使用TP, PT 合成法內基本結構之探索及應用

Exploration of Fundamental Structures for Synthesized Nets Using TP- and PT-generations and Its Applications

計畫編號：NSC 88-2213-E-004-001

執行期限：87 **年** 8 **月** 1 **日至** 88 **年** 7 **月** 31 **日**

主持人：趙玉 yaw@mis.nccu.edu.tw　**國立政治大學資訊管理學系(所)**

一、中文摘要

針織技術是簡單、有力的，而且可以像 CAD **工具一樣自動化。它合成出一個** PN **的新階層(比** FC net **更大)，也就是所謂的** Synchronized Choice(sc) nets**。**

證明活性，也就是解決一般 PN **的通達性問題**(reachability)**是困難的問題而且是** PSPACE hard**。**

SC **是有趣的，因為如果一個設計的** PN **不是** SC**，那麼它很有可能會出現死結或無界限**(unbound)**的設計錯誤。同樣地，它的分析需要多項式時間**(polynomial time)**。初步研究指出，在發現最簡單且基礎的死結結構上有重大結果，且同時考量了結構及標記**(marking)**。**

吾人曾發展出產生 TP **及** PT **新路徑之合成法則**; **可處理資源共享**. **但法則太多以至於使用者難以掌握且難以加以併入目前之電腦輔助工具**. **尋找死結之簡單結構及條件可使得其分析只須多項式時間**. **吾人可繼作彈性製造之排程**.

本提案延續及引用 SC **之研究，將其推廣至由** TP **及** PT **合成法則所形成之新類別網路**

計畫之工作如下:

(1) **找出既能分類且可區分之簡單區域結構。**

(2) **重審目前之** TP **及** PT **合成法則，研究如何加以簡化。**

(3) **研究**(1)**內所發現結構之各種狀況以**

- (3.a) **簡化** TP **及** PT **合成法則**
- (3.b) **加強法則使能合成所有良性之前述新類別網路**
- (3.c) **找尋死結和非單調性標記的基本條件**

(3.d) **研究由** TP **及** PT **合成法則所形成之新類別網路之性質如** reachability **。**

關鍵詞：關鍵詞： 派屈網路 活性 有限性 重復性 良性 同部選擇網路 合成 分析

Abstract

The knitting technique is simple, powerful and can be automated as a CAD tool. It synthesizes a new class (larger than Free-Choice FC nets) of PNs called Synchronized Choice (SC) nets.

Proving liveness or equivalently, solving reachability problem for general PNs is a difficult problem and is PSPACE hard problem in the net model. One is interested in finding the largest class of nets that can be analyzed in polynomial time.

SC is interesting because if a designed PN is not an SC, then most likely it suffers from design errors of deadlocks or unbounded. Also its analysis takes polynomial time. This lead to significant results of finding the most simple and fundamental structure for deadlocks considering both structure and marking.

Previously, we proposed synthesis rules for TP- and PT-path generations that can deal with resource sharing. But there are too many rules for a designer to grasp and for automation as a CAD tool [9]. Finding out simple structures and conditions for deadlocks are important because we then can analyze the net in polynomial time and we

can proceed to perform schedulings for a FMS.

This proposal aims to extend the same approach for SCs to nets synthesized using TP- and PT- generations. We

(1) Search local simple structures that both classify and characterize the nets.
(2) Review current rules for TP- and PT- generations and study how to simplify them.
(3) Study all possible cases of the above structures to
   (3.1) Simplify the rules,
   (3.2) Enhance the rules to synthesize all well-behaved nets in the class
   (3.3) Find conditions for deadlocks and irreversibility. Study its properties such as reachability.

Keywords: Petri Nets, Live, Bounded, Reversible, Well-behaved, Synchronized-Choice, Free-Choice, TP- and PT generations.

二、緣由與目的

The knitting technique is simple, powerful and can be automated as a CAD tool [1-9]. It synthesizes a new class (larger than Free-Choice FC nets) of PNs called Synchronized Choice (SC) nets. SC nets, however, are limited in dealing with applications such as FMS that involve resource sharing. Expanding the synthesis rules to allow forbidden generations, we can synthesize more classes of Petri nets. Previously, we investigated TP and PT generations [8], but the rules are too many to be automated and difficult for a designer to follow. There exists a need for their simplification. Also we need to study the properties of the new class of nets, called second-order nets, due to TP and PT generations.

We have obtained outstanding result for our NSC87 [10] proposal. We discover that local structures play a role not only in the classification but also in the characterization of SC nets. These local structures determine not only whether an SC has deadlocks but also whether it is irreversible. They also simplify the synthesis rules to a great extent. Most important, the new synthesis rules can generate all SC nets; in other words, the old rules are enhanced.

Therefore, the research intends to investigate the new local structures associated with the new class of nets resulting from TP and PT generations. The local structures are fundamental and very simple so that the properties of which can be easily investigated. More important, global properties such as deadlocks may be inferred from which and therefore it forms an important research topic.

Afterwards, the conditions for the local structures to be well-behaved can be exploited to simplify and enhance the synthesis rules just as we do for our current NSC project. We will also apply the concept to PN duality to simplify and enhance our research tasks. The dual of a PN results from replacing transitions in the PN with places and vice versa. It is called a reverse dual if we further reverse the direction of any arc.

In the knitting technique, Rule TT.4 becomes Rule PP.2 [1] if we perform the above reverse dual operation. Thus, Rule PP.2 can be eliminated resulting in the simplification of the synthesis rules. For SC, we can eliminate either TT or PP rule (not pure). There are two conditions for a net to be SC and these two conditions are mutually dual to each other. One condition leads to well-behaved Free-Choice nets; it and its dual lead to SC. Duality also applies to the local simple structure. The presence of TP inconsistent pair discovered in the local structure leads to deadlocks. Its dual is

PT inconsistent pair which leads to irreversibility. Thus, the duality of PNs helps us understand more about PN structures, discover new rules, simplify existing rules, discover more conditions for deadlocks and irreversibility, simplify conditions for deadlocks and irreversibility.

四、計畫成果自評

A set of theorems and algorithms have been developed accordingly. We have been able to simplify and enhance previous rules. A number of journal papers will result from this research. They will be submitted to journals for evaluation. The resulting technique should advance and help us understand the PN structure theory. We have completed all our project objectives. The new results are significant and applications of them will be outstanding.

An *asymmetrical* first-order structure with $n_s \in T(P)$ and $n_e \in P(T)$ may result in unboundedness (nonliveness). One way to fix the problem is to insert bridges into the above first-order structure. This results in a new class of nets called Synchronized Choice Ordinary Petri Nets (SNC). However, this class of nets is limited. For instance, there are no ordering of firings among a set of resource-sharing transitions that are exclusive to each other. Sometimes, these transitions must execute one by one. Also, if the synthesized net is initially safe, it stays to be safe for any reachable marking. It is marking monotonic, that is, it will not evolve into a deadlock by adding more tokens. The synchronic distance between any two transitions in a synthesized net is either one or infinite.

To create classes of nets with more general properties, we have to find more alternatives to fix the problem. In one alternative, the two *asymmetrical* first-order structures should be combined to compensate their ill behaviors. This combination is also necessary to have the nets covered by S-invariants to make them

bounded.

Note that it must be that $n_{e1} \leftrightarrow n_{s2;}$ i.e., they are in a circle. Otherwise, the extra tokens from the TP first-order structure cannot be consumed by the PT first-order structure. The net is live if the two output transitions of the n_s place of the PT first-order structure are synchronized to have synchronic distance of one. In general, a number of TP (PT) FOS may be combined to form a composite structure so that more than one extra token generated (consumed). Also, there may be more than one TP first-order structure in combination with more than one PT first-order structure. The above conditions must be generalized. Also previously one TP generation must be immediately followed by a PT generation. We have extended this to allow mingling a number if TP and PT generations; thus, multiple TP generations are followed by multiple PT generations. Such a net is defined as a Composite net (CNET) We have developed theory to ensure the condition for mingling to maintain structure correctness.

We then develop theory to maintain marking correctness. This is more difficult than SNC where marking correctness can be guaranteed by making each covering P-component contain at least one token. Because CNET is a special class, we are able to find its bad siphons and controlling S-invariant. Hence, we are able to determine the exact algebra marking equation for liveness.

We found reasons for too many rules: (1) There are at least two generations; combinations of temporal relationships (sequential late or early, concurrent, exclusive) of their n_s and n_e lead to many rules. (2) Each TP- and PT- Generation must also incorporate rules in the previous knitting technique. (3) Synchronic distance between transitions may render a net not live. This is due to bad siphons. Synchronic distance is marking related and complicates the synthesis.

In addition, we found that the rules can be enhanced to extend the class of synthesized nets in the following ways: (1) Allow mingling a number of TP and PT generations; thus, multiple TP generations are followed by multiple PT generations. (2) The extra tokens by a TP-generation need not be immediately balanced by a PT-generation. The balance can be achieved over a number of composite TP- and PT-generations. The theory behind this has been developed based on our knitting technique for General Petri nets and the multiple rate data flow graphs. As a result, firing ratio between two transitions (or the ratio between two places, or between a place and a transition or vice versa) may be more than one. The rule, however, can be simplified by performing the synthesis in a specific way such that enhancement (2) can be eliminated. (3) Synchronic distances between output transitions of n_s of the PT-generation can be more than one as it was before. The tokens at the n_s no longer distribute uniformly among its output transitions. Since it involves markings, it might be a reachability problem. We attack this problem by breaking the problem into two parts: structure and marking correctness. We follow the knitting technique with a new twist to guarantee the structure correctness. We must ensure the ratio between any two nodes after the generation must remain equal among all paths between the two nodes. For marking correctness, we employ the concept of bad siphons capable of being emptied. *We have established that a TP-generation creates new traps, while a PT- generation creates new siphons. Upon the creation of each new bad siphons, we assign appropriate tokens to places in the bad siphon to ensure it not able to be emptied.*

Based on this bad siphon theory, we can answer the question "What is the least marking to make a SNC live?". The following two questions are *reachability* related.

(1) Given an initial marking, decide whether a target marking is reachable.
(2) Given an initial marking and a target reachable marking, find the firing count vector.

Reachability has been determined as a P-SPACE hard problem. This, however, no longer holds true for SNC. We have proved that for a minimally marked live SNC, each reachable marking corresponds to a GCN; i.e., the set of places marked is a GCN and the set of reachable markings equals the set of all GCNs. Reachability problem can be translated into structure problem for an SNC where each home place holds exactly one token. Namely, a marking is reachable from M_0 if and only if the corresponding set of places holding tokens is a GCN. This nice reachable property still holds for the case of multiple GCNs where each place in the GCNs holds a token because of the algebraic additive nature.

Similarly, for the new class nets with TP- and PT-generations, reachable markings inside a local structure are only affected by the markings surrounding and structure characteristics inside the local structure. We can exhaust all possible reachable markings and develop rules to enumerate them from its initial marking without exhaustive reachability analysis. This combined with the linear analysis for other parts of the net that conforms to SNC requirements may render the analysis efficient. Recently, we have discovered that any net can be decomposed into four basic kinds of first order structures. It is easy to study their reachable markings and develop rules.

We have shown that the TP-PT rules

cover that of synchronization and cyclic interactions as subsets. Thus, the knitting technique distincts the most from other synthesis techniques in that we explicitly show the rules can be continuously enhanced. As more and more rules are discovered, the reduction and analysis process becomes more and more powerful.

五、參考文獻

[1]. Chao, D.Y. and Wang, D.T., "Two Theoretical and Practical Aspects of Knitting Technique Invariants and A New Class of Petri Net," IEEE Transactions on System, Man, and Cybernatics, Vol. 27, No.7, 1997, pp.962-937.

[2]. Chao, D.Y., Zhou, M.C., and Wang, D.T., "Extending Knitting Technique to Petri Net Synthesis Of Automated Manufacturing Systems," *The Computer Journal*, Oxford University Press, Vol. 37, No. 1-2, January, 1994, pp. 1-10.

[3] Chao, D.Y. and Wang, D.T., "A Synthesis Technique Of General Petri Nets," Journal of Systems Integration, Vol. 4, No. 1, February, 1994, pp. 67-102.

[4]. Chao, D.Y. and Wang, D.T., "A Synthesis Technique Of General Petri Nets," *Journal of Systems Integration*, Vol. 4, No. 1, February, 1994, pp. 67-102.

[4]. Chen, W.T. Tsai, and D.Y. Chao, "Dependency Analysis ----A Compositional Technique for Building Large Petri nets," *IEEE Trans. on Parallel and Distributed Systems*, Vol. 4, No. 4, pp. 414-426, 1993.

[5]. Chao, D.Y. and Wang, D.T., "Application of Knitting Technique and Structural Matrix to Deadlock Analysis and Synthesis of Petri Nets With Sequential Exclusion," *International Conference on System, Man, and Cybernatics,* San Antonio, pp. 1332-1339.

[6]. Chao, D.Y., “Application of A Synthesis Algorithm to Flexible Manufacturing System,” Journal of Information Science and Engineering, Vol. 14, No. 2, June 1998, pp. 409-447.

[7]. Chao, D.Y., “Petri Net Synthesis and Synchronization Using Knitting Technique,” Journal of Information Science and Engineering, Vol. 18, No. 5, 1999, pp. 543-568.

[8]. Chao, D.Y. and D.T. Wang, “Knitting Technique with TP-PT Generations for Petri Net Synthesis,” (Invited), Proc. 1995 IEEE Int'l Conf SMC, Vancouver, Canada, pp.1454-1459, October 22-25, 1995.

[9] Chao, D.Y. and Wang, D.T., "An Interactive Tool for Design, Simulation, Verification, and Synthesis for Protocols," Software-Practice and Experience, an International Journal, Vol. 24, No. 8, August 1994, pp. 747-783.

[10] D. Y. Chao, Jau-Hung Tseng, "Some Properties of Synchronized Choice Ordinary Petri Nets,” Invited Session paper, 1999 IFAC, Beijing China, July 5-9, 1999, pp.193-197.