JBNsO@M}7?8@81KL1 K*1k%4!<%k!&9%1%8%e!<%j%s%0:GE,2=<jK!

An Efficient Goal Scheduling Method of Parallel Logic Programming Language KL1

0K@n 2mI'
(Masahiko Ikawa)

J?@.9G/2 7n

Abstract

JBNsO@M}7?8@81KL1 GO!"01$D01$D$N%4!<%k$,JB9T<B9T$NC10L$G$"$k$?$a!"$=$N:YN3EY$NJB9T@-@)8f$KH<$&%*!<%P%X%C%I$,B.EYDc2<$r0z$-5/$3$7$F$$k!#7?$,$G$F!"%W%m%0%i%'$N;}$DJBNsEY$rDc2<5;JSDxEY$KJB9T<B9TC10L$NN3EYrBg-$/$9k3H,G-lP!"<B9T;~$N%*!<%P%X%C%I$r7Z8:9k3H$,$G$-$k!#

0lHL$KKL1 JI$NJB9T!?JBNs7?$N%W%m%0%i%_%s%08@81$N%9%1%8%e!<%j%s%0GO!"$=$N%W%m%0%i%'Cf$KB8:_9kITI,MW$JJBNs@-$r$$+$K=|5n$9$k+$,=EMWG"$k!#$3$1$^GNB?$/$NKL1=hM}7OGO!"%W%m%0%i%'$r?<5!?:8M@h$K<B9T9kN,C<!<B9T$N:GE,%7!<%1%s%9$H$_$J7F$$k!#7+7J$,$i!"%W%m%0%i%'$N@-<A$,3Nh&$JC1=c$J?dDjKOE,9g7J$$3H,7P7P$"$j!"MM!9$J@-G=>e$NLdBjE@$,H/@8$9$k!#$=3GK\O@GO!"3F%W%m%0%i%'$KE,9g$7$?C<!2=$r9T$&$3HKhj!"F0E*$J%9%1%8%e!<%j%s%0%*!<%P%X%C%I$r7Z8:$9$k:GE,2=<jK!$NDs0F$r9T$&!#

K\<jK!GO!"%3%s%Q%$k;~$K%W%m%0%i%'$N%G!<%?0MB82r@O$r9T$&$3HG!"%G%C%I%m%C%/$r5/$3$5$J$$h$&$K%W%m%0%i%'$N0lIt$N<B9T=g=x$r@EE*$K7hDj9k!#K\9FGO3NC<!2=5l$?%4!<%k7ONs$r%9%1%C%I$H8F$V!#$=$7$F!"$3$N%9%1%C%I$rJB9T<B9TC10LH9k3HKhG$F!"$=$NF0E*$JJB9T@-@)8f$KH<$&%*!<%P%X%C%I$r7Z8:$9$k!#$^$?!"%4!<%k$N<B9T=g=x$r@EE*$K8GDj7?3HKh$j!"%9%1%C%IFb$N%4!<%k$K4X$7FO%9%?%C/$rMQ$$$?8zN(E*$J<BAu$r9T$&$3H,G-$k!#

7+7J$,$i!"%9%1%C%I2=Kh$j%9%1%8%e!<%j%s%0C10L$,Bg$-$/Jk3H$GF1;~$K%9%1%8%e!<%k2DG=$J%4!<%k$N?0t$,8:>/$7F7$^$$!"%W%m%0%i%'$N;}$DJBNs@-$,Dc2<$9kH$$$&LdBj$,@8$8$k

3NF0E*$JJBNs@-$NDc2<$N1F6A$r:G>.8BKHIak?aK$O!"%N!<%I4V$NMW5aKBP9$kJV?.$OG-$k8B$jAa$/9T$oJ/FOJi$J$$!#7+7J$,$i!"<B9T;~$N%4!<%k!&9%1%8%e!<%j%s%0$G$O!"MW5a&G!<%?$r@8@.9k%4!<%k$,M%@hE*$K%9%1%8%e!<%k$5$1kh$&$J5!9=$,B8:_$7$J$$?$a!"MW5a&a%C;!<%8$KBP9k1~Ez@-$OJ]>Z$5$1$J$$!#3NLdBj$O%9%1%8%e!<%kC10L$NBg$-$$%9%1%C%I!&9%1%8%e!<%j%s%0GO?<9oG"$j!"MW5a&G!<%?$N@8@.$KL54X7$+$D<B9T;~4V$ND9$$%9%1%C%I$,%9%1%8%e!<%k$5$1$F7^$&$H!"MW5aB&$N%"%$%I%k;~4V$,Hs>o$KD9$/$JGF7^$!"UBNs<B9T$N8z2L$,$GJ/Jk2DG=@-$,$"$K!"MW$J6qBN2=$dF10l2=$r9T$&%4!<%k$r4^$'%9%1%C%I$rM%@hE*$K%9%1%8%e!<%k$9$k**reply first scheduling**<jK!$rDs0F$9$k!#

reply first scheduling $rMQ$$$k3H$G!"JB9T<B9T$K$*$1$k%G!<%?0MB82L$,G-$k8B$jA}d7!"%9%1%C%I2=5l$?%W%m%0%i%'$N;}$DJBNs@-$r:GBg8B$K0z$-=P$9$3H,G-$k!#$^$?!"1%N!<%D>e$N<B9T$K4X$7Fb!"4X78N"$k%9%1%C%I,%9%1%8%e!<%k$5$1$k?$a!"FHN)@-$N9b$$=hM}$,J#?t$"$k>19g$O!"%a%b%j$N;HMQ8zN($r2~A1$9$k3H$,$G$-$k!#

K\8&5fGO3liN<jK!$rKL1=hM}7OKLIC>e$K<BAu$7!"$=$N8z2L$rI>2AMQ%W%m%0%i%'$rMQ$$FD4:7?!#

C'<!4D6-2<GO%W%m%0%i%'$r%9%1%C%I2=$9k3HKhj%Y%s%A%^!<%/%W%m%0%i%'GO1.3!A2.9G\$N@-G=8~>e$,C#@.$G$-$?!#

0lJ}!"UBNs4D6-K*$$F$OJBNs@-$NDc2<Kh$j%9%1%C%I2=$N$_$NE,MQGO=>MhHGhj$b<B9TB.EY$NMnAkLdBj$d!"=>Mh$NF0E*%9%1%8%e!<%j%s%0<jK!GOJBNs@-$rCj=P$G$-$:$KC<!<B9T$hjb@-G=$,Dc2<$9$kLdBj$bB8:_7?!#$3$1i$N%W%m%0%i%'$KBP7F$O%9%1%C%I$NF0E*%9%1%8%e!<%j%s%0<jK!H7$Freply first scheduling<jK!$rMQ$$k3H$G!"$=$N%W%m%0%i%'$N;}$DJBNs@-$r0z$-=P$9$3$H$K@.8y$7!"UBNs<B9TK*$$F$b=>MhHG$KHfYFLs1.3!A1.6G\$NB.EY8~>e$,C#@.$G$-$?!#

Abstract

In the conventional run-time system for the parallel logic programming language KL1, its fine-grained concurrency control frequently causes unnecessary goal switching which degrades its execution performance.

Generally, in scheduling at concurrent/parallel programming language as KL1, reducing redundant parallelism is important in the goal scheduling for concurrent/parallel programming language as KL1. Although many KL1 systems uses depth-first goal scheduling strategy, it is not optimal for the behavior of many programs. If the scheduling strategy is not appropriate for the target program, the scheduling overhead may cause significant performance degradation.

This paper proposes an optimization scheme of goal scheduling that sequentializes execution of goals and thus reduces overhead of dynamic scheduling.

In this scheme, we first make analysis of data dependency among goals. Using this information, we derive groups of goals that each goals of a group do not have mutual dependencies. As these goals are statically ordered without causing deadlocks, we compile each goal group into a *thread*, which is a sequence of sequentialized goals. By making this thread as unit of concurrent execution, the overhead of dynamic concurrency control is reduced. The overhead of executing goals in a thread can be also reduced, because sequentialization of goals enables the efficient implementation of goal environment using stack.

However, compiling goals into thread may cause degradation of parallelism. In our scheme, the number of concurrent execution unit is reduced and execution time of each unit is increased. This increases the possibility of making some nodes idle. In order to obtain maximum parallelism, the data request from other node must be replied as soon as possible. However, in the current KL1 goal scheduling, producer goals for the requested data does not have priority over other goals. This may cause significant inefficiency in our scheme.

So we proposed a dynamic thread scheduling scheme, named *reply first scheduling*. This scheme gives a priority to each thread so that a generator thread of a requested data is scheduled prior to other threads. Using this scheme, we can improve the responsibility to the requested data in parallel execution, which extracts maximum parallelism of the program. It also improves efficiency of sequential execution on 1 node, because the scheduling of related threads are prior to other threads.

We implement these schemes on KLIC, a portable KL1 system, and evaluated the performance using some programs.

By *threading* some benchmark programs, we achieved 1.3 - 2.9 speedups in the execution on one node. However, in the execution on several nodes, the performance of some programs were less efficient. This inefficiency is due to the decrease of parallelism caused by threading. By applying reply first scheduling for such programs, we could extract their parallelism and could obtain the maximum speedups of threading.

1 =xO@

1.1 8&5f$NGX7J

6aG/!"UBNs7W;;4D6-$N%O!<%I%&%'%"E*$J4pHW$,5^B.$K@0Hw5lDD$"$kNKBP$7!"%=%U%H%&%'%"$K4X9k2]Bj$O;3@Q$7F*$j!"FC$K9b$$@-G=$rH/4x$9$k%W%m%0%i%'$rMF0W$K3+H/$9$k5;=Q$,6/$/5a$ail$F$$k!#

=>MhJBNs%W%m%0%i%'$O!"C'<!=hM}8@8l$KJBNs<B9T$r;XDj$9$k5!9=$HF14|N?aN5!9=$rD I2C$7!"UBNs=hM}$K;HMQ$G$-$kh&K7$?8@8l$rMQ$$F!"5-=R$,9T$olF$-$?!#3liN8@8lKO

- JBNs2=%3%s%Q%$%i
- C'<!8@8l+%a%C%;!<%8%Q%C%7%s%0%i%$%V%i%j(PVM [2] JI)

JI$,B8:_$7$F$$k$,!"$=l>$l0J2<$Nh&$JLdBjE@$,B8:_9k!#

JBNs2=%3%s%Q%$%i FORTRAN JI$NC'<!8@8l$G=q$+l?%W%m%0%i%'$rBP>]H7!"%3%s%Q%$%k;~$K%W%m%0%i%'$N;}$DJBNs@-$rCj=P$7!"UBNs2=5l$?%3!<%I$r@8@.9k!#%W%m%0%i%^$,JBNs2=N?aN>pJs$r%3%s%Q%$%i$KEC9bNH$=$&GJ$$$bNH$N2<oN'$,B8:_9k!#7+$7!"$bHb$HC'<!$G=q$+$l$?%W%m%0%i%'$rJBNs2=9k$?$a!"UBNs2=2DG=$JItJ,$O%G!<%?JBNsItJ,$K8B$ilk!#3N$?$a!"5-9f=hM}JI$N7W;;Ii2Y$,@EE*$KM=B,$G$-$J$$LdBjGO8zN(E*$J%3!<%I$r@8@.9k3HOG$-$J$$!#

%a%C%;!<%8%Q%C%7%s%0%i%$%V%i%j 3l$O!"%W%m%0%i%^$,F14|$dDL?.$H$$$C$?%l%Y%k$N5-=R$r9T$&$?$a$N%i%$%V%i%jG"$k!#$[Hs$IA4$F$N7W;;5!>e$G%5%]!<%H5lF*$j!"$-aN:Y$+$JBNs=hM}$N5-=R$,2DG=G"$k!#$7$+$7F14|$dDL?.$H$$$C$?%l%Y%k$N5-=R$b%W%m%0%i%^$,9ToJ1lPJiJ$$!#F14|Kh$k%P%0$O:F8=@-$,$J$$$?a%G%P%C%0$OHs>o$K:FqKJk!#3N$?a!"MM!9$JJBNs2=%"%k%4%j%:%'$r;n$9I,MW$,$"$k>l9g$JIO!"%W%m%0%i%'$r=q$-D>$9EY$KB?Bg$JO+NO$rI,MWH9$k!#

3liNLdBj$r2r7h$9k?aKJBNsO@M}7?8@8lJI!"?7$7$$%?%$%W$NJBNs8@8l$,Ds0F$5lF$$$k!#KL1 $OJBNsO@M}7?8@8l$N0lDG$"$j!"<!Nh$&$JFCD'rb$D!#

- 8@8l$N<B9T%b%G%k$,JBNs<B9T$r4pK\$K7F$$$k$?$a!"UB9T!?JBNs%W%m%;%9$N%M%C%H%o!<%/$r<+A3$K5-=R$G$-$k!#3N$?$a!"$$$ofk%G!<%?JBNs$KN1$^iJ$$B?<cB?MM$J1~MQ$H%W%m%0%i%_%s%0!&Q%i%@%$%'$KBP9k9b$JqMFNO$bM-7F$$$k!#
- %G!<%?%U%m!<F14|5!9=$NF3F~$Khj!"F14|$r<+F02=$9k3HGF14|KHbJ$&%P%0:.F~$N2DG=@-$rGS=|$7$F$$$k!#
- %7%s%?%C%/%9$,4J7i$GJ,$+$jd9$!#

3&7?FCD'N*$+2$G!"KL1 $rMQ$$$k3H$G!"UBNs=hM}%=%U%H%&%'%"$N3+H/O+NO$rBgI}$K7Z8:9k3H$,$G$-$k!#

7+7J$,$i!"JBNs=hM}$N=EMW$JB&LLG"$k9bB.@-$N4QE@$+$i$O!"$3li$NJB9T!?JBNs7?8@8l$N=hM}%7%9%F'$N@-G=$O==J,HO8@$($J$!#$3$N@-G=>e$NLdBjE@NBg-$JM}M3$K!"8@8l$NK\<A$G$"$kJB9T@-@}8fKHbJ$&*!<%P%X%C%I$,$"$k!#KL1 O=$NC<E*$JNc$N0l$DG"$j!"3F!9$N%4!<%k$,JB9T<B9T$NC10LG"$k?$a!"%4!<%k!&9%1%8e!<%j%s%0$NJ}<0$,%W%m%0%i%'$N@-<A$KE,9g7F$$J$$H!"K\MhC'<!E*$K<B9T$9kN$,:GE,$JItJ,$rJB9T<B9T$9kJ$I!"L5BL$J=hM}Kh$k%*!<%P%X%C%I$,Cx7/Bg$-$/Jk>l9g$,$"$k!#

1.2 8&5f$NL\E*

=>Mh$NC'<!8@8l$NJBNs2=GO!"$=$N%W%m%0%i%'$N;}$}$DJBNs@-$r$$$+$KCj=P$9k3H,G-k+$,=EMW$G$"$k!#0lJ}!"JB9T!?JBNs7?$N%W%m%0%i%_%s%08@8l$GOJBNs@-$NCj=P$OMF0WG"$kH?LL!"%W%m%0%i%'$CfK B8:_9kITI,MW$JJBNs@-$r$$$+=K=|5n9k$+$,=EMWKJ$k!#8@$4$9$(kHJB9T!?JBNs7?$N%W%m%0%i%'$N%9%1%8e!<%j%s%0GO!"C'<!<B9T$,:GE,$G$"$kh&$J?7!<%1%s%9$rH/8+$7!"$=lNC'<!<B9T$,=EMW$G$"$k!#3l$^$G$NB?/$NKL1=hM}7OGO!"%W%m%0%i%'$r?<5!?:8M%@h$K<B9T9kN,C'<!<B9T$N:GE,%7!<%1%s%9$H$_$JJJH9M$($k3H$,$G$-$k!#7+$7%W%m%0%i%'$N@-<A$,!"$3Nh$&$JC1=c$J?dJ$K$CE,9g$7$J$$$3H,7P7P$"$j!"MM!9$J@-G=>e$NLdBjE@$,H/@8$9$k!#

7?$,$G$F!"%3%s%Q%$%k;~Kh$j>\:Y$J2r@O$r9T$C$F!"%W%m%0%i%'$N@-<A$KE,9g$7$?C'<!2=$r9T$&$3H,!"$^$:h0l$NL\E*$HJk!#<!$K!"E,@Z$KC'<!2=5l$?%W%m%0%i%'$CGJR$r8zN(E*$K<B9T9kKO!"K\<AE*$JUB9TF0:n$H$N4X7$JIKhkC'<!<B9T$NCfCG$KBP7F!":G>.$N%*!<%P%X%C%I$GBP=hG-kh$&$K9k3HbI,MWG$"$k!#3N<B9T%a%+%K%:%'$r5a$ak3H,!"K\8&5f$NBhFs$NL\E*G"$k!#

1.3 K\O@$N9=@.

K\8&5fGO!"KL1 $N%4!<%k!&9%1%8e!<%j%s%0$r:GE,2=9k3H$rL\E*$H$7!"%W%m%0%i%'$N@-<A$rBP1~$7$?%k7CNs$KJ,3d9k<jK!G"$k%9%l%C%I2=<jK!$H!"%9%l%C%I$rJBNs<B9T$9$k:]$KJBNs@-$r:GBg8B$K3NJ]9k$?a$N%9%1%8e!<%kJ}K!G"$k**reply first scheduling**<jK!$NDs0F!"<BAu!"I>2A

$r9T$C$?!#0J2<!"K\O@J8$G$O!"$3$1$i$N:GE,2=<jK!$r<!Nh$&$J9=@.$G=R$Y$k!#

Bh2>OGCK\8&5f$NGX7J$H$7F!"K\8&5f$NBP>]8@81$*$h$S<BAuBP>]$N=hM}7OG"$k!"UBNsO@M}7?8@81KL1 $*$h$SKL1 =hM}7OKLIC KD$$F@bL@7?NA!"=>Mh$NKL1 =hM}7O$K$*$$F:NMQ$5$1F-$?%4!<%k!&9%1%8%e!<%j%s%0<jK!KD$$F=RYk!#

Bh3>OGO!"K\:GE,2=<jK!KD$$F%W%m%0%i%'$NC'<!2=<jK!$H!"$=$NC'<!2=$5$1$?%W%m%0%i%'CGJR$NF0E*$J%9%1%8%e!<%j%s%0<jK!$G$"$kreply first scheduling KD$$F=RYk!#

Bh4>OGO!"K\:GE,2=<jK!$NKLIC XN<BAuKD$$F=RYk!#

Bh5>OGO!"I>2AKD$$F=RYk!#

Bh6>OGO!"4XO"8&5f$NHf3S$H:#8e$N2]Bj$K$D$$F=RYk!#

Bh7>OGO!"7kO@$r=R$Y$k!#

2 GX7J

2.1 JBNsO@M}7?8@81KL1 H=$N=hM}7OKLIC

2.1.1 KL1

K\@aGO!"JBNsO@M}7?8@81KL1 [3] KD$$F=RYk!#

%W%m%0%i%'9=B$ KL1 $OFlat GHC[4] $K4p$E$/8@81$G!"0J2<$N7A$r7?@a$N=89g$GI=$5$1$k!#

$$H:-G_1,\cdots,G_m|B_1\cdots,B_n.$$

H, G, B $O=R81$G$"$j!"$=$1$>$l%/%m!<%:%X%C%I!"%,!<%I%4!<%k!"%\%G%#%4!<%k$H8F$P1k!#=R81$O'=R8lL>/0z?t$N8D?t'$GI=5-$5$1$k!#|'$O%3%_%C%H%a%s%H%P!<$H8FP1!"@aCfG3$1$N:8B&$NItJ,$r%,!<%It!"1&B&$r%\%G%#t%H8F$V!#%,!<%I%4!<%kH7F5v$5$1kbNOAH9~=R81N_$G!"%\%G%#%4!<%k$H$7F$O!"AH9~=R81$H%f!<%6Dj5A=R81$r5-=RG-$k!#^?!"%\%G%#%4!<%k$O=1>lrJBNs$K<B9T$G$-$k!#

<B9T5,B' K\@aGO!"KL1 %W%m%0%i%'$,$INh$&$K<B9T$5$1k+KD$$F@bL@9k!#KL1 GN<B9T$NC10L$O%4!<%k$H8F$P1k!#%4!<%k$N<B9T$O0J2<$N5,B'$K7?$,$C$F9T$olk!#

1. M?$($i1?%4!<%kG $H%X%C%I$H$NF10l2=$*hS%,!<%I%4!<%k$N<B9T!#

   $3$1iN<B9TKhCFG $N0z?t$r6qBN2=7FOJiJ$$!#

2. 1 $,@.8y$7$?@a$N$&$A$N$$:1+0lDN@a$N%\%G%#%4!<%k$r?7$?$J<B9T2DG=%4!<%kH9$k!#

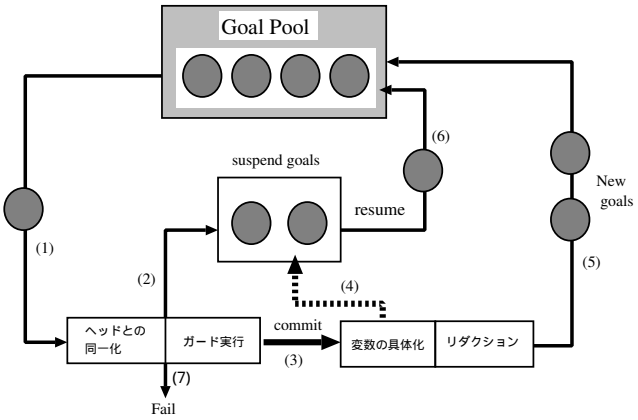
   $^$?!"%\%G%#%4!<%kGNF10l2=%4!<%k$N<B9T(%\%G%#f%K%U%#1!<%7%g%s) GO!"JQ?tNCMr7hak3H(JQ?t$N6qBN2=) $,$G$-$k!#JQ?t$N6qBN2=$O%W%m%0%i%'CfG?$@0l2s$7$+9T$&3H$,$G$-$J$$!#

$3$1$r<B9T2DG=$,%4!<%k$,$J$/$Jk^$G7+$jJV$9!#?^1$KKL1 $N<B9T%b%G%k$r<($9!#

3N%k!<%k$K4p$E$-!"?^2$K<($9%W%m%0%i%'$rMQ$$F!"KL1 $N<B9T%a%+%K%:%'$r@bL@9k!#3N%W%m%0%i%'OZ = |X| * 2 $r<B9T$9k%W%m%0%i%'G"$k!#

KL1 GO=i4|%4!<%kH7$Fmain/0 $,M?$(i1$k!#main@a $N<B9T$KhC$F%4!<%ktmp(-10,Z) $,<B9T2DG=%4!<%k$r0l;~4IM}9k$?$a$NNN0h$K3JG<$5$1$k(?^1.(5))!#$3$NN0h$r$3$3G$O%4!<%k%W!<%k$H8F$V!#

%4!<%k' tmp(-10,Z)' $N<B9T$KhC$F!"%X%C%I$,tmp/2 G"$k(1)@a$,A*Br$5$1!"'abs(-10,Y),mul2(Y,Z)' $H$$$&2



?^1: KL1 $N<B9T%b%G%k

```
main :- tmp(-10,Z).                                   (0)
tmp(X,Z) :- abs(X,Y),mul2(Y,Z).                       (1)
abs(X,Y) :- X>=0 | Y := X.                            (2)
abs(X,Y) :- X<0 | Y := -X.                            (3)
mul2(Y,Z) :- integer(Y) | Z := Y * 2.  (4)
```

*integer(Y) : Y $,*integer*$+I&$+$rD4YkAH$_9~$_=R81

?^2: $Z = |X| * 2$ $r5a$a$kKL1 %W%m%0%i%'

DN%4!<%k,%4!<%kW!<%k$K3JG<$5$1$k(?^1.(5))!#3NH-!"bH$N%4!<%k'tmp(-10,Z)' $O%4!<%kW!<%k$+iJ$/$J$k!#$3$NA'n$r8@$$4$9($k$H!"%4!<%k'tmp(-10,Z)' $,$\%G%#%4!<%k'abs(-10,Y),mul2(Y,Z)' $K=q$-4$9($i1?$H$$($k!#$3$N01O"$N%4!<%k$N=q$-4$9($NA'n$r%4!<%k$N%j@%/%7%gsH$$$&!#

=q$-4$9(i1$?2 DN%4!<%k$O%4!<%kW!<%k$+$i<h$j=P51l!"<B9T$5$1$k(?^1.(1))!#$9Jo$A!"'abs(-10,Y)' $H(2),(3)@a!"'mul2(Y,Z)' $H(4)@a$H$NF10l2=$,;n$_$i1k!#3N>19g!"'abs(-10,Y)' $N%j@%/%7%g$sGO%,!<%I%4!<%k$N<B9T$,@.8y9k(3)@a$,A*Br$5$1(?^1.(3))!"%\%G%#%4!<%k'Y:=-(-10)',<B9T$5$1$k!#01J}'mul2(Y,Z)' $NU}$OBh010z?t$NY $,6qBN2=$5$1$F$$$J$$?a'mul2(Y,Z)' $O<B9T$rCfCG$7!"Y $,6qBN2=$5$1$kNrBTD3HKJk(?^1.(2))!#$3$1$r%4!<%k$N%5%9%Z%s%I(suspend) $H8F$V!#$=$7$F'add1/2' $N<B9T$,=*N;$7!"Z NCM,10 $K6qBN2=$5$1$k$H(?^1.(4))!"'mul2/2' $O<B9T$r:F3+9k(?^1.(6))!#$3$1$r%j%8%e!<%\'(resume) $H8F$V!#

KL1 $N<B9T$O3Nh&$JA'n$r7+jJV9$3$HKhCF?J$_!"%4!<%kW!<%k$K%4!<%k,J/Jk$H<B9T$,=*N;9k!#3NH-!"CfCGCf$N%4!<%k,B8:_$9$k>19g$O<B9T,%G%C%I%m%C%/7F$$k$H$$$&$&!#

$^$?Prolog HO0cCF%P%C%/%H%i%C%/$O9T$o$:!"$b$7Y $,integer 0J30$NCM$K6qBN2=$5$1$k>19g$d!"%\%G%#%4!<%k$G$NF10l2=$K<:GT7?>19g$O!"%W%m%0%i%'$O<B9T$r<:GT$7=*N;9k(?^1.(7))!#

%G!<%?9=B$ KL1 $N%G!<%?9=B$$K$O!"<!$N#3DNbN$,$"j^$k!#

- O@M}JQ?t
  O@M}JQ?t$O;2>H%]%$%s%?$GI=8=$5$1!"FCDj$N7?$O;}$?$J$$!#6qBN2=KhCFBP>]XN%]%$%s%?$,3JG<$5$1$k!#$^$?!"0lEY6qBN2=$5$1$k$H!"UL$NCM$K:F$S6qBN2=9k3HOG$-$J$$(C10lBeF~5,B')!#

I= 1: KLIC $N%G! <%?7?

%?%0		%G! <%?7?
REF	(00)	O@M}JQ?t
CONS	(01)	%3%s%9%;%k(%j%9%H)
FUNC	(10)	%j%9%H0J30$N9=B$%G! <%?7?
ATOMIC	(11)	%7%s%\%j%C%/%"%H%`, @0?t

- %"%H%_%C%/%G! <%?7?
  %"%H%_%C%/%G! <%?$OFbIt9=B$$r; }$?$J$%G! <%?$G$"$j! "CM $=$NbN$,0UL#$r; }CF$$$k! #NcH7$F! "%7%s%\%j%C%/%" %H% `$d@0?t$,$"$k! #
- 9=B$%G! <%?7?
  9=B$%G! <%?$OJ#?t$N%;%k$+iJ$j! "$3li$N%;%k$KOG0U $N7?$N%G! <%?(XN%]%$%s%?) $r3JG<$9k3H,G-$k! # 0lHIE*$JbNH7FO%U%!%s%/%?$d%j%9%H$,$"$k! #

2.1.2 KLIC

KLIC [5] [6] $O! "ICOT $G3+H/$5l?KL1 $N=hM}7O$G$"$j! "KL1 %W%m%0%i%`$r$$$C$?$sC %W%m%0%i%`$KJQ49$7! "%*%V%8%'%/%H%3! <%I$N@8@.$O%?! <%2%C%H%^%7%s$NC %3%s%Q%$%i$,9T$&J}<0rHCF$$$k! #hC$F! "DL?.4X78$JIN5!<o0MB8It$r=|$-0\?"@-$N9b$$=hM}7OHJCF$$$k! #8=:_! "HFMQJBNsDL?.%i%$%V%i%j$G$"$kPVM[2] $rMQ$$?%o! <%/%9%F! <%7%g$sHGKLIC JI$,2TF/CfG"$k! #

<B9T%W%m%0%i%`$OKL1 %W%m%0%i%`$+$iF@il$?%*%V%8%'%/%H%3! <%I$HKLIC $N%i%s%?%$%`%i%$%V%i%j$r%j%s%/$9$k$3$H$G:n@.$5$l$k! #KB9T%4! <%k$NA*Br$J$I$N%W%m%0%i%`A4BN$N@)8f$O! "%i%s%?%$%`%7%9%F%`Cf$N=hM}7O3KHhPl$kItJ,$,9T$&! #

%G! <%?9=B$ $3$3GO! "KLIC $G;HMQ$5lk%G! <%?9=B$$K$D$$$F=RYk! #J*KLIC GO9YFN%G! <%?9=B$$O! "$=$N@8@.$*$h$S>CHq%4! <%k$,<B9T;~$^$GH=L@7J$$?$a%R! <%W>e$G4IM}5l$k! #

4pK\%G! <%?9=B$:

KLIC GOKL1 $N%G! <%?$r%?%0IU$-%;%k$^$?$O! "%?%0IU$-%;%k$K;X5l$?9=B$BN$GI=$7$F$$$k! #%?%0$O2<0L2 %S%C%H$G$"$j! "REF, CONS, FUNC, ATOM $N4 <oN`$,B8:_9k! #

%4! <%k%l%3! <%I:

<B9T$NC10L$G$"$k%4! <%k$O! "%4! <%k%l%3! <%I$H7FI=8=5l! "<!$K<B9T$5lk%4! <%kXN%]%$%s%?! "BP1~$9$k%3! <%I$X$N%]%$%s%?! "0z?t$+$iJk! #

Generic object:

KLIC KO! "KL1 $N4pK\%G! <%?$NB>$Kgeneric object $H8F$Plk%G! <%?9=B$$,B8:_9k! #generic object $O%G! <%?NN0h$H%G! <%?$rA`:n$9$k%a%=%C%I$H8FPl$k<jB3$-$+$iJk! #generic object KOdata, consumer, generator $N#3$D$N%?%$%W$,$"$j! "MQES$K1~8F;H$J,$1il$k! #

consumer object $Hgenerator object $OO@M}JQ?t$NI=8=J}K!$N0l<o$G$"$k! #3l$i2 DN%*%V%8%'%/%HKBP7! "6qBN2=$d;2>H$JIN2?i+$N%"%/%7%g$s$,$"C?>19g! "%a%=%C%I$H8F$Plk<jB3$-$,<+F0E*$K5/F0$5lk! #0lHI$K! "consumer object $O6qBN2=$Khj! "$=$N6qBNCM$r>CHq$9$k UNIFY %a%=%C%I$,! "generator object $O;2>H$Khj! ";2>H%G! <%?$r@8@.$5$;$kGENERATE %a%=%C%I$,5/F0$9$k! #$^$?data object $O4pK\%G! <%?9=B$0J30$N?7$7$$%G! <%?9=B$$r<B8=9k<jCJH7$FMQ$$$ilk! #NcH7$F! "vector 7?! "float 7?$dstring 7?JI$,$"$k! #

C`<!<B9TJ}<0 %W%m%0%i%`$N<B9T$O! "=hM}7O3K$,A*Br$7$?%4! <%k$KBP1~9k3! <%I$r<B9T$7! "$=$NCf$GF@$il?%\%G%#4! <%k$r%4! <%k%-%e! <$N@hF,KDJ0$3$H$G9T$olk! #?^3$KKLIC $N<B9T$NMM;R$r<($9! #

<B9TCf$N%4! <%kg$GL$Dj5AJQ?tX$r;2>H9k$H! "X$O6qBN2=BT$AJQ?t(%U%C%/JQ?t) KJ$j! "3N%4! <%k$r;X$9! #$3l,%4! <%kg$,CfCG7F$$$k>uBVG"$j! "gJQ?tX$K%U%C%/7F$$$k$H$$$&! #=hM}7O3K$OCfCG=hM}$r9TO?8e! "?7$?$J%4! <%k$r%4! <%k%-%e! <$+$i<h$j=P$7<B9T$rB3lk! #$=$N8eX$,6qBN2=$5lk$H! "X$KDJ$,$l$F$$?%4! <%k$O<B9T2DG=%4! <%k%-%e! <$N@hF,KLa5lk! #3Nh&$KKLIC GO%j%8%e! <%`$5$l$?%4! <%k$,M%@hE*$K%9%1%8%e! <%k$5$l$k! #$3$NA`:n$r7+jUV7! "<B9T2DG=%4! <%k%-%e! <$+$i%4! <%k$,L5$/Jk$H%W%m%0%i%`$O=*N;9k! #

KLIC J,;6=hM}7O KLIC J,;6=hM}7O[7] $N7W;;%b%G%k$O! "6I=j%a%b%j$r;}$A%M%C%H%o! <%/$G7k9g$5l?%N! <%I$,!"8_$$K%a%C%;!<%8DL?.r7J,$i=hM}$r9T$&$H$$$&bNG"$k! #<+F0Ii2YJ,;6$O9Tol$:!"Ii2YJ,;6$r9T$&$K$OL@<(E*$K%W%m%0%i%`Cf$K;XDj$7$J$l$l$P$J$i$J$$! #goal($X_1, \cdots, X_n$)@node($N_c$) $H$$&7A$N%\%G%#4! <%k$,%N! <%I$N_p$>e$K8=$l$k$H! "$3$N%4! <%k$O%N! <%I$N_c$KAw$i$l! "$=$3$G<B9T$5$l$k! #A4$F$N%N! <%I$G<B9T2DG=$J%4! <%k$,$J$/$J$k$H! "%W%m%0%i%`$N<B9T$O=*N;9k! #

30It;2>H%]%$%s%? JQ?t$d9=B$%G! <%?$NAw?.$,9T$olk$H! "%N! <%I4V$KEO$k;2>H%]%$%s%?$,@8$^lk! #3l$r30It;2>H%]%$%s%?$H$$&! #3N%]%$%s%?$O<u?.B&(;R%N! <%I) $+$iAw?.B&(?F%N! <%I) XNC1J}8~$N%]%$%s%?G"$k! #$3N?a! "6qBN2=%N! <%I$,<u?.B&! "Aw?.B&$NIAiG$"$k$+$KhC$F! "6qBNCM$NAw?.J}K!$,0[$J$k! #

;R%N! <%I$,6qBN2=:?FB&$+iO6qBNCMXN%]%$%s%?$,B8:_7J$$?%a! "6qBN2=7?;~$K! ";R%N! <%I$,?F%N! <%IKBP7$F6qBNCM$rAw?.! #

?F%N! <%I$,6qBN2=:;R%N! <%I$+iNMW5aKhCF! "?F%N! <%I$,6qBNCM$rAw?.! #

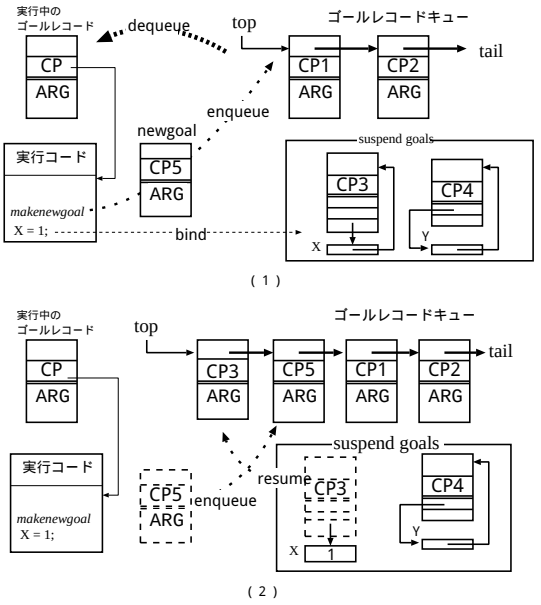
$^$?$"$kJQ?tXKBP9$kMW5a$r<u?.7?H-$K! "X$,L$6qBN2=$GJV?.$r9T$($J$$>19g! "=hM}7OOXKBP$7! "JV?.MQ$N consumer object $r%U%C%/$5$;$k! #3N5!9=Kh$j! "X$N6qBN2=;~K3$N%*%V%8%'%/%H$NUNIFY %a%=%C%I$rMQ$$F<+F0E*$KJV?.$,9Tolk3HKJk! #

3Nh&$K3OIt;2>H%]%$%s%?$r7PM3$7$?;2>H$d6qBN2=KO%a%C;! <%8DL?.$H$$$&5!<o$K0MB8$7$?=hM}$rH<$&! #=$3$G! "30It;2>H%]%$%s%?$rgeneric object $rMQ$$F<EAu$7! "$3li$N=hM}$r%a%=%C%I$rMQ$$F9T$&$3HG! "%+! <%M%k$N0\?"@-$r9baF$$k! #

2.2 KL1 $N%4! <%k%9%1%8%e! <%j%s%0<jK!

K\@aGO>Mh$NKL1=hM}7O$G:NMQ5lF-$?4! <%k!&%9%1%8%e! <%j%s%0<jK!KD$$F@bL@9k! #

8=:_KL1=hM}7O$GDs0F$5lF$$$k%9%1%8%e! <%j%s%0<jK! H7$F! "%W%m%;%9;X8~%9%1%8%e! <%j%s%0$H%a%C%;!<%8;X8~%9%1%8%e! <%j%s%0[8] $N2 D,$"$k! #$=l>$lKD$$F@bL@9kA0$K! "KL1 Gh$/;H$olk%W%m%;%9%H%9%H%j! <%`$rMQ$$?%W%m%0%i%_%s%0%9%?%$%k[9] KD$$F@bL@9k! #



?^3: KLIC $N<B9T$NMM;R

%W%m%;%9$H%9%H%j!<%`KL1 $N%W%m%0%i%`$O%W%m%;%9$H8F$Plk<B9T$N4pK\MWAG$r!"%9%H%j!<%`$H8F$P$l$k%W%m%;%94V$G$N>pJs$N$d$j$H$j$r9T$&$?$a$N'7PO)'$rMQ$$FAH$_9g$o$;$k$3$H$G9=@.$5$l$k$3$H$,B?$$!#3F%W%m%;%9$O%9%H%j!<%`$+$iN.lF$/$k@)8f>pJs$d%G!<%?$K4p$E$$$F<+%W%m%;%9$NFbIt>uBV$rJQ$(,$?$j!"$"$k<o$N7W;;$r9T$G$?$j7F!"$=$N7k2L$r:F$S%9%H%j!<%`$KN.$9$H$$$&A`:n$r7+$jJV$9!#

KL1 K*lk%W%m%;%9HO$"$kDxEYNBg-5rbC$?O"B3@-$N$"$k7W;;2aDxG"$j!"%W%m%;%9$H7FB8:_9k$?$a$K:F5"8F=P$7$rMQ$$$k!#0J2<GO%4!<%k$/n $G;O$^$k%W%m%;%9$rC1$K%W%m%;%9$/n $H8F$V!#%9%H%j!<%`$OKL1 GO%j%9%H$r;HCF<B8=$5lk!#%j%9%H$Ncar ItJ,$,:G=i$N%a%C%;!<%8!"cdr ItJ,$,;DjN%a%C%;!<%8ItJ,$rI=$9!#

KL1 %W%m%0%i%`$NNc$H$7$F?^4(a) $K%W%m%;%94VDL?.$r9T$&%W%m%0%i%`r"2F$*$/!#$^$??^4(b) O3$N%W%m%0%i%`$N9=B$$rLZ9=B$$GI=$7$?$b$N$r<($9!#?^4$N%W%m%0%i%`$NNcGO(1) $N@a$NXHY,%9%H%j!<%`UQ?tHJCF$*$j!"q/3, p/2 $NN>%W%m%;%94V$NDL?.O)$NLr3d$r2L$?$7$F$$$k!#

3Nh&$J?^$O0J8e$bMQ$$$kNG!"?^$N@bL@$r9T$&!#

: %X%C%I%f%K%U%#%1!<%7%g%s$H%,!<%I4!<%k<B9T$rI=$9!#

goal (n) : %3%_%C%H7?@a((n) @a) $N%\%G%#It$N<B9T$r<($7!"%\%G%#%f%K%U%!%$$*hS4!<%k$N%j%@%/%7%g%s$r9T$&!#

goal : %j%@%/%7%g%sKhCF@8@.5l$?4!<%k$r<($9!#

: AH9~=R81$N%j%@%/%7%g%s5Z$S<B9T$r<($9!#

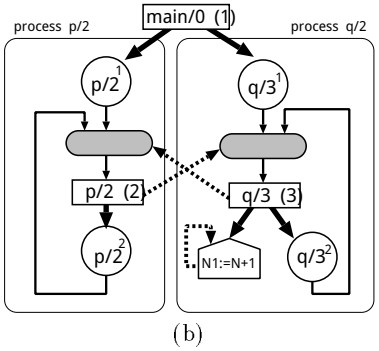
: %G!<%?%U%m!<$rI=$9!#

: %3%s%H%m!<%k%U%m!<$rI=$9!#

$^$?!"%W%m%0%i%`Cf$NF1L>%4!<%k$r6hJL9k$?$a$K!"I,MW$K1~8Fp/2[1] Nh$&$K=R81L>$NL&8*$KHV9frD1k!#5i$K!":F5"$KhjJ#?t2s8FPl$k%4!<%k$K$D$$$F$O!":F5"$Khk%k!<%W$N3F%9%F%C%W$r9M$(!"%k!<%W$Nk2sL\$G@8@.5l$k%4!<%kgoal $rgoal$_k$ $HI=$9$3$HK9$k!#

```
main :- p([ack(0)|X],Y)[1],q(Y,X,1)[1].                    (1)
p([ack(N)|X],Y) :- Y=[read|Y1],p(X,Y1)[2].                 (2)
q([read|X],Y,N) :- Y=[ack(N)|Y1],N1:=N+1,q(X,Y1,N1)[2].    (3)
```

(a)



(b)

?^4: %W%m%0%i%`communication

2.2.1 %W%m%;%9;X8~%9%1%8%e!<%j%s%0

%W%m%;%9;X8~%9%1%8%e!<%j%s%0$O%4!<%k$N%9%$%C%A%s%0$r8:i9$3$H$rL\E*$H7?%9%1%8%e!<%j%s%0J}<0G"$k!#0lC6%4!<%k$,<B9T$r3+;O$^$?$O:F3+9k$H!"2DG=$J8Bj=$N%4!<%k$N%5%V%4!<%k$r<B9T$9$k!#$D$^$j?<$5M%@h$N%4!<%k!&%9%1%8%e!<%j%s%0<jK!G"$k!#

?^4$N%W%m%0%i%`$rMQ$$F<B:]KINh$&$K%4!<%k$,%9%1%8%e!<%k$5lF$$/$+$r8+$F$$/3HK9$k!#

3N%W%m%0%i%`$N%G!<%?0MB8$O<!NDLjG"$k!#

- $q/3_n$, $p/2_n$ $Kp/2_{n+1}$, $q/2_n$ K=l>$l%G!<%?0MB8$9$k!#

<!$K<B9T=g=x$O<!Nh$&$KJk!#

```
main/0 → p/2[1] (2) → p/2 (susp) → q/3[1](3)(rsm p/2)
→ N1:=N+1 → q/3(susp) → p/2[3](2) → p/2(susp) → ···
```

goal (n) : goal $,$n$N@a$Kcommit
goal (susp) : goal $,CfCG
goal1 (n)(rsm goal2) :
nHV$N@a$Ngoal1 $N<B9T$,goal2 $r%j%8%e!<%`

3Nh&$Kq/3 $Hp/2 $,1 2s%a%C%;!<%8$rdj<hj9kEYK!"3F!9$,1EY$:$DCfCG$7F7$^$&!#3Nh&$K%W%m%;%9;X8~%9%1%8%e!<%j%s%0GO!"%G!<%?0MB8$9$k$H!"%9%1%8%e!<%j%s%0$O%4!<%k4V$N@Z$jBX$(;~$K%4!<%kCfCG$,@8$8F7$^$&!#

%W%m%;%9;X8~%9%1%8%e!<%j%s%0GO%9%H%j!<%`$O%2DG=$JH-$KFbMF$r=hM}9k%P%C%U%!!"WH7$F?6Iq$&!#%W%m%;%9;X8~%9%1%8%e!<%j%s%0$H$$$($k!#

2.2.2 %a%C%;!<%8;X8~%9%1%8%e!<%j%s%0

%a%C%;!<%8;X8~%9%1%8%e!<%j%s%0$O%4!<%k%9%$%C%A%s%0$N%3%9%H$H%G!<%?E>Aw$N%3%9%H$r8:i9$3$H$rL\E*$H7?%9%1%8%e!<%j%s%0G"$k!#$3$N<jK!$G$O!"B>%4!<%k$KBP9k%a%C%;!<%8$,!¥u?.B&$KBP$7@8$f$r0\$9!WF/$-$r9k!#3N$?$a!"%a%C%;!<%8$r<u?.$7$?%4!<%k$,<B9T$r3+;O$9k3HKJk!#

?^4$N%W%m%0%i%`$N<B9T=g=x$O<!$Nh&KJ$k!#

```
main/0 → p/2^1(2) → q/3^1 (3) → p/2^2(2) → p/2(susp)
→ M1:=M+1 → q/3^2(3) → p/2^2(2) → ···
```

%a%C%;!<%8;X8~%9%1%8%e!<%j%s%0$O1~Ez@-;X8~$N%9%1%8%e!<%j %s%0Hb$$$($k!#

2.2.3 KL1 $N%4!<%k!&9%1%8%e!<%j%s%0$N<B:]

8=:_!"<BMQ2=$5$1$F$$$kKL1 $N=hM}7O$K$*$1$k!"%4!<%k!&9 %1%8%e!<%j%s%0<jK!KO%W%m%;%9;X8~%9%1%8%e!<%j%s%0$,:NMQ $5$1F~$?!#Nc$($P!"Multi-PSI [10] $dPIM [11] $JS I$N=hM} 7O$,$3$NJ}<0$r:NMQ7F$$$k!#

7+7J$,$i!"%W%m%;%9;X8~J}<0GO!"@8@.!&2>H%W%m%; %94V$N%4!<%k@ZBX$,I,$:CfCG$G5/CF7^$$!"$=$N%*!<%P%X%C %I$,Bg$~$/$JCF7^$&$H$$$&LdBj$,$"$k!#

$=$3$GKLIC GO!"3N%*!<%P%X%C%I$r7Z8:$9k?aK!" $"$k%4!<%k$,%j%8%e!<%`$5$1$?$H$~!"%W%m%0%i%`$N@)8fr=$N %j%8%e!<%`$5$1$?%4!<%k$KO\$9h&$J%9%1%8%e!<%j%s%0<jK!$r <hCF$$$k!#3NJ}<0$Oresumption first scheduilng J}<0 $H8F$P1F$$$k!#

3NJ}<0GO!"CfCG%4!<%kKBP9$k%a%C%;!<%8$KhC$F!" %a%C%;!<%8;X8~E*$J%4!<%k$N@ZBX$r9T$&$?$a!";2>HB&$,CfCG$7 $F$$$kH~$N!"@8@.%W%m%;%9$+$i;2>H%W%m%;%9$X$N%4!<%k$N@Z BX$,Dc%*!<%P%X%C%I$G9To1$k!#

3 :GE,2=<jK!

3.1 %9%1%C%I2=<jK!

3.1.1 =>Mh<jK!$NLdBjE@

0lHL$KJB9T!?JBNs7?%W%m%0%i%`$N%9%1%8%e!<%j%s%0$G$O!"C`<! <B9T$,:GE,$G$"$kh&$J%7!<%1%s%9$rH/8+$7!"$=1rC`<!<B9T $9$k:GE,2=$,=EMW$G$"$k!#Nc$($PKLIC $J$I$3$l$^$G$NKL1 =hM}7O$G$O!"%W%m%0%i%`$r:8!??<$5M%@h$K<B9T$9kN$,C`<!<B 9T$N:GE,%7!<%1%s%9$H8+$J$7$F$$$k!#$7$+$7!"%W%m%0%i%`$N@- <A$,!"$3Nh$&$JC1=c$J?cDj$K$OE,9g$7$J$$3H,IaDLG"$j!" MM!9$JLdBj$,@8$8k3H,$"$k!#K\@aGO$^$:KL1%W%m%0%i%` $N<B9T$K$*$$FINh&$J%*!<%P%X%C%I$,B8:_9k$+$r<($9!#= $N8e!"<B:]$K%W%m%;%9;X8~%9%1%8%e!<%j%s%0J}<0$dresumption first scheduling J}<0$rMQ$$?>19g$K@8$8$kLdBjE@$K$D$$F=R Yk!#

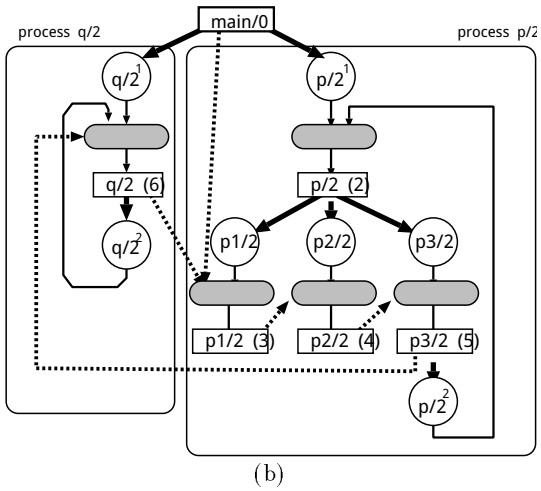
%4!<%k<B9T$N%*!<%P%X%C%I 0lHL$K$"$k%4!<%k$r@8@.$7F=$1 $r<B9T$9k^$G@8$8$k%*!<%P%X%C%I$K$O<!$Nh&JbN,$"$k!#

- %4!<%k%1%3!<%I$N%R!<%W>e$X$N3NJ]
- %4!<%k$N<B9T2DG=%4!<%k%~%e!<$+iN%(%s%~%e!<$*$h$S %4!<%k%~%e!<$X%G%~%e!<(0J2<C1$K%4!<%k$N%(%s%~%e!<!? %G%~%e!<$H8F$V)
- %5%9%Z%s%I%A%C%/

$^$?!"%4!<%k$,%5%9%Z%s%I$7F7$^$C$?>19g$O!"%j%8%e!< %`$5$1k^$G!"$=$N%4!<%k$,%9%1%8%e!<%k$5$1$J$$$h$&$K9k $?$a$N=hM}$,9To1$k!#$^$?!"UQ?t$N6qBN2=$N:]$K:F$S!"%4!< %k$N%(%s%~%e!<!?%G%~%e!<N?aN=hM}$,I,MW$KJk!#3l$i N&$A!"FC$K%4!<%k$N%5%9%Z%s%I$KBP9k%*!<%P%X%C%I$OHs>o KBg~JbNHJG$F$$$k!#

```
main :- q(Y,X)^1,p([ack|X],Y)^1 .                (1)
p(X ,Y) :- p1(X,X1),p2(X1,X2),p3(X2,Y).          (2)
p1([ack|X],Y) :- Y = [f1|X].                     (3)
p2( [f1|X], Y) :- Y = [f2|X].                    (4)
p3( [f2|X], Y) :- Y = [read|Y1],p(X,Y1)^2.       (5)
q([read|X],Y) :- Y=[ack|Y1], q(X,Y1)^2.          (6)
```

(a)



(b)

?^5: %W%m%0%i%`communication2

%W%m%;%9;X8~J}<0K*1kLdBjE@ A0@a$G=R$Y$?$h$&$K!"%W%m %;%9;X8~J}<0KO!";2>H!@8@.%W%m%;%94V$N@ZBX$,I,$:CfCG$G 9To1kH$$$&LdBj$,$"$k!#

3NLdBj$O!";2>H%4!<%k$,J#?tB8:_9k>19g$d!";2>H%W%m %;%9$N=PNC$K0MB8$9$k%4!<%k$,B??tB8:_9k>19gKFCKBg$~$/ Jk!#

Nc$($P!"?^5NMMJ>19g$r9M$(F_$k!#$3NNcN%G!<%?0M B8$O<!$NDLjG$"$k!#

- q/2$_n$, p1/3$_n$, p1/3$_{n+1}$, q/2$_n$, p2/2$_{n+1}$, p1/3$_n$, p3/2$_{n+1}$, p2/2$_n$ K=1>$1%G!<%?0MB8$9$k!#

3NNcGN%9%1%8%e!<%j%s%0=g=x$O<!$Nh&KJ$k!#

```
q/2^1 (susp) → p/2^1 → p1/2 → p2/2 → p3/2  (rsm  q/2^1)
→ p/2^2 → p1/2 (susp) → p2/2 (susp) → p3/2 (susp) →
q/2^1  (rsm  p1/2) → q/2^2  (susp) → p1/2  (rsm  p2/2)
→ p2/2 (rsm  p3/2) → p3/2 (rsm  q/2^2) → p/2^2 → ···
```

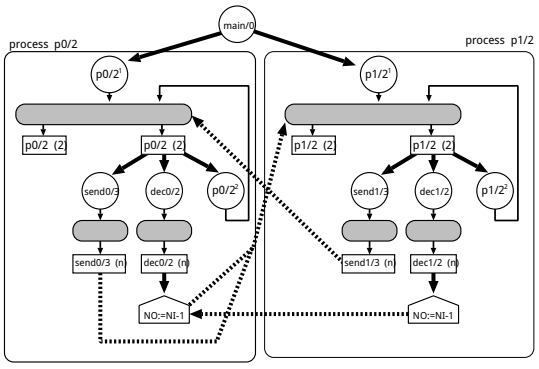
3Nh&$K!"p1/2 $NCfCG$,p2/2, p3/2 KbEAHB$7!"p/2 B&$N %W%m%;%9$Hq/2 B&$N%W%m%;%9H,1 2s%a%C%;!<%8rd$j<h$j$9 kEYK!"7W3 2sbNCfCG$,5/$~F7$^CF$$$k!#

D^$j!"%W%m%;%9;X8~%9%1%8%e!<%j%s%0GO!"$"$k%G!<%?$r I,MW$H9k%4!<%k$d!"$=$N%4!<%k$K%G!<%?0MB8$9$kh&$J%4!< %k$rLUL\E*$K%9%1%8%e!<%k$7F7$^$$!"$=$N7k2IB??t$N%4!<%k $,CfCG$7F7$^$&2DG=@~$,$"$k!#

resumption first J}<0K*1kLdBjE@ %W%m%;%9;X8~%9%1 %8%e!<%j%s%0$G@8$8$?!"@8@.%!&2>H%W%m%;%94V$N%4!<%k$N@Z$j BX$($,%4!<%k$NCfCG;~$K9To1kH$$$&LdBj$O!"%a%C%;!<%8;X 8~E*$J%4!<%k$N%9%1%8%e!<%j%s%0@dN,$rHk3H$G2r7h$G~$k!#

```
main :- p0([int(100)|L1],L2)^1,p1(L1,L2)^1.                    (1)
p0(L1,L2) :- L1=[int(N)|NL1],N>0
   | send0(NN,L2,NL2),dec0(N,NN),p0(NL1,NL2)^2.                (2)
p0(L1,L2) :- L1=[N|L1Left],N=<0 | L2=[].                       (3)
dec0(NI,NO) :- NO:=NI-1.                                       (4)
send0(N,L,NL) :- L=[int(N)|NL].                                (5)
p1(L1,L2) :- L2=[int(N)|NL2]
    | send1(NN,L1,NL1),dec1(N,NN),p1(NL1,NL2)^2.               (6)
p1(L1,L2) :- L2=[] | L1=[].                                    (7)
dec1(NI,NO) :- int(NI)|NO:=NI-1.                               (8)
send1(N,L,NL) :- L=[int(N)|NL].                                (9)
```

(a)



(b)

?^6: %W%m%0%i%`hand_shake

3NLdBjKBP7!"KLIC GO!"%j%8%e!<%`4!<%k$rM%@hE*$K%9%1%8%e!<%k$9%k$3HGBP1~7F$$$k!#

$3$1Kh$j!";2>H!@8@.%W%m%;%94V$N%4!<%k@ZBXN&$A!";2>H%4!<%k$,CfCG7F$$$k>19g$K!"%4!<%k$N@ZBX$,DI>o$N%j%@%/%7%gsKhG$F9T$o1k3HKJ$k!#Nc$($P!"?^4$NNcGO!"

```
main/0 → p/2^1(2) → q/3^1 (3) → p/2(2) → p/2(susp) →
N1:=N+1 → q/3 → q/3(3) → p/2(2) → ···
```

Nh$&$J<B9T=gKJ$j!"=i4|$N>uBV$r=|$1$P!"%a%C%;!<%8;X8~J}<0$HF1Ey$N%9%1%8%e!<%k$,9To1$F$$$k!#

$?$@$7!"$3$N%j%8%e!<%`$Khk@)8f0\9T$O<u?.B&$,$=$N%a%C%;!<%8$G=hM}$,9T$($k$+$I$&$+$r9MN8$9$k;v$J$/!"L5>r7o$G9To1$k!#$3N?$a!"%4!<%k$NCfCG$N860x$HJC$?L$6qBN2=JQ?t$,J#;($J9=B$%G!<%?$K6qBN2=$5$1$k>19g$K$O!"%G!<%?$,40A4JbNHJkA0$KCfCG%4!<%k$r:F3+7F7^$&2DG=@-$,$"$k!#3N>19g!":F3+$5$1$?%4!<%k$d$=$N%5%V%4!<%k$,%G!<%?Cf$NL$6qBN2=ItJ,$r;2>H$7!":F$SCfCG7F7^$&62$1$,$"$k!#

Nc$($P!"?^6Nh$&$JNc$r9M$(F_$k!#resumption first scheduling GN%9%1%8%e!<%j%s%0=g=x$O<!$Nh&KJ$k!#

```
p0/2^1 → send0/3 → dec0/2 → p0/2^2 (susp) → p1/2^1 →
send1/3 (rsm p0/2^2) → p0/2^2 (susp) →
dec1/2 (rsm p0/2^2) → p0/2^2 → ···
```

%4!<%kp0/2 $Osend1/3, dec1/2 N9YF$N=PNC$r;2>H9k!#hC$FCfCG7?p0/2 $N<B9T$r:F3+9kKOsend1/3, dec1/2 $NN>J}$N%4!<%k$N<B9T$,I,MWG"$k!#

7+7J$,$iresumption first scheduling GO!"3N2 DN%4!<%kN&$A`send1/3' $,<B9T$5$1$?$(@$1$G@)8f$,p0/2 $K0\$CF7$^$!"$=$N7k2Lp0/2 $O%a%C%;!<%8$KIT40A4JbNr8+D1CfCG7F7^$&!#$3Nh$&$K3NNcGOp0/2 $N1 %k!<%W$"$?$j7W22s$NCfCG$,5/3k!#$3$1$O!"p0/2 $G;2>H$9$k%G!<%?$K7?$,$=Nh$&$JbN$,$"kN$G!"$=lr<%?9=B$$,J#;(G"lP"k[$ICfCG2s?t$OB?$/$J$j!"0lHL$K$O;2>HB&$,I,MWH9$k0l$D$N9=B$%G!<%?r$n 8D$N%4!<%k$,@8@.$9kh$&$J>19g!":G0-$n 2s$NCfCG$,5/$-k3HKJk!#0lJ}!"3NNc$r%W%m%;%9;X8~%9%1%8%e!<%j%s%0$G%9%1%8%e!<%k$9kH!"p0/2 $G;2>H$9$k%G!<%?$K$NU#;($5$K4X$oi:!"CfCG2s?t$O2 2s/1%k!<%W$HJk!#

3Nh&$K!"resumption first GO9=B$7?%G!<%?$N6qBN2=$,IT40A4$G$"$k>19g!"ITMW$J@)8f0\9T$,@8$8$k2DG=@-$,$"$k!#$3$N7k2L!">19g$KhCFO%W%m%;%9;X8~%9%1%8%e!<%j%s%0hj@-G=$r0-2=$5$;$F7^$&$3H,h/$"$k!#

3.1.2 %9%1%C%I2=<jK!$N35MW

$^$:!"A0@a$G=R$Y$?LdBj$O

%W%m%;%9;X8~J}<0: CfCG%4!<%k$K%G!<%?$N9=B8$9$k%4!<%k$r!"CfCG%4!<%k$,%j%8%e!<%`$5$1k^$G%9%1%8%e!<%j%s%0$7$J$$!#

resumption first J}<0: %W%m%0%i%`$,%G%C%I%m%C%/$7$J$$HO0C$G!"$G$-$k$@$1@$1@8@.B&%W%m%;%9$+$i>CHq<IB&%W%m%;%9$X$N@)8f0\9T$rCYi;$k!#

Nh$&$J<jK!rHk3HG2r7hG-$k!#

$3$1iN2r7hJ}K!$r<B8=$9k?aK!"K\8&5fGO%4!<%kN%9%1%C%I2=Kh$k%W%m%0%i%`$NItJ,E*$J@EE*%9%1%8%e!<%j%s%0<jK!$rDs0F$9$k!#

KL1 %W%m%0%i%`GO!"%3%s%Q%$%k;~$K0MB82r@C$r9T$&3HKhCF!"<B9T=g=x$r@EE*$K7hDjG-$k%4!<%k$b>/J/$J$$!#$=$3$GK\8&5f$G$O!"%3%s%Q%$%k;~$K0MB82r@C$r9T$$!"$"$k@aN%4!<%kg_i, g_j KBP7$F!"g_i $Hg_j $N4V$KARJ}8~$N%G!<%?0MB84X78$,B8:_7J$$>19g!"$3$1iN%4!<%k$N<B9T=g=x$,7hDj$5$1$?%4!<%k$N7CNs$rK\8&5f$G$CC\<!<B9T$,:GE,$J%4!<%k$N7CNs$H9M$($k!"$3$N%4!<%k7CNs$rK\9FGC%9%1%C%I$H8F$V!#

3F%9%1%C%I$C=$1$>lESCf$G%5%9Z%s%I9k3HC"$b!"FbIt$N%4!<%k$N<B9T=g=x$,F~lBXok3HC$J$$!#7$?$,CF!"%9%1%C%ICfN"%k%4!<%k$G;2>H%G!<%?$,L$6qBN2=$@G?>19gKO!"%9%1%C%I$4H%5%9%Z%s%I$7$FB>$N%9%1%C%I$K<B9T$r@ZjBX(Fb!"%G%C%I%m%C%/$r@8$8k3HO$J$$!#

$^$?!"%9%1%C%IFb$O:GE,$JC\<!<B9T$r9T$&h&$K@EE*$K%9%1%8%e!<%j%s%0$9$k3H$G!"8$5$N%W%m%0%i%`$NIt$rF0E*$K%9%1%8%e!<%j%s%0$9$k$3$H$G!"8$5$N%W%m%0%i%`$,M-9kK\<AE*$JUB9TF0:n$r<B8=$7!"%G!<%?$N0MB84X78$rJ]$D3H$,2DG=$KJk!#

K\<jK!$rMQ$$k3HKh$j!"%W%m%;%9;X8~J}<0$N!"CfCG%4!<%k$K0MB8$7$?%4!<%k$N%9%1%8%e!<%j%s%0$OHCfCG$,7+jUV5$1$kLdBj$O!":G=i$NCfCG$G%9%1%C%I$4$HCfCG$5$1$k$?$a2sHrG$-$k!#$^$?!"resumption first J}<0$N!"IT40A4$J6qBN2=$G;2>HB&%4!<%k$K0MB8$7$?%4!<%k$N%9%1%8%e!<%j%s%0$O%G!<%?N%9%1%8%e!<%j%s%0$,%j%8%e!<%`$5$1$k$^$G$N%9%1%C%I$K0MB8$9$k$?$a!"$=$lir0l$D%9%1%C%I$K$^$a$F!"@EE*$K<B9T=g=x$r8GDj$9$k!#$3$1$KhC$F!"F10l%9%1%C%IFb$N%4!<%k$r=g$K<B9T9k2aDxGO!"F0E*%9%1%8%e!<%j%s%0$N%*!<%P%X%C%I$r:c8:G-$k!#$^$?!"%9%1%C%IFb$N%4!<%k$N<B9T=g=x$,7hDj$5$1$?$3HKhj!"%4!<%k4D6-$r=>Mh$N%R!<%WNBej$K%9?%C%/$GJ];}9k3H$,$G$-$k!#3N$?a!"D94|%G!<%?$O=>Mh$I*$j%R!<%W$GJ];}$7!"C;L;G"k3$H,B?$$%4!<%k4D6-$O%9?%C%/$G4IM}9k<BAu$r9T$&3HKhCF!"GC $N2s?t$r8:i9$3$H$,$G$-$k!#

0J2<! "%4! <%k$N@EE*%9%1%8%e! <%j%s%0$N$?$a$N@EE*0MB82r@O<jK!$K$D$$F4JC1$K=R$Y$?8e! "2r@O$KhCF(il$k>pJs$rMQ$$F! "<B:]$K%W%m%0%i%`$,INh&$K%9%1%C%I$KJ,3d5lk+KD$$F=RYk! #

@EE*0MB82r@O KL1 $N%W%m%0%i%`$G$N%4! <%k4V$N0MB8$K$O! "<! $N2<cN`$,B8:_9k! #

- @)8f0MB8
  %4! <%kc,<B9T5lkK$O! "$=$NA0$Kc$r%\%G%#%4! <%k$H7F@8@.9k?F%4! <%kp$,<B9T$5lF$$J1lPJiJ$$! #
- %G! <%?0MB8
  $"$k%4! <%kr$,<B9T$5lkKO! "$=$N%4! <%k$G;2>H$5lkCM$r6qBN2=$9$k%4! <%kw1,...,wn$,9Y$F<B9T$5lF$$$J1lPJiJ$$! #

KLIC JI=>Mh$N=hM}7C$G$O! "%3%s%Q%$%k;~$K%G! <%?0MB8$JIN2r@O$rA4/9T$o$:! "%G! <%?0MB8$r9MN8$7$?%9%1%8%e! <%j%s%0$r9T$C$F$$$J$$! #3N$?$a! "r$,wi$h$j@h$K%9%1%8%e! <%j%s%0$5$lk3HOh/$"$k! #3NH-r$O! "CM$r;2>H7h$&$H7?CJ3,$GCfCG$7! "wi$N<B9T$Khj$=$NCM$,6qBN2=$5lkHrN<B9T$r:F3+$9$k! #$3lKBP$7! "K\<jK!$G$O! ";vA0$K%G! <%?0MB82r@O$r9T$!$! "wi$N<B9T8eKrr%9%1%8%e! <%k9k3HKhCF! "3NCfCG!&F3+$KH<$&*! <%P%X%CIrHr1k3H$,$G$-$k! #

0lJ}! "@)8f0MB8KD$$F$O! "K\<jK!$G$O7;Do%4! <%k$N=g=xN_$r7hDj$9$k<jK!$rHk$?$a! "?F%4! <%k$,;R%4! <%k$NBe$K%9%1%8%e! <%j%s%0$5lF7^$&$3HO$J$$! #7?$,$C$F! "$3lr=g=x7hDj$N:]$K9MN8$K$$$lkI,MWO$J$$! #

0J2<;2>H! "6qBN2=5l$kJQ?t$r$=$l$>$lF~NO! "=PNOH_J9$H! "$"$k%4! <%kgi$,<B9T2DG=KJk?aK$O! "F~NOJQ?t$N3F! 9KD$$F! "$=$lir=PNOJQ?tH9$k%4! <%k$N<B9T,9Y$F=*N;$7$F$$$lPh$$$3HKJk! #

7+$7! "KL1 GNF10l2=$OBP>]$HJkJQ?t$N6qBNCM$rI,$:$7bI,MWH7J$$$?$a! "UJQ?t4V$NO@M}E*$J%G! <%?$NN.l,9Y$F0MB8$KJkHO8BiJ$$! #7?$,$G$F! "<B9T>e! "?$KI,MW$J0MB8$r<1JL9kI,MW$,$"$k! #Nc$($P! "@0?t2C;;$r9T$&AH9~=R8l add/3 $O! "F~NO0z?t$,6qBN2=5lk^$G<B9T$G$-$J$$! #7+$7! "JQ?tF1;N$NF10l2=X=Y $N>19g$O! "X $+$iY XN%G! <%?%U%m! <$,B8:_$7$F$$$kH7Fb! "X $N6qBNCM$rI,MWH7$J$$$?$a! "X $,6qBN2=$5lkA0Gb<B9TG-$k! #

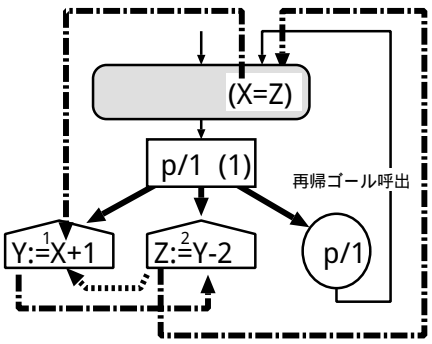
K\<jK!GO! "2r@O%W%m%0%i%`$N1 DN=R8l$KBP1~9k%4! <%k$9YF$r1 %N! <%I$GBeI=5;$?! "@EE*$J%0%i%U9=B$$r9M$($k! #3N%b%G%kGO! "%4! <%k$N:F5"8F=P$Khj%0%i%UCf$K%k! <%W=B$$,7A@.5l$k>19g! "%k! <%W$NA0@BeG:nil$k%4! <%k$X$N0MB8$,F1@BeNF1L>%4! <%kXN0MB8$H6hJL$,D+$J$$$?$a! "8+3]$1>e! "Aj8_0MB8$HH=CG$5lk2DG=@-$,$"$k(?^7)! #$=3G! "gi$N;R%4! <%kgj$K$D$$F! "gj$,gi$N@hAD%4! <%kGb$"$k>19gKO! "3N;R%4! <%kH7FN=P8=$r:F5"%4! <%k$H8FV3HK$7! "F10l2=$Khk%G! <%?%Q%9,3N:F5"%4! <%k$r7PM3$9k+H]$+$KhC$F! "%k! <%W$NF1@BeX$N0MB8$+I&$+$r6hJL9k! #

Nc$($P?^7NNcG$O! "Z:=Y-2 $OY:=X+1 $K! "Y:=X+1 $OA0@$Be$NZ:=Y-2 $K0MB8$7F*j! "8+3]$1>e! "Fs$D$N%4! <%k$OAj8_0MB8$7$F$$$kh&$K8+$($k! #$7$+$7! "3N>19g! "8e<T$N0MB8$O<! @BeKo?$k0MB8$G$"$k$?$a! "9MN8$9$kI,MWOJ$/! "Y:=X+1, Z:=Y-2 $N=g$K%9%1%8%e! <%k5l$k! #

$^$?! "%9%1%C%I2=$N:]$K7;Do%4! <%k$N=g=x7hDj$7$+9T$o$J$$$3HG! "=>7;Do4X78K"$k%4! <%k$r4^al$P@EE*$K<B9T=g=x$,7hDj2DG=$J%W%m%0%i%`Gb! "2K\$N%9%1%C%I$KJ,3d$5lF$7

[1] $n+1$ @$BeL\$NY:=X+1 $,<B9T$5lkH-KO! "I,$:$n @$BeL\$NZ:=Y-1 $N<B9T$O=*N;7F$$$k

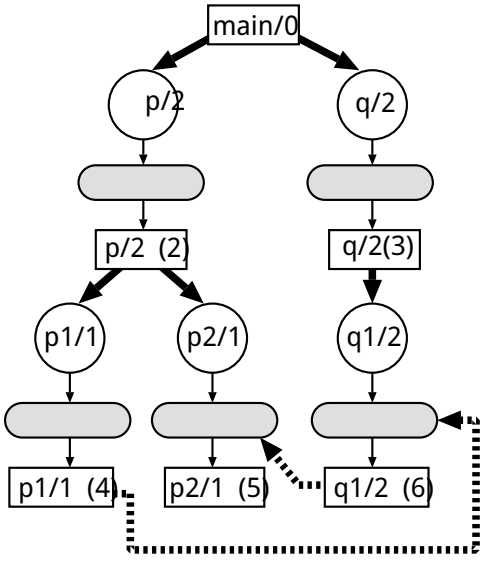
p(X) :- Y:=1X+1,Z:=2Y-2,p(Z)1.



：見掛け上のデータフロー

：実際のデータフロー

?^7: %k! <%W7PM3$N0MB8



?^8: 8+3]$1>e$NUB9T%W%m%0%i%`

$^$&3H$,$"$k!#Nc$($P!"?^8$NNcGO!"=>7;Do4X78K"$k%4!<%k$r4^al$P!"

$$p/2 \rightarrow p1/1 \rightarrow q/2 \rightarrow q1/1 \rightarrow p2/1$$

$N=g$G@EE*$K<B9T=g=x$,7hDjG-k,!":#2s$NJ}K!$G$O!"p/2 $Hq/2 $rJI&9%l%C%I$KJ,$1$6k$rF@$J$!#

7+$7!"$3$N8+3]$1>e$NJB9T@-$r2r>C9kh&$K%W%m%0%i%`$r=q$-D>9$3HOMF0W$G"$j!"<B:]K3$&$7$?5-=R$,5lk3Hb>/$J$$$H9M$($ilk!#5UK3$N@)8B$r@_1k3HKh$j!"2r@O$,4JC1KJ$k!"%9%?%C/$rMQ$$$?8zN(E*$J<BAu$,G-$k!"$JINMxE@$,F@$ilk!#

2r@O<jK!　K\<jK!GO!"0JA02f!9$,Ds0F$7$?7?2r@O<jK![12]$r3HD%$7!"8D!9$NJQ?tKD$$F0MB8%4!<%k>pJsIU$-$N7?2r@O$r9T$&!#3N>pJsKh$j!"6qBNCM$NINItJ,$,$I$N%4!<%k$K0MB8$7$F$$k$+$,L@i+KJk?$a!"$=$NItJ,$r;2>H9k%4!<%k$N0MB8%4!<%k$bH=L@9k!#3liN>pJs$+$i%4!<%k$N<B9T=g=x7hDj$N$?$a$N@)Ls>r7o$r5aak!#J*!"U88%[12]$N<jK!$HF1MM!"K\<jK!$G07$&%W%m%0%i%`$O!"well-moded[13]!"$9Jo$AL7=b$7$J$$F~=PNOBN7O$r;}$A!"8_$$K6%9g9kh&JCMN=PNO(6qBN2=)$,@8$8$J$$bNH9k!#

K\<jK!GO7;Do%4!<%k$N=g=x7hDj$N$_$r9T$&$?$a!"%4!<%k$p_i$N<B9T$Khj%4!<%k$q_1, \ldots, q_m$,@8@.5lkH$-!"F1MM$Kq_kN4V$G<B9T=g=x$r7hDj$7!"$^$@<B9T$5lF$$$J$$$p_j(j \neq i)d=$N;RB9%4!<%k$O!"q_k*hS$=$N;RB9$,$9YF=*ok$^$G<B9T5l$J$$$!#7?$,$G$F!"@aC$N%\%G%#Ht$b_1, \ldots, b_m$K$D$$F!"%\%G%#%4!<%k$b_i, b_j(i \neq j)$4V$N0MB84X78$K4pE-N><T$N=g=xIU$1$r9T$(Ph$S!#$b_i, b_j$N;RB9%4!<%k$N=89grS_i, S_jH9kH!"b_i,@h$K<B9T$5lJS3HKJk!#7?$,$G$F!"$a C$N%\%G%#Ht$b_1, \ldots, b_mKD$$F!"%\%G%#%4!<%k$b_i, b_j(i \neq j)$4V$N0MB84X78$K4pE-N><T$N=g=xIU$1$r9T$(Ph$S!#$b_i, b_j$N;RB9%4!<%k$N=89grS_i, S_jH9kH!"b_i,@h$K<B9T$5lJS3HKJk!#7?$,$G$F!"$q_k$*$hS=$N;RB9$,9Y$F=*$ok^$G

$r9T$&%?%$%_%s%0$H$9%l$P!"3Nh&$JLdBj$rHr1k3H$,$G$-$k!#7+7J$,$i:F5"8F=P$7;~$K>o$K%a%C;!<%8;X8~E*$J%9%l%C%I$N@ZBX$r5v7F7^$&$H!";2>HB&$,I,MW$H9k%G!<%?$r%k!<%W$rMQ$$$F@8@.9k>l9g^2!"9=B$%G!<%?$N:G30B&NCM,6qBN2=5l$?CJ3,$G!"%9%l%C%I$N@ZBX$,5/$-$F7^$!"IT40A4$J%a%C;!<%8Kh$k%9%l%C%I$N@ZjBX($,IQH/$7F7$^$&!#7?$,$C$F8zN($Nh%9%l%C%I@ZBX$r9T$&$?$aKO!"$"$k:F5"8F=P7G$O@ZBX$r9T$!"JL$N:F5"8F=P7G$O@ZBX$r9ToJ$$$h$&$K7J1lPJiJ$$!#

$3$3$G!"$"$k%9%l%C%IFb$N%k!<%W9=BCfNUQ?t$r!"

1. $=$N%k!<%WCf$G6qBN2=$,9Tol!"7+$bB>$N%9%l%C%I$,;2>H$9$kJQ?t
2. B>$N%9%l%C%I$G6qBN2=$,9T$o$l!"$=$N%k!<%WFb$G;2>H9kJQ?t
3. 1,20J30$NUQ?t

$N3$D$KJ,N'9$k$H!"1$NUQ?t$,B8:_$7J>l9g$O!"$=$N%k!<%W$N<B9TKhCF%j%8%e!<%'5l$k%9%l%C%I$OB8:_7J$$$?$a%9%l%C%I$r@ZBXkI,MWO$J$$!#0lJ}2$NUQ?t$,B8:_9k>l9g$O!"2$NUQ?t$r;2>H$7$F%9%l%C%I$,CfCG7F7^$&2DG=@-$,$"$k!#5U$r$$($P2$,B8:_7J$>l9g$O!"$=$N%k!<%W$N<B9TCf$K$=$N%9%l%C%I$,CfCG$7F7$^$&3HOJ$$!#

7?$,$C$F!"3$NUQ?t$O%9%l%C%I$N%5%9%Z%s%I!"%j%8%e!<%'$K4XM?$7$J$$3Hr9M$($k$H!"1,2$NUQ?t$,$,Hb$KB8:_$9$k>l9g$N$_!"%a%C;!<%8;X8~E*$K%9%l%C%I$r@ZBX$lPh$$3H,o+$k!#

3.2 %9%l%C%I$NF0E*%9%1%8e!<%j%s%0<jK!

3.2.1 reply first scheduling <jK!$N3EMW

KL1 $N%4!<%k%9%1%8e!<%j%s%0$H7F%9%l%C%I2=<jK!$rMQ$$$k3H$G!"UBNs<B9TC10L$NN3EY$,Bg$-$/$J$k!#$3lO!"%W%m%0%i%'$NUB9T@-@)8f$N%*!<%P%X%C%I$r>.$5$/$9$kH?LL!"%W%m%0%i%'$N;}$DUBNs@-$rDc2<5;F7$^$&&LdBj$,$"$k!#FC$K!"B>%N!<%I$+$i$NUVEz$rBTCFCfCG7?%9%l%C%I$,BT$?5lk3HKh$kF0E*$JUBNs@-$NDc2<$,@-G=$RM?$($k1F6A$O!"%9%l%C%I2=$r9T$&3H$G!"=>Mh$NbNhjbBg-JbNKJCF7$^$&!#

Nc($P!"$"$k%N!<%I$NeN%9%l%C%IT_c,B>$N%N!<%I$N_p KBP7$F%a%C;!<%8$NMW5a$r=P$7$?>l9g$r9M$($F$_$k!#3N>l9gT_cOMW5a7?%G!<%?$,E~Ce$9k^$GCfCG$9k,,!"3NH-$N_c $K<B9T2DG=$J%9%l%C%I$,B8:_$7$J$$$H!"%N!<%IN_cO%"%$%k>uBV$KJCF7$^$&!#3l$,!"%W%m%0%i%'$NUBNs@-$,Dc2<$7$?>uBV$G$"$k!#3N1F6A$r:G>.8B$K2!5(k?aK$O!"%G!<%?MW5a%a%C;!<%8$KBP9kJV?.$O2DG=$J8BjAa/9T$&I,MW$,$"$k!#

7+$7!"=>Mh$N%4!<%k!&%9%1%8e!<%j%s%0J}K!GO!"MW5a%G!<%?$r@8@.$9$k%4!<%k$,M%@h5lkh$&$J5!9=$,$J$$$?a!"MW5a%a%C;!<%8KBP9$k1~Ez@-$OJ]>Z5l$J$$!#3NLdBj$O%9%1%8e!<%j%s%0C10L$NBg$-$$%9%l%C%I!&%9%1%8e!<%j%s%0GO?<9oG"$j!"MW5a%G!<%?$N@8@.$KL54X78$+$D<B9T;~4V$ND9$$%9%1%C%I$,%9%1%8e!<%j%s%0$5lF7^$&$H!"$N%"%$%k;~4V$,Hs>o$KD9$/$J$k2DG=@-$,$"$k!#

$=$3$GK\8&5f$G$O!"CfCG%9%l%C%I$KMW5a5l$?%G!<%?rJV?.$9k?aKI,MWJ6qBN2=$dF10l2=$r9T$&%9%l%C%I$rM%@hE*$K%9%1%8e!<%j%s%0$9$k**reply first scheduling** J}<0$rDs0F$9$k!#K\J}<0$G$O!"B>%N!<%I$+$i%G!<%?MW5a%a%C;!<%8$,E~Ce7?$j!"<+%N!<%I$G$N<B9T%9%l%C%I$,L$6qBN2=UQ?t$X$N;2>H$GCfCG7?j7$?>l9g!"3:Ev%G!<%?$r6qBN2=9k%9%l%C%I$r%9%1%8e!<%j%s%0$9$k!#$3lKKh$j!"UBNs<B9T$K$*$$F%G!<%?MW5aXN1~Ez@-$,8~>e$7!"UBNs@-$r0z$-=P$9$3H,G-$k!#$^$?!"1%N!<%I>e$N<B9T$K4X$7Fb!"4X78N"$k%9%9%l%C%I$,%9%1%8e!<%j%s%0$5$lk?a!"FHN)@-$N9b$$=hM}$,J#?t$"$k>l9g$O!"8D!9$r=gHV$K=hM}9k3HKhCF%a%b%j$N;HMQ8zN($r2~A1$9$k3H$,$G$-$k!#

3NJ}<0$r<B8=$9kK$O!"%9%l%C%I4V$K$^$?$,$C$F;2>H!6qBN2=$5lkJQ?tKD$$F!"IN%9%l%C%I,6qBN2=$r9T$&N+$r CN$kI,MW$,$"$k!#KL1 %W%m%0%i%'$G$O%b!<%I?dO@[13][14] $r9T$&3HKhCF!"$"$kJQ?tXN6qBNCM$r@8@.$9$k2DG=@-$N$"$k4!<%k$rFCDj$G$-$k!#hC$F%9%l%C%I$_$,L$6qBN2=JQ?tKhCFCfCG7?>l9g!"3N2r@O>pJsKhjX$r6qBN2=$9$k2DG=@-$N$"$k%9%l%C%I$_$,Hs>o$KD9$/Jk2DG=@-$,$"$k!#$3$NJ}<0$rmMxMQ$7!"<B9T;~$KF0E*$K7hDj$5lkItJ,$rDI@W$9$k5!9=$r@8@.%3!<%ICfKAH_9~$'$3HG!"3N%9%1%8e!<%j%s%0J}K!$rreply first scheduling $N<B8=$KI,MW$J2r@O>pJs$K$D$$F=RY?NA!"$=$N2r@O>pJs$rMQ$$F<B:]$K%9%l%C%I$,INh&$K%9%1%8e!<%j%s%0$5lk$+$K$D$$F=RYk!#

3.2.2 reply first scheduling N?aN@EE*2r@O

K\<jK!GO!"KL1 $NUQ?t$r%9%l%C%I4V$N6&M-JQ?t$HHs6&M-JQ?t$K6hJL$9$k!#Hs6&M-JQ?t$O;2>H%9%l%C%IFb$G6qBN2=$5lk$+$i!";2>H;~KO6qBN2=:Q$G"$k3H$,J]>Z$5lk!#7?$,$C$F!"6&M-JQ?t$N$_$r9MN8$9$lPh$$!#

reply first scheduling $r9T$&KO!"L$6qBN2=JQ?t$X$N;2>H$,5/$-$?:]$K!"$3$l$rreply first scheduling $N<B8=$KI,MW$J2r@O>pJs$,I,MWKJ$k!#K\<jK!$G$O0MB82r@O$GF@il$k>pJs$N$&$A!"%b!<%I2r@O[13] Kh$jF@$ilk>pJs$rMxMQ$9$k!#

%b!<%I2r@OKh$j!"$"$k@a$K$*$1$k%9%1%8e!<%j%s%0J}K!$O!"3Nh&$JLdBj$r2r7hJ}K!$K4X$9$k>pJs$r;}CF$$$k3H$,K>$^$7$$!"$H$$$&3HKJj^$9

3Nh&$Kwell-moded KL1 %W%m%0%i%`$G$O!"0l$D$N@a$K$*$$F!"$"$kJQ?t$X$N=PNO=P8=$001$D$7$+$J$!#$3$N$?$a!"%4!<%kg$, $X$r=PNC0z?t$H$7$F; }$D$H$-!"$=$N%W%m%0%i%`$G!"B>$KXr=PNC0z?tH7$F; }$D%4!<%kOgND>@\$N@hAD $g_{p1}, \cdots, g_{pn}$^$?$O!"g$N; RB9 $g_{c1}, \cdots, g_{cm}$ $K8B$ilk!#g$,@8@.$5lF$$$k>19g$O!"$g_{pi}$N<B9T$O=*N;7F$*$j!"g_{ci}Og$,<B9T$5lk$^$G@8@.5l$J$$$!#3N$?$a!"$=$N; ~E@$KB8:_$9$k%4!<%k$N$&$A!"Xr=PNC0z?t$K; }$D%4!<%kOgM#01D7$+$B8:_7J$$!#

0J>eN3H+$i!"reply first scheduling $r<B8=$9kK$O!"L$6qBN2=$N6&M-JQ?t$KBP9k; 2>H$^$?$OCFI=PMW5a<u?.; ~$K!"$=$N; ~E@G=$N6&M-JQ?t$r=PNC0z?tH7$F; }$D%4!<%k$r4^$`%9%1%C%I$r%9%1%8%e!<%k$7FdlPNI$$$3H,J,$+$k!#

3.2.3 reply first scheduling Kh$k%9%1%C%I@ZBX

K\<jK!GO!"B>%N!<%IKBP9$kJV?.$r2DG=$J8B$jAa$/9T$&$?$a$K!"MW5a$5l?%G!<%?$r@8@.$7!"$=$l$rJV?.$9$k%4!<%k$r4^$`%9%1%C%I$rM%@hE*$K%9%1%8%e!<%k$9$k!#K\9F$GO3$NMW5a%G!<%?$rJV?.9k$?$a$K%9%1%8%e!<%k$5lk%9%1%C%I$r ***reply thread*** $H8F$V!#$^$?!"$"$k; ~E@$G<B9T$5lF$$$k%9%1%C%Ir=$N; ~E@$N ***active thread*** $H8F$V!#

0lC6 *reply thread* HJG?%9%1%C%I$OMW5a$KBP9kJV?.KI,MWJ%4!<%k$r<B9T$9k^$G!"B>$N<B9T2DG=$J%9%1%C%I$KBP7FM%@hE*$K%9%1%8%e!<%k$5$l!"JV?.$KI,MW$J%4!<%k$N<B9T$,=*N;$9kH!"0J8e$OCDL>o$N%9%1%8%e!<%j%s%0=g=x$K=>$&!#0J2<GO3NMW5a%G!<%?$rJV?.$9k?aK%9%1%8%e!<%k5l$k%9%1%C%I$r **reply first scheduling** $^$?$O XKBP9k **reply first scheduling** $H8F$V!#

K\<jK!GO!"MW5a<u?.; ~$K *reply thread* rCNkI,MW$,$"k,!"3l$O6&M-JQ?t$KBP$7 *reply thread* XN%]%$%s%?$r; }$?$;Fdk3HG<B8=9k!#

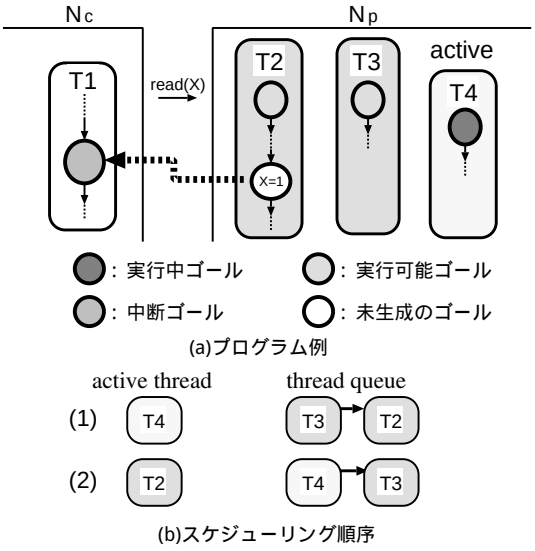
7+7J$,$iKL1 GO!"<B9T; ~$KF1L>%4!<%k$,J#?t@8@.5l$?$j!"; ~9oKhCF$=$NJQ?t$r=PNC$KbD%4!<%k$,JQ2=$9k?$a!"%3%s%Q%$%k; ~$K6&M-JQ?t$KBP7F%9%1%C%IXN%]%$%s%?$rJ]; }5;k3HC$G-$J$$!#$=$3$G *reply thread* $NF0E*$JJQ2=$KBP1~$9k?aK!"K\<jK!GO6&M-JQ?t@8@.; ~$K6qBN2=$r9T$&%4!<%k$r4^$`%9%1%C%I(6qBN2=%9%1%C%I) XN%]%$%s%?$rJ]; }5;F*$-!"6qBN2=%9%1%C%I$,JQ2=9k>19g$O!"%]%$%s%?$rF0E*$KJQ9$5$;$kJ}K!$r<h$k!#

0J2<GOreply first scheduling $,$INh$&$K9Tolk+KDSF=RYk!#

C1=c$J>19g ?^10$Nh&$J>19g$r9M$($F$_$k!#?^$N(a) $O read(X) <u?.; ~$N>uBV$rI=$7!"(b) O=$l0J8e$N%9%1%8%e!<%j%s%0=g=x$rI=$7FS$k!#read(X) $OX KBP9$kFI=PMW5a$r<($9!#0J2<=g$rD ICF@hL@9k!#%N!<%I N_pB&$O%N!<%I N_c+$i $Nread(X) $r<u?.$9$k(?^10.(b).(1)) $H!"X $N6qBN2=%4!<%k$r4^$`%9%1%C%IT2 $, *active thread* H7$F%9%1%8%e!<%k5l!"*read(X)* KBP9$kreply first scheduling $r9T$&!#3lKhCF!"read(X) KBP9$kJV?.$,M%@hE*$K9T$olk3HKJ$j!"%N!<%I4V$NJENs@-$NDc2<$r:G>.8B$K2!$5$($k3H$,$G-$k!#

3NNcGO!"*reply thread* $,FOE*$KJQ2=9k3H$,$J$+$C$?$,!"

1. *reply thread* $,JV?.A0$KCfCG9k>19g!#
2. <B:]$KJV?.$r9T$&%9%1%C%I$,L$@8@.$N>19g!"
3. 6qBNCM$NJV?.$N$?$aKJ#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>19g



?^10: reply first scheduling

$N>19g$K$O!"FOE*$K *reply thread* $,JQ2=$9$k!#0J2<$G$O"$kJQ?tXKBP9kFI=PMW5a$r *read*$(X)$!"$3lKhC$F *reply thread* H7$F%9%1%8%e!<%k$5lk%9%1%C%I$r T_X $HI=$9$3$HK7!"$e5-$N$=$l$>$l>19gKDSF@hL@9k!#

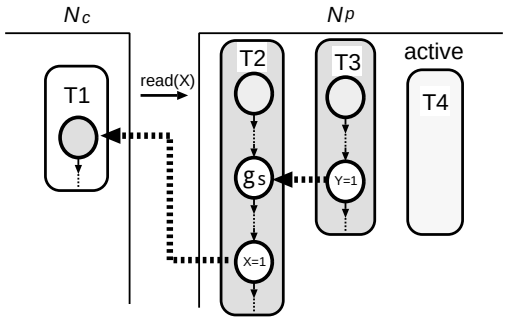
1. JV?.A0$KCfCG$9$k>19g$N=hM} FI=PMW5a *read*(X) KhCF *reply thread* H7$F%9%1%8%e!<%k$5l?T_X,!"JV?.$r9T$&A0$K!"L$6qBN2=JQ?t(Y) KBP9$k; 2>H$KhC$FCfCG$9$k>19g$r9M$($F$_$k!#JV?.$r2DG=$J8BjAa/9T$&$?aK$O!"$T_X$r%j%8%e!<%`$9$k%9%1%C%I$rM%@hE*$K%9%1%8%e!<%k$7$F$d$kI,MW$,$"$k!#$3$N$H$-$X$r6qBN2=$9$k%9%1%C%I$T_Y$,<+%N!<%IF b$KB8:_$9$k>19g$O!"$3$N%9%1%C%I$rM%@hE*$K%9%1%8%e!<%k$7$F$d$l$P$h$$!#$3$N$h$&$K$9$k$3$H$G=$N8e!"$T_X$,%j%8%e!<%`$5lk$H!"$:FST_X,M%@hE*$K%9%1%8%e!<%k$5lk3HKJ$k!#

3NYXN; 2>HrT_X,F10l%N!<%IF b$N%9%1%C%I$G"$kT_Y KBP7$F%G!<%?$r@8@.MW5a$r=P7F$$$k$H9M$(!"T_YKh$kY $N6qBN2=$r3NMW5aKBP9$kJV?.$H9M$($k$H!"$3li$N>19g$bY KBP9$k reply first scheduling $r9T$G$F$$$k$H$$$(k!#D^$jK\<jK!$G$O!"B>%N!<%I$NFI=PMW5a<u?.; ~$H<+%N!<%IF b$K6qBN2=%9%1%C%I$,B8:_$9$k6&M-JQ?t$KBP9k; 2>H; ~$K reply first scheduling $r9T$&!#

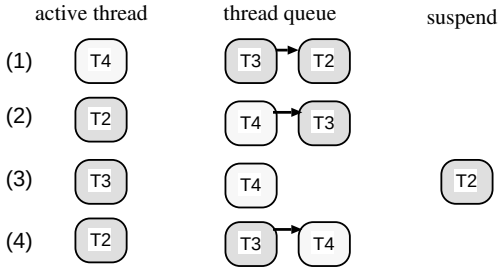
0lJ}!"Y$r6qBN2=$9$k%9%1%C%I$,B>%N!<%I$KB8:_$9$k>19g$O!"B>%N!<%IKBP7%G!<%?$r@8@.MW5a$r=P$7!"T_X $O<B9T$rCfCG9k!#3N; ~E@$G!"*read*$(X)$ KBP9$kreply first scheduling $O01lC6CfCG$5$l!"DL>o$N%9%1%8%e!<%j%s%0KLak!#$=$N8e!"JV?.$(Y $N6qBNCM) $r<u?.$7!"T_X$,%j%8%e!<%`$5lk$H!"*read*$(X)$ KBP9$kreply first scheduling $r:F3+$7!"0J8eT_X $O!"M%@hE*$K%9%1%8%e!<%k5lk3HKJk!#

$^$?!"*read*(X) <u?.; ~$KT_X $,B>%N!<%I$G6qBN2=5l$kJQ?t$KBP7FCfCG7F$$$k>19g$O!"*read*$(X)$ KBP9$kreply first scheduling $r9T$&3HOG$-$J$$!#3N>19g$O!"B>%N!<%I$+iNJV?.KhCFT_X $,%j%8%e!<%`$5lk?; ~$K!"T_X $r *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k7Fdk3H$G!"*read*(X) KBP9$kreply first scheduling $r9T$&3H$,$G-$k!#

reply thread $,ESCf$GCfCG9kNcH7$F?^11$r$"$2$k!#^11$NNcGO%N!<%I N_c+$i N_p XNFI=PMW5a(**read(X)**) $N<u?.(?^11.(b).(1)) KhCF!"X $N6qBN2=%4!<%k(‘**X=1**’) $r; }$D%9%1%C%IT2 $, *active thread* H7$F%9%1%8%e!<%k$5lk(?^11.(b).(2))!#



(a)プログラム例



(b)スケジューリング順序

?^11: *reply thread* $NCfCG

$=$N8e%4!<%kg_sr<B9T7h$&$H7F!"L$6qBN2=JQ?tY $r;2>H$7!"T2 $O<B9T$rCfCG9k!#3NH-!"*Y* $N6qBN2=%4!<%k('Y=1') $r;}$D%9%l%C%IT3 $,M%@hE*$K*active thread* H7$F%9%1%8%e!<%k$5lk(?^11.(b).(3))!#$=$7$F!"Y=1' $N<B9T$Khj!"*Y* $,6qBN2=$5l?8e$G!"%9%l%C%I$N@ZjBX(%?%$_%s%0$,MhkH!"%j%8%e!<%'5l$?T2 $, *active thread* H7$F!"%9%1%8%e!<%k$5lk(?^11.(b).(4))!#

2. JV?.$r9T$&%9%l%C%I$,L$@8@.$N>l9g$N=hM} MW5a%G!<%?*X* $r6qBN2=$7!"MW5aKBP7$FUV?.$r9T$&%4!<%k*g_b* $r4^$'%9%l%C%I*T_b* $,L$@8@.G"$k>l9g!"$=$N%N!<%IF'b$K$O*T_b* $N@hAD%9%l%C%I*T_{ancester_b}* $,I,$:B8:_$7!"$7$+$b$=$N%9%l%C%I$N@hF,%4!<%k$K$*$1$kX $N%b!<%I$O=PNOG"$k!#$7$?$,CFMW5a<u?.;~KO!"*T_{ancester_b}* $r *reply thread* H7$F!"M%@hE*$K%9%1%8%e!<%k$7!"$=$N8e!"*T_{ancester_b}* $N<B9T$KhC$F!"%9%l%C%I*T_b* $,@8@.$5l?;~$K!"*reply thread* $r*T_b* $K@Z$jBX$($F!"*T_b* $rM%@hE*$K%9%1%8%e!<%k9kh&K9lP$h$$!#

?^12NNcG$O!"%9%l%C%IT1 $+$i$NFI=PMW5a *read(X)* $r<u?.$7$?;~(?^12.(b).(1)) KO!"X $N6qBNCM$r@8@.9k%9%l%C%IT4 $O:n@.$5lF$*$i$:!"%9%1%8%e!<%k$9k3H,G-$J$$!#hC$FT4 $N@hAD%9%l%C%I$G$"$kT2 $r!"*active thread* H7$F%9%1%8%e!<%k9k(?^12.(b).(2))!#$=$N8eT2 $N<B9T$G$^$:T3 $,@8@.$5lk$,!"$3lOMW5a5l$?6&M-JQ?t$r=PNO0z?tH7$F;}$?$J$$?a!"*active thread* $OT2 N^^{G}"$k(?^12.(b).(3))!#$=7FT4,T5 $,@8@.$5lk$H!"*active thread* $rT4 $K@Z$jBX$($F<B9T$r7QB3$9$k(?^12.(b).(4))!#

3. J#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>l9g $"$kJQ?t*X* KBP9$kFI=PMW5a$X$NUV?.$r9T$&$?aK!"0lDN6qBN2=%4!<%k*g_b* $H!"*n* 8D$NJQ?tF1;N$NF10l2=(=/2_1,⋯,=/2_n) $,I,MW$J>l9g$r9M$(F_$k!#$^$?!"$3li$N%4!<%k$r0lDG$b4^$'%9%l%C%I$r*T_{r_1},⋯,T_{r_m}* H9$k!#

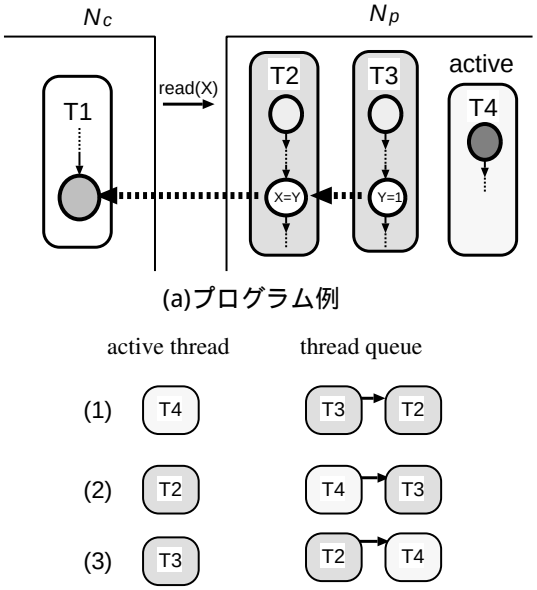
JQ?tF1;N$NF10l2=$O!"N><T$,$HbKL$6qBN2=$G$b<B9T2DG=$G$"$kNG!"*T_{r_1},⋯,T_{r_n}* $rG!2?$J$k=g=x$G<B9T7Fbh$$!#hC$F!"$3$N>l9g$K9Tol$k=hM}$O<!NDLjG"$k!#

1. $"$k*T_{r_i}* KBP7!"*T_{r_i}* $K4^$^l*g_b* b7$/$O=/2_i $NA4$F$N<B9T$,=*N;9k$^G!"*T_{r_i}* $r *reply thread* H7$F%9%1%8%e!<%k9k!#
2. *reply thread* rJLN*T_{r_j}* $K@Z$jBX$($FFlMM$N=hM}$r9T$&!#
3. 9YFN*T_{r_k}* $N *reply thread* H7FN<B9T$,=*N;$7$?$H$-$K!"JV?.$,9T$olk!#

K\<jK!GO*X* $r=PNO0z?t$K;}$D%9%l%C%I$r$^$:!"*reply thread* H7$F%9%1%8%e!<%k$9$k!#$=$N8e!"*X* HL6qBN2=$NF~NO0z?t*Y* HNF10l2=$,9T$olk$H!"*reply thread* $r*Y* $r=PNO0z?t$K;}$D%9%l%C%I$K$r@Z$jBX$($k!#0J2<3N=hM}$,!"6qBN2=%4!<%k$N<B9T$^$?$O6qBN2=$5lF$$$kF~NO0z?tHNF10l2=$r9T$&$^$GB3$1$ilk!#

Nc$($P?^13NNcG$O!"%N!<%I*N_pB&$,T1 $+$iNFI_=P$7MW5a$r=hM}9k$?$aKO!"T2,T3 $NN>%9%l%C%I$rM%@hE*$K%9%1%8%e!<%k$9kI,MW,$"$k!#

3NNcGOT1 $+$i$NFI=PMW5a$NE~Ce(?^13.(b).(1)) KhCF!"$=$N;~X $HB>$NF~NO0z?tHNF10l2=%4!<%k(X=Y) $r4^$'%9%l%C%IT2 $r *active thread* H7$F%9%1%8%e!<%k9k(?^13.(b).(2))!#$=7F!"X $,Y $,F10l2=$5lk$H!"Y $r6qBN2=$9$k%4!<%k%4!<%k(Y=1) $r4^$'%9%l%C%I$,<!$Nreply thread HJ$j(?^13.(b).(1))!"Y $r1 $K6qBN2=$9$k!#$3$N6qBN2=$KhC$FX $,1 $K6qBN2=$5$l!"T1 KBP7$FX $N6qBNCM$rJV?.9k!#



(a)プログラム例

(b)スケジューリング順序

?^13: JV?.$KJQ?tF1;N$NF10l2=$,I,MW$J>l9g

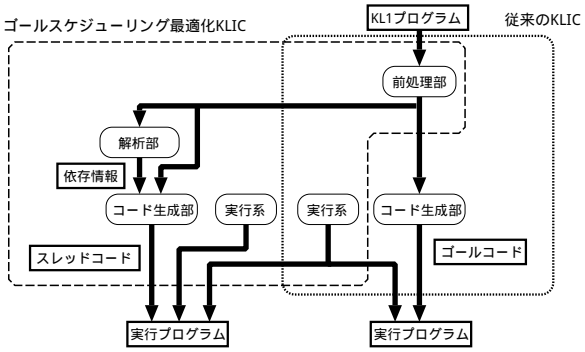
J#?t$NFI=PMW5a$,B8:_9k>l9g$N=hM} <!$K%N!<%INO!"(2)@a$N<B9T$K$*$$FG"$k!#DlJ}Z$N@8@.%4!<%k$Oq/1$G$"$j!"reply first scheduling $r9T$&$?$aKO!"(2)@a$N<B9T;~$Kq/1XN%]%$%s%?$,I,MWG"$k!#$7$+$7J,$i!"DI>o(2)@a$N<B9T;~$K%]%$%s%?$,H=L@$9$k%9%l%C%I$O!"<B9TCf$N%9%l%C%I$H(2)@a$G?7$?$K@8@.$5lk%9%l%C%IN_G"$k!#$3N?$a!"@EE*$Kq/1XN%]%$%s%?$r6&M-JQ?t$KJ];}$5$;$kI,MW$,$"k,!"3l$O0lHL$K$OIT2DG=[3]$G$"$k!#0lHLK3Nh$&$J>u67$O!"9=B$%G!<%?$NFbIt%G!<%?$,$=$N=P8=$G=PNO$G$"$k>l9g$K5/$3$k!#$3N?$aK\<jK!$G$O!"$3Nh$&$J>l9gKOreply first scheduling $r9T$o$J$$bNH9k!#

%9%l%C%I@ZBX$N%?%$_%s%0 reply first scheduling K*$$FM%@hE*$K%9%1%8e!<%k$5lkY-%9%l%C%I$,@8$8$k%?%$_%s%0$O

1. MW5a<u?.;~
2. %9%l%C%I$NCfCG;~
3. 2$N%9%l%C%I$r%j%8e!<%\7$?>l9g
4. JV?.<u?.;~

G"$k!#$d!"3$G%j%8e!<%\5$l$k%9%l%C%I$,B>%N!<%IKBP9$kJV?.$K4XM?7J$>l9g$O!"=>Mh$N@ZBX%?%$_%s%0$G%9%l%C%I$r@ZjBX(FbJBNs@-$,Dc2<$9k3HO%J$$!#

0lJ}1$d!"3$G%j%8e!<%\5lk%9%l%C%I$,B>%N!<%I$KBP9kJV?.$K4XM?$9$k>l9g$K!"=>Mh$N%?%$_%s%0$G%9%l%C%I$N@ZjBX($r9T$&$H!"UBNs@-$NDc2<$N1F6A$,Bg$-$/Jk>l9g$,$"$k!#1,3$N;~$K<B9TCf$N%9%l%C%I$,Hs>o$KBg$-$/!"7+$kD9;~4VCfCG$J7G<B9TG-$k>l9g$,3lK"$?$j!"3NH-M%@hE*$K%9%1%8e!<%k$9kY$-%9%l%C%I$,%9%1%8e!<%k5lkN$,BgI}$KCYlF7^$$!"reply first scheduling $N8z2L$,GJ$$!#



?^14: =hM}7O35MW

$=$3G3li$N>l9g$O!"B(:B$K%9%l%C%I$N@ZjBX($r9T$&3HK9$k!#$3$&$9k3HG!"MW5a<u?.$+$iJV?.$^$G$K<B9T$5lk%4!<%k$N?t$r:G>.K9k3H,G-$k!#

reply first scheduling $N;HMQ>r7o$K4X9k9M;! :#2s$N<BAu$G$O!"6&M-JQ?t$N@8@.;~$K!"F10l@aFb$N$=$NJQ?t$r=PNO0z?t$H7F;}$D%4!<%k$r4^$`%9%l%C%I$X$N%]%$%s%?$,I,MW$G$"$k!#

$3$3$G<!$Nh&$J%W%m%0%i%`$r9M$($F$_$k!#

```
main :- p(X,Y),q(Y)@node(1).      (1)
p(X,Y):-Y=f(Z),r(Z)@node(1).      (2)
q(Y):-Y=f(Z)|Z=1.                 (3)
```

3NNcGO!"Z$,=i$a$F@8@.$5lkNO!"(2)@a$N<B9T$K$*$$FG"$k!#DlJ}Z$N@8@.%4!<%k$Oq/1$G$"$j!"reply first scheduling $r9T$&$?$aKO!"(2)@a$N<B9T;~$Kq/1XN%]%$%s%?$,I,MWG"$k!#$7$+$7J,$i!"DI>o(2)@a$N<B9T;~$K%]%$%s%?$,H=L@$9$k%9%l%C%I$O!"<B9TCf$N%9%l%C%I$H(2)@a$G?7$?$K@8@.$5lk%9%l%C%IN_G"$k!#$3N?$a!"@EE*$Kq/1XN%]%$%s%?$r6&M-JQ?t$KJ];}$5$;$kI,MW$,$"k,!"3l$O0lHL$K$OIT2DG=[3]$G$"$k!#0lHLK3Nh$&$J>u67$O!"9=B$%G!<%?$NFbIt%G!<%?$,$=$N=P8=$G=PNO$G$"$k>l9g$K5/$3$k!#$3N?$aK\<jK!$G$O!"$3Nh$&$J>l9gKOreply first scheduling $r9T$o$J$$bNH9k!#

4 <BAu

K\8&5fGO!"3l$^$G$K=R$YF-$?>2$4!<%k!&9%1%8e!<%j%s%0:GE,2=<jK!$r!"KLIC $K<BAu$7$?!#K\>O$GO3$N<BAu$K$D$$$F=RYk!#

4.1 %7%9%F%`9=@.

%4!<%k!&9%1%8e!<%j%s%0:GE,2=KLIC $O!"A0=hM}It$H2r@0It$H%3!<%I@8@.It$+iJ$k<3%s%Q%$iIt!"JiSK=hM}7O3K$dAH9~=R8l$JI+iJ$k<B9T7O$KhC$F9=@.$5lk(?^14)!#<BAu$O!"4{B8$NKLIC =hM}7OKBP9$k3HD%$N7A$G9T$&!#

%3%s%Q%iItO!"4{B8$NKLIC %3%s%Q%$i$N0lIt$N7AGAH_9~$^$l$k!#

2r@0It$OA0=hM}8e$N%W%m%0%i%`$r<u<h$j!"6qBN2=%4!<%k>pJs$rIU2C$7$?7?2r@0$r9T5!"UQ?t$N7?>pJs$*hS%4!<%k4V$N%G!<%?8>pJs$rCj=P9k!#<BAu>eO[Hs$IFHN)$7$?b%8e!<%k

[3] 4QA4$J2r@0$r9T$&$3HG2DG=KJk+b7lJ$$$,!"2r@0$N%3%9%H$H<B9T;~$N%3%9%H$r9M$($k$H8=<BE*$GOJ$$

HJ$j!"4{B8KLIC $GA0=hM}$,=*oC$?%W%m%0%i%`$r<u$1<h$j!"2r@O>pJs$rIU2C$7$?%W%m%0%i%`$r=PNO9k!#3l$O:#8e$NKLIC $N2~NI$KBP1~7d9/9k$HF1;~$K!"B>$N:GE,2=$rJ;MQ9k>l9g$K!"2r@OIt$N3HD%$rMF0W$K9k$?$aG"$k!#

%3!<%I@8@.It$C%3%s%Q%$%iIt$N=PNO$r<u<h$j!"3F%9%l%C%I$N:GE,2=%3!<%I$r@8@.$9$k!#@8@.$9$k%3!<%I$,%9%l%C%IC10L$NC`<!%3!<%I$H$$&=>Mh$H$O0[$J$C$?$b$N$K$J$k$?$a!"$3$NItJ,$O4{B8KLIC $N%3!<%I@8@.It$rCV$-49$($k7A$K$J$k!#$7$+$7!"KL1@a$+$iC $X$NJQ49ItJ,$O=>Mh$N%3!<%I$H4pK\E*$KF1$8$G$"$j!"%9%l%C%I2=$K$h$j?7$?$KI,MW$JA`:n$N@8@.$r2C$($?$j!"ITMW$JA`:n$N@8@.$r<h$j=|$/$?aNJQ99$r2C$(k@1G$"$kNG!"<BAu$O=>Mh$NbN$r%Y!<%9$H7F9T$&!#

<B97T0C$OKLIC %i%s%?%$`!&7%9%F%`$N0lIt$H7FAH$_9~$^$l!"@8@.$5l?J#?t$N%9%l%C%I$NUB9T<B9T$*$h$S4IM}$r9T$&!#3F%9%l%C%I$O=>Mh$N=hM}7O$K$*$1$k4!<%k$HF1MM!"%9%l%C%I$N<B9T4D6-$r3JG<7?%l%3!<%I(%9%l%C%I%l%3!<%I)$rMQ$$F!"4IM}5l$k!#$^$?!"%9%l%C%IFb$N<B9T4D6-$O:"3F%9%l%C%I$K$=$l$>$lFHN)7?%9%?%C%/$r;}$?$;$k3H$G!"%4!<%k$N@ZBX%*!<%P%X%C%I$N8:>/$d!"%R!<%WNN0h$N8zN(E*$J;HMQ$r<B8=$9$k!#<BAu$O:"3l$iK\<jK!$G?7$?$KI,MWJbNN$_$rBP>]H7!"$=$l0J30$NItJ,$O4{B8NbNr$=$N$^$^MxMQ9k7A$G9T$&!#3N$?$a!"%8%'%M%j%C%/!&*%V%8%'%/%HJI4{$K:n@.$5l?f!<%6Dj5A%b%8%e!<%k$rJQ99$9kI,MWO$[$HsI$J$$!#

4.2 %3%s%Q%$%iIt

%3%s%Q%$%iIt$G9Tol$k=hM}$O!"

1. %=!<%9%3!<%I$rF~NO$9$k!#
2. 2r@OItKh$j!"2r@O>pJs$rIU2C7?%W%m%0%i%`$KJQ49$9$k!#
3. %3!<%I@8@.ItKh$j!"%9%l%C%I2=$5l?C%3!<%I$r@8@.$9$k!#
4. 3$NC%3!<%I$r%3%s%Q%$%k$7!"%9%l%C%IMQ%i%s%?%$%`%i%$%V%i%j$H%j%s%/$7<B9T%3!<%I$rF@$k!#

$N4 DG$"$k!#

3KhCFF@il$kC%3!<%I$O!"%i%s%?%$%`%i%$%V%i%j$N0lIt$G$"$k=hM}7O3K$+$ihP$l!"%f!<%6Dj5A=P8l$N%X%C%IF10l2=!&,!<%I<B9T$*$h$S%\G%#It$N<B9T$r9T$&!#

$3$3GO!"%9%l%C%I2=<jK!K*$$F%3%s%Q%$%iIt$N2r@OIt$H%3!<%I@8@.It$G9T$&=hM}$K$D$$F@bL@9k!#

4.2.1 2r@OIt

%9%l%C%I2=N?aN2r@O %W%m%0%i%`$NG!<%?0MB82r@O$r9T$$!"$=$N7k2IF@$i$l$?>pJs$rMQ$$!"%W%m%0%i%`$N%9%l%C%I2=$r9T$&!#

$"$k@aC$N%\G%#%4!<%k(B = {b1,⋯,bn}) $rAPJ}8~$N%G!<%?0MB8$,B8:_$7$J$$%4!<%k$N=89g

$$B = \{T_1, T_2, \cdots, T_n\},\ T_i = \{b_{i1}, b_{i2}, \cdots, b_{im}\}$$

$$(\overline{prec(b_{ij}, b_{ik}) \wedge prec(b_{ik}, b_{ij})})$$

$KJ,3d$7!"$=$l$>$lNCfG$N<B9T=g=x$r@EE*$K7hDj$9$k!#

3F=89gNCfG:G$hMWA$G$NB?$$$bN,!"BF=P$7B&4!<%k$HF10l%9%l%C%I$K%9%1%8%e!<%k$5$l!"$prec(b_{i_m}, b_{i_n})$ $rK~$?9h$&$K!"$=$N@a$N@hF,$+$i=g$KJBYBX(il$k!#B3$$F!"JL=89g$,?7%9%l%C%I$H7F%9%1%8%e!<%k5l!"$=$N=89gFb$G<B9T=g=x@)Ls$r$_$?9h$&$KJBY+$($i$l!"$=$N@hF,$N%4!<%kKO?7%9%l%C%I$N@8@.$r0UL#9k%W%i%0%^H7$F@thread $rIU2C$9$k!#

Nc$($P!"<!Nh$&$J@aKBP7$F!"

m:-p,q,r,s,t.

p → {q,r}, r → q, p ↔ {s,t}, t → s Nh$&$J%G!<%?$rMQ$$$k!"B8:_9kH-!"

m:- p,r,q,t@thread,s.

Nh$&$J=PNO$,F@$ilk!#

$^$?!"@node IU$-%4!<%k$CDL>cB>%N!<%I$G<B9T$9$k%4!<%k$G$"$kNG!"F10l@aFb$NB>$N%4!<%kHNMB8HOL54X78$K?7%9%l%C%I$N@hF,%4!<%kH7$F%9%1%8%e!<%k$9$k!#

$=$NB>$N:GE,2=$N$?$a$N2r@O $3$3GO!"@thread 0J30$K2r@O$KhC$F?7$?$KIU2C$5lk%W%i%0%^KD$$F=RYk!#

@loop <!$N%9%F%C%W$GCfCG9k2DG=@-N"$k:F5"8F=P$7;~KO!"M%@hE*$K%9%1%8%e!<%k$9Y-%9%l%C%I$,B8:_$9k+I&$+$N%A%'%C%/$r9T$&!#$=$3G3li4!<%k$OB>$N%4!<%k$H6hJL$9$k?$a$K!"@loop $H$$&%W%i%0%^$rIU2C$7$?=PNO$r9T$&!#

dummy@go %f!<%6Dj5A%4!<%k$r4^$^$J$$@aGb!"<!<B9T%4!<%k$N%3!<%I$XD>@\%8%c%s%W9k$?$a$K!"<B9T$5lk%4!<%k(goal/n) $,F10l%b%8%e!<%kFb$K$"$k>l9g$K!"$=$N@a$K dummy@go(goal,n,F)(F=loop or nonloop) $H$$&%W%i%0%^IU$-%4!<%k$rIU2C7?=PNO$r9T$$!"%3!<%I@8@.;~$K%8%c%s%WL?Na$rA^F~9k!#F=loop NH$-$O$=$N8F=P7,:F5"8F=P7G$"$k3H$r<($7!"%9%l%C%I@ZBX$r9T$&$+$I$&$+$N%A%'%C%/$r9T$&!#

6&M-JQ?tN?aN2r@O reply first scheduling GO!"%9%l%C%I4VK^$?$,kL6qBN2=$N6&M-JQ?t$X$N;2>H$,5/$-$?:]$K!"$3lr6qBN2=9k%9%l%C%I$N>pJs$,I,MWHJ$k!#

KLIC K*1k6&M-JQ?tHO!"$"$k@aK*$$F@thread, @node IU$-%4!<%k$N0z?tN&A!"B>$N%4!<%k$K$bB8:_$9$kJQ?t$G$"$k!#$^$?!"6&M-JQ?tv_i,L$6qBN2=JQ?t$v_j$r4^$`9=B$7?%G!<%?$6qBN2=5l$?$H$-!"$v_j$bF1MM$K6&M-JQ?tG"$k!#

reply first scheduilng $r9T$&$?$aKO!"3.2@a$G=R$Y$?$h$&$K!"MW5a<u?.;~$KMW5a$5l?6&M-JQ?t$r=PNO0z?t$KbD%9%l%C%I$,H=L@$9lPNI$/!"6&M-JQ?t$K$=$N%9%l%C%IXN%]%$%s%?$r J];}5;lPNI$!#$7$+$7!"3N!"$"$k6&M-JQ?t$r=PNO0z?t$KbD%9%l%C%I$H$$&$&$N$O<B9T;~$KJQ2=9k$?$a!"%3%s%Q%$%k;~$K7hDj9k3HOG$-$J$$!#3N$?$a!"2r@O;~KO!"<B9T;~$K6&M-JQ?t$,J];}5;lPNI$/!"$=N?$a!"%3%s%Q%$%k$r@1$N>pJs$r=PNO$9kI,MW,$"$k!#

$=$3$G2r@OIt$G$O!"6&M-JQ?t$N3F=P8=KBP7!"$=$N=P8=$G=PNO$G$"$k$+$+I&$+$rD4$Y!"$=l>lKBP$7%b!<%I:f4V%3!<%I$r@8@.9k!#

6qBNE*KO Cf4V%3!<%I$GJQ?t$rI=$9 varilable(0) $r variable(0,mode) Nh$&$KJQ7A9k!#

?^6$N%W%m%0%i%`$N2r@OIt$N=PNO$r?^15$K<($9!#$?$C%3!<%I$r@8@.$9$k!#0J2<$GJQ99E@N&A!"3F%W%i%0%^IU$-%4!<%k$+iINh$&$J%3!<%I$,@8@.$5lk$+$H!"6&M-JQ?tKBP9$k=hM}$K$D$$F=RYk!#

4.2.2 %3!<%I@8@.It

%9%l%C%I2=MQ=hM}7O3KK"o;$?C%3!<%I$r@8@.9k!#0J2<$GJQ99E@$N$&A!"3F%W%i%0%^IU$-%4!<%k$+$iINh&$J%3!<%I$,@8@.5lk+$H!"6&M-JQ?t$KBP9k=hM}KD$$F=RYk!#

```
main :- p0([int(100)|L1],L2),p1(L1,L2)@thread.
p0(L1,L2) :- L1=[int(N)|NL1],N>0
   | send0(NN,L2,NL2),dec0(N,NN),p0(NL1,NL2)@loop.
p0(L1,L2) :- L1=[N|L1Left],N=<0 | L2=[].
dec0(NI,NO) :- NO:=NI-1,dummy@go(p0,2,loop).
send0(N,L,NL) :- L=[int(N)|NL],dummy@go(dec0,2,nonloop).
p1(L1,L2) :- L2=[int(N)|NL2]
    | send1(NN,L1,NL1),dec1(N,NN),p1(NL1,NL2)@loop.
p1(L1,L2) :- L2=[] | L1=[].
dec1(NI,NO) :- int(NI)|NO:=NI-1,dummy@go(p1,2,loop).
send1(N,L,NL) :- L=[int(N)|NL],dummy@go(dec1,2,nonloop).
```

?^15: %9%l%C%I2=5l$?%W%m%0%i%`

%W%i%0%^IU$-%4!<%k$N%3!<%I@8@.

goal@node

?7$7$/3NJ]7?%9%?%C%/NN0h$K%4!<%k$N<B9T4D6-$rpush $7!"$=$N%9%l%C%I%l%3!<%I$rB>%N!<%I$KAw?.$9$k%3!<%I$r@8@.9k!#

goal@thread

KvHx$+$iD4YF!"$=$N@a$G*i* HVL\$K=P8=9k@thread D-%4!<%k$r *goal*$_i$@thread $H5-=R$9kH!"*goal*$_i$@thread $H *goal*$_{i-1}$@thread $K64$^lk%4!<%k$O *goal*$_i$@thread $r@hF,%4!<%k$H9k?7%9%l%C%I$K4^$^lk%4!<%kG"$k!#$=3G!"?7$7$/3NJ]7?%9%l%C%IKBP7$F!"$=li$N%4!<%k$N<B9T4D6-$rpush 9k%3!<%I$r@8@.9k!#

goal@loop %4!<%k$N>l9g

%9%l%C%I$N@ZBX$r9T$&$+I&$+$N%A%'%C%/$r9T$&%4!<%k$r%9%?%C%/$Kpush $7!"$=$N8e!"*goal*$N<B9T4D6-$r%9%?%C%/$Kpush 9k%3!<%I$r@8@.$9$k!#

dummy@go(*goal*, *n*, nonloop) %4!<%k$N>l9g

%9%?%C%/$K3JG<$5lF$$k*goal*/*n* $N<B9T4D6-$rpop $7!"*goal*/*n* $N<B9T%3!<%I$K%8%c%s%W9k%3!<%I$r@8@.$9$k!#

dummy@go(*goal*, *n*, loop) %4!<%k$N>l9g

M%@hE*$K%9%1%8%e!<%k$9kY$-%9%l%C%I$,B8:_9k$+$I$&$+$N%A%'%C%/$r9T$!"B8:_$9lP%9%l%C%I$N@ZBX=hM}$r9T$&!#B8:_$7J1lP%9%?%C%/$K3JG<$5lF$$k*goal*/*n* $N<B9T4D6-$rpop $7!"*goal*/*n* $N<B9T%3!<%I$K%8%c%s%W9k%3!<%I$r@8@.$9$k!#

6&M-JQ?tKBP9$k=hM} 2r@OIt$KhjF'@il$?%b!<%I>pJs$rMQ$$$F!"6&M-JQ?t$NJ];}$9$k%9%l%C%I$X$N%]%$%s%?$,!">o$K!"<+?H$r=PNO$K;}$D%9%l%C%I$X$N%]%$%s%?$G"$kh&$K!"F'0E*$KDI@W!'&JQ99$9$k%3!<%I$r@8@.$9$k!#

6qBNE*KO!"

- $"$k@a*CK*$$$F!"%\%G%#ItN_$K=P8=$9$k6&M-JQ?t*X* KO!"@a*C$G*X*$r=PNO0z?t$K;}$D%\%G%#%4!<%k$r4^$'%9%l%C%IXN%]%$%s%?$rJ];}5;$k!#

- $"$k@a*CK*$$$F!"%X%C%IIt$K=P8=$9$k6&M-JQ?t$,!"$=$N@a$G?7$?$K@8@.$5lk%9%l%C%I*($N=i4|%4!<%k$K$*$$$F=PNO0z?tG"$k>l9g$K$O!"$=$N6&M-JQ?t$NJ];}9k%9%l%C%IXN%]%$%s%?$r*$N=i4|%4!<%k$K=q$-4$9$($k!#

Nh$&$J%3!<%I$r@8@.$9$k!#

4.3 <B9T7O

A0@aNh$&$K7EF'@il$?<B9T%3!<%I$O!"<B9T;~KO!"?7%9%l%C%I$,@8@.$5lk4HK=$N4D6-$r%R!<%W>e$K@8@.$7!"$=$N%9%l%C%IMQ$N%9%?%C%/NN0h$r3djEvF$k!#0J8e!"$=$N%9%l%C%I$N<B9TCf$O!"%4!<%k4D6-$r%9%?%C%/>e$K@8@.$7J,$i!"%3!<%I>e$G8GDj5l$?=g$K%9%l%C%IF'b%4!<%k$r<B9T$9$k!#$3$N<B9TJ}<0$Khj!"=>Mh=hM}7O$G%4!<%k$N@8@.4H$K%4!<%k4D6-$r%R!<%W>e$K@8@.$7$F$$?NHHf3S9k$H!"%R!<%W$N>CHqNL$rBgI}$K:o8:G-$k!#

$"$k%4!<%k$N<B9T$GF~NQJQ?t$,L$6qBN2=$@$C$?>l9g!"$=$NJQ?t$CB>$N%9%l%C%I$Khj6qBN2=5lk3H,J]>Z5l$F$$$k!#7?$,$C$F!"<B9TCf$N%9%l%C%I4HCfCG$7!"F'0E*%9%l%C%I!&9%1%8%e!<%j%s%0Kh$jB>$N%9%l%C%I$r<B9T$9$k!#

?^16$K%9%l%C%I<B9T$N=hM}$NN.$l$r<($9!#

0J2<!"<BAu7?%9%l%C%IMQ$N=hM}7C3K$N$&$A!"stack <BAu$K4X$9$kItJ,$Hreply first scheduling $r9T$&$?$a$K9T$C$?3HD%$K$D$$F=RYk!#

4.3.1 %9%?%C%/<BAu

K\%9%l%C%I2=<jK!K*lk<B9T;~$N%*!<%P%X%C%I$K$O<!$Nh&JbN,$"$k!#

$^$:!"?7$7$$%9%l%C%I$,@8@.$5lkH-$N%*!<%P%X%C%I$H7F$O!"

- %9%l%C%I%l%3!<%I$N%R!<%W>e$X$N3NJ]
- ;HMQ9k%9%?%C%/NN0h$N3NJ]
- %9%l%C%I$N%(%s%-%e!<!?%G%-%e!<

$,$"$k!#

$^$?!"K\<BAuGO%9%?%C%/$rMQ$$$F!"%9%l%C%IF'b$N%4!<%k4D6-$rJ];}9k$?$a!"$"$k%9%l%C%I$G%4!<%k$r@8@.7F$=$l$r<B9T$9k^GK@8$8$k%*!<%P%X%C%IH7FO!"

1. %4!<%k4D6-$N%9%?%C%/$X$Npush
2. %4!<%k4D6-$N%9%?%C%/$X$Npop
3. %5%9%Z%s%I%A%'%C%/

$,$"$k!#0lHL$K1$N=hM}$O!"%4!<%k%l%3!<%IK+$+$k%*!<%P%X%C%IH[$\F1Ey$G$"$j!"2$N=hM}$O<B9T$N:]$K%4!<%k%l%3!<%IF'b$N0z?t$rF1$_=P$9$?$a$N%*!<%P%X%C%I$H$[$\F1EyG"$k!#$3N?$a!"%4!<%k$N%(%s%-%e!<!?%G%-%e!<$,>JN,$5lF$$kJ,$@$1!"<B9T;~K*%1$j%@%/%7%g$s$N%*!<%P%X%C%I$,7Z8:5l$F$$k!#

$^$?!"%4!<%k$N4D6-$r%9%?%C%/$rMQ$$$F<B8=9k3H$G!"C;L?$G$"$k3H$,B?$$%4!<%k4D6-KhCF"R!<%W$,L5BL$K>CHq5lkN$rKI0$3H,G-$k!#$3N?$a!"<B9T;~$N%R!<%W>CHqNL$rBgI}$K:o8:G-!"GC $N%*!<%P%X%C%I$,8:>/9k!#

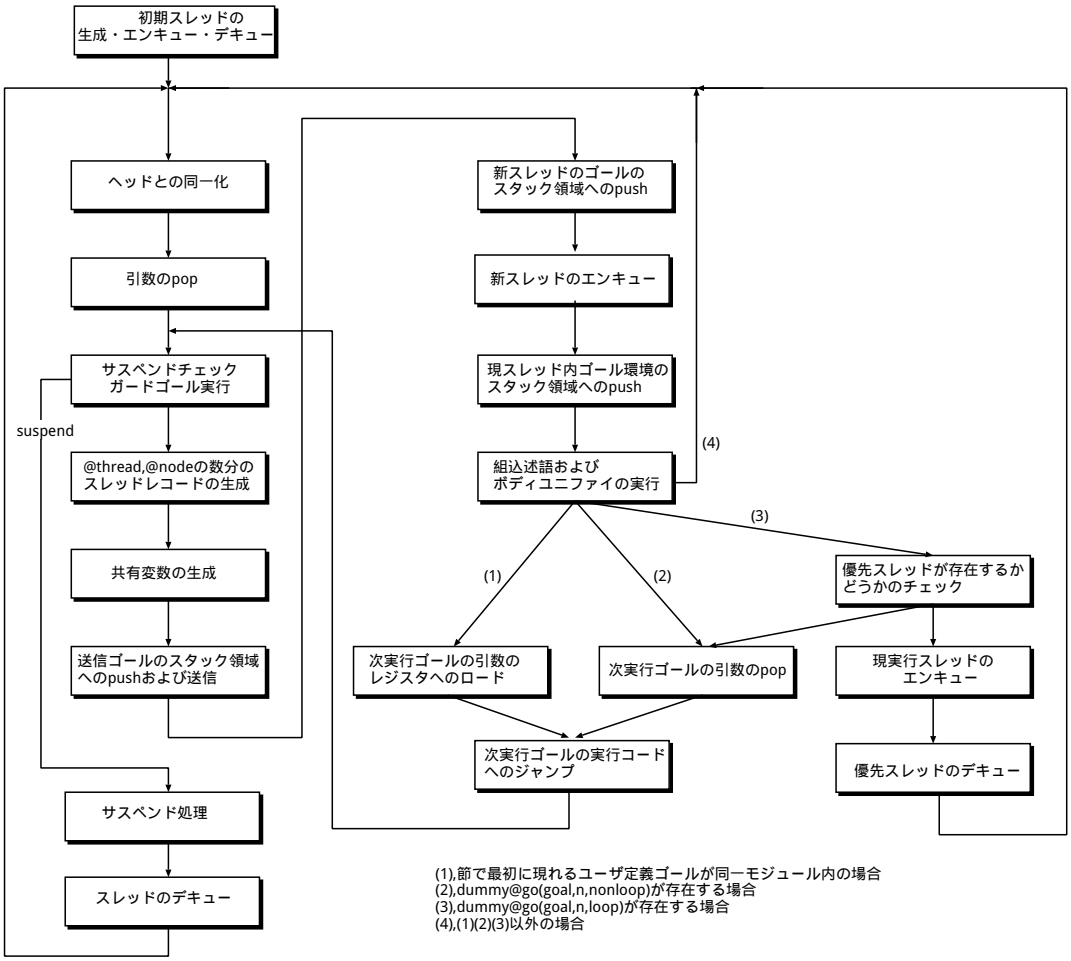
4.3.2 reply first scheduling N?aN3HD%

%G!<%?9=B$

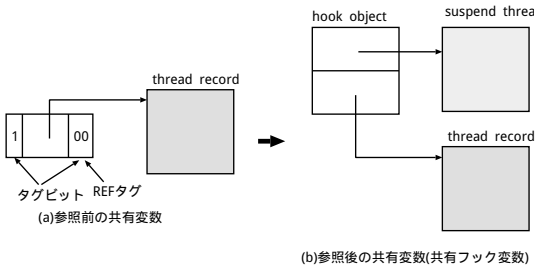
6&M-JQ?t L$6qBN2=$N6&M-JQ?t$O!";2>H$5lkA0$H;2>H8e$HGO$=$N>uBV$,0[$J$k(?^17)!#$^$:;2>HA0$N6&M-JQ?t$O!";2>H$KhC$F<+J,$r=PNO0z?tKb$D%4!<%k$r4^$'%9%l%C%I$r *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k9kI,MW$,$"$k!#

$=$3GL6qBN2=$N6&M-JQ?t$N<B8=J}K!H7FO!"

1. generator object $NMxMQ


初期スレッドの
生成・エンキュー・デキュー
ヘッドとの同一化
引数のpop
サスペンドチェック
ガードゴール実行
suspend
@thread,@nodeの数分の
スレッドレコードの生成
共有変数の生成
送信ゴールのスタック領域
へのpushおよび送信
サスペンド処理
スレッドのデキュー
新スレッドのゴールの
スタック領域へのpush
新スレッドのエンキュー
現スレッド内ゴール環境の
スタック領域へのpush
組込述語および
ボディユニファイの実行
(4)
(3)
(1)
(2)
優先スレッドが存在するか
どうかのチェック
次実行ゴールの引数の
レジスタへのロード
次実行ゴールの引数のpop
現実行スレッドの
エンキュー
次実行ゴールの実行コード
へのジャンプ
優先スレッドのデキュー
(1),節で最初に現れるユーザ定義ゴールが同一モジュール内の場合
(2),dummy@go(goal,n,nonloop)が存在する場合
(3),dummy@go(goal,n,loop)が存在する場合
(4),(1)(2)(3)以外の場合

?^ 16: %9%l%C%I<B9T



?^17: 6&M-JQ?t

2. %?%0$rA}$d$7!"@lMQ$N%G!<%?9=B$$r:n$k

$N2 D,9M$($ilk!#A0<T$OF10l2=5!9=$JIK<j$r2C$(k3HJ$/<EAu2DG=G"kH$$$&MxE@$,$"k,!"UQ?tNN0h3NJ]$N%*!<%P%X%C%I$d%a%b%j8zN($NDc2<!"<B9T8zN($NDc2<JI$N7gE@$,$"$k!#

0lJ}8e<T$O!"%a%b%j!&B9T8zN($O=>MhHGH[$\F1Ey$G$"$k$,!"F10l2=5!9=$J$I=hM}7O3K$rJQ99$9$kI,MW$,$"$k!#

K\<EAuGO!"<B9T;~$N%*!<%P%X%C%I$r7Z8:9k$?$a$K8e<T$NU}K!rH$k!#2<0L2%S%C%H$,REF%?%0G"$k>19g$K8B$j!">e0L1%S%C%H$r6&M-JQ?tN?aN%?%0H7$FMQ$$$k3HK7$?!#0J2<$3$NUQ?t$rC1=c$K6&M-JQ?t$H8F$V!#

;2>H8e$NUQ?t$O=>Mh$NKLIC$HF1MM%U%C%/JQ?t$G<B8=$5lk!#=>Mh$N9=B$$H0[JkNO%U%C%/JQ?t$,!"$=$NUQ?t$N6qBN2=$r9T$&%9%l%C%I$N%]%$%s%?$rJ];}$7$F$$$kE@G"$k!#0J2<$3$N>uBV$N6&M-JQ?t$r6&M-%U%C%/JQ?t$H8F$V!#

request_record FI=PMW5a$N<u?.$d<B9TCf%9%l%C%I$NCfCG$KhC$F!"%7%9%F%'$O*request_record*$H8F$V%l%3!<%I$r@8@.$9$k!#$3lO=$NMW5a$KhC$F6qBN2=$5lkY-6&M-%U%C%/JQ?tXN%]%$%s%?$rJ];}9k%l%3!<%IG"$k!#$^$?=hM}7O3K$O8=:_=hM}$r9T$C$F$$$kMW5a$N*request_record*$rJ];}9k!#

%9%l%C%I%l%3!<%I reply first scheduling GC%-e!<KDJ,lF$$$k%9%l%C%I$r@hF,$KbCF/kI,MW,$"$k$?$a!"*reply thread*$r%-e!<$+$iH4$$?>19g$K%-e!<$r:F9=@.9kI,MW$,$"$k!#$3$N%*!<%P%X%C%I$r>.5/2!5(k?$a!"K\<jK!$G$O%9%l%C%I%-e!<$rAPJ}8~j%s%/$rMQ$$F<B8=9k!#

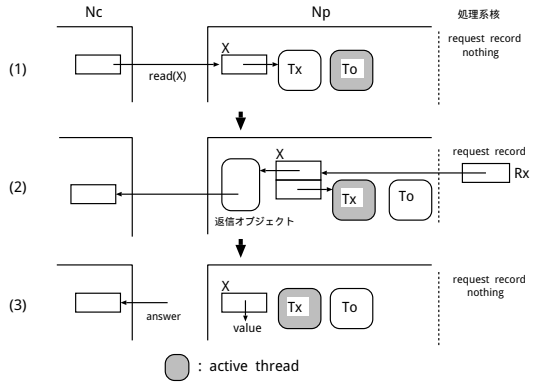
$^$?CfCGA0$K=hM}$7$F$$$?MW5a$d!"CfCGCf$KE~Ce7?MW5a$r%j%8e!<%'8e$K=hM}G-kh$&$K3F%9%l%C%IO=$NFbIt%G!<%?$H7F!"$=$N%9%l%C%IKBP9$kMW5a$N*request_record*$rFIFO%-e!<$N7A$G=j;}$9$k!#

reply first scheduling $N<B:]<!$K!"3.2.3$N@a$G=RY?MM!"9$J>19g$G$N!"reply first scheduling $N<EAuJ}K!$K$D$$$F=RYk!#0J2<GOMW5a5l$?6&M-JQ?t$,XG$"$k>19g!"3NXrJV?.9k$?$a$K%9%l%8e!<$k5l$k%9%l%C%I$rTX!"3NMW5aKBP9$k*request_record*$rRX$HI=$9$3$HK9$k!#

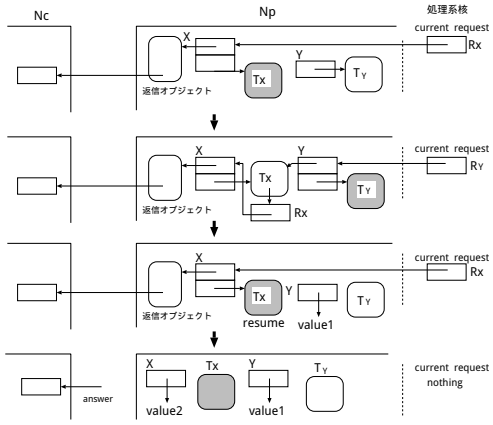
C1=c$J>19g?^18$rMQ$$F@bL@9k!#MW5a<u?.;~(1)KXO6&M-%U%C%/JQ?t$KJQ2=$7!"X$NU];}$9$k%9%l%C%ITX$r*reply thread*H7$F%9%1%8e!<$k9k!#$^$?3NH$-=hM}7O3K$OXXN%]%$%s%?$rJ];}9kRX$r@8@.$7!"=hM}7O3KK3$N%l3!<%IrJ];}$5;$k(2)!#$3Nh$&$K7F%9%1%8e!<%k5l$?TX$N<B9TKhCFX$,6qBN2=$5$l!"UV?.$,9Tol$k(3)!#$3NH$-=hM}7O3K$O<+iNU];}9kRX$rGK4~$7!"$=$N8e$CDI>o$N%9%1%8e!<%k$,9T$olk!#

reply thread $NCfCG?^19$rMQ$$F@bL@9k!#XKBP9$k*reply thread*TX$,JV?.A0$K6&M-JQ?tY$KBP9k;2>HKhCFCfCG9k>19g(1)$r9M$(F_$k!#6&M-JQ?tY$XN;2>HKhCFTXOYKBP$7%U%C%/$7!"YO3$N;~E@$G6&M-%U%C%/JQ?t$KJQ2=$9$k!#$^$?!"7$?$K*request_record(RY)*$,@8@.5l$k!#$=7F@8@.9Y$-6&M-JQ?t$,X$+$iYKJQoC?$a!"=hM}7O3K$ORXrTXKJ];}5;!"<+iORYrJ];}9k(2)!#$=$N8e!"TY$N<B9T$KhCFY,6qBN2=5l?>19g!"=hM}7O3K$O<+i$NJ];}9kRX$r8+$D1@$7!"$3lr<!$N*reply thread*$H7FM%@hE*$K%9%1%8e!<$k9k(3)!#$^$?YGJlP!"$=$N$^$^TY$,*reply thread*$H7FM%@hE*$K%9%1%8e!<$k5l$k!#

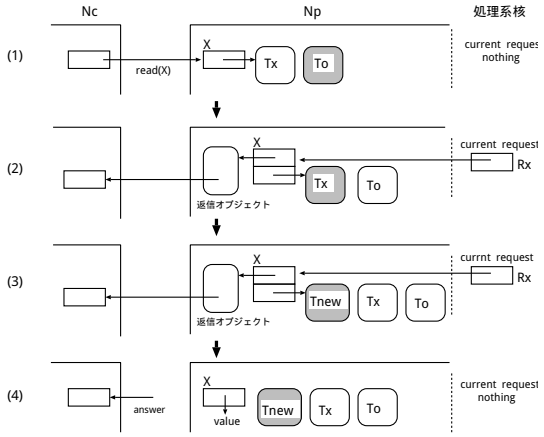
6qBN2=$r9T$&%9%l%C%I,L$@@.$N>19g?^20$rMQ$$F@bL@9k!#K\<jK!GOXKBP9$kF1=PMW5a$KhC$F!"$=$N;~E@$GX$r=PNO0z?t$KbD%4!<%k$r4^$`%9%l%C%ITX$r*reply*



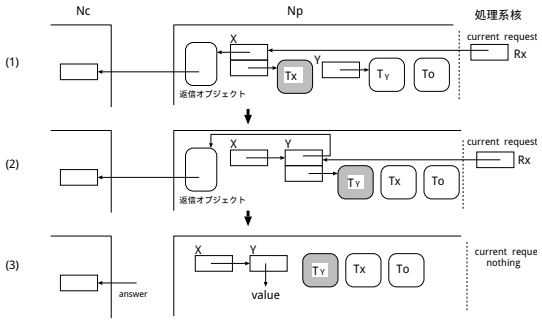
?^18: reply first scheduling K*1k=hM}7O$NF0:n(C1=c$J>19g)



?^19: *reply thread*$,CfCG$9$k>19g$N=hM}7O$NF0:n



?^20: 6qBN2=%9%1%C%I$,L$@8@.$N>19g$N=hM}7O$NF0:n



?^21: J#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>19g$N=hM}7O$NF0:n

$thread$H7F%9%1%8%e!<%k9k(2)!#$=$N8e!"@thread IU $-%4!<%k g_{new} @thread $N<B9T$KhC$F?7$?$K%9%1%C%I T_{new} $,@8@.$5lkH-$K!"$g_{new}$N%4!<%k$N0z?t$K X, =PNOH7$F=P8=7F$$$k$+$I$&$+$r R_X rMQ,$$FH=CG$7!" =P8=$7$F$$$k>19g$O%9%1%C%I T_{new} $r reply thread$H7F M%@hE*$K%9%1%8%e!<%k$9$k(3)!#B8:_$7J>19g$O!"$T_X$ $r $=$N$^$^ reply thread$H$7$F%9%1%8%e!<%k$9$k!#

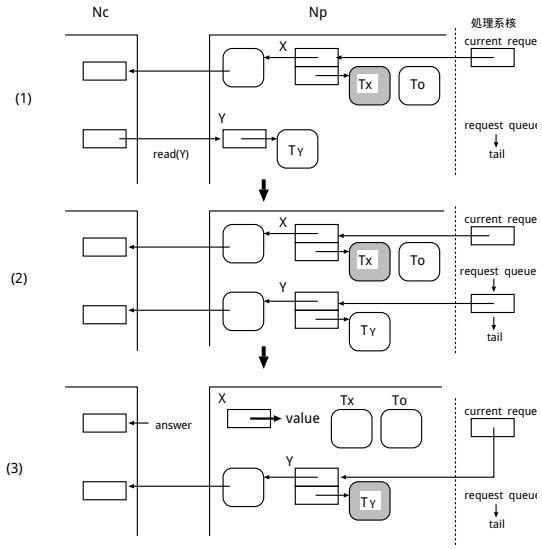
J#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>19g X_i $K BP$9$k reply thread$H7F%9%1%8%e!<%k5l$?%9%1%C%I T_{X_i} $N<B9T$G6&M-JQ?tF1;N(X_j, X_k) $NF10l2=$,9Tol$k >19g$r9M$ (F_$k!#

3N;~!"X_j, X_k $N$$$:l+0lJ}$, X_i G"$k>19g$O!"3N F10l2=%4!<%k$N<B9TKhCF!"reply thread$r@ZBX$kI,MW $,$"$k!#(i = j$G$"$k>19g$r9M$ (kH!"%4!<%k'$X_i = X_k$' $N3FJQ?t$OX_i (=PNO)!"X_k(F~NO) G"kN$G!"<!$K reply thread$H$7$F%9%1%8%e!<%k$5lkY-%9%1%C%I$O T_{X_k} $H $$&3HKJ$k!#

=hM}7O3K$O!"$R_{X_i}$ $rMQ$$F!"X_j, X_k $N$$$:l+0lJ}$, X_i G"k+I&$+$rD4$Y!"Nc$ ($P j = i$ G"$k>19g$O R_{X_i} $NFbIt%G!<%?$rX_i+$i X_k $KJQ99$7 X_k $NJ];}$9$k%9%1%C %I T_{X_k} $r<!$N reply thread$H$7$FM%@hE*$K%9%1%8%e!<%k 9k!#

Nc$ ($P!"?^21$NNcGO!"N_c+iN read %a%C%;!<%8$N<u ?.$KhC$F N_pB&GO XN6qBN2=%9%1%C%IG"$k T_X $r reply thread$H7F%9%1%8%e!<%k$7!"$X$O6&M-%U%C%/JQ?t KJ$k(1)!#$=$N8e!"T_X Cf$N%4!<%k $X = Y$,<B9T5l!" reply thread$, T_X $+$i T_Y $K@Z$jBX$($ilk(3)!#T_Y $N<B 9T$G X, Y $O6qBN2=$5$l N_C KBP9$kJV?.$,9Tol$k(4)!# 0lJ}$i \neq j, i \neq k$N>19gKO!"=PNOB&$NJQ?tKBP7$F!"F~ NOB&$NJQ?tXN%]%$%s%?$rBeF~7FdlPh$/!"3&9k 3H$G!"$3li$N6&M-JQ?t$O!"3NF10l2=%4!<%kGNF~NO B&0z?t$N6qBN2=%9%1%C%I$N%]%$%s%?$rJ];}9k3H$,$G $-$k!#3lKhCF X_j, X_k $N$$$:lX$N;2>H$KhCFb!" 0J8e$O X_j, X_k $N6qBN2=%9%1%C%I$r reply thread$H$7$FM% @hE*$K%9%1%8%e!<%k9k3H$,$G$-$k!#$3$3$G!"$X_j, X_k N&$A8=:_<B9TCf$N%9%1%C%IXN%]%$%s%?$rJ];}7F$$$k J}$,=PNOB&JQ?t$G$"$k!#

J#?t$NFI=PMW5a$,B8:_9k>19g J#?t$NFI=PMW5a$,B8:_9k>1 9g$N=hM}$N$?a$K!"=hM}7O3K$O request_record$r FIFO $G



?^22: J#?t$NFI=PMW5a$,B8:_9k>19g$N=hM}7O$NF0:n

=hM}9k$?$a$N%−%e!<(%j%/%(%9%H%−%e!<) $rJ];}$9$k!#
E~Ce7?FI=PMW5aO3$N%−%e!<$N:G8eHxKDJ,$l!"<B9T
Cf$Nreply first scheduling $,=*N;$9k+CfCG7?>19g$K!"
<h$j=P$5lF=hM}5l$k!#$3$N;~!"$=$NMW5a%G!<%?$,JV?.
:QG"k+I&$+$N%A%%C%/$r9T$$!"UV?.:QG"lP<!$N
MW5a$,=hM}$5lk!#

$^$?!"3N;~$K *reply thread* H7F9%1%8%e!<%j%s%0$5
lkY−%9%l%C%I$,30It;2>H%]%$%s%?XN;2>HKhCFCf
CG7F$$$k>19g$O!"UV?.$KhC$F%j%8%e!<%'$5lk$^$G$=
$N%9%l%C%I$r%9%1%8%e!<%k9k3HOG$−$J$$$N$G!"$=$N
request_record r=$NCfCG%9%l%C%I$KJ];}5;F*$/!#$=
$N8e!"$=$N%9%l%C%I$,JV?.$r<u$1<h$j%j%8%e!<%'$5lk;~
K=$N*request_record* $r%j%/%(%9%H%−%e!<$KLa7Fdk!#

?^22NNcG$O!"$N_p$B&$OXKBP9$kreply first scheduling
$r9T$C$F$$$k:GCf(1) $K!"$YKBP9$kFI=PMW5a*read*(Y) $r
<u?.$7!"$YKBP9$k%j%/%(%9%H%l%3!<%I R_Yr@8@.9k!#
3NH−3NMW5a$O%j%/%(%9%H%−%e!<$KDJ$,$l$k(2)!#
$=$N8eX,6qBN2=5l!"XKBP9kreply first scheduling
$,=*N;$7$?$"HG!"$=hM}7C3K$OR_Yr%−%e!<$+$i<h$j=P$7!"
YN6qBN2=%9%l%C%IG"kT_Y$r *reply thread* H7$F%9%1
%8%e!<%k9k(3)!#

5 I>2A

K\>OGO!"A0>O$^$G$G=R$Y$?%4!<%k!&%9%1%8%e!<%j%s%0:GE,2=
<jK!$NI>2A$r9T$&!#

5.1 B,Dj>r7o

5.1.1 B,Dj4D6−

B,Dj$O

- KLIC version.2.002
- SPARC Station 20 (1!A3Bf)
- PVM version.3.3.11

$G9T$C$?!#C%3%s%Q%$%i$Ogcc $rMQ$$!":GE,2=%*%W%7%g%s
$N;XDj$O9ToJ$+$C$?!#$^$?<B9T;~$K;HMQ9k%a%b%jNN0hH7
$F!"%R!<%WNN0h$O1%a%,%o!<%I!"%9%?%C/NN0h$OA4BN$G1%−%m
%o!<%I;HMQ7?!#

5.1.2 BP>]%W%m%0%i%'

I>2ABP>]$N%W%m%0%i%'$H7F

- handshake
- reverse
- circle_to_square
- master_slave

$N4$D$N%W%m%0%i%'$rMQ$$$?!#**handshake** $O?^6$N%W%m%0
%i%'G"$k!#**reverse** $OIUO?A$N%W%m%0%i%'G"$j!"Dj$a$i
l?<j=gK7$?$,CF%*%;%m%2!<%'$r9T$&%W%m%0%i%'G"$k!#
circle_to_square $OIUO?B$N%W%m%0%i%'G"$j!"J#?t$N%N!<
%I$G0[$JkFsD$Nd KD$$FD>7Bd $Nl_$NLI@Q$H0lJUd $N@5J}
7A$NLI@QHf$r5aak!#**master_slave** $OIUO?C$N%W%m%0%i%'$G
$"$j!"J#?t$N%W%m%;%9$,$=$l$>$l@0?t%j%9%H$r@8@.$7!"$"$k%W
%m%;%9$,$=li$r=87W$9kh$&$J%W%m%0%i%'G"$k!#

I=2: handshake GN@−G=I>2A

	;~4V (sec)	GC 2s?t	CfCG2s?t
=>MhHG	19.21	24	1000000
%%l%C%I2=	9.42	7	500001
reply first	10.77	11	500001

I=3: reverse GN@−G=I>2A

	;~4V (sec)	GC 2s?t	CfCG2s?t
=>MhHG	79.42	119	2964000
%%l%C%I2=	27.37	17	92999

5.2 handshake

%%l%C%I2=$*$h$Sreply first scheduling Kh$kCfCG2s?t!&GC
$N2s?t$NJQ2=!"<B9T;~4V$rI=2$K<($9!#

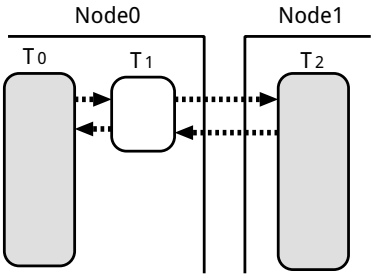
3N%W%m%0%i%'$OJBNs@−$,$[$HsI$J$$?$a!"C'<!4D6−$N
$_$G$NI>2A$r9T$&!#=>MhHG$HHf$Y!"CfCG2s?t$OH>J,KJCF$$
$k!#$3lO3.1.1@a$G=R$Y$?9=B$7?%G!<%?$N0lIt$@1,6qBN2=
5l$?CJ3,$G;2>HB&$K@)8f$,0\$k$H$$&LdBj$,%9%l%C%I2=$K$h
$j2r>C$5l?aG$"$k!#$^$?!"GC 2s?t$,Ls1/3 $K8:>/$7$F
$*$j!"%4!<%k4D6−$N%9%?%C/$Khk<BAu$G!"%R!<%W$N>CHqNL$,
BgI}$K:o8:$5l?3H$r<($7$F$$$k!#3liK2C$(!"%9%l%C%I
Fb%4!<%kKD$$F%9%1%8%e!<%j%s%0$N%*!<%P%X%C%I$,8:>/7?
$?$aA4BNGOLs2G\$NB.EY8~>e$,F@$il?!#

reply first scheduling $r;HMQ$7$?>19g$O!";HMQ7J$$$b$N
KBP7$F13d$[$IB.EY$,CY$$!#3l$Oreply first scheduling $N
$?$a$N=hM}$K!"%*!<%P%X%C%I$,B8:_$9k?aG$"$k!#$^$?3N
%W%m%0%i%'GO!";HMQ7J$>19g$HF1MM$N%9%1%8%e!<%k$r9T$&
$?$a!"3N%*!<%P%X%C%I$NJ,$@$1B.EYDc2<$r5/$3$7$F$$k$H9M
$($ilk!#

5.3 reverse

IUO?A$N%W%m%0%i%'$G$"$k!#3N%W%m%0%i%'$OA0$bCFM?$($i
l?<j=gK7$?$,CF!"%*%;%m%2!<%'$r9T$&%W%m%0%i%'G"$k!#
3N$?$a!"2?M$N%W%l%$%d!<A(@h<j),B(8e<j)N&&A!"A $,@P
rCV/4V$OB $O2?$b7J$$!#F1MM$KB $,@P$rCV$/4V$OA $O2?
b7$J$$!#hCF!"3N%W%m%0%i%'KOJBNs@−$,A4$/B8:_7J
$$!#0lJ}!"F1;~$KB8:_$9$k%9%l%C%I$N?t$O:GBg$G2 D7$+$J$$
NG!"reply first scheduling $r9T$&0UL#$,$J$$!#7?$,$C$F!"
3N%W%m%0%i%'$O%9%l%C%I2=<jK!$K$D$$FC'<!4D6−2<GN@−G=
I>2AN_$r9T$&!#%9%l%C%I2=Kh$kCfCG2s?t!&GC $N2s?t$NJQ
2=!"<B9T;~4V$rI=3$K<($9!#

%9%l%C%I2=Kh$j!"CfCG2s?t$,Ls1/32 $K8:>/$7$F$$k!#$3
lO=>MhHGGO8e<jG"$kB $N<B9TESCf$Gresumption first
scheduling Kh$j!"B B&$N1<jJ,$N=hM}A4$F$,=*$o$kA0$K!"A
B&$N<!$N1<jXN=hM}$K@)8f$,0\$C$F$$?N,!"%9%l%C%I2=$K
hj!"B $N1<jJ,$N=hM}$,A4$F=*N;9k$^$G!"A B&XN@)8f0\
9T$r5/$3$5$J$/$JC?$?$aG"$k!#$^$?!"GC 2s?t$b1/7 $K8:
>/7F$*$j!"3liN7k2LH7$F!"Ls2.9 G\$N@−G=8~>e$,F@$i
lF$$$k!#



?^23: %W%m%0%i% `circle_to_square

5.4 circle_to_square

IUO? B$N%W%m%0%i% `$G$"$k!#%9%l%C%I2=$*$h$S reply first scheduling Kh$kCfCG2s?t!&GC $N2s?t$NUQ2=!"<B9T;~4V$*$h$S3F%N!<%I$N%"%$%I%k;~4V$rI=4$K<($9!#

3N%W%m%0%i% `$CD>7B$d$N1_$Hd$HF1$8D9$5$N0lJU$r;}$D@5J}7A$NLL@Q$NHf$r!"Fs$D$N$d(d_1,d_2)$K$D$$F5a$a$k%W%m%0%i% `G"$j!"7W;;$OD.Nh$&$J%"%k%4%j%:% `$G9T$&!#

@5J}7AH=lKFb@\$9$k1_$r9M$($?>19g$K!"$=$N@5J}7A$r3J;R>u$KJ,3d$7!"3F3J;RE@KD$$F$=$l$,1_$NFbB&!$0B&$N$$:l+G"k+$rH=Dj$7!"$=$l$>$lKD$$FAmOB$r5a$a$?$N$A!"1_$H@5J}7A$NLL@QHf$r5aak!#

d_1, d_2N$=$l$>$lKBP9$k7W;;$OFHN)$KJL%N!<%I$G9Tol$k!#$3N?$a=>MhHG$G$O2Bf$GLs1.6G\$NBf?t8z2L$,F@$ilF$$$k!#

%9%l%C%I2=$r9T$&$H!"?^23$Nh&$J9=B$$KJj!"%N!<%I0B&GOT_0, T_1NFsDN%9%l%C%I$,%9%l%8%e!<%k$5$l!"%N!<%I1B&$GOT_2$,%9%l%8%e!<%k$5lk!#T_0, T_2OLL@QHf$r5a$a$k%9%l%C%I$G!"T_1OT_0, T_2,;HMQ9kd$r@8@.$9$k%9%l%C%I$G$"$k!#

%N!<%I1KEj2il$?$T_2OT_1$N@8@.$9$k%G!<%?$rBTCFCfCG$7!"%N!<%I0$KBP$7FI=PMW5a$r9T$&!#$7$+$7J,$i!"%N!<%I0$G$O!"$T_0$,%9%l%8%e!<%k$5lF$*$j!"7+b3$N%9%l%C%I$OCfCG$;$:$K<B9T$r=*N;9k!#T_1,%j%8%e!<%`5lkN$O!"$T_0$N<B9T$,=*N;7F$+$iG"$j!"JBNs4D6-$G$OJBNs@-$,A4$/$G$J$$!#3l$O%9%l%C%I2=$KhCFdr@8@.9k%4!<%k$N<B9T$,8e2s7K5l?$?$aG"$k!#

3N$?$aC\<!4D6-GO<B9T8zN($N>e>:$+$i!"Ls1.3G\$NB.EY8~>e$,F@$ilF$$$kKb$+$+oi$:!"JBNs4D6-$G$O=>MhHG$hjbCY/JCF7$^$C$F$$k!#

0lJ}reply first scheduling rE,MQ9kH!"T_2+iNFI=PMW5a$G%9%l%C%I2=$KhC$F8e2s$7K5lF$$$kT_1rM%@hE*$K%9%1%8%e!<%k$9k?$a!"JBNs@-$r3NJ]9k3H$,$G$-$k!#3N7k2LC\<!4D6-2<$HF1MM!"=>MhHG$KHf$YLs1.3G\$NB.EY8~>e$,F@$ilF$$$k!#

5.5 master_slave

IUO? C$N%W%m%0%i% `$G$"$k!#%9%l%C%I2=$*$h$S reply first scheduling Kh$kCfCG2s?t!&GC $N2s?t$NUQ2=!"<B9T;~4V$*$h$S3F%N!<%I$N%"%$%I%k;~4V$rI=5$K<($9!#

3N%W%m%0%i% `$O!"@0?t%j%9%H$r@8@.9kJ#?t$N%9%l%$%V%W%m%;%9H=li$+$i$N=PNO$r=87W9k%^%9?!<%W%m%;%9$+$iJj!"JBNs4D6-K*$$F$O%9%l%$%V%W%m%;%9$,%N!<%I0>e$K%^%9%?!<%W%m%;%9$,%N!<%I1>e$KB8:_9k!#%^%9%?!<%W%m%;%9O"$kFCD$j$N=g=x$K=>CF!"3F%9%l%$%V%W%m%;%9$N=PNO$r<u$1<h$k!#0lJ}3F%9%l%$%V%W%m%;%9$N<B9T=g=x$O5,Dj5l$F$$$J$!#$7$?$,CF=>Mh<jK!$d%9%l%C%I2=<jK!$N$_$NE,MQGOI,$:$7$b%^9%?!<%W%m%;%9$NI,MWH9$k=g$K%9%l%$%V%W%m%;%9$,%9%1%8%e!<%j%s%0$5$l$J$$?$a!"%^%9%?!<%W%m%;%9$,$=$N;~E@GI,MWH9k=PNOrBTC$FCfCG$7!"%N!<%I1$O%"%$%I%k;~4V$rI=$7!"JBNs@-$r0z$-=P$9$3H,G-$:!"JBNs<B9T$Khk@-G=8~>e$,F@$ilJ$$$P$+$j$+!"C\<!<B9T$h$jb<B9TB.EY$,Dc2<7F7^CF$$k!#

0lJ}!"reply first scheduling $rMQ$$k3H$G!"%^%9%?!<B&$NMW5a$G!<%?$r@8@.9k%9%l%$%V%W%m%;%9$,M%@hE*$K%9%1%8%e!<%k$5lk!#7?$,$C$F!"%^%9%?!<B&$,%9%l%$%V$+iNUV?.rBTC$FCfCG$9$k;~4V$O=>MhNbNKHfYFhj>/$J$$$bNHJk!#$=$N7k2L!"SS-20 2BfKh$kJBNs<B9T$G!"C\<!<B9TKBP7$F!"Ls1.4G\$NB.EY8~>e$,F@$ilF$$$k!#

6 9M;!

6.1 4XO"8&5fHNHf3S

$3$3GO4XO"8&5fH7$FB.C.Massey $HE.Tick $N8&5f[15] $H!"9SLZ$N8&5f[16] $r<h$j>e2k!#

B.C.Massey $HE.Tick $N8&5f B.C.Massey $HE.Tick $OBP>]%W%m%0%i% `$KBP$7!"0J2<$N$h$&$J@)8B$r@_$1$k$3$H$G!"%W%m%0%i% `$NC\<!2=$r9T$G$F$$$k!#

fully-moded: J88%[13] $N<jK!$G%4!<%k$N0z?t$N%b!<%I$,A4$F7hDj9k

feedback-free: $"$k@a$N%\%G%#4!<%k$N0z?t4V$K%5%$%/%j%C%/$J%G!<%?0MB84X78$,B8:_7J$$$3$H

3Nh&$J@)8B$r@_1k3H$G!"%0%m!<%P%k$J2r@O$r9T$&3HJ/!"@aFb$N%4!<%k$N<B9T=g=x$r%3%s%Q%$%k;~$K40A4$K7hDj9k3H$,$G$-$k!#

3Nfeedback-free $H$$&@)8B$O!"%W%m%0%i% `$@8l$N;}$DK\<AE*$J5-=RG=NO$r8ED j$9$k$b$N$G$O$J$$!#$7$+$7$J$,$iLdBj$K$h$C$F$O!"%W%m%0%i% `$r=q$/$3HOG-$J$$$bNbB8:_$7!"$7$+$b$=$&$$$G$?LdBj$O>/J/$J$$!#$^$?3N$?a!"8=:_=q$+lF$$$kB?$/$N%W%m%0%i% `$K!"feedback-free $G$O$J$$%W%m%0%i% `$OB??tB8:_$7!"3NJ88%$K*$1$kC\<!2=$r3liN%W%m%0%i% `$KE,MQ$9$k$?a$K$O$=$l$rfeedback-free $K=q$-D>$9I,MW$,$"$k!#$3$l$i$N$3$H$+$i!"H `iN2]7?@)8B$OCh>o$K87$7$$$H$$($k!#

0lJ}2f!"$N<jK!$Owell-moded $J%W%m%0%i% `$J$iA4$FE,MQ2DG=G"$k!#

9SLZ$N8&5f Committed-Choice 7?8@8lFleng $O!"KL1F1MM!"<B9TN3EY$,>.5$$?$a%*!<%P%X%C%I$,Bg$-$$!#3N8&5fGOFleng K*$$F%W%m%0%i% `$N0UL#$rJQ2=5;k3HJ$/N3EY$r:GE,2=9k3H$rL\I8$H$7F$$k!#$=$N<jCJH7F$F!"%4!<%k$N%U%)!<%/$r8F$S=P5l$k%4!<%k$NDj5A$GE83+$9$k%s%s%i%$%sE83+$H$$$&J}K!$H!"U#?t$N%4!<%k$r0l$DK^Ha$k%4!<%kM;9g$H$$$&J}K!$rMQ$$F$$k!#

$^$?!"N3EYrBg-$/$7$9.$k3HKh$k!"JBNsEY$NDc2<$NLdBj$K4X$7F$O!"!¥P%s%P%sN3EY@)8f!W[17] $rMxMQ$7!"9bIi2YMQ!"DcIi2YMQ$NFs<dN`$N%3!<%I$r@8@.$9k3HGBP=h$7F$$k!#

8F=P$7LZ$K%5%$%/j%C%/$J0MB84X78$,B8:_$7$J$$$3H,7P7Plk!"%4!<%kM;9g$r9T$&!#3l$O!"K\<jK!$K$*$$F!"C\lJ}8~$N%G!<%?0MB8$,B8:_9k>19gN_!"F10l%9%l%C%IH7FC\<!2=5lkN$HF1MM$G$"$k!#

0lHL$K!"%W%m%0%i% `$N0UL#rJQ($:$K0BA4$KC\<!2=$r9T$&$K$O!"2r@O;~$K!"0MB8$,H=L@$7J$$>19gKO!"APJ}8~$K0MB8$,$"$kbNH9$k!#$3$N?$a!"2r@O$N@:EY$,C\<!2=$N8z2L$KBg$-$J4Xoj$r;}$GF/$k!#

I=4: circle_to_square GN@-G=I>2A

	;~4V (sec)	GC 2s?t (9g7W)	CfCG2s?t (9g7W)	idle(N_0) (sec)	idle(N_1) (sec)
C\<!					
=>MhHG	53.03	84	3	-	-
%9%l%C%I2=	39.61	30	1	-	-
JBNs(2+1 Bf)					
=>MhHG	33.00	84	9	10.72	0.06
%9%l%C%I2=	40.94	30	2	24.40	16.56
reply first	25.43	30	2	8.34	0.13

I=5: master_slave GN@-G=I>2A

	;~4V (sec)	GC 2s?t (9g7W)	CfCG2s?t (9g7W)	idle(N_0) (sec)	idle(N_1) (sec)
C\<!					
=>MhHG	60.40	0	0	-	-
%9%l%C%I2=	60.42	0	0	-	-
reply first	60.44	0	0	-	-
JBNs(2+1 Bf)					
=>MhHG	70.78	0	3108	39.49	31.00
%9%l%C%I2=	69.44	0	1019	37.86	34.93
reply first	44.07	0	1020	6.59	9.27

7+$7!"U88%[16] GO!"%4!<%k4V$N2r@OGO!"=hM}7O$,J#;(KJkNr-iC$F!"Ho8F=P$7B&$+$i8F=P$7B&XN2r@O>pJs$NEAC#7+9TCF$$J$$!#Ho8F=P$7B&$N2r@O$r9T$&NK!"8F=P$7B&$N2r@O>pJs$,I,MW$J>l9g$H$$&NO!"MF0W$K9M$(il!"3N@)8BKh$j2r@O$N@:EY$,BgI}$KMnAF$$k$H$$($k!#

$^$?!"9=BBNNCf?H$^$G4^a?2r@O$r9T$C$F$$J$$H$$&LdBjb"$k!#9=B$BN$HJQ?t$H$NF10l2=$N>l9gKO!"<B:]KOB8:_7J$$2>A[E*$J0MB84X78$rIU2C7F$*$j!"2r@O$N@:EY$rMn7F$$k!#

0lJ}K\8&5fGO!"8F=P$7B&$+$iHo8F=P$7B&XN2r@O>pJs$NEAC#!"9=B$BN$NCf?H$^$G4^$a$?2r@O$rHb$K9T$CF*$j!"$3$&$$$C$?LdBj$O@8$8$J$$!#

6.2 :#8e$N2]Bj

reply first scheduling $N5/F0$K4X9k9M;! 8=:_$N reply first scheduling GO!"FI=PMW5a(read %a%C%;!<%8) Kh$k5/F0$N$_$r9M$($F$$$k!#7+$7!"2.1.2@a$G=RY?h&$K!"KLIC GN30It;2>H%]%$%s%?$O!"C1J}8~$N%j%s%/7+D%$ilF$$J$$!#

0J2<!"UQ?tXrAw?.7?B&$rN_p, Aw?.$5$l30It;2>H%]%$%s%?$,@8@.$5l?B&rN_cH9k$H!"N_cB&$GNXKBP9k;2>HGO!"read %a%C%;!<%8$rAw?.$7!"N_pB&$Greply first scheduling $,9T$olk$,!"N_pB&$G$N;2>H$G$O!"N_c$G$Nreply first scheduling $O9T$olJ$$!#

B>%N!<%I$G@8@.$5lk6qBNCMKBP7FO!"I,$:reply first scheduling $r9T$&3H$,K>$^$7$$!"7?$,,$C$F!"N_pB&$G$N;2>H$G$"$CFb!"N_cB&$Greply first scheduling $r9T$(kh$&$J5!9=$NF3F~$,I,MWG"$k!#

Nc$($P!"$"$kJQ?tXKBP7$FN_pB&$G6qBN2=$,9T$olJ$$$3HO!"2r@OKhCFJ]>ZG-$k!#$hCF3&$$C$?JQ?t$K4X7F$O!"%G!<%?$NAw?.@e!"UV?.@h$r;}$D acknowlege rN_c+$i<u$1<h$j!"N_pB&$+$iN_cB&$X$N%]%$%s%?$rD%$kJ}K!$,9M$(il$k!#

DL?.9bB.2=<jK!HNJ;MQ XKBP9$kFI=PMW5a$Khj!"reply first scheduling $r9T$C$?>l9g!"X$,,9=B$7?%G!<%?$K6qBN2=5l$k>l9g!"X$N:G30B&NCM,,6qBN2=5l$?$@1G!"UV?.r*3JCF7^$&!#;2>HB&$,,9=B$%G!<%?$NFbIt$^$G!";2>H9k>l9gKO!"b&0lEYFI=PMW5a$r9T$&I,MW$,$"$k!#

3l$r!"%9%l%C%I$N@ZBX%?%$_%s%0$^$GAw?.$rCYi;!"0JA02f!9$,DsOF$7$?0l3gAw?.<jK![18] $rMQ$$k3H$G!"$3Nh$&$J:YN3EY$NDL?.$rHrlk3H$,$G$-$k!#

7 7kO@

K\O@GO!"@EE*2r@O$rMxMQ$7$?JBNsO@M}7?8@81KL1 $N%4!<%k%9%1%8e!<%j%s%0:GE,<jK!H=lNKL1=hM}7OKLIC KBP9$k<BAu$K$D$$F=RY?!#

K\<jK!GO!"@EE*2r@OKh$j%4!<%k4V$N0MB8>pJs$rCj=P$7!"%3%s%Q%$%k;~$K=g=x7hDj2DG=$J%4!<%k$N=89g$r%9%l%C%I$H7F!"%9%l%C%IFb$N@EE*%9%1%8e!<%j%s%0$r9T$&!#$3lKhj!"<B9T;~$N%4!<%k$N%j@%/%7%gsK4X9k*!<%P%X%C%IrBg-$/8:$i$9$3H,G-$k!#$^$?!"%4!<%k$N<B9T=g=x$r@EE*$K8GD j7?3HKh$j!"%9%?%C/$rMQ$$?8zN(E*$J<BAu$r9T$&$3H,G-$?!#$3lKhj!"%R!<%WNN0h$N;HMQ8zN($c<B9T8zN(r"2k3H$,$G$-$?!#

$^$?!"%9%l%C%I=Kh$jJBNs@-$,Dc2<9kh&$JLdBj$K4X7F$O!"MW5a$G!<%?rG$-$k8BjAa/@8@.9kh&$K%9%l%C%I$r%9%1%8e!<%j%s%0$9$kreply-first J}<0$rMQ$$!"C\<!2=5l$?%W%m%0%i\'N;}$DJBNs@-$r:GBg8B$KCj=P9k3H$G!"8zN(E*$J%9%l%C%I!&%9%1%8e!<%j%s%0$r9T$&3H$,$G$-$k!#

K\<jK!$r=>Mh$NKL1=hM}7OKLIC >e$K<BAu$7!"@-G=I>2A$r9T$C$?7k2L!"%9%l%C%I=<jK!$K4X7F$O!"C\<!4D6-$K$*$$F$O!"1.3!A2.9 G\$NB.EY8~>e$,F@$il?!#0lJ}JBNs4D6-GO!"<B9T;~$NJBNs@-$NDc2<Kh$j=>MhG$hjbB.EYDc2<$r5/$3$9LdBj$d=>Mh$N<jK!$G$O=$N%W%m%0%i\'N;}$DJBNs@-$rCj=PG-$:$KC\<!<B9Thj$b@-G=$,Dc2<9kLdBj$bB8:_$7$?!#$=$&$$C$?%W%m%0

%i% '$K4X$7FO! "reply first J}<0rE,MQ9k3HGJBNs@-$r3N J]$G$-! "$=$N7k2LJBNs4D6-$K$*$$F$b=>MhHG$KHfYFLs1.3!A 1.6 G\$NB.EY8~>e$,F@$il?! #

$^$?: #8e$N2]Bj$H7F! "6.2@a$G=R$Y$?<jK!$NE,MQ$d! "$h$j Bg5,LO$J%W%m%0%i% 'GN@-G=I>2A$,$"2ilk! #

<UK-

K\8&5f$N5!2q$rM?$ (F/$@$5G?IYEDbC<#65<x$K?<?S$J<U0U$r I=$7$^$9! #E,@Z$J8f;XF3$r;roG$?CfEg9@=u65<x$*hS?9bC0l O:=u65<x! "?t!9$NM-MQ$J8f0U8+$rBW$$?8^Eg@5M5=u<j$K?4$+$i 46<UCW$7$^$9! #

$^$?! "3F<o;qNA$rDs6!$7$FBW$$?(:b) ?7@$Be%3%s%T%e!<%? 3+H/5!9=$*hS@hC<>pJs5;=Q8&5f=j! "5i$K! "6&F18&5f<I$G$" $kBgLnOBI';a$dKL1%?%9%/%0%k!<%W$NDEM8 8x6G;a! "9uED7=;a rO8aH7$F! "F|:"8fF$O@D:$$$?5~EIBg3X9)3XI>pJs9)3X2J IYED8&5f<<$N=t7;$K46<U$$?7^$9! #

:G8e$K! "I.<T$HO+6l$r6&$K7?M'?M=t;a! "5Z$SF|:"@$OC$r $+$1$F$$kN>?F$K8fNiCW$7$^$9! #

;29MJ88%

[1] 0K@r2mI', BgLnOBI', 8^Eg@5M5, ?9bC0lO:, CfEg9@, IYEDbC<#. KLIC K*1k%4!<%k!&9%1%8%e!<%j%s%0:GE,2=. >p=h8&Js,96-PRO-10, pp. 43–48, 1996.

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[6] Cg@%L@I', F#@%E/O/, 6a;3N4. %]!<%?%V%kKL1=hM}7OKLIC $N35 MW. >pJs=hM}3X2qBh47 2sA49qBg2q9V1iO@J8=8, pp. 5–55–5–56, October 1993.

[7] O;Bt0l><, Cf@%L@I', 6a;3N4, F#@%E/O/. Klic J,;6%a%b%j=hM}7O$N @_7W$H=i4|I>2A. In *JSPP'95*, pp. 153–160, June 1995.

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[16] 9SLZBsLi, EDCflQI'. Committed-choice 7?8@81fleng K*1k@E E*N3EY:GE,2=. >pJs=hM}3X2q8&5fJs9p 96-PRO-8, pp. 109–114, August 1996.

[17] F|9b9/M:, >.CSHFJ?, EDCflQI'. Pie64 K*1kJ#9gN3EYJBNs=hM} $rMQ$$?:GE,N3EY@)8f-:YN3EYJBNs$HADN3EYJBNs;Fs$D$N0[<A$J @$3&$NJ,N%$HM;9g-. In *JSPP'95*, pp. 115–122, 1995.

[18] 0K@n2mI', BgLnOBI', CfEg9@, IYEDbC<#. JBNsO@M}7?8@81=hM}7O KLIC K*1kDI?.$N9bB.2=. >p=h8&Js95-PRO-2, pp. 105–112, 1995.

A %W%m%0%i% %j%9%H(reverse)

```
:- module main.


main
 :- playloop(1000, 0, 0).

playloop(N, F1, F2)
 :- N > 0,
    F1 = 0,
    F2 = 0
  | play(NewF1, NewF2),
    playloop(~(N-1), NewF1, NewF2).
playloop(N, F1, F2)
 :- N = 0
  | true.

play(F0, F1)
 :- init(Board, Moves0, Moves1),
    player([Board | L1], L2, 'O', 1, Moves0, F0),
    player(L2, L1, 'X', 1, Moves1, F1).

init(Board, Moves0, Moves1)
 :- Board = [row('.','.','.','.','.','.','.','.','.','.'),
             row('.','.','.','.','.','.','.','.','.','.'),
             row('.','.','.','.','.','.','.','.','.','.'),
             row('.','.','.','.','O','X','.','.','.','.'),
             row('.','.','.','.','X','O','.','.','.','.'),
             row('.','.','.','.','.','.','.','.','.','.'),
             row('.','.','.','.','.','.','.','.','.','.'),
             row('.','.','.','.','.','.','.','.','.','.')],
    Moves0 = [move(3,5),move(4,6),move(6,6),move(3,3),move(6,4),move(5,3),
              move(3,7),move(1,6),move(4,8),move(3,1),move(4,2),move(7,2),
              move(1,4),move(2,4),move(6,8),move(6,7),move(6,1),move(8,3),
              move(5,2),move(4,7),move(4,1),move(2,7),move(2,8),move(8,8),
              move(1,2),move(7,4),move(2,2),pass,     move(8,5),move(7,6),
              move(8,7)],
    Moves1 = [move(3,6),move(5,6),move(3,4),move(6,5),move(4,3),move(6,3),
              move(2,6),move(3,8),move(3,2),move(5,8),move(5,7),move(1,5),
              move(2,5),move(8,1),move(7,8),move(6,2),move(7,1),move(8,2),
              move(5,1),move(8,4),move(2,1),move(1,8),move(7,3),move(1,3),
              move(1,7),move(1,1),move(2,3),move(7,5),move(8,6),move(7,7)].

player([BoardIn | LILeft], LO, Marker, Turn, [Move | MovesLeft],F)
 :- Move = pass
  | LO = [BoardIn | LOMid],
    player(LILeft, LOMid, Marker, ~(Turn+1), MovesLeft,F).
player([BoardIn | LILeft], LO, Marker, Turn, [Move | MovesLeft],F)
 :- Move = move(X,Y)
  | move(Marker, X, Y, BoardIn, BoardOut),
    LO = [BoardOut | LOMid],
    player(LILeft, LOMid, Marker, ~(Turn+1), MovesLeft,F).
player(LI, LO, Marker, Turn, [],F)
 :- LO = [],
    F = 0.

move(Marker, X, Y, BoardIn, BoardOut)
 :- split(Y, BoardIn, BoardUIn, LineIn, BoardDIn),
    functor(LineIn, _, Size),
    reverse(X, Size, Marker, BoardUIn, BoardUMid),
    reverse_list(BoardUMid, BoardUOut),
    put_marker(X, Marker, Size, LineIn, LineOut),
    reverse(X, Size, Marker, BoardDIn, BoardDOut),
    append(BoardUOut, [LineOut], BoardMid),
    append(BoardMid, BoardDOut, BoardOut).
```

```
put_marker(X, Marker, Size, LineIn, LineOut)
 :- setarg(X, LineIn, Marker, Line0),
    reverse_line(~(X+1), 1, Size, Marker, Line0, Line1),
    reverse_line(~(X-1), -1, Size, Marker, Line1, LineOut).

reverse_line(X, Offset, Size, Marker, LineIn, LineOut)
 :- check_marker_line(X, Offset, Size, Marker, LineIn, F),
    reverse_marker_line(F, X, Offset, Size, Marker, LineIn, LineOut).

check_marker_line(X, Offset, Size, Marker, LineIn, F)
 :- X = 0
  | F = no.
check_marker_line(X, Offset, Size, Marker, LineIn, F)
 :- X > Size
  | F = no.
otherwise.
check_marker_line(X, Offset, Size, Marker, LineIn, F)
 :- arg(X, LineIn, Stat),
    Stat = '.'
  | F = no.
check_marker_line(X, Offset, Size, Marker, LineIn, F)
 :- arg(X, LineIn, Stat),
    Stat = Marker
  | F = yes.
otherwise.
check_marker_line(X, Offset, Size, Marker, LineIn, F)
 :- check_marker_line(~(X+Offset), Offset, Size, Marker, LineIn, F).


reverse_marker_line(no, X, Offset, Size, Marker, LineIn, LineOut)
 :- LineOut = LineIn.
reverse_marker_line(yes, X, Offset, Size, Marker, LineIn, LineOut)
 :- X = 0
  | LineOut = LineIn.
reverse_marker_line(yes, X, Offset, Size, Marker, LineIn, LineOut)
 :- X > Size
  | LineOut = LineIn.
reverse_marker_line(yes, X, Offset, Size, Marker, LineIn, LineOut)
 :- arg(X, LineIn, Stat),
    Stat = Marker
  | LineOut = LineIn.
otherwise.
reverse_marker_line(yes, X, Offset, Size, Marker, LineIn, LineOut)
 :- setarg(X, LineIn, Marker, LineMid),
    reverse_marker_line(yes, ~(X+Offset), Offset, Size, Marker,
                        LineMid, LineOut).

reverse(X, Size, Marker, BoardIn, BoardOut)
 :- check_marker(~(X-1), -1, Size, Marker, BoardIn, FL),
    reverse_marker(FL, ~(X-1), -1, Size, Marker, BoardIn, Board0),
    check_marker(X,       0, Size, Marker, BoardIn, FM),
    reverse_marker(FM, X, 0, Size, Marker, Board0, Board1),
    check_marker(~(X+1),  1, Size, Marker, BoardIn, FR),
    reverse_marker(FR, ~(X+1), 1, Size, Marker, Board1, BoardOut).

check_marker(X, Offset, Size, Marker, [], F)
 :- F = no.
check_marker(X, Offset, Size, Marker, BoardIn, F)
 :- X = 0
  | F = no.
check_marker(X, Offset, Size, Marker, BoardIn, F)
 :- X > Size
  | F = no.
otherwise.
check_marker(X, Offset, Size, Marker, [Line | BoardLeft], F)
 :- arg(X, Line, Stat),
    Stat = '.'
  | F = no.
```

```
check_marker(X, Offset, Size, Marker, [Line | BoardLeft], F)
 :- arg(X, Line, Stat),
    Stat = Marker
  | F = yes.
otherwise.
check_marker(X, Offset, Size, Marker, [Line | BoardLeft], F)
 :- check_marker(~(X+Offset), Offset, Size, Marker, BoardLeft, F).


reverse_marker(no, X, Offset, Size, Marker, BoardIn, BoardOut)
 :- BoardOut = BoardIn.
reverse_marker(yes, X, Offset, Size, Marker, BoardIn, BoardOut)
 :- X = 0
  | BoardOut = BoardIn.
reverse_marker(yes, X, Offset, Size, Marker, BoardIn, BoardOut)
 :- X > Size
  | BoardOut = BoardIn.
reverse_marker(yes, X, Offset, Size, Marker, [LineIn | BoardLeft], BoardOut)
 :- arg(X, LineIn, Stat),
    Stat = Marker
  | LineOut = LineIn,
    BoardOut = [LineOut | BoardLeft].
otherwise.
reverse_marker(yes, X, Offset, Size, Marker, [LineIn | BoardLeft], BoardOut)
 :- setarg(X, LineIn, Marker, LineOut),
    BoardOut = [LineOut | BoardMid],
    reverse_marker(yes, ~(X+Offset), Offset, Size, Marker,
                   BoardLeft, BoardMid).


split(Y, Board, BoardU, Line, BoardD)
 :- split(~(Y-1), Board, [], BoardU, Line, BoardD).

split(Y, [Row | BoardLeft], BoardUIn, BoardUOut, Line, BoardD)
 :- Y > 0
  | BoardUMid = [Row | BoardUIn],
    split(~(Y-1), BoardLeft, BoardUMid, BoardUOut, Line, BoardD).
split(Y, [Row | BoardLeft], BoardUIn, BoardUOut, Line, BoardD)
 :- Y = 0
  | BoardUOut = BoardUIn,
    Line = Row,
    BoardD = BoardLeft.

reverse_list(LIn, LOut)
 :- reverse_list1(LIn, [], LOut).

reverse_list1([D|LLeft], LMid, LOut)
 :- reverse_list1(LLeft, [D|LMid], LOut).
reverse_list1([], LMid, LOut)
 :- LOut = LMid.

append([D | L1Left], L2, LOut)
 :- LOut = [D | LMid],
    append(L1Left, L2, LMid).
append([], L2, LOut)
 :- LOut = L2.
```

B %W%m%0%i% %j%9%H(circle_to_square)

```
:- module main.

main
 :- gen(100, N0, N1, NN0),
    gen(110, N1, N0, NN1),
    circle(NN0),
    circle(NN1)@node(1).
gen(N, N0, N1, NOut)
 :- N0 = N,
```

```
    partition(N0, N1, Par),
    gen_n(Par, 0, NOut).

partition(N0, N1, Par)
 :- Par := N0*150/(N0+N1).

gen_n(N, SumIn, SumOut)
 :- N > 0
  | SumMid := SumIn + N,
    NewN := N-1,
    gen_n(NewN, SumMid, SumOut).
gen_n(N, SumIn, SumOut)
 :- N = 0
  |
    SumOut = SumIn.

circle(NN1)
 :- yloop(~(-NN1), NN1, 0, 0, ISum, OSum),
    Prop := ISum*100/(ISum+OSum),
    io:outstream([print(Prop),nl]),
    true.

yloop(YIn, NN1, ISumIn, OSumIn, ISumOut, OSumOut)
 :- YIn =< NN1
  | xloop(~(-NN1), NN1, YIn, ISumIn, OSumIn, ISumMid, OSumMid),
    NewYIn := YIn + 1,
    yloop(NewYIn, NN1, ISumMid, OSumMid, ISumOut, OSumOut).
yloop(YIn, NN1, ISumIn, OSumIn, ISumOut, OSumOut)
 :- YIn > NN1
  | ISumOut = ISumIn,
    OSumOut = OSumIn.


xloop(XIn, NN1, Y, ISumIn, OSumIn, ISumOut, OSumOut)
 :- XIn =< NN1
  |
    sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid),
    NewXIn := XIn + 1,
    xloop(NewXIn, Y, NN1, ISumMid, OSumMid, ISumOut, OSumOut).
xloop(XIn, NN1, Y, ISumIn, OSumIn, ISumOut, OSumOut)
 :- XIn > NN1
  | ISumOut = ISumIn,
    OSumOut = OSumIn.

sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid)
 :- XIn*XIn+Y*Y =< NN1*NN1
  | ISumMid := ISumIn+1,
    OSumMid = OSumIn.
sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid)
 :- XIn*XIn+Y*Y > NN1*NN1
  | ISumMid = ISumIn,
    OSumMid := OSumIn+1.
```

C %W%m%0%i% `%j%9%H(master_slave)

```
:- module main.

main
 :- gen(100, N0, N1, NN0),
    gen(110, N1, N0, NN1),
    circle(NN0),
    circle(NN1)@node(1).
gen(N, N0, N1, NOut)
 :- N0 = N,
    partition(N0, N1, Par),
    gen_n(Par, 0, NOut).

partition(N0, N1, Par)
```

```
 :- Par := N0*150/(N0+N1).

gen_n(N, SumIn, SumOut)
 :- N > 0
  | SumMid := SumIn + N,
    NewN := N-1,
    gen_n(NewN, SumMid, SumOut).
gen_n(N, SumIn, SumOut)
 :- N = 0
  |
    SumOut = SumIn.

circle(NN1)
 :- yloop(~(-NN1), NN1, 0, 0, ISum, OSum),
    Prop := ISum*100/(ISum+OSum),
    io:outstream([print(Prop),nl]),
    true.

yloop(YIn, NN1, ISumIn, OSumIn, ISumOut, OSumOut)
 :- YIn =< NN1
  | xloop(~(-NN1), NN1, YIn, ISumIn, OSumIn, ISumMid, OSumMid),
    NewYIn := YIn + 1,
    yloop(NewYIn, NN1, ISumMid, OSumMid, ISumOut, OSumOut).
yloop(YIn, NN1, ISumIn, OSumIn, ISumOut, OSumOut)
 :- YIn > NN1
  | ISumOut = ISumIn,
    OSumOut = OSumIn.


xloop(XIn, NN1, Y, ISumIn, OSumIn, ISumOut, OSumOut)
 :- XIn =< NN1
  |
    sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid),
    NewXIn := XIn + 1,
    xloop(NewXIn, Y, NN1, ISumMid, OSumMid, ISumOut, OSumOut).
xloop(XIn, NN1, Y, ISumIn, OSumIn, ISumOut, OSumOut)
 :- XIn > NN1
  | ISumOut = ISumIn,
    OSumOut = OSumIn.

sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid)
 :- XIn*XIn+Y*Y =< NN1*NN1
  | ISumMid := ISumIn+1,
    OSumMid = OSumIn.
sum(XIn, Y, NN1, ISumIn, ISumMid, OSumIn, OSumMid)
 :- XIn*XIn+Y*Y > NN1*NN1
  | ISumMid = ISumIn,
    OSumMid := OSumIn+1.
```