Modularization of a specification in LOTOS

Kentaro Goh and Norio Shiratori

Research Institute of Electrical Communication
Tohoku University
2-1-1, Katahira, Sendai, 980 Japan

Abstract

In this paper we propose a transformation algorithm of LOTOS specifications from monolithic style to constraint-oriented style. The objective of this transformation is to decompose a monolithic LOTOS behaviour into two processes composed by the parallel operator. In order to make behaviours observation congruent before and after the decomposition, the algorithm creates an additional process from the given specification and adds to the decomposed processes using parallel operator. The additional process consists of n interleaved subprocesses ($n \geq 1$). There are no internal interaction gates among decomposed processes and the added process. The interactions among them occur only at the visible gates. This transformation has the following applications: (1) modularization or decomposition of a specification, (2) restructuring of complex specifications and (3) derivation of protocol specifications from service specifications.

1 Introduction

In the design of large and complex systems like communication protocols and information networks, the use of top-down approach based on the stepwise refinement is effective. On this approach a requirement specification of the system to be developed is decomposed and refined step by step. Formal Description Techniques (FDTs) have the advantages of (1) elimination of ambiguity and (2) verification and validation on specifications, so the use of FDTs on the design steps is very effective. However, on the stepwise approach an equivalence relation between specifications before and after the decomposition or the refinement is necessary.

LOTOS[1] is one of FDTs developed within the ISO and has the mathematical basis based on an equivalence. Therefore the correctness of transformations of specifications on the design steps can be formally proved. The transformations of specifications correspond to the decomposition or the refinement of specifications.

The transformation method preserving a correctness of specifications may be divided into following two approaches:

(a) the approach which after transformation, verifies whether the result is correct or not and if it is not correct the transformation steps are repeated until the correct result is obtained.

(b) the approach which uses transformation tools that always preserve the correctness of the refined specification.

In practice the approach (a) can be difficult for large specifications, therefore in the actual system development the approach (b) is more effective.

In LOTOS, the approach (b) is called the Correctness Preserving Transformation (CPT) [2] and plays an important role in the LOTOS-based development strategy. In order to develop large systems by the stepwise refinement effectively, the systematic CPTs for decomposition methods are desired.

The algorithm presented in this paper is one of the CPTs. The objective of this transformation is to decompose a LOTOS behaviour into parallel modules while the transformation preserves their correctness.

The works on the LOTOS transformation method aimed at the decomposition or the modularization published in the literature include [5], [6], [7], [8] and [9]. The main purpose of [5], [6], [7] and [8] is to derive protocol specifications from service specifications. Thus, these methods transform a specification into *resource-oriented style*, in which protocol entities and communication channels are expressed by certain processes respectively. Subprocesses decomposed by their methods correspond to protocol entities, and these subprocesses synchronize at internal gates via communication channel processes. Therefore, their methods do not achieve a high degree of parallelism among decomposed processes. In the case of distributed development of the modules these methods lead to low productivity, since negotiations about internal synchronization gates must be necessary. In [5], which is extended in [6], the number of decomposed processes is n. However the proof of correctness is not given. Limitations of a process to be decomposed are as follows: (1) No internal action **i** and (2) No choice between events of different subprocesses. In [7], the number of decomposed processes is 2, and the proof of correctness is given for the observation equivalence. A limitation of a process to be decomposed is no **i**. The **i** should be expressed by the hiding operator. [8] is an extension of [7] to increase the number of decomposed processes to n. Contrary to these methods, [9] decomposes a specification into modules which do not synchronize at internal synchronization gates. Thus the method can achieve a high degree of parallelism between decomposed processes. The proof of

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Table 1: Summary of the main features of decomposition methods in LOTOS

	[5],[6]	[7]	[8]	[9]	Our work
Specification style after the application	Resource -oriented	Resource -oriented	Resource -oriented	Resource -oriented	Constraint -oriented
Parallelism	Not maintain	Not maintain	Not maintain	Maintain	Maintain
No. of decomp. proc.	n	2	n	2	2
Proof of correctness	None	Observation equivalence	Observation equivalence	Observation equivalence	Observation congruence
Limitations	No i (1)	No i (2)	No i (2)	No i No recursion (3)	No i No recursion (4)
Application area	(a)	(a)	(a)	(a)	(b)

(1) No choice between events of different subprocesses
(2) i should be expressed by hiding operator
(3) Satisfy a specific predicate (It results from the parallel composition of two subprocesses)
(4) Each gate is used only once

(a) Implementation phase
(b) Requirement capturing phase (Specification phase)

correctness is given for the observation equivalence. Limitations of processes to be decomposed are as follows: (1) No i, (2) No recursion and (3) Satisfying a specific predicate, i.e. it results from the parallel composition of two processes. If a process does not satisfy the predicate, the method creates hidden internal gates which are strategically located in the process to be decomposed. Therefore the specification style after decomposition in [9] can be recognized as resource-oriented style.

In this paper, we propose a new decomposition algorithm for LOTOS specifications. The presented algorithm is a transformation algorithm for LOTOS specifications from monolithic style to *constraint-oriented style*[3][4]. The objective of this transformation is to decompose a monolithic LOTOS behaviour into two processes composed by parallel operator. Decomposed processes model minimal local constraints of the system interactions. In order to make behaviours observation congruent before and after the decomposition, the algorithm creates and adds an additional process to the decomposed processes using parallel operator. The additional process consists of n interleaved subprocesses ($n \geq 1$). These subprocesses model minimal remote (or end-to-end) constraints of interactions between decomposed processes. There are no internal interaction gates among decomposed processes and the added process. The interactions among them occur only at the visible gates. The advantage of our method over [9] is that our method handles the increase in number of processes to be decomposed while keeping the high parallelism of decomposed processes. The transformation to constraint-oriented style corresponds to a decomposition of a process without decrease of its abstraction level, while the transformation to resource-oriented style decreases a process abstraction level. Therefore the transformation to constraint-oriented style is useful for an application to the requirement capturing (or the specification) phase in a system development process. The summary of the main features of decomposition methods in LOTOS is shown in Table 1.

The formal language used in this paper is a subset of LOTOS, but the approach could also be adopted to other process algebra formalisms like CCS[10], CSP[11] or ACP[12]. The essential common feature of these formalisms is that they allow Labelled Transition Systems (LTSs)[1][10].

This transformation has many practical applications such as, (1) modularization or decomposition of a specification, (2) restructuring of complex specifications and (3) derivation of protocol specifications from service specifications.

This paper is organized as follows. In section 2, we introduce the decomposition problem and formalize the problem. In section 3, we present our decomposition method and show an application example. Finally in section 4, we conclude the paper.

2 Formalization of the decomposition problem

2.1 Example of the decomposition

In order to get a better intuitive understanding of the decomposition problem we first illustrate it with a simple example. We take the question/answer service[4], for an example.

Example 1 A question is generated by a user Q (action Q_q) and forwarded by the service to an another user A (A_q). The latter is required to generate an answer (A_a) which is returned by the service to the user Q (Q_a). An architecture and action sequence of this service are shown in Figure 1(a). The process "B" below is a monolithic representation of the question/answer service as given in the informal definition.

$$B \equiv Q_q; A_q; A_a; Q_a; \mathbf{stop}$$

In order to refine this specification by a team of specifiers the specification must be decomposed. The first design decision might be to split the specification into two processes, LC_1 and LC_2 such that:

- the set of actions of LC_1 is concerned with actions which occur at the user Q side and
- the set of actions of LC_2 is concerned with actions which occur at the user A side.

In other words, LC_1 and LC_2 decide the temporal relationship between observable interactions at the Q side and the A side respectively. These are local constraints of the service, so these are expressed by separate processes.

Moreover, an equivalence relation between before and after the decomposition is necessary. So we add an additional process RC which acts for a remote constraint of the service. RC models remote, or end-to-end, constraints of the temporal ordering of observable interactions. It consists of n interleaved subprocesses RC_is, and a RC_i decides minimal temporal ordering of observable interactions. The number of RC_is, n, depends on the frequency of interactions between LCs. If we write an equivalence relation as $\cong$, we can formulate the problem of decomposition of the question/answer service as follows (See Figure 1(b)):

Find two processes LC_1 and LC_2, and an additional process RC such that

$$(LC_1 \;|||\; LC_2) \;|[G]|\; RC \cong B$$

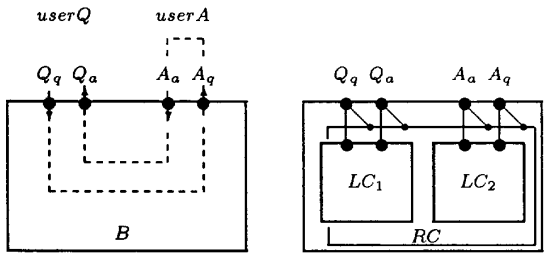
where G which is a subset of $\{Q_q, A_q, A_a, Q_a\}$ is a set of actions at which two LCs and RC synchronize, and RC consists of n interleaved subprocesses as follows:

$$RC \equiv RC_1 \;|||\; RC_2 \;|||\; ... \;|||\; RC_n \;(n \geq 1)$$

We obtain the following processes as a solution of this problem if we take the observation congruence as an equivalence relation:

$$LC_1 \equiv Q_q; Q_a; \mathbf{stop}, \quad LC_2 \equiv A_q; A_a; \mathbf{stop}$$
$$RC_1 \equiv Q_q; A_q; \mathbf{stop}, \quad RC_2 \equiv A_a; Q_a; \mathbf{stop}$$

and, $G = \{Q_q, Q_a, A_q, A_a\}$. □



(a) Before decomposition (b) After decomposition

Figure 1: Question/answer service "B"

2.2 Notations and Assumptions

Assumption 1 In this paper we use only the Basic LOTOS as we do not deal with data types and value expressions, and the LOTOS operators that are treated are **stop**, action prefix, choice and parallel. We assume that the processes before and after decomposition, i.e. B, LC_1 and LC_2, and the additional processes RC_is, make use of only **stop**, action prefix and choice. □

Assumption 2 In this paper we use *observation congruence* [10] for a basis of an equivalence relation between processes before and after the transformation, notated as $\cong$. □

Assumption 3 In this paper we assume that the specification style of the process B to be decomposed is the *LOTOS monolithic style* [4]. □

The general form of the monolithic style is as follows[7]:

$$B \equiv \sum\{a_i; B_i \mid i \in I\}$$

for some finite index set I, where each B_i is either a process identifier or an expression in a general form of the monolithic style. By $\sum\{P_i \mid i \in \{1, 2, ..., n\}\}$ we mean $P_1 \;[]\; P_2 \;[]\; ... \;[]\; P_n$ and by $\sum\emptyset$ we mean **stop**.

Notation 1 The set of all observable actions (so not including δ and $\mathbf{i}$) that occur anywhere in process B is denoted by $Act(B)$. □

For example, if $B \equiv a; b; \mathbf{stop} \;[]\; c; \mathbf{stop}$ then $Act(B) = \{a, b, c\}$.

Now we formalize the decomposition problem.

Definition 1 (Decomposition problem)
Given:

- a monolithic process B
- a partitioning of $Act(B)$ into A_1 and A_2, i.e. $A_1 \cup A_2 = Act(B)$ and $A_1 \cap A_2 = \emptyset$

Problem: find two processes LC_1 and LC_2, and an additional process RC with the following properties:

- $Act(LC_1) = A_1$, $Act(LC_2) = A_2$ and $Act(RC) \subseteq Act(B)$
- $(LC_1 \;|||\; LC_2) \;|[G]|\; RC \cong B$ where $RC \equiv RC_1 \;|||\; RC_2 \;|||\; \cdots \;|||\; RC_n$ $(n \geq 1)$, $G \subseteq Act(B)$ □

Assumption 4 The transformation presented here imposes further restrictions, which are given below, to the process to be decomposed.

(1) no internal actions $\mathbf{i}$,
(2) no recursion and
(3) each action of the process can be distinguished by a distinct name. □

These restrictions are not essential drawback of the transformation since these can be dealt by slight extensions of the algorithm. Same restrictions are adopted by [9]. We discuss about the restrictions on section 4.

Although, by our method a process is decomposed into two processes, it can be decomposed into n processes by application of the algorithm $n - 1$ times.

3 Decomposition method

In this section we develop the decomposition algorithm. First of all, in section 3.1 we give some definitions. In section 3.2 we describe the decomposition algorithm. In section 3.3 we show properties of the

algorithm. In section 3.4 we show an application example of the algorithm. Finally in section 3.5 we show a decomposition example of a recursive process.

3.1 Definitions

Definition 2 A *potential process* of a process B is defined as a state of LTS of the process B. □

For example, the potential processes of a process B are B, B_1, B_2 and B_3, where $B \equiv a;(b;\mathbf{stop}\ []\ c;\mathbf{stop}), B_1 \equiv b;\mathbf{stop}\ []\ c;\mathbf{stop}, B_2 \equiv \mathbf{stop}$ and $B_3 \equiv \mathbf{stop}$.

Definition 3 A *preaction* of a process B, $Pre(B)$, is a preceding action of the process B. □

For example, if $B \equiv a;B_1$ then $Pre(B_1) = a$.

Definition 4 The set of actions in which a process B can immediately participate at any point in the unfolding of its behaviour is called the *initials* of the process B, denoted by $Init(B)$. □

For example, if $B \equiv a;B_1\ []\ b;B_2$ then $Init(B) = \{a,b\}$.

Definition 5 A *contact set* of actions of a process B, $Cont(B)$, is defined as a set of $Init(B) \cup \{Pre(B)\}$. A $Cont(B)$ is equal to a $Init(B)$, if the B has no $Pre(B)$. □

For example, if $B \equiv a;B_1$ and $B_1 \equiv b;B_2\ []\ c;B_3\ []\ d;B_4$ then $Cont(B_1) = \{a,b,c,d\}$.

Definition 6 A potential process B except the **stop** is called a *joint process* if and only if $Cont(B) \subseteq A$, where A is a set of actions. □

For example, if $B \equiv a_1;B_1\ []\ a_2;B_2$ and $B_1 \equiv a_3;B_3\ []\ a_4;B_4$, and $A = \{a_1,a_2,a_3,a_4\}$, then B and B_1 are joint processes by A(See Figure 2(a)).

Definition 7 A potential process B except the **stop** is called a *disjoint process* if and only if $Cont(B) \cap A_1 \neq \emptyset$ and $Cont(B) \cap A_2 \neq \emptyset$, where A_1 and A_2 are disjoint sets of actions. □

For example, if $B \equiv a_1;B_1\ []\ b_1;B_2$ and $B_1 \equiv b_2;B_3\ []\ a_2;B_4$, and $A_1 = \{a_1,a_2\}$ and $A_2 = \{b_1,b_2\}$, then B and B_1 are disjoint processes by A_1 and A_2(See Figure 2(b)).

Definition 8 If we construct a new potential process P, which has the identical preaction and initials as other potential process Q, then the potential process P is called the *reconstruction* of the potential process Q. □

For example, if $B \equiv a;B_1$ and $B_1 \equiv b;B_2\ []\ c;B_3$, and we construct $C \equiv x;a;C_1$ and $C_1 \equiv b;C_2\ []\ c;C_3$, then C_1 is the reconstruction of B_1 since $Pre(B_1) = Pre(C_1) = a$ and $Init(B_1) = Init(C_1) = \{b,c\}$(See Figure 3).

In order to extract a process, whose actions are a set of action A, from a process B, we define a restriction function $Rest(B,A)$ as follows:

Definition 9 For a process $B \equiv \sum\{a_i;B_i \mid i \in I\}$ and a set of actions A, $Rest(B,A)$ is defined as follows:

$$Rest(B,A) \equiv \sum\{a_i;Rest(B_i,A) \mid a_i \in A, i \in I\}\ []\ \sum\{Rest(B_i,A) \mid a_i \notin A, i \in I\}$$

where I is a finite index set. Ordinarily it is assumed that $Rest(\mathbf{stop},A) \equiv \mathbf{stop}$. □

For example, if $B \equiv a;(b;c;\mathbf{stop}\ []\ d;e;\mathbf{stop})\ []\ f;g;h;\mathbf{stop}$ and $A = \{a,b,e,h\}$, then $Rest(B,A) \equiv$

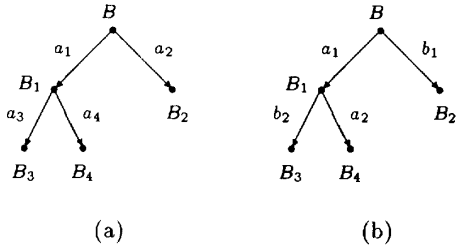


Figure 2: LTSs of examples of a joint process and a disjoint process

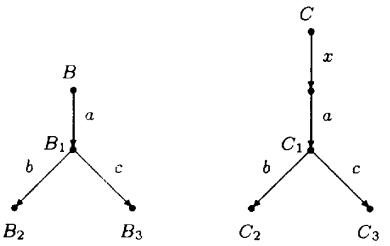


Figure 3: LTSs of an example of a reconstruction of processes

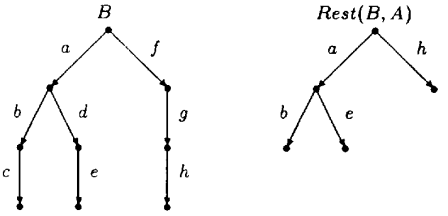


Figure 4: LTSs of an example of the function *Rest*

$a;(b;\mathbf{stop}\ \square\ e;\mathbf{stop})\ \square\ h;\mathbf{stop}$. LTSs of B and $Rest(B,A)$ are shown in Figure 4.

3.2 Algorithm

In view of a parallelism of decomposed processes and reconstructions of the processes, let us consider the following strategy.

Strategy

(1) *The construction method of LCs*
We map LC_1 and LC_2 from the given process B onto processes based on the disjoint sets of actions A_1 and A_2 by using the $Rest(B,A_1)$ and $Rest(B,A_2)$ respectively.

(2) *The construction methods of joint processes and disjoint processes*
For each potential process of the given process B,
(a) if the potential process is a joint process of A_1 then we reconstruct the potential process to LC_1, else if the potential process is a joint process of A_2 then we reconstruct the potential process to LC_2, and
(b) if the potential process is a disjoint process by A_1 and A_2 then we reconstruct the potential process to one of RC_is.

(3) *The construction method of sets of actions of which RC_is consist*
We make a set of actions C_i of which RC_i consists as follows:

$$\bigcup_{i\in\{1,2,\ldots,n\}} C_i \subseteq Act(B)$$

where C_is are pairwise disjoint.

(4) *The construction method of the set of synchronization gates*
We make the set of synchronization gates G as follows:

$$G = \bigcup_{i\in\{1,2,\ldots,n\}} C_i$$

where C_i is a set of actions of which RC_i consists. □

We shall now describe the decomposition algorithm, which is a solution of the problem mentioned in section 2.2, based on the strategy.

Algorithm

Input: A monolithic process B and a partitioning of $Act(B)$ into A_1 and A_2.

Output: Two decomposed processes LC_1 and LC_2, and an additional process $RC \equiv (RC_1 \ |||\ \cdots\ |||\ RC_n)$ with $n \geq 1$.

Step 1: Find action sets $C_1, C_2, ..., C_n$ which construct RC_is based on the strategy by using following four substeps:

Step 1.1: For each potential process of B except for **stop**, make the contact set of actions of the potential process. These sets are named by suffix $1, 2, 3, ...$ respectively.

Step 1.2: Eliminate sets which are subsets of A_1 or A_2 from the sets made on step 1.1.

Step 1.3:
(i) Make a new set by taking union of sets of step 1.2 if the intersection of those sets is not an empty set. Eliminate old sets and suffix new sets with the smallest suffix number of old sets.
(ii) Repeat (i) until the intersection of sets is an empty set.

Step 1.4: Rename the sets which made until step 1.3 by $C_1, C_2, ..., C_n$ in order of small suffix respectively.

Step 2: Construct the processes LC_1, LC_2 and $RC_1, RC_2, ...RC_n$ using the function $Rest$ as follows:

$$LC_1 \equiv Rest(B,A_1), \quad LC_2 \equiv Rest(B,A_2)$$
$$RC_1 \equiv Rest(B,C_1), \ ..., \ RC_n \equiv Rest(B,C_n)$$

□

3.3 Properties of the algorithm

The processes LCs and RC_is generated by the algorithm have the following properties.

Proposition 1 For each potential process of B to be decomposed,

(1) if the potential process is a joint process of A_1 then the reconstruction of the potential process exists only in LC_1, else if the potential process is a joint process of A_2 then the reconstruction of the potential process exists only in LC_2, and
(2) if the potential process is a disjoint process then the reconstruction of the potential process exists only in one of RC_is.

(proof) This is obvious by the algorithm based on strategy (2) and by the definition of the function $Rest$. □

Proposition 2

(1) The number of joint processes of A_1 in B is equal to the number of reconstructions of the joint processes in LC_1, and the number of joint processes of A_2 in B is equal to the number of reconstructions of the joint processes in LC_2.
(2) The number of disjoint processes in B is equal to the number of reconstructions of the disjoint processes in RC.

(proof) This is obvious by the algorithm based on the strategy and by the definition of the function $Rest$. □

Theorem Let LC_1, LC_2 and $RC_1, RC_2, ..., RC_n$ be generated by the algorithm. Let B be a monolithic process restricted as Assumption 4. Then B is transformed into the process D:

$$D \equiv (LC_1 \ |||\ LC_2)\ |[G]|\ (RC_1 \ |||\ RC_2 \ |||\ \cdots\ |||\ RC_n)$$

where $G = \bigcup_{i\in\{1,2,\ldots,n\}} C_i$, and $B \cong D$.

(proof) See Appendix A. □

3.4 Application example

In this section, we demonstrate an application of the decomposition algorithm to a simple protocol. As we have explained earlier, this decomposition is a transformation from a monolithic style to a constraint-oriented style. For further examples reader should refer to [13].

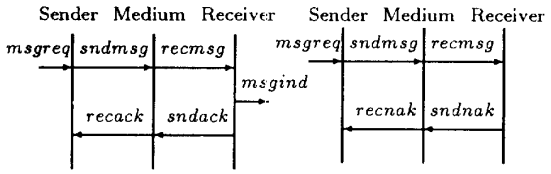
Example 2 Sequence charts of the simple protocol, SP, are shown in Figure 5. This is a simple protocol to realize reliable communication using underlying unreliable medium. The sender gets a request *msgreq* from the user and sends a message *sndmsg*

to the medium. Then the receiver receives *recmsg*. If the message is correct then the receiver gives the user *msgind* and sends an acknowledgement *sndack* to the medium, else if the message is corrupt then the receiver sends a negative acknowledgement *sndnak*. Finally the sender receives *recack* or *recnak*. SP can be described as the following monolithic process.

$$SP \equiv msgreq; sndmsg; recmsg; (msgind; sndack; recack; \mathbf{stop} \ [] \ sndnak; recnak; \mathbf{stop})$$

As a basis of a decomposition, we partition a set of actions of the process SP into following two sets of actions:

- $\{msgreq, sndmsg, recack, recnak\}$, which occur at Sender side, and
- $\{msgind, recmsg, sndack, sndnak\}$, which occur at Receiver side.



(a) Normal sequence (b) Abnormal sequence

Figure 5: Sequence charts of Simple protocol

Here, if we input the process SP and the above two sets of actions to the algorithm then the algorithm decomposes the process SP into two processes LC_1 and LC_2 with an additional process RC via following steps:

Step 1: In order to find action sets $C_1, C_2, ..., C_n$ which construct RC_is, following four substeps are carried out.

Step 1.1: On this step, following seven sets of actions are made.

$\{msgreq\}_1, \{msgreq, sndmsg\}_2,$
$\{sndmsg, recmsg\}_3, \{recmsg, sndnak, msgind\}_4,$
$\{sndnak, recnak\}_5, \{msgind, sndack\}_6,$
$\{sndack, recack\}_7$

Step 1.2: The four sets of actions suffixed 1,2,4 and 6 are eliminated from the sets of actions made on the step 1.1, since the sets suffixed 1 and 2 are subsets of the set of Sender side actions and the set suffixed 4 and 6 are subsets of the set of Receiver side actions. Thus the following sets of actions are left.

$\{sndmsg, recmsg\}_3, \{sndnak, recnak\}_5,$
$\{sndack, recack\}_7$

Step 1.3: The sets of actions suffixed 3, 5 and 7 satisfy the exit condition of the step 1.3, thus the algorithm is proceeded to next steps.

Step 1.4: On this step, the sets of actions suffixed 3, 5 and 7 are renamed by C_1, C_2 and C_3 respectively.

$\{sndmsg, recmsg\}_3 = C_1,$
$\{sndnak, recnak\}_5 = C_2,$
$\{sndack, recack\}_7 = C_3$

Step 2: Construct the processes LC_1, LC_2 and RC_1, RC_2 and RC_3 using the function *Rest* as follows:

$$LC_1 \equiv Rest(SP, A_1)$$
$$\equiv msgreq; sndmsg; (recnak; \mathbf{stop} \ [] \ recack; \mathbf{stop})$$
$$LC_2 \equiv Rest(SP, A_2)$$
$$\equiv recmsg; (sndnak; \mathbf{stop} \ [] \ msgind; sndack; \mathbf{stop})$$
$$RC_1 \equiv Rest(SP, C_1)$$
$$\equiv sndmsg; recmsg; \mathbf{stop}$$
$$RC_2 \equiv Rest(SP, C_2)$$
$$\equiv sndnak; recnak; \mathbf{stop}$$
$$RC_3 \equiv Rest(SP, C_3)$$
$$\equiv sndack; recack; \mathbf{stop}$$

As a result, the decomposed processes are LC_1 and LC_2, thus by the theorem, the following process:

$$SP' \equiv (LC_1 \ ||| \ LC_2) \ |[G]| \ (RC_1 \ ||| \ RC_2 \ ||| \ RC_3)$$

with $G = \{sndmsg, recmsg, sndnak, recnak, sndack, recack\}$ is observation congruent with the process SP. The process SP whose specification style is a monolithic style is transformed into the process SP' whose specification style is a constraint-oriented style.

LTSs of Example 2 are shown in Figure 6. □

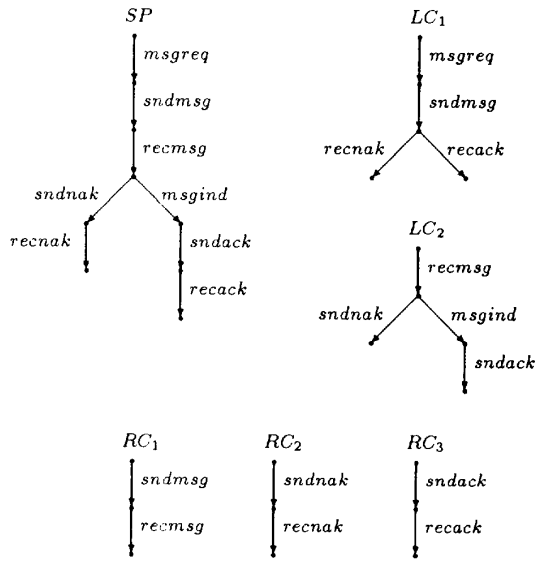


Figure 6: LTSs of Example 2

3.5 Recursive processes

As presented in Assumption 4(2), the algorithm does not deal with recursive processes. However this limitation can be easily eliminated by checking parts of a recursive call of a process and by reconstructing

it to decomposed processes. We consider the following example.

Example 3 The simple protocol with a recursion, SR, is based on SP on Example 2. If the sender receives ***recnak*** from the medium then sends the message ***sndmsg*** again. SR can be described as the following monolithic process.

$$
\begin{aligned}
SR &\equiv msgreq; RE \\
RE &\equiv sndmsg; recmsg; \\
&\quad (msgind; sndack; recack; \mathbf{stop} \\
&\quad [] \; sndnak; recnak; RE)
\end{aligned}
$$

As a basis of a decomposition, we partition a set of actions of the process SR into following two sets of actions:

- $\{msgreq, sndmsg, recack, recnak\}$, and
- $\{msgind, recmsg, sndack, sndnak\}$.

We input the process SR and the above two sets of actions to the algorithm and then we obtain the following processes if we modify the function *Rest* into which it can check recursive calls and halt.

$$
\begin{aligned}
LC_1 &\equiv msgreq; RP_1 \\
&\quad RP_1 \equiv sndmsg; (recnak; RP_1 \; [] \; recack; \mathbf{stop}) \\
LC_2 &\equiv recmsg; (sndnak; LC_2 \; [] \; msgind; sndack; \mathbf{stop}) \\
RC_1 &\equiv sndmsg; recmsg; RC_1 \\
RC_2 &\equiv sndnak; recnak; RC_2 \\
RC_3 &\equiv sndack; recack; \mathbf{stop}
\end{aligned}
$$

It can be conformed that the following process:

$$SR' \equiv (LC_1 \; ||| \; LC_2) \; |[G]| \; (RC_1 \; ||| \; RC_2 \; ||| \; RC_3)$$

with $G = \{sndmsg, recmsg, sndnak, recnak, sndack, recack\}$ is observation congruent with the process SR. LTSs of Example 3 are shown in Figure 7. □

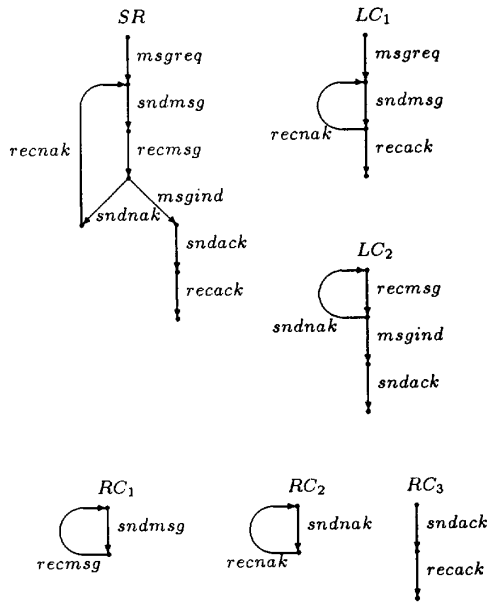


Figure 7: LTSs of Example 3

4 Discussions and Conclusions

In this paper we have presented a transformation algorithm of LOTOS specifications from a monolithic style to a constraint-oriented style. The objective of this transformation is to decompose a monolithic LOTOS behaviour into two processes composed by the parallel operator. In order to make behaviours observation congruent before and after the decomposition, the algorithm creates and adds an additional process to the decomposed processes using parallel operator. The additional process consists of n interleaved subprocesses ($n \geq 1$). There are no internal interaction gates among decomposed processes and the added process. The interactions among them occur only at the visible gates.

The decomposition method presented in this paper is a transformation method of LOTOS specification styles from monolithic style to constraint-oriented style. When we want to change a general parallel operator between LCs and RC to a full synchronization operator, we should, for each action a where $a \in Act(B)$ and $a \notin Act(RC)$, construct a process "a; **stop**" and add this process to RC_is in parallel.

A process which can be decomposed by our method has the following restrictions:

(1) no internal actions **i**,
(2) no recursion and
(3) each action of the process can be distinguished by a distinct name.

(1) is not a serious restriction because the internal actions **i** can be expressed by using the hiding operator. (2) which has mentioned section 3.5 can be easily eliminated by checking parts of a recursive call of a process and by reconstructing it to decomposed processes. Elimination of (3) is now under research, however it is possible that processes without choice operator and actions with same names can be decomposed by the algorithm presented in this paper.

Although, by our method a process is decomposed into two processes, it can be decomposed into n processes by application of the algorithm $n-1$ times.

The presented transformation has the following applications: (1) modularization or decomposition of a specification, (2) restructuring of complex specifications and (3) derivation of protocol specifications from service specifications.

Finally, the directions of further research are summarized as follows:

(a) elimination of all restriction of processes to be decomposed,
(b) incorporation of full LOTOS, i.e. including data types and value passing, and
(c) development of a support environment for decomposition of LOTOS specifications implementing the algorithm.

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A Proof of Theorem

In order to prove that B is observation congruent with D, we prove that the LTS of B is identical with the LTS of D by showing that:

(A) the initials of B are identical with the initials of D, and

(B) for any potential process B' of B and for any potential process D' of D if the preaction of B' is identical to the preaction of D' then the initials of B' are identical with the initials of D'.

First of all, by Definition 6 and 7, each potential process of B is divided into three categories: (a) joint process, (b) disjoint process, and (c) **stop**. **stop** is a completely inactive process. It cannot perform any action. Thus we only consider (a) and (b) here.

Proof of (A)

By Definition 6 and 7, there are two cases with subcases.

Case 1: B is a joint process.

An action which can be occurred at B is one of the actions of initials of B. Here, B is only reconstructed in LC_1 or LC_2 of D with the same initials, and is not reconstructed in RC of D from Proposition 1 and 2.

Regarding the succeeding process of an action, the action which can be occurred at B is divided into three subcases:

(i) preaction of a joint process,
(ii) preaction of a disjoint process, and
(iii) preaction of **stop**.

In subcase (i), the action only exists in either LC_1 or LC_2 of D, therefore only occurs at D and does not synchronize with other actions. In subcase (ii), the action exists not only in either LC_1 or LC_2 but also in RC_i of D. Thus the action which occurs at D is the synchronization of either LC_1 or LC_2 and RC_i. The subcase (iii) is the same as (i).

From the above, by considering the parallel composition of LC_1 and LC_2, the parallel composition among $RC_1, RC_2, ..., RC_n$, and the parallel composition of LCs and RC_is, the initials of B are identical with the initials of D.

Case 2: B is a disjoint process.

An action which can be occurred at B is one of the actions of initials of B. Here, B is only reconstructed in one of the RC_is of D with the same initials, and is not reconstructed in LCs of D from Proposition 1 and 2.

Regarding the succeeding process of an action, the action which can be occurred at B is divided into three subcases like Case 1. However in all subcases, the action exists not only in either LC_1 or LC_2 but also in RC_i of D. Thus the action which occurs at D is synchronization of either LC_1 or LC_2 and RC_i.

From the above, by considering the parallel composition of LC_1 and LC_2, the parallel composition among $RC_1, RC_2, ..., RC_n$, and the parallel composition of LCs and RC_is, the initials of B are identical with the initials of D.

Proof of (B)

Let B' and D', which are potential processes of B and D respectively, have the same preactions. According to the succeeding process of B', the action which can be occurred at B' is divided into three categories like (A). It is obvious, by similar discussion to (A), that the initials of B' are identical with the initials of D' by parallel compositions among processes of D'.

Therefore, the LTS of B is identical with the LTS of D, and B is observation congruent with D. □