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A New Graph-Based Method Dealing with Blocking in Supervisory Control of Discrete Event Systems

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Abstract: In this article, a new graph-based method dealing with supervisory control problem with blocking (SCPB) is presented, it can be used to analyze and solve SCPB effectively and intuitively. Besides, several techniques improving each of satisfying measure (SM) and blocking measure (BM) are given. Finally, we point out the properties of the techniques got in our paper and develop strategies to improve both measures successively in order to optimize a given supervisor.

Key words: discrete event systems; supervisory control; feedback logic; blocking problem in DES

1 Introduction

In discrete event systems, blocking is an important issue. Supervisory control problem with blocking (SCPB) is more general than supervisory control problem of nonblocking[1], and a blocking supervisor may actually perform better than a nonblocking one, because a nonblocking supervisor is conservative in the sense that it must prevent all behaviors that lead to blocking, which may considerably constrain the behavior of the system if there are several uncontrollable events. Thus one may be willing to risk blocking in order not to overly constrain the behavior of the system. If blocking indeed occurs, then it will be resolved by some external intervention and the execution of the system will be resumed. In the following, the description of SCPB and its performance measures will be given briefly.

The behavior of a discrete event process G is usually modeled in terms of two "languages" $L(G)$ and $L(G)$, If $\overline{Lm(G)}=L(G)$ then G is said to be nonblocking. This means that every trace that G generates can be extended to a marked trace. In supervisory control, it is customary to assume that an uncontrolled discrete event process G is nonblocking. However, this may no longer be true when G is being controlled by a supervisor S. If $\overline{L_c(S/G)}\subset L(S/G)$, then S is said to be blocking. In order to solve SCPB, briefly, one must design a supervisor S such that $L(S/G)\subseteq La$ and $Lc(S/C)\subseteq Lam$ where La and Lam are two given languages representing the admissible behavior for all traces and the admissible behavior for marked traces respectively. They are required to satisfy following constraints:

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$$La = \overline{La}, \quad La \subseteq L(G), \quad Lam \subseteq Lm(G), \quad \text{and } \overline{Lam} \subseteq La.$$

The performance of a supervisor is characterized in terms of a satisfying measure (SM) and a blocking measure (BM), which are $Lc(S/G) \cap Lam$ and $L(S/G) - \overline{Lc(S/G)}$[2] respectively. Thus the design problem is one of trade-off between SM and BM, since an improvement of the former is generally accompanied by a deterioration of the latter, and vice-versa. It is clear that SCPB does not possess a unique optimal solution generally. Therefore, we define the class of admissible solutions of SCPB as:

$$Las := \{K: (\overline{Lam\uparrow} \subseteq K \subseteq La\uparrow) \wedge (K = \overline{K}) \wedge (\overline{K}\Sigma u \cap L(G) \subseteq \overline{K}\}$$

under the additional assumption $Lam = La \cap Lm(G)$. If $L(S/G) \in Las$, then we say that S is an admissible solution of SCPB. When we combine both measures into a unified performance measure, SCPB could be formulated as follows. Examine constraints given above, and find S such that $L(S/G) \in Las$ minimize the performance measure:

$$J := [Lam - \mathrm{SM}(S)] \dot{\cup} \mathrm{BM}(S) = \mathrm{SM}^c(S) \dot{\cup} \mathrm{OBM}(S) \dot{\cup} \mathrm{IBM}(S)$$

where $\mathrm{SM}^c(S) = Lam - \mathrm{SM}(S) = Lam - Lc(S/G)$,

$$\mathrm{OBM}(S) = L(S/G) - \overline{Lam}, \quad \mathrm{IBM}(S) = L(S/G) \cap \overline{Lam} - \overline{Lc(S/G)}.$$

Because of the disjoint unions in the expression of J, there are several incomparable languages in the lattice Las that minimize J.

In the following sections, we will give some graph- based description about regular languages among which there are some relations and properties of the description. Then, several techniques improving each of SM and BM are presented. Finally, some properties of these techniques are pointed out and the advantage of our method is reviewed briefly.

2 Graph-Based Description

A discrete event process can be modeled as a directed-graph $G = (V, E)$. $E(v\text{-})$ is defined as all edges which are directed from v to any states in G, and $R_G(A)$ is the set of all states in G that are reachable from A. If v is a state in G then $G - v$ denotes a subprocess of G obtained by deleting v and all edges incident on v from G. If e is a edge in G, then $G - e$ is a subprocess of G obtained by deleting e from G. A subprocess $G' = (V', E') \subseteq G = (V, E)$ is called an induced subprocess if E' contains all the edges of E whose end points are in V', in this case we say that G' is induced by V' and $G' = G - (V', E')$. The process induced by V' is denote by $\langle V' \rangle_G$ A subprocess $G = (V', E')$ is called realizable if given $v \in V', \forall\ \sigma$, such that $(v, \sigma, u) \in Eu$, get $u \in V'$. That is, a subprocess $G' \subseteq G$ is realizable if and only if every uncontrollable edge going out of a state in G' is an edge of G'.

In this section we will develop some methods combining several automata whose languages possess some including relations, into one directed-graph which has specified constructive character. In the following, we assume that all language concerned are regular languages such that they can be described by finite automata. In addition, the directed-graphs in this paper are also assumed to be deterministic.

Given languages L_1, L_2, L_3, s. t. $L_1 \supseteq L_2 \supseteq L_3$, whose automata, correspondingly, are $G_i = (Q_i, \Sigma, \delta_i, q_{i0}, Q_{im})$ $(i=1,2,3)$ s. t. $G_i = Ac(G_i)$, $Lm(G_i) = L_i$, $L(G_i) = \overline{L_i}$; construct automata $H_i (i=1,2,3)$ as follows.

Let
$$H'_3 = (X_3, \Sigma, f_3, x_0, X_{3m}),$$
where
$$X_3 = Q_3 \times Q_2 \times Q_1, \quad \forall \ (q_3, q_2, q_1) \in X_3,$$
$$f_3(\sigma, (q_3, q_2, q_1)) = \begin{cases} (\delta_3(\sigma, q_3),\ \delta_2(\sigma, q_2),\ \delta_1(\sigma, q_1)), & \text{if } \delta_i(\sigma, q_i)! \ (i=1,2,3), \\ \text{undefined}, & \text{otherwise}. \end{cases}$$
Let $X_{3ac} = \{x : x \in X_3, \exists \ \omega \in \Sigma^*,\ f_3(\omega, x_0) = x\}$, thus $X_{3m} = (Q_{3m} \times Q_{2m} \times Q_{1m}) \cap X_{3ac}$, then
$$H_3 = (X_{3ac},\ \Sigma,\ f_3,\ x_0,\ X_{3m}).$$
Let $H'_2 = (X_2,\ \Sigma,\ f_2,\ x_0,\ X_{2m})$, where $X_2 = (Q_3 \dot{\cup} q_{3e}) \times Q_2 \times Q_1, \forall \ (q_3, q_2, q_1) \in X_2$,
$$f_2(\sigma, (q_3, q_2, q_1)) = \begin{cases} (\delta_3(\sigma, q_3),\ \delta_2(\sigma, q_2),\ \delta_1(\sigma, q_1)), & \text{if } \delta_i(\sigma, q_i)! \ (i=1,2,3), \\ (q_{3e},\ \delta_2(\sigma, q_2),\ \delta_1(\sigma, q_1)), & \text{if } \delta_i(\sigma, q_i)! \ (i=1,2), \\ \text{undefined}, & \text{otherwise}. \end{cases}$$
Let $X_{2ac} = \{x : x \in X_2, \exists \ \omega \in \Sigma^*,\ f_2(\omega, x_0) = x\}$, thus $X_{2m} = ((Q_3 \dot{\cup} q_{3e}) \times Q_{2m} \times Q_{1m}) \cap X_{2ac}$, then
$$H_2 = (X_{2ac},\ \Sigma,\ f_2,\ x_0,\ X_{2m}).$$
Let $H'_1 = (X_1,\ \Sigma,\ f_1,\ x_0,\ X_{1m})$, where $X_1 = (Q_3 \dot{\cup} q_{3e}) \times (Q_2 \dot{\cup} q_{2e}) \times Q_1, \forall \ (q_3, q_2, q_1) \in X_1$,
$$f_1(\sigma, (q_3, q_2, q_1)) = \begin{cases} (\delta_3(\sigma, q_3),\ \delta_2(\sigma, q_2),\ \delta_1(\sigma, q_1)), & \text{if } \delta_i(\sigma, q_i)! \ (i=1,2,3), \\ (q_{3e},\ \delta_2(\sigma, q_2),\ \delta_1(\sigma, q_1)), & \text{if } \delta_i(\sigma, q_i)! \ (i=1,2), \\ (q_{3e},\ q_{2e},\ \delta_1(\sigma, q_1)), & \text{if } \delta_1(\sigma, q_1)!, \\ \text{undefined}, & \text{otherwise}. \end{cases}$$
Let $X_{1ac} = \{x : x \in X_1, \exists \ \omega \in \Sigma^*,\ f_1(\omega, x_0) = x\}$, thus $X_{1m} = ((Q_3 \dot{\cup} q_{3e}) \times (Q_2 \dot{\cup} q_{2e}) \times Q_{1m}) \cap X_{1ac}$, then
$$H_1 = (X_{1ac},\ \Sigma,\ f_2,\ x_0,\ X_{1m}).$$

Proposition 1 $L(H_i) = \overline{L_i}$, $Lm(H_i) = L_i$, $i=1,2,3$. H_i is nonblocking process, and they are induced by their states.

Proposition 2 H_3 is the subgraph of H_2, H_2 is the subgraph of H_1, and $X_{3m} \subseteq X_{2m} \subseteq X_{1m}$.

Proposition 3 $\forall \ x \in X_{2ac} - X_{3ac}$, $e = (x, \sigma, y) \in E_2(x-)$, then $y \overline{\in} X_{3ac}$;

$\forall \ x \in X_{1ac} - X_{2ac}$, $e = (x, \sigma, y) \in E_1(x-)$, then $y \overline{\in} X_{2ac}$.

That is, the states outside H_3 can not be connected to H_3 but the states within H_3 may be connected to states outside H_3, so is H_2.

Given finite automation with blocking G s. t. $L(G) = L$, $Lm(G) = Lm$, $\overline{Lm(G)} \subset L(G)$, its directed-graph can be drawn out as following. According to method given above, construct H_1 and H_2 such that $L(H_1) = L$, $H_1 = Ac(H_1)$, $L(H_2) = \overline{Lm}$, $Lm(H_2) = Lm$, $H_2 = Ac(H_2)$, thus H_2 is the subgraph of H_1. If X_{2m} is redefined as X_{1m} without other changes, the redefined H_1 could model the behavior of G.

So, given closed language L_1, L_2, L_3, s. t. $L_1 \supseteq L_2 \supseteq L_3$, and languages L_{1m}, L_{2m}, L_{3m}, there exist bolcking automata $G_i(i=1,2,3)$, which satisfy $L(G_i)=L_i$, $Lm(G_i)=L_{im}$. H_i can be constructed by similar ways given above just changing a little as following. Let

$$X_{3m} = (Q_{3m} \times Q_2 \times Q_1) \cap X_{3ac},$$

$$X_{2m} = ((Q_3 \dot{\cup} q_{3e}) \times Q_{2m} \times Q_1) \cap X_{2ac},$$

$$X_{1m} = ((Q_3 \dot{\cup} q_{3e}) \times (Q_2 \dot{\cup} q_{2e}) \times Q_{1m}) \cap X_{1ac}.$$

Apart from $X_{3m} \subseteq X_{2m} \subseteq X_{1m}$ and nonblocking property, the other properties given in proposition 1~3 are remained.

Proposition 4 If $L_{im} \subseteq L_{jm}$, $i \neq j$, then $X_{im} \subseteq X_{jm}$.

Given closed languages L_1, L_2, L_3, s. t. $L_1 \supseteq L_2$, $L_1 \supseteq L_3$ and language L_{1m}, L_{2m}, L_{3m}, the correspondent $G_i(i=1,2,3)$ with blocking s. t. $L(G_i)=L_i$, $Lm(G_i)=L_{im}$.

Construct $H'_3=(X_3, \Sigma, f_3, x_0, X_{3m})$, where $X_3=Q_1 \times (Q_2 \dot{\cup} q_{2e}) \times Q_3$, $\forall$ $(q_1,q_2,q_3) \in X_3$,

$$f_3(\sigma,(q_1,q_2,q_3)) = \begin{cases} (\delta_1(\sigma,q_1), \delta_2(\sigma,q_2), \delta_3(\sigma,q_3)), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,2,3), \\ (\delta_1(\sigma,q_1), q_{2e}, \delta_3(\sigma,q_3)), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,3), \text{ and } \delta_2(\sigma,q_2) \text{ undefined}, \\ \text{undefined, otherwise.} \end{cases}$$

Define X_{3ac} as above, thus $X_{3m}=(Q_1 \times (Q_2 \dot{\cup} q_{2e}) \times Q_{3m}) \cap X_{3ac}$, then $H_3=(X_{3ac}, \Sigma, f_3, x_0, X_{3m})$

Construct $H'_2=(X_2, \Sigma, f_3, x_0, X_{2m})$, where $X_2=Q_1 \times Q_2 \times (Q_3 \dot{\cup} q_{3e})$, $\forall$ $(q_1,q_2,q_3) \in X_2$,

$$f_2(\sigma,(q_1,q_2,q_3)) = \begin{cases} (\delta_1(\sigma,q_1), \delta_2(\sigma,q_2), \delta_3(\sigma,q_3)), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,2,3), \\ (\delta_1(\sigma,q_1), \delta_2(\sigma,q_2), q_{3e}), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,2), \text{ and } \delta_3(\sigma,q_3) \text{ undefined}, \\ \text{undefined, otherwise.} \end{cases}$$

Define X_{2ac} as above, thus $X_{2m}=(Q_1 \times Q_{2m} \times (Q_3 \dot{\cup} q_{3e})) \cap X_{2ac}$, then $H_2=(X_{2ac}, \Sigma, f_2, x_0, X_{2m})$

Construct $H'_1=(X_1, \Sigma, f_1, x_0, X_{1m})$, where $X_1=(Q_1 \times (Q_2 \dot{\cup} q_{2e}) \times (Q_3 \dot{\cup} q_{3e}))$, $\forall$ $(q_1,q_2,q_3) \in X_1$,

$$f_1(\sigma,(q_1,q_2,q_3)) = \begin{cases} (\delta_1(\sigma,q_1), \delta_2(\sigma,q_2), \delta_3(\sigma,q_3)), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,2,3), \\ (\delta_1(\sigma,q_1), q_{2e}, \delta_3(\sigma,q_3)), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,3), \text{ and } \delta_2(\sigma,q_2) \text{ undefined}, \\ (\delta_1(\sigma,q_1), \delta_2(\sigma,q_2), q_{3e}), \text{ if } \delta_i(\sigma,q_i)!\,(i=1,2), \text{ and } \delta_3(\sigma,q_3) \text{ undefined}, \\ (\delta_1(\sigma,q_1), q_{2e}, q_{3e}), \text{ if } \delta_1(\sigma,q_1)!, \text{ and } \delta_i(\sigma,q_i)\ (i=2,3) \text{ undefined}, \\ \text{undefined, otherwise.} \end{cases}$$

Define X_{1ac} as above, thus $X_{1m}=(Q_{1m} \times (Q_2 \dot{\cup} q_{2e}) \times (Q_3 \dot{\cup} q_{3e})) \cap X_{1ac}$, then $H_1=(X_{1ac}, \Sigma, f_1, x_0, X_{1m})$.

Proposition 5 H_2 and H_3 are subgraph of H_1; $L(H_i)=L_i$, $Lm(H_i)=L_{im}$, $i=1,2,3$; H_i are induced by their states.

Proposition 6 $\forall$ $x \in X_{1ac}-X_{2ac}$, $(x,\sigma,y) \in E_1(x-)$, then $y \overline{\in} X_{2ac}$;

$\forall$ $x \in X_{1ac}-X_{3ac}$, $(x,\sigma,y) \in E_1(x-)$, then $y \overline{\in} X_{3ac}$.

That is, the states outside H_2 can not be connected to H_2, but the states within H_1 may be connected to H_2, so is H_3.

Proposition 7 if $L_{3m} \subseteq L_{2m} \subseteq L_{1m}$, then $X_{3m} \subseteq X_{2m} \subseteq X_{1m}$.

3 Improving Blocking Solutions

Given discrete event process G s. t. $L(G)=\overline{Lm(G)}$; given specification languages Lam, La s. t. $\overline{La}=La$, $Lam\subseteq Lm(G)$, $\overline{Lam}\subseteq La\subseteq L(G)$; design supervisor S such that $L(S/G)\subseteq La$ and $Lc(S/G)\subseteq Lam$, which makes S become admissible. The additional desires will be given in detail respectively in the following.

To design S, first we will develop a graph description about $L(G)$, La, $\overline{Lam}$ in one directed-graph, then find the subgraph $L(S/G)$ which satisfies the whole given specification. Thus we can get closed system language $L(S/G)$ and state feedback rule f from the subgraph $L(S/G)$ of $L(G)$.

3.1 Finding Optimal Nonblocking Solution

Assume H_1, H_2, H_3 denote the graph of $L(G)$, La, $\overline{Lam}$ respectively, then $X_{3m}\subseteq X_{1m}$, H_1 and H_3 are co-accessible. Because the states outside H_3 can not be connected to X_{3m}, to make S become nonblocking, the graph of $L(S/G)$ must be co-accessible and the maximal realizable subgraph of H_3. So we get the following algorithm computing the subgraph $L(S/G)$ of $L(G)$.

Algorithm 1 let $F=H_2=(Y,E_y)$ iterate

① let $Y_0=\{x:\forall\ x\in Y\cap X_{3m},\ \exists\ (x,\sigma,y)\in Eu(x-),y\overline{\in}Y\}$,

iterate $Y_{k+1}=Y_k\cup\{x:\forall\ x\in Y-Y_k,\ \exists\ (x,\sigma,y)\in Eu(x-),y\in Y_k\}$,

terminate when $Y_{k+1}=Y_k$,

if $Y_k=\varnothing$, or $x_0\in Y_k$, then stop.

let $F_5=F-Y_k=(X_5,E_5)$.

② compute max $P(X_5\cap X_{3m})$ within X_5,

let $X_6=\max P(X_5\cap X_{3m})$,

if $x\overline{\in}X_6$, then $F=\varnothing$, stop.

③ let $F_6=\langle X_6\rangle_{F_5}$

④ compute $R_{F_6}(x_0)$,

let $X_7=R_{F_6}(x_0)\cap X_6, F_7=\langle X_7\rangle_{F_6}$,

let $F=F_7$,

go to ①.

Where $P(X)$ represents a pre-stable subset of state set X[3]. When the algorithm stops, the graph of $L(S/G)$ is F, its marked states are $Y\cap X_{3m}$.

3.2 Finding Completely Satisfying Solution (CSS) under Constraint Min BM

CSS means $Lc(S/G)=Lam$, in consideration of that H_3 is co-acccessible, so the graph of $L(S/G)$ must include the graph of $\overline{Lam}$; to minimize BM, the graph of $L(S/G)$ should be as small as possible. Thus the graph of $L(S/G)$ must be the minimal realizable subgraph of $L(G)$, which contains the graph $\overline{Lam}$, if it is within the maximal realizable subgraph of La with respect to $L(G)$. Then the following algorithm computes the graph $L(S/G)$ desired.

Algorithm 2 let $F=H_3=(Y,E_y)$, $Y_0=Y$, $E_{0_y}=E_y$,

iterate $Y_{k+1}=Y_k\cup\{u:\forall\ u\in Y_k,\ \forall\ \sigma,$ such that $(v,\sigma,u)\in Eu(v-)\}$,

$E_{k+1,y}=E_{ky}\cup Eu(Y_k-)$,

terminate when $Y_{k+1}=Y_k$,

then $F=(Y_k, E_{ky})$, stop.

If F is the subgraph of H_2, then F is the graph about $L(S/G)$. If $Y_k-X_{2ac}\neq\varnothing$, then CSS $\neq\varnothing$.

3.3 Reducing BM without Reducing SM

Given S s. t. $L(S/G)\subseteq La$, $Lc(S/G)\subseteq Lam$, S with blocking. It is desired to find S_1 on the basis of S in order to min BM without reducing SM. Assume H_1, H_2, H_4 denote the graph of $L(G)$, La, $L(S/G)$ respectively. Apparently, $X_{4m}\subseteq X_{1m}$. The graph $L(S_1/G)$ is certain to be within H_4. Find maximal state set X_c which can be connected to X_{4m} in H_4, and construct a induced subgraph of H_4 by X_c. Hence, it is easy to get the graph $L(S_1/G)$. The algorithm is as following.

Algorithm 3 let $Y_0=X_{4m}$

iterate $Y_{k+1}=Y_k\cup\{x:\forall\ x\in X_4,\ \exists\ (x,\sigma,y)\in E(x-),y\in Y_k\}$

terminate when $Y_{k+1}=Y_k$

then $X_c=Y_k$

let $F=\langle X_c\rangle_{H_4}=(Y,E_y)$, $Y_0=Y$,

iterate $Y_{k+1}=Y_k\cup\{y:\forall\ x\in Y_k,\ \forall\ \sigma$, such that $(x,\sigma,y)\in Eu(x-)\}$,

terminate when $Y_{k+1}=Y_k$,

let $X_5=Y_k$, $E_5=E_y\cup Eu(Y_k-)$,

denote $F_5=(X_5,E_5)$, stop.

Thus F_5 is a graph of $L(S_1/G)$. Because the graph of $L(S/G)$ is realizable. F_5 is a subgraph of it.

Besides, if S is given such that $L(S/G)=La\uparrow$, that is, the graph of $L(S/G)$ is the maximal realizable subgraph of La, then $L(S_1/G)$ got by this algorithm is the optimal solution which min BM on the premise of max SM.

3.4 Increasing SM without Increasing BM

Given S s. t. $L(S/G)\subseteq La$, $Lc(S/G)\subseteq Lam$, S with blocking. It is desired to find S_1 on the basis of S to max SM without increasing BM. Let H_1, H_2, H_3, H_4 denote $L(G)$, La, $\overline{Lam}$, $L(S/G)$ respectively. Apparently, $X_{4m}\subseteq X_{3m}\subseteq X_{1m}$. To increase SM, the graph of $L(S_1/G)$ should be got by adding a subgraph of H_3 to the graph H_4, moreover, it must be a realizable subgraph of $L(S/G)\cup\overline{Lam}$ in order not to increase BM. Hence, we get the following algorithm computing the graph of $L(S_1/G)$.

Algorithm 4 let $F=H_3\cup H_4=(X_3\cup X_4,E_3\cup E_4)=(Y,E_y)$

① $U=Y-X_4$,

$Y_0=\{x:\forall\ x\in U,\ \exists\ (x,\sigma,y)\in Eu(x-),y\overline{\in}U\}$,

iterate $Y_{k+1}=Y_k\cup\{x:\forall\ x\in U-Y_k,\ \exists\ (x,\sigma,y)\in Eu(x-),y\overline{\in}Y_k\}$,

terminate when $Y_{k+1}=Y_k$,

if $Y_k=\varnothing$, then stop.

let $U_1=Y_k$,

$F_5=F-U_1=(X_5,E_5)$.

② let $U_2=X_{3m}-X_{4m}-U_1$,

compute max $P(U_2)$ within $U-U_1$in terms of F_5,

let $X_6=\max P(U_2)$.

③ let $X_7=X_6\bigcup X_4, F_7=\langle X_7\rangle_{F_5}$,

compute $R_{F_7}(x_0)$,

let $X_8=R_{F_7}(x_0)\bigcap X_7, F_8=\langle X_8\rangle_{F_7}$,

let $F=F_8$,

go to ①.

Thus, the graph F is the graph of $L(S_1/G)$, $X_8\bigcap X_{3m}$ is its marked states. Besides there may exist an additional improve to IBM of H_4 because U is added to H_4.

3.5 The Properties of the Algorithm

In the following, assume S to be the admissible solution of SCPB. It is easy to get the following results.

Proposition 8 Assuming that S_1 be got by using algorithm 3 to reduce BM of S, and S_2 be got by using algorithm 3 to reduce BM of S_1, then $L(S_2/G)=L(S_1/G)$.

Proposition 9 Assuming that S_1 be got by using algorithm 4 to increase SM of S, and S_2 be got by using algorithm 4 to increase SM of S_1, then $L(S_2/G)=L(S_1/G)$.

Proposition 10 Assuming that S_1 be got by using algorithm 3 and algorithm 4 successively to improve BM and SM of S in turn; and S_2 be got by using algorithm 3 to reduce BM of S_1, then $L(S_2/G)=L(S_1/G)$.

Proposition 11 Assuming that S_1 be got by using algorithm 4 and algorithm 3 successively to improve SM and BM of S in turn; and S_2 be got by using algorithm 4 to increase SM of S_1, then $L(S_2/G)=L(S_1/G)$.

Proposition 12 Assuming that S_1 be got by using algorithm 4 and algorithm 3 successively to improve SM and BM of S in turn; but S_2 be got by using algorithm 3 and algorithm 4 successively to improve BM and SM of S in turn, then $\mathrm{SM}(S_2)\subseteq\mathrm{SM}(S_1)$.

Corollary Given S_1 and S_2 as proposition 12, then $\mathrm{IBM}(S_2\subseteq\mathrm{IBM}(S_1)$, $\mathrm{OBM}(S_2)\subseteq\mathrm{OBM}(S_1)$, $\mathrm{SM}(S_2)\subseteq\mathrm{SM}(S_1)$.

In one word, given admissible solution S, in order to improve both SM and BM of S, it only requires that algorithm 3 and algorithm 4 be used one by one for once. If SM is improved first, then more SM increasing can be got; if BM is improved first, then more BM reducing can be got.

4 Conclusion

In this paper, a graph-based method dealing with SCPB is proposed, it is more intuitive and effective than the language-based method in[2]. The state set which induces outside blocking or inside blocking can be found out clearly by using the method given in this paper. Besides, it is easy to point out the SM or BM improving direction from the graph description. Using the graph-based method also can delete the additional constraint $La \cap Lm(G) = Lam$ desired by the language-based method.

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基于图形处理离散事件系统监控阻塞的新方法

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摘要：本文提出了一种基于图形处理监控阻塞问题(SCPB)的新方法,用该方法可有效、直观地分析、求解 SCPB. 为此,本文给出了改进满意程度(SM)和阻塞程度(BM)的几种方法,并指出了这些方法的特性,从而得以同时改进 SM 和 BM,并优化现有的监控器.

关键词：离散事件系统；监控；状态反馈逻辑；离散事件系统阻塞问题

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