出國報告（出國類別：參加 SSCI 國際會議）

2014 年 IEEE 計算智能控制和自動化學術研討會

服務機關： 政治大學
姓名職稱： 趙玉教授
派赴國家： 美　　國
出國期間：103/12/09-12/12
報告日期：104/05/04

摘要

本報告描述本人出席2014年IEEE計算智能控制和自動化學術研討會，過程、感想及建議。此次會議內容廣泛精彩，參加此會議受益良多，可一覽國外最新研究趨勢。諸如智能嵌入式系統。透過傳感器，執行器和計算智能型運算能力的嵌入式處理系統之整合，智能運算已逐漸溶入我們之日常生活，而目前之技術也能夠在不斷變化之環境中針對特定目的和情境做互動。類似之研究主題包括:網絡物理系統之計算智能應用、智能故障診斷系統、物聯網的智能解決方案、智能傳感器和機器人及在環境演變/變化的環境中自適應系統解決方案。

另外對於邁向21世紀值得注意之議題為認知運算:

電腦和人腦介面(BCI)，透過BCI技術可以讓人腦和電腦直接溝通，該方面之研究在將演講直譯成文字有顯著的成就。

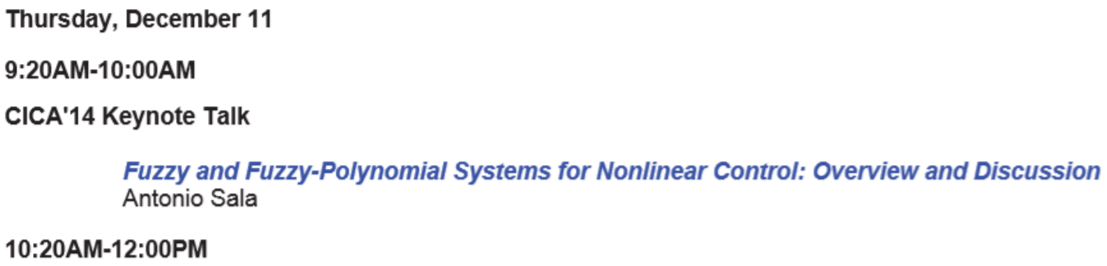
認知機器人：在輔助設備和工業應用上機器人的開發是計算智能研究的一個重要領域。如何在機器人開發自己對世界的理解。腦啟發認知(Brain-inspired cognitive)機器人變得越來越流行，並在自治系統的設計和實作上等領域有突破之發展。

目次

壹、目的

計算智能已廣泛應用於各種生活領域，透過研討會各領域之智能計算，希望能尋求派翠網路在相關領域之應用。以資訊管理的角度檢視其發展方向及系統整合過程，都免不了面對資源及最佳化以提高效率之議題。透過參加研討會可以廣泛瞭解各項智能計算所面臨之問題及現行解決方式，同時在會議之問題及尋求更佳解決方案之討論過程，均可提供資訊系統未來應用在計算智能系統整合之研究方向。

貳、會議過程



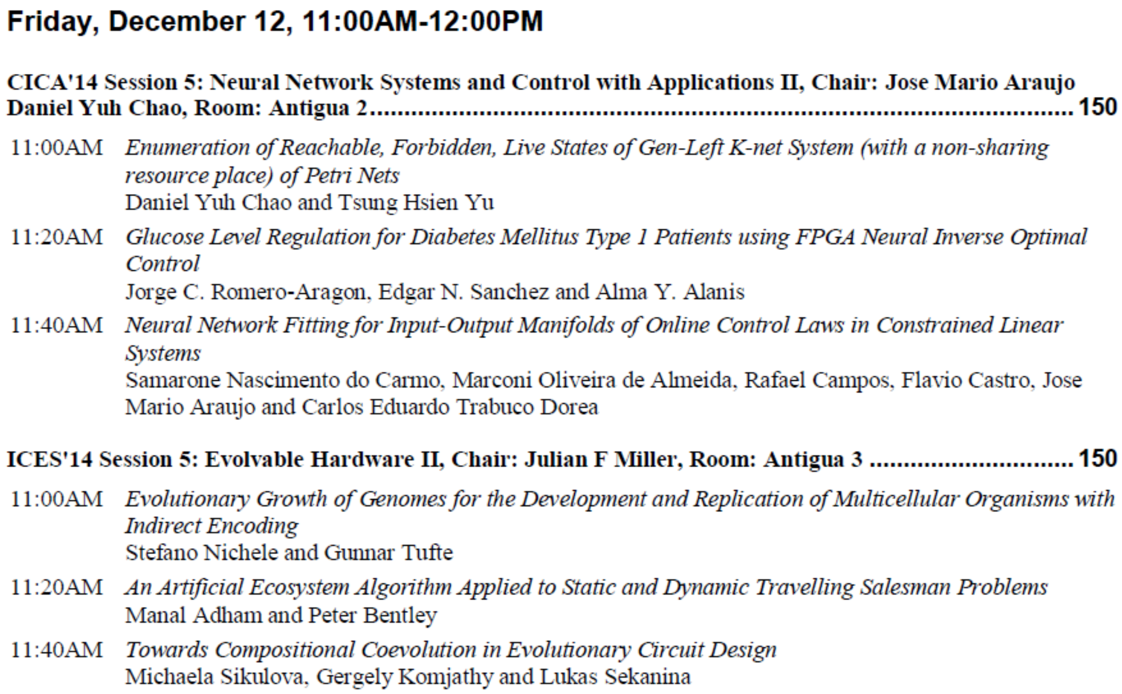
Thursday, December 11

9:20AM-10:00AM

CICA'14 Keynote Talk

Fuzzy and Fuzzy-Polynomial Systems for Nonlinear Control: Overview and Discussion
Antonio Sala

10:20AM-12:00PM



Friday, December 12, 11:00AM-12:00PM

CICA'14 Session 5: Neural Network Systems and Control with Applications II, Chair: Jose Mario Araujo Daniel Yuh Chao, Room: Antigua 2 150

11:00AM *Enumeration of Reachable, Forbidden, Live States of Gen-Left K-net System (with a non-sharing resource place) of Petri Nets*
Daniel Yuh Chao and Tsung Hsien Yu

11:20AM *Glucose Level Regulation for Diabetes Mellitus Type 1 Patients using FPGA Neural Inverse Optimal Control*
Jorge C. Romero-Aragon, Edgar N. Sanchez and Alma Y. Alanis

11:40AM *Neural Network Fitting for Input-Output Manifolds of Online Control Laws in Constrained Linear Systems*
Samarone Nascimento do Carmo, Marconi Oliveira de Almeida, Rafael Campos, Flavio Castro, Jose Mario Araujo and Carlos Eduardo Trabuco Dorea

ICES'14 Session 5: Evolvable Hardware II, Chair: Julian F Miller, Room: Antigua 3 150

11:00AM *Evolutionary Growth of Genomes for the Development and Replication of Multicellular Organisms with Indirect Encoding*
Stefano Nichele and Gunnar Tufte

11:20AM *An Artificial Ecosystem Algorithm Applied to Static and Dynamic Travelling Salesman Problems*
Manal Adham and Peter Bentley

11:40AM *Towards Compositional Coevolution in Evolutionary Circuit Design*
Michaela Sikulova, Gergely Komjathy and Lukas Sekanina

參、會議重點摘錄

本次年會焦點在於計算智能及相關應用。包括：計算智能的類人智能、計算智能生產和物流系統、IEEE機器人在康復和輔助技術、計算智能調度、計算智能車輛和運輸系統、演變與自主學習系統、計算智能、智能代理…等多項研究議題。

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肆、與會心得與建議

從會議之主題及參訪過程，覺得SSCI是兼顧學術性及應用性的會議，許多論文之發表均有顯示真正實作影片之介紹，其中也不乏企業界贊助所發表之論文。同時在會議進行過程也提供企業展示解決方案及資訊交流之平台。正當我們正朝著無孔不入，無處不在的計算模式前進，環境感知系統在過去十年是被廣為研究之議題，已成為隨時隨地和任何計算的新時代。為用戶提供可以接受的服務要求服務要知道自己的背景，並能夠對不斷變化的環境自動適應。環境感知建模是環境感知的生命週期的一個重要部分，處理和表示環境感知而認識意味著推理有關上下文。每個環境感知建模方法隨之帶來一個推理方法。基於關係的概念分析，形式概念分析的擴展環境感知模型，並採用關係型概念分析的源實體和描述邏輯的目標元素之間現有的映射規則，以獲得FL-E知識庫和能夠推理環境感知。

物聯網（IOT）是指唯一可識別物體和人，以及在類似互聯網的基礎設施。第一和第二次工業革命後，物聯網已被喻為我們一生的下一次技術革命，成為一個不可或缺和使能技術的智能系統，例如，智能城市和智能家居。由於物聯網，才使系統更“智能”化，例如具有決策、學習的能力、動態適應，並且在數據接收，發送，和/或處理，以提高其和環境互動能力。物聯網啟用智能系統來進行自我檢測，自我診斷，自我修正，

自我監督，自我組織，自我複製，自我控制的功能。他們的設計和實施需要方法和體系結構能夠有效地收集，管理和處理大型/複雜的數據集和流程，並最終管理和不同層次的控制自己（從地方到全球），因為它們是由許多不同測量尺度之實體網絡組成（智能對象，傳感器和執行器，嵌入式計算機，移動設備，機器，工廠，建築物和人）。物聯網功能的智能系統的大規模自然引起了一些具體的挑戰和問題，包括：有效的數據收集，清理和存儲;數據延遲和實時大數據分析;新方法的全球系統的控制;大型管理平台，有效地發展;明確定義的物聯網技術的控制界面;和各種物聯網的標準。這次研討會介紹一些最近的進展和舉措對這些問題的解決，並勾勒出智能城市，智能電網，智能工廠，智能樓宇和智能住宅的一些應用前景。

伍、個人簡報資料

“Enumeration of Reachable, Forbidden, Live States of Gen-Left K-net System (with a non-sharing resource place) of Petri Nets” 。論文摘要如下:

Earlier, Chao pioneered the very first closed-form solution of the number of reachable and other states for marked graphs (MG) and *k*-th order system which is the simplest class of S^3PR (Systems of Simple Sequential Processes with Resources). This paper progresses one step further on enumerating reachable (forbidden, live, and deadlock) states for general *k-net* systems (one non-sharing resource place in the general position of the Left-side process) with a formula depending on parameter k for a subclass of nets with k sharing resources. The results are also verified by *Top-Left-k-net, Bottom-Left-k-net* and *Middle-Left-k-net* system.

先前，趙玉率先建構標示圖及和K階系統之可達及其他狀態之封閉解。K階系統是最簡單的類 S3PR（與資源簡單的順序流程系統）。本文前進了一步以附加 k 參數及非共享資源位置之公式 列舉K-網系統（在左側過程的一般位置存在一個非共享資源的地方）之可達（禁止，生活和死鎖）之個數。其解果也經左上-K-網，底左K-網和中東左-K-Net系統也驗證等模型之資料驗證。

Enumeration of Reachable, Forbidden, Live States of *Gen-Left K-net* System (with a non-sharing resource place) of Petri Nets
枚舉派翠網路一般化左**K-NET**系統(存在一非共享資源)之可達,禁止,生存狀態

Daniel Yuh Chao
Tsung Hsien Yu

Department of Managment Information Systems,
National Chengchi University

SSCI 2014

December 9-12, 2014

Outline

- **Introduction(介紹)**
- **Contributions of our series papers (我們一系列論文的貢獻)**
- **Computation of *Gen-Left k-net* system Control related states (一般化左K-NET系統控制相關狀態的計算)**
- **Conclusion(結論)**

Introduction

- Professor Chao pioneered the very first closed-form solution of the number of reachable and other states for marked graphs (MG) and *k*-th order *S^3PR* (*Top-Right, Bottom-Right, Middle-Right, Top-Left, Right-Left, Middle-Left*)
- This paper progresses one step further on enumerating reachable (forbidden, live, and deadlock) states for *Gen-Left k-net* systems

Introduction

- 趙教授率先建構標示圖及和**K**階系統之可達及其他狀態之封閉解（右上，右下，右中，左上，左下，左中）
- 本研究進了一步列舉一般化左**K-NET**系統之可達（禁止，生活和死鎖）狀態

Introduction

- **Large PN** models may take **one month** to complete the reachability analysis
- An alternative **control policy** is employed, the total number of reachable states is needed to estimate the **percentage of lost states.**

Introduction

- In **deadlock recovery**, to estimate deadlock probability among all reachable states. We needs to compute the total number of reachable states to find the percentage**(deadlock/ reachable states)**—rather difficult for arbitrary nets.

Introduction

- 大**PN**模型可能需要一個月才能完成的可達性分析
- 當引用任何選項之控制策略**,** 為計算丟失狀態的百分比**,** 需要估計可達狀態的總數
- 在恢復死結，估計所有可達狀態之死結概率。我們需要計算可達狀態的總數以便找到百分比（死鎖/可達狀態）-對任一網路架構而言都是高難度挑戰。

Contributions of our series papers k-th order system (Chao 2014)

(*Gen-Left*) k-th order system ：

- A subclass of S^3PR with k resource places r_1, $r_2, \ldots, r_k$ shared between two processes N_1 and N_2. and one non-sharing resource place r'_{gen} (=r^*) used by an operation place p^* in P_1
- $M_0(r_1) = M_0(r_2) = \ldots M_0(r_k) = M_0(r'_{gen}) = 1$.
- N_1(resp. N_2) uses $r_1, r_2, \ldots, r_k$ (resp. $r_k, r_{k-1}, \ldots, r_1$)

Contributions of our series papers
k-th order system (Chao 2014)

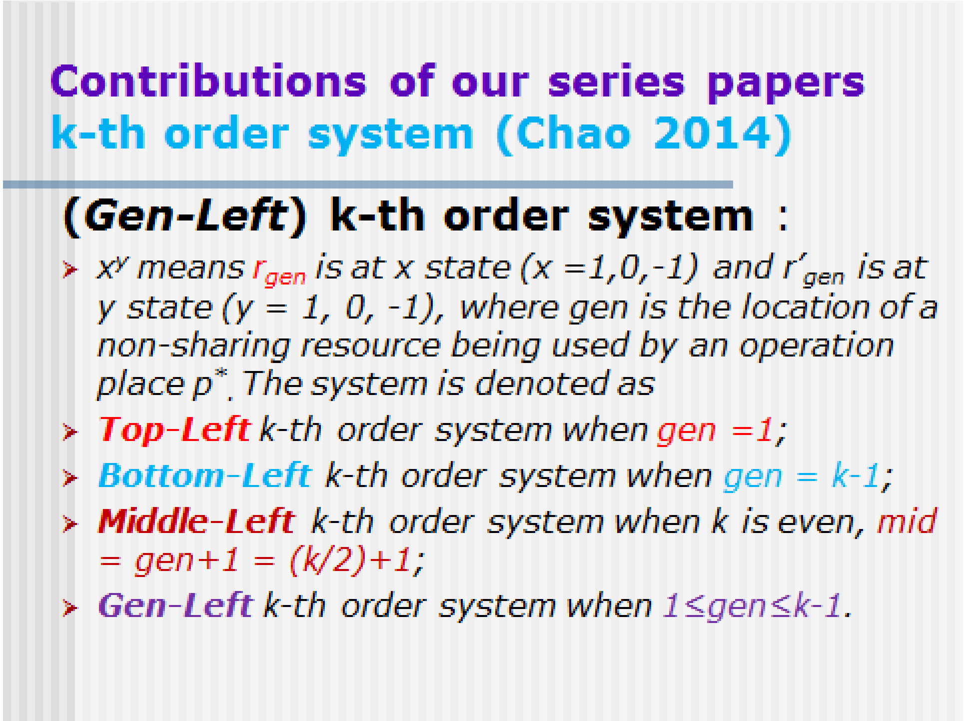
(*Gen-Left*) k-th order system :

- $M_0(p_0) = k+1, M_0(p'_0)=k$, where p_0 and p'_0 are the idle places in processes N_1 and N_2
- Holder places of r_j in N_1 and N_2 are denoted as p_j and p'_jrespectively.
- The compound circuit containing $r_i, r_{i+1}, \ldots, r_{j-1}, r_j$ is called (r_i-r_j)-region.
- If r'_h does not exist, then it is called a k-th order system.

Contributions of our series papers
k-th order system (Chao 2014)

(*Gen-Left*) k-th order system :

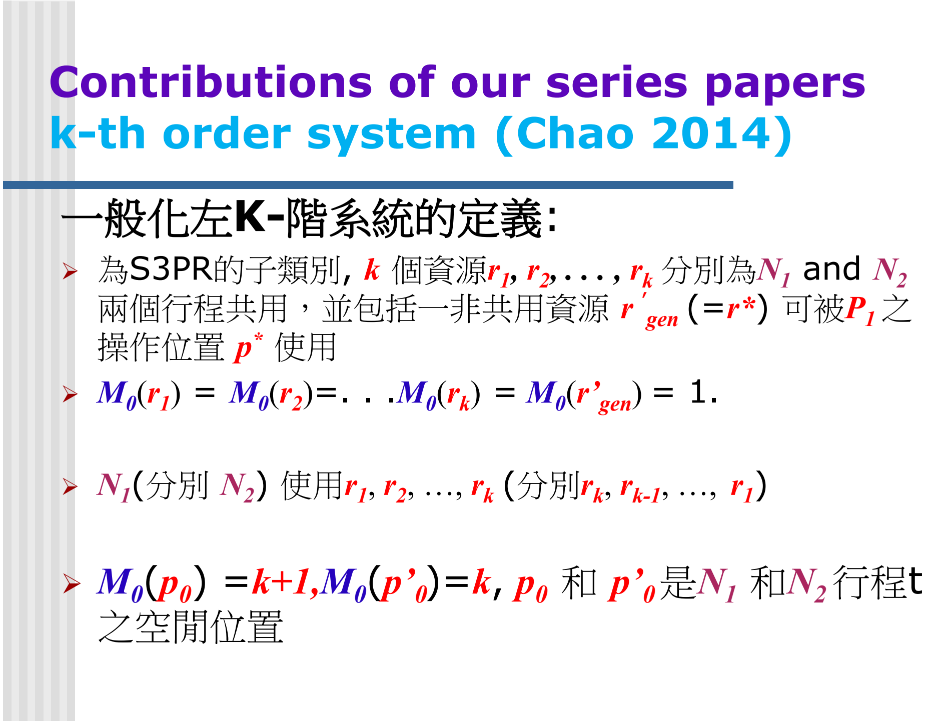
- There are 3 possibilities for the token initially at r_i to sit at: p_i (N_1), p'_i, (N_2),and r_i. The corresponding token or r_i state is denoted by 1, -1 and 0, respectively.



Contributions of our series papers
k-th order system (Chao 2014)

(*Gen-Left*) k-th order system ：

- *x^y means r_{gen} is at x state (x =1,0,-1) and r'_{gen} is at y state (y = 1, 0, -1), where gen is the location of a non-sharing resource being used by an operation place p^*. The system is denoted as*
- ***Top-Left*** *k-th order system when gen =1;*
- ***Bottom-Left*** *k-th order system when gen = k-1;*
- ***Middle-Left*** *k-th order system when k is even, mid = gen+1 = (k/2)+1;*
- ***Gen-Left*** *k-th order system when 1≤gen≤k-1.*



Contributions of our series papers
k-th order system (Chao 2014)

一般化左**K**-階系統的定義:

- 為S3PR的子類別, k 個資源$r_1, r_2, . . . , r_k$ 分別為N_1 and N_2 兩個行程共用，並包括一非共用資源 r'_{gen} (=r^*) 可被P_1之操作位置 p^* 使用
- $M_0(r_1) = M_0(r_2) = . . . M_0(r_k) = M_0(r'_{gen}) = 1.$
- N_1(分別 N_2) 使用$r_1, r_2, …, r_k$ (分別$r_k, r_{k-1}, …, r_1$)
- $M_0(p_0) = k+1, M_0(p'_0) = k$, p_0 和 p'_0是N_1 和N_2行程t之空閒位置

Contributions of our series papers
k-th order system (Chao 2014)

一般化左**K-**階系統的定義:

- 在 N_1 和N_2 中使用 r_j之操作位置分別記為 p_j 和 p'_j.
- 包含 $r_i, r_{i+1}, \ldots, r_{j-1}, r_j$ 之複合線路稱為 (r_i-r_j)-區域.
- 如果 r^* 不存在則稱為 k-階系統.
- 當r_i符記初使位置於: p_i (N_1), p'_i (N_2),和r_i時有三種可能性。相關之符記或 r_i 之狀態分別記為 1, -1 和 0.

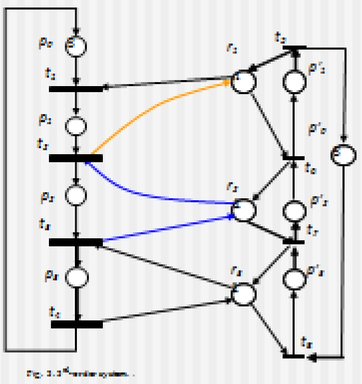
Contributions of our series papers
k-th order system (Chao 2014)

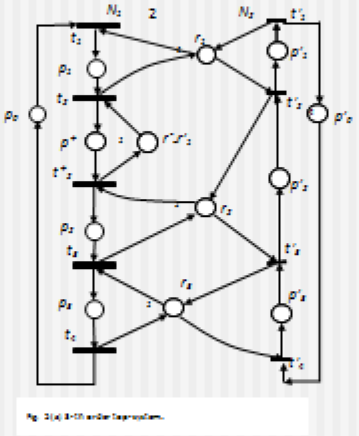
一般化左**K-**階系統的定義:

- x^y 意味r_{gen}是處於x狀態 (x =1,0,-1)而r'_{gen} is處於 y狀態(y = 1, 0, -1), gen是被p^*操作位置使用之非共享資源的位置
- 當*gen =1* 時稱為左上k階系統
- 當*gen = k-1* 時稱為左下k階系統
- 當*mid = gen+1 = (k/2)+1* 時稱為左中k階系統
- 當$1 \leq gen \leq k-1$時稱為一般化左k階系統

Contributions of our series papers
k-th order system (Chao 2014)

(*Gen-Left*) *3*-th order system :





Contributions of our series papers
k-th order system (Chao 2014)

Important Lemmas and Theorems

Lemma 1: *Any forbidden state in N is nonreachable in N^r.*

Lemma 2: *Any nonreachable state in N is a forbidden one or a nonreachable one in N^r.*

Contributions of our series papers
k-th order system (Chao 2014)

重要引理和定理

*引理**1**：任何在N中為禁止狀態,在N^r中必為非可達狀態.*

*引理**1** :任何在 N中為非可達狀態,在N^r中必為非可達狀態或禁止狀態.*

Contributions of our series papers
k-th order system (Chao 2014)

Important Lemmas and Theorems

Theorem 1:

F(k)=¥(k) – B(k), where

F(k) : No. of forbidden states

¥(k) : No. of nonreachable states,

B(k) : No. of nonreachable +empty-siphon states

Contributions of our series papers
k-th order system (Chao 2014)

重要引理和定理

定理 **1:**

***F(k)*=*¥(k)* – *B(k)*,**

***F(k)* :** 為禁止狀態之個數

***¥(k)* :** 為非可達狀態之個數

***B(k)* :**為非可達且為空虹吸狀態之個數

Contributions of our series papers
k-th order system (Chao 2014)

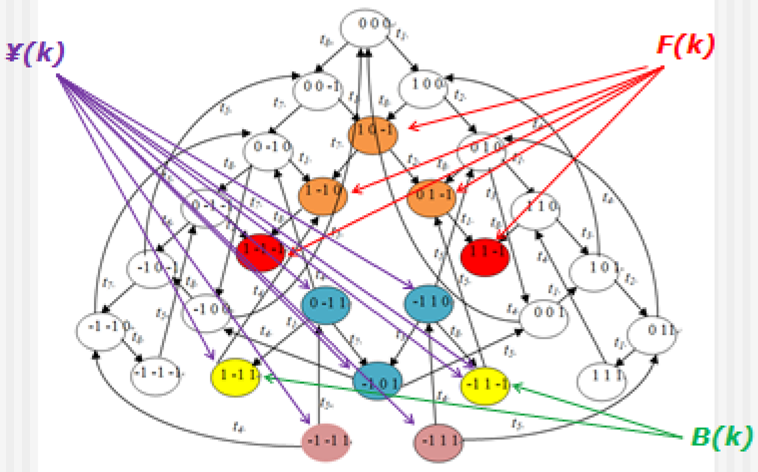
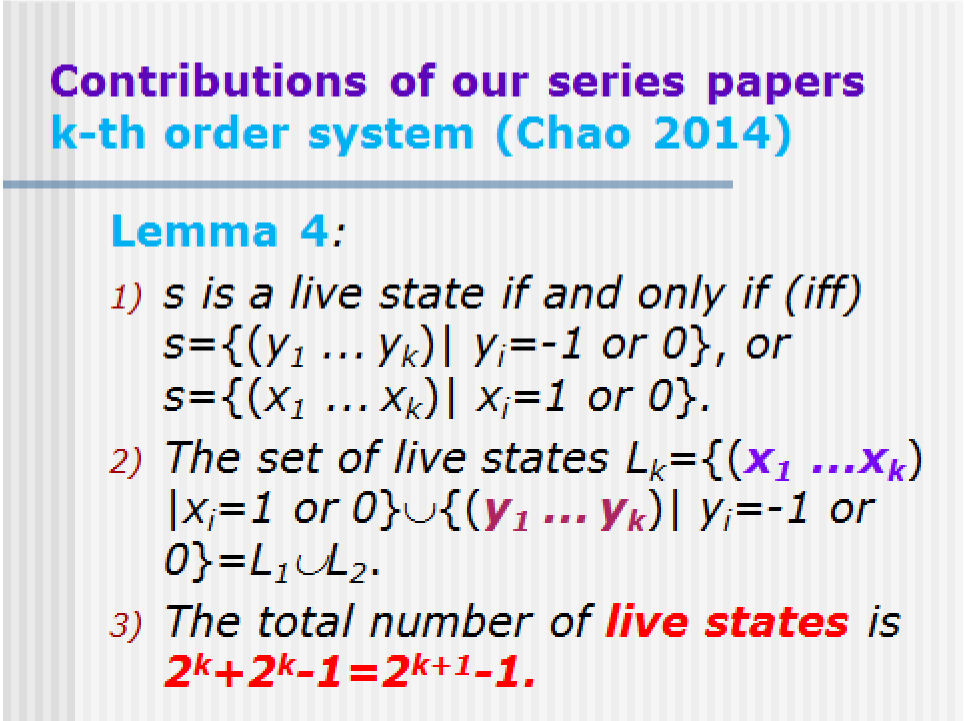


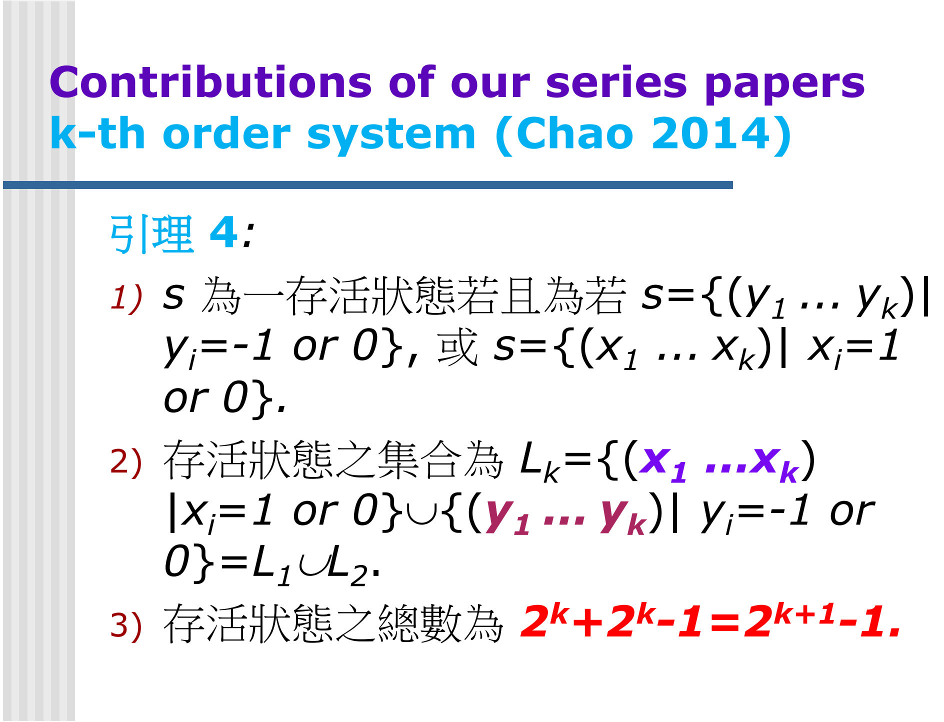
Fig. 6 Complete reachability graph of a 3rd-order system.



Contributions of our series papers
k-th order system (Chao 2014)

Lemma 4:

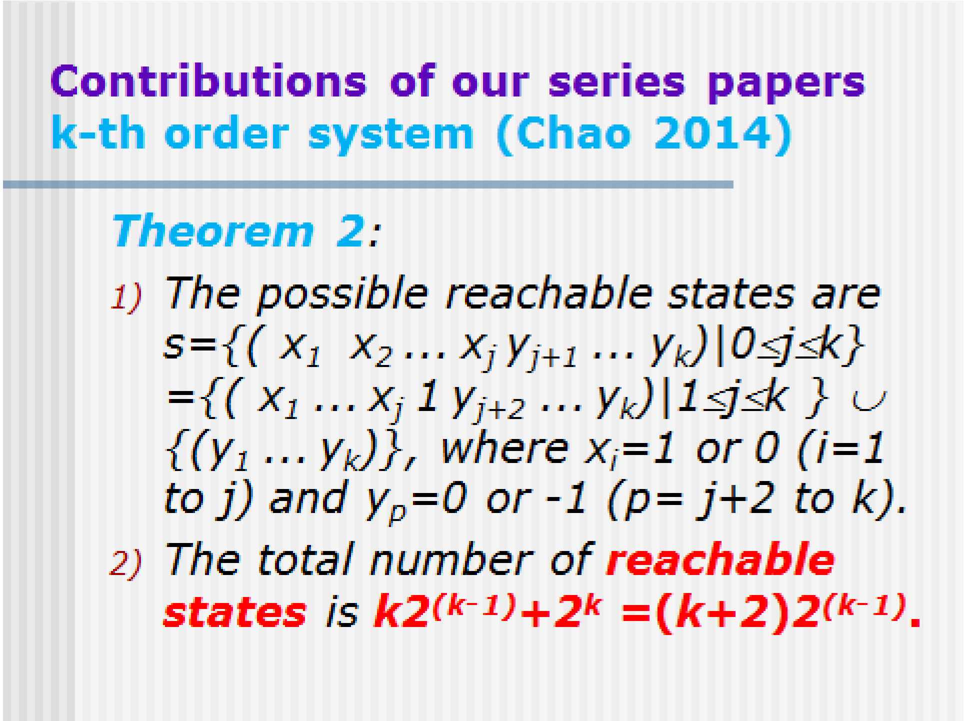
1) *s is a live state if and only if (iff)* $s=\{(y_1 \ldots y_k) \mid y_i=-1 \text{ or } 0\}$, or $s=\{(x_1 \ldots x_k) \mid x_i=1 \text{ or } 0\}$.
2) *The set of live states* $L_k=\{(\mathbf{x_1} \ldots \mathbf{x_k}) \mid x_i=1 \text{ or } 0\} \cup \{(\mathbf{y_1} \ldots \mathbf{y_k}) \mid y_i=-1 \text{ or } 0\}=L_1 \cup L_2$.
3) *The total number of* ***live states*** *is* $2^k+2^k-1=2^{k+1}-1$.



Contributions of our series papers
k-th order system (Chao 2014)

引理 4:

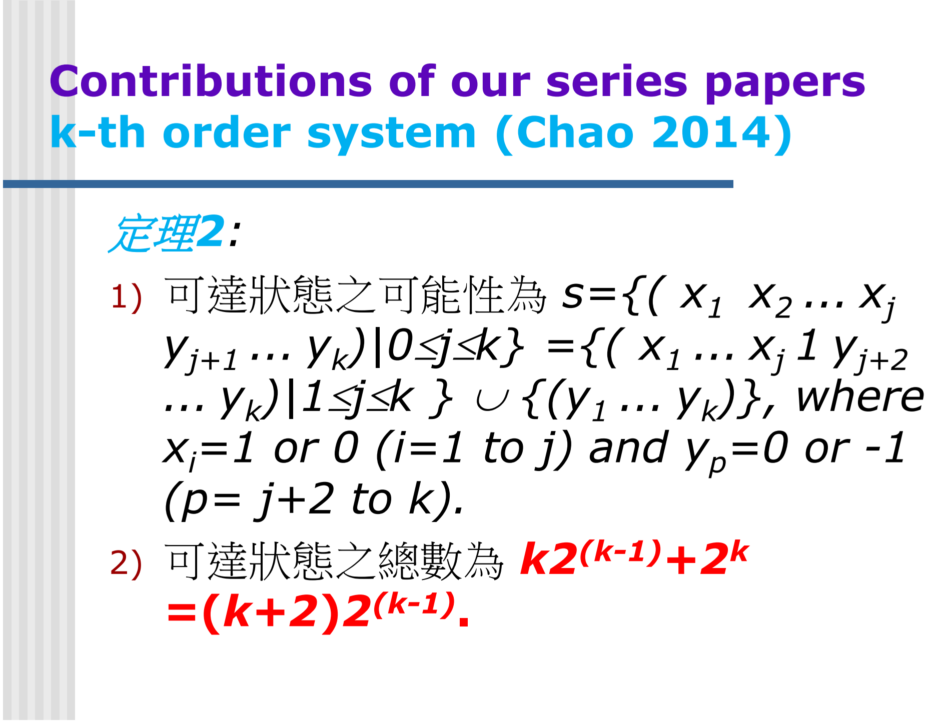
1) s 為一存活狀態若且為若 $s=\{(y_1 \ldots y_k) \mid y_i=-1 \text{ or } 0\}$, 或 $s=\{(x_1 \ldots x_k) \mid x_i=1 \text{ or } 0\}$.
2) 存活狀態之集合為 $L_k=\{(\mathbf{x_1} \ldots \mathbf{x_k}) \mid x_i=1 \text{ or } 0\} \cup \{(\mathbf{y_1} \ldots \mathbf{y_k}) \mid y_i=-1 \text{ or } 0\}=L_1 \cup L_2$.
3) 存活狀態之總數為 $2^k+2^k-1=2^{k+1}-1$.



Contributions of our series papers
k-th order system (Chao 2014)

Theorem 2:

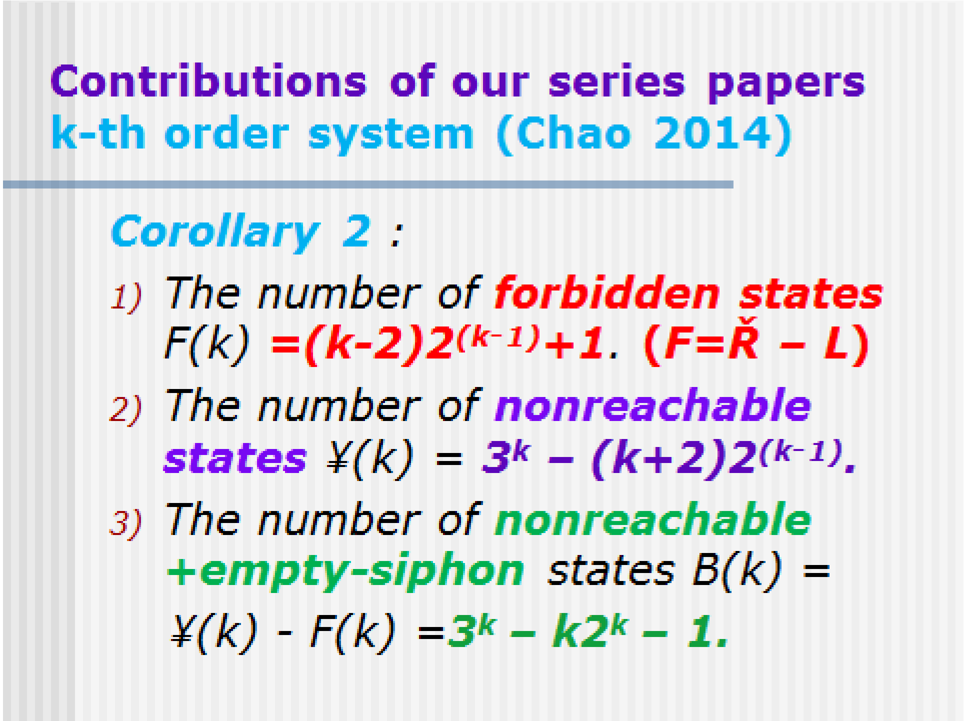
1) *The possible reachable states are $s=\{(x_1\ x_2 \dots x_j\, y_{j+1} \dots y_k) \mid 0 \le j \le k\}$ $=\{(x_1 \dots x_j\, 1\, y_{j+2} \dots y_k) \mid 1 \le j \le k\} \cup \{(y_1 \dots y_k)\}$, where $x_i=1$ or 0 ($i=1$ to j) and $y_p=0$ or -1 ($p= j+2$ to k).*
2) *The total number of **reachable states** is $k2^{(k-1)}+2^k=(k+2)2^{(k-1)}$.*



Contributions of our series papers
k-th order system (Chao 2014)

定理2:

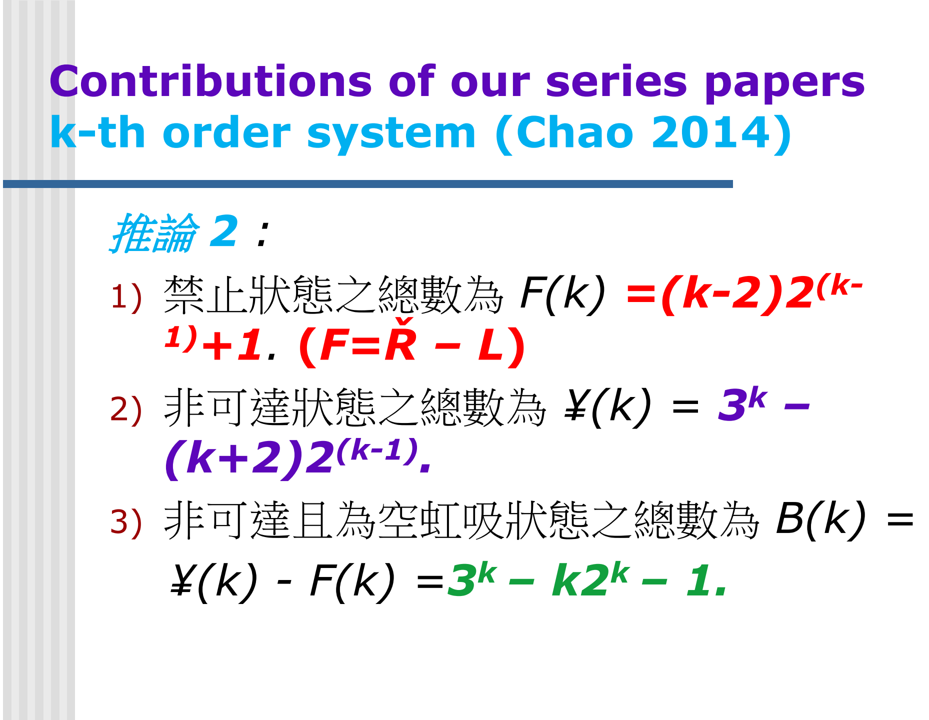
1) 可達狀態之可能性為 $s=\{(x_1\ x_2 \dots x_j\, y_{j+1} \dots y_k) \mid 0 \le j \le k\}$ $=\{(x_1 \dots x_j\, 1\, y_{j+2} \dots y_k) \mid 1 \le j \le k\} \cup \{(y_1 \dots y_k)\}$, *where* $x_i=1$ *or* 0 ($i=1$ *to* j) *and* $y_p=0$ *or* -1 ($p= j+2$ *to* k).
2) 可達狀態之總數為 $\boldsymbol{k2^{(k-1)}+2^k=(k+2)2^{(k-1)}}$.



Contributions of our series papers k-th order system (Chao 2014)

Corollary 2 :

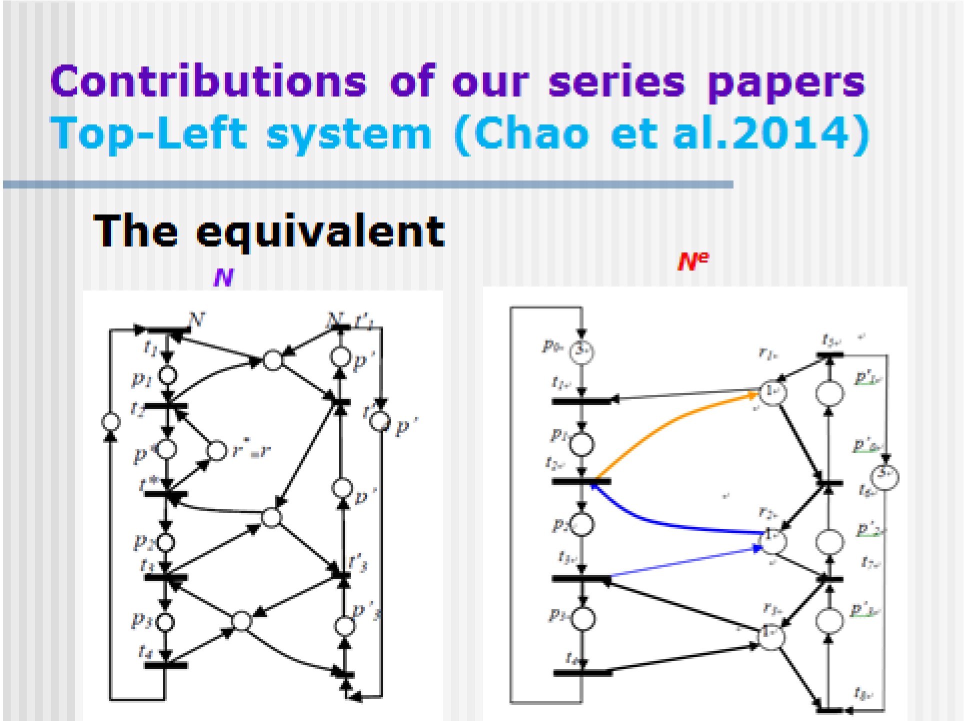
1) *The number of* ***forbidden states*** *F(k)* $=(k-2)2^{(k-1)}+1$. $(F=\check{R}-L)$
2) *The number of* ***nonreachable states*** *¥(k)* $= 3^k - (k+2)2^{(k-1)}$.
3) *The number of* ***nonreachable +empty-siphon*** *states B(k) = ¥(k) - F(k)* $=3^k - k2^k - 1$.



Contributions of our series papers k-th order system (Chao 2014)

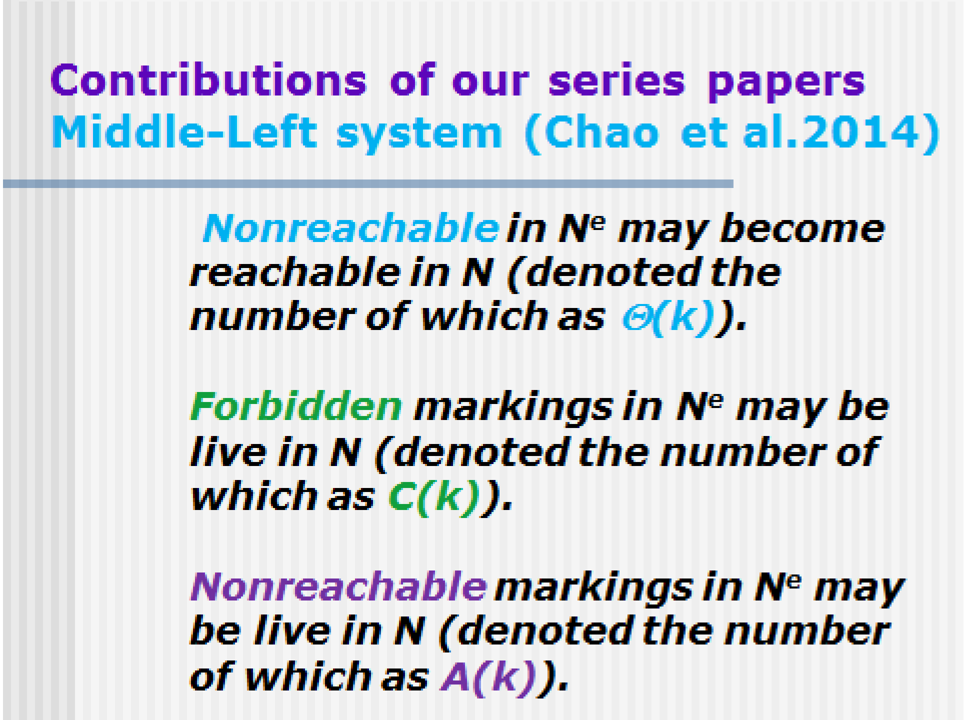
推論 2 :

1) 禁止狀態之總數為 *F(k)* $=(k-2)2^{(k-1)}+1$. $(F=\check{R}-L)$
2) 非可達狀態之總數為 *¥(k)* $= 3^k - (k+2)2^{(k-1)}$.
3) 非可達且為空虹吸狀態之總數為 *B(k) = ¥(k) - F(k)* $=3^k - k2^k - 1$.



Contributions of our series papers
Top-Left system (Chao et al.2014)

The equivalent



Contributions of our series papers
Middle-Left system (Chao et al.2014)

***Nonreachable* in N^e may become reachable in N (denoted the number of which as $\Theta(k)$).**

***Forbidden* markings in N^e may be live in N (denoted the number of which as $C(k)$).**

***Nonreachable* markings in N^e may be live in N (denoted the number of which as $A(k)$).**

Contributions of our series papers
Middle-Left system (Chao et al.2014)

在N^e中為非可達註記,但在 N 中可能為可達狀態記為 $\Theta(k)$).

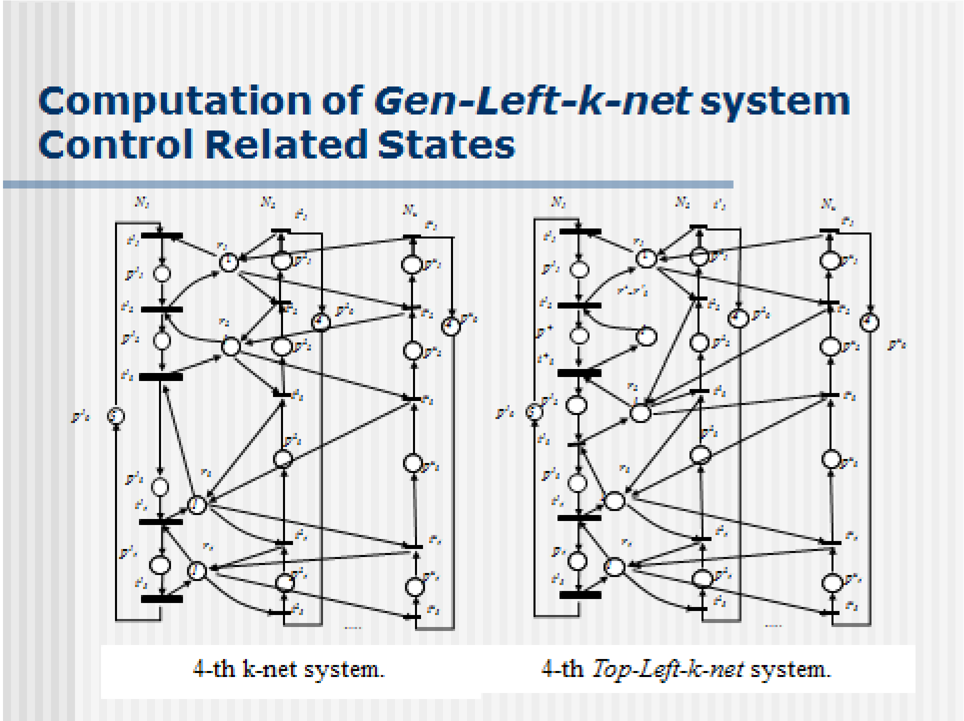
在N^e中為禁止註記,但在 N中可能為存活狀態記為$C(k)$).

在N^e中為非可達註記,但在 N中可能為存活狀態記為$A(k)$).

Contributions of our series papers
Middle-Left system (Chao et al.2014)

$R'=2R+\Theta(k)$.

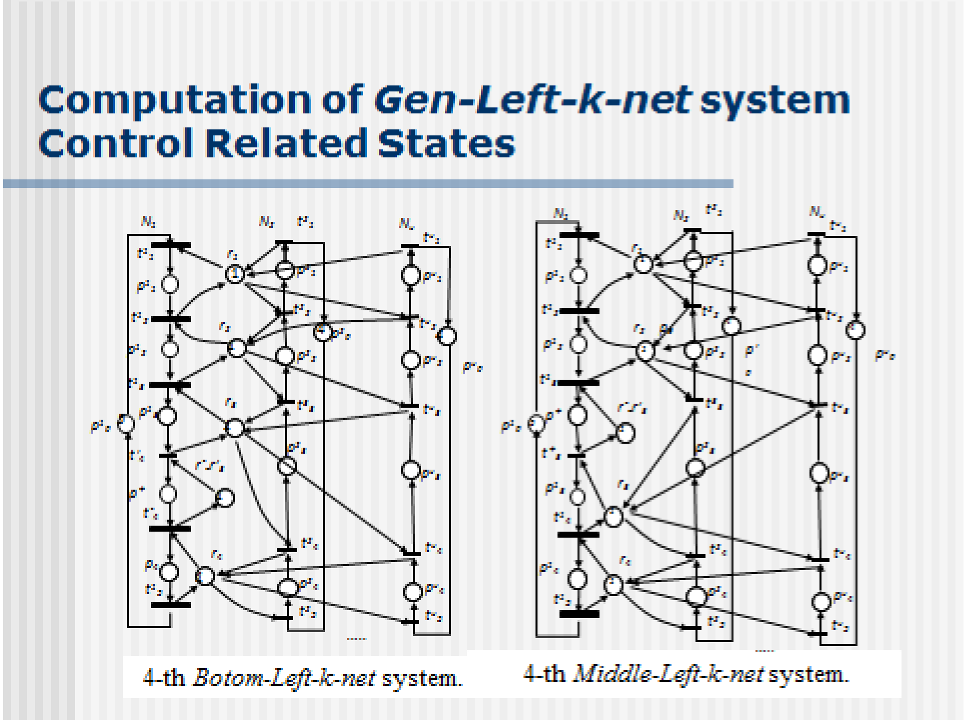
$L'=2L+A(k)+C(k)$.



Computation of *Gen-Left-k-net* system Control Related States

4-th k-net system.

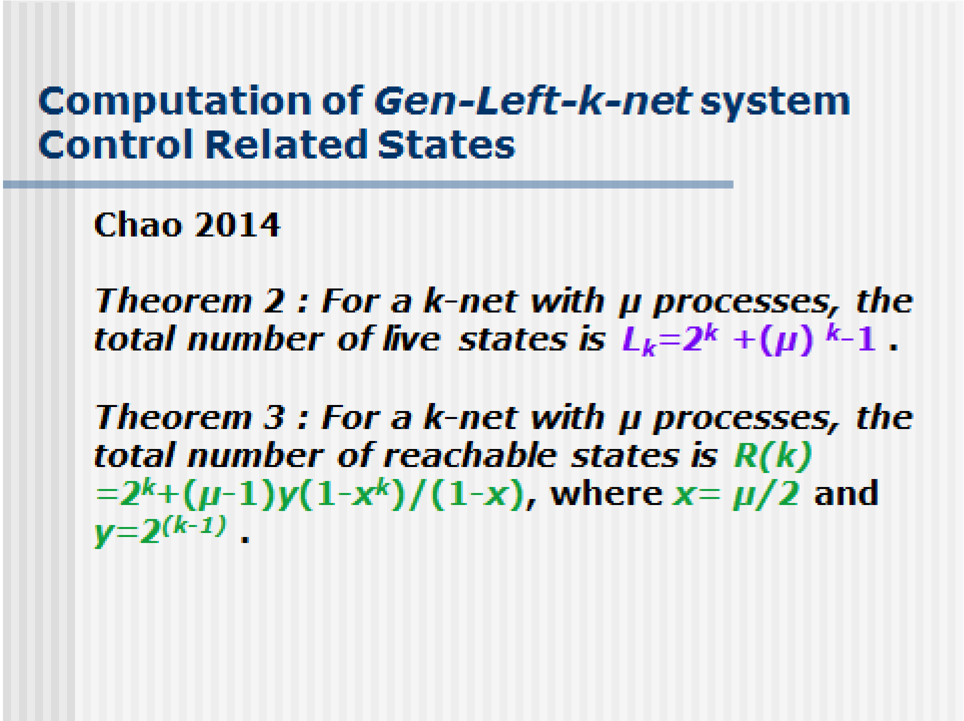
4-th *Top-Left-k-net* system.



Computation of *Gen-Left-k-net* system Control Related States

4-th *Botom-Left-k-net* system.

4-th *Middle-Left-k-net* system.

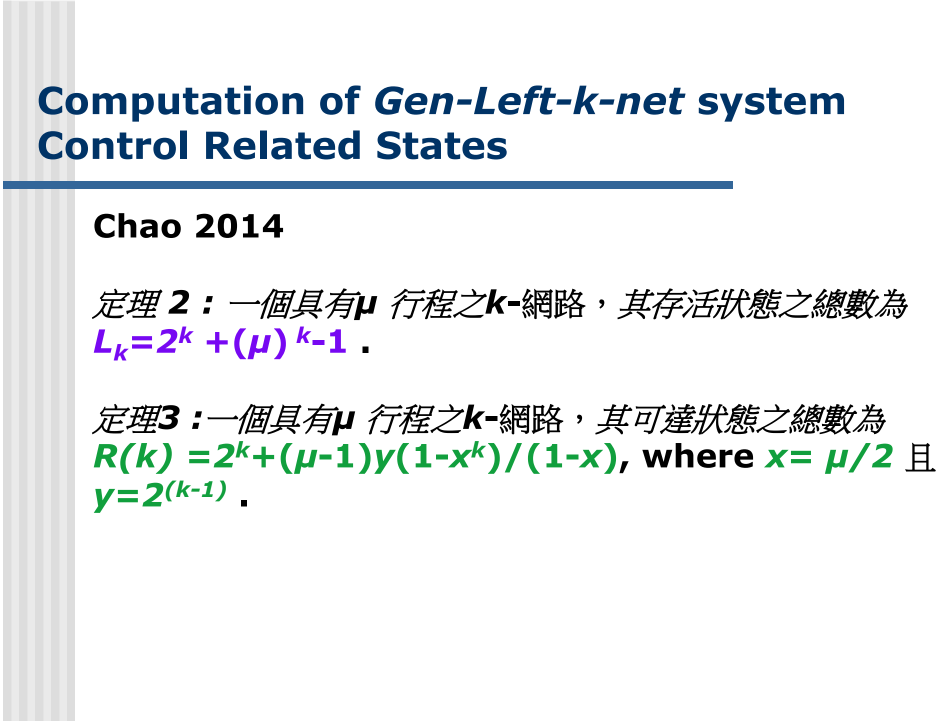


Computation of *Gen-Left-k-net* system Control Related States

Chao 2014

Theorem 2 : For a k-net with μ processes, the total number of live states is $L_k=2^k+(\mu)^{k}-1$.

Theorem 3 : For a k-net with μ processes, the total number of reachable states is $R(k) =2^k+(\mu-1)y(1-x^k)/(1-x)$, **where** $x=\mu/2$ **and** $y=2^{(k-1)}$.



Computation of *Gen-Left-k-net* system Control Related States

Chao 2014

定理 **2 :** *一個具有***μ** *行程之***k-**網路，*其存活狀態之總數為* $L_k=2^k+(\mu)^{k}-1$.

*定理***3 :***一個具有***μ** *行程之***k-**網路，*其可達狀態之總數為* $R(k) =2^k+(\mu-1)y(1-x^k)/(1-x)$, **where** $x=\mu/2$ 且 $y=2^{(k-1)}$.

Computation of *Gen-Left-k-net* system Control Related States

Gen-Left k-net

$\text{Ł}'_k=2L_k+A'(k)+C'(k).$

The total number of forbidden markings that may be live, $C'(k)=(gen)((\mu)^{(k-gen)}-1)$.

The total number of nonreachable markings that may be live, $A'(k)=(u^{(gen)}-1)(k-gen)$.

Theorem 4: For a Gen-Left k-net with μ processes the total number of live markings

$$\text{Ł}'_k=2\,L_k+(gen)((\mu)^{(k-gen)}-1)+(u^{(gen)}-1)(k-gen)$$

Computation of *Gen-Left-k-net* system Control Related States

一般化左**K-**網路

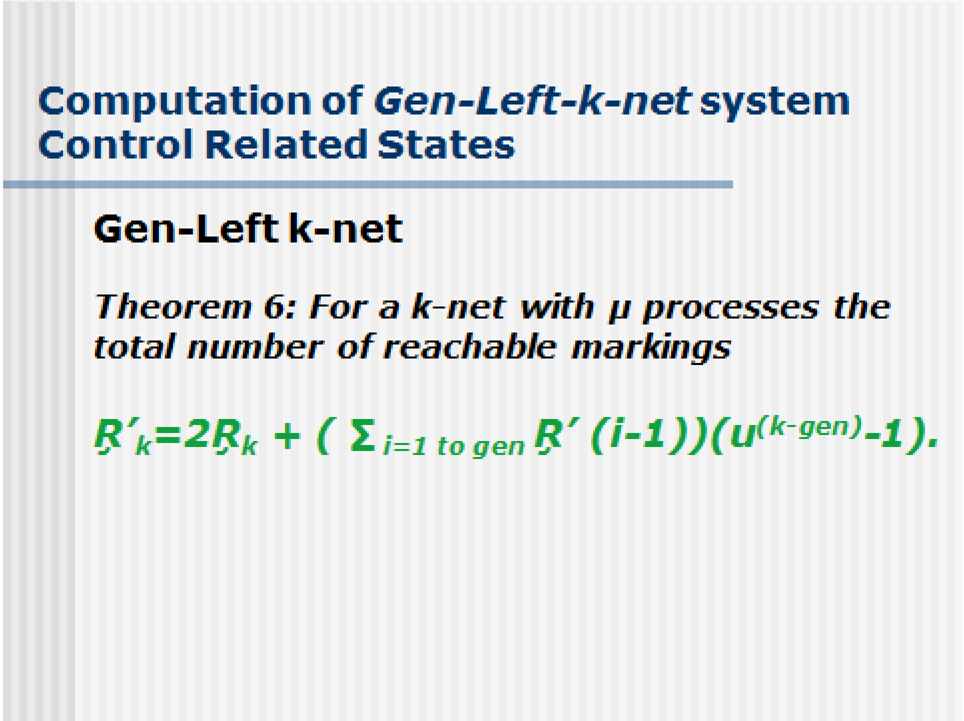
$\text{Ł}'_k=2L_k+A'(k)+C'(k).$

*在**k-**網為禁止註記但可能存活狀態之總數為*$C'(k)=(gen)((\mu)^{(k-gen)}-1)$.

*在**k-**網為非可達註記但可能存活狀態之總數為* $A'(k)=(u^{(gen)}-1)(k-gen)$.

*定理**4:**一般化左**K-**網路之所有存活狀態總數為*

$$\text{Ł}'_k=2\,L_k+(gen)((\mu)^{(k-gen)}-1)+(u^{(gen)}-1)(k-gen)$$

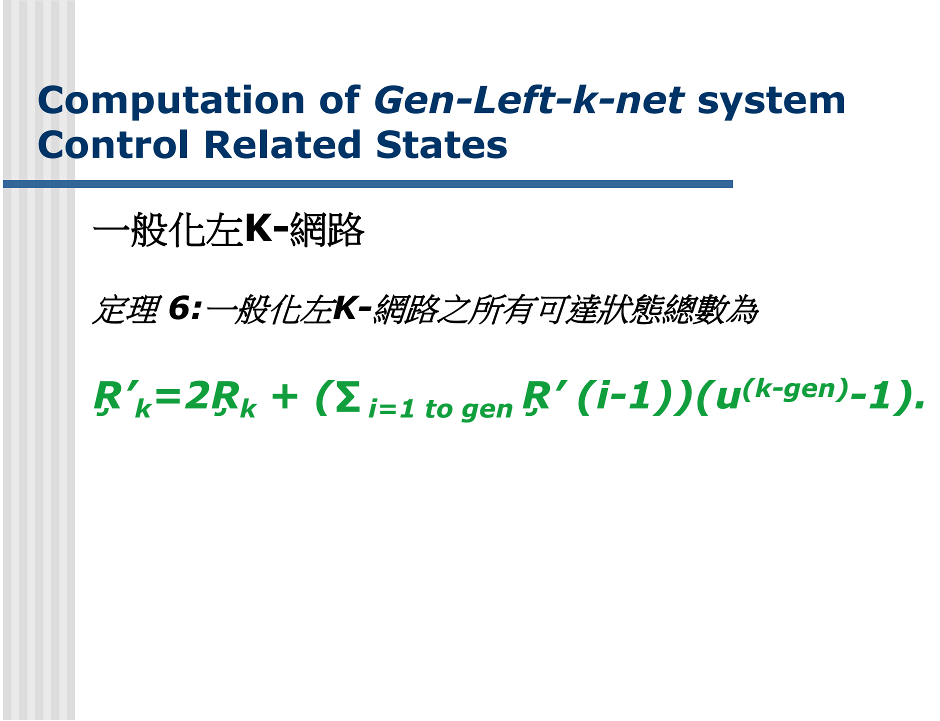


Computation of *Gen-Left-k-net* system Control Related States

Gen-Left k-net

Theorem 6: For a k-net with μ processes the total number of reachable markings

$$R'_k=2R_k + \left(\Sigma_{i=1 \text{ to } gen} R'(i-1)\right)(u^{(k-gen)}-1).$$



Computation of *Gen-Left-k-net* system Control Related States

一般化左**K-**網路

定理 **6:***一般化左***K-***網路之所有可達狀態總數為*

$$R'_k=2R_k + \left(\Sigma_{i=1 \text{ to } gen} R'(i-1)\right)(u^{(k-gen)}-1).$$

Computation of *Gen-Left-k-net* system Control Related States

k	4	4
μ	3	4
k –net		
R	146	376
L	96	271
F	50	105
D	14	39
Total states	256	625
Top-Left-k-net		
C'	26	63
A'	6	9
R'	318	815
Ł'	224	614
F'	94	201
Total states	512	1250

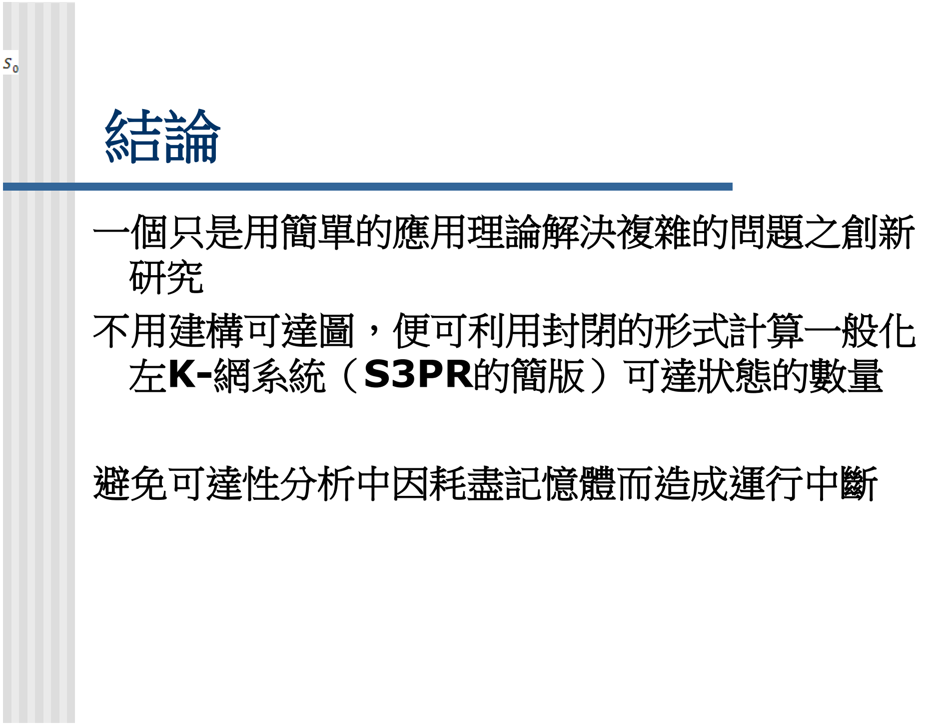
S_0

Conclusion

A innovation research just apply simple theory to solve complicated problem

To compute in closed form the number of reachable states of *Gen-Left k-net* system (a simple version of S3PR) without constructing a reachability graph.

Avoid the dire situation of mid-run abortion of reachability analysis due to exhausted memory



S_0

結論

一個只是用簡單的應用理論解決複雜的問題之創新研究

不用建構可達圖，便可利用封閉的形式計算一般化左**K-**網系統（**S3PR**的簡版）可達狀態的數量

避免可達性分析中因耗盡記憶體而造成運行中斷

六、攜回資料名稱及內容

攜回資料有:研討會之proceedings 及論文電子檔。

Parameterized Control Related States of *Gen-Left* K-th Order S3PR System (with a left side non-sharing resource place) of Petri Nets

Daniel Yuh Chao, Tsung Hsien Yu
Department of Management and Information Science
National Cheng Chi University
Taipei, Taiwan, ROC
yuhyaw@gmail.com;100356506@nccu.edu.tw

***Abstract*—Earlier, Chao pioneered the very first closed-form solution of the number of reachable and other states for marked graphs (MG) and *k*-th order system which is the simplest class of *S^3PR* (Systems of Simple Sequential Processes with Resources). This paper progresses one step further on enumerating reachable (forbidden, live, and deadlock) states for general *k*-th order systems (one non-sharing resource place in the any position of the Left-side process) with a formula depending on parameter k for a subclass of nets with k sharing resources.**

***Keywords*—Control systems; discrete event systems; flexible manufacturing systems; Petri nets; large scale optimization, graph theory.**

I. INTRODUCTION

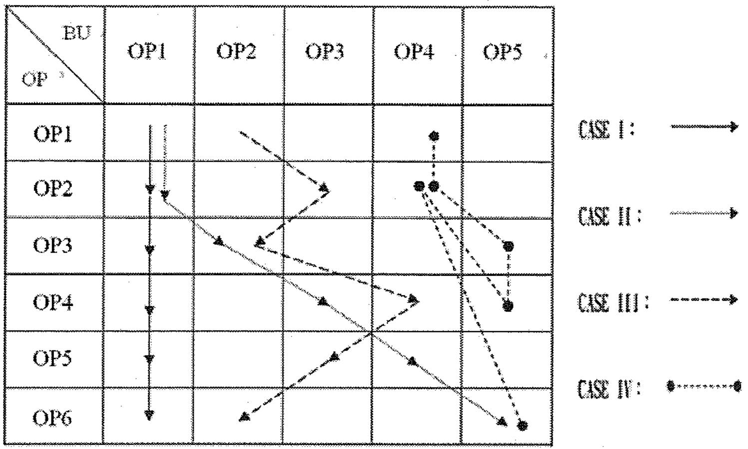
PETRI nets (PN) have been used for modeling and analyzing concurrent systems such as flexible manufacturing (or resource allocation) systems (FMS) (or RAS) [1-9]. Reachability [11-16] can be used to verify system properties of liveness, boundedness, reversibility, etc. However, the ever problem of using PN for modeling various systems is the large number of states generated (called the state explosion problem). It has been shown that the complexity of the reachability problem of a Petri net is EXPSPACE-hard in [12]. Lee *et al.* [12] show that the reachability problem (whether a marking is reachable) is NP-complete for even a live and safe Free Choice net (LSFC).

To resolve real time optimal dynamic resources allocation decision problem of Petri nets, the most important challenge is to efficiently break the ever exponential time plight of getting control states information into reasonable computation time. Chao [20] pioneered the very first solution for *S^3PR* using closed-form methodology by applying simple graph theory and combinatorial mathematics. This allows the exponential computation time to be reduced to intra-seconds! we have applied Chao [20] key methodology to enumerate reachable, forbidden, live, and deadlock states of various k-th order systems with a non-sharing resource r^* in different specific locations (*Top-Right*[21], *Top-Left*[22], *Bottom-Right*[23], *Bottom-Left*[24] *and Middle-Left*[25] defined in Defintion 1), respectively. Here, we extend one more step further by constructing generalization formula of k-th order systems (*Gen-Left*) with r* on the left side but at arbitrary locations

Definition 1: *A k-th order system is a subclass of S^3PR with k resource places r_1, r_2, ..., r_k shared between two processes N_1 and N_2 and one non-sharing resource place r'_{gen} $(=r^*)$ used by an operation place p^* in P_1 or P_2*

1. *$M_0(r'_{gen})=1$ and $\forall r \in P_R$, $M_0(r)=1$.*
2. *N_1 (resp. N_2) uses r_1, r_2, ..., r_k (resp. r_k, r_{k-1}, ...r_2, r_1) in that order.*
3. *When p^* in P_1* (resp. P_2) *$M_0(p_0)=k+1$, $M_0(p'_0)=k$* (resp. *$M_0(p_0)=k$, $M_0(p'_0)=k+1$), where p_0 and p'_0 are the idle places in processes N_1 and N_2, respectively.*
4. *Holder places of r_j in N_1 and N_2 are denoted as p_j and p'_j respectively.*
5. *The compound circuit containing r_i, r_{i+1}, ..., r_{j-1}, r_j is called $(r_i$-$r_j)$-region.*
6. *If r'_{gen} does not exist, then it is called a k-th order system.*
7. *There are 3 possibilities for the token initially at r_i to sit at: $p_i(N_1)$, p'_i, (N_2), and r_i. The corresponding token or r_i state is denoted by 1, -1 and 0, respectively.*
8. *x^y means r_{gen+1} is at x state (x=1,0,-1) and r'_{gen} is at y state (y= 1, 0, -1), where gen is the location of non-sharing resource being used by an operation place p^*. The system is denoted as Top-Left k-th order system when gen=1 and p^* in P_1; Top-Right k-th order system when gen =1 and p^* in P_2; Bottom-Left k-th order system when gen=k-1 and p^* in P_1; Bottom-Right k-th order system when gen=k-1 and p^* in P_2; Middle-Left k-th order system when k is even, mid = gen+1 = (k/2)+1 and p^* in P_1; Middle-Right k-th order system when k is even, mid = gen+1 = (k/2)+1 and p^* in P_2; Gen-Right k-th order system when $1 \leq gen \leq k-1$ and p^* in P_2; Gen-Left k-th order system when $1 \leq gen \leq k-1$ and p^* in P_1.*

Examples are shown in Figs. 1-4.



OP: operation BU: business unit

Figure 4. Pool-Lane Chart with respect to Operation-Unit Relationship

3.5. Research into the integrative BPM method by means of case study

The case study has been employed as the research method and a museum was chosen as the research objective. The study also analyzes the business process with module tools to evaluate the difference in performance before and after the implementation of ubiquitous computing service. Among others, the following BPM tasks and computerized tools stand for the most crucial parts of the study

4. Case Study

4.1. U-Intellectual Properties Systems of National Palace Museum

Image Archive Management System of National Palace Museum (herein referred to as NPM) was chosen as the research objective. Since the last decade, NPM has achieved the great success in digital heritage development, which includes the Digital Archives, Digital Museum and E-learning project [17] [2]. Based on the previous achievement, NPM decided to step further to build the U-Museum service. Image Archive Management System is one of the U-Intellectual Properties Management System under U-Museum project (Figure 5), and it was undertaken by the Department of Marketing and Licensing.

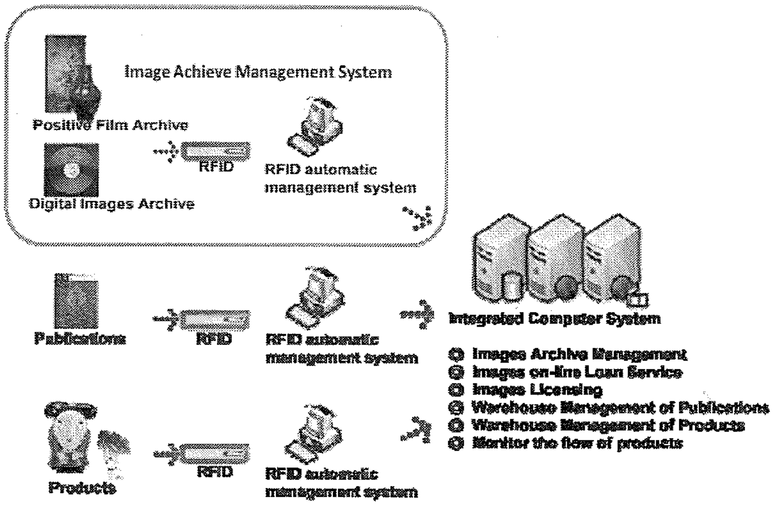


Figure 5. U-Intellectual Properties Management System of NPM

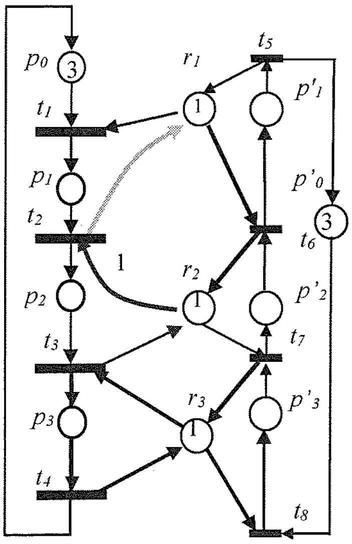


Fig. 1. 3-th order system N^e..

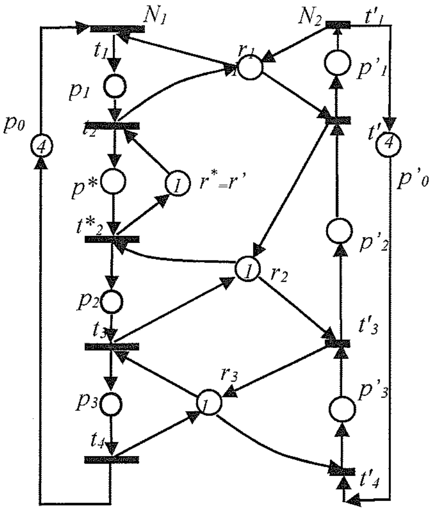


Fig. 2 *Top-Left* 3-th order system.

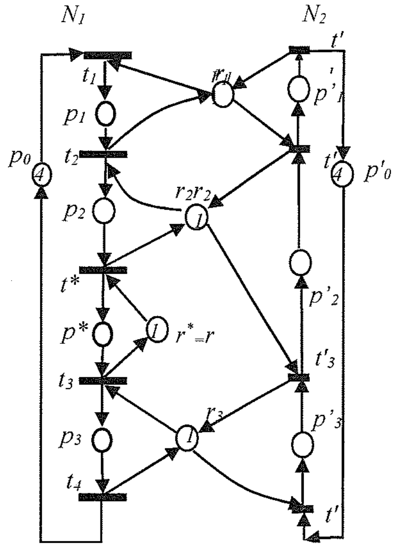


Fig. 3 *Bottom-Left* 3-th order system.

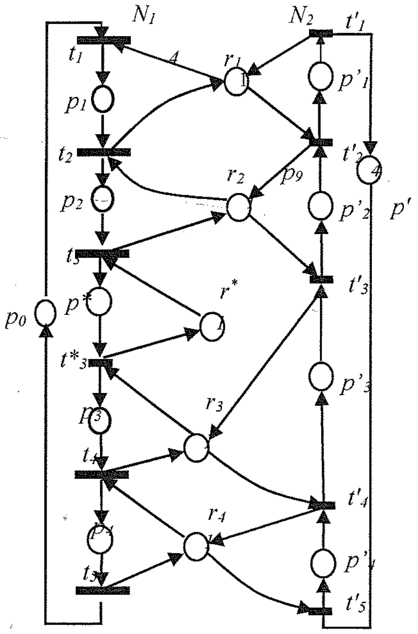


Fig. 4. (a) *Middle-Left* 4-th order (gen=2)system *N*.

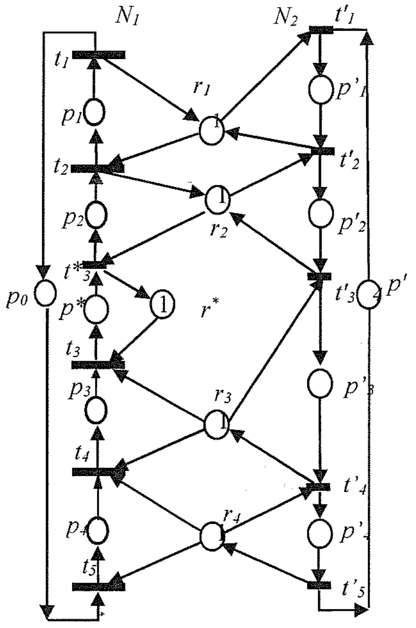


Fig. 4. (b) *Middle-Left* 4-th order (gen=2)system reverse N^r.

The approach is explained as follows. The only one token at each r_i initially can stay at r_i, p_i (left holder place), or p'_i (right holder place); i.e., 3 possibilities. All together, there are 3^k possibilities or states[20]. But some states are not reachable from initial marking via a certain firing sequence. It is easy to find and enumerate the patterns of token distribution for reachable ($\check{R}$) and live (L) states. From that, one can infer the number F of forbidden states as their difference ($F=\check{R}-L$). The number of nonreachable states is $3^k - \check{R}$. Reachability problem becomes trivial as one can check whether the marking fits the reachable pattern and hence whether it is reachable.

In the previous project, NPM has digitized enormous amount of museum collections into digital form, and reproduce them into a variety of formats, such as multimedia DVDs, films, web sites, publications, and products. Before applying ICT, the operation of relic image archives (include positive film and digital images) were all done by hand and recorded loaning information by paper work. In order to effectively manage these products, NPM decided to use ICT such as ubiquitous technology (mobile appliances, RFID, wireless sensor networks and etc.,) in this management system. This system aims to manage the positive film archives and the digital images. Prior to the application of digital cameras, the museum had stored a great amount of positive films taken by traditional cameras. In order to integrate two types of image archives, the RFID tags were attached to the outer of positive films. Then each film could be found by RFID readers, which can automatically transmit data to management system. In this way, the administrators can easily find out the required image and process the image loan service or image licensing.

4.2. Process Re-appearance phase (AS-IS)

After the field-observation, we described the image archives management process in three parts, i.e. (1) New Films Creating, Films In-stock (sub-process), (2) Films loaning, Films Out-stock (sub-process), and (3) Expired Films Recalling. Units involved in the image archives management process are Licensing Division, Film Archives Library, Photo Room and Loaning Units. Following is the AS-IS process of the image archives management which is described by standard modeling tools BPMN we have selected (Figure 6 and Figure 7).

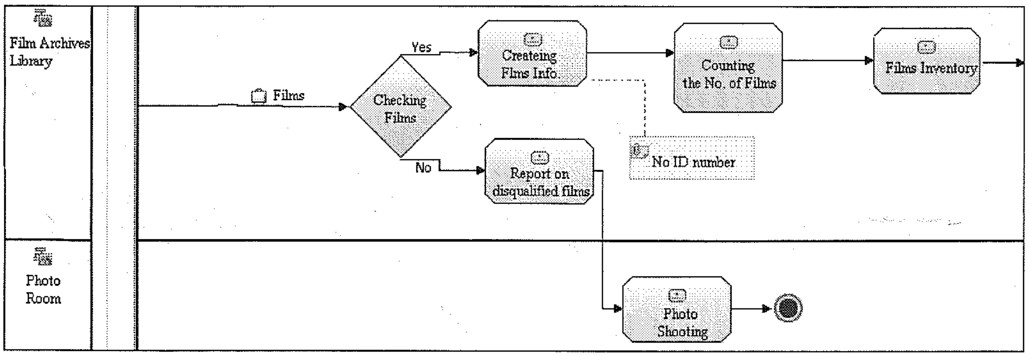


Figure 6. Films in-stock process (AS-IS)

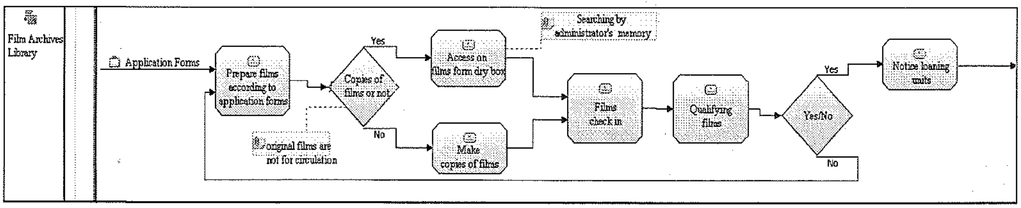


Figure 7. Films Out-stock process (AS-IS)

4.3. Process Analysis and process re-design phase (TO-BE)

In this phase we described TO-BE process by standard modeling tools BPMN shown in Fig.8 and Fig.9. Comparing with AS-IS process (Figure 6 and Figure 7) we found that after applying the system, the mainly change of image archives manage process is in Film Archives Library. For example, through the system, RFID readers can automatically transmit data to management system. In this way, the administrators can easily find out the required image and process the image loan service or image licensing.

In the sequel , we first list important contributions of our series papers in section II. Based on the results obtained, we will extend it to *Gen-Left* k-th order system in section III.

II. CONTRIBUTTIONS OF OUR SERIES PAPAERS

A. K-th order system[20]

Let N is a Petri net, N^r is the reverse net of N. By the concept of complete reachability graph (Fig 5) that contains live, forbidden and nonreachable states, we have *Lemma 1* 、*Lemma 2 and Theorem 1.*

Lemma 1: Any forbidden state in N is nonreachable in N^r.

Lemma 2: Any nonreachable state s in N is a forbidden one or a nonreachable one in N^r.

Theorem 1: $\vartheta(k)$ = ¥(k) − $B(k)$, *where* ϑ ***(k), ¥(k), and B(k)*** *are the number of* ***forbidden, nonreachable, and nonreachable +empty-siphon states*** *in a k-th order system, respectively.*

In Fig 5, Deadlock (resp. forbidden but not deadlock, live) states are the nodes that are pointed by dashed line from *D(k)*. Pointed From *¥(k)* and *B(k)* are nonreachable states. States nonreachable in both N and N^r are *(1,-1,1)* and *(-1 1 -1)*. Note that there are no directed paths 1) from a forbidden state to live states and 2) from reachable states to nonreachable ones.

For the 3rd order system, there are 3 kinds of unmarked (resp. nonreachable) siphon states: *(1 -1 x)*, *(x 1 -1)*, and *(1 0 -1)* [resp. *(-1 1 x)*, *(x -1 1)*, and *(-1 0 1)*], where *x=-1, 0, 1.*

Definition 2: *$s=(x_1\ x_2\ \ldots\ x_k)$, $x_i=1, 0, -1$, $k\geq i\geq 1$ is a state for a k-th order system N. $(x_i\ x_{i+1}\ \ldots\ x_q\ x_{q+1})$, $k\geq q\geq i\geq 1$ (embedded in s) is a substate of s.*

By Definition 2, we have some characteristics of nonreachable and forbidden states about k-th order system.

A substate of (-1 x x ... x 1) (x=1 0 -1) corresponds to a nonreachable state.

A substate of (1 x x ... x -1) (x=1 0 -1) corresponds to a forbidden or a nonreachable state.

state s=(x x ... x 1 x x... x -1 x x ...x 1 x x... x -1 x x ... x) cannot be a reachable state. It means that a reachable state cannot have two substates of *(1 x x... x -1)*.

If $s=(x_1\ x_2\ \ldots x_{i-1}\ 1_i\ x_{i+1}\ x_{i+2}\ \ldots\ x_k)$, does not carry a substate of $(1_g\ x_{g+1}\ x_{g+2}\ \ldots\ x_k)$, $g>i$, then s with $x_m=0$ or 1, $m=1$ to $i-1$ and $x_j=0$ or -1, $j=i+1$ to k are the only reachable states.

A deadlock state has the pattern: *$(1_1\ 1_2\ \ldots\ 1_m\ -1_{m+1}\ -1_{m+2}\ \ldots\ -1_k)$, $1\leq m<k$.*

Finally , belows are the total number of each type of states in k-th order system that we have proved in [20].

The total number of states is 3^k.

The total number of live states $L(k)=\ 2^{k+1}-1$.

The total number of reachable states $R(k) = (k+2)2^{(k-1)}$.

The number of forbidden states $\vartheta(k) = (k-2)2^{(k-1)}+1$. 2).

The number of nonreachable states ¥(k) = $3^k-(k+2)2^{(k-1)}$.

The number of nonreachable +empty-siphon states $B(k) = 3^k-k2^k-1$.

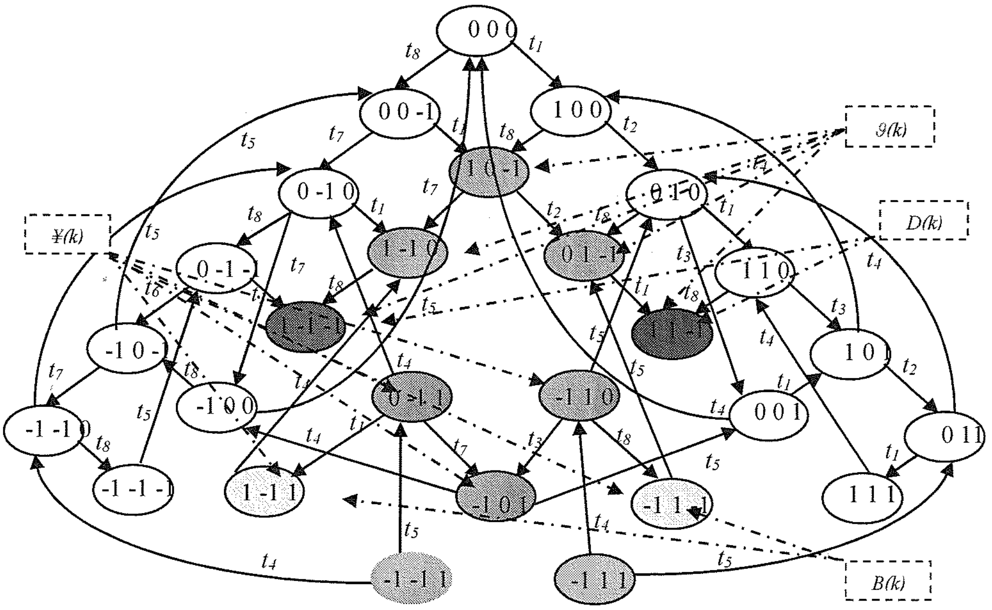


Fig. 5 Complete reachability graph of a 3rd-order system (Fig. 1).

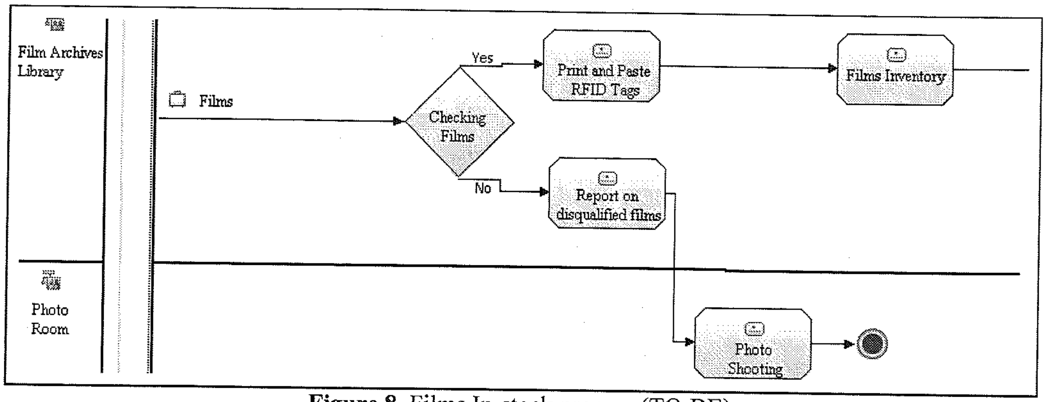


Figure 8. Films In-stock process (TO-BE)

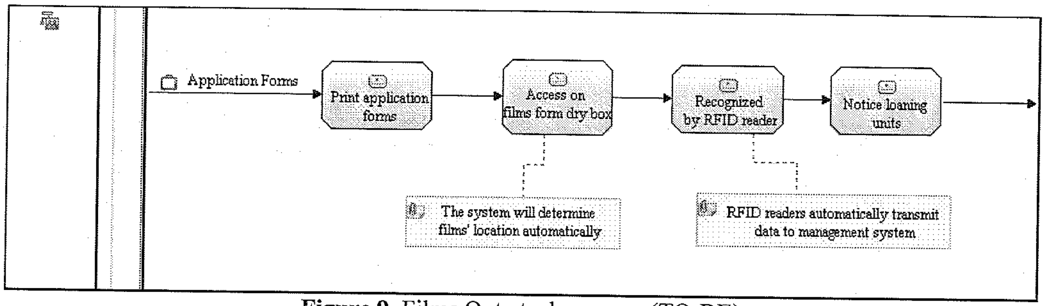


Figure 9. Films Out-stock process (TO-BE)

After describing TO-BE process, we used Pool-Lane Chart to figure the physical movement lines along the image archives operation and also able examine the rationality of each physical movement line and identify problems. Table I shows the Pool-Lane Chart of Films Out-stock process, through the chart we can see that the outbound process can be independently complete by one unit. It is the most simple and the best line of the operation. Some tasks can be completely replaced by ubiquitous service i.e. the operation of counting and checking films. By applying the system, it significantly reduced the process shown as Table 1 and Table 2.

Table 1. Dispatch Flow of archives Out-stock process (AS-IS)

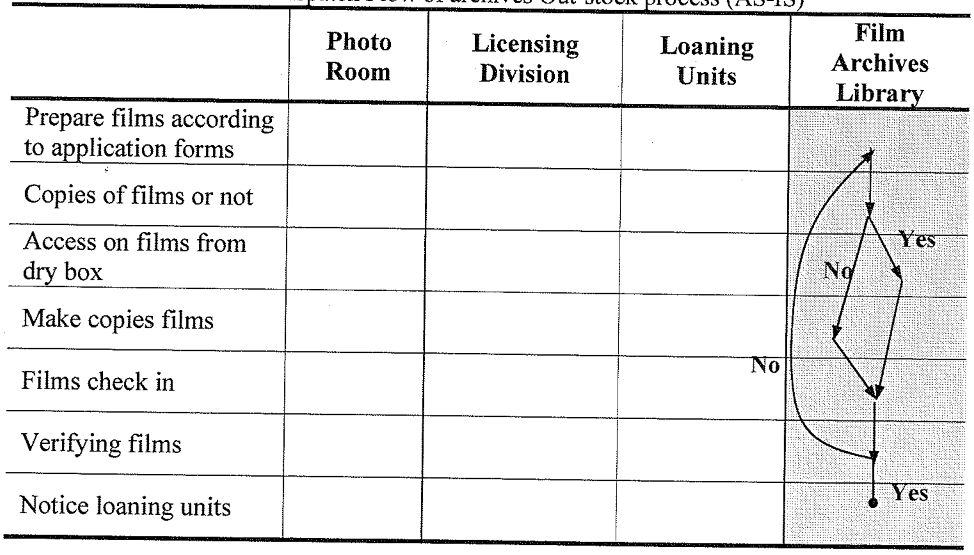


	Photo Room	**Licensing Division**	**Loaning Units**	**Film Archives Library**
Prepare films according to application forms				
Copies of films or not				
Access on films from dry box				
Make copies films				
Films check in				
Verifying films				
Notice loaning units				

The total number of deadlock states $D(k)=k-1$.

B. *Top-Left ,Bottom-Left and Middle-Left system[22, 24, 25]*

Definition3: The equivalent $N^e=(P^e \cup P^e{}_R, T^e, F^e)$ *of a net* $N=(P \cup P_R, T, F)$ *(*P_{NR} *is the set of non-sharing places) is defined as*

1. $P^e{}_R = P_R \setminus P_{NR}$;
2. $P^e = P \setminus \bigcup_{r \in P_{NR}} H(r)$;
3. $T^e = T \setminus \bigcup_{r \in P_{NR}} r^{\bullet}$;
4. $F^e = (F \bigcup_{r \in P_{NR}} ({}^{\bullet}r, r^{\bullet\bullet}) \cup ({}^{\bullet}(r^{\bullet}), {}^{\bullet}r) \setminus \bigcup_{r \in P_{NR}} [(H(r), H(r)^{\bullet}) \cup$
$({}^{\bullet}H(r), H(r)) \cup ({}^{\bullet}r, r) \cup (r, r^{\bullet}) \cup (r^{\bullet}, r^{\bullet\bullet}) \cup ({}^{\bullet}(r^{\bullet}), r^{\bullet})]$;

Definition 4 : The reverse net of N^e *is denoted as* N^{er}.

We say the net in Fig. 1 (*k*-th order system) the equivalent of the net in Fig. 2, 3, 4(a) since the net is exactly the same as the net except that the net has one non-sharing resource place r^*.

Let N be a net that contains a nonsharing resource in left process side (for example *Top-Left ,Bottom-Left and Middle-Left*). We have showed that in N the number of reachable states $>2R$ and the number of live states $>2L$.

Because of a nonsharing resource, we have showed that 1).markings nonreachable in N^e, they may become reachable in N. 2). forbidden markings in N^e may be live in N (denoted the number of which as $C(k)$). 3) nonreachable markings in N^e may be live in N (denoted the number of which as $A(k)$).

The phenomenon is explained as follows:

*C(k):*In *Top-Left* structure, by holding at p_1 left-side process can wait for right-side process going through their own work flow. Set of current states belongs to set of forbidden states in N^e. While after firing t_2 in *Top-Left*, it may be live in N[22].

*A(k):*In *Bottom-Left* structure, by holding at p^* left -side process can wait for right -side process going through their own work flow. While after firing t^*_{k-1} in *Bottom-Left*, set of succeeding states belongs to set of unreachable states in N^e[24].

III. COMPUTATION OF STATES OF *GEN-LEFT K*-TH ORDER SYSTEM FORBIDDEN AND NON-REACHABLE STATES

This section computes the number of states for a *Gen-Left* *k*-th order system, where the symbols for different kinds of states are superscripted with " ' " . For instance , R' denotes the number of reachable states of *Gen-Left k-th* order system.

We will derive *R'(F', L', ...etc)* in terms of *R(F,L, ...etc)* based on the concept of equivalent *k*-th order system of a *Gen-Left* *k*-th order system.

For every reachable (respectively, live) state s $(x\ x\ \ldots\ x\ x)$ in N^e (a *k*-th order system) both states $(x\ \ldots\ x^0 \ldots\ x)$ and $(x\ \ldots\ x^{-1} \ldots\ x)$ are reachable (respectively, live) in *N(Gen-Left k*-th order system). (x^0 and x^{-1} are defined in definition 1, x^{-1}means r_{gen} is at state x and r'_{gen} is at state -1; x^0 means r_{gen} is at state x and r'_{gen} is at state 0.

There are forbidden states in N^e (due to empty siphon), but live (due to marked siphon) or reachable in N since an empty siphon in N^e may become marked in N. Hence $R'>2R$ and $L'>2L$. To compute R' and L' exactly, we need to know that how many forbidden and nonreachable states in N^e, become reachable or live in N.

Observation 1: 1) Any unmarked siphon state carries a substate of $(1\ \ 0 \ldots 0^1\ \ 0 \ldots -1)$*[* 0^1*means* r_{gen} is at state 0 and r'_{gen} *is at state 1], and 2) Any nonreachable state carries a substate of* $(-1\ \ 0\ \ldots\ 0^1\ 0\ \ldots\ 1)$*, where the number of '0' (including '*0^1*') goes from 0 to k-2.*

Note that $(1\ \ 0 \ldots 0^0\ 0 \ldots -1)$ obtained by replacing 0^1 with 0^0 is not an unmarked siphon state since r_{gen} is not used by any process and t_3 (see Fig.4(a)) is potentially firable (i.e., such that $\exists\sigma\ M_0[\sigma>M_1$ and $M[>)$.

For the 4rd order system, there are 6 kinds of unmarked (resp. nonreachable) siphon states: $(x\ 1\ -1^1\ y)$, $(x\ y\ 1^1\ -1)$, and $(x\ 1\ 0^1\ -1)$ [resp. $(x\ -1\ 1^1\ y)$, $(x\ y\ -1^1\ 1)$, and $(x\ -1\ 0^1\ 1)$], where $x, y=-1, 0, 1$.

Lemma 3: A substate of $(-1\ x\ \ldots\ x^1\ x\ \ldots\ 1)$ $(x=1,0,-1)$ *corresponds to a nonreachable state, where the number l of x's (including '*x^1*') goes from 0 to k-2; l=0 to k-2.*

Corollary 1: A substate of $(1\ x\ \ldots\ x^1\ x \ldots -1)$ $(x=1,0,-1)$ *corresponds to a forbidden or a nonreachable state, where the number l of x's (including '*x^1*') goes from 0 to k-2; l=0 to k-2.*

Lemma 4: Let M be a reachable marking in N^e*, then both* $M^*=M+r^*$ *and* $M'=M+p^*$ *are reachable in N.*

The following lemma helps to prove in the sequel that some states are legal ones.

Lemma 5: Both $s=(1\ \ 0_2 \ldots\ 0^0\ \ldots -1_i)$ *and* $s'=(-1\ \ 0_2 \ldots\ 0^0 \ldots 1_i)$ *where gen =1 to k-1; i = gen+1 to k, correspond to two legal markings M.*

For markings nonreachable in N^e, they may become reachable in N.

Lemma 6: Let M be such that only the r_{gen}*-*r_k *region in* N^{er} *is unmarked.*

1. *M is nonreachable in* N^e.
2. $M^*=M+r^*$ *is reachable in N.*

In general, we have

Lemma 7: Let $s=(x_1\ \ldots -1_i\ \ldots 0^0\ 1_j\ \ 1_{j+1}\ 1_{j+2} \ldots\ \ x_k)$ *where* $1 \leq i \leq gen$ *;* $gen+1 \leq j \leq k$ *;be such that only the* r_i*-*r_j *siphon in* N^{er} *is unmarked.*

1. *M is nonreachable in* N^e.
2. $M^*=M+r^*$ *is reachable in N.*
3. *The total number of such* M^* *is* $(2^{(k-j)})R(i-1)$..

Theorem 2: The total number of reachable states in N is $R'=2R+\sum_{i=1\ to\ gen}(\sum_{j=gen+1 to\ k} R(i-1)\ (2^{(k-j)}))$.

Table 2. Dispatch Flow of archives Out-stock process (TO-BE)

	Photo Room	**Licensing Division**	**Loaning Units**	**Film Archives Library**
Print application list from system				│
Access on films from dry box				↓
Recognized by RFID reader of work station				↓
Notice loaning units				●

5. Discussion

The outcome of this research is a novel development approach for the RFID-based ubiquitous services, which can align the system design with the business vision and strategy. For this purpose, BPM tools such as BPEL/BPMN and Pool-lane Chart are integrated into the development of the system of ubiquitous technology. The overall suits is implemented and verified by means of a case study on the ubiquitous technology for improving the museum relic image archives management. Through the case study, including field observation and interviews, targeted expectation can be classified into two parts, i.e. quantitative KPIs: time and manpower, quality KPIs: security and transparency of image archives dispatch flow. As the consequence, this paper also presents the evaluation of the improvement by the quantitative as well as qualitative KPIs.

5.1. Quantitative KPI Improvement: Time and Manpower

After integrating BPM tools into the development of the ubiquitous computing technology, some improvements have been identified. Table III illustrates in-stock pre and post system applying improvement (time and manpower).

Table IV shows out-stock pre and post system applying improvement (time and manpower). Each image archive in-stock process, we can save 70 man-min (84-14), and the reduction rate is 83.33% (70/84). Each image archive out-stock process, we can save 51 man-min (66-15), and the reduction rate is 77.27% (51/66).

Table 3. Improvement of Inbound Process in relation to Time and Man-Power

Activity	**AS-IS(min/person)**	**TO-BE(min/person)**
Checking Films	1/1=1	1/1=1
Report on disqualified films	3/1=3	3/1=3
Creating Films Info.	30/1=30	-/-=0
Print and paste RFID tags	-/-=0	5/1=5
Counting the No. of Films	45/1=45	-/-=0
Films Inventory	10/1=5	5/1=5
	84	14

Corollary 2: $R'(k) = 2\cdot(k+2)2^{(k-1)} + [(gen)\,2^{(gen-1)}]\,(2^{(k-gen)} - 1)$.

Lemma 8: Let M be a live marking in N^e*, then both* $M^* = M + r^*$ *and* $M' = M + p^*_h$ *are live in N.*

The number of markings for each case is computed by the following lemma.

Lemma 9: Let $s = (x_1\ x_2\ \ldots 1_j \ldots 0^0\ 0\ \ldots\ -1_i\ \ldots x_k)$ $1 \le j \le gen$, $gen+1 \le i \le k$ *correspond to Marking M such that there are unmarked siphons in only the* r_j-r_i *region in* N^{er}*. The total number of possible live markings under M is* $2^{(k-i-1)}$.

Theorem 3: The total number of forbidden markings in N^e *that may be live in N is* $C(k) = (gen)(2^{(k-gen)} - 1)$.

Lemma 10: Let $s = (x_1\ x_2\ \ldots -1_j\ 0^0\ \ldots 1_i\ \ldots\ x_k)$ $gen+1 \le i \le k$ *correspond to nonreachable marking M such that there are unmarked siphons in only the* r_{gen}-r_i *siphon in* N^r*. The total number of possible live markings under M is* $(2^{(j-1)} - 1)$.

Theorem 4: The total number of nonreachable markings in N that may be live in N^e *is* $A(k) = (k-gen)\,[(2^{(gen)} - 1)]$

Theorem 5: $L'(k) = 2((2^{k+1}) - 1)) + (gen)(2^{(k-gen)} - 1) + (k-gen)\,[(2^{(gen)} - 1)]$.

Theorem 6: $F'(k) = (k-2)\,2^{(k)} + (2^{(gen)} - 1)\,[(k-gen)(2^{(k-gen+1)} - 1)] - (gen)\,(2^{(k-gen)} - 1) + 2$.

Theorem 7: $¥'(k) = 2\times 3^k - 2\cdot(k+2)2^{(k-1)} + [(gen)\,2^{(gen-1)}]\,(2^{(k-gen)} - 1)$.

Theorem 8: $D'(k) = (k-1) + k - gen - 1 + [2(k-gen)+1](gen-1)$.

See Table 2 for the above results.

Table 1. R'(k) (number of reachable states), for a Gen-Left k-th order system(Include Top-Left,Middle-Left,Bottom-Left).

K	***Top***	*Middle*	*Bottom*	*R'(k) (Top)*	*R'(k) (Middle)*	*R'(k) (Bottom)*
1	1	-	1	6	-	6
2	1	1	1	17	17	17
3	1	-	2	43	-	44
4	1	2	3	103	108	108
5	1	-	4	239	-	256
6	1	3	5	543	596	592
7	1	-	6	1215	-	1344
8	1	4	7	2687	3040	3008
9	1	-	8	5887	-	6656
10	1	5	9	12799	14768	14592
11	1	-	10	27647	-	31744
12	1	6	11	59391	69440	68608
13	1	-	12	126975	-	147456
14	1	7	13	270335	319040	315392

Table 2. L'(k) (number of Live states), for a *Gen-Left* k-th order system(Include *Top-Left,Middle-Left, Bottom-Left*).

K	***Top***	*Middle*	*Bottom*	*R'(k) (Top)*	*R'(k) (Middle)*	*R'(k) (Bottom)*
1	1	-	1	6	-	6
2	1	1	1	16	16	16
3	1	-	2	35	-	35
4	1	2	3	72	74	72
5	1	-	4	145	-	145
6	1	3	5	290	296	290
7	1	-	6	579	-	579
8	1	4	7	1156	1142	1156
9	1	-	8	2309	-	2309
10	1	5	9	4614	4404	4614
11	1	-	10	9223	-	9223
12	1	6	11	18440	17138	18440
13	1	-	12	36873	-	36873
14	1	7	13	73738	67312	73738

Table 3. D'(k) (number of Deadlock states), for a Gen-Left k-th order system(Include Top-Left,Middle-Left,Bottom-Left).

K	***Top***	*Middle*	*Bottom*	*R'(k) (Top)*	*R'(k) (Middle)*	*R'(k) (Bottom)*
1	1	-	1	-	-	-
2	1	1	1	1	1	1
3	1	-	2	2	-	3
4	1	2	3	3	5	5
5	1	-	4	4	-	7
6	1	3	5	5	13	9
7	1	-	6	6	-	11
8	1	4	7	7	28	13
9	1	-	8	8	-	15
10	1	5	9	9	53	17
11	1	-	10	10	-	19
12	1	6	11	11	91	21
13	1	-	12	12	-	23
14	1	7	13	13	145	25

Remark: The larger the system (or *k*) is, the smaller the deadlock probability. If one sets the threshold to be 1%, then for $k<7$ (resp. $k>7$), deadlock prevention or detection (resp. recovery) should be employed.

Application: The k-th order system is a special case of Gadara RAS in [26], where MIP (mixed integer programming)

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is employed and hence cannot handle very large Gadara RAS. The approach in this paper allows us to compute different types of states avoiding the state explosion problem suffered in [26]. However, only two processes are considered in this paper. To extend to more than two processes, assuming any resource place is shared between exactly two resource places, the state between any two processes is independent to states in other pairs of processes. Let π_1, π_2, ..., π_k be the pairs of two processes, then the total number of reachable states is $\Pi^k_{i=1} R_i$, where R_i is the number of reachable states of π_i.

IV. CONCLUSION

We report the very first method to compute in closed form the number of reachable states of *Gen-Left* k-th order system (a simple version of S^3PR) without constructing a reachability graph, just using closed form formula with only 2 parameters : the location of no non-sharing resource and the value k. This helps to estimate the percentage of deadlocks and legal-state losses due to the addition of a monitor, and avoid the dire situation of mid-run abortion of reachability analysis due to exhausted memory. The formal result is important even if specific since manufacturing systems correspond generally to higher order (k much larger than 3) S^3PR systems, which can model concurrent programs where a locked data item can be represented by a single resource place with one token [26]. Current tools may not be able to handle such high order S^3PR systems due to the state explosion problem. Here, we kick off a new era of real-time dynamical resource allocation decision.

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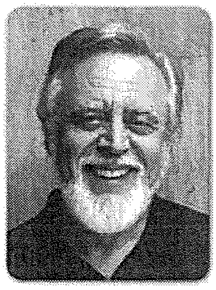

Dimitri P. Bertsekas

McAfee Professor of Engineering, Massachusetts Institute of Technology

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CCMB 2014

IEEE SSCI 2014 Symposia

Symposia-at-a-glance

- ADPRL'14
- CCMB'14
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- CIBCI'14
- CIBD'14
- CIBIM'14
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- CICARE'14
- CIComms'14
- CICS'14
- CIDM'14
- CIDUE'14
- CIEL'14
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- CIHLI'14
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- CIPLS'14
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- FOCI'14
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- IES'14
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Leonid Perlovsky

Principal Research Physicist and Technical Advisor at the AF Research Lab and Visiting Scholar at Harvard University

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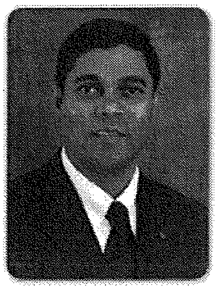
CIASG 2014



G. Kumar Venayagamoorthy

the Duke Energy Distinguished Professor of Electrical and Computer Engineering at Clemson University, Clemson, USA

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CIBIM 2014

Qinghan Xiao

Defence Scientist at the Defence R&D Canada-Ottawa Research Centre 加拿大

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CICA 2014

Antonio Sala

Associate Editor of IEEE Transactions on Fuzzy Systems and Area Editor of Fuzzy Sets and Systems

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CIComms 2014

Andrea Massa

Full Professor of Electromagnetic Fields at the University of Trento

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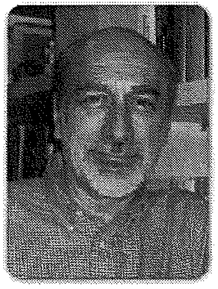
CICS 2014



Jose C. Principe

Distinguished Professor of Electrical and Biomedical Engineering at the University of Florida

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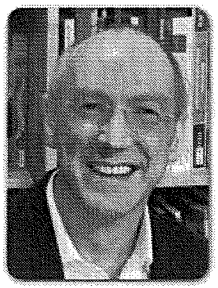
ICES 2014



Alan Winfield

Professor of Electronic Engineering and Director of the Science Communication Unit at the University of the West of England (UWE), Bristol, and Visiting Professor at the University of York

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ISIC 2014

Gary B. Fogel

Fellow of the IEEE and member of Sigma Xi
Editor-in-chief of BioSystems

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MC 2014

Jim Smith

Professor in Interactive Artificial Intelligence (AI) at the University of the West of England, Bristol, UK 英國

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MCDM 2014

Kaisa Miettinen

Professor of Industrial Optimization at the Department of Mathematical Information Technology, University of Jyvaskyla in Finland 芬蘭

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RiiSS 2014

Naoyuki Kubota

Professor with the Department of System Design, Tokyo Metropolitan University, Tokyo, Japan

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SDE 2014

P. N. Suganthan

Editorial Board Member of the Evolutionary Computation Journal, MIT Press

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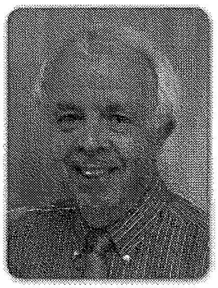
SIS 2014



Russ Eberhart

The Chief Technology Officer at Phoenix Data Corporation based in Indiana, USA

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Welcome to IEEE SSCI'14 in Orlando, Florida, December 9 to 12, 2014