JBNsO@M}7?8@8lKL1 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?@.9 G/2 7n

Abstract

JBNsO@M}7?8@8lKL1 GO!"0l$D0l$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$$$k!#7?$,$C$F!"%W%m%0%i%`$N;}$DJBNsEY$rDc2<5;$J$$DxEY$KJB9T<B9T$NC10L$NN3EY$rBg$-$/9k3H$,$G$-$l$P!"<B9T;~$N%*!<%P%X%C%I$r7Z8:$9k3H,G-$k!#

0lHL$KKL1 JI$NJB9T!?JBNs7?$N%W%m%0%i%_%s%08@8l$N%9%1%8%e!<%j%s%0GO!"$=$N%W%m%0%i%`Cf$KB8:_$9$kITI,MW$JJBNs@-$r$$$+$K=|5n$9$k$+$,=EMW$G$"$k!#$3$l$^$G$NB?$/$NKL1=hM}7O$G$O!"%W%m%0%i%`$r?<$5!?:8M%@h$K<B9T9kN,C`<!<B9T$N:GE,%7!<%1%s%9$H$_$J$7$F$$$k!#$7$+$7$J$,$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=$r9T$&3HKh$j!"F0E*$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$&$3$H$G!"%G%C%I%m%C%/$r5/$3$5$J$$$h$&$K%W%m%0%i%`$N0lIt$N<B9T=g=x$r@EE*$K7hDj9k!#K\9FGO3NC`<!2=5l$?%4!<%k7ONs$r%9%l%C%I$H8F$V!#$=$7$F!"$3$N%9%l%C%I$rJB9T<B9TC10LH9k3HKhC$F!"$=$NF0E*$JJB9T@-@)8f$KH<$&%*!<%P%X%C%I$r7Z8:$9$k!#$^$?!"%4!<%k$N<B9T=g=x$r@EE*$K8GDj7?3HKh$j!"%9%l%C%IFb$N%4!<%k$K4X$7FO%9%?%C%/$rMQ$$$?8zN(E*$J<BAu$r9T$&$3H,G-$k!#

7+7J$,$i!"%9%l%C%I2=Kh$j%9%1%8%e!<%j%s%0C10L$,Bg$-$/Jk3H$GF1;~$K%9%1%8%e!<%k2DG=$J%4!<%k$N?t$,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$$!#7+7J$,$i!"=>Mh$N%4!<%k!&%9%1%8%e!<%j%s%0GO!"MW5a%G!<%?$r@8@.$9$k%4!<%k$,M%@hE*$K%9%1%8%e!<%k$5lkh&$J5!9=$,B8:_7J$$$?$a!"MW5a%a%C%;!<%8$KBP9k1~Ez@-$OJ]>Z$5lJ$$!#3NLdBj$O%9%1%8%e!<%kC10L$NBg$-$$%9%l%C%I!&%9%1%8%e!<%j%s%0GO?<9oG"$j!"MW5a%G!<%?$N@8@.$KL54X78$+$D<B9T;~4V$ND9$$%9%l%C%I$,%9%1%8%e!<%k$5lF7^$&$H!"MW5aB&$N%"%$%I%k;~4V$,Hs>o$KD9$/$JCF7^$$!"JBNs<B9T$N8z2L$,GJ$/$J$k2DG=@-$,$"$k!#

$=$3$GK\O@$GO3$NLdBj$KBP=h9k$?$a$K!"B>%4!<%k$KMW5a5l$?%G!<%?$rJV?.9k$?$aKI,MWJ6qBN2=$dF10l2=$r9T$&%4!<%k$r4^$`%9%l%C%I$rM%@hE*$K%9%1%8%e!<%k$9$k**reply first scheduling**<jK!$rDs0F$9$k!#

reply first scheduling $rMQ$$$k3H$G!"JB9T<B9T$K$*$1$k%G!<%?MW5a$X$N1~Ez@-$r8~>e5;!"%9%l%C%I2=5l$?%W%m%0%i%`$N;}$DJBNs@-$r:GBg8B$K0z$-=P$9$3H,G-$k!#$^$?!"l%N!<%I>e$NK<B9T$K4X$7Fb!"4X78N"$k%9%l%C%I$,%9%1%8%e!<%k5lk?$a!"FHN)@-$N9b$$=hM}$,J#?t$"$k>l9g$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<$G$O%W%m%0%i%`$r%9%l%C%I2=$9k3HKhj%Y%s%A%^!<%/%W%m%0%i%`GO1.3!A2.9 G\$N@-G=8~>e$,C#@.$G$-$?!#

0lJ}!"JBNs4D6-K*$$$F$OJBNs@-$NDc2<Kh$j%9%l%C%I2=$N$_$NE,MQGO=>MhHGhj$b<B9TB.EY$NMnAkLdBj$d!"=>Mh$NF0E*%9%1%8%e!<%j%s%0<jK!GOJBNs@-$rCj=P$G$-$:$KC`<!<B9T$h$j$b@-G=$,Dc2<$9$kLdBj$bB8:_$7$?!#$3$l$i$N%W%m%0%i%`$KBP7F$O%9%l%C%I$NF0E*%9%1%8%e!<%j%s%0<jK!H7$Freply first scheduling<jK!$rMQ$$$k3H$G!"$=$N%W%m%0%i%`$N;}$DJBNs@-$r0z$-=P$9$3$H$K@.8y$7!"JBNs<B9TK*$$$F$b=>MhHG$KHfYFLs1.3!A1.6 G\$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/!"JBNs7W;;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$r;XDj9k5!9=$HF14|$N$?$a$N5!9=$rDI2C$7!"JBNs=hM}$K;HMQG-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!"JBNs2=$5$l$?%3!<%I$r@8@.$9$k!#%W%m%0%i%^$,JBNs2=$N$?$a$N>pJs$r%3%s%Q%$%i$KEO$9$b$N$H$=$&$G$J$$$b$N$H$N2<oN`$,B8:_9k!#7+$7!"bHbHC`<!$G=q$+$l$?%W%m%0%i%`$rJBNs2=$9k?$a!"JBNs2=2DG=$JItJ,$O%G!<%?JBNsItJ,$K8Bil$k!#$3N?$a!"5-9f=hM}$JIN7W;;Ii2Y$,@EE*$KM=B,G-$J$$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$K:$FqKJ$k!#$3N?$a!"MM!9$JJBNs2=%"%k%4%j%:%`$r;n$9I,MW$,$"$k>l9g$J$I$O!"%W%m%0%i%`$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$$B?<oB?MM$J1~MQ$H%W%m%0%i%_%s%0!&Q%i%@%$%`$KBP9k9b$$JqMFNO$bM-$7$F$$$k!#
- %G!<%?%U%m!<F14|5!9=$NF3F~$Khj!"F14|$r<+F02=$9k3HGF14|KHbJ$&%P%0:.F~$N2DG=@-$rGS=|$7$F$$$k!#
- %7%s%?%C/%9$,4J7i$GJ,$+$jd9$$!#

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

7+7J$,$i!"JBNs=hM}$N=EMW$JB&LLG"$k9bB.@-$N4QE@$+$i$O!"$3li$NUB9T!?JBNs7?8@8l$N=hM}%7%9%F%`$N@-G=$O==J,$H$O8@$($J$$!#$3$N@-G=>e$NLdBjE@$NBg$-$JM}M3$K!"8@8l$NK\<A$G$"$kJB9T@-@)8f$K$H$b$J$&%*!<%P%X%C%I$,$"$k!#KL1 $O$=$NC<E*$JNc$N0l$D$G$"$j!"3F!9$N%4!<%k$,JB9T<B9T$NC10L$G$"$k$?$a!"%4!<%k!&%9%1%8%e!<%j%s%0$NJ}<0$,%W%m%0%i%`$N@-<A$KE,9g7F$$$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=$G$O!"$=$N%W%m%0%i%`$N;}$DJBNs@-$r$$$+$KCj=P$9k3H,G-k+$,=EMW$G$"$k!#0lJ}!"UB9T!?JBNs7?$N%W%m%0%i%_%s%08@8l$G$OJBNs@-$NCj=P$OMF0W$G$"$kH?LL!"%W%m%0%i%`Cf$KB8:_$9$kITI,MW$JJBNs@-$r$$$+$K=|5n$9$k$+$,=EMW$K$J$k!#8@$$49$($k$HUB9T!?JBNs7?$N%W%m%0%i%`$N%9%1%8%e!<%j%s%0$G$O!"C`<!<B9T$,:GE,$G$"$k$h$&$J%7!<%1%s%9$rH/8+$7!"$=$l$NC`<!<B9T$,=EMWG"$k!#$3l^GNB?$/$NKL1=hM}7OGO!"%W%m%0%i%`$r?<$5!?:8M%@h$K<B9T$9$k$N$,C`<!<B9T$N:GE,%7!<%1%s%9$H$_$J7F$$$k$H9M$(k3H,G-$k!#$7$+$7%W%m%0%i%`$N@-<A$,!"3Nh&$JC1=c$J?dDjKOE,9g7J$$$3H,7P7P$"$j!"MM!9$J@-G=>e$NLdBjE@$,H/@8$9$k!#

7?$,$C$F!"%3%s%Q%$%k;~Kh$j>\:Y$J2r@O$r9T$C$F!"%W%m%0%i%`$N@-<A$KE,9g$7$?C`<!2=$r9T$&$3H,!"$^$:Bh0l$NL\E*$HJk!#<!$K!"E,@Z$KC`<!2=$5$l$?%W%m%0%i%`CGJR$r8zN(E*$K<B9T9kKO!"K\<AE*$JJB9TF0:n$H$N4X78$JIKhkC`<!<B9T$NCfCG$KBP$7$F!":G>.$N%*!<%P%X%C%I$GBP=h$G$-$k$h$&$K$9$k$3$H$bI,MW$G$"$k!#$3$N<B9T%a%+%K%:%`$r5a$ak3H,!"K\8&5f$NBhFs$NL\E*G"$k!#

1.3 K\O@$N9=@.

K\8&5fGO!"KL1 $N%4!<%k!&%9%1%8%e!<%j%s%0$r:GE,2=$9k3HrL\E*H7!"%W%m%0%i%`$r%9%l%C%I$H$h$VC`<!2=5l$?%4!<%k7ONs$KJ,3d9k<jK!G"$k%9%l%C%I2=<jK!$H!"%9%l%C%I$rJBNs<B9T$9$k:]$KJBNs@-$r:GBg8B$K3NJ]9k$?$a$N%9%1%8%e!<%kJ}K!$G$"$k**reply first scheduling** <jK!$NDs0F!"<BAu!"I>2A

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

Bh2>OGOK\8&5f$NGX7J$H7F!"K\8&5f$NBP>]8@8l$*hS<BAuBP>]$N=hM}7O$G$"$k!"JBNsO@M}7?8@8l KL1 $*$h$S KL1 =hM}7O KLIC KD$$$F@bL@7?NA!"=>Mh$N KL1 =hM}7O$K$*$$$F:NMQ5lF-$?%4!<%k!&%9%1%8%e!<%j%s%0<jK!KD$$$F=RYk!#

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

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

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

Bh6>OGO!"4XO"8&5fHNHf3S$H:#8e$N2]BjKD$$$F=RYk!#

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

2 GX7J

2.1 JBNsO@M}7?8@8l KL1 H=$N=hM}7O KLIC

2.1.1 KL1

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

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

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

H, G, B $O=R8l$G$"$j!"$=$l$>$l%/%m!<%:%X%C%I!"%,!<%I%4!<%k!"%\%G%#%4!<%k$H8F$Plk!#=R8l$O‘=R8lL>/0z?t$N8D?t’ $GI=5-$5lk!#‘|’ $O%3%_%C%H%a%s%H%P!<$H8FPl!"@aCfG3lN:8B&$NItJ,$r%,!<%IIt!"1&B&$r%\%G%#It$H8F$V!#%,!<%I%4!<%k$H7F5v5lkbNOAH9~=R8lN_$G!"%\%G%#%4!<%k$H7F$O!"AH9~=R8l$H%f!<%6Dj5A=R8l$r5-=R$G$-$k!#$^$?!"%\%G%#%4!<%kO=l>lrJBNs$K<B9T$G$-$k!#

<B9T5,B′ K\@aGO!"KL1 %W%m%0%i%`$,$INh$&$K<B9T5lk+KD$$$F@bL@9k!#KL1 GN<B9T$NC10L$O%4!<%k$H8F$Plk!#%4!<%k$N<B9T$O0J2<$N5,B′$K7?$,$C$F9T$olk!#

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

   3liN<B9TKhCF G $N0z?t$r6qBN2=7FOJiJ$$!#

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

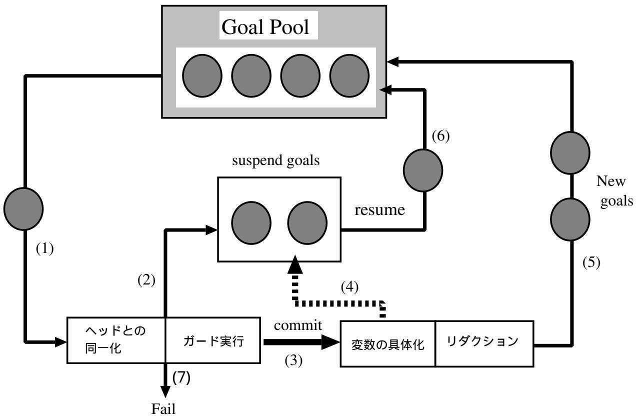
   $^$?!"%\%G%#%4!<%kGNF10l2=%4!<%k$N<B9T(%\%G%#%f%K%U%#%1!<%7%g%s) GO!"JQ?tNCMr7hak3H(JQ?t$N6qBN2=) $,$G$-$k!#JQ?t$N6qBN2=$O%W%m%0%i%`CfG?$@0l2s$7$+9T$&3H$,$G$-$J$$!#

3l$r<B9T2DG=$,%4!<%k$,$J$/$Jk^$G7+$jJV$9!#?^1$K KL1 $N<B9T%b%G%k$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%`$O $Z = |X| * 2$ $r<B9T$9$k%W%m%0%i%`G"$k!#

KL1 GO=i4|%4!<%kH7$F main/0 $,M?$(il$k!#main @a$N<B9TKhCF%4!<%k tmp(-10,Z) $,<B9T2DG=%4!<%k$r0l;~4IM}9k$?$a$NNN0h$K3JG<5l$k(?^1.(5))!#$3$NNN0h$r$3$3GO%4!<%k%W!<%k$H8F$V!#

%4!<%k‘ tmp(-10,Z)’ $N<B9T$KhC$F!"%X%C%I$,tmp/2 G"$k(1) @a$,A*Br5l!"‘abs(-10,Y),mul2(Y,Z)’ $H$$$&2 DN%4!<%k$,%4!<%k%W!<%k$K3JG<5l$k(?^1.(5))!#$3NH$-!"$bHN%4!<%k‘tmp(-10,Z)’ $O%4!<%k%W!<%k$+iJ$/$J$k!#$3$NA`:n$r8@$$49$($k$H!"%4!<%k‘tmp(-10,Z)’ $,%\%G%#%4!<%k‘abs(-10,Y),mul2(Y,Z)’ $K=q$-49$($i$l$?$H$$$($k!#$3$N0lO"$N%4!<%k$N=q$-49$($NA`:n$r%4!<%k$N%j%@%/%7%g%s$H$$$&!#



?^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$&$+$rD4$YkAH_9~$_=R8l

?^2: $Z = |X| * 2$ $r5a$a$k KL1 %W%m%0%i%`

=q-49(il$?2 DN%4!<%k$O%4!<%k%W!<%k$+$i<h$j=P5l!"<B9T5l$k(?^1.(1))!#$9Jo$A!"‘abs(-10,Y)’ $H(2),(3) @a!"‘mul2(Y,Z)’ $H(4) @a$H$NF10l2=$,;n$_$ilk!#3N>l9g!"‘abs(-10,Y)’ $N%j%@%/%7%g%s$G$O%,!<%I%4!<%k$N<B9T$,@.8y$9$k(3) @a$,A*Br5l(?^1.(3))!"%\%G%#%4!<%k‘Y:=-(-10)’ $,<B9T$5lk!#0lJ}‘mul2(Y,Z)’ $NJ}$OBh0l0z?t$N Y $,6qBN2=$5lF$$$J$$$?$a‘mul2(Y,Z)’ $O<B9T$rCfCG$7!"Y $,6qBN2=$5lkNrBTD3HKJk(?^1.(2))!#3l$r%4!<%k$N%5%9%Z%s%I(**suspend**) $H8F$V!#$=$7$F‘add1/2’ $N<B9T$,=*N;$7!"Z NCM,10 $K6qBN2=$5lk$H(?^1.(4))!"‘mul2/2’ $O<B9T$r:F3+9k(?^1.(6))!#3l$r%j%8%e!<%`(**resume**) $H8F$V!#

KL1 $N<B9T$O3Nh&$JA`:n$r7+jJV9$3$HKhCF?J$_!"%4!<%k%W!<%k$K%4!<%k$,$J$/$JkH<B9T$,=*N;$9$k!#$3NH$-!"CfCGCf$N%4!<%k$,B8:_$9$k>l9g$O<B9T$,%G%C%I%m%C%/$7$F$$$k$H$$$&!#

$^$?Prolog HO0cCF%P%C%/%H%i%C%/$O9T$o$:!"$b$7Y $,integer 0J30$NCM$K6qBN2=$5lk>l9g$d!"%\%G%#%4!<%k$G$NF10l2=$K<:GT7?>l9g$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$,$"$k!#

- O@M}JQ?t

  O@M}JQ?t$O;2>H%]%$%s%?$GI=8=$5$l!"FCDj$N7?$O;}$?$J$$!#6qBN2=KhCFBP>]XN%]%$%s%?$,3JG<5l$k!#$^$?!"0lEY6qBN2=$5lk$H!"JL$NCM$K:F$S6qBN2=9k3HOG$-$J$$(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#$r;}$C$F$$$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%?)$r3JG<9k3H$,$G$-$k!#0lHLE*JbNH7F$O%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$$$C$?$s C %W%m%0%i%`$KJQ49$7!"%*%V%8%'%/%H%3!<%I$N@8@.$O%?!<%2%C%H%^%7%s$NC %3%s%Q%$%i$,9T$&J}<0rHCF$$$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$,2TF/Cf$G$"$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$k!#<B9T%4!<%k$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,1ilk!#

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$,$"$C$?>l9g!"%a%=%C%I$H8FPl$k<jB3$-$,<+F0E*$K5/F0$5$l$k!#0lHL$K!"consumer object $O6qBN2=$Khj!"$=$N6qBNCM$r>CHq$9$kUNIFY %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$KBP1~9k%3!<%I$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$Dj5AJQ?t$X$r;2>H$9kH!"XO6qBN2=BT$AJQ?t(%U%C%/JQ?t)$KJj!"3N%4!<%k$r;X$9!#3l$,%4!<%k$g$,CfCG$7$F$$$k>uBVG"$j!"$g$,JQ?t$X$K%U%C%/$7$F$$$k$H$$$&!#=hM}7O3K$OCfCG=hM}$r9TC?8e!"?7$?$J%4!<%k$r%4!<%k%-%e!<$+$i<h$j=P$7<B9T$rB3$1$k!#$=$N8eX,6qBN2=5lkH!"XKDJ$,$l$F$$$?%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$r7+jJV7!"<B9T2DG=%4!<%k%-%e!<$+$i%4!<%k$,L5$/$JkH%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$1$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$,<u?.B&!"Aw?.B&NIAiG"k+KhCF!"6qBNCM$NAw?.J}K!$,0[Jk!#

;R%N!<%I$,6qBN2= : ?FB&$+iO6qBNCMXN%]%$%s%?$,B8:_7J$$$?$a!"6qBN2=$7$?;~$K!";R%N!<%I$,?F%N!<%I$KBP7F6qBNCM$rAw?.!#

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

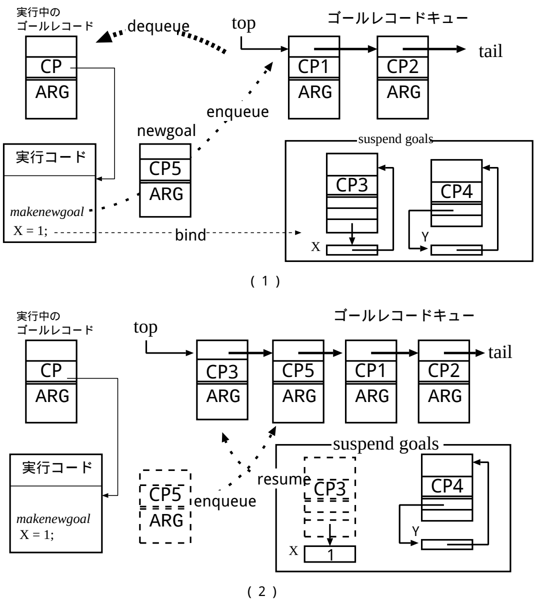
$^$?$"$kJQ?t X KBP9$kMW5a$r<u?.7?H-$K!"$X$$,L$6qBN2=$GJV?.$r9T$($J$$>l9g!"=hM}7OOX$$KBP$7!"JV?.MQ$N consumer object $r%U%C%/$5$;$k!#3N5!9=Kh$j!"$X$$N6qBN2=;~K3$N%*%V%8%'%/%H$NUNIFY %a%=%C%I$rMQ$$$F<+F0E*$KJV?.$,9Tolk3HKJk!#

3Nh&$K30It;2>H%]%$%s%?$r7PM3$7$?;2>H$d6qBN2=KO%a%C%;!<%8DL?.$H$$$&5!<o$K0MB8$7$?=hM}$rH<$&!#$=3G!"30It;2>H%]%$%s%?$rgeneric object $rMQ$$$F<BAu$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$$$F<+%W%m%;%9$NFbIt>uBV$rJQ$($?$j!"$"$k<o$N7W;;$r9T$C$?$j7F!"$=$N7k2L$r:F$S%9%H%j!<%`$KN.$9$H$$$&A`:n$r7+$jJV$9!#

KL1 K*1k%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!<%kg/n $G;O$^$k%W%m%;%9$rC1$K%W%m%;%9$g/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) $N@a$NX $HY $,%9%H%j!<%`JQ?t$HJCF*$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$H%,!<%I%4!<%k<B9T$rI=$9!#

goal (n) : %3%_%C%H7?@a((n) @a) $N%\%G%#It$N<B9T$r<($7!"%\%G%#%f%K%U%!%$%*$h$S%4!<%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!#

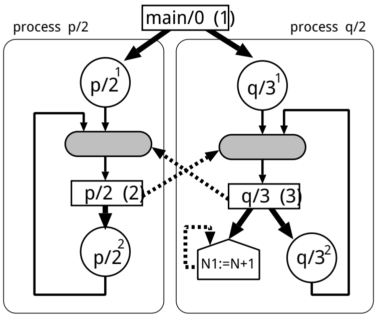
⇢ : %G!<%?%U%m!<$rI=$9!#

→ : %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=R8lL>$N1&8*$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!#

$$\texttt{main :- p([ack(0)|X],Y)}^{1}\texttt{,q(Y,X,1)}^{1}\texttt{.} \tag{1}$$
$$\texttt{p([ack(N)|X],Y) :- Y=[read|Y1],p(X,Y1)}^{2}\texttt{.} \tag{2}$$
$$\texttt{q([read|X],Y,N) :- Y=[ack(N)|Y1],N1:=N+1,q(X,Y1,N1)}^{2}\texttt{.} \tag{3}$$

(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=$N%4!<%k$N5%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=1>$1%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 $,CfCG
goal1 (n)(rsm goal2) :
n HV$N@a$N**goal1** $N<B9T$,**goal2** $r%j%8%e!<%`

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

%W%m%;%9;X8~%9%1%8%e!<%j%s%0GO%9%H%j!<%`$O!ZDG=$JH-$KFbMF$r=hM}9k%P%C%U%!!WH7$F?6Iq$&!#%W%m%;%9;X8~%9%1%8%e!<%j%s%0$O%9%k!<%W%C%H;X8~$N%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$KBP9k%a%C%;!<%8$,!Vu?.B&$KBP$7@)8f$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/2¹(2) → q/3¹ (3) → p/2²(2) → p/2(susp)
→ N1:=N+1 → q/3²(3) → p/2²(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=5l$F$$$k KL1 $N=hM}7O$K$*$1$k!"%4!<%k!&%9%1%8%e!<%j%s%0<jK!KO%W%m%;%9;X8~%9%1%8%e!<%j%s%0$,:NMQ$5lF$-$?!#Nc$($P!"Multi-PSI [10] $d PIM [11] JI$N=hM}7O$,3NJ}<0$r:NMQ7F$$$k!#

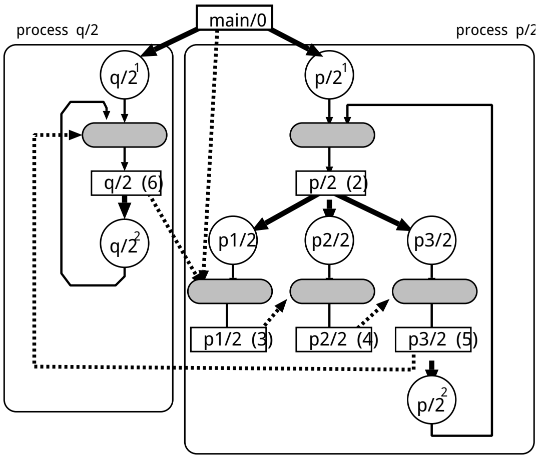
7+7J$,$i!"%W%m%;%9;X8~J}<0GO!"@8@.!&2>H%W%m%;%94V$N%4!<%k@ZBX$,I,$:CfCG$G5/CF7^$$!"$=$N%*!<%P%X%C%I$,Bg$-$/$JCF7^$&$H$$$&LdBj$,$"$k!#

$=$3$G KLIC GO!"3N%*!<%P%X%C%I$r7Z8:$9k?aK!"$"$k%4!<%k$,%j%8%e!<%`$5$l$?$H$-!"%W%m%0%i%`$N@)8fr=$N%j%8%e!<%`$5l?%4!<%k$K0\$9h&$J%9%1%8%e!<%j%s%0<jK!$r<hCF$$$k!#3NJ}<0$O **resumption first scheduilng** J}<0$H8F$PlF$$$k!#

3NJ}<0GO!"CfCG%4!<%kKBP9$k%a%C%;!<%8$KhC$F!"%a%C%;!<%8;X8~E*$J%4!<%k$N@ZBX$r9T$&$?$a!";2>HB&$,CfCG7F$$$kH-$N!"@8@.%W%m%;%9$+$i;2>H%W%m%;%9$X$N%4!<%k$N@ZBX$,Dc%*!<%P%X%C%I$G9Tol$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

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+$7!"$=lrC`<!<B9T$9$k:GE,2=$,=EMW$G$"$k!#Nc$($P KLIC $J$I$3$l$^$G$N KL1 =hM}7O$G$O!"%W%m%0%i%`$r:8!??<$5M%@h$K<B9T$9kN$,C`<!<B9T$N:GE,%7!<%1%s%9$H8+$J$7$F$$$k!#$7$+$7!"%W%m%0%i%`$N@-<A$,!"$3Nh$&$JC1=c$J?dDj$K$OE,9g$7$J$$$3H,IaDLG"$j!"MM!9$JLdBj$,@8$8k3H,$"$k!#K\@aGO$^$:KL1 %W%m%0%i%`$N<B9T$K$*$$$FINh&$J%*!<%P%X%C%I$,B8:_9k$+$r<($9!#$=$N8e!"<B:]$K%W%m%;%9;X8~%9%1%8%e!<%j%s%0J}<0$d resumption first scheduling J}<0$rMQ$$$?>l9g$K@8$8$kLdBjE@$K$D$$$F=RYk!#

%4!<%k<B9T$N%*!<%P%X%C%I 0lHL$K$"$k%4!<%k$r@8@.$7F=lr<B9T9k$^$G@8$8$k%*!<%P%X%C%IKO<!Nh$&$JbN$,$"$k!#

- %4!<%k%l%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$7F7$^$C$?>l9g$O!"%j%8%e!<%`5lk^$G!"$=$N%4!<%k$,%9%1%8%e!<%k5l$J$$$h$&$K9k$?$a$N=hM}$,9Tol$k!#$^$?!"JQ?t$N6qBN2=$N:]$K:F$S!"%4!<%k$N%(%s%-%e!<!?%G%-%e!<N?aN=hM}$,I,MW$KJk!#3liN$&$A!"FC$K%4!<%k$N%5%9%Z%s%IKBP9$k%*!<%P%X%C%I$OHs>oKBg-JbNHJC$F$$$k!#

%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,$:CfCG$G9TolkH$$$&LdBj$,$"$k!#

3NLdBj$O!";2>H%4!<%k$,J#?tB8:_9k>l9g$d!";2>H%W%m%;%9$N=PNO$K0MB8$9$k%4!<%k$,B??tB8:_9k>l9gKFCKBg$-$/Jk!#

Nc$($P!"?^5NMMJ>l9g$r9M$(F_$k!#$3NNcN%G!<%?0MB8$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$=$l$>$l%G!<%?0MB8$9$k!#

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

```
q/2¹ (susp) → p/2¹ → p1/2 → p2/2 → p3/2 (rsm q/2¹)
→ p/2² → p1/2 (susp) → p2/2 (susp) → p3/2 (susp) →
q/2¹ (rsm p1/2) → q/2² (susp) → p1/2 (rsm p2/2)
→ p2/2 (rsm  p3/2) → p3/2 (rsm q/2²) → p/2² → ···
```

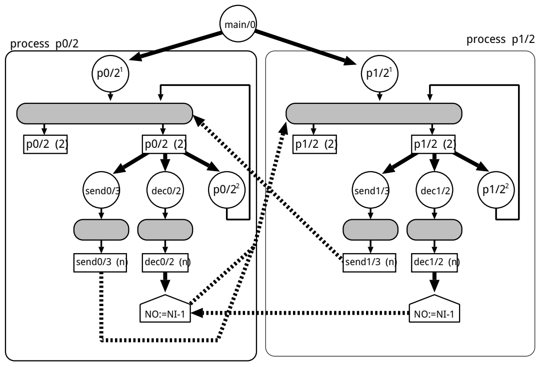
3Nh&$K!"p1/2 $NCfCG$,p2/2, p3/2 KbEAHB$7!"p/2 B&$N%W%m%;%9$Hq/2 B&$N%W%m%;%9H,1 2s%a%C%;!<%8rd$j<h$j9kEY$K!"7W3 2s$b$NCfCG$,5/$-$F7^CF$$$k!#

D^$j!"%W%m%;%9;X8~%9%1%8%e!<%j%s%0GO!"$"$k%G!<%?rI,MWH9k%4!<%k$d!"$=$N%4!<%k$K%G!<%?0MB8$9$kh&$J%4!<%k$rLUL\E*$K%9%1%8%e!<%k$7F7$^$$!"$=$N7k2LB??t$N%4!<%k$,CfCG7F7^$&2DG=@-$,$"$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$jBX$($,%4!<%k$NCfCG;~$K9TolkH$$$&LdBj$O!"%a%C%;!<%8;X8~E*$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!<%k9k3H$GBP1~$7$F$$$k!#

3lKh$j!";2>H!@8@.%W%m%;%94V$N%4!<%k@ZBXN&$A!";2 >H%4!<%k$,CfCG7F$$$k>l9g$K!"%4!<%k$N@ZBX$,DL>o$N%j%@%/ %7%g%sKhCF9Tolk3HKJk!#Nc$($P!"?^4NNcG$O!"

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$,9Tol$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$G9T ol$k!#$3N?$a!"%4!<%k$NCfCG$N860x$HJC$?L$6qBN2=JQ?t $,J#;($J9=B$%G!<%?$K6qBN2=5l$k>l9g$K$O!"%G!<%?$,40A4$J bNHJ$kA0$KCfCG%4!<%k$r:F3+$7F7$^$&2DG=@-$,$"$k!#$3 $N>l9g!":F3+$5l?%4!<%kd=$N%5%V%4!<%k$,%G!<%?CfNL6q BN2=ItJ,$r;2>H$7!":F$SCfCG$7F7$^$&62l,$"$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=PNO$r;2>H9k!# hC$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 $D $N%4!<%k$N$&$A'send1/3' $,<B9T$5l?$@$1$G@)8f$,p0/2 $K 0\$CF7$^$$!"$=$N7k2Lp0/2 $O%a%C%;!<%8$KIT40A4JbNr 8+D1CfCG7F7^$&!#$3Nh$&$K3NNcGOp0/2 $N1 %k!<%W$"$?$j7W2 2s$NCfCG$,5/3k!#3l$O!"p0/2 $G;2>H$9$k%G!< %?9=B$$,J#;(G"lP$"$k$[$ICfCG2s?t$OB?$/Jj!"0lHLKO ;2>HB&$,I,MW$H9k0lDN9=B$%G!<%?$rn 8D$N%4!<%k$,@8@.$9 kh$&$J>l9g!":G0-n 2s$NCfCG$,5/$-$k3HKJ$k!#0lJ}!"$3 NNcr%W%m%;%9;X8~%9%1%8%e!<%j%s%0$G%9%1%8%e!<%k$9kH!" p0/2 $G;2>H$9$k%G!<%?$NJ#;(5K4Xoi$:!"CfCG2s?t$O2 2s/1 %k!<%WHJ$k!#

3Nh&$K!"resumption first GO9=B$7?%G!<%?$N6qBN2= $,IT40A4$G$"$k>l9g!"ITMW$J@)8f0\9T$,@8$8$k2DG=@-$,$"$k!# 3N7k2L!">l9gKhCF$O%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!<%?0MB8$9$k%4!<%k$r!"Cf CG%4!<%k$,%j%8%e!<%`$5lk$^$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$$HO 0O$G!"$G$-$k$@$1@8@.B&%W%m%;%9$+$i>CHq<TB&%W%m%;%9$X $N@)8f0\9T$rCYi;$k!#

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

3liN2r7hJ}K!$r<B8=$9k?aK!"K\8&5fGO%4!<%k$N %9%1%C%I2=$Khk%W%m%0%i%`$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@O$r9T$&3H KhCF!"<B9T=g=x$r@EE*$K7hDjG-$k%4!<%k$b>/J/$J$$!# $=$3$GK\8&5f$G$O!"%3%s%Q%$%k;~$K0MB82r@O$r9T$$!"$"$k@a$N %4!<%k$g_i, g_j$ KBP7$F!"$g_i$ Hg_j$ $N4V$KAPJ}8~$N%G!<%?0MB84X78$, B8:_7J$$>l9g!"3liN%4!<%k$N<B9T=g=x$r@EE*$K7hDj$9$k!# 3Nh&K7$F@EE*$K<B9T=g=x$,7hDj$5l?%4!<%k$N7ONs$rK\ 8&5fGOC`<!<B9T$,:GE,$J%4!<%k$N7ONs$H9M$($k!#"3N%4!<%k 7ONs$rK\9FGO%9%1%C%I$H8F$V!#

3F%9%1%C%IO=l>$l1ESCf$G%5%9%Z%s%I9k3HO"CF $b!"FbIt$N%4!<%k$N<B9T=g=x$,F~lBXok3HO$J$$!#7?$,$C $F!"%9%1%C%ICf$N$"$k%4!<%k$G;2>H%G!<%?$,L$6qBN2=$@C?>l 9gKO!"%9%1%C%I4H%5%9%Z%s%I7FB>$N%9%1%C%I$K<B9T$r@Z jBX(Fb!"%G%C%I%m%C%/$r@8$8k3HO$J$$!#

$^$?!"%9%1%C%IFb$O:GE,$JC`<!<B9T$r9T$&$h$&$K@EE*$K%9%1 %8%e!<%j%s%0$r9T$$$D$D!"$5$i$K!"%9%1%C%I$rF0E*$K%9%1%8%e!< %j%s%0$9$k$3$H$G!"85$N%W%m%0%i%`$,M-$9$kK\<AE*$JJB9TF0:n $r<B8=$7!"%G!<%?$N0MB84X78$rJ]D3H,2DG=KJ$k!#

K\<jK!$rMQ$$$k3HKh$j!"%W%m%;%9;X8~J}<0$N!"CfCG%4!< %k$K0MB8$7$?%4!<%k$N%9%1%8%e!<%j%s%0$HCfCG$,7+jJV5lk LdBj$O!":G=i$NCfCG$G%9%1%C%I$4$HCfCG$5lk$?$a2sHrG-$k!# $^$?!"resumption first J}<0$N!"IT40A4$J6qBN2=$G;2>HB&%4!< %k$K@)8f$,0\9T$9$kLdBj$O!"6qBN2=B&%9%1%C%I$,CfCG$9k^$G ;2>HB&%9%1%C%I$K@)8f$,0\$i$J$$$3HG2r7h5l$k!#

3.1.3 @EE*%9%1%8%e!<%j%s%0

K\<jK!GO!"%G!<%?0MB82r@O$r9T$&3HKhCF%3%s%Q%$%k;~ $K<B9T=g=x$,7hDjG-$k%4!<%k$K4X7F$O!"$=li$r0l$D%9%1%C %IK^Ha$F!"@EE*$K<B9T=g=x$r8GDj$9$k!#$3lKhC$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$r:o8:G-$k!#$^$?!"%9%1%C%IFb$N%4!<%k $N<B9T=g=x$,7hDj5l$?$3HKhj!"%4!<%k4D6-$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"k3H,B?$$%4!< %k4D6-$O%9%?%C%/$G4IM}9k<BAu$r9T$&3HKhCF!"GC $N 2s?t$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!"<!$N2<oN`$,B8:_9k!#

- @)8f0MB8
  %4!<%k c $,<B9T$5lkKO!"$=$NA0$K c $r%\%G%#%4!<%k$H7F@8@.9k?F%4!<%k p $,<B9T$5lF$$$J1llPJi$J$$!#
- %G!<%?0MB8
  $"$k%4!<%k r $,<B9T$5lkKO!"$=$N%4!<%k$G;2>H$5lkCM$r6qBN2=$9$k%4!<%k $w_1, \ldots, w_n$ $,$9YF<B9T5l$F$$$J1lPJiJ$$!#

KLIC JI=>Mh$N=hM}7O$G$O!"%3%s%Q%$%k;~$K%G!<%?0MB8$JIN2r@O$rA4$/9To:!"%G!<%?0MB8$r9MN8$7$?%9%1%8%e!<%j%s%0$r9TCF$$$J$$!#3N$?$a!"r $, w_i hj@h$K%9%1%8%e!<%j%s%0$5lk3HOh$/$"$k!#$3NH$-r $O!"CM$r;2>H7h$&$H7?CJ3,$GCfCG$7!"w_i $N<B9T$Khj$=$NCM$,6qBN2=$5lk$H r $N<B9T$r:F3+9k!#3lKBP7!"K\<jK!GO!";vA0$K%G!<%?0MB82r@O$r9T$$!"w_i $N<B9T8e$K r $r%9%1%8%e!<%k$9k3HKhC$F!"$3$NCfCG!&F3+$KH<$&%*!<%P%X%C%I$rHr1k3H$,$G$-$k!#

0lJ}!"@)8f0MB8KD$$$F$O!"K\<jK!$G$O7;Do%4!<%k$N=g=xN_$r7hDj$9$k<jK!$rHk$?$a!"?F%4!<%k$,;R%4!<%k$N8e$K%9%1%8%e!<%j%s%0$5lF7^$&$3HO$J$$!#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!<%k g_i $,<B9T2DG=$KJk$?$aKO!"F~NOJQ?t$N3F!9$K$D$$$F!"$=$lir=PNOJQ?tH9$k%4!<%k$N<B9T$,$9YF=*N;7F$$$lPh$$$3HKJk!#

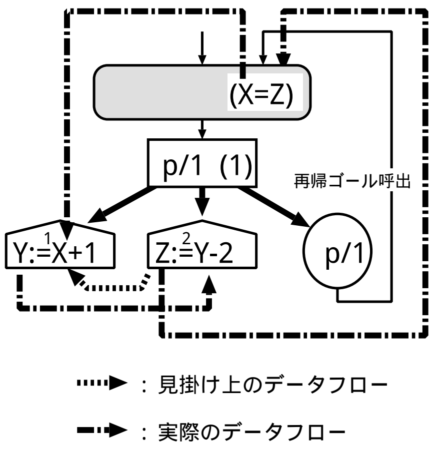
7+$7!"KL1 GNF10l2=$OBP>]$HJkJQ?t$N6qBNCM$rI,$:$7bI,MWH7J$$$?$a!"JQ?t4V$NO@M}E*$J%G!<%?$NN.l,9Y$F0MB8$KJkHO8BiJ$$!#7?$,$C$F!"<B9T>e!"??$KI,MW$J0MB8$r<1JL9kI,MW$,$"$k!#Nc$($P!"@0?t2C;;$r9T$&AH9~=R8l **add/3** $O!"F~NO0z?t$,6qBN2=5lk^$G<B9T$G$-$J$$!#7+$7!"JQ?tF1;N$NF10l2= **X=Y** $N>l9g$O!"**X** $+$i **Y** XN%G!<%?%U%m!<$,B8:_$7$F$$$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$$r9M$($k!#3N%b%G%kGO!"%4!<%k$N:F5"8F=P$Khj%0%i%UCf$K%k!<%W9=B$$,7A@.5l$k>l9g!"%k!<%W$NA0@BeG:nil$k%4!<%k$X$N0MB8$,F1@BeNF1L>%4!<%kXN0MB8$H6hJL$,D+$J$$$?$a!"8+3]$1>e!"Aj8_0MB8$HH=CG$5lk2DG=@-$,$"$k(?^7)!#$=3G!"g_i $N;R%4!<%k g_j KD$$$F!"g_j $, g_i $N@hAD%4!<%k$Gb"$k>l9g$K$O!"$3$N;R%4!<%k$H7F$N=P8=$r:F5"%4!<%k$H8F$V3HK7!"F10l2=Kh$k%G!<%?%Q%9$,3N:F5"%4!<%k$r7PM3$9k+H]$+$KhC$F!"%k!<%W$NF1@BeX$N0MB8$+I&$+$r6hJL9k!#

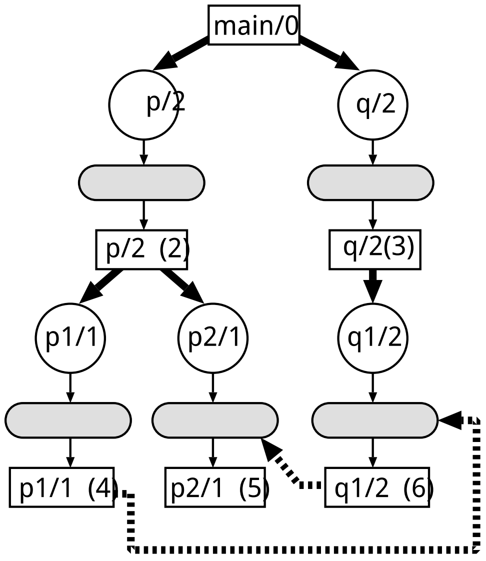
Nc$($P?^7NNcG$O!"**Z:=Y-2** $O**Y:=X+1** $K!"**Y:=X+1** $OA0@$Be$N**Z:=Y-2** $K0MB8$7F*$j!"8+3]$1>e!"FsDN%4!<%k$OAj8_0MB8$7$F$$$kh&$K8+$($k!#$7$+$7!"3N>l9g!"8e<T$N0MB8$O<!@BeKo?$k0MB8$G$"$k$?$a!"9MN8$9$kI,MWOJ$/[1]!"**Y:=X+1, Z:=Y-2** $N=g$K%9%1%8%e!<%k5l$k!#

$^$?!"%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!"2 K\$N%9%l%C%I$KJ,3d$5lF$7

`p(X) :- Y:=`^{1}`X+1,Z:=`^{2}`Y-2,p(Z)`^{1}`.`



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



?^8: 8+3]$1>e$NJB9T%W%m%0%i%`

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

$^$&3H$,$"$k! #Nc$($P! "?^ 8$NNcGO! "=>7;Do4X78K"$k%4! <%k$r4^a1$P! "

p/2 → p1/1 → q/2 → q1/1 → p2/1

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

7+$7! "$3$N8+3]$1>e$NJB9T@-$r2r>C9kh&$K%W%m%0%i%`$r=q$-D>$9$3$H$OMF0W$G$"$j! "<B:]K3$&$7$?5-=R$,$5$1k3Hb>/$J$$$H9M$($i1k! #5UK3$N@)8B$r@_1k3HKh$j! "2r@O$,4JC1KJ$k! "%9%?%C%/$rMQ$$$?8zN(E*$J<BAu$,G-$k! "$JINMxE@$,F@$i1k! #

2r@O<jK! K\<jK!GO! "0JA02f!$$,DsOF7?7?2r@O<jK! [12] $r3HD%$7! "8D!$NJQ?t$K$D$$$F0MB8%4! <%k>pJsIU$-$N7?2r@O$r9T$&! #3N>pJsKh$j! "6qBNCM$NINItJ,$,$I$N%4! <%k$K0MB8$7$F$$$k$+$,L@i+KJk?$a! "$=$NItJ,$r;2>H9k%4! <%k$N0MB8%4! <%k$bH=L@9k! #$3$1iN>pJs$+$i%4! <%k$N<B9T=g=x7hDj$N$?$a$N@)Ls>r7o$r5aak! #J$*! "U88%[12] $N<jK!$HF1MM! "K\<jK!$G07$&%W%m%0%i%`$O! "well-moded [13]! "$9Jo$AL7=b$7$J$$F~=PNOBN7O$r;}$A! "8_$$$K6%9g9kh&JCMN=PNO(6qBN2=)$,@8$8$J$$$bNH9k! #

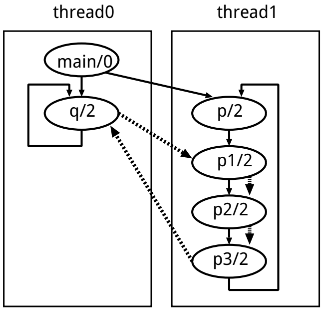
K\<jK!$G07;Do%4! <%k$N=g=x7hDjN_$r9T$&$?$a! "%4! <%k p_i $N<B9T$Khj%4! <%k $q_1, \ldots, q_m$ $,@8@.$5$1$kH-! "F1MM$K q_k $N4V$G<B9T=g=x$r7hDj$7! "$^$@<B9T$5$1$F$$$J$$ $p_j (j \neq i)$ c=$N;RB9%4! <%k$O! "q_k $*$hS=$N;RB9$,9Y$F=*$ok^$G<B9T$5$1$J$$! #7?$,$C$F! "@a C $N%\%G%#It $b_1, \ldots, b_m$ KD$$$F! "%\%G%#%4! <%k b_i, $b_j (i \neq j)$ 4V$N0MB84X78$K4pE-N><T$N=g=xIU$1$r9T$(Ph$$! #b_i, b_j $N;RB9%4! <%k$N=89g$r S_i, S_j H9kH! "b_i $,@h$K<B9T$5$1$?>19g! "$S_i$ $N<B9T$,9Y$F=*$ok^$G b_j $O<B9T$5$1$J$$$3HKJk! #7?$,$C$F! "$"$k $s_k \in S_i, s_l \in S_j$ KD$$$F b_j $+$i s_k KBP9$k0MB8! "$^$?$O s_l $+$i s_k XN0MB8$N$$$:1+$,B8:_$9$k>19g! "$b_i$ $O b_j hj@h$K<B9T$7J1$1PJiJ$$$H=DjG-$k! #$3$N@)Ls$r! "0J2<! "$prec(b_i, b_j)$ $H5-=R$9$k! #

%9%1%C%IJ,3d %3! <%I@8@.;~KO! "@EE*2r@OKh$k7;Do%4! <%k4V$N<B9T=g=x@)Ls $\{prec(b_i, b_j)\}$ $rK~$?9h$&$K! "3F@a$N%\%G%#%4! <%k$NJBSBX($r9T$$! "$=$N=g=x$G%4! <%k$rC`<!<B9T9k! #$?$@$7! "$prec(b_i, b_j)$ $+$D $prec(b_j, b_i)$ $N>19g$K$O! "$b_i$, b_j $*$hS=$N;RB9$N4V$KAj8_0MB8$,B8:_9kNG! "@EE*$K<B9T=g=x$r7hDjG-$J$$! #$=$3$G! "$b_j$ $O?7%9%1%C%I$N@hF,%4! <%kH7$F%9%1%8%e! <%k$5$1$k! #

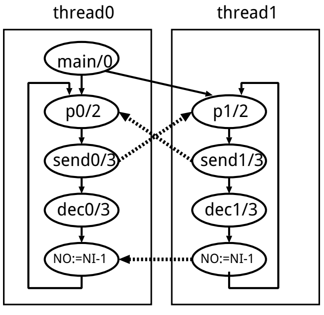
3.1.4 %9%1%C%I$N<B9T

$"$k%9%1%C%IFb$G i HVL\$K<B9T$5$1$k%4! <%k$r $goal_i$ $HI=5-$9k3HK9k$H! "$"$k%9%1%C%ICf$N%4! <%k $goal_i$ $N<B9T$K$*$$$F! "L$6qBN2=$NF~NO0z?t$,8=$1$?>19g$O! "$=$N0z?t$r6qBN2=$9kN$OB>%9%1%C%I$N%4! <%kG"$k! #$=3G! "%9%1%C%I<+BN$rCfCG$5$;$F! "$goal_j (j > i)$ $r%9%1%8%e! <%k$7$J$$$h$&$K7F$b! "%G%C%I%m%C%/$r@8$8$F7^$&$3HO$J$$! #0lJ}! "3Nh&K9k3HG! "$goal_i$ KG! <%?0MB8$9$kF10l%9%1%C%IFb$N8eB3%4! <%k $goal_j (j > i)$ $O $goal_i$ $,%j%8%e! <%`$5$1! "<B9T$5$1$k$^$G! "%9%1%8%e! <%k$5$1J/Jk! #$=$N7k2LH7$F! "%W%m%;%9;X8~J}<0$G@8$8$?! "CfCG%4! <%k$N=PNO$rBT$D%4! <%k$rL5>r7o$K%9%1%8%e! <%k$7F7$^$&! "$H$$$&LdBjE@$r! "B?$/$N>19g$KHr1k3H$,$G$-$k! #

Nc$($P! "?^ 5$N%W%m%0%i%`$G$O! "?^ 9.(a) Nh$&$K%9%1%C%I2=$5$1$k! #3N7k2L! "%4! <%kp1/2 $NCfCG$Othread1 A4BN$NCfCG$HJk$?$a! "p2/2, p3/2 $O%9%1%8%e! <%k$5$1$:$Kthread0 $K@)8f$,0\$j! "p2/2, p3/2 $rCfCG$9k3HJ$/<B9T$,9To1$k! #



(a) %W%m%0%i%`communication



(b) %W%m%0%i%`handshake

?^ 9: %9%1%C%I2=$5$1$?%W%m%0%i%`

$^$?! "K\<jK!GO$"$k%9%1%C%I$,<B9T$r3+;O9k$H! "F~NO0z?t$,$=$mCF$$$k8B$j! "%9%1%C%IFb$N%4! <%k$rC`<!E*$K<B9T$7! "%9%1%C%I$N@Z$jBX$($O9T$o$1$J$$! #$3$1$K$h$j! "%W%m%0%i%`$,%G%C%I%m%C%/7J$$$HO0$G@)8f$,0\9T9kNrcYi;k3H,G-! "resumption first $G5/$-$?LdBjE@$rB?$/$N>19gHr1k3H$,$G$-$k! #

Nc$($P! "?^ 6$N%W%m%0%i%`$O! "?^ 9.(b) Nh$&$K%9%1%C%I2=$5$1$k! #$3$N%9%1%C%I2=$KhC$F! "p0/2 $NCfCG8e! "@)8f$Othread1 $K0\$j! "%4! <%kp1/2 $+$i 'NO:=NI-1' $^$G$r%9%1%C%I$r@ZjBX(k3HJ$/<B9T$9$k! #$3N?$a! "p0/2 $,<!$K%9%1%8%e! <%k$5$1$?$H$-! "p0/2 NI,MWH9k%G! <%?O9YF6qBN2=:Q$_$G$"$k! #hC$F! "resumption first scheduling $G5/$-$?p0/2 GNIT40A4$J6qBN2=$KhkCfCG$OKI;_G-$F$$$k! #

%9%1%C%I@ZBX %9%1%C%I$N@Z$jBX$($r%9%1%C%I$NCfCG$*hS=*N;;~$^$G9ToJ$$$h$&$K9k$H! "%W%m%;%9;X8~$G@8$8$?@8@. ! &;2>H%W%m%;%94V$N%4! <%k(%9%1%C%I) $N@Z$jBX$($,CfCG$G9T$o1F7^$&$H$$$&LdBj$O2r7h$G$-$J$$! #

Nc$($P0E*$J%9%1%C%I$N%9%1%8%e! <%j%s%0<jK!H7$F! "%9%1%C%IC10L$Nresumption first scheduling J}<0$r:NM$7$?>19g$r9M$($F$_$k! #?^ 4NNcG$O! "p/2 $N<B9T$Gq/2 $,%j%8%e! <%`$5$1$F$b! "@Z$jBX$($r9To:! "p/2 $N<B9T$rB39T9k$?$a! "%W%m%;%9;X8~%9%1%8%e! <%j%s%0$N%9%1%8%e! <%j%s%0=g=x$HF1$8$KJCF7$^$&! #

3NLdBj$r2r7h$9k?aK$O! "%9%1%C%I$N<B9T$NESCf$G$"$CFb! "%9%1%C%I$r%a%C%;! <%8;X8~E*$K@ZjBX(kh$&$J5!9=$,I,MW$G$"$k! #3N@8@. ! &;2>H%W%m%;%94V$NCfCG$Khk@ZjBX($NIF6A$,:GbBg-$$$H9M$($i1kNO! "?^ 4Nh$&$K! "@8@. ! &;2>H%9%1%C%IFbK=1>1k! <%W9=B$$,B8:_$7! "$=$N%k! <%WFb$N%4! <%kF1;N$,%9%1%C%I4V$GDL?.$r9T$&>19gG"$k! #

hC$F:F5"8F=P$7;~$r%a%C%;! <%8;X8~E*$J%9%1%C%I$N@ZBX

$r9T$&%?%$%_%s%0$H$9%1$P! "3Nh&$JLdBj$rHr1k3H$,$G $-$k! #7+7J$,$i:F5"8F=P$7; ~$K>o$K%a%C; ! <%8; X8~E*$J%9 %1%C%I$N@ZBX$r5v7F7^$&$H! "; 2>HB&$,I,MW$H9k$G! <%?$r %k! <%W$rMQ$$$F@8@.9k>1[9]g[2] ! "9=B$%G! <%?$N:G30B&NCM,6q BN2=$5$1$?CJ3,$G! "%9%1%C%I$N@ZBX$,5/$-$F7^$$! "IT4 0A4$J %a%C; ! <%8$Khk%9%1%C%I$N@Z$jBX$($,IQH/7F7^$&! #$7$? $,$C$F8zN($N$h$$%9%1%C%I@ZBX$r9T$&$?$aKO! "$"$k:F5"8F=P 7G$O@ZBX$r9T$$$! "UL$N:F5"8F=P$7GO@ZBX$r9T$o$J$$$h$&$K 7J$1$1PJiJ$$! #

$3$3$G! "$"$k%9%1%C%IFb$N%k! <%W9=BCfNJQ?t$r! "

1. $=$N%k! <%WCf$G6qBN2=$,9To1! "7+$bB>$N%9%1%C%I$,; 2 >H$9$kJQ?t
2. B>$N%9%1%C%I$G6qBN2=$,9T$o$1! "$=$N%k! <%WFb$G; 2>H9k JQ?t
3. 1, 2 0J3 0$NJQ?t

$N3 DKJ,N`$9$k$H! "1$NJQ?t$,B8:_$7$J$$>1[9]g$O! "$=$N %k! <%W$N<B9T$K$h$C$F%j%8%e! <%`$5$1$k%9%1%C%I$OB8:_7J$$ $?$a%9%1%C%I$r@ZBX$kI,MWOJ$$! #0 1J} 2$NJQ?t$,B8:_9k>1 9g$O! "2$NJQ?t$r; 2>H$7$F%9%1%C%I$,CfCG7F7^$&2DG=@-$, $"$k! #5U$r$$ ($P 2$,B8:_7J$$>1[9]g$O! "$=$N%k! <%W$N<B9TCf K=$N%9%1%C%I$,CfCG7F7^$&$3HO$J$$! #

7?$,$C$F! "3$NJQ?t$O%9%1%C%I$N%5%9%Z%s%I! "%j%8%e! <%` $K4XM?$7$J$$$3Hr9M$($k$H! "1, 2$NJQ?t$,$,Hb$KB8:_$9$k >1[9]g$N$_! "%a%C; ! <%8; X8~E*$K%9%1%C%I$r@ZBX$1Ph$$$3H, o+$k! #

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

3.2.1 reply first scheduling <jK!$N35MW

KL1 $N%4! <%k%9%1%8%e! <%j%s%0H7$F%9%1%C%I2=<jK!$rMQ$$$k 3H$G! "UBNs<B9TC10 1$NN3EY$,Bg$-/Jk! #$3$1$O! "%W%m%0%i % `$NJB9T@-@)8f$N%*! <%P%X%C%I$r>.$5$/$9$kH?LL! "%W%m%0%i%` $N; }$DJBNs@-$rDc2<$5$; F7$^$&LdBj$,$"$k! #F<$K! "B>%N! <%I $+$i$NJVEz$rBTCFCfCG7?%9%1%C%I$,BT$?$5$1k3HKhk F0E*$JJBNs@-$ND c2<$,@-G=$KM?$($k1F6A$O! "%9%1%C%I2=$r9T$& 3H$G! "=>Mh$NbNhjbBg-JbNKJCF7$^$&! #

Nc$($P! "$"$k%N! <%I N_c >e$N%9%1%C%I T_c $,B>$N%N! <%I N_p $K BP$7$F%a%C; ! <%8$NMW5a$r=P$7$?>1[9]g$r9M$($F$_$k! #3N>1[9]g T_c $OMW5a$7$?%G! <%?$,E~Ce9k$^$GCfCG9k$,! "$3NH$-$N_c$ $K<B9T2DG=$J%9%1%C%I$,B8:_$7$J$$$H! "%N! <%I N_c $O%"%$%I%k >uBVKJCF7^$&! #$3$1$,! "%W%m%0%i%`$NJBNs@-$,Dc2<7? >uBVG"$k! #$3$NIF6A$r:G>.8B$K2!$5$($k$?$aKO! "%G! <%?MW 5a%a%C; ! <%8KBP9$kJV?.$O2DG=$J8B$jAa$/9T$&I,MW$,$"$k! #

7+$7! "=>Mh$N%4! <%k ! &%9%1%8%e! <%j%s%0J}K!GO! "MW5a %G! <%?$r@8@.$9$k%4! <%k$,M%@h$5$1kh$&$J5 !9=$,$J$$$?$a! " MW5a%a%C; ! <%8$KBP9k1~Ez@-$O0J]>Z$5$1$J$$! #3NLdBj$O%9 %1%8%e! <%j%s%0C10 1$NBg$-$$%9%1%C%I ! &%9%1%8%e! <%j%s%0GO ?<9oG"$j! "MW5a%G! <%?$N@8@.$KL54X78$+$D<B9T; ~4V$ND9$$%9 %1%C%I$,%9%1%8%e! <%j%s%0$5$1$F7^$&$H! "N_c $N%"%$%I%k; ~4V $,Hs>o$KD9$/$J$k2DG=@-$,$"$k! #

$=$3$GK\8&5f$G$O! "CfCG%9%1%C%I$KMW5a$5$1$?%G! <%?$rJV?. 9k$?$aKI,MWJ6qBN2=$dF10 12=$r9T$&%9%1%C%I$rM%@hE*$K%9 %1%8%e! <%j%s%0$9$kreply 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%1%C%I$,L$6qBN2=JQ?t$X$N; 2>H$GCfCG7? j7$?>1[9]g! "3 :Ev%G! <%?$r6qBN2=9k%9%1%C%I$r%9%1%8%e! <%j

$%s%0$9$k! #$3$1$Khj! "UBNs<B9TK*$$$F%G! <%?MW5aXN1~Ez @-$,8~>e$7! "UBNs@-$r0z$-=P$9$3H,G-$k! #$^$?! "1 %N! <%I >e$N<B9T$K4X$7Fb! "4X78N"$k%9%1%C%I$,%9%1%8%e! <%j%s%0 $5$1k?$a! "FHN)@-$N9b$$=hM}$,J#?t$"$k>1[9]g$O! "8D!9$r=gHV $K=hM}$9k3HKhC$F%a%b%j$N; HMQ8zN($r2~A1$9k3H,$G $-$k! #

3NJ}<0$r<B8=$9kK$O! "%9%1%C%I4V$K$^$?$,$C$F; 2>H! &6q BN2=$5$1$kJQ?tKD$$$F! "IN%9%1%C%I$,6qBN2=$r9T$&$N$+$r CN$kI,MW$,$"$k! #KL1 %W%m%0%i%`GO$b! <%I?dO@[13] [14] $r 9T$&3HKhCF! "$"$kJQ?t X $N6qBNCM$r@8@.9k2DG=@-N" $k%4! <%k$rFCD jG-$k! #$hCF%9%1%C%I T_{susp} $,L$6qBN2=JQ?t X KhCFCfCG7?>1[9]g! "3N2r@O>pJsKh$j X $r6qBN2=$9 $k2DG=@-$N$"$k%9%1%C%I T_{unify} $rFCD j$9k3H,2DG=G"$k! # KL1 GO X $,6qBN2=$5$1$kNO 1 EY$@$,! "<B9T%Q%9KhCF $O! "$X$ $r6qBN2=$9$k%9%1%C%I$,0 [Jk2DG=@-$,$"$k! #$3N?$a! " @EE*$K$O T_{unify} $r0 10 U$KD jak3HOG$-$J$$! #$=$3$GK\<jK! GO! "3N@EE*2r@O>pJs$rMxMQ$7! "<B9T; ~$KF0E*$K7hD j$5$1$k ItJ,$rDI@W9k5 !9=$r@8@.$3! <%ICfKAH_9~$`$3HG! "3N%9 %1%8%e! <%j%s%0J}<0$r<B8=$9$k! #

0J8e! "K\@aGOreply first scheduling $N<B8=$KI,MW$J2r@O >pJs$K$D$$$F=RY?NA! "$=$N2r@O>pJs$rMQ$$$F<B:]$K%9%1%C %I$,INh&$K%9%1%8%e! <%j%s%0$5$1$k$+$K$D$$$F=RYk! #

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

K\<jK!GO! "KL1 $NJQ?t$r%9%1%C%I4V$N6&M-JQ?t$HHs6&M-JQ?t $K6hJL$9$k! #Hs6&M-JQ?t$O; 2>H%9%1%C%IFb$G6qBN2=$5$1$k$+$i! " ; 2>H; ~KO6qBN2=: QG"k3H,J]>Z$5$1$k! #$7$?$,CF! "6& M-JQ?tN_$r9MN8$9$1$P$h$$! #

reply first scheduling $r9T$&KO! "L$6qBN2=JQ?t$X$N; 2>H $,5/$-$?:]$K! "$3$1$r6qBN2=$9$k%9%1%C%I$N>pJs$,I,MW$KJk! # K\<jK!GO0MB82r@O$GF@$i1k>pJsN&$A! "%b! <%I2r@O[13] $K hjF@i1$k>pJs$rMxMQ9k! #

%b! <%I2r@OKh$j! "$"$k@a$K$*$1$k%\%G%#%4! <%k g_i $N0z?t $,=PNO/F~NO$N$$$:1G$"$k$+$,7hD jG-$k! #$3$3$G! "g_i $N0z?t N&$A! "g_i $^$?$O g_i $N%5%V%4! <%k$,6qBNCM$^$?$OB>$NF~NO0z?t HNF10 12=$r9T$&h&$J0z?t$r=PNO0z?t$HD j5A$9$k! #

0J2<GO! "reply first scheduling $r<B8=$9k?aK! "IN h&$K%b! <%I?dO@$KhjF@i1$k>pJs$rMxMQ9k$+$K$D$$$F=R Yk! #

%b! <%I?dO@ $^$:%b! <%I?dO@KD$$$F4JC1$K=R$Y$k! #%b! <%I?d O@$K$D$$$F$N>\$7$$@bL@$O; 29MJ88%[13] Ey$r; 2>H$5$1$?$$! #

well-moded $J%W%m%0%i%`$K$*$1$k%b! <%I?dO@$N%a%$%s%"%k %4%j%:%`$O! "

1. 1 DN@aFbG"$kJQ?t$,$"$k%4! <%k$N=PNO$J$i! "$=$NJQ?t $r6&M-$7$F$$$kB>$N%4! <%k$G$OF~NO$G$"$k! #
2. 1 DN@aFbG"$kJQ?t$,0 1Dr= |$$$?A4FN%4! <%k$GF~NO Ji! "; DjN0 1DN%4! <%kGO=PNOG"$k! #

G"$k! #Nc$($P! "

`p(X,Y):- q(X,Y),r(Y,Z),...`

Nh$&$J@a$G! "q/2 $NBh0 10 z?t$NX $,F~NO$GBhFs0z?t$NY $,=P NO$H?dO@$5$1$?>1[9]g! "r/1 $NBh0 10 z?t Y $OF~NO$H?dO@$5$1$k! # %b! <%I?dO@$G$O! "%X%C%I$b%\%G%#%4! <%k$HEy2A$K07$&$?$a! "p/2 $NBh0 10 z?t X $O=PNO! "BhFs0z?t Y $OF~NO$H?dO@$5$1$k! #$3$1$O! " p/2 $N8F=P$7B&K*1k0z?t$N%b! <%I$HOAg&$IH?BP$KJC $F$$$k! #

---

[2] D9$5 n $N%j%9%H$r@8@.9k>1[9]gJI$,$3NNcK$"$?$j! "KL1 GOI QHK$K8=1k

3Nh&$Kwell-moded KL1 %W%m%0%i%`$G$O!"0l$D$N@a$K$*$$$F!"$"$kJQ?t $X$ $N=PNO=P8=$O0l$D$7$+$J$$!#$3$N$?$a!"%4!<%k $g$ $,$X$ $r=PNO0z?t$H$7$F;}$D$H$-!"$=$N%W%m%0%i%`$G!"B>$K X $r=PNO0z?t$H7F;}$D%4!<%k$O g $ND>@\$N@hAD $g_{p1}, \cdots, g_{pn}$ $^$?$O!"$g$ $N;RB9 $g_{c1}, \cdots, g_{cm}$ $K8B$ilk!#g $,@8@.$5lF$$$k>l9g$O!"$g_{pi}$ $N<B9T$O=*N;7F$*$j!"g_{ci} $O g $,<B9T$5lk$^$G@8@.5l$J$$!#3N$?$a!"$=$N;~E@$KB8:_$9$k%4!<%k$N$&$A!"X $r=PNO0z?t$K;}$D%4!<%k$O g $M#0l$D7+B8:_7J$$!#

0J>eN3H+$i!"reply first scheduling $r<B8=$9kK$O!"L$6qBN2=$N6&M-JQ?t$KBP9k;2>H$^$?$OFI=PMW5a<u?.;~$K!"$=$N;~E@G=$N6&M-JQ?t$r=PNO0z?tH7$F;}$D%4!<%k$r4^$`%9%l%C%I$r%9%1%8%e!<%k$7FdlPNI$$$3H,J,$+$k!#

3.2.3 reply first scheduling Kh$k%9%l%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%l%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$5lk%9%l%C%I$r ***reply thread*** $H8F$V!#$^$?!"$"$k;~E@$G<B9T$5lF$$$k%9%l%C%Ir=$N;~E@$N ***active thread*** $H8F$V!#

0lC6 *reply thread* HJC?%9%l%C%I$OMW5a$KBP9kJV?.KI,MWJ%4!<%k$r<B9T$9k^$G!"B>$N<B9T2DG=$J%9%l%C%I$KBP7FM%@hE*$K%9%1%8%e!<%k$5$l!"JV?.$KI,MW$J%4!<%k$N<B9T$,=*N;$9kH!"0J8e$ODL>o$N%9%1%8%e!<%j%s%0=g=x$K=>$&!#0J2<GO3Nh&$J!"L$6qBN2=JQ?t X KBP9$kFI=PMW5a $(read)$ <u?.8e$K X $NJV?.$r9T$&$^GN%9%l%C%I!&%9%1%8%e!<%j%s%0$r $read$ KBP9$k **reply first scheduling** $^$?$O X KBP9$k **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!#

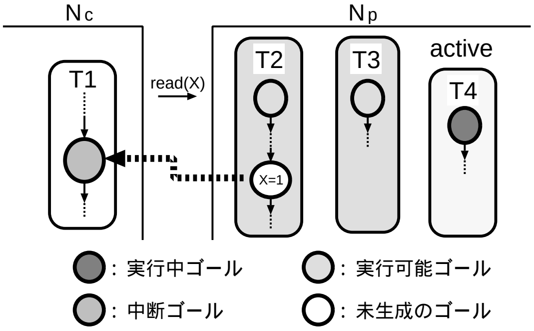
7+7J$,$i KL1 GO!"<B9T;~$KF1L>%4!<%k$,J#?t@8@.5l$?$j!";~9oKhCF$=$NJQ?t$r=PNO$KbD%4!<%k$,JQ2=$9k?$a!"%3%s%Q%$%k;~$K6&M-JQ?t$KBP7F%9%l%C%IXN%]%$%s%?$rJ];}5;k3HOG-$J$$!#$=$3$G *reply thread* $NF0E*$JJQ2=$KBP1~$9k?aK!"K\<jK!GO6&M-JQ?t@8@.;~$K6qBN2=$r9T$&%4!<%k$r4^$`%9%l%C%I (6qBN2=%9%l%C%I) XN%]%$%s%?$rJ];}5;F*$-!"6qBN2=%9%l%C%I$,JQ2=9k>l9g$O!"%]%$%s%?$rF0E*$KJQ99$5$;$kJ}K!$r<h$k!#

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

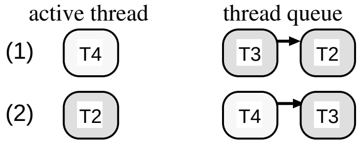
C1=c$J>l9g ?^ 10$Nh&$J>l9g$r9M$($F$_$k!#?^$N (a) $O read(X) <u?.;~$N>uBV$rI=$7!"(b) O=$l0J8e$N%9%1%8%e!<%j%s%0=g=x$rI=$7$F$$$k!#read(X) $O X KBP9$kFI=PMW5a$r<($9!#0J2<=g$rDICF@bL@9k!#%N!<%I N_p B&$O%N!<%I N_c $+$i$N read(X) $r<u?.$9$k (?^ 10.(b).(1)) $H!"X $N6qBN2=%4!<%k$r4^$`%9%l%C%I T2 $, *active thread* H7$F%9%1%8%e!<%k5l!"*read(X)* KBP9$kreply first scheduling $r9T$&!#3lKhCF!"read(X) KBP9$kJV?.$,M%@hE*$K9T$olk3HKJ$j!"%N!<%I4V$NJBNs@-$NDc2<$r:G>.8B$K2!$5$($k3H$,$G$-$k!#

3NNcGO!"*reply thread* $,F0E*$KJQ2=9k3H$,$J$+$C$?$,!"

1. *reply thread* $,JV?.A0$KCfCG9k>l9g!#
2. <B:]$KJV?.$r9T$&%9%l%C%I$,L$@8@.$N>l9g!"
3. 6qBNCM$NJV?.$N$?$a$KJ#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>l9g



(a)プログラム例



(b)スケジューリング順序

?^ 10: reply first scheduling

$N>l9g$K$O!"F0E*$K *reply thread* $,JQ2=$9$k!#0J2<$GO"$kJQ?t X KBP9$kFI=PMW5a$r $read(X)$!"3lKhCF *reply thread* H7$F%9%1%8%e!<%k$5lk%9%l%C%I$r T_X $HI=$9$3$HK7!">e5-N=l>$l>l9g$K$D$$$F@bL@9k!#

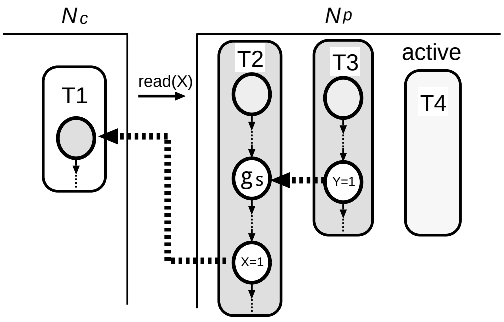
1. JV?.A0$KCfCG$9$k>l9g$N=hM} FI=PMW5a $read(X)$ KhCF *reply thread* H7$F%9%1%8%e!<%k$5l? T_X $,!"JV?.$r9T$&A0$K!"L$6qBN2=JQ?t (Y) KBP9$k;2>HKhCFCfCG9k>l9g$r9M$(F_$k!#JV?.$r2DG=$J8BjAa/9T$&$?aK$O!"T_X $r%j%8%e!<%`$9$k%9%l%C%I$rM%@hE*$K%9%1%8%e!<%k$7$F$d$kI,MW$,$"$k!#$3$N$H$- $X$ $r6qBN2=$9$k%9%l%C%I $T_Y$ $,<+%N!<%IFb$KB8:_$9$k>l9g$O!"$3$N%9%l%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!":F$S T_X $,M%@hE*$K%9%1%8%e!<%k5lk3HKJk!#

3N Y XN;2>H$r T_X $,F10l%N!<%IFb$N%9%l%C%IG"$k T_Y KBP7$F%G!<%?$N@8@.MW5a$r=P7F$$$k$H9M$(!"T_Y Kh$k Y $N6qBN2=$r3NMW5aKBP9$kJV?.$H9M$($k$H!"$3li$N>l9g$b Y KBP9$kreply first scheduling $r9T$C$F$$$k$H$$$($k!#$D$^$jK\<jK!GO!"B>%N!<%I$+$i$NFI=PMW5a<u?.;~$H<+%N!<%IFb$K6qBN2=%9%l%C%I$,B8:_9k6&M-JQ?tKBP9$k;2>H;~$Kreply first scheduling $r9T$&!#

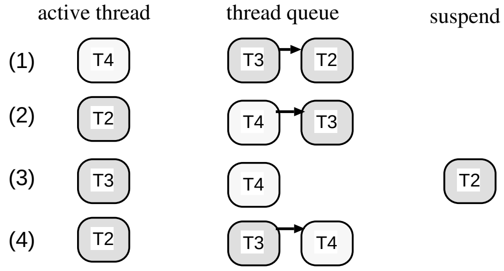
0lJ}!"Y $r6qBN2=$9$k%9%l%C%I$,B>%N!<%I$KB8:_$9$k>l9g$O!"B>%N!<%IKBP7%G!<%?$N@8@.MW5a$r=P$7!"$T_X$ $O<B9T$rCfCG9k!#3N;~E@$G!"$read(X)$ KBP9$kreply first scheduling $O0lC6CfCG$5$l!"DL>o$N%9%1%8%e!<%j%s%0KLak!#$=$N8e!"JV?.(Y $N6qBNCM) $r<u?.$7!"T_X $,%j%8%e!<%`$5lk$H!"$read(X)$ KBP9$kreply first scheduling $r:F3+$7!"0J8e T_X $O!"M%@hE*$K%9%1%8%e!<%k5lk3HKJk!#

$^$?!"$read(X)$ <u?.;~$K T_X $,B>%N!<%I$G6qBN2=5l$kJQ?t$KBP7FCfCG7F$$$k>l9g$O!"$read(X)$ KBP9$kreply first scheduling $r9T$&3HOG$-$J$$!#3N>l9g$O!"B>%N!<%I$+iNJV?.KhCF T_X $,%j%8%e!<%`$5l?;~$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 NNcG$O%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%l%C%I T2 $, *active thread* H7$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

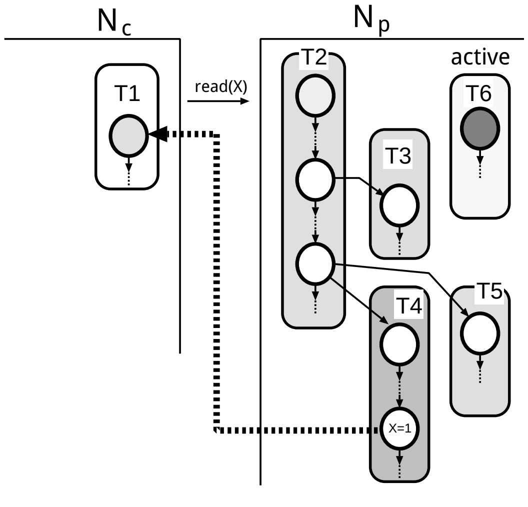
$=$N8e%4!<%k g_s $r<B9T$7h&H7$F!"L$6qBN2=JQ?t Y $r;2>H $7!"T2 $O<B9T$rCfCG9k!#3NH-!"Y $N6qBN2=%4!<%k('Y=1') $r;}$D%9%1%C%IT3 $,M%@hE*$K *active thread* H7$F%9%1%8%e!< %k$5$1$k(?^11.(b).(3))!#$=$7$F!"Y=1' $N<B9T$Khj!"Y $,6q BN2=$5$1$?8e$G!"%9%1%C%I$N@ZjBX(%?%$%_%s%0$,MhkH!"%j %8%e!<%'$5$1$?T2 $, *active thread* H7$F!"%9%1%8%e!<%k$5$1 $k(?^11.(b).(4))!#

2. JV?.$r9T$&%9%1%C%I$,L$@8@.$N>l9g$N=hM} MW5a%G!<%?X $r6qBN2=$7!"MW5aKBP7$FJV?.$r9T$&%4!<%k g_b $r4^$`%9%1%C%I T_b $,L$@8@.G"$k>l9g!"$=$N%N!<%IFb$K$O T_b $N@hAD%9%1%C%I $T_{ancester_b}$ $,I,$:B8:_$7!"$7$+$b$=$N%9%1%C%I$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%1%C%I T_b $,@8@.$5$1$?;~ $K!"*reply thread* $r T_b $K@Z$jBX$($F!"T_b $rM%@hE*$K%9%1%8%e!< %k9kh&K9$1$P$h$$!#

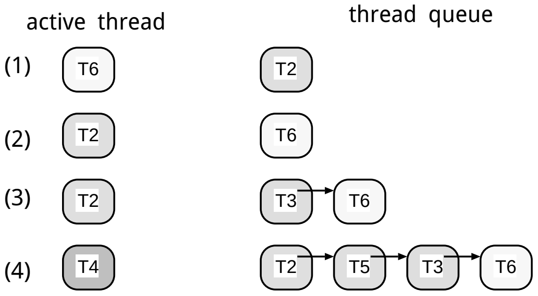
?^12NNcG$O!"%9%1%C%I T1 $+$i$NFI=PMW5a read(X) $r <u?.$7$?;~(?^12.(b).(1)) KO!"X $N6qBN2CM$r@8@.9k%9%1%C %IT4 $O:n@.$5$1$F$*$i$:!"%9%1%8%e!<%k$9k3H,G-$J$$!# hC$FT4 $N@hAD%9%1%C%I$G$"$kT2 $r!"*active thread* H7$F%9 %1%8%e!<%k9k(?^12.(b).(2))!#$=$N8eT2 $N<B9T$G$^$:T3 $, @8@.$5$1$k$,!"$3$1$CMW5a$5$1$?6&M-JQ?t$r=PNO0z?tH7$F;} $?$J$$$?$a!"*active thread* $OT2 N^$^G"$k(?^12.(b).(3))!# $=$7$FT4,T5 $,@8@.$5$1$k$H!"*active thread* $rT4 $K@Z$jBX$($F<B9T$r7QB3$9$k(?^12.(b).(4))!#

3. J#?t$NF1012=%4!<%k$N<B9T$,I,MW$J>l9g $"$kJQ?t X $KBP 9kFI=PMW5aXNJV?.$r9T$&$?aK!"01DN6qBN2=%4!<%k g_b $H!"$n$ 8D$NJQ?tF1;N$NF1012=$(= /2_1, \cdots, = /2_n)$ $,I,MW$J>l9g $r9M$(F_$k!#$^$?!"$3$1$i$N%4!<%k$r01DG$b4^$`%9%1%C%I $r $T_{r_1}, \cdots, T_{r_m}$ H9$k!#

JQ?tF1;N$NF1012=$O!"N><T$,$HbKL$6qBN2=$G$b<B9T2DG=$G $"$kNG!"$T_{r_1}, \cdots, T_{r_n}$ $rG!2?$J$k=g=x$G<B9T7Fbh$$!#hC $F!"$3$N>l9g$K9To1$k=hM}$O<!NDLjG"$k!#



(a)プログラム例



(b)スケジューリング順序

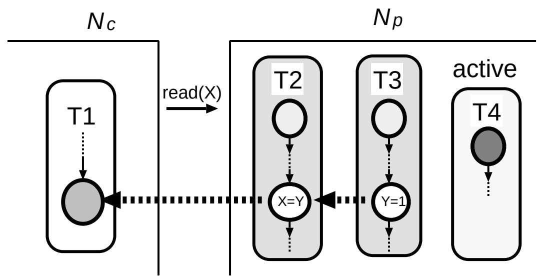
?^12: JV?.$r9T$&%9%1%C%I$,L$@8@.$N>l9g$N=hM}

1. $"$k T_{r_i} KBP7$F!"$T_{r_i}$ $K4^$^1k 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$($FF1MM$N=hM}$r9T$&!#
3. 9YFN T_{r_k} $N *reply thread* H7FN<B9T$,=*N;$7$?$H$- $K!"JV?.$,9To1$k!#

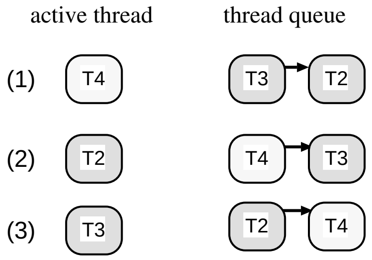
K\<jK!GO X $r=PNO0z?t$K;}$D%9%1%C%I$r1$^$:!"*reply thread* H7$F%9%1%8%e!<%k$9$k!#$=$N8e!"$X$ HL6qBN2=$NF~NO0z?t Y HNF1012=$,9T$o1k$H!"*reply thread* $r Y $r=PNO0z?t$K;}$D %9%1%C%I$K$r@Z$jBX$($k!#0J2<3N=hM}$,!"6qBN2=%4!<%k$N<B 9T$^$?$O6qBN2=$5$1$F$$kF~NO0z?tHNF1012=$r9T$&$^$GB3$1 i1$k!#

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

3NNcGOT1 $+$i$NFI=PMW5a$NE~Ce(?^13.(b).(1)) $K hC$F!"$=$N;~X $HB>$NF~NO0z?tHNF1012=%4!<%k(X=Y) $r 4^$`%9%1%C%IT2 $r *active thread* $H$7$F%9%1%8%e!<%k$9$k(?^ 13.(b).(2))!#$=$7$F!"X $,Y $,F1012=$5$1$k$H!"Y $r6qBN2=$9 $k%4!<%k%4!<%k(Y=1) $r4^$`%9%1%C%I$,<!$Nreply thread HJ $j(?^13.(b).(1))!"Y $r1 $K6qBN2=$9$k!#$3$N6qBN2=$KhC$F X $,1 $K6qBN2=$5$1!"T1 KBP7$FX $N6qBN2CM$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!<%I N_p $G!"$"$kFI=PMW5a $read_0$ KBP9$kreply first schedluing $r9T$C$F$$$k:GCf$K!"JL$NFI=PMW5a $read_1, \cdots, read_n$ $,$3$N=g$G!"%N!<%I N_p $KE~Ce$9$k>l9g$r9M$($F$_$k!#3NH-K\<jK!GO!" $read_i$ KBP9$kreply first scheduling $N=*N;(6qBNCM$NJV?.) b7$/$OCfCG(B>%N!<%I$N%9%l%C%I$K%G!<%?0MB8) NNAK!" $read_{i+1}$ KBP9$kreply first scheduling $r9T$&!#3N;~!" $read_{i+1}$ KBP9$kJV?.$,9TolF7$^$C$F$$$?>l9g$O!" $read_{i+2}$ KBP9$k=hM}$r9T$&!#

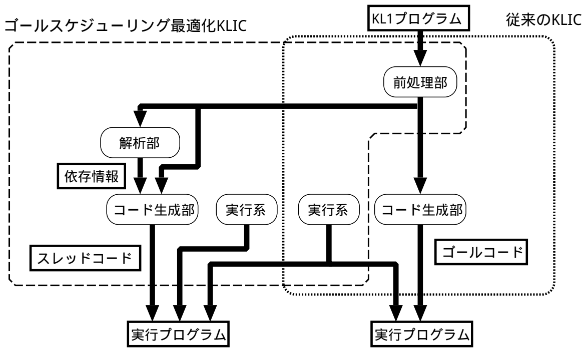
$^$?!"*reply thread* G"$k T_{r_i} $NCfCG$KhC$F!" $read_i$ KBP9$kreply first scheduling $,CfCG$7!"B>%N!<%I$+$i$N6qBNCM$NJV?.$d!"JL$N%9%l%C%I$N<B9T$KhC$F T_{r_i} $,%j%8%e!<%`$5l?>l9g!"3N $read_i$ KBP9$kreply first scheduling $N:F3+$O!"$=$NH-B8:_9kA4FNFI=PMW5aKBP9$kreply first scheduling $,=*N;$b7/$OCfCG$7$?8e$G9Tol$k!#

%9%l%C%I@ZBX$N%?%$%_%s%0　reply first scheduling K*$$$$FM%@hE*$K%9%1%8%e!<%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%8%e!<%`7?>l9g
4. JV?.<u?.;~

G"$k!#1$d!"3$G%j%8%e!<%`$5lk%9%l%C%I$,B>%N!<%I$KBP9kJV?.$K4XM?$7$J$$>l9g$O!"=>Mh$N@ZBX%?%$%_%s%0$G%9%l%C%I$r@Z$jBX$($F$bJBNs@-$,Dc2<9k3HOJ$$!#

0lJ}1$d!"3$G%j%8%e!<%`5l$k%9%l%C%I$,B>%N!<%IKBP9$kJV?.$K4XM?9k>l9g$K!"=>Mh$N%?%$%_%s%0$G%9%l%C%I$N@Z$jBX$($r9T$&$H!"JBNs@-$NDc2<$N1F6A$,Bg$-$/$J$k>l9g$,$"$k!#1, 3$N;~$K<B9TCf$N%9%l%C%I$,Hs>oKBg-$/!"$7$+$bD9;~4VCfCGJ7$G<B9T$G$-$k>l9g$,$3lK$"$?$j!"$3NH$-M%@hE*$K%9%1%8%e!<%k9kY-%9%l%C%I$,%9%1%8%e!<%k$5lkN,BgI}KCYlF7$^$$!"reply first scheduling $N8z2L$,GJ$$!#



?^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$K$*$$$FG"$k!#0lJ}Z $N@8@.%4!<%k$Oq/1 G"$j!"reply first scheduling $r9T$&$?$aKO!"(2) @a$N<B9T;~$Kq/1 XN%]%$%s%?$,I,MWG"$k!#$7$+$7J,$i!"DL>o(2) @a$N<B9T;~$K%]%$%s%?$,H=L@$9$k%9%l%C%I$O!"<B9TCf$N%9%l%C%I$H(2) @a$G?7$?$K@8@.$5lk%9%l%C%IN_G"$k!#$3N?$a!"@EE*$Kq/1 XN%]%$%s%?$r6&M-JQ?t$KJ];}$5$;$kI,MW$,$"k,!"3l$O0lHL$K$OIT2DG=[3] G"$k!#0lHL$K3Nh&$J>u67$O!"9=B$%G!<%?$NFbIt%G!<%?$,$=$N=P8=$G=PNOG"$k>l9g$K5/3k!#3N$?$aK\<jK!GO!"3Nh&$J>l9gKOreply first scheduling $r9T$o$J$$$bNH9k!#

4 <BAu

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

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

%4!<%k!&%9%1%8%e!<%j%s%0:GE,2=KLIC $O!"A0=hM}It$H2r@OIt$H%3!<%I@8@.It$+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%$%iIt$O!"4{B8$NKLIC %3%s%Q%$%i$N0lIt$N7AGAH_9~$^$l$k!#

2r@OIt$OA0=hM}8e$N%W%m%0%i%`$r<u<h$j!"6qBN2=%4!<%k>pJs$rIU2C$7$?7?2r@O$r9T$$!"JQ?t$N7?>pJs$*hS%4!<%k4V$N%G!<%?0MB8>pJs$rCj=P9k!#<BAu>eO[Hs$IFHN)$7$?%b%8%e!<%k

---

[3] 40A4$J2r@O$r9T$&$3HG2DG=KJk+b7lJ$$$,!"2r@O$N%3%9%H$H<B9T;~$N%3%9%H$r9M$($k$H8=<BE*$GOJ$$

HJ$j!"4{B8 KLIC $GA0=hM}$,=*oC$?%W%m%0%i%`$r<u$1<h$j!"2r@O>pJs$rIU2C$7$?%W%m%0%i%`$r=PNO9k!#$3$1$O:#8e$N KLIC $N2~NI$KBP1~7d9/9k$HF1;~$K!"B>$N:GE,2=$rJ;MQ9k>19g$K!"2r@OI t$N3HD%$rMF0W$K9k$?$aG"$k!#

%3!<%I@8@.It$O%3%s%Q%$%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$H7F9T$&!#

<B9T7O$OKLIC %i%s%?%$%`!&%7%F%`$NO1lIt$H7FAH$_9~$^$1!"@8@.$5$1$?J#?t$N%9%l%C%I$NJB9T<B9T$*$h$S4IM}$r9T$&!#3F%9%l%C%I$O=>Mh$N=hM}7O$K$*$1$k%4!<%k$HF1MM!"%9%l%C%I$N<B9T4D6-$r3JG<7?%1%3!<%I(%9%l%C%I%1%3!<%I) $rMQ$$$F!"4IM}$5$1$k!#$^$?!"%9%l%C%IFb$N<B9T4D6-$O!"3F%9%l%C%I$K$=$l$>$lFHN)7?%9%?%C%/$r;}$?$;$k3H$G!"%4!<%k$N@ZBX$*!<%P%X%C%I$N8:>/$d!"%R!<%WNN0h$N8zN(E*$J;HMQ$r<B8=9k!#<BAu$O!"$3$1$iK\<jK!$G?7$?KI,MWJbNN_$rBP>]$H$7!"$=$10J30$NItJ,$O4{B8$NbNr=N^^MxMQ9$k7A$G9T$&!#$3N?$a!"%8%"%M%j%C%/!&%*%V%8%"%/%HJI4{$K:n@.$5$1$?%f!<%6Dj5A%b%8%e!<%k$rJQ99$9kI,MWO$[$HsI$J$$!#

4.2 %3%s%Q%$%iIt

%3%s%Q%$%iIt$G9To1$k=hM}$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=$5$1$?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@i1$kC %3!<%I$O!"%i%s%?%$%`%i%$%V%i%j$N0lIt$G$"$k=hM}7O3K$+$ihP$1!"%f!<%6Dj5A=R8l$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%`$N%G!<%?0MB82r@O$r9T$$!"$=$N7k2IF@$i$1$?>pJs$rMQ$$!"%W%m%0%i%`$N%9%l%C%I2=$r9T$&!#

$"$k@aCN%\%G%#%4!<%k($B = \{b_1, \cdots, b_n\}$) $rAPJ}8~$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$7!"$=$1$>$1NCfG$N<B9T=g=x$r@EE*$K7hDj$9$k!#

3F=89gNCfG:G$bMWA$G$NB?$$bN,!"8F=P$7B&$4!<%k$HF10l%9%l%C%I$K%9%l%8%e!<%k$5$1!"$prec(b_{i_m}, b_{i_n})$ $rK~$?9h$&$K!"$=$N@a$N@hF,$+$i=g$KJBYBX(i1$k!#B3$$$F!"UL=89g$,?7%9%l%C%I$H7F%9%l%8%e!<%k$5$1!"$=$N=89gFb$G<B9T=g=x@)Ls$r$_$?9h$&$KJBY+$($i$1!"$=$N@hF,$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!<%?0MB8$,B8:_$9kH$-!"

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

Nh$&$J=PNO$,F@$i1k!#

$^$?!"@node IU$-%4!<%k$O@DI>cB>%N!<%I$G<B9T$9$k%4!<%k$G$"$kNG!"F10l@aFb$NB>$N%4!<%kHN0MB8HOL54X78$K?7%9%l%C%I$N@hF,%4!<%kH7$F%9%l%8%e!<%k$9$k!#

$=$NB>$N:GE,2=$N$?$a$N2r@O $3$3GO!"@thread 0J30$K2r@O$KhC$F?7$?$KIU2C$5$1$k%W%i%0%^KD$$$F=RYk!#

@loop <!$N%9%F%C%W$GCfCG9k2DG=@-N"$k:F5"8F=P$7;~KO!"M%@hE*$K%9%l%8%e!<%k$9Y-%9%l%C%I$,B8:_$9k+I&$+$N%A%'%C%/$r9T$&!#$=$3G3$1$i%4!<%k$OB>$N%4!<%k$H6hJL$9k?aK!"@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$5$1$k%4!<%k(goal/n) $,F10l%b%8%e!<%kFb$K$"$k>19g$K!"$=$N@a$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!"$3$1$r6qBN2=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!<%kKbB8:_9kJQ?tG"$k!#$^$?!"6&M-JQ?t$v_i$ $,L$6qBN2=JQ?tv_j $r4^$`9=B$7?%G!<%?$G6qBN2=$5$1$?$H$-!"$v_j$ $bF1MM$K6&M-JQ?tG"$k!#

reply first scheduilng $r9T$&$?$aKO!"3.2@a$G=R$Y$?$h$&$K!"MW5a<u?.;~$KMW5a$5$1$?6&M-JQ?t$r=PNO0z?t$KbD%9%l%C%I$,H=L@$9$1$PNI$/!"6&M-JQ?t$K$=$N%9%l%C%IXN%]%$%s%?$rJ];}5;1PNI$$!#7+$7!"$3$N!"$"$k6&M-JQ?t$r=PNO0z?tKb$D%9%l%C%I$H$$$&NO<B9T;~$KJQ2=$9k?$a!"%3%s%Q%$%k;~$K7hDj$9k3HO$G-$J$$!#3N$?$a!"2r@O;~KO!"<B9T;~$K6&M-JQ?t$,J];}9k%9%l%C%IXN%]%$%s%?$r@ZBXk3H,$G-$k$@$1$N>pJs$r=PNO9kI,MW$,$"$k!#

$=$3$G2r@OIt$G$O!"6&M-JQ?t$N3F=P8=KBP7!"$=$N=P8=$G=PNO$G$"$k$+$I$&$+$rD4$Y!"$=$1$>$1KBP7%b!<%I$rIU2C$7$?Cf4V%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<($9!#$?$@$76&M-JQ?t$N%b!<%I>pJs$O>JN,$7$F$$$k!#

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

%9%l%C%I2=MQ=hM}7O3KK"o;$?C %3!<%I$r@8@.9k!#0J2<GOJQ99E@N&$A!"3F%W%i%0%^IU$-%4!<%k$+$iINh&$J%3!<%I$,@8@.$5$1k+$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%1%C%I2=$5$1$?%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@aGi$ 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$$!"B8:_9l$P%9%l%C%I$N@ZBX=hM}$r9T$&!#B8:_7J1l$P%9%?%C%/$K3JG<5l$F$$$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%]%$%s%?G"kh$&$K!"F0E*$KDI@W!&JQ99$9$k%3!<%I$r@8@.9k!#

6qBNE*KO!"

- $"$k@a$C$$K$*$$$F!"%\%G%#ItN_$K=P8=$9$k6&M-JQ?t X KO!"@a$C$$G X $r=PNO0z?t$K;}$D%\%G%#%4!<%k$r4^$`%9%l%C%I$X$N%]%$%s%?$rJ];}$5$;$k!#
- $"$k@a$C$$K$*$$$F!"%X%C%II t$K=P8=$9$k6&M-JQ?t$,!"$=$N@a$G?7$?$K@8@.$5lk%9%l%C%I (T_{new}) $N=i4|%4!<%k$K$*$$$F=PNO0z?tG"$k>l9g$K$O!"$=$N6&M-JQ?t$NJ];}9k%9%l%C%IXN%]%$%s%?$r T_{new} XN%]%$%s%?$K=q-49($k!#

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

4.3 <B9T7O

A0@aNh$&$K7FF@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$K%9%l%C%IFb%4!<%k$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~NOJQ?t$,L$6qBN2=$@$C$?>l9g!"$=$NJQ?t$OB>$N%9%l%C%I$Khj6qBN2=5lk3H,J]>Z5l$F$$$k!#7?$,$C$F!"<B9TCf$N%9%l%C%I4HCfCG$7!"F0E*%9%l%C%I!&9%1%8%e!<%j%s%0Kh$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$N=hM}7O3K$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*1k<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%IFb$N%4!<%k4D6-$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!<%I$N3NJ]$K$+$+$k%*!<%P%X%C%I$H$[$\F1EyG"$j!"2$N=hM}$O<B9T$N:]$K%4!<%k%l%3!<%IFb$N0z?trFI_=P9?aN%*!<%P%X%C%IH[$\F1Ey$G$"$k!#3N$?$a!"%4!<%k$N%(%s%-%e!<!?%G%-%e!<$,>JN,5l$F$$$kJ,$@$1!"<B9T;~K*1k%j%@%/%7%g%s$N%*!<%P%X%C%I$,7Z8:5l$F$$$k!#

$^$?!"%4!<%k$N4D6-$r%9%?%C%/$rMQ$$$F<B8=9k3H$G!"C;L?$G$"$k3H$,B?$$%4!<%k4D6-KhCF!"%R!<%W$,L5BL$K>CHq5lkNrKI0$3$H$,$G$-$k!#3N$?$a!"<B9T;~$N%R!<%W$N>CHqNL$rBgI}$K:o8:G-!"GC $N%*!<%P%X%C%I$,8:>/9k!#

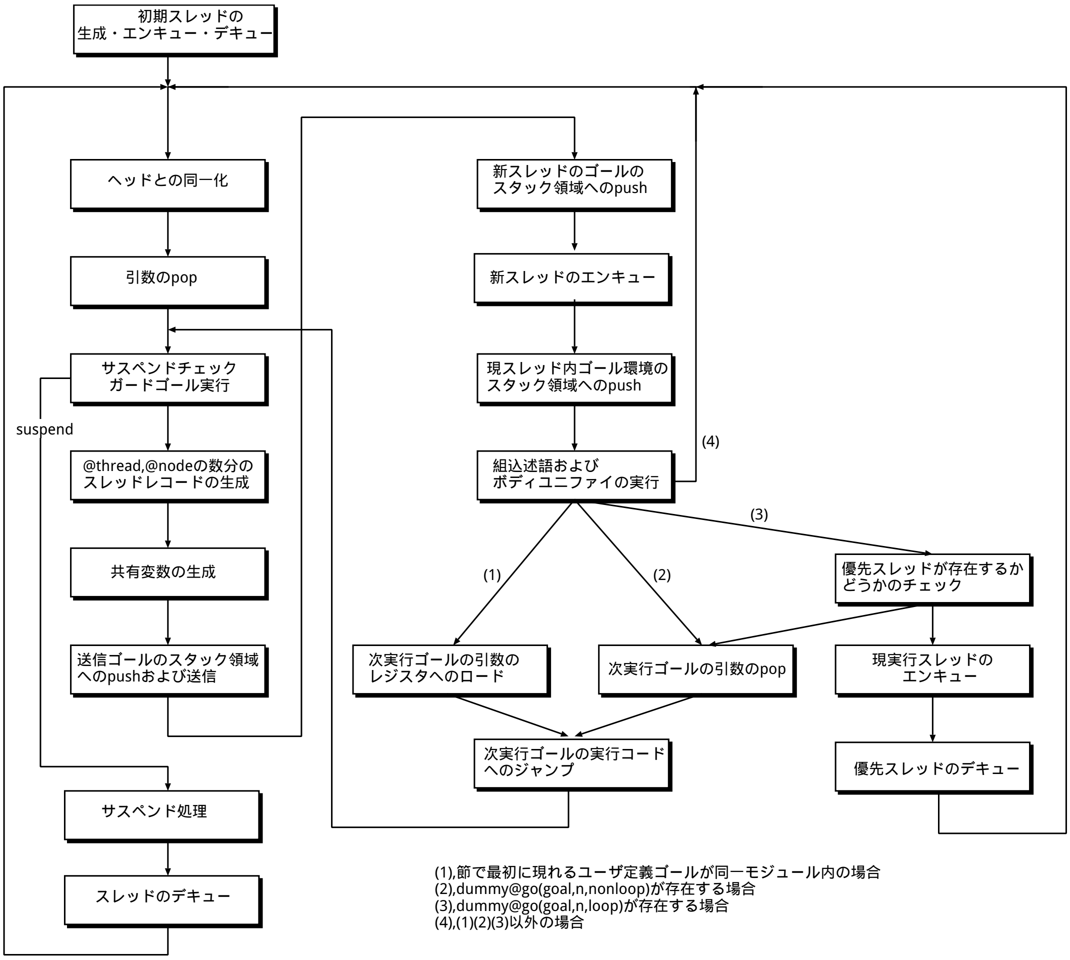
4.3.2 reply first scheduling N?aN3HD%

%G!<%?9=B$

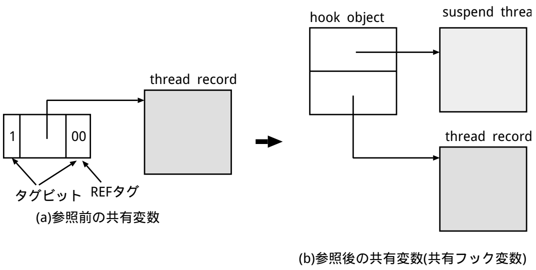
6&M-JQ?t L$6qBN2=$N6&M-JQ?t$O!";2>H$5lkA0$H;2>H8e$HGO$=$N>uBV$,0[$J$k(?^17)!#$^$:;2>HA0$N6&M-JQ?t$O!";2>H$KhC$F<+J,$r=PNO0z?tKb$D%4!<%k$r4^$`%9%l%C%I$r *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k9kI,MW$,$"$k!#

$=$3GL6qBN2=$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



(a)参照前の共有変数

(b)参照後の共有変数(共有フック変数)

?^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$(k3HJ$/<BAu2DG=G"kH$$$&MxE@$,$"k,!"JQ?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\<BAuGO!"<B9T;~$N%*!<%P%X%C%I$r7Z8:9k$?$a$K8e<T$NJ}K!rH$k!#2<0L2%S%C%H$,REF%?%0G"$k>l9g$K8B$j!">e0L1%S%C%H$r6&M-JQ?tN?aN%?%0H7$FMQ$$$k3HK7$?!#0J2<$3$NJQ?t$rC1=c$K6&M-JQ?t$H8F$V!#

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

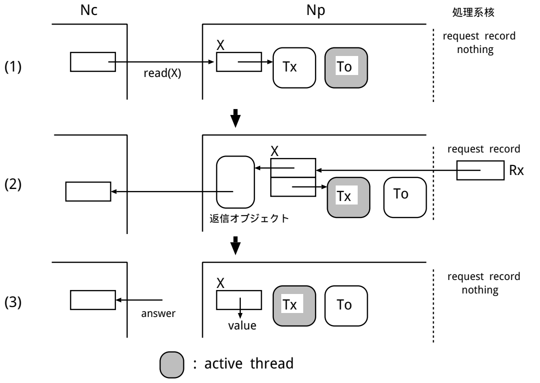
request_record FI=PMW5a$N<u?.$d<B9TCf%9%l%C%I$NCfCG$KhC$F!"%7%9%F%`$O*request_record*$H8F$V%l%3!<%I$r@8@.$9$k!#$3lO$=$NMW5aKhCF6qBN2=5lkY$-6&M-%U%C%/JQ?t$X$N%]%$%s%?$rJ];}$9$k%l%3!<%I$G$"$k!#$^$?=hM}7O3K$O8=:_=hM}$r9TCF$$$kMW5a$N*request_record*$rJ];}9k!#

%9%l%C%I%l%3!<%I reply first scheduling GO%-%e!<KDJ,lF$$$k%9%l%C%I$r@hF,$KbCF/kI,MW,$"$k$?$a!"*reply thread*$r%-%e!<$+$iH4$$$?>l9g$K%-%e!<$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!#

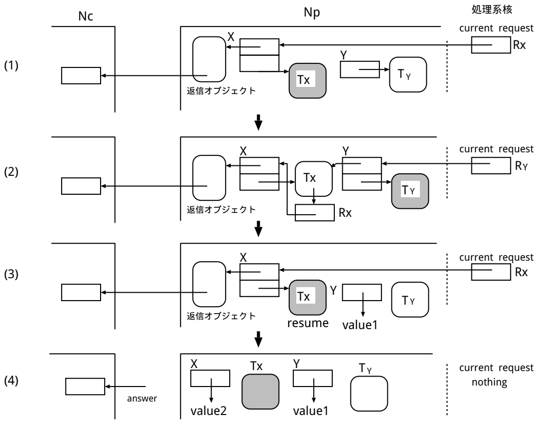
$^$?CfCGA0$K=hM}$7$F$$$?MW5a$d!"CfCGCf$KE~Ce7?MW5a$r%j%8%e!<%`8e$K=hM}G-kh$&$K3F%9%l%C%IO=$NFbIt%G!<%?$H7F!"$=$N%9%l%C%IKBP9$kMW5a$N*request_record*$rFIFO%-%e!<$N7A$G=j;}$9$k!#

reply first scheduling $N<B:] <!$K!"3.2.3$N@a$G=RY?MM!9$J>l9g$G$N!"reply first scheduling $N<BAuJ}K!$K$D$$$F=RYk!#0J2<GOMW5a5l$?6&M-JQ?t$,$X$$G$"$k>l9g!"3N$X$$rJV?.9k$?$a$K%9%l%8%e!<%k$5lk%9%l%C%IrT_X$!"$3$NMW5a$KBP9k*request_record*rR_X$$HI=$9$3HK9k!#

C1=c$J>l9g ?^18$rMQ$$$F@bL@9k!#MW5a<u?.;~(1)KX$$O6&M-%U%C%/JQ?t$KJQ2=$7!"$X$$NJ];}9k%9%l%C%I$T_X$$r*reply thread*H7$F%9%l%8%e!<%k$9$k!#$^$?$3NH$-=hM}7O3K$O$X$$X$N%]%$%s%?$rJ];}$9kR_X$$r@8@.$7!"=hM}7O3K$K3N%l%3!<%I$rJ];}$5$;$k(2)!#3Nh&K7$F%9%l%8%e!<%k$5l?$T_X$$N<B9TKhCF$X$$,6qBN2=5l!"JV?.$,9T$olk(3)!#3NH-=hM}7O3K$O<+$i$NJ];}$9kR_X$$rGK4~$7!"$=$N8e$ODL>o$N%9%l%8%e!<%k$,9Tol$k!#



?^18: reply first scheduling K*1k=hM}7O$NF0:n(C1=c$J>l9g)

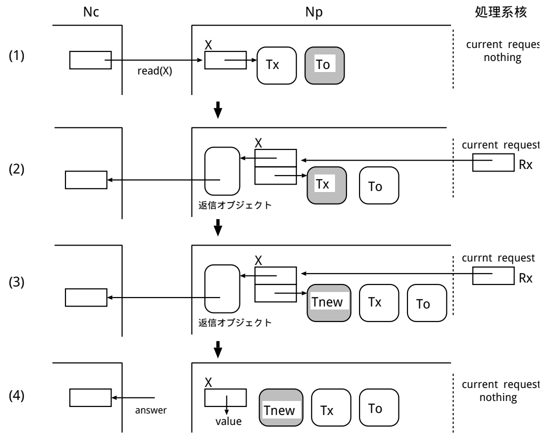


?^19: *reply thread* $,CfCG$9$k>l9g$N=hM}7O$NF0:n

reply thread $NCfCG ?^19$rMQ$$$F@bL@9k!#$X$$KBP9k*reply thread* $T_X$$,JV?.A0$K6&M-JQ?t$Y$ KBP9$k;2>H$KhC$FCfCG$9$k>l9g(1)$r9M$($F$_$k!#6&M-JQ?t$Y$$X$N;2>H$KhCFT_X$$O$Y$$KBP$7%U%C%/$7!"$Y$$O3N;~E@$G6&M-%U%C%/JQ?t$KJQ2=9k!#$^$?!"?7$?$K$Y$$KBP9k*request_record*(R_Y)$,@8@.$5lk!#$=$7$F@8@.$9Y-6&M-JQ?t$,$X$$+iY$$KJQoC$?$?$a!"=hM}7O3K$O$R_X$$r$T_X$$KJ];}5;!"<+iO$R_Y$$rJ];}9k(2)!#

$=$N8e!"$T_Y$$N<B9TKhCF$"$k6&M-%U%C%/JQ?t$,6qBN2=$5l?>l9g!"=hM}7O3KO=$NJQ?t$K%U%C%/9k%9%l%C%I$r%j%8%e!<%`$9$k!#$3$N$H$-$R_Y$$rMQ$$$F$=$N6&M-JQ?t$,$Y$$G$"$k$+$I$&$+$rH=CG$7!"$=$N7k2L6qBN2=$5$l$?JQ?t$,$Y$$G$"$l$P$R_Y$$rMQ$$$F!"%j%8%e!<%`$5l?%9%l%C%INCf+$i!"$T_X$$r8+D1$@$7!"3l$r<!$N*reply thread*H7$FM%@hE*$K%9%1%8%e!<%k9k(3)!#$^$?$Y$$GJ1lP!"$=$N$^$^$T_Y$$,*reply thread*H7$FM%@hE*$K%9%1%8%e!<%k5l$k!#

6qBN2=$r9T$&%9%l%C%I$,L$@8@.$N>l9g ?^20$rMQ$$$F@bL@9k!#K\<jK!GO$X$$KBP9kFI=PMW5aKhCF!"$=$N;~E@GX$$r=PNO0z?tKb$D%4!<%k$r4^$`%9%l%C%I$T_X$$r*reply*



?^20: 6qBN2=%9%1%C%I$,L$@8@.$N>l9g$N=hM}7O$NF0:n

thread H7$F%9%1%8%e!<%k$9$k(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 $,=PNO$H7F=P8=7F$$$k$+$I$&$+$r R_X $rMQ$$$FH=CG$7!"=P8=$7$F$$$k>l9g$O%9%1%C%I T_{new} $r *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k9k(3)!#B8:_7J$$>l9g$O!"$T_X$ r=N^$^ *reply thread* H7$F%9%1%8%e!<%k9k!#

J#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>l9g X_i $K

BP9k *reply thread* H7$F%9%1%8%e!<%k$5l?%9%1%C%I T_{X_i} $N<B9T$G6&M-JQ?tF1;N(X_j, X_k) $NF10l2=$,9Tol$k>l9g$r9M$($F$_$k!#

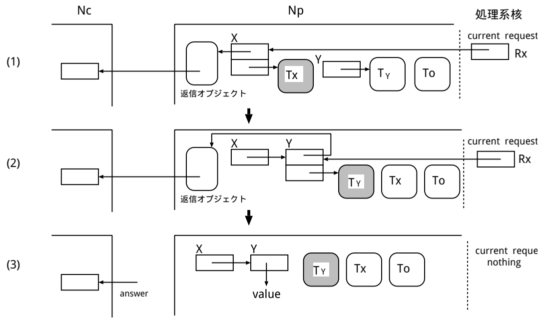
3N;~!"X_j, X_k $N$$$:l+0lJ}$, X_i G"$k>l9g$O!"3NF10l2=%4!<%k$N<B9TKhCF!"*reply thread* $r@ZBX$kI,MW$,$"$k!#$i = j$ G"$k>l9g$r9M$($k$H!"%4!<%k'$X_i = X_k$' $N3FJQ?t$O X_i (=PNO)!"X_k (F~NO) G"kN$G!"<!$K *reply thread* H7$F%9%1%8%e!<%k$5lkY-%9%1%C%I$O T_{X_k} $H$$$&3HKJ$k!#

=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"$k>l9g$O R_{X_i} $NFbIt%G!<%?$r X_i $+$i X_k $KJQ99$7 X_k $NJ];}$9$k%9%1%C%I T_{X_k} $r<!$N *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k9k!#

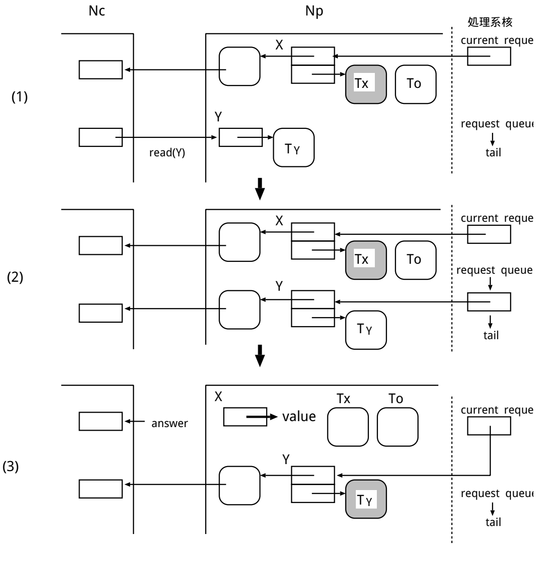
Nc$($P!"?^21NNcG$O!"$N_c$ $+$i$N *read* %a%C%;!<%8$N<u?.KhCF N_p B&GO X $N6qBN2=%9%1%C%I$G$"$k T_X $r *reply thread* H7$F%9%1%8%e!<%k$7!"X $O6&M-%U%C%/JQ?t$KJk(1)!#$=$N8e!"T_X Cf$N%4!<%k $X = Y$ $,<B9T$5$l!"*reply thread* $,$T_X$ $+$i T_Y $K@Z$jBX$($ilk(3)!#T_Y $N<B9T$G X, Y $O6qBN2=$5$l N_C KBP9$kJV?.$,9Tol$k(4)!#

0lJ}$i \neq j, i \neq k$ $N>l9g$K$O!"=PNOB&$NJQ?tKBP7$F!"F~NOB&$NJQ?tXN%]%$%s%?$rBeF~7FdlPh$/!"$3$&$9k3HG!"3liN6&M-JQ?t$O!"$3$NF10l2=%4!<%k$G$NF~NOB&0z?t$N6qBN2=%9%1%C%I$N%]%$%s%?$rJ];}$9k3H,G-$k!#$3lKhC$F X_j, X_k $N$$$:lX$N;2>H$KhCFb!"0J8e$O X_j, X_k $N6qBN2=%9%1%C%I$r *reply thread* H7$FM%@hE*$K%9%1%8%e!<%k9k3H$,$G$-$k!#$3$3$G!"$X_j, X_k$ N&$A8=:_<B9TCf$N%9%1%C%IXN%]%$%s%?$rJ];}7F$$$kJ}$,=PNOB&JQ?t$G$"$k!#

J#?t$NFI=PMW5a$,B8:_9k>l9g J#?t$NFI=PMW5a$,B8:_9k>l9g$N=hM}$N$?$a$K!"=hM}7O3K$O *request_record* $r FIFO $G



?^21: J#?t$NF10l2=%4!<%k$N<B9T$,I,MW$J>l9g$N=hM}7O$NF0:n



?^22: J#?t$NFI=PMW5a$,B8:_9k>l9g$N=hM}7O$NF0:n

=hM}9k$?$a$N%-%e!<(%j%/%(%9%H%-%e!<) $rJ];}$9$k!#E~Ce$7$?FI=PMW5a$O3N%-%e!<$N:G8eHx$KDJ$,$l!"<B9TCf$Nreply first scheduling $,=*N;$9k+CfCG7?>l9g$K!"<h$j=P5l$F=hM}$5lk!#3N;~!"$=$NMW5a%G!<%?$,JV?.:Q$G$"$k$+$I$&$+$N%A%'%C%/$r9T$$!"JV?.:QG"lP<!$NMW5a$,=hM}5l$k!#

$^$?!"3N;~$K *reply thread* H7$F%9%1%8%e!<%j%s%0$5lkY-%9%1%C%I$,30It;2>H%]%$%s%?XN;2>HKhCFCfCG7F$$$k>l9g$O!"JV?.$KhC$F%j%8%e!<%`$5$l$k$^$G$=$N%9%1%C%I$r%9%1%8%e!<%k$9$k$3$H$O$G$-$J$$$N$G!"$=$N *request_record* $r$=$NCfCG%9%1%C%I$KJ];}$5$;$F$*$/!#$=$N8e!"$=$N%9%1%C%I$,JV?.$r<u$1<h$j%j%8%e!<%`$5lk;~K=$N *request_record* $r%j%/%(%9%H%-%e!<$KLa7Fdk!#

?^22NNcG$O!"$N_p$B&$OX KBP9$kreply first scheduling $r9T$C$F$$$k:GCf(1) $K!"$Y$ KBP9$kFI=PMW5a$read(Y)$ $r<u?.$7!"Y KBP9$k%j%/%(%9%H%l%3!<%I R_Y $r@8@.$9$k!#$3NH$-$3$NMW5a$O%j%/%(%9%H%-%e!<KDJ,lk(2)!#$=$N8eX $,6qBN2=$5$l!"$X$ KBP9$kreply first scheduling $,=*N;$7$?$"HG!"=hM}7O3KOR_Y$ $r%-%e!<$+$i<h$j=P$7!" Y $N6qBN2=%9%1%C%I$G$"$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%j$NNN0h$H7F!"%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$$$?!#handshake $O?^6$N%W%m%0%i%`$G$"$k!#reverse $OIUO?A$N%W%m%0%i%`$G$"$j!"Dj$a$i$l$?<j=g$K$7$?$,$C$F%*%;%m%2!<%`$r9T$&%W%m%0%i%`$G$"$k!#circle_to_square $OIUO?B$N%W%m%0%i%`G"$j!"J#?t$N%N!<%I$G0[$JkFsD$N d KD$$$FD>7B d $N1_$NLI@Q$H01JU d $N@5J}7A$NLI@QHf$r5a$a$k!#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@.$7!"$"$k%W%m%;%9$,$=$l$i$r=87W$9$k$h$&$J%W%m%0%i%`G"$k!#

I=2: handshake GN@-G=I>2A

	;~4V (sec)	GC 2s?t	CfCG2s?t
=>MhHG	19.21	24	1000000
%9%1%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
%9%1%C%I2=	27.37	17	92999

5.2 handshake

%9%1%C%I2=$*$h$Sreply first scheduling Kh$kCfCG2s?t!&GC $N2s?t$NJQ2=!"<B9T;~4V$rI=2$K<($9!#

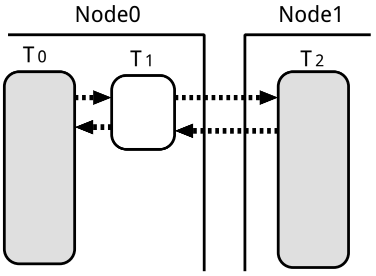
3N%W%m%0%i%`$OJBNs@-$,$[$H$s$I$J$$$?$a!"C`<!4D6-N_GNI>2A$r9T$&!#=>MhHGHHfY!"CfCG2s?t$OH>J,$KJC$F$$$k!#3l$O3.1.1@a$G=RY?9=B$7?%G!<%?$N0lIt$@$1$,6qBN2=$5l?CJ3,$G;2>HB&$K@)8f$,0\$k$H$$$&LdBj$,%9%1%C%I2=$Khj2r>C5l$?$?aG$"$k!#$^$?!"GC 2s?t$,Ls1/3 $K8:>/$7F*$j!"%4!<%k4D6-$N%9%?%C%/Kh$k<BAu$G!"%R!<%W$N>CHqNL$,BgI}$K:o8:$5l?3H$r<($7$F$$$k!#3liK2C$(!"%9%1%C%IFb%4!<%k$K$D$$$F%9%1%8%e!<%j%s%0$N%*!<%P%X%C%I$,8:>/7?$?$aA4BNGOLs2 G\$NB.EY8~>e$,F@$il?!#

reply first scheduling $r;HMQ$7$?>l9g$O!";HMQ7J$$$bNKBP7F1 3d$[$IB.EY$,CY$$!#3l$Oreply first scheduling N?aN=hM}$K!"%*!<%P%X%C%I$,B8:_9k$?$aG"$k!#$^$?$3$N%W%m%0%i%`$G$O!";HMQ$7$J$$>l9g$HF1MM$N%9%1%8%e!<%k$r9T$&$?$a!"3N%*!<%P%X%C%I$NJ,$@$1B.EYDc2<$r5/$3$7$F$$$k$H9M$(il$k!#

5.3 reverse

IUO?A$N%W%m%0%i%`$G$"$k!#$3$N%W%m%0%i%`$OA0bC$FM?$(il$?<j=g$K7?$,$C$F!"%*%;%m2!<%`$r9T$&%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$$!#F1MM$KB $,@P$rCV$/4V$OA $O2?$b7J$$!#hC$F!"$3$N%W%m%0%i%`$K$OJBNs@-$,A4$/B8:_$7$J$$!#0lJ}!"F1;~$KB8:_$9$k%9%1%C%I$N?t$O:GBg$G2 $D$7$+$J$$$N$G!"reply first scheduling $r9T$&0UL#$,$J$$!#$7$?$,$C$F!"$3$N%W%m%0%i%`$O%9%1%C%I2=<jK!KD$$$FC`<!4D6-2<GN@-G=I>2AN_$r9T$&!#%9%1%C%I2=Kh$kCfCG2s?t!&GC $N2s?t$NJQ2=!"<B9T;~4V$rI=3$K<($9!#

%9%1%C%I2=Kh$j!"CfCG2s?t$,Ls1/32 $K8:>/$7$F$$$k!#3l$O=>MhHG$G$O8e<j$G$"$k B $N<B9TESCf$Gresumption first scheduling Kh$j!"B B&$N1 <jJ,$N=hM}A4$F$,=*$o$kA0$K!"A B&$N<!$N1 <jXN=hM}$K@)8f$,0\$C$F$$$?N,!"%9%1%C%I2=Kh$j!"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!"$3li$N7k2L$H7F!"Ls2.9 G\$N@-G=8~>e$,F@$ilF$$$k!#



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

5.4 circle_to_square

IUO? B$N%W%m%0%i%`$G$"$k!#%9%1%C%I%e!<%k%j%s%0%"%k%4%j%:%`$H7F$O!"reply first scheduling Kh$kCfCG2s?t!&GC $N2s?t$NJQ2=!"<B9T;~4V$*$h$S3F%N!<%I$N%"%$%I%k;~4V$rI=4$K<($9!#

3N%W%m%0%i%`$O<B9T$5$l$k!J%M%C%H%o!<%/$r7A@.$9$k!K%?%9%/$r!"%N!<%I4V$GD>@\E*$K%a%C%;!<%8$rAw$k$3$H$K$h$C$F7W;;$r9T$&%W%m%0%i%`G"$k!#

3N%W%m%0%i%`$OD>7B$d$N1_$H$d$HF1$8D9$5$N0lJU$r;}$D@5J}7A$NLI@Q$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$($?>l9g$K!"$=$N@5J}7A$r3J;R>u$KJ,3d$7!"3F3J;RE@KD$$$F$=$l$,1_$NFbB&!&30B&NIAiK"k+$rH=Dj$7!"$=$l$>$lKD$$$FAmOB$r5a$a$?$N$A!"1_$H@5J}7A$NLI@Q$NHf$r5a$a$k!#

$d_1,d_2$$N$=$l$>$lKBP9$k7W;;$OFHN)$KJL%N!<%I$G9Tol$k!#$3N?$a=>MhHG$G$O2 Bf$GLs1.6 G\$NB.f?t8z2L$,F@$ilF$$$k!#

%9%1%C%I%e!<%j%s%0KD$$$F$O!"?^23$Nh&$J9=B$$KJj!"%N!<%I0 B&GO$T_0,T_1$$NFsDN%9%1%C%I%e!<%k%9%l%C%I$,%9%1%8%e!<%k$5$l!"%N!<%I1 B&$GOT_2$$,%9%1%8%e!<%k5l$k!#$T_0,T_2$$OLI@QHf$r5a$a$k%9%1%C%I$G!"$T_1$$O$T_0,T_2$$,;HMQ9kdr@8@.9k%9%1%C%IG"$k!#

%N!<%I1 KEj2il$?$T_2$$O$T_1$$N@8@.9k%G!<%?rBTC$FCfCG$7!"%N!<%I0 KBP7F1I=PMW5a$r9T$&!#7+7J$,$i!"%N!<%I0 GO!"$T_0$$,%9%1%8%e!<%k5lF*$j!"$7$+$b3N%9%1%C%I$OCfCG$;$:$K<B9T$r=*N;$9$k!#$T_1$$,%j%8%e!<%`5lkN$O!"$T_0$$N<B9T$,=*N;$7F+iG$"$j!"JBNs4D6-GOJBNs@-$,A4$/GJ$$!#3l$O%9%1%C%I%e!<%K$hCFdr@8@.9k%4!<%k$N<B9T$,8e2s7K5l$?$?aG$"$k!#

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

0lJ}reply first scheduling rE,MQ9kH!"$T_2$$+iNF1I=PMW5a$G%9%1%C%I%e!<%K$hCF8e2s7K5l$F$$$k$T_1$$rM%@hE*$K%9%1%8%e!<%k$9k?$a!"JBNs@-$r3NJ]9k3H$,$G$-$k!#3N7k2LC`<!4D6-2<$HF1MM!"=>MhHG$KHf$YLs1.3 G\$NB.EY8~>e$,F@$ilF$$$k!#

5.5 master_slave

IUO? C$N%W%m%0%i%`$G$"$k!#%9%1%C%I%e!<%j%s%0%"%k%4%j%:%`$H7F$O!"reply first scheduling Kh$kCfCG2s?t!&GC $N2s?t$NJQ2=!"<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*$$$F$O%9%l%$%V%W%m%;%9$,%N!<%I0 >e$K%^%9%?!<%W%m%;%9$,%N!<%I1 >e$KB8:_9k!#%^%9%?!<%W%m%;%9O"$kFCDj$N=g=x$K=>$C$F!"3F%9%l%$%V%W%m%;%9$N=PNO$r<u$1<h$k!#0lJ}3F%9%l%$%V%W%m%;%9$N<B9T=g=x$O5,Dj$5lF$$$J$$!#7?$,$C$F=>Mh<jK!$d%9%1%C%I%e<jK!N_NE,MQG$OI,$:7b%^%9%?!<%W%m%;%9NI,MWH9k=g$K%9%l%$%V%W%m%;%9$,%9%1%8%e!<%j%s%0$5lJ$$$?$a!"%^%9%?!<%W%m%;%9$,$=$N;~E@GI,MWH9k=PNOrBTC$FCfCG$7!"%N!<%I1 $O%"%$%I%k>uBVHJCF7^$&!#$=$N7k2L!"%W%m%0%i%`$NJBNs@-$r0z$-=P$9$3$H$,$G$-$:!"JBNs<B9T$K$h$k@-G=8~>e$,F@$i$l$J$$$P$+$j$+!"C`<!<B9Thj$b<B9TB.EY$,Dc2<7F7^CF$$$k!#

0lJ}!"reply first scheduling $rMQ$$$k3H$G!"%^%9%?!<B&$NMW5a%G!<%?$r@8@.$9$k%9%l%$%V%W%m%;%9$,M%@hE*$K%9%1%8%e!<%k5l$k!#$7$?$,CF!"%^%9%?!<B&$,%9%l%$%V$+$i$NJV?.$rBTCFCfCG9k;~4V$O=>Mh$NbNKHfYFh$j>/$J$$$bNHJk!#$=$N7k2L!"SS-20 2 BfKh$kJBNs<B9T$G!"C`<!<B9TKBP7$F!"Ls1.4 G\$NB.EY8~>e$,F@$ilF$$$k!#

6 9M;!

6.1 4XO"8&5fHNHf3S

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

B.C.Massey $H E.Tick $N8&5f B.C.Massey $H E.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=$r9T$C$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$$$&@)8B$O!"%W%m%0%i%`8@8l$N;}$DK\<AE*$J5-=RG=NO$r8BDj$9$k$b$N$G$O$J$$!#$7$+$7$J$,$iLdBj$K$h$C$F$O!"%W%m%0%i%^$,$+$J$j0U<1$7$F=q$+$J$$$8B$j!"feedback-free $J%W%m%0%i%`$r=q$/$3HOG-$J$$$bNbB8:_$7!"$7$+$b$=$&$$$C$?LdBj$O>/J/OJ$$!#$^$?3N$?$a!"8=:_=q$+$l$F$$$kB?$/$N%W%m%0%i%`$K!"feedback-free $G$O$J$$%W%m%0%i%`$OB??tB8:_$7!"3NJ88%K*1kC`<!2=$r$3$l$i$N%W%m%0%i%`KE,MQ9k?aKO=$l$rfeedback-free $K=q$-D>$9I,MW$,$"$k!#3liN3H$+$i!"H`iN2]7?@)8B$OHs>o$K87$7$$$H$$$($k!#

0lJ}2f!9$N<jK!$O well-moded $J%W%m%0%i%`$J$iA4$FE,MQ2DG=G"$k!#

9SLZ$N8&5f Committed-Choice 7?8@8l Fleng $O!"KL1 F1MM!"<B9TN3EY$,>.$5$$$?$a%*!<%P%X%C%I$,Bg$-$$!#3N8&5fGO Fleng K*$$$F%W%m%0%i%`$NOUL#$rJQ2=5;k3HJ$/N3EY$r:GE,2=9k3H$rL\I8$H7F$$$k!#$=$N<jCJH7$F!"%4!<%k$N%U%)!<%/$r8F$S=P5l$k%4!<%k$ND j5A$GE83+$9$k%$%s%i%$%sE83+$H$$$&J}K!$H!"J#?t$N%4!<%k$r0l$DK^Ha$k%4!<%kM;9g$H$$$&J}K!$rMQ$$$F$$$k!#

$^$?!"N3EYrBg-$/$7$9$.k3HKhk!"JBNsEY$NDc2<$NLdBj$K4X$7FO!"!VP%s%P%sN3EY@)8f!W[17] $rMxMQ$7!"9bI i2YMQ!"DcI i2YMQ$NFs<oN`$N%3!<%I$r@8@.$9k3HGBP=h7F$$$k!#

8F=P$7LZ$K%5%$%/%j%C%/$J0MB84X78$,B8:_$7$J$$>l9g$K!"%4!<%kM;9g$r9T$&!#$3lO!"K\<jK!K*$$$F!"C1J}8~$N%G!<%?0MB8$,B8:_9k>l9gN_!"F10l%9%1%C%IH7$FC`<!2=$5lkNHF1MMG"$k!#

0lHL$K!"%W%m%0%i%`$NOUL#$rJQ$($:$K0BA4$KC`<!2=$r9T$&$K$O!"2r@O;~$K!"0MB8$,H=L@$7$J$$>l9gKO!"APJ}8~$K0MB8$,$"$kbNH9$k!#$3N?$a!"2r@O$N@:EY$,C`<!2=$N8z2LKBg-$J4X$ojr;}CF$/$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%1%C%I2=	39.61	30	1	-	-
JBNs(2+1 Bf)					
=>MhHG	33.00	84	9	10.72	0.06
%9%1%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%1%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%1%C%I2=	69.44	0	1019	37.86	34.93
reply first	44.07	0	1020	6.59	9.27

7+$7!"J88%[16] GO!"%4!<%k4V$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*$J0MB84X78$rI U2C7F$*$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=:_$Nreply first scheduling GO!"F I=PMW5a(read %a%C%;!<%8) Kh$k5/F0$N$_$r9M$($F$$$k!#7+$7!"2.1.2@a$G=RY?h&$K!"KLIC GN3 0It;2>H%]%$%s%?$O!"C1J}8~$N%j%s%/7+D%$ilF$$$J$$!#

0J2<!"JQ?tX $rAw?.$7$?B&$rN_p, Aw?.5l30It;2>H%]%$%s%?$,@8@.5l$?B&$rN_c H9kH!"N_cB&GNX KBP9$k;2>H$G$O!"read %a%C%;!<%8$rAw?.$7!"$N_p$B&$Greply first scheduling $,9T$olk$,!"$N_p$B&$G$N;2>H$G$O!"$N_c$ GNreply first scheduling $O9T$olJ$$!#

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

Nc$($P!"$"$kJQ?tX KBP7$F N_pB&$G6qBN2=$,9Tol$J$$$3HO!"2r@OKhCFJ]>ZG-$k!#$hCF3&$$$C$?JQ?t$K4X7F$O!"%G!<%?$NAw?.8e!"JV?.@h$r;}$D acknowlege $r N_c $+$i<u$1<h$j!"N_pB&$+$i N_cB&XN%]%$%s%?$rD%$kJ}K!$,9M$($ilk!#

DL?.9bB.2=<jK!HNJ;MQ X KBP9$kF I=PMW5a$Khj!"reply first scheduling $r9T$C$?>l9g!"$X$ $,9=B$7?%G!<%?$K6qBN2=$5lk>l9g!"X $N:G30B&$NCM$,6qBN2=$5l?$@$1$G!"JV?.$r$*$3JCF7$^$&!#;2>HB&$,9=B$%G!<%?$NFbIt$^$G!";2>H$9$k>l9g$K$O!"$b$&0lEYF I=PMW5a$r9T$&I,MW$,$"$k!#

3l$r!"%9%1%C%I$N@ZBX%?%$%_%s%0$^$GAw?.$rCYi;!"0JA02f!9$,Ds0F$7$?0l3gAw?.<jK![18] $rMQ$$$k3H$G!"$3Nh$&$J:YN3EY$NDL?.$rHr1k3H$,$G$-$k!#

7 7kO@

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

K\<jK!GO!"@EE*2r@OKh$j%4!<%k4V$N0MB8>pJs$rC j=P$7!"%3%s%Q%$%k;~$K=g=x7hDj2DG=$J%4!<%k$N=89g$r%9%1%C%I$H7F!"%9%1%C%IFb$N@EE*%9%1%8%e!<%j%s%0$r9T$&!#$3lKhj!"<B9T;~$N%4!<%k$N%j%@%/%7%g%s$K4X$9$k%*!<%P%X%C%I$rBg$-$/8:i9$3$H$,$G$-$k!#$^$?!"%4!<%k$N<B9T=g=x$r@EE*$K8GDj$7$?$3HKhj!"%9%?%C%/$rMQ$$$?8zN(E*$J<BAu$r9T$&$3H,G-$?!#$3lKhj!"%R!<%WNN0h$N;HMQ8zN($d<B9T8zN(r"2k3H$,$G$-$?!#

$^$?!"%9%1%C%I2=Kh$jJBNs@-$,Dc2<9kh&$JLdBj$K4X7F$O!"MW5a%G!<%?$rG-$k8B$jAa$/@8@.$9kh$&$K%9%1%C%I$r%9%1%8%e!<%j%s%0$9$kreply-first J}<0$rMQ$$!"C`<!2=$5$l$?%W%m%0%i%`$N;}$DJBNs@-$r:GBg8B$KC j=P9k3H$G!"8zN(E*$J%9%1%C%I!&%9%1%8%e!<%j%s%0$r9T$&3H$,$G$-$k!#

K\<jK!$r=>Mh$NKL1 =hM}7O KLIC >e$K<BAu$7!"@-G=I>2A$r9T$C$?7k2L!"%9%1%C%I2=<jK!$K4X7F$O!"C`<!4D6-$K$*$$$F$O!"1.3!A2.9 G\$NB.EY8~>e$,F@$i$l$?!#0lJ}JBNs4D6-$G$O!"<B9T;~$NJBNs@-$NDc2<$K$h$j=>MhHG$h$j$bB.EYDc2<$r5/$3$9LdBj$d=>Mh$N<jK!$G$O$=$N%W%m%0%i%`$N;}$DJBNs@-$rC j=PG-$:$KC`<!<B9Thj$b@-G=$,Dc2<9kLdBj$bB8:_$7$?!#$=$&$$$C$?%W%m%0

%i%`$K4X$7FO!"reply first J}<0rE,MQ9k3HGJBNs@-$r3N J]$G$-!"$=$N7k2LJBNs4D6-$K$*$$$F$b=>MhHG$KHfYFLs 1.3 !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$/$@5C$?IYEDbC<#65<x$K?<?S$J<U0U$r I=7^$9!#E,@Z$J8f;XF3$r;r$oC?CfEg9@=u65<x$*$h$S?9bC0l O:=u65<x!"?t!9$NM-MQ$J8f0U8+$rBW$$$?8^Eg@5M5=u<j$K?4$+$i 46<UCW$7$^$9!#

$^$?!"3F<o;qNA$rDs6!$7$FBW$$$?(:b) ?7@$Be%3%s%T%e!<%? 3+H/5!9=$*hS@hC<pJs5;=Q8&5f=j!"5i$K!"6&F18&5f<T$G$" $kBgLnOBI';a$dKL1 %?%9%/%0%k!<%W$NDEM8 8x6G;a!"9uED7=;a rO8aH7$F!"F|:"8fF$O@D:$$$?5~ETBg3X9)3XIt>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@n2mI', 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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[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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[17] F|9b9/M:, >.CSHFJ?, EDCf1QI'. 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@8l=hM}7O KLIC K*1kDL?.$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.
```