KL1 8@8l=hM}7O KLIC $N F0E*N3EY@)8f$KhkDL?.9bB.2=

9uED 7=

J?@.9G/2 7n14F|

Abstract

K\8&5f$O!"JBNsO@M}7?8@8l KL1 $N=hM}7O$G$"$k KLIC $N<B9T;~$K$*$1$kDL?.%*!<%P%X%C%I$r:o8:9k3H$rL\E*$H7?bNG"$k!#

KL1 $OJBNs=hM}$N5-=R$KE,$7$?%W%m%0%i%`8@8l$G!"Bh8^@$Be%3%s%T%e!<%?%W%m%8%'%/%H$,$=$NL\I8$H$7$F$-$?JBNs?dO@%7%9%F%`$NCf3KHJ$kJBNs?dO@%^%7%s$N6&DL3K8@8lH7$F!"9-$/MQ$$$ilF$-$?!#

$=$N=hM}7OG"$k KLIC $O!"KL1 %W%m%0%i%`$r C %W%m%0%i%`$K%3%s%Q%$%k$7!"$=$l$r%[%9%H%7%9%F%`$N C %3%s%Q%$%i$G%3%s%Q%$%k$7!"<B9T;~%i%$%V%i%j$H%j%s%/7F<B9T9k!"$H$$$&J}<0rHCF$$$k!#3&7?J}<0Kh$j0\?"@-$N9b$$=hM}7O$r<B8=$7$F$$$k!#0lJ}!"%a%C%;!<%88r4970?JBNs7W;;5!$d%o!<%/%9%F!<%7%g%s%/%i%9%?$rBP>]$H7?>l9g!"IQH/9k:YN3EYDL?.$N%*!<%P%X%C%I$,B.EYDc2<NBg-$JMW0x$KJk!#3NLdBj$r2r7h$9k?aK!"9G$KC1J}8~DL?.<jK!!"0l3gAw?.<jK!JI$H$$$C$?DL?.:GE,2=<jK!$,Ds0F5l!"<BAu5l$F$$$k!#

0l3gAw?.<jK!$O!"9=B$%G!<%?$NAw?.$N:]$K!"$9GK6qBN2=5l$F$$$k%G!<%?N&AG<u?.B&$,I,MW$H9k%G!<%?$r0l3g$7$FAw?.$9$k<jK!$G$"$k!#3lKhCF!"9=B$%G!<%?Aw?.;~$K:YN3EYDL?.$,IQH/$9kH$$$&LdBj$rOHr$1il$k!#$7$+$7$3$N<jK!$OAw?.MW5a$KBP7FB(:B$KJV?.$r9T$&$?$a!"Aw?.B&$N%G!<%?@8@.B.EY$,CY$$>l9g$O==J,$JNL$N%G!<%?$rJV?.G-$J$$!#$=$N$?$a!"LdBj$N@-<A$KhCFO==J,$JB.EY8~>e$rK>aJ$$>l9g$,$"$k!#

$=$3$GK\8&5f$GOFCK3N0l3gAw?.<jK!$N3HD%$r9T$$!"DL?.$NN3EY@)8f$rF0E*$K9T$&CY1dAw?.<jK!$rDs0F!"<BAu$7$?!#$3$NCY1dAw?.<jK!$O!"%G!<%?$NAw?.MW5a$KBP$7JV?.$rE,EY$KCY1d$5$;$k3H$GN3EY$N@)8f$r9T$&<jK!G"$k!#

$^$:!"JBNs%W%m%0%i%`$NF0:n$r4JC1$K%b%G%k2=$7$F:GE,$JAw?.NL$r5a$a$k<0$rF3=P7?!#:GE,$JAw?.NL$r7W;;9k:]KO!"Am%G!<%?NLrCNkI,MW$,$"k,!"0lHLKO<B9T;~$KAm%G!<%?NL$rCNk3HOG-$J$$!#$=$3$G<BAu>e$O!"<B9T;~$K%G!<%?NL$r%+%&%s%H7F$$$-!"Aw?.MW5a$,Mh$?;~E@$^$G$N%G!<%?NL$rAm%G!<%?NL$H2>Dj$7$F:GE,$JAw?.NL$r6a;w$9kH$$$&J}<0rHC?!#

CY1d$NDxEY$O<g$KCY1d;~4V$KhC$FI=8=$9k3HK$7!"7W;;$G5aa?:GE,$JAw?.NL$KHfYF<B:]$NAw?.NL$,ITB-7F$$$k>l9g$OCY1d;~4V$rA}2C5;$k!"$H$$$&@)8f$r9T$C$?!#$=$&$7$?>l9g$KLdBjHJkN$O2a>j$JCY1dKh$k@-G=Dc2<$G$"$k!#$=$lrKI0$?$a$K!"Aw?.$r9T$&$4HK:GE,Aw?.NL$rD6$($F$$$k$+$I$&$+$N%A%'%C%/$r9T$$!"b7D6$($F$$$?>l9gKOCY1d;~4V$r8:$i$9!"$H$$$&@)8f$r9T$C$?!#$3lKhjCY1d;~4V$O!"Aw?.NL$,:GE,JbNK6aE/h&$K%U%#!<%I%P%C%/@)8f$5lk3HKJ$k!#

$=$7F3$NCY1dAw?.$N8z2L$rD4$Yk?aK!"4vD+$N%W%m%0%i%`$rMQ$$$F<B9T;~4V$HJ*M}DL?.2s?t$r7WB,$7$?!#$=$N7k2L!"%Y%s%A%^!<%/%W%m%0%i%`$G$O!":G$bNI$$>l9g!"0l3gAw?.KHfY$F<B9TB.EY$, 2.5 G\!"J*M}DL?.2s?t$, 1/16 KJkH$$$&NI9%$J7k2L$,F@il$?!#$^$?!"%^%k%A%W%k%"%i%$%a%s%H$r9T$&1~MQE*$J%W%m%0%i%`$KBP7F$b!"<B9TB.EY$, 1.6 G\!"J*M}DL?.2s?t$, 1/2 KJ$j!"CY1dAw?.$N<BMQ@-$r3NG'$9k3H,G-$?!#

Abstract

This research aims at decreasing overhead of communication in executions on KLIC of parallel logic programming language KL1 system.

KL1 is a programming language suited to parallel processing. It have been widely used as the common kernel language of the parallel inference machine which constitutes major part of the parallel inference system aimed by the 5th generation computer project.

KLIC is a system for KL1. Its method of execution consists of a series of processes, which are to compile KL1 programs to C programs, to make object codes by compiling them with a C compiler on the host system, and to link them to the runtime library. The processing system with high portability is realized by such a method. On the other hand, on message-passing multiprocessors or work station clusters, the overhead of frequent fine-grained communications becomes the big factor of the speed decline. To solve this problem, communication optimizing techniques such as the technique of *one-way-send* method and *packing-send* method have already proposed and implemented.

Packing-send method is the technique to transmit bounded data which the reception node needs, by lumping together it in case of transmission of structured data. This method solves the problem that fine-grained communications occur frequently at transmission of structured data. However, the reception node immediately answers for a request by this method. So, when the data generation speed on the transmission side is slow, the data with enough quantity can not be answered. Therefore, depending on the nature of the problem, sometimes it is impossible to gain enough speed improvement.

In this research, I propose and implemented *delay-send* method. This method dynamically controls granularity of inter-PE communication as extending *packing-send* method. *Delay-send* method is the technique to control communication granularity by delaying an answer for a transmission request of data moderately.

First, I derive a expression to compute optimized transmission quantity by modeling a behavior of parallel programs. When computing it, the whole quantity of data must be known. However, it can not be known generally when executing. So, on the implementation I take the method to use an approximate value instead of the optimal value. To compute the approximate value, number of data must be counted when executing. The approximate value is computed by assuming that such counted number of data when the transmission request comes is the real number of all data.

I use real time for expressing delay degree. Delay time increases at the case that real transmission quantity is less than theoretical optimized one. However, too much delay causes performance declining. To avoid this problem, system checks with every transmission whether real transmission quantity is over the theoretical optimized one. And if over then system decreases delay time. In this way, delay time is controlled with feedback and transmission quantity comes near of optimized one.

Then, to examine the effect of *delay-send*, I measured execution times and physical communication numbers by using some programs. As the result, in the executions of benchmark programs, the execution speed is 2.5 times faster than *packing-send* and the physical communication number becomes 1/16 at the best. Also, in a applicational program to solve multiple-arraignment problem, the execution speed is 1.6 times faster and the physical communication number becomes 1/2. This result shows *delay-send* method's practicality.

L\<!

1 O8aK

KL1[1] $O!"JBNsO@M}7?8@8l Guarded Horn Clauses[2] $K4p$E$$$F@_7W5l$?JBNs=hM}$N5-=R$KE,$7$?%W%m%0%i%_%s%08@8l$G$"$j!"$=$NFCD'$r0l8@$G8@$&$JiP5-9f=hM}$rJBNs$K9T$&$?aN8@8l$H$$$&3HKJ$k!#

KLIC[3, 4] $O KL1 $N=hM}7O$G$"$j!"KL1 %W%m%0%i%`$r$$$C$?$s C %W%m%0%i%`$K%3%s%Q%$%k$7!"$=lr%[%9%H%7%9%F%`$N C %3%s%Q%$%i$G%3%s%Q%$%i$7!"<B9T;~%i%$%V%i%j$H%j%s%/$7$F<B9T$9$k!"$H$$$&J}<0$r$H$C$F$$$k!#$7$+$7$J$,$i KLIC $K$h$k KL1 %W%m%0%i%`$N<B9T$O!"IQH/9k:YN3EYDL?.JIKh$k%*!<%P%X%C%I$N$?$a<jB3$-7?8@8l$N=hM}7OHHfY$F<B9TB.EY$NLLGK5ZP:!"<BMQE*$J=hM}7O<B8=$N$?$aKO<B9T7A<0$N2~NI$,I,MWG"$k!#

<B9TB.EY8~>eN?aN2~NIH7FO!"KLIC %i%s%?%$%`%k!<%A%s$N3HD%Kh$jDL?.2s?t$N:o8:$r9T$&C1J}8~DL?.<jK![6, 7] $d0l3gAw?.<jK![8, 9] $,$9GKDs0F5l$F$$$k!#K\8&5fGO!"3N0l3gAw?.<jK!$N3HD%$H7FCY1dAw?.<jK!$rDs0F$9$k!#$3$NCY1dAw?.<jK!$G$O!"0l3gAw?.$r9TCFbJ$*DL?.$,:YN3EY2=7F$=$N8z2L$,$"$^$jF@il$J$$>l9g$KCeL\$7!"<B9T;~>pJs$rMQ$$$F%G!<%?$NAw?.MW5a$KBP7FJV?.rE,EYKCY1d5;$k!#$3$&$7$?DL?.$NF0E*N3EY@)8fKh$j!"$5iJ$kDL?.2s?t$N:o8:$r?^$C$?!#

0J2<!"Bh 2>OGOGX7JH7$FJBNsO@M}7?8@8l KL1 H=$N=hM}7O KLIC!"$5iKK\8&5f$NEZBf$HJk0l3gAw?.<jK!KD$$$F@bL@$7!"Bh 3>O$G$OK\<jK!$NL\E*$H35MW$r=RYk!#<!$KBh 4>O$G$=$N<BAuJ}<0KD$$$F5-=R7?8e!"Bh 5>O$G@-G=I>2A$r9T$$!"Bh 6>OG^Ha$r9T$&!#

2 GX7J

K\>OGO$^$:!"K\8&5f$NGX7J$HJk!"JBNsO@M}7?8@8l KL1 5ZS=$N=hM}7O KLIC $N35MW$K$D$$$F@bL@$7!"$=$N8eK\8&5f$NEZBfHJ$k!"KLIC K*1kDL?.$N:GE,2=<jK!G"$k0l3gAw?.<jK!KD$$$F@bL@9k!#

2.1 JBNsO@M}7?8@8 l **KL1**

2.1.1 %W%m%0%i%`9=B$

KL1 $OFlat GHC $K4p$E$/8@8 l$G!"0J2<$N7A$r 7?@a$N=89g$GI=5l$k!#

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

H, G, B $O=R8 l$G$"$j!"$=$l$>$l%/%m!<%:%X%C%I!"%,!<%I%4!<%k!"%\%G%#%4!<%k$H8F$Plk!#=R8 l$O ‘=R8 lL>/0z?t$N8D?t’ $GI=5-$5lk!#

<B9T$NC10L$O%4!<%k$H8F$Plk!#M?$($il?%4!<%k$HF10l2=$G$-$kh&$J%X%C%I$r;}$D@a$N0lDrA*Br$7!"$=$N@a$N%\%G%#%4!<%k$r<!$N?7$?$J<B9T%4!<%kH9$k!#$3$N2aDx$r7+jJV9$3$HKhCF%W%m%0%i%`$N<B9T$,9Tol$k!#%,!<%I%4!<%k$H7F=q1kNOAH$_9~$_=R8 lN_G"$j!"$^$?0z?t$N6qBN2=$r9T$&3HOG$-$J$$!#%\%G%#%4!<%kH7FOAH$_9~$_=R8 l$H%f!<%6Dj5A=R8 l$r5-=RG-!"JQ?t$N6qBN2=$b9Tol$k!#

=R8 l H $rDj5A$9$k3F@a$N%X%C%I H_i HNF10l2=$*$h$S%,!<%IIt $G_{i1}, \cdots, G_{im}$ $N<B9T$rJBNs$K9T$&3H$,$G$-$k!#B3$$$F!"%,!<%IIt$,@.8y$7$?@a$N$&$A0lD,A*Br5l!"$=$N%\%G%#It $B_{i1}, \cdots, B_{in}$ $rJBNs<B9T$G$-$k!#$^$?$"$k%4!<%k$H%X%C%I$H$NF10l2=$d!"%,!<%I%4!<%k$N<B9T2aDx$GL$6qBN2=JQ?t$X$N;2>H$,9TolkH!"$=$N%4!<%k$N<B9T$O$=$NJQ?t$N6qBN2=BT$AHJCFCfCG$7JL$N%4!<%k$,A*Br$5$l<B9T$,B3$1$ilk!#JQ?t$,6qBN2=$5lk$H!"$3$NCfCG%4!<%k$O<B9T2DG=%4!<%kHJ$k!#

2.1.2 %G!<%?9=B$

KL1 $N%G!<%?9=B$$K$O!"<!$N#3<oN`$,$"$j!"%;%k$H8FPl$k4pK\C10L$G9=@.5l$k!#

- O@M}JQ?t: ;2>H%]%$%s%?$GI=8=5l!"FCDj$N7?$O;}$?$J$$!#6qBN2=KhCFCMXN%]%$%s%?$,3JG<5l!"0lEY6qBN2=5lkHJLNCMK:F$S6qBN2=$9k3HOG-$J$$!#
- %"%H%_%C%/%G!<%?: %7%s%\%j%C%/%"%H%`$d@0?t$JI,3lK"$?$j!"CM$,%;%k$KD>@\3JG<5l$F$$$k!#
- 9=B$7?%G!<%?: J#?t$N%;%k$+$iJj!"3liN%;%kKOG$0U$N7?$N%G!<%? ($^$?$O%G!<%?XN%]%$%s%?) $r3JG<$9k3H,G-$k!#0lHLE*$JbNH7FO%U%!%s%/%?$d%j%9%H$,$"$k!#

2.2 **KL1** =hM}7O **KLIC**

KLIC[3, 4] $O!"KL1 $N=hM}7O$G$"$j!"KL1 %W%m%0%i%`$r$$$C$?$s C %W%m%0%i%`$KJQ49$7$F%*%V%8%'%/%H%3!<%I$N@8@.$O%?!<%2%C%H%^%7%s$N C %3%s%Q%$%i$,9T$&$H$$$&J}<0Kh$j!"9b$$0\?"@-$r<B8=$7$F$$$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$O!"%+!<%M%k$H8F$Plk%i%s%?%$%`%k!<%A%s$,9T$&!#

2.2.1 %G!<%?9=B$

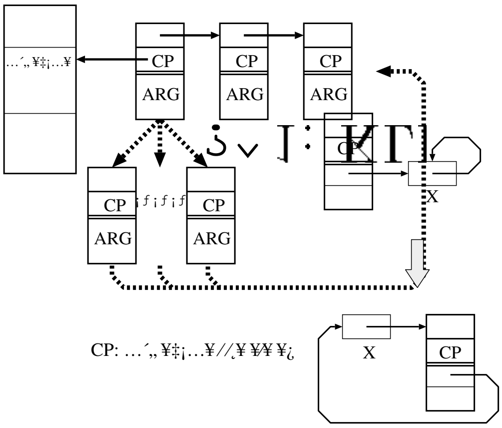
KLIC K*1k%G!<%?9=B$$K$O!"4pK\%G!<%?9=B$!"%4!<%k%1%3!<%I!"Generic object $N3 DN%G!<%?9=B$$,$"$j!"$=$l$>$l0J2<Nh$&$JbNG"$k!#

4pK\%G!<%?9=B$ KLIC GOA0=R$N KL1 $N%G!<%?$r%;%k$K%?%0$rD1k3HKhC$FI=8=$7$F$$$k!#

%4!<%k%1%3!<%I <B9T$NC10L$G$"$k%4!<%k$O%4!<%k%1%3!<%I$H7FI=8=5l!"<!$K<B9T$5lk%4!<%kXN%]%$%s%?!"BP1~$9$k<B9T%3!<%I$X$N%]%$%s%?!"0z?t$+$iJk!#

Generic object KLIC KO!"KL1 $N4pK\%G!<%?$NB>$Kgeneric object $H8F$Plk%G!<%?9=B$$,B8:_9k!#generic object $O%G!<%?NN0h$H%G!<%?$rA`:n$9$k%a%=%C%I$H8FPl$k<jB3$-$+$iJk!#generic object KO data, consumer, generator $N3 DN%?%$%W$,$"$j!"MQES$K1~8F;H$$J,1ilk!#consumer object $H generator object $O6&$KL$6qBN2=JQ?t$rI=$9%?%0$NIU$$$?%;%k(0J2< REF $H8F$V3HK9$k) $K;X$5lF$$$k!#3Nh&$J>uBV$rK\O@GO object $,REF $K%U%C%/$7$F$$$k$H$$$&!#

%+!<%M%k$O generic object $NB8:_$N$_$rCNCF$*$j!"A`:n$rDj5A$7$F$$$k%a%=%C%IrI,MWK1~$8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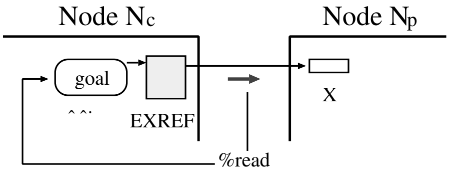
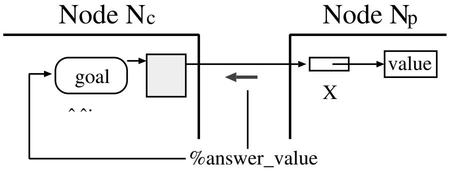
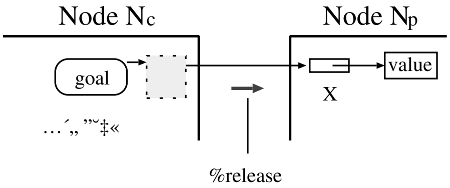


(a)read¥Æ¥ˆ¥»¡…¥/¸` ¿fi



(b)¶æ´¸˜˝⁄¸˚ ¿fi



(c)‡ »†¨¥ ¥⁄¥ ¥¿⁄¸† ˚

?^3: 3OIt;2>H%]%$%s%?$N;2>H

5/$-$?H-$O!"unify %a%C%;!<%8$Khj6qBNCM$r N_p KAwk!#

3. answer_value %a%C%;!<%8$r%N!<%I N_c $,<u?.$9kH!"CfCG%4!<%k goal $O<B9T2DG=%4!<%k%-%e!<$KDJ$,$l$k!#$=7F!"%N!<%I4V%,!<%Y%8%3%l%/%7%g%sN?aK%N!<%I N_p KBP7$F release %a%C%;!<%8$rAw$j!"X $, goal $+$i;2>H5lJ/JC$?$3HrCNi;$k(?^3(c))!#

2.3 0l3gAw?.<jK!

2.3.1 KLIC $NLdBjE@

KLIC GOJQ?t$N6qBN2=$d;2>H$r9T$&%N!<%I$,0lHIE*$K$O<B9T;~$^$GH=L@$;$:!"I,MW$HJC$?;~E@$GAw?.$rMW5a$9kH$$$&MW5a6nF0E*$J%G!<%?$NdjHj$r9T$&!#$=$N$?$a$K!"2.2.3 9`$G=R$Y$?$h$&$K0l2s$N%G!<%?$N$d$j<h$j$K$*$$$F read, answer, release $H$$$&3<oN`$NJ*M}DL?.$,I,MW$HJk!#3N$?$a!":YN3EYDL?.$,IQH/$7Bg$-$J%*!<%P%X%C%IKJ$k!#

$^$?KLIC $N4pK\%b!<%I$G$O!"Aj<j$,I,MWH7$J$$%G!<%?$NAw?.$rHr1k$?$a$K[1]!"$"$kJQ?t X $,9=B$%G!<%?$K6qBN2=$5lF$$$?>l9gKO!"9=B$%G!<%?$N:G30B&NCM7$+JV?.$5lJ$$!#9JoAJ#;($J9=B$%G!<%?$r;2>H$9$k>l9g$K$O%M%9%HKh$K%a%C%;!<%8DL?.$,I,MW$KJj!"3lKhCF$b%a%C%;!<%8?t$,A}Bg9k!#

2.3.2 0l3gAw?.<jK!$N35MW

KLIC GOAw?.$N%b!<%I$r!"9=B$%G!<%?$NAw?.$N:]$K:G30B&$@$1GJ$/A4$Fr^Ha$FAw?.$9kH$$$& !V%P%C%AE>Aw%b!<%I!W$K;XDj$G$-$k!#3N%P%C%AE>Aw%b!<%IGO!"0lEY$N%a%C%;!<%8DL?.$G9=B$%G!<%?Cf$N6qBN2=5l$F$$$kA4FNMWAG$rAw?.$G$-$k!#$=$NH?LL!"Aj<j%W%m%;%9$,;2>H$7$J$$%G!<%?$bAw?.$7F7$^$&$H$$$&LdBj$,$"$k!#$3lKBP$70l3gAw?.$O9=B$%G!<%?$NAw?.$K:]$7$F!"8=:_$G$-$F$$$k$&$A$GAj<j%W%m%;%9$NI,MWH9$k%G!<%?A4$F$r0l3g$7$FAw?.$9$k!#$3lKhj;2>H5l$J$$%G!<%?$rAw?.$9k3HJ$/!"=>Mh$h$j%a%C%;!<%8?t$r8:>/5;k3H,2DG=KJ$k!#

0l3gAw?.$r9T$&:]KO$"$kJQ?tKBP7$F0l3gAw?.$rE,MQ9kY-$+H]$+!"$^$?9=B$7?%G!<%?$K$*$$$FAj<j$,I,MW$H9kNOIN?<5^GJN+$NH=CG$r9T$&I,MW$,$"$k!#

0lJ}!"KL1 GOO0lHL$KJQ?t$O<B9T;~$^$G$=$N%G!<%?7?$,H=L@$7$J$$!#7+$7!"%?%$%W2r@O!"%b!<%I2r@O[9, 10] $H$$$C$?@EE*2r@O$KhC$F!"<B9T;~$K<h$jF@$k%G!<%?7?$N=89g!"JQ?t$N3F=P8=K*1k;2>H!&6qBN2=$NJL!"$H$$$&bN$,$=l>$lH=L@$9$k!#$3li$N>pJs$rMQ$$$k3H$G!">e5-$NH=CG$,2DG=$HJk!#

$=$3$G0l3gAw?.$GO^$:!"@EE*2r@O>pJs$rMQ$$$F!"%G!<%?Aw?.;~$K6qBN2=$5lF$$$k%G!<%?N&$A!"Aj<j$NI,MWH9$kItJ,$rAw?.%P%C%U%!$K3JG<$9$k KL1 %3!<%I$r:n@.9k!#3l$r0l3gAw?.%3!<%I$H8F$V!#$=7F!"<B9T;~K3$N%3!<%I$r<B9T9k3HKhCF!"A0=R$N0l3gAw?.$r9T$&!#

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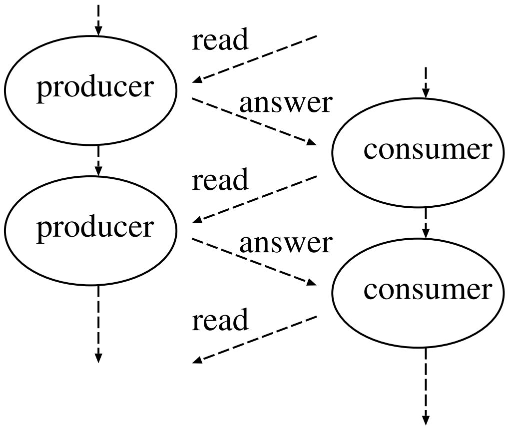
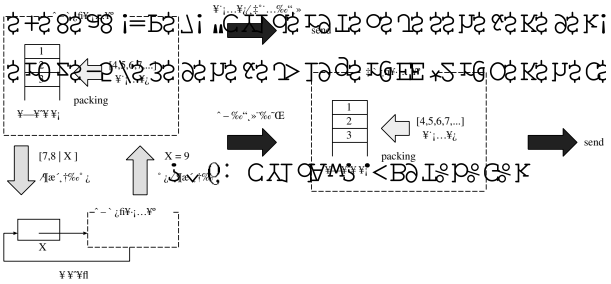
[1] KL1 $N%W%m%0%i%_%s%0%9%?%$%kH7$F!"Nc$($P f(g(h(a))) $H$$$&9=B$%G!<%?$KBP7F!";2>HB&$O30B&$N f(g(_)) $^$G7+;2>H7J$$$H$$$&h&J3HOh/$"$k!#


read
producer
answer
consumer
read
producer
answer
consumer
read

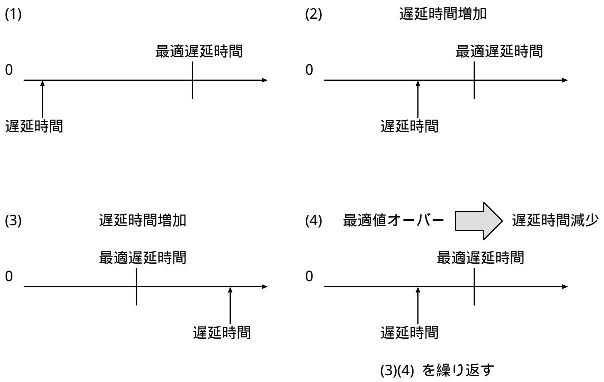

1
[4,5,6,7,...]
packing
send
[7,8 | X]
X = 9
X
1
2
3
[4,5,6,7,...]
packing
send

Dj9kNOFq$7$$!#CY1dAw?.$N8z2L$r>e2k$?$aKO!"CY1d;~4V$r<B9T;~$KF0E*$KJQ2=$5$;!">u67$K$"$o$;$?=@Fp@-$N9b$$N3EY@)8f$r9T$&3H$,I,MW$HJk!#

5FCY1dAw?.<jK!$N<g$?$kL\E*$O!"0l3gAw?.<jK!$GDL?.$,:YN3EY2=9k>l9grHr1k3HG$"$k!#D^$jK\<jK!$G$O!"$^HakNL,ITB-7F$$$k>l9g$K!"CY1d$9k3HKhC$F==J,$JNL$rJV?.$9$k!"$H$$$&N,4pK\E*$JJ}?K$HJk!#hC$F==J,$H;WolkNLr$^$Hailkh&KJk^GO4pK\E*$KCY1d;~4V$OA}2C5;k3HK9k!#7+$7CY1d;~4V$,D9$9$.F"kNLrD6$($k$H!"%G!<%?$N$^$Ha9$.$KhC$F5U$K8zN($,Dc2<$7F7$^$&!#$=$3$G!"0J2<$Nh&$J%U%#!<%I%P%C%/@)8f$r9T$&$3HK9k!#

- CY1d;~4V$O:G=i$OA}2C5;$F$$$/!#
- $=$lKhCF!":GE,$JAw?.NL$rD6$($k%G!<%?$,Aw$ilk3H$,$"$k!#
- $=$N>l9g$O!"<!$NAw?.;~KOCY1d;~4V$r8:$i9h$&$K9k!#
- :GE,$JAw?.NL$rD6$($J$$NL7+Aw?.7J$+$C$?$i!"<!2s$OCY1d;~4V$rA}d9!#

3Nh&K7$F%U%#!<%I%P%C%/@)8f$r9T$&$3HG!":G=*E*KOCY1d;~4V!"Aw?.NL$,$=l>$l:GE,$JCM$K<}B+$7$F$$$/3H$,4|BT$G$-$k!#CY1d;~4V$NA}8:$O;X?t4X?tE*$K9T$&3H$G!":GE,CM$X$N<}B+B.EY$,Aa$^$kh&K9$k!#$=$&$7$?;X?t4X?t$N4p?t$r0J8e$OJQF0N($H8F$V3HK9$k!#$D$^$j!"JQF0N(rVH9kH!"DL>o$OCY1d;~4V$rVG\$7!"Aw?.$7$9$.$?>l9gO1/V$G\$9$k!#$3Nh$&$J@)8f$GCY1d;~4V$,:GE,CMXH6a$E$$$F$$$/MM;R$r?^7$K<($9!#?^$N(1), (2), (3)$N4V$OCY1d;~4V$OJQF0N($K1~8FA}2C7F$$$/!#(3)GO:GE,$H;W$olkAw?.NL$rD6$($?$H7F!"<!$N(4)$GCY1d;~4V$O8:>/$9$k!#



?^7: :GE,CMXN<}B+

3.6 I>2A4X?t

CY1d;~4V$r%U%#!<%I%P%C%/@)8f$GA}8:5;$k>l9g!":GE,$JAw?.NL$rD6$($?$+I&$+$NH=CG$r9T$oJ1lPJi$J$$!#$=$N$?$a$NI>2A4X?t$rINh&$K@_Dj$9k+KD$$$F$3$3GO=RYk!#

$^$:!"I>2A4X?tO=NCMH7F1$+0$NIAi+7+Hi$J$$$bNH9k!#:GE,$H9M$($kAw?.NL$K$^$@C#7F$$$J$$$H$-$OI>2A4X?tCM$r0$K!":GE,JNLr3$($k%G!<%?$,Aw?.$5l?>l9g$OI>2A4X?tCM$r1K9kbNH9k!#

0J2<GO!"ogCMHJk:GE,$JAw?.NL$rIl$/$i$$$K8+@Qbk$+$K$D$$$F8!F$$7$F$$$/!#

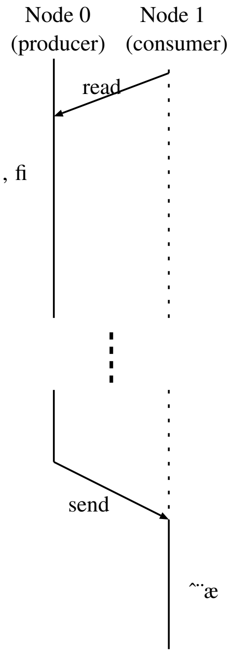
3.6.1 N3EY@)8f$K4X$9$k0lHIE*9M;!

JBNs<B9TKhCF:GBg8B$NB.EY8~>e$rF@kKOI$&$9lP$h$$$+KD$$$F8!F$$9$k!#$9GK$"$2$?!"?^4$Nh&$Jproducer consumer LdBj$KBP7F0lHIE*$K8@$(k3HH7F!"JBNs<B9T$N8zN($r>e2k$?$aKO<!NFsD$NAjH?$9$kMWAG$r9M$($kI,MW$,$"$k!#

1. C`<!<B9T$N3d9g$NA}2CKh$k%G!<%?<u?.B&idle;~4V$NA}2C
2. JBNs<B9T$N3d9g$NA}2CKh$kDL?.2s?t$NA}2C

Aw?.MW5aKBP7$F%G!<%?$r$"$kDxEY$^$HaAwj9k3HK9kH7F!"$=$l$>$l$N6KC<$J>l9g$r?^8$K<($9!#1$N6KC<$J>l9g$O!"A4FN%G!<%?$r@8@.$7=*oCF+$i0l5$$KAwkH$$$&>l9gG"$k!#2$N6KC<$J>l9g$O1$N>l9g$H5U$K!"Aw?.MW5a$r<u$1<h$C$?$i$9$0KG$-$F$$$kJ,$N%G!<%?$rAwkH$$$&>l9gG"$k!#1$N>l9g$O40A4$KC`<!E*$K%W%m%0%i%`$rF0:n$5$;$k$?$a!"consumer B&$N=hM}$,CY$$>l9g$KHs>o$K<B9T;~4V$,$+$+$k!#2$N>l9g$OJBNs<B9T@-$O9b$$$,$=$NJ,DL?.2s?t$,B?$/Jj!"

1.⁄˛¶¸ˆ..⁄ „


Node 0
(producer)
Node 1
(consumer)
read
, fi
send
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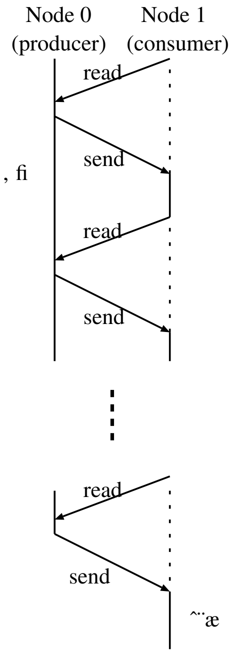
2.⁄˛¶¸ˆ..⁄ „


Node 0
(producer)
Node 1
(consumer)
read
, fi
send
read
send
read
send
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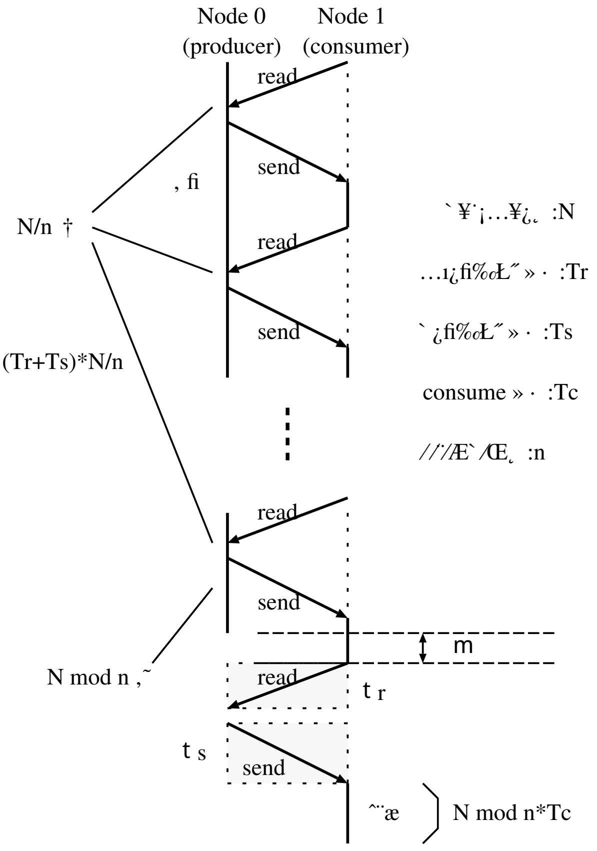


?^10: %H%l!<%I%*%UE@\$N7W;;

0lJ}!"?^\$NE@\$G6/D4\$5\$l\$?ItJ,\$N!"read \$Hsend \$,Aj<jB&\$KE~Ce\$9\$k\$^\$G\$K\$+\$+\$k;~4V\$r\$=\$l\$>\$l τ_r, τ_s \$H\$7!"producer \$,%G!<%?@8@.\$r40N;\$7\$?;~E@\$Gconsumer \$,L\$=hM}\$G\$"\$k%G!<%?NL\$rμ\$H\$9\$k\$Hproducer \$N=*N;8e\$K;D\$k=hM};~4V\$O!"

$$\mu T_c + \tau_r + T_r + k(N\ mod\ n) + \tau_s + (N\ mod\ n)T_c$$

\$H\$J\$k!#

\$3\$N\$3\$H\$+\$i!"n 8D\$:\$D\$^\$H\$aAw\$j\$9\$k\$H\$-\$NJBNs<B9T\$K\$h\$k%3%9%H$c(n)$ \$O0J2<\$N\$h\$&\$J<0\$GI=\$5\$l\$k!#

$$c(n) = (T_r + kn)\frac{N}{n} + \tau_r + T_r + k(N\ mod\ n) +$$

$$\tau_s + (N\ mod\ n + \mu)T_c$$

0lHL\$Kμ\$O$0 \le \mu < n$ \$G\$"\$k\$,!"<B:]\$Nμ\$NCM\$O T_p\$NCM\$d read,send \$N%?%\$%_%s%0\$K0MB8\$7\$F\$*\$j!"\$3\$l\$r5a\$a\$k\$N\$OFq\$7\$\$!#\$h\$C\$Fμ\$O\$=\$N4|BTCM$n/2$ \$G6a;w\$9\$k\$3\$H\$K\$9\$k!#\$^\$?$N\ mod\ n$ \$bF1MM\$K\$=\$N4|BTCM$n/2$ \$G6a;w\$9\$k\$3\$H\$K\$9\$k\$H!"<!\$N\$h\$&\$J<0\$K\$J\$k!#

$$c(n) = (T_r + kn)\frac{N}{n} + \tau_r + T_r + \frac{kn}{2} + \tau_s + nT_c \quad (1)$$

\$3\$N$c(n)$ \$rn \$K\$D\$\$\$FHyJ,\$7\$F6K>.CM\$r\$H\$kkn \$r5a\$a\$k\$H!"<!\$N\$h\$&\$K\$J\$k!#

$$c'(n) = -T_r\frac{N}{n^2} + \frac{k}{2} + T_c$$

$$c'(n) = 0 \text{ \$h\$j!"} n = \sqrt{N\frac{T_r}{T_c + \frac{k}{2}}}$$

\$3\$Nn \$rn_0\$H\$9\$k\$H!"n_0\$OJBNs<B9T\$N%3%9%H\$r>.\$5\$/\$9\$k\$h\$&\$J0l\$D\$NL\0B\$rM?\$(\$k\$H9M\$(\$i\$l\$k!#

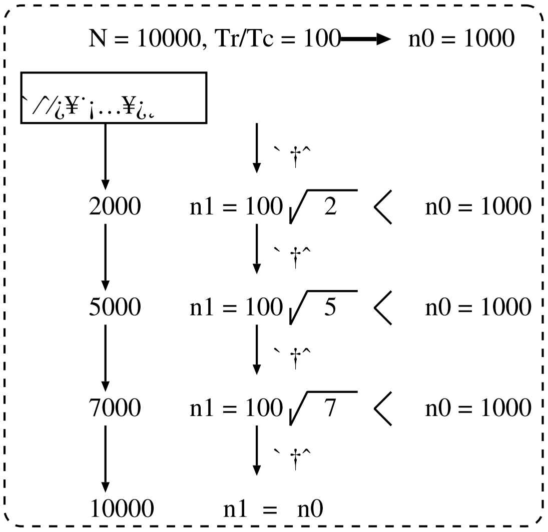
3.6.2 n_0\$N6a;w

$n_0 = \sqrt{NT_r/(T_c + k/2)}$\$rAw?.NL\$H\$7\$F<B9T\$r9T\$&\$H!"\$+\$J\$j8zN(\$N\$h\$\$CY1d\$,9T\$(\$k!#\$7\$+\$7 n_0\$N<0\$NCf\$K\$ON, T_r, T_c, k \$H\$\$\$C\$??tCM\$,4^\$^\$l\$F\$\$\$k!#\$3\$N\$&\$A!"T_r, T_c, k\$O<B9T;~\$K7WB,\$9\$k\$3\$H\$G8m:9\$OBg\$-\$/\$H\$b0l1~F@\$k\$3\$H\$,\$G\$-\$k\$,!"0lHL\$KN\$r<B9T;~\$KCN\$k\$3\$H\$OIT2DG=\$G\$"\$k!#\$=\$N\$?\$a!"0J2<\$N\$h\$&\$Kn_0 \$r6a;w\$9\$kJ}<0\$r9M\$(\$?!#

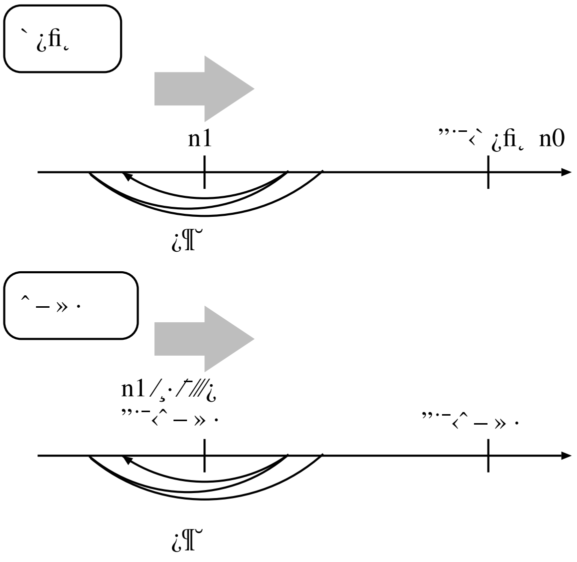
- <B9T;~\$K!"\$3\$l\$^\$G\$KAw?.\$7\$?NL\$r%+%&%s%H\$7\$F\$\$\$/!#
- A02s%+%&%s%H\$7\$?NL\$,N\$@\$C\$?\$H2>Dj\$7\$Fn_0 \$r7W;;\$9\$k!#\$3\$l\$rn_1\$H\$9\$k!#
- <!\$NCY1dAw?.NL\$r\$=\$&\$7\$F7W;;\$7\$?n_1\$K\$9\$k!#

\$3\$N\$h\$&\$JJ}<0\$r\$H\$k\$H!"6a;wCMn_1\$O?^11\$N\$h\$&\$KA}2C\$7\$F\$\$\$/\$,!"\$3\$&\$7\$F7h\$a\$?6a;wCM\$On_0\$r>o\$K2<2s\$k\$N\$G!"CY1d\$7\$9\$.\$F\$7\$^\$&\$H\$\$\$&4m81\$OHr\$1\$i\$l\$k!#

\$3\$Nn_1\$rI>2A4X?t\$K\$*\$1\$kogCM\$H\$7\$FMQ\$\$\$k\$3\$H\$K\$7!"\$=\$N>19g\$NCY1d;~4V\$NJQF0\$NMM;R\$r?^12\$K<(\$9!#n_1\$N7W;;\$K\$O\$3\$l\$^\$G\$NAw?.NL\$N9g7W\$rMQ\$\$\$k\$N\$G!"n_1\$NCM\$O<B9T\$,?J\$s\$GAw?.NL\$,A}\$(\$k\$4\$H\$KBg\$-\$/\$J\$C\$F\$\$\$/!#\$=\$l\$KH<\$C\$FCY1d;~4V\$b?6F0\$r7+\$jJV\$7\$J\$,\$i:GE,CY1d;~4V\$X\$H6a\$E\$\$\$F\$\$\$/!#

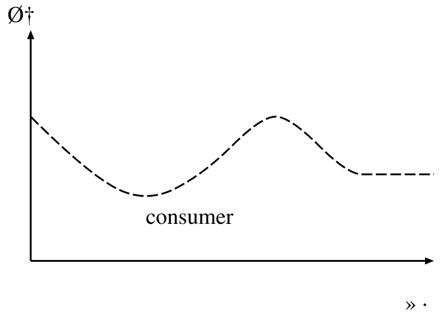


?^ 11: n_0 $N6a;w



?^ 12: <}B+E@$N0\F0

3.7 JQF0N($N@_Dj$HI]2Y%P%i%s%9$NJQ2=



CY1d;~4V$,:GE,CM$NA08e$G?6F0$9$k:]$N?6F0$NI}$O!"JQF0N(NBg-5KHfNc9k!#JQF0N($r>.$5$/$9lP?6F0$NI}$,>.5/Jj!"hj:GE,CM$K6a$$CY1d;~4V$r<B8=$G$-$k$,!"$7$+$7JQF0N($O>.$5$1$l$P>.$5$$[Ih$$H$$$&o1GO$J$$!#2>$KJQF0N($,Hs>o$K>.$5$+$C$?$H9l$P!">.$-6_$JCY1d;~4V$N?6F0$,2DG=$KJC$F:GE,CY1d;~4V$r>o$K<B8=$G$-$kh&$K8+$($k!#$7$+$7<B:]>e!"I>2A4X?t$NogCM$H7FMQ$$$kNO n_0 GOJ/ n_1 G"$k!#$3$N n_1 <+BN$,!"<B9T;~$KA}2C7F$$$/!"$=$N;~E@GN2>$N:GE,Aw?.NL$G$"$k!#hCF3$N?tCM$K87L)$K=>$&3H$,40A4$K:GE,G"kH$$$&3HKOJi$J$$!#7+b3$N n_1 $H$$$&?tCMO3l^GNAw?.NL$rA4BN$H8+J7F=$N;~E@$G=iaF7W;;5l$k?tCM$G$"$j!":G=i$+$i$=$NNL$:$DAwCF$$$l$P:GE,$@C?!"$H$$$&0UL#G7$+$J$$!#3liN3H$r9M$(kH!"JQF0N($r>.$5$/$7$F>o$K n_1 $K6a$$NL$GAw?.$r9T$&$3HKO5$[$IBg$-$J0UL#$,$J$$$3H,J,$k!#$5iK!"$"$^jKJQF0N($,>.$5$$$HCY1d;~4V$NA}2C$N%9%T!<%I$,>.$5$/$JCF==J,JNLrAw?.G-$J$$!"$H$$$&3H$b9M$(il$k!#

3&7?3H$+$i!"JQF0N(O"$kDxEY$NBg$-$5$NDj?tCM$GM?$($k3HK9$k!#$3lKhj!"CY1d;~4V$NA}8:$O;X?t4X?tE*$JB.EY$G9TolkN$G!"A}2C!"$"$k$$$O8:>/$NB.EY$,CY$$!"$H$$$&3HOHr1il$k!#K\Mh!"JQF0N($NBg$-$5$,E,Ev$+I&

%i%`$NF0:n$,$"$kDxEY0BDj7F$$$kH-KOJQF0N($O>.$5JbNHJC$F$$$kO:G"$k!#$=N?$a!"?7$?$J:GE,CM$X$H:F<}B+$5$;$k:]KOJQF0N($r:F$SBg$-$JbNK7$F!"<}B+$NB.EY$r>e$2J1lPJi$J$$!#

3N>l9gLdBjHJkN$O!"Ii2Y$,JQ2=7?3HrINh$&$J4p=`$G8!CN$9$k$+$H$$$&$3$H$G$"$k!#0lHL$K$O@EE*2r@O$G$OD)j@-E*$J@-<A$7$+J,$i$J$$$?$a!"Nc$($P%k!<%W$r$"$k2s?t2s$C$?$i0c$&=hM}$K0\$k!"$H$$$&$h$&$JF0:n$N6h@Z$j$r2r@O$9$k$3$H$O$G$-$J$$7!"Ii2Y$N=E$5$rAjBPE*$KI=8=$9$k$3$H$bFq$7$$!#0lJ}!"F0E*$KIi2Y%P%i%s%9$NJQ2=$r8!=P$9$k>l9g$K$b$=$N$?$a$N4p=`rDjaJ1lPJi$J$$!#9M$($ilkJ}K!H7FO!"<!Nh$&$JFsD,$"$k$@$m$&!#

- consumer B&$N%G!<%?0l$D$"$?jN=hM};~4V$r7WB,$7F*$-!"$=NBg-$JJQ2=$r>u67JQ2=$N4p=`$H7F!"JQF0N(rBg-JbNK:F@_Dj9k!#
- JQF0N($r consumer B&$N%G!<%?0lDJUj$N=hM};~4V$N4X?tH9$k!#

A0<T$O!"!Bg$-$JJQ2=!W$r7k6I$OogCM$GI=$9$3HKJj!"K\<AE*$JLdBj$N2r7hHOJi$J$$!#8e<T$O!"Nc$($P consumer B&$N=hM};~4V$KHfNc$5$;$kH7Fb!"$=$NHfNcDj?trINh$&$KDjak$+$,LdBj$G!"$3lbA0<T$HF1$8$/7P83E*$KDjak7+$J$$!#3Nh&$K!"JQF0N($rF0E*$K@)8f$9kH$$$&J}<0rHkH!"Ii2Y%P%i%s%9$NJQ2=$KBP9kBP1~$H$$$&LdBj$,@8$8F7$^$&!#3l$OJQF0N($r>.5/7F1 $K6a$E1k3H$+$i@8$8$kLdBjG"$k!#$3$&$7$?<BAu>e$NLdBj$+$i8+Fb!"JQF0N($rF0E*@)8f$9k3HN%a%j%C%H$O>.$5$$$H9M$($ilk!#3&7?3H$+$i$b!"JQF0N($O8GDj9kJ}$,NI$$$H9M$($ilk!#

3.8 =i4 |CY1d;~4V$N@_Dj

CY1d;~4V$O:G=iHs>o$K>.5JbN$K@_Dj$7!"2?EY$bF1$8h&$KAw?.MW5a$,9TolkH=y!9$KA}2C$7$F$$$/!#7+$7!"I,$:>.5J=i4 |CM$rM?$($F$$$k$H8z2L$,A4$/$G$J$$$h$&$JNc$,$"$k!#$=lO>.$-$6$_$K%4!<%k$rB>$N%N!<%IKEj2$F<B9T$9$k>l9g$G!"$"$kDxEY>.5J%G!<%?NLKBP9k^H^C?=hM}$r!"2?EY$bB>%N!<%I$KI i2YJ,;6$5$;$kh&$J%W%m%0%i%`$NH-G"$k!#$3lO producer consumer LdBj$r%9%1!<%k$r>.5/7F2?EY$b7+$jJV$9!"$H$$$&h&$K9M$(k3H,G-$k!#$3Nh$&$J>l9g!"0l;~E*$K producer consumer E*$J9=B$$,=PMh>e$,$k$,!"$9$0$K9=B$$,>CLG7F7^$&$N$G!"CY1d;~4V$,=i4 |CM$+$i$"$^$jA}$($J$$H$$$&LdBj$,@8$8$k!#

3&7?LdBj$KBP=h$9k?aK!"$=$&7?producer consumer E*$J9=B$$,$$$C$?$s>CLG9k:]K=$N;~E@$NCY1d;~4V$rJ]B8$7F*$-!"<!2s$N=i4 |CMO=$NJ]B8CM$K@_Dj9kJ}<0rHC?!#F1$8$h$&$J9=B$$,G-$k>l9g$K$O!"$=lKBP9kCY1dAw?.%4!<%k$bF1$8<dN`$N$b$N$,<B9T$5$l$k$3$H$K$J$k$N$G!"CY1dAw?.%4!<%k$N<dN`4HK=$&$7$?CY1d;~4V$rJ]B8$9$kNN0h$r3NJ]$9k3HG3NJ}<0$r<B8=$7$?!#

3Nh&K9k3HG!"=i4 |CM<+BN$r:G=i$+i"$kDxEYBg$-JbNK@_Dj9k3H$,$G$-$k!#5i$K!"$3$N=i4 |CM$H$$$&NO$"$kDxEY$N2s?t$=$&$7$?7+$jJV7,9Tol$?8e$O!"n_0 rbHK7???$N:GE,CY1d;~4V$KJC$F$$$k$H9M$(il$k!#$D$^$j!"n_1 NCM,:G8e$NCJ3,$GOn_0$ K+Jj6a$$$bNKJC$F$$$?O:$G!"$3lr4p=`H7$F@_Dj$5l?:G=*E*$JCY1d;~4V$O??$N:GE,CY1d;~4V$K6a$$$bNKJC$F$$$k!"$H9M$(k3H,G-kNG"$k!#

4 <BAuJ}<0

4.1 n_1 $N<B9T;~$K$*$1$k7W;;

n_0 $N6a;wCM$n_1$ $r7W;;$9k?aK$O!"$^$::$T_c, T_r, k$ $r<B9T;~$K7WB,7J1lPJiJ$$!#3NJ}K!$r0J2<$K<($9!#

?^14$G9M$($k!#producer B&$O!"%a%C%;!<%8$N<u?.$K$+$+$k=hM};~4V$T_r$ $r7WB,$9$k!#<!$K!"%G!<%?$N3JG<3+;O$N;~9oT_0 $H3JG<=*N;$N;~9oT_1 $N:9$H!"Aw?.%G!<%??t n $+$i k $,5a$ail$k!#$=7F n $H k $rJV?.$KIU$12C$($F consumer B&$KAw$k!#

0lJ} consumer B&$OJV?.$r<u$1<h$C$?:]$K;~9o$rD4$Y!"3N;~9orT_2$ H9$k!#$=7F:F$SAw?.MW5a$r9k:]$K;~9o$rD4$Y($3l,T_3)!"3l$H<u$1<hC?%G!<%??t n $+$i $T_c = (T_3 - T_2)/n$ $r5a$ak3H,G-$k!#$5iK!"3l$^$G$K<u$1<hC?%G!<%?$NAmNL$r?t$($F$*$-!"3l$rA4%G!<%?NL N

NBeojH9k!#$3$1iN?tCM$+$i<!$NCY1dAw?.NL$H7F n_1 $r7hDj$7!":#2sAwi1F-$?%G!<%??t n HNHf3S$KMQ$$$k!#

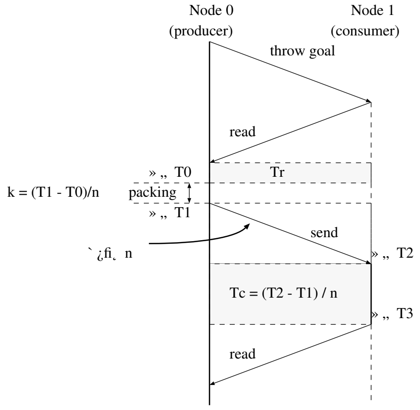
$?$@$7$3$1$G$O T_r, T_c, k NCMKPiD-$,GkNG!"$3$1$iNCMO$3$1$^GNJ?6QCM$H7FNCMK9k!#D^$jA02s!"A0!92s!"!D$N T_r, T_c, k NCMOC_@Q5;$F$$$-!"$=$1iNCM$H:#2s7WB,$7$?CM$rJ?6Q9k3HK9$k!#

4.2 idle >uBV$N8!=P

CY1d;~4V$rA}$d$7$9$.$FBTA9$.$?7k2L!"$=$N%N!<%IFb$G<B9T$G$-$k%4!<%k$,$J$/$JCF7^$&>19g$,$"$k!#B>$N%N!<%I$N<B9T$N1F6A$GL$6qBN2=JQ?t$,6qBN2=$5$1!"<B9T2DG=%4!<%k$,?7$?$KA}$(F=1Khj%G!<%?$,$G$-$k!"$H$$$&2DG=@-$r=|30$9kH!"3N>19gO3$10J>eCY1d$9kN$OL5BL$G$"$k$+$i$9$0$K%?%$%`%"%&%HN?aN%U%i%0$rN)$FkY$-$G$"$k!#3&7?@)8f$r<B8=$9k?aK!"<!Nh$&$JJ}<0rH$j$$$1$?!#

- CY1dAw?.%4!<%k$N<B9T3+;O$HF1;~$K!"idle process $H$$$&%4!<%k$r<B9T$9$k!#$3$1$O%?%$%`%"%&%H$N$?$a$N%U%i%0$r6qBN2=9k$@$1$N%4!<%k$G$"$k!#
- KLIC GO%4!<%k$N<B9TM%@hEY$r5-=RG-kN$G!"$3$N5!G=$r;HCF idle process $N<B9TM%@hEY$O$"$ifk%4!<%kNCfG:G$bDc$$$!":GDcM%@hEY0 $K@_Dj$9$k!#

%N!<%IFb$K<B9T2DG=$J%4!<%k$,$J$/$Jk^G3$N idle process $O<B9T$5$1$J$$!#$3$1KhCF!"%N!<



I=1: 3F%W%m%0%i%‘$N<B9T7k2L

pro_con (%N!<%I?t 2)						
cons/prod	%N!<%^%k		0l3gAw?.		CY1dAw?.	
	;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t
0.033	114.3	30002	28.78	7188	11.55	464
0.17	115.2	30002	26.88	6360	11.45	441
0.33	116.7	30002	23.73	5203	11.49	458
0.50	118.8	30002	20.08	3912	11.31	443
0.67	122.4	30002	18.34	3203	11.47	504
0.83	126.6	30002	13.96	1608	11.33	538
1.00	125.8	30002	10.28	177	10.28	156
1.33	130.7	30002	13.04	45	13.09	43
1.67	134.9	30002	16.08	31	16.13	31

hand_shake (%N!<%I?t 2)					
%N!<%^%k		0l3gAw?.		CY1dAw?.	
;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t
152.0	54006	27.97	6602	11.90	422

pia (%N!<%I?t 3)					
%N!<%^%k		0l3gAw?.		CY1dAw?.	
;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t	;~4V(IC)	DL?.2s?t
211.8	41704	78.30	17843	49.45	8881

$@$1=‘Hw5lF=l,GSB>@)8f5l$F$$$?!#$=$N$?$a4vD+$N0l3gAw?.%4!<%k$,F1;~$KF0$3$&$H9k3HOJ$/!"@h$K5/F0$5$l$?0l3gAw?.%4!<%k$,=*N;9k$^$G$O;D$j$N0l3gAw?.%4!<%k$O%-%e!<KDJ,lFBT5!9k9=B$$KJC$F$$$?!#CY1dAw?.<jK!GO3Nh&$J=hM}$r9k$H!"A0$K@8@.5l$?CY1dAw?.%4!<%k$NCY1d;~4V$H$$$&NO8e$K@8@.$5l?CY1dAw?.%4!<%k$NCY1d;~4V$KbJCF7^$&!#$3lrHr1k$?$a!"%P%C%U%!NN0h$NGSB>@)8f$OHjda$FCY1dAw?.%4!<%kKh$K%P%C%U%!NN0h$r3NJ]$9$kJ}<0$K7?!#$?$@$7$3lG$ONN0h3NJ]$N$?$a$N%*!<%P%X%C%I$,Bg$-$9$.$kNG!"%P%C%U%!NN0hO"i+8a4vD+3NJ]7F$*$-!"$=$NCf$+$i8=:_;HMQ5l$F$$$J$$$bNr;H$&$3HK7?!#%P%C%U%!$N?t$,B-jJ$/$JC?$iDI2C$7!";H$$$=*oC$?%P%C%U%!$OB>$NCY1dAw?.%4!<%k$,:FMxMQG-kh$&$K9k!#

5 @-G=I>2A

5.1 I>2ABP>]

I>2AMQ$N=hM}7O$H7F!"0J2<NbNrMQ$$$?!#

- PVM version 3.3.11, KLIC versin 2.002, %$!<%5%M%C%H$G7k9g7?SPARCStation 20 4 Bf

$^$?!"I>2AMQ$N%W%m%0%i%‘$H7F<!$N3 DN%W%m%0%i%‘$rMQ$$$?!#

pro_con :G$bC1=c$J producer consumer E*F0:nr9$k%W%m%0%i%‘$G$"$k!#

hand_shake %N!<%I4V$G!"$*8_$$$K$^$H$^$G$?%G!<%?$rdj<hj7J,$i6(D4F0:n$9$k%W%m%0%i%‘$G$"$k!#

pia %?%s%Q%/<AG[Ns$NN‘;wItJ,$rB7$($k%^%k%A%W%k%"%i%$%a%s%H$r9T$&%W%m%0%i%‘$G$"$k!#

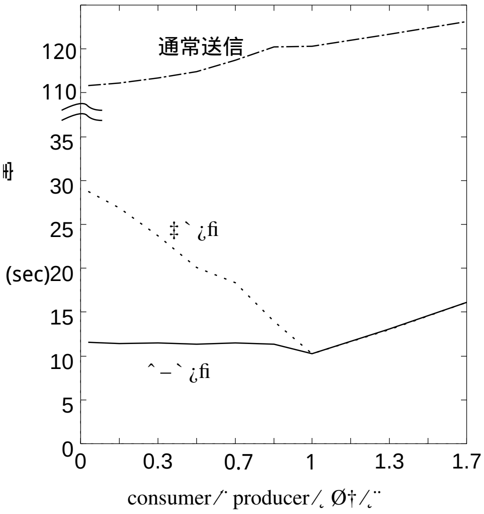
5.2 <B9T7k2L

A0=R$N3 DN%W%m%0%i%‘KD$$$F!"%*%j%8%J%k KLIC HG!"0l3gAw?.HG!"CY1dAw?.HGN=l>lG<B9T$7!"@-G=I>2A$r9TC?!#7WB,9‘L\$O<B9T;~4V$*$h$SJ*M}DL?.2s?t$G$"$k!#$=$N7k2L$rI=1$K<($9!#FC$Kpro_con KD$$$F$O%W%m%0%i%‘$N%Q%i%a!<%?$rMM!9$KJQ2=5;$F@-G=I>2A$r9TC?!#

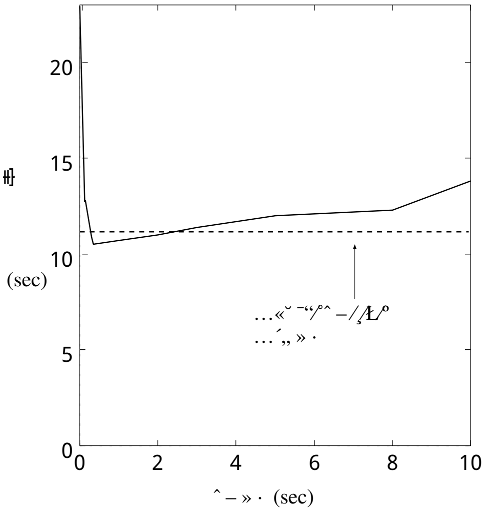
5.2.1 pro_con

Am%G!<%??tN $r10000 $K8GDj$7!"producer, consumer $NAPJ}$G!"0lDN%G!<%?=hM}4H$K6u%k!<%W$r2s7FI i2Yr+1F$$$k!#I=$N%G!<%?$O!"producer B&$K==J,$J0lDjI i2Yr+1F!"0l3gAw?.GOAwj-lJ$$%G!<%?$,B??tB8:_$9kh$&$K7?>l9gNbNG$"$k!#I=Cf$Ncons/prod $O!"APJ}$NI i2YNHfG$"$k!#

producer $H consumer $NI i2Y$,N%lF$$$k>l9gKO!":G$bNI$$>l9g$G0l3gAw?.$KHfYF<B9TB.EY$,2.5 G\!"DL?.2s?t$,1/16 KJCF$*$j!"Hs>oKBg-$J8z2L$,F@il$F$$$k$,!"consumer B&$NI i2YrJQ(kH!"CY1dAw?.$N8z2L$bJQoCF-$F$$$k!#$=$NMM;R$r%0%i%U$K7?N,?^15G"$k!#?^$h$j!"producer consumer E*$J9=B$$r;}C?%W%m%0%i%‘K*$$$F$b!"consumer B&$NI i2Y$,producer B&0J>e$KJl$P!"producer B&$,Aw?.MW5a$N9g4V$N;~4V$G==J,$JNL$N%G!<%?$r@8@.G-kh$&$KJk$?$a$K!"CY1d$r9ToJ$/$F$bE,@Z$JN3EY$GDL?.$,9T$($k3H$,$o$+$k!#3l$O!"$n_0$ $N<0$GT_c $,J,J1$K8=lF$$$k$?$a!"3N?tCM$,Bg$-1l$P:GE,Aw?.NL$,>.5/Jk!"$H$$$&3H$KBP1~$7$F$$$k!#D^$j!"0l3gAw?.$HHfYFCY1dAw?.$N8z2L$,8=lkNO!"producer HHfY$F consumer $NI i2Y$,>.$5$$>l9gG"kH$$$($k!#



?^15: consumer B&$NIi2Y$HCY1d8z2L



?^16: <jF0CY1dHNHf3S

$^$?!"CY1dAw?.$r9T$&$H<B9TB.EY$,consumer B&$NIi2Y$NJQ2=$K1F6A$5$1$K$/$/Jk$H$$$&FOD’b"$k!#$3$1$OE,EY$KCY1d$r9T$&$?$a!"consumer B&$N=hM};~4V$,producer B&$N=hM};~4V$K1#JC$5$1$k$?$a$@$H9M$($i1k!#$=$1$H4X78$7$F!"consumer B&$NIi2Y$,producer B&$NIi2YhjbBg-$/$J$k cons/prod=1 $NIU6a$r6-$K!"CY1dAw?.$Khk<B9T;~4V$O0l3gAw?.$N$=$1$K0lCW$7$FA}2C$7;OaF$$$k!#

<!$K!"prod/cons=0.33 $K@_Dj$7!"CY1d;~4V$r8GDj$5$;$?>l9g$H<+F0$GCY1d;~4V$rJQF0$5$;$?>l9g$N<B9T;~4V$rHf3S7?!#$=$N7k2L$r?^16$K<($9!#2#<4$,$"$i$+$8$a8GDj$7F*$/CY1d;~4V$G!"=D<4$,<B9T;~4V$G$"$k!#<jF0$G7P83E*$KCY1d;~4V$rJQ2=$5$;$?>l9g$O!"0.1 $+$i 0.5 IC$NCY1d;~4V$G:G$b<B9TB.EY$,B.$/$JCF$$$k!#<+F0E*$KCY1d;~4V$r@)8f7?>l9g$N<B9T;~4V$O:GE,CM$N 10.5 IC$KBP$7 11.5 IC$H!"7P83E*$K5a$a$?M}A[E*$J>l9g$HB=?’$J$$<B9TB.EY$,F@$i1F$$$k3H$,J,$k!#

3&7? procuder $H consumer HKo+1?9=B$$O0lHLKh$/8+$i1k7AG"kN$G!"B>$N1~MQE*$J%W%m%0%i%`$KBP7F$bCY1dAw?.$N8z2L$O==J,$K4|BTG-kH8@$($k!#

5.2.2 hand_shake

FsDN%W%m%;%9$,$"$kDxEY$NI}$r;}$C$?%G!<%?$r$*8_$$$Kdj<hj7$F6(D4F0:n$9$k%W%m%0%i%`$G$"$k!#JRJ}$N%W%m%;%9$K$@$1$"$kDxEY$NIi2Y$r$+$1$F$*$j!"$3$1$O pro_con $,$*8_$$$K$=$NLr3d$r8rBe$7$J$,$iF0:n$9$k%W%m%0%i%`$H$$$&8+J}$,$G$-$k!#hC$FCY1dAw?.$N8z2L$bNI9%$JbN$,F@$i1F!"0l3gAw?.HHfY$F<B9TB.EY$,2.4 G\!"DL?.2s?t$,Ls 1/15 KJCF$$$k!#

5.2.3 pia

%^%k%A%W%k%"%i%$%s%a%s%H$r9T$&1~MQE*$J%W%m%0%i%`$G$"$k!#$3$N%W%m%0%i%`$O!"$"$"$kDxEY>.5J$^$H$^$C$?=hM}$r4vD+$N%N!<%I$KIi2YJ,;6$7$F!"$=$N7k2LrbHK:F$SF1$8h&$J=hM}$r7+jJV9$H$$$&9=B$$KJC$F$$$k!#$=$N$?$a!"$=$&7?=hM}$N 1 %5%$%/%k$N4V$K$O==J,$JCY1d;~4VKJk3H,G-$J$$!#7+$7!"3.89 `$G=RY?h&$JCY1d;~4V$N=i4|CMKBP9$k%U%#!<%I%P%C%/=hM}$r9T$&$3HG==J,$JCY1d$r9T$&$3H,G-$?!#$=N?$a!"$3$NLdBj$KBP7F$bCY1dAw?.$N8z2L$,$G$F!"0l3gAw?.$KHfYF<B9TB.EY$,1.58 G\!"DL?.2s?t$,1/2 KJCF$$$k!#

6 $*$ojK

K\O@GO!"KLIC K*1k0l3gAw?.<jK!$N3HD%$H7F$NCY1dAw?.<jK!$H!"$=$N@-G=I>2AKD$$$F=RY?!#

K\8&5fGO!"%G!<%?$N@8@.B&$N%9%T!<%I$,CY$/

0l3gAw?.KhCFbJ$*DL?.$,:YN3EY2=9k>l9g KBP7!"JV?.rE,EYKCY1d5;$FDL?.$NN3EY$r>e$2 $kCY1dAw?.<jK!$rDs0F!"<BAu7?!#<B9T;~$K%U%#!< %I%P%C%/@)8f$r9T$&$3HGE,EY$JJV?.CY1d$r<B8= $7!"$=lKhC$F<B9TB.EY$N8~>e$rC#@.$9k3H, G-$?!#$^$?!":GE,$JAw?.NL$N7W;;<0$rbH$a!"<B 9T;~$K$=$N6a;wCM$rMQ$$$k3H$G2aEY$NCY1dKh $k@-G=$NDc2<$H$$$&LdBj$r2r7h$9k3H,G-$?!#

4JC1$J4v$D$+$N%Y%s%A%^!<%/%W%m%0%i%`$K$*$$ $F@-G=$rI>2A$7$?$H$3$m!"M}A[E*$JN3EY@)8f$K$h $k<B9T$N>l9g$HB=?'$J$$<B9TB.EY$r<B8=$G$-!"Hs >o$KNI9%$J7k2L$rF@$i$l$?!#$^$?l~MQE*$J%W%m%0 %i%`KBP7Fb!"0l3gAw?.KHfY$FLs 1.6 G\$NB. EY8~>e$,F@$i$l!"<BMQLL$K$*$$$F$bCY1dAw?.$,M- 8zG"k3Hr3NG'9k3H$,$G$-$?!#

0lJ}!"CY1d;~4V$dJQF0N($NA}8:$O!":Y$+$$@)8f $r9T$C$F$$$J$$!#3&7?A}8:$r%Q%i%a!<%?$rMQ $$$F:Y$+$/%3%s%H%m!<%k9kh&$K3HD%$9k3$H $OMF0W$G$"$k!#$=$Nh&K9k3HG!"CY1d;~4V $dJQF0N($rhj7P83E*$K:Y$d$+$KDjak3H$,2D G=$HJj!"$=$&7?LdBj$K9g$o$;$?CY1d@)8fKh$C F5iKB.EY$r8~>e5;$k3H$,G-kH9M$($i lk!#

<UK-

K\8&5f$N5!2q$rM?$($F$/$@5C$?IYEDbC<#65<x $K?<?S$J<U0U$rI=$7$^$9!#E,@ZJ4;XF3$r;r$C$? CfEg9@=u65<x!"?9bC0lO:=u65<x$*$h$S?t!9$NM-1W J40U8+$rD:$$$?8^Eg@5M5=u<j$K46<UCW$7$^$9!#

$^$?!"MM!9$K5.=E$J$4=u8@$r7FD:$$$?KL1 %? %9%/%0%k!<%W$NBgLnOBI';a!"0K@n2mI';a!"DEM88x 6G;arO8aH7$F!"F|:"8fF$O@D:$$$?5~ETBg3X 9)3XIt>pJs9)3XEJIYED8&5f<<$N=t;a$K$*Ni?=$7>e 2^$9!#

:G8e$K!"$3l^$G;Y$(HJCF$/$l$?M'?M!"5Z$S 6lO+r+1F$$$kN>?F$K?4$+iN46<UrCW7$^$9!#

;29MJ88%

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[6] 9b;32mM[, “JBNsO@M}7?8@8l=hM}7O KLIC $K $*$1$kC1J}8~DL?.$N<BAu$HI>2A”, FCJL8&5fJs 9p=q,1996.

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[8] 0K@n2mI', BgLnOBI', CfEg9@, IYEDbC<#, “JBNsO@M}7?8@8l=hM}7O KLIC K*1kDL?.$N9bB.2=”, >p=h8&Js 95-PRO-2,pp.105-112,1995.

[9] BgLnOBI', 0K@n2mI', ?9bC0lO:, CfEg9@, IYEDbC<#, “@EE*2r@OKh$kJBNsO@M}7?8@8l KL1 $NDL?.:GE,2=”, JSPP’95,pp.169-176,1995.

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