process Algebras.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

Stochastic Well Formed Nets and Stochastic Process Algebras are high level description languages for the specification and the performance evaluation of concurrent systems. In both formalisms the performance analysis of the modelled system can be performed by generating a continuous time Markov chain of the size of the model state space: this often leads to the so called state space explosion problem which can prevent the possibility of completing the desired analysis. In this chapter we will present two state space aggregation techniques, each working on one of the two formalisms, allowing efficient performance analysis. The advantages and disadvantages of the two techniques will be discussed and compared.

[60] FREIHEIT, J.; ZIMMERMANN, A.: *Extending a Response Time Approximation Technique to Colored Stochastic Petri Nets.* In: Proc. 4th Int. Workshop on Performability Modeling of Computer and Communication Systems (PMCCS 4), pages 67–71. 1998.

For the analysis of large systems modeled with stochastic Petri nets, state explosion is a well-known problem. Many real-life systems are thus impossible to analyze. Several research activities try to overcome this limitation. Diverse approaches can be found in the literature. This paper presents an iterative approximation technique for the steady-state throughput computation of complex concurrent systems. The proposed technique makes use of the divide and conquer principle. It is derived from the response time approximation method presented by Campos, Perez-Jimenez and others. We generalize this approach to a special class of hierarchical colored stochastic Petri nets.

[61] FREY, G.; SCHETTLER, H.-G.: *Algebraic Analysis of Petri Net based Control Algorithms.* In: Proceedings of the The Fourth International Workshop on Discrete Event Systems (WODES'98), Cagliari, pages 94–96. IEE, 1998.

The algebraic analysis of Petri Nets combines structural analysis (Transition and Place-Invariants) with information about the initial marking of the net. The main advantage of algebraic analysis over graph based methods is, that the problem of state space explosion is avoided. Hence, algebraic conditions are – in most cases – easier to check for large systems. In this contribution necessary and sufficient algebraic conditions for the correctness of Petri Net based control algorithms are presented.

[62] FREYTAG, T.: *How to construct maximal conflict-free processes from Petri net simulations.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 49–54. 1998.

Partial-order semantics of a Petri net can be defined either by the set of (conflict-free) processes or by one single (and coherent) branching process. Processes are compact and usable for visualization but their systematic simulative construction is difficult and ineffective. Branching processes are an efficient data structure for storing simulation data but tend to become complex and not suitable for visualization. This contribution describes a two-step simulation method to exploit the advantages of both representations and presents an algorithm to construct the set of maximal processes embedded in a given branching process.

[63] FRICKS, R.M.; PULIAFITO, A.; TRIVEDI, K.S.: *Perfromance analysis of distributed real-time databases.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 184–194. 1998.

In a distributed process control system, information about the behavior of physical processes is usually collected and stored in a real-time database which can be remotely accessed by human operators. This paper proposes an analytical approach to compute the response time distribution of operator consoles in a distributed process control environment. The developed technique is based on Markov regenerative processes and is described with the assistance of deterministic and stochastic Petri nets. Exact models are constructed for performance analysis of centralized and decentralized database architectures. However, due to limitations on the exact solution, an approximate solution is also proposed which is then used to study response time distributions of large systems.

[64] GAETA, R.; BEGAIN, K.; AJMONE MARSAN, M.: *Stop and Go ABR in ATM LANs: performance analysis with GSPNs.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 64–75. 1998.

Generalized stochastic Petri nets (GSPNs) are used in this paper for the performance analysis of asynchronous transfer mode (ATM) local area networks (LANs) that adopt a peculiar version of the available bit rate (ABR) service category, called 'Stop and Go ABR'. This is a simplified ABR algorithm designed for the provision of best-effort services in low cost ATM LANs, according to which sources can transmit only at two different cell rates, the peak cell rate (PCR) and minimum cell rate (MCR). Results obtained from the solution of GSPN models of simple ATM LAN setups comprising Stop and Go ABR as well as UBR (unspecified bit rate) users are first validated through detailed simulation, and then used to show that Stop and Go ABR is capable of providing good performance and fairness in a number of different LAN configurations.

[65] GERMAN, R.: *Markov regenerative stochastic Petri nets with general execution policies: supplementary variable analysis and a prototype tool.* In: Lecture Notes in Computer Science, Vol. 1469: Computer Performance Evaluation, pages 255–266. Springer-Verlag, 1998.

Stochastic Petri nets (SPNs) with general firing time distributions are considered in this paper. The generally timed transitions can have general execution policies: the preemption policy may be preemptive repeat different (prd) or preemptive resume (prs), and the firing time distribution can be marking-independent or marking-dependent through constant scaling factors. A stationary analysis method covering all possible combinations is presented by means of supplementary variables. The method is implemented in a prototype tool based on Mathematica. An example illustrates the analysis method and the use of the tool.

[66] GEROGIANNIS, V.C.; KAMEAS, A.D.; PINTELAS, P.E.: *Comparative study and categorization of high-level Petri nets.* In: Journal of Systems and Software, Vol. 43, No. 2, pages 133–160. 1998.

The graphical formalism of Petri nets (PNs) is established on a strong mathematical foundation that can be applied in systems specification, analysis and verification. However, classical (low-level) models suffer from the state explosion problem as resulting PNs become large. Thus, their ability to represent and analyze large-scale realistic systems is reduced. High-level PNs have been introduced in order to extend the modeling power of low-level models. This paper presents an assessment of high-level PNs from an engineering perspective. A set of categories is proposed for classifying several extensions presented in the literature. Models which belong to the same category are compared by discussing the formalism, the descriptive power in the inherent limitations of each. All categories are compared using a set of general criteria including compactness, ease of analysis, degree of supporting refinement/abstraction and specifying communication. The modeling power of representative models of each category is discussed be presenting illustrative application examples.

[67] GILL, M.R.; DICESARE, F.: *A portable framework for distributed simulation of colored stochastic Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 61–65. 1998.

This paper describes the development of a Java-based simulator which has the capability to perform distributed simulation of colored stochastic Petri nets. The design specifics are presented, along with initial results using a single processor. This simulator is built based on algorithms which were developed to combine the race condition of stochastic Petri nets and the additional modeling convenience of colored Petri nets. Distributed simulation capabilities are being added to these tools, using inexpensive workstations connected solely by low cost LAN equipment. The new simulation software supports even more computing platforms than previous work, utilizing SUN Microsystem's Java to achieve processor and operating system portability. Future work is discussed, including development of new automatic partitioning and synchronization methods, which should yield significant improvements when simulating large colored Petri net models.

[68] GONCHAROV, M.V.; KLOTCHKOV, I.V.; SMIRNOV, A.B.; STARODOUBTSEV, N.A.: *Timing extensions of STG model and a method to simulate timed STG behavior in VHDL environment.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 120–129. 1998.

This paper includes an overview of the signal transition graph (STG) model extensions that make it possible to specify switching and signal propagation delays in an STG. Extended STGs are Petri nets with timed places and timed transitions. The correspondence of the STG timing models to the implementation of asynchronous circuits is studied. A method to simulate the behavior specified by consistent and bounded timed STG in VHDL environment is proposed. For illustration, a possible use of the VHDL-based STG representation in asynchronous circuit design is discussed.

[69] GORDON, S.; BILLINGTON, J.: *Modelling and Analysis of an Air-to-Air Missile Engagement Simulator using Coloured Petri Nets.* In: Proc. 3rd Biennial Engineering Mathematics and Applications Conference (EMAC'98), 13-16 July 1998, pages 225–228. 1998. Adelaide, Australia.

[70] GRODE, J.; MADSEN, J.: *A unified component modeling approach for performance estimation in hardware/software codesign.* In: Proc. 24-th EUROMICRO Conference, 25-27 August 1998, Vasteras, Sweden, Vol. 1, pages 65–69. 1998.

This paper presents an approach to abstract modeling of hardware/software architectures using hierarchical colored Petri nets. The approach is able to capture complex behavioral characteristics often seen in software and hardware architectures, thus it is suitable for high-level codesign issues such as performance estimation. In this paper, the development of a model of the ARM7 processor is described to illustrate the full potential of the modeling approach. To further illustrate the approach, a cache model is also described. The approach and related tools are currently being developed in the LYCOS system.

[71] HANISCH, H.-M.; THIEME, J.; LAUTENBACH, K.; SIMON, C.: *Timestamp nets in technical applications.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 119–124. 1998.

Timestamp Petri nets, introduced in this paper, offer a new method to deal with time critical problems in the field of automation of manufacturing systems. The each token in a timestamp net, a timestamp is assigned, which denotes the time when the token was put on its place. In those nets, intervals are assigned to the incoming arcs of transitions, which describe the permeability of the arc relative to the token on the adjacent place. In timestamp nets it is possible that synchronizing transitions are not able to fire although they are supplied with tokens sufficiently, because their incoming arcs are not permeable simultaneously. In this case the transition is said to be timewise stuck. This paper examines how transitions of a timestamp net are getting timewise stuck. Based on a symbolic analysis, these investigations can be reduced to solving systems of linear inequalities. The method can also be used to determine parameters for a timestamp net in order to prevent transitions from getting timewise stuck. The paper shows the method's applicability by the dynamic model of a small technical plant as an example. Forbidden states of the uncontrolled system are described by transitions which can get timewise stuck. The method is used to determine time parameters of a controller, which ensures that forbidden states in the controlled system are unreachable.

HAVERKORT, B.R.: *Performance of Computer-Communication Systems.* Pages 1–515. John Wiley and Sons, 1998. Web site at `http://www-lvs.informatik.rwth-aachen.de/pccs/`.

The 18 chapters of the book comprise a very wide overview of modern performance evaluation techniques and shows their applicability for the evaluation of computer and communication systems. The emphasis in the book is on the problem-solving capabilities of the models, rather than on the mathematical aspects; the models are used to understand the operation of systems. This fact plus the about 100 exercises make the book very well suited for courses on performance evaluation.

Among the techniques covered are: Little's law, stochastic processes, birth-death queueing systems, M|G|1, G|M|1, G|G|1 and PH|PH|1 queueing models, cyclic server models, open and closed queueing network models with and without load-dependent service rates (including the MVA and convolution method), BCMP networks and the QNA method, stochastic Petri nets, numerical analysis of Markov chains (steady-state and transient) and stochastic Petri nets with matrix-geometric solution, simulation techniques and the statistical evaluation of simulations. Among the applications covered are: multiprogramming systems, ATM multiplexers with complex schedulers, central server systems, token ring systems (IBM and FDDI), connection management systems in ATM, packet-switched communication networks, reliability studies.

HE, X.: *Transformations of hierarchical predicate transition nets: refinements and abstractions.* In: Proc. 22-nd Annual Int. Computer Software and Applications Conf. (COMPSAC-98), 19-21 August 1998, Vienna, Austria, pages 164–169. 1998.

In this paper, a set of useful refinement rules on hierarchical predicate/transition nets (HPrTNs) is presented. These rules help a user to develop a large HPrTN in a stepwise approach, supporting both top-down and bottom-up development styles. Furthermore, it is shown that these rules either preserve or facilitate the verification of many system behavioral properties. Another nice feature of these rules is that their applications always result in a valid partial view and an extended and integrated definition of the original HPrTN. Related work on refinement techniques based on Petri nets and other specification methods are also described.

HEINER, M.: *Petri Net Based System Analysis without State Explosion.* In: Proc. High Performance Computing '98, Boston, April 1998, pages 394–403. San Diego: SCS Int., 1998. ISBN 1-56555-145-1.

Among those Petri net analysis techniques suitable for strong verification purposes there is an increasing amount of promising methods avoiding the construction of the complete interleaving state space, and by this way the well-known state explosion problem. These alternative approaches are summarized and compared with each other: structural analysis, integer programming, compressed and composite state space representations, lazy state space constructions, and partial order representations. The main lesson learned is that the different methods do not compete, but complement each other. Finally, objectives of an open integrated tool box to support Petri net based dependability engineering are outlined.

HEINER, M.; MENZEL, T.: *A Petri Net Semantics for the PLC Language Instruction List.* In ITALY, AUGUST 1998: Proc. IEE Workshop on Discrete Event Systems (WODES '98), Cagliari, pages 161–165. 1998. ISBN 0-85296-710-1.

In this paper we describe a Petri net semantics of the PLC language Instruction List (IL) defined in IEC 1131-3. This is a necessary prerequisite to be able to analyse functional and especially safety requirements of IL programs. We introduce a subset of IL (IL0) and give formal definitions as reference semantics for this subset. After this, the reference semantics is transformed into a Petri net model.

6] HEINER, M.; MENZEL, T.: *Instruction List Verification Using a Petri Net Semantics.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 716–721. 1998. ISBN 0-7803-4778-1/98.

In order to adapt a Petri net based verification framework to programmable logic controllers, a Petri net semantics is introduced formally for a subset of the standardized Instruction List language (IEC 1131-3). For that purpose, the subset's syntax as well as static and operational semantics are specified strictly. Having that, the operational reference semantics is substituted by an equivalent Petri net semantics. Due to this prudent practice, the equivalence proof of the substitution step is obvious.

7] HIRASAWA, K.; OHBAYASHI, M.; SAKAI, S.; HU, J.: *Learning Petri network and its application to nonlinear system control.* In: IEEE Trans. on Systems, Man, and Cybernetics - Part B, Vol. 28, No. 6, pages 781–789. 1998.

According to recent knowledge of brain science, it is suggested that there exists 'functions distribution', which means that specific parts exist in the brain to realize specific functions. This paper introduces a new brain-like model called learning Petri network (LPN) that has the capability of functions distribution and learning. The idea is to use Petri net to realize the functions distribution and to incorporate the learning and representing ability of neural network into the Petri net. The obtained LPN can be used in the same way as a neural network to model and control dynamic systems, while it is distinctive to a neural network in that it has the capacity of functions distribution. An application of the LPN to nonlinear crane control systems is discussed. It is shown via numerical simulations that the proposed LPN controller has superior performance to the commonly used neural network one.

[78] HUANG, J.S.; MURATA, T.: *A Constructive Method for Finding Legal Transition Sequences in Petri Nets.* In: Journal of Circuits, Systems and Computers, Vol. 8, No. 1, special issue on Selected Topics in Petri nets, pages 189–222. 1998.

[79] HUSBERG, N.: *Verifying SDL programs using Petri nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 208–213. 1998.

The use of an SDL front-end Emma generating models for the PROD predicate/transition net reachability analyzer is presented and the practical problems in industrial applications are discussed. The new modular analyzer Maria is also presented.

[80] JENG, M.D.; CHEN, S.C.: *Heuristic search based on Petri net structures for FMS scheduling.* In: IEEE Trans. on Industry Applicatiions, Vol. 35, No. 1, pages 196–202. 1999.

A heuristic search method using Petri net structures for flexible manufacturing system (FMS) scheduling is presented. To minimize makespan, an FMS scheduling problem is formulated as finding a firing sequence from the initial state to the final state of a timed Petri net model, such that the sequence reveals the minimal cost. The reachability graph is partially generated and searched. The search process is guided by a heuristic function based on firing count vectors of the state equation, predicting the total cost. Since this heuristic search exploits the linear characteristics of the state equation, which contains sufficient global information, it can efficiently generate a near-optimal or optimal solution. To deal with large systems, the proposed algorithm exploits the concurrency information to reduce the searched state space.

[81] JENG, M.D.; PENG, M.Y.: *Augmented reachability trees for 1-place unbounded generalized Petri nets.* In: IEEE Trans. on Systems, Man, and Cybernetics – A, Vol. 29, No. 2, pages 173–183. 1999.

An augmented reachability tree (ART) is proposed to extend the capability of the classical reachability tree (RT) for analyzing qualitative properties, such as liveness, of a class of unbounded generalized Petri nets, called 1-place unbounded nets, where there is at most one unbounded place for each net. The idea is based on the computation fo the minimal marking for each node in the tree. An algorithm for obtaining the minimal marking is given. Examples are included to illustrate the technique. In addition to liveness, the proposed method can verify other properties such as reversibility and feasible firing sequences. Furthermore, properties verifiable by RT are also verifiable by ART.

[82] JENSEN, K.: *An Introduction to the Practical Use of Coloured Petri Nets.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

The paper focuses on the practical use of Coloured Petri Nets. It introduces the basic ideas behind the CPN language, and it illustrates how CPN models can be analysed by means of simulation, state spaces and condensed state spaces. The paper also describes how CP-nets can be extended with a time concept. In this way it is also possible to use CP-nets for performance evaluation, i.e., to evaluate the speed by which a system operates. Finally, we describe a set of computer tools that support the use of CP-nets. This tool set is used by more than three hundred organisations in forty different countries – including seventy-five commercial companies. It is available free of charge, also for commercial use.

[83] JOHNSSON, C.; ARZEN, K.-E.: *Grafchart for recipe-based batch control.* In: Computers and Chemical Engineering, Vol. 22, No. 12, pages 1811–1828. 1998.

The paper presents how Grafchart, a toolbox based on Grafcet, object-oriented programming ideas and high-level Petri nets, can be used to implement a batch control recipe execution and recipe representation system. A brief overview of Grafchart is given and it is shown how its concepts fit the models defined in the recent ISA batch control standard S88.01. A simulated batch process cell scenario is presented together with several alternative ways of representing batch recipes.

[84] JONES, A.H.; UZAM, M.: *A Formal Technique for the Synthesis of Petri Net Supervisors for Discrete Event Systems.* In: Proceedings of the International Conference on Control (CONTROL'98), Swansea, UK, September 1-4, 1998, pages 845–852. University of Wales, 1998.

In this paper a formal technique for the synthesis of Petri-net-based supervisors for Discrete Event Systems is proposed to solve the forbidden state problem. The solution has close parallels to the Finite State Machine

approach proposed by Ramadge and Wonham. The technique thus provides a Petri net equivalent method to act as further stimulus to solving the synthesis of supervisory control problems. The methodology is explained in detail by considering a discrete manufacturing system.

] JUAN, E.Y.T.; TSAI, J.J.P.; MURATA, T.: *Compositional verification of concurrent systems using Petri net based condensation rules.* In: ACM Trans. on Programming Languages and Systems, Vol. 20, No. 5, pages 917–979. 1998.

The state explosion problem of formal verification has obstructed its application to large-scale software systems. This paper introduces a set of new condensation theories: IOT-failure equivalence, IOT-state equivalence, and firing-dependence theory to cope with this problem. The proposed condensation theories are much weaker than current theories used for the compositional verification of Petri nets. More significantly, the proposed condensation theories can eliminate the interleaved behaviors caused by asynchronously sending actions. Therefore, the proposed technique provides a much more powerful means for the compositional verification of asynchronous processes. This technique can efficiently analyze several state-based properties: boundedness, reachable markings, reachable submarkings, and deadlock states. Based on the notion of the proposed theories, a set of condensation rules is developed for efficient verification of large-scale software systems. The experimental results show a significant improvement in the analysis of large-scale concurrent systems.

6] KLEMPIEN-HINRICHS, R.: *Net refinement by Pullback Rewriting. Asymmetric Event Structures.* In NIVAT, M.: Lecture Notes in Computer Science, Vol. 1378: Proceedings of 5th Intern. Conf. on Foundations of Software Science and Computation Structures (FOSSaCS'98) held as part of the Europ. Conf. on Theory and Practice of Software, ETAPS'98 in Lisbon, Portugal, pages 190–202. Springer, 1998.

The theory of graph grammars is concerned with the rule-based transformation of graphs and graph-like structures. As the formalism of Petri nets is founded on a particular type of graphs, the various net refinement methods proposed for their structured design are in particular graph transformations. This paper aims at applying a recently developed technique for graph rewriting, the so-called pullback approach, to describe net refinement. The translation of the this technique, which is based on (hyper)graph morphisms, into terms of net morphisms yields a well-defined mechanism closely related to pullback rewriting in hypergraphs. A variant allows to elegantly characterize a particular net refinement operation which modifies the context of the refined transition.

7] KOMENDA, J.; ELMOUNDI, A.; ZERHOUNI, N.: *The use of conventional and minplus algebra for the modeling of hybrid Petri nets.* In: Cybernetics and Systems, Vol. 29, No. 8, pages 869–884. 1998.

In this paper we are interested in a mathematical description of the class of hybrid systems, which can be modeled by hybrid Petri nets (HPNs). A state space model using conventional algebra for the continuous subsystem and minplus algebra for the discrete subsystem is given. The interface between the discrete and continuous part appears in our model. This model is illustrated through an example. We introduce the concept of discrete control of HPNs.

8] KONDRATYEV, A.; CORTADELLA, J.; KISHINEVSKY, M.; LAVAGNO, L.; TAUBIN, A.; YAKOVLEV, A.: *Identifying state coding conflicts in asynchronous system specification using Petri net unfoldings.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 152–163. 1998.

State coding conflict detection is a fundamental part of synthesis of asynchronous concurrent systems from their specifications as signal transition graphs (STGs), which are a special king of labeled Petri nets. The paper develops a method for identifying state coding conflicts in STGs, that is intended to work within a new synthesis framework based on Petri net unfolding. The latter offers potential advantages due to a partial order representation of highly concurrent behavior as opposed to the more traditional construction of a state graph, known to suffer from combinatorial expansion. A necessary condition for coding conflicts to exist is developed by using an approximate state covering approach. Being computationally easy, yet conservative, such a solution may produce fake conflicts. A technique for refining the latter, with extra computational cost, is provided.

89] KORIEM, S.M.: *Fast and simple decomposition techniques for the reliability analysis of interconnection networks.* In: Journal of Systems and Software, Vol. 45, No. 2, pages 155–171. 1998.

To study and analyze the reliability of complex systems such as multistage interconnection networks (MINs) and hierarchical interconnections networks (HINs), this paper proposes two analytical decomposition techniques for computing (approximately) the transient state space solution of large stochastic Petri net (SPN) models of MINs and HINs. In the first technique, a large scale SPN model is partitioned into smaller submodels. These submodels are compressed and combined to calculate the entire net. The second approach uses the topological properties of HINs to build an SPN generic modeling methodology to aid the reliability evaluation of different HIN configurations. It has been shown that the proposed techniques give results quite close to those obtained by the exact method with an enormous saving in computation time and memory usage.

[90] Kostin, A.E.; Tchoudaikina, S.A.: *Yet Another Reachability Algorithm for Petri Nets.* In: SIGACT News, Vol. 29, No. 4, pages 98–110. 1998.

A new algorithm for the determination of a marking in generalized Petri nets is proposed. The algorithm is based on the matrix-equation approach. Given a Petri net, a so called complemented Petri net is created that consists of the given Petri net and a complementary transition with input and output places depending on the initial and target markings of the given Petri net. Then the reachability task is reduced to the investigation of T-invariants of the complemented Petri net. Using a technique of search for T-invariants, the algorithm determines minimal-support T-invariants, that include the complementary transitions, and then calculates the finite set of their linear combinations. For each T-invariant, the algorithm tries to create sequentially all reachability paths from the given initial marking to the target marking or determines that there are no such paths at all. During the creation of the reachability paths, the algorithm needs memory only for storing the reachability path being created. If it is sufficient to determine only one firing sequence transforming the initial marking into the target one, then the algorithm may be terminated after successful creation of the first reachability path.

[91] Koutny, M.; Best, E.: *Operational and denotational semantics for the box calculus.* In: Theoretical Computer Science, Vol. 211, No. 1-2, pages 1–83. 1998.

This paper describes general theory underpinning the operational semantics and the denotational Petri net semantics of the box algebra including recursion. For the operational semantics, inductive rules for process expressions are given. For the net semantics, a general mechanism of refinement and relabeling is introduced, using which the connectives of the algebra are defined. The paper also describes a denotational approach to the Petri net semantics of recursive expressions. A domain of nets is identified such that the solution of a given recursive equation can be found by fixpoint approximations from some suitable starting point. The consistency of the two semantics is demonstrated. The theory is generic for a wide class of algebraic operators and synchronization schemes.

[92] Kun, L.J.: *Work in process (WIP) analysis of the flexible manufacturing system using time Petri net unfolding.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 136–141. 1998.

This paper suggests a WIP (work in process) of FMS analysis methods based on the TPN (time Petri net) unfolding. Unfolding of PN is a partial order based method for the verification of concurrent system without the state space explosion. The aim of this work is to formulate the general cyclic state scheduling problem to minimize the WIP to satisfy economical constraints. The method is based on unfolding of the original net into the equivalent acyclic description.

[93] Lee, E.A.; Sangiovanni-Vincentelli, A.: *A framework for comparing models of computation.* In: IEEE Trans. on Computer-Aided Design of Integrated Circuits and Systems, Vol. 17, No. 12, pages 1217–1229. 1998.

We give a denotational framework (a meta model) within which certain properties of models of computation can be compared. It describes concurrent processes in general terms as sets of possible behaviors. The framework is used to compare certain essential features of various models of computation, including Kahn process networks, dataflow, sequential processes, concurrent sequential processes with rendezvous, Petri nets, and discrete-event systems.

[94] Lee, W.J.; Cha, S.D.; Kwon, Y.R.: *Integration and analysis of use cases using modular Petri nets in requirements engineering.* In: IEEE Trans. on Software Engineering, Vol. 24, No. 12, pages 1115–1130. 1998.

In this paper, we propose the Constraints-based Modular Petri Nets(CMPNs) approach as an effective way to formalize the informal aspects of use cases. CMPNs, an extension of Place/Transition nets, allow the formal and incremental specification of requirements. The major contributions of our paper, in addition to the formal definitions of CMPNs, are the development of a systematic procedure to convert use cases stated in natural language to a CMPN model and a set of guidelines to find inconsistency and incompleteness in CMPNs. We demonstrate an application of our approach using use cases developed for telecommunications services.

[95] Liu, Z.: *Performance analysis of stochastic timed Petri nets using linear programming approach.* In: IEEE Trans. on Software Engineering, Vol. 24, No. 11, pages 1014–1030. 1998.

Stochastic timed Petri nets are a useful tool in performance analysis of concurrent systems such as parallel computers, communication networks, and flexible manufacturing systems. In general, performance measures of stochastic timed Petri nets are difficult to obtain for practical problems due to their sizes. In this paper, we provide a method to compute efficiently upper and lower bounds for the throughputs and mean token numbers for a large class of stochastic timed Petri nets. Our approach is based on uniformization technique and linear programming.

Maciel, P.; Barros, E.; Rosenstiel, W.: *A Petri net based approach for performing the initial allocation in hardware/software codesign.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 505–510. 1998.

This work presents a method of hardware/software partitioning considering multiple software components. The proposed method uses Petri nets as a common formalism to perform quantitative and qualitative analysis. The use of Petri nets permits one to use a specification non-dependent partitioning method. As an intermediate format Petri net allows one to analyze properties of the specification and formally compute performance indices which are used in the partitioning process. This paper highlights methods of computing load balance, precedence relation degree and communication cost of behavioral description in order to perform the initial allocation along with partitioning. This paper is devoted to describing the initial allocation algorithm, although an overview of the general partitioning method of also presented.

] Magalhaes, L.P.; Raposo, A.B.; Ricarte, I.L.M.: *Animation modeling with Petri Nets.* In: Computers and Graphics, Vol. 22, No. 6, pages 735–743. 1998.

This paper introduces the use of Petri Nets as a modeling and analysis tool for animation environments. Firstly, the original formulation for Petri Nets is applied in two animation situations, one modeled as a state machine and another exploring interdependent transitions. Increasing the complexity level, some modeling extensions are discussed and more sophisticated animation examples are studied.

5] Maione, G.; DiCesare, F.: *A Petri net and digraph-theoretic approach for deadlock avoidance in flexible manufacturing systems.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 605–610. 1998.

This paper combines Petri nets and digraphs to implement control policies avoiding deadlocks in flexible manufacturing systems. Some digraph deadlock characterization is translated into Petri net deadlock markings. Thus, inequality constraints on the token distribution to avoid deadlock can be deduced. By using control places, place invariants can be defined to respect these constraints.

9] Mihalache, V.: *Decidability problems in grammar systems.* In: Theoretical Computer Science, Vol. 215, No. 1-2, pages 169–189. 1999.

Most of the basic decision problems concerning derivations in cooperating distributed grammar systems have so far been open, possibly because of the lack of unifying methods and techniques. In this paper such a unifying device is proposed. It is called a coverability tree because it bears some resemblance to the coverability graph of place/transition Petri nets and vector addition systems. The coverability tree is always finite, which leads to rather strong decidability properties concerning both arbitrary and terminal derivations. Our method is largely independent of the mode of the derivations and answers most of the direct decidability questions about the components of the system.

0] Miyamoto, T.; Kumagai, S.: *Calculating place capacity for Petri nets using unfoldings.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 143–151. 1998.

Although Petri nets have powerful mathematical verification ability, the state space needs to be constructed in many cases. Place capacity is the maximum number of tokens in this place for all reachable markings. This capacity can be determined by reachability analysis or place invariants. This paper proposes a method to find place capacities by using net unfolding, and compares it withe the other methods.

01] Mizobuchi, S.; Sumitomo, T.; Fuketa, M.; Aoe, J.-I.: *A method for understanding time expressions.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 1151–1155. 1998.

This paper proposes a method for understanding time expressions. For components of which time expressions consist, 31 concepts are defined. Formal representations are provided for these concepts and an algorithm is proposed to analyze the meaning of time expressions. The representation includes both conceptual and quantitative aspects. Experiments for about 2,000 time expressions extracted from actual documents show that the proposed method yields correct interpretation in about 93 percent of the cases.

02] Moody, J.O.; Antsaklis, P.J.: *Supervisory Control of Discrete Event Systems Using Petri Nets.* Pages 1–208. Kluwer Academic Publishers, 1998.

The book presents a novel approach for the supervisory control of discrete event systems using Petri nets. The concepts of supervisory control and discrete event systems are explained, and the background material on general Petri net theory necessary for using the book's control techniques is provided. A large number of examples are used to illustrate the concepts and techniques presented in the text, and there are plenty of references for those interested in additional study or more information on a particular topic.

The text is written from an engineering perspective, but it is also appropriate for students of computer science, applied mathematics, or economics. The book contains enough background material to stand alone as an introduction to supervisory control with Petri nets, but it may also be used as a supplemental text in a course on discrete event systems or intelligent autonomous control.

[103] NAEDELE, M.; JANNECK, J.W.: *Design patterns in Petri net system modeling.* In: Proc. 4-th IEEE Int. Conf. on Engineering of Complex Computer Systems, 10-14 August 1998, Monterey, CA, pages 47–54. 1998.

Petri nets are an established and well researched means for systems modeling and simulation, but its use in the engineering community is not as widespread as the applicability of the formalism would suggest. A reason for this might lie in the fact that there is no established concept for the concise presentation of reusable Petri net design knowledge. This paper proposes Petri net design patterns as a style of presentation of such design knowledge ranging from building blocks to architectural considerations. The template for description is introduced using a number of examples taken from the authors' design experience.

[104] NEAGU, G.: *Petri Net Based Modeling of Job-Shop Resource Allocation in Generic Prototyping Approach.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), San Diego, USA, pages 96–100. 1998.

In the framework provided by the Generic Prototyping Approach, the paper presents the Decision Control Petri Nets (DCPN) formalism for behaviour modeling in discrete event systems. In case of components with inherent decision making capabilities, this formalism proposes the decision transition mechanism to activate suitable decision support resources. The job-shop model has been chosen to illustrate this modeling approach. The Resource Allocation Center (RAC) concept is introduced as a support for analysis of scheduling and dispatching related decision making processes, and the DCPN model of the processing type RAC is presented in detail. A multi-agent simulator is envisaged to generate a scheduling solution based on job-shop representation as a network of interconnected RACs.

[105] NIELSEN, M.; SASSONE, V.: *Petri Nets and Other Models of Concurrency.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 587–642. Springer-Verlag, 1998.

This paper retraces, collects, and summarises contributions of the authors – in collaboration with others – on the theme of Petri nets and their categorical relationships to other models of concurrency.

[106] NIGRO, L.; PIPO, F.: *A modular approach to real-time programming using actors and Java.* In: Control Engineering Practice, Vol. 6, No. 12, pages 1485–1491. 1998.

This paper describes an actor-based approach to real-time programming, which focuses on the separation of functional from timing behavior. The approach favors modularity and time predictability. Clusters of actors, allocated on distinct processors, are orchestrated by a control machine which provides an event-driven and time-driven customizable scheduling framework. The approach can be hosted by Java, which fosters a clean and type-safe programming style. Temporal analysis can be formally assisted by Coloured Petri Nets.

[107] PASTOR, E.; CORTADELLA, J.; KONDRATYEV, A.; ROIG, O.: *Structural methods for the synthesis of speed-independent circuits.* In: IEEE Trans. on Computer-Aided Design of Integrated Circuits and Systems, Vol. 17, No. 11, pages 1108–1129. 1998.

Asynchronous circuits can be modeled as concurrent systems in which events are interpreted as signal transitions. The synthesis of concurrent systems implies the analysis of a vast state space that often requires computationally expensive methods. This work presents new methods for the synthesis of speed-independent circuits from a new perspective, overcoming both the analysis and computation complexity bottlenecks. The circuits are specified by free-choice signal transition graphs (STG's), a subclass of interpreted Petri nets. The synthesis approach is divided into the following steps: correctness, binary coding, implementability conditions, and logic synthesis. Each step is efficiently implemented by applying a set of structural techniques that analyze STG's without explicitly enumerating the underlying state space. Experimental results show that circuits can be generated from specifications that exceed in several orders of magnitude the largest STG's ever synthesized. Computation times are also dramatically reduced. Nevertheless, the quality of results does not suffer from the use of structural techniques.

[108] PECCOUD, J.: *Stochastic Petri nets for genetic networks.* In: Medicine Sciences, Vol. 14, No. 8-9, pages 991–993. 1998.

Keywords: Petri nets, genetic networks.

[109] PIETKIEWICZ-KOUTNY, M.: *Synthesis of ENI-systems using minimal regions.* In: Lecture Notes in Computer Science, Vol. 1466: Concurrency Theory (CONCUR'98), pages 565–580. Springer-Verlag, 1998.

The paper considers the synthesis problem for elementary net systems with inhibitor arcs (ENI-systems) executed according to the a priori semantics. The relationship between nets and transition systems generated by them

(TSENI) is established via the notion of a region. The general synthesis problem for ENI-systems was shown earlier (LNCS-1248); this paper optimizes the solution using only minimal regions and selected inhibitor arcs. The proposed method of eliminating arcs in ENI-systems is compared with that introduced earlier; it is shown that the two methods have similar effects.

[110] RECALDE, L.; TERUEL, E.; SILVA, M.: *On linear algebraic techniques for liveness analysis of P/T system.* In: Journal of Circuits, Systems and Computers, Vol. 8, No. 1, pages 223–265. 1998.

Liveness is a basic property that in many discrete event dynamic systems is considered essential for their correct behavior. It expresses that no action (transition in P/T models) will ever become unattainable. A polynomial time necessary condition for the existence of a live and bounded marking of a P/T net is given. This condition is shown to be also sufficient for some subclasses. The applicability of these results is extended by the use of transformation techniques that allow for their exploitation in the analysis of more general nets. Some results for the structural analysis of actual liveness are also overviewed, in particular, sufficient conditions for deadlock-freeness and absence of dead transitions.

[111] REISIG, W.: *Elements of Distributed Algorithms: Modeling and Analysis with Petri Nets.* Pages 1–302. Springer-Verlag, 1998. ISBN 3-540-62752-9.

A variety of distributed algorithms are presented and proven correct in this book. A (Petri net based) technique to model and to analyze distributed algorithms is coincidently presented. This technique focusses on local states, independent actions, and synchronization of distributed threads of control.

This book's scope is modest, as it sticks to a choice of small and medium size distributed algorithms. Compositionality, stepwise refinement, interface specification, abstraction, etc., are not covered. Nevertheless, this book's claims are ambitious: Just as PASCAL-like programming structures and Hoare-style proof techniques appear optimal for a wide class of sequential algorithms, this book's formalism is suggested to be optimal for a wide class of distributed algorithms.

[112] REISIG, W.; KINDLER, E.; VESPER, T.; VÖLZER, H.: *Distributed Algorithms for Networks of Agents.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

A network algorithm is a schema, intended to run on any network in a whole class of networks. Such an algorithm can be modeled as a high-level Petri net schema. Each interpretation of the schema yields an algorithm for a concrete network. This paper suggests a variety of Petri net models of network algorithms, formally represents their most decisive properties, and proves their validity. To this end, well-known techniques such as place invariants and traps are adjusted to Petri net schemata, and new techniques to prove progress properties axe suggested.

[113] REISIG, W.; ROZENBERG, G.: *Informal Introduction to Petri Nets.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models. Springer-Verlag, 1998.

[114] RIBARIC, S.; DALBELO BASIC, B.; TOMAC, D.: *Program implementation of reasoning using fuzzy and fuzzy time Petri nets.* In: Proc. 20-th Int. Conf. on Information Technology Interfaces (ITI'98), 16-19 June 1998, Pula, Croatia, pages 101–108. 1998.

A new formal model for fuzzy temporal knowledge representation and reasoning in temporally rich domains is described. The model is based on the modification if Petri nets, called fuzzy and fuzzy time Petri nets (FTPN). The paper also considers the the object-oriented implementation of the model and its use.

[115] ROZENBERG, G.; ENGELFRIET, J.: *Elementary Net Systems.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 12–121. Springer-Verlag, 1998.

[116] SAGOO, J.S.; BOARDMAN, J.T.: *Towards the formalization of soft systems using Petri net theory.* In: IEE Proc. on Control Theory Applications, Vol. 145, No. 5, pages 463–471. 1998.

The analytical capability of conceptual models that are used in a soft systems methodology to capture the processes within a business organizations is examined and extended. Specifically, the models known as systemigrams, which form part of the Boardman soft systems methodology, are considered. The informal nature of the systemigrams allows a nonspecialist to easily create models of processes, but it does not permit analysis of the resulting model. This problem is addressed by presenting a translation algorithm that converts systemigram descriptions into Petri net models. This translation allows the behavior, represented by a systemigram, to be analyzed via Petri net theory. Application of this algorithm is shown via a case study that translates and analyzes a systemigram of a realistic process that forms the order intake phase of a product's life cycle.

[117] SAKAGUCHI, T.; SOMANI, A.K.: *Hierarchical stochastic reword net solver package.* In: Lecture Notes in Computer Science, Vol. 1469: Computer Performance Evaluation, pages 369–373. Springer-Verlag, 1998.

This paper describes the design and application of the hierarchical stochastic reward net solver package (HSP) to compute system reliability, availability, maintainability, and other system performance metrics. This enables us to model systems with hierarchy and/or modular redundancy efficiently.

[118] SCARPA, M.; BOBBIO, A.: *Kronecker representation of stochastic Petri nets with discrete PH distributions.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 52–61. 1998.

In recent years, several classes of stochastic Petri net (SPN) models have been elaborated which incorporate some non-exponential characteristics in their definition. Among the various approaches that have been proposed in the literature for handling non-exponential SPNs, the paper investigates the class of models in which the firing time associated with each transition is a discrete phase type (DPH) random variable, so that the evolution of the marking process is mapped into an expanded discrete-time Markov chain (DTMC). In order to alleviate the state space explosion problem, the expanded state space is expressed via Kronecker algebra operators, starting from the knowledge of the reachability graph of the untimed PN and the DPH random firing times assigned to each PN transition. The discrete case is very appealing sing it allows to mix distributions with finite and infinite support. However, the problem of simultaneous firings arises, and the related semantics must be carefully considered.

[119] SHEN, V.R.L.; LAI, F.P.: *Requirements specification and analysis of digital systems using fuzzy and marked Petri nets.* In: IEEE Trans. on Systems, Man, and Cybernetics, part B, Vol. 28, No. 5, pages 748–754. 1998.

Fuzzy information often appears in the system requirements. Fuzzy Petri nets FN) are Petri nets in which certain fuzzy truth-values are assigned to its transitions. In this paper, we show how the FPN model can be used for formal specification and verification of digital systems. The consistent FPN model is actually a state machine, from which we can obtain a consistent marked Petri net (MPN) model. Based on the consistent MPN model, the hardware prototype at register transfer level can be easily induced by using the optimization rules. Finally, main results are presented in the form of three theorems and are supported by some experiments.

[120] SHIH, T.K.; JIANG, D.R.; HUNG, J.C.; PAI, W.C.; WANG, C.C.: *Asynchronous multimedia processing using timed Petri nets.* In: Proc. 13-th Int. Conf. on Computers and Their Applications, 25-27 March 1998, Honolulu, HA, pages 314–317. 1998.

This paper describes how to present different multimedia objects on a multimedia abstract machine with a structured mechanism. The structural mechanism is based on a timed Petri net. The features of a Petri net are used to display the behavior of multimedia objects and to introduce the concepts of navigation messages of users in the timed Petri net model. The paper explains the algorithm of the proposed model. The main goal of this structural mechanism provides a feasible method to represent a schedule and the navigation of different multimedia objects with navigation messages of users. Users only input a data flow diagram and a control flow diagram to the multimedia abstract machine, and the system displays all situations of multimedia presentation. Users can dynamically change requests to result in different results during the multimedia presentation.

[121] SIEGLE, M.: *Techniques and tool for symbolic representation and manipulation of stochastic transition systems.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 1–272. 1998.

A new approach to the compact symbolic representation of stochastic transition systems is developed which is based on decision node BDDs, a novel stochastic extension of BDDs. Parallel composition of components can be performed on the basis of this new data structure. Symbolic state space reduction by Markovian bisimulation is also discussed.

[122] SILVA, M.; TERUEL, E.; COLOM, J.M.: *Linear Algebraic and Linear Programming Techniques for the Analysis of Place/Transition Net Systems.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 309–373. Springer-Verlag, 1998.

The structure theory of Place/Transition net systems is surveyed – incorporating new contributions – in a tutorial style, mainly from a linear algebraic perspective. Topics included are: state equation based analysis of safety properties (e.g. boundedness, mutual exclusion, deadlock-freeness, etc.), linear invariants, siphons and traps, implicit places and their application to improve the accuracy of the state equation, and rank theorems (structural conditions for liveness and boundedness based on the rank of the incidence matrix).

[123] SILVA, M.; TERUEL, E.; VALETTE, R.; PINGAUD, H.: *Petri Nets and Production Systems.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

Modern production systems pose a diversity of problems all along their life cycle which are often treated with particular independent formalisms and techniques. Production systems can be viewed as discrete event, continuous, or hybrid systems. Petri nets are a family of formalisms which can be used for the modelling, analysis, implementation, and control of these systems, with the benefit of improving the communication between stages of the life cycle. The utilisation of Petri nets in several of these stages is illustrated in this tutorial paper through a selected set of examples.

] SMITH, E.: *Principles of High-Level Net Theory.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 174–210. Springer-Verlag, 1998.

The paper gives an introduction to fundamentals and recent trends in the theory of high-level nets. High-level nets are first formally derived from low-level nets by means of a quotient construction. Based on a linear-algebraic representations, we develop an invariant calculus that essentially corresponds to the algebraic core of the well-known coloured nets. We demonstrate that the modelling power of high-level nets stems from the use of expressive symbolic annotation languages, where as a typical model we consider predicate-transition nets, both concrete models and net-schemes. As examples of specific high-level analysis-tools we discuss symbolic place-invariants and reachability-trees.

5] SPRANGER, J.: *Combining Structural Properties and Symbolic Representation for Efficient Analysis of Petri Nets.* In: Workshop on Concurrency, Specifiction & Programming (CSP '98), Berlin, September 1998, pages 236–244. 1998. ISSN 0863-095.

In this paper we combine structural analysis of Petri nets with the symbolic representation of state spaces by Binary Decision Diagrams (BDDs). The size of a BDD is determined by the number of its variables and by their order. We suggest two methods based on structural properties (precisely one-token-P-invariants) which improve the encoding of states. One method attempts to derive a good variable order. The other tries to reduce the needed number of variables by compacting the encoding of states.

6] SREENIVAS, R.S.: *An application of independent, increasing, free-choice Petri nets to the synthesis of policies that enforce liveness in arbitrary Petri nets.* In: Automatica, Vol. 34, No. 12, pages 1613–1615. 1998.

The class of Independent, Increasing, Free-Choice Petri nets (II-FCPNs) was introduced in 1997 and it was shown that any II-FCPN can be made lice via supervision using a readily available policy. In a lice Petri net (PN) (Peterson (1981): Petri Net Theory and Modeling of systems, Reisig (1985): Petri Nets), it is possible to fire any transition from every reachable marking, although not necessarily immediately. In this paper we identify a class of PNs, where every transition is controllable, that are not necessarily II-FCPNs, that can be made live via supervision using a readily available policy constructed from the policy that enforces liveness in an II-FCPN.

7] SREENIVAS, R.S.: *On supervisory policies that enforce liveness in a class of completely controlled Petri nets obtained via refinement.* In: IEEE Trans. on Automatic Control, Vol. 44, No. 1, pages 173–177. 1999.

The authors consider Petri nets (PN's), where each transition can be prevented from firing by an external agent, the supervisor. Earlier work provided necessary and sufficient conditions for the existence of a supervisory policy that enforces liveness in a PN that is not live. A PN is said to be live if it is possible to fire any transition from every reachable marking, although not necessarily immediately. The procedure involves the construction of the coverability graph which can be computationally expensive. Using the refinement/abstraction procedure of Suzuki and Murata, where a single transition in an abstracted PN, N is replaced by a PN N' to yield a larger refined PN N". We show that when N' belongs to a class of marked-graph PN's, there is a supervisory policy that enforces liveness in the refined PN N" if and only if there is a similar policy for the abstracted PN N. Since the coverability graph of the PN N is smaller than that of the PN N", it is possible to achieve significant computational savings by using the process of abstraction on N'. This is illustrated by example.

28] STREHL, K.; THIELE, L.: *Interval Diagram Techniques for Symbolic Model Checking of Petri Nets.* In: Proceedings of the Design, Automation and Test in Europe Conference (DATE'99), Munich, Germany, March 9-12, 1999, pages 756–757. 1999.

Symbolic model checking tries to reduce the state explosion problem by implicit construction of the state space. The major limiting factor is the size of the symbolic representation mostly stored in huge binary decision diagrams. A new approach to symbolic model checking of Petri nets and related models of computation is presented, outperforming the conventional one and avoiding some of its drawbacks. Our approach is based on a novel, efficient form of representation for multi-valued functions called interval decision diagram (IDD) and the corresponding image computation technique using interval mapping diagrams (IMDs). IDDs and IMDs are introduced, their properties are described, and the feasibility of the new approach is shown with some experimental results.

29] SZUCS, A.; GERZSON, M.; HANGOS, K.M.: *An intelligent diagnostic system based on Petri nets.* In: Computers and Chemical Engineering, Vol. 22, No. 9, pages 1335–1344. 1998.

Keywords: Petri nets, chemical engineering, diagnostic systems.

[130] TARASYUK, I.V.: *Equivalence notions applied to designing concurrent systems with the use of Petri nets.* In: Programming and Computer Software, Vol. 24, No. 4, pages 162–175. 1998.

This paper is dedicated to the study of behavioral equivalences of concurrent systems modeled by Petri nets. The main notions of equivalence known from the literature are complemented by new ones and analyzed on the whole class of Petri nets and on the subclass of sequential nets (nets without concurrency). A complete description of relationships between equivalences is obtained. Whether or not equivalence notions are preserved under the refinement operation, which makes it possible to consider the behavior of nets at a lower abstraction level, is also analyzed.

[131] TAUBIN, A.; KONDRATYEV, A.; KISHINEVSKY, M.: *Deadlock prevention using Petri nets and their unfoldings.* In: International Journal of Advanced Manufacturing Technology, Vol. 14, No. 10, pages 750–759. 1998.

Unfoldings of Petri nets (PN) provide a method for the analysis of concurrent systems without restoring the state space of a system. This allows one to overcome the 'state explosion' problem. Many properties of the initial PN (boundedness, safety; persistency and hazards) can be checked by constructing the unfolding. A deadlock prevention procedure first detects deadlocks using an unfolding. Then, the first method reduces the unfolding to a set of deadlock-free subunfoldings that cover all live behaviors. The second method uses a direct transformation at the level of the original PN. The methods are implemented as subroutines by the Berkeley program SIS. Although the deadlock detection problem is known to be NP-complete, experimental results show? that for highly parallel specifications deadlock prevention by unfoldings is typically more efficient than deadlock prevention based on symbolic BDD (binary decision diagrams) traversal of the corresponding reachability graph.

[132] TELEK, M.; HORWATH, A.: *Supplementary variable approach applied to the transient analysis of Age-MRSPNs.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 44–51. 1998.

This paper extends the applicability of the supplementary variable approach to a class of Markov regenerative stochastic Petri nets in which the preemptive resume policy can also be assigned to the transitions of the net.

[133] TERHOFSTEDE, A.H.M.; PROPER, H.A.: *How to formalize it – formalization principles for information system development methods.* In: Information and Software Technology, Vol. 40, No. 10, pages 519–540. 1998.

Although the need for formalization of modeling techniques is generally recognized, not much literature is devoted to the actual process involved. This is comparable to the situation in mathematics where focus is on proofs but not on the process of proving. This paper tries to accommodate for this lack and provides essential principles for the process of formalization in the context of modeling techniques as well as a number of small but realistic formalization case studies.

[134] THIAGARAJAN, P.S.; HENRIKSEN, J.G.: *Distributed Versions of Linear Time Temporal Logic: A Trace Perspective.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 643–682. Springer-Verlag, 1998.

[135] TOKMAKOFF, A.; BILLINGTON, J.: *Reachability Analysis of the ODP Trader using Equivalence Classes.* In: Proc. Software Engineering Education & Practice Conference, Dunedin, New Zealand, 26-29 January, 1998, pages 16–23. IEEE Computer Society, 1998. ISBN: 0-8186-8828-9.

As part of the ISO/IEC standardisation of the Reference Model for Open Distributed Processing (RM-ODP), a Trading Function has been identified. It is an important infrastructure service that allows clients to locate services using service types and associated parameters as selection criteria. This paper introduces the reader to the concept of Service trading and presents a Coloured Petri Net model of the trader's object interactions. The Model is Analysed using Occurrence Graphs with Equivalence Classes which results in a significantly reduced equivalent Occurrence Graph.

[136] TOKMAKOFF, A.; BILLINGTON, J.: *Reachability analysis of the ODP trader using equivalence classes.* In: Proc. Software Engineering: Education and Practice, 26-29 January 1998, Dunedin, New Zealand, pages 16–23. 1998.

As part of the ISO/IEC standardization of the Reference Model for Open Distributed Processing (RM-ODP), a trading function has been identified. It is an important infrastructure service that allows clients to locate services using service types and associated parameters as selection criteria. This paper introduces the reader to the concept of service trading and presents a colored Petri net model of trader's object interaction. The model is analyzed using occurrence graphs with equivalence classes which results in a significantly reduced equivalent occurrence graph.

[137] TOMBUYSES, B.: *Automatic construction of Markov transition matrices under state and functional dependences.* In: Reliability Engineering and Systems Safety, Vol. 64, No. 1, pages 49–58. 1999.

This paper deals with the construction of the transition rate matrix of a system with state and 'functional' dependences. Functional dependences are introduced by operational rules and are characterized by multiple transitions. The construction of the transition rate matrix of a three-motor system (one in standby) is given as an application.

8] TOMBUYSES, B.: *Reduction of the Markovian system by the influence graph method – error bound and reliability computation.* In: Raliability Engineering and System Safety, Vol. 63, No. 1, pages 1–11. 1999.

In a previous article, a new method allowing the treatment of large Markovian problems was presented. Based on a graph describing the influences between the components of the system, it performs successive approximate aggregations on the exact Markovian system to reduce its size. The main drawback of this method, as of any approximate method, is to assess its validity. That is why we develop a new presentation of the method here and we define, from this presentation, error bounds for the approximate results. They are then tested for two applications, one being very large. We also extend the method, initially defined for availability problems, to reliability problems.

39] USHER, M.; JACKSON, D.: *A concurrent visual language based on Petri nets.* In: Proc. 1998 IEEE Symp. on Visual Languages (VL'98), 1-4 September 1998, Halifax, NS, Canada, pages 72–73. 1998.

This paper presents a concurrent visual programming language based on Petri nets. Most concurrent visual programming languages address concurrency by extending a non-concurrent paradigm and representation with additional control and synchronization mechanisms and notation. It is argued here that clearer and more concise concurrent program representations are possible if the concurrency is inherent in the paradigm. The language described demonstrates that Petri nets provide such a paradigm.

40] USTIMENKO, A.P.: *Colored cause-effect structures.* In: Information Processing Letters, Vol. 68, No. 5, pages 219–225. 1998.

We suggested the extension of the class of cause-effect structures by colored tokens. As an example of a colored cause-effect structure we use the well-known dining philosophers' problem. Relationships between the classes of colored cause-effect structures and colored Petri nets introduced by Jensen are investigated.

41] UZAM, M.: *Petri-net-based supervisory control of discrete event systems and their ladder logic diagram implementations.* Pages 1–413. PhD Thesis — Salford, UK: University of Salford, 1998.

The thesis investigates the use of Petri nets in supervisory control. Both the forbidden state problem and the desired string problem are solved. In other words, this work presents systematic approaches to the synthesis of Petri-nets-based supervisors (controllers) for both the forbidden state problem and the desired string problem and introduces the details of supervisory design procedures. The supervisors obtained are the form of a net structure as oppose to supervisors given as a feedback function. This means that a controlled model of the system can be constructed and analysed using the techniques regarding to Petri net models. In particular the thesis considers discrete manufacturing systems. An approach to the conversion from the supervisors to ladder logic diagrams (LLDs) for implementation on a programmable logic controller (PLC) is proposed. A discrete manufacturing system example is then considered. The aim of this is to illustrate the applicability, strengths and drawbacks of the design techniques proposed.

142] UZAM, M.; JONES, A.H.: *A Methodology for the Synthesis of Petri-Net-Based Supervisory Controllers for Manufacturing Systems: Part I – The Synthesis Procedure.* In: Proceedings of the 2nd International Symposium on Intelligent Manufacturing Systems (IMS'98), Sakarya, Turkey, Vol. II, pages 1013–1024. Sakarya University, 1998.

143] UZAM, M.; JONES, A.H.: *A Methodology for the Synthesis of Petri-Net-Based Supervisory Controllers for Manufacturing Systems: Part II – An Application.* In: Proceedings of the 2nd International Symposium on Intelligent Manufacturing Systems (IMS'98), Sakarya, Turkey, Vol. I, pages 535–546. Sakarya University, 1998.

144] UZAM, M.; JONES, A.H.: *Discrete Event Control System Design Using Automation Petri Nets and Their Ladder Diagram Implementation.* In: International Journal of Advanced Manufacturing Systems, special issue on Petri Nets Applications in Manufacturing Systems, Vol. 14, No. 10, pages 716–728. 1998.

In this paper, automation Petri nets (APN) are introduced to provide a new method for the design and implementation of discrete event control systems (DECSs). The APN is particularly well suited to multiproduct systems and provides a more effective solution than Grafcet in this context. Since ordinary Petri nets do not deal with sensors and actuators of DECSs, the Petri net concepts are extended, by including actions and sensor readings as formal structures within the APN. Moreover, enabling and inhibitor arcs, which can enable or disable transitions through the use of leading-edge, falling-edge and level of markings, are also introduced. In this paper, the methodology is explained by considering a fundamental APN structure. The conversion of APNs into the IEC1131-3 ladder diagrams for implementation on a PLC is also explained by using the token passing logic concept.

[145] VALMARI, A.: *The State Explosion Problem.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1491: Lectures on Petri Nets I: Basic Models, pages 429–528. Springer-Verlag, 1998.

State space methods are one of the most important approaches to computer-aided analysis and verification of the behaviour of concurrent systems. In their basic form, they consist of enumerating and analysing the set of the states of system can ever reach. Unfortunately, the number of states of even a relatively small system is often far greater than can be handled in a realistic computer. The goal of this article is to analyse this state explosion problem from several perspectives. Many advanced state space methods alleviate the problem by using a subset or an abstraction of the set of states. Unfortunately, their use tends to restrict the set of analysis or verification questions that can be answered, making it impossible to discuss the methods without some taxonomy of the questions. Therefore, the article contains a lengthy discussion on alternative ways of stating analysis and verification questions, and algorithms for answering them. After that, many advanced state space methods are briefly described. The state explosion problem is investigated also from the computational complexity point of view.

[146] VAN DER AALST, W.M.P.: *Modeling and analyzing interorganizational workflows.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 262–272. 1998.

Workflow management systems are a key technology for improving the effectivity and efficiency of business processes within one organization. Todays workflow management systems focus on processes focus on processes which are circumscribed by the bounds of an organization. However, most workflows cross organizational boundaries. Workflows may interact with individual customers, suppliers, subcontractors, and governmental departments. Moreover, phenomena such as electronic commerce, extended enterprises and the Internet stimulate the cooperation between organizations. Therefore, it is interesting to consider workflows distributed over a number of organizations. Interorganizational workflow offers companies the opportunity to re-shape business processes beyond the boundaries of individual organizations. This paper models interorganizational workflows in terms of Petri nets and focuses on technologies to verify the correctness of these workflows.

[147] VAN DER AALST, W.M.P.: *The application of Petri nets to workflow management.* In: Journal of Circuits, Systems and Computers, Vol. 8, No. 1, pages 21–66. 1998.

Workflow management promises a new solution of an age-old problem: controlling, monitoring, optimizing, and supporting business processes. What is new about workflow management is the explicit representation of of the business process logic which allows for computerized support. This paper discusses the use of Petri nets in the context of workflow management. Petri nets are an established tool for modeling and analyzing processes. On the one hand, Petri nets can be used as a design language for the specification of complex workflows. On the other hand, Petri net theory provides for powerful analysis techniques which can be used to verify the correctness of workflow procedures. This paper introduces workflow management as an application domain for Petri nets, presents state-of-the-arts results with respect to the verification of workflows, and highlights some Petri net based workflow tools.

[148] VERMA, R.M.; RUSINOWITCH, M.; LUGIEZ, D.: *Algorithms and Reductions for Rewriting Problems.* In NIPKOW, T.: Lecture Notes in Computer Science, Vol. 1379: 9th International Conf. RTA'98 Rewriting Techniques and Applications, Tsukuba, Japan, pages 166–180. 1998.

In this paper we initiate a study of polynomial-time reductions for some basic decision problems of rewrite systems. We the give a pollynomial-time algorithm for Unique-normal-form property of ground systems for the first time. Next we prove undecidability of these problems for a fixed string rewriting system using our reductions. Finally, we prove partial decidability results for Confluence of Commutative semi-thue systems. The Confluence and Unique-normal-form property are shown Expspace-hard of commutative semi-thue systems. We also show that there is a family of string rewrite systems for which the world problem is trivially decidable but confluence undecidable, and we show a linear equational theory with decidable word problem but undecidable linear equational matching.

[149] VOELZER, H.: *Verifying fault tolerance of distributed algorithms formally - an example.* In: Proc. 1998 Int. Conf. on Application of Concurrency to System Design (CSD'98), 23-26 March 1998, Fukushima, Japan, pages 187–197. 1998.

It is shown how fault-tolerant distributed algorithms can be formally verified using the Petri net based verification framework DAWN. A complete example study, the verification of a distributed self-diagnosis algorithm, is presented to demonstrate the benefits of the proposed approach.

[150] VOGLER, W.; SEMENOV, A.; YAKOVLEV, A.: *Unfolding and finite prefix for nets with read arcs.* In: Lecture Notes in Computer Science, Vol. 1466: Concurrency Theory (CONCUR'98), pages 501–516. Springer-Verlag, 1998.

Petri nets with read arcs are investigated with respect to their unfolding, where read arcs model reading without consuming, which is often more adequate than the destructive read-and-rewrite modeled with loops in ordinary nets. The paper redefines the concepts of a branching process and unfolding for nets with read arcs and proves that the set of reachable markings of a net is completely represented by its unfolding. The specific feature of branching processes of nets with read arcs is that the notion of a co-set is no longer based on the binary concurrency relation between the elements of the unfolding, contrary to ordinary nets. It is shown that the existing conditions that finite prefix construction can only be applied to a subset of nets with read arcs, the co called read-persistent nets. Although this class is restrictive, it is sufficiently practical due to its conformance to the notion of hazard-freedom in logic circuits. The latter appears to be one of the most promising applications of nets with read arcs.

[151] VON UTHMANN, C.; BECKER, J.: *Machen Ereignisgesteuerte Prozeßketten (EPK) Petrinetze für die Geschäftsprozeßmodellierung obsolet?*. In 1998: In: EMISA FORUM - Mitteilungen der GI-Fachgruppe 'Entwicklungsmethoden für Informationssysteme und deren Anwendung', Heft 1, pages 100–107. 1998. In German.

In this paper event-driven process chains by Scheer et al. and Petri nets are compared regarding their applicability for business process modelling. Possible future paths of development are discussed and a general assessment of the techniques' usability is given.

[152] VON UTHMANN, C.; BECKER, J.: *Managing Complexity of Modeling Industrial Processes with P/T Nets.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, USA, pages 1–6. 1998.

Due to necessary specifications of manifold co-ordination for managing resource interdependencies and corresponding control data flows the design of Petri Nets (here is referred to P/T Nets) describing industrial processes tend to generate considerably high complexity itself. With regard to economic efficiency of process modeling and simulation studies it is essential to cope with this complexity on a systematic basis. The paper will take up this problem, which has rarely been regarded so far. Three major mutually dependent topics are focused on, and are applied in a case study: View-oriented phases of the model construction, the use of model components and the application of the Guidelines of Modeling (GoM).

[153] WAKEFIELD, R.R.: *Application of extended stochastic Petri nets to simulation and modeling of construction systems.* In: Civil Engineering and Environmental Systems, Vol. 15, No. 1, pages 1–22. 1998.

An extended stochastic Petri net approach to modeling and simulation of construction systems is developed. The basics of Petri nets, a technique previously used for modeling computer systems and automated manufacturing, are described. Extended stochastic Petri net features useful in construction systems modeling are detailed along with structures that can represent characteristics commonly present in construction systems. Two illustrative examples are presented and the advantages and disadvantages of extended stochastic Petri nets as a tool for construction system modeling are discussed.

[154] WALLNER, F.: *Model-checking LTL using net unfoldings.* In: Lecture Notes in Computer Science, Vol. 1427: Proceedings of CAV'95, 10th International Conference on Computer Aided Verification), Vancouver, Canada, pages 207–218. Springer-Verlag, 1998.

[155] WANG, J.: *Timed Petri Nets: Theory and Application.* Pages 1–290. Kluwer Acadamic Publishers, USA, 1998.

[156] WANG, J.; DENG, Y.: *Component-level reduction rules for time Petri nets with application in C2 systems.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 125–130. 1998.

This paper proposes a set of component-level reduction rules for TPNs. Each of these reduction rules transforms a TPN component to a constant size of simple one while maintains the net's external observable timing properties. Consequently, the method works at a coarser level than that in individual transition level, and fewer applications of the rules are needed ti reduce the size of the TPN under analysis. The use and benefits of the proposed reduction rules are illustrated by modeling and analyzing the response time of a command and control system to its external arriving messages.

[157] WEGRZYN, M.; ADAMSKI, M.A.; MONTEIRO, J.L.: *The application of reconfigurable logic to controller design.* In: Control Engineering Practice, Vol. 6, No. 7, pages 879–887. 1998.

This paper presents part of a broad project in the field of hardware, software co-design. The main purpose is to develop different implementations of controllers using a simple, standard and well-known design methodology like SFC (Grafcet) or Petri nets. The paper deals exclusively with the design of FPGA-based controllers.

[158] WEITZ, W.: *Combining structured documents with high-level Petri-nets for workflow modeling in Internet-based commerce.* In: International Journal of Cooperative Information Systems, Vol. 7, No. 4, pages 275–296. 1998.

This article discusses the application of a new variant of high-level Petri nets, the so-called SGML nets, for modeling business processes in the area of Internet-based commerce. SGML nets are designed to capture the process of generating and manipulating structured documents based on the international standard SGML.

Since the currently most relevant document standards on the Internet are HTML (an SGML application) and XML (a subset of SGML), SGML nets offer an elegant way to integrate central aspects of Electronic Commerce applications into a unified formal workflow model. The article gives an introduction to the central concepts of SGML nets and includes an example of their application from the area of online order processing.

[159] WOLTER, K.: *Virtual waiting time in queues obtained from second order FSPNs.* In: Proc. 3-rd IEEE Annual Int. Computer Performance and Dependability Symposium (IPDS'98), 7-9 September 1998, Durham, NC, pages 1–273. 1998.

In fluid stochastic Petri nets (FSPNs) the level of fluid in a fluid place decreases and increases continuously. With introducing jump transitions for the fluid places, sudden changes in the fluid levels can be incorporated in the formalism.

[160] WU, J.-S.: *A Petri net algorithm for multiple contingencies of distribution system operation.* In: IEEE Trans. on Power Systems, Vol. 13, No. 3, pages 1164–1171. 1998.

In this paper, a Petri net (PN) algorithm combined with a new restoration approach is implemented for multiple distribution contingencies.

[161] YAKOVLEV, A.V.; KOELMANS, A.M.: *Petri Nets and Digital Hardware Design.* In REISIG, W.; ROZENBERG, G.: Lecture Notes in Computer Science, Vol. 1492: Lectures on Petri Nets II: Applications. Springer-Verlag, 1998. ISBN: 3-540-65307-4.

Petri nets are a powerful language for describing processes in digital hardware, and particularly asynchronous or self-timed circuits. Self-timed circuits are designed to operate without the use of a global clock signal. Applications for such circuits are likely to increase during the next decade, due to problems with on-chip event coordination as VLSI technology approaches a density of one hundred million transistors per chip. Designing such circuits without help of formal tools does not seem to be possible. We present an overview of the methods for specification, verification and synthesis of asynchronous circuits with the aid of Petri nets. We present a number of design examples which are used to illustrate the authors' belief that Petri nets could become widely accepted by digital system designers as a design method.

[162] YANG, S.J.H.; CHU, W.; LIN, S.; LEE, J.: *Specifying and verifying temporal behavior of high assurance systems using reachability tree logic.* In: Proc. 3-rd Int. IEEE High-Assurance Systems Engineering Symposium, 13-14 November 1998, Washington, DC, pages 150–156. 1998.

This paper presents reachability tree logic (RTL) and its integration with time Petri nets to specify and verify temporal behavior of high-assurance systems. In addition, the paper demonstrates how to reduce the complexity of model checking algorithm by using the reachability tree. A specification and verification toolkit, called NCUPN (National Central University Petri Net toolkit), has been implemented using Java. NCUPN is available on the Internet at `http://140.115.50.137`.

[163] YANG, S.J.H.; LEE, A.S.; CHU, W.C.; YANG, H.: *Rule base verification using Petri nets.* In: Proc. 22-nd Annual Int. Computer Software and Applications Conf. (COMPSAC-98), 19-21 August 1998, Vienna, Austria, pages 476–481. 1998.

This paper proposes a Petri net formalism for the verification of rule based systems. Typica structural errors in a rule based system are redundancy, inconsistency, and circularity. Since the verification is proposed on Petri nets and their incidence matrix, the rules need to be translated into a Petri net. In order to let a rule-based system be immune from the above errors, it was observed that in all columns of the incidence matrix, all positive entires must be above all negative entries. Base on this observation, a tool was developed consisting of the following four phases: rule normalization, rule ordering, rule-to-Petri-net transformation, and rule verification. In phase one, rules are normalized to Horn clauses. Normalized rules are reordered in phase two, and then transformed into a Petri net and its corresponding incidence matrix, used in phase four.

[164] YANG, S.K.; LIU, T.S.: *A Petri net approach to early failure detection and isolation for preventive maintenance.* In: Quality and Reliability Engineering International, Vol. 14, No. 5, pages 319–330. 1998.

To improve preventive maintenance, this study uses a hybrid Petri net modeling method coupled with parameter trend and fault tree analysis to perform early failure detection and isolation. A Petri net arrangement is proposed that facilitates alarm, early failure detection, fault isolation, event count, system state description and automatic shutdown or regulation. These functions are very useful for health monitoring and preventive maintenance of a system. A fault diagnosis system for district heating and cooling facilities is employed as an example to demonstrate the proposed method.

[165] YEUNG, W.H.R.; MOORE, P.R.: *Towards a fault-tolerant cell controller for flexible assembly systems – and approach using colored Petri nets.* In: Mechatronics, Vol. 8, No. 7, pages 747–764. 1998.

Colored Petri-Nets (CPN) can be used within distributed cell controllers for the design, control and monitoring of flexible assembly systems. This paper presents a methodology using CPN to enhance the flexibility, usability and fault tolerance of assembly Systems. In particular, flexible process plans and a Genetic Algorithm based scheduler are derived to improve the operational versatility of the system. Moreover, a novel method is described which enables non-Petri-Net experts to automatically generate the CPN based controller from the input of the system parameters within a suite of graphical editors. This approach demonstrates tremendous versatility in the operation of the cell controller, including being able to respond to fault conditions and re-configuring the cell to allow continued operation in most circumstances by dynamically modifying the routings and operation schedules. The proposed methods are seen to be highly effective for small batch production, in particular, where reconfiguration of the physical systems is frequently required.

[166] ZHOU, M.-C.; TWISS, E.: *Design if industrial automated system via relay ladder logic programming and Petri nets.* In: IEEE Trans. on Systems, Man, and Cybernetics - Part C, Vol. 28, No. 1, pages 137–150. 1998.

For the past decades, programmable logic controllers (PLCs) using relay ladder logic (RLL) programming have been the workhorse for controlling event-driven industrial automated systems. This paper adopts an industrial scale system to compare RLL and PN design methods so that the advantages of PN-like approaches are fully recognized. The criteria are the understandability that relates to the ability to evaluate the programmed logic, to verify its correctness, and to maintain the control system as well as the flexibility that relates to the easy modification of logic with the specification changes. To the authors' knowledge this is the first work that takes an existing industrial system, conduct discrete-event control design by using both RLL programming and PN methods, and performs a comparative study on them. Together with the previous comparison results through small-scale systems, the results of this study support that PN-like advanced discrete-event control design methods are better than RLL, in terms of the understandability and flexibility of a resulting control design.

[167] ZHOU, Y.; MURATA, T.: *Fuzzy-Timing Petri Net Model for Distributed Multimedia Sychronization.* In: Procs. of the 1998 IEEE International Conference on Systems, Man, and Cybernetics, Lolla, California, pages 244–249. 1998.

[168] ZIEGLER, P.; SZCZERBICKA, H.: *Performance and performability evaluation of FMS using GSPN.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, CA, pages 511–516. 1998.

Generalized stochastic Petri nets (GSPNs) allow easy modeling of processes in flexible manufacturing systems (FMSs). Due to the rich possibilities of this modeling concept, performance aspects and failure in this kind of systems can be investigated. Depending upon the goal of analysis, pure performance or performance combined with availability, the evaluation procedure of the generalized stochastic Petri net has to be carefully chosen to get trustworthy results. Two models of an FMS, where one shows loss of machines, will be used to discuss the problems of a correct evaluation.

[169] ZIMMERMANN, A.; FREIHEIT, J.: *TimeNETMS - An Integrated Modeling and Performance Evaluation Tool for Manufacturing Systems.* In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'98), 11-14 October 1998, San Diego, USA, pages 535–540. 1998.

There is a need for modeling and performance evaluation techniques and tools for a fast and reliable design of modern manufacturing systems. This paper introduces TimeNETMS, a software tool which integrates manufacturing system modeling and performance analysis with an easy-to-use graphical user interface. It is based on a concept of independent models for the manufacturing system structure and work plans, both using a dedicated class of colored stochastic Petri nets. TimeNETMS is implemented as an extension of the more general Petri net modeling and analysis tool TimeNET. An industrial application example shows the use of the tool.

[170] ZIMMERMANN, A.; KÜHNEL, A.; HOMMEL, G.: *A Modelling and Analysis Method for Manufacturing Systems Based on Petri Nets.* In: Proc. Computational Engineering in Systems Applications (CESA'98), Nabeul-Hammamet, pages 276–281. 1998.

A new modelling technique for manufacturing systems is proposed in this paper. Models are constructed with functional blocks known from the field of manufacturing. They are automatically translated into a hidden Petri net. Thus, existing powerful analysis techniques and tools can be applied to the model without knowledge of Petri nets. We emphasise the independent modelling of the manufacturing systems structure and the work plans. Numerical analysis or discrete event simulation of the Petri net model allows to evaluate the performance and dependability of a manufacturing system. A simple application example shows the usefulness of the approach.

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