FCJL8&5fJs9p=q

<+F0JBNs2=%3%s%Q%$%i **TINPAR** $N@-G=I>2A

;XF36541 IYEDbC<#65<x

5~ETBg3X9)3XIt>pJs9)3X2J

EDCfMxI’

J?@.10G/27n13F|(6b)

<+F0JBNs2=%3%s%Q%$%i **TINPAR** $N@-G=I>2A

EDCf MxI'

FbMF9<35

6aG/!"J,; 6%a%b%j7?JBNs7W;;5!MQ$N%G!<%?JBNs5-=R8@8 l$H7F HPF(High Performance Fortran) $,CmL\$r=8$a!"; v<B>e$NI8=`$rL\; X$7$F8=:_$bI8=`2=:n6H$, ?J$ail$F$$$k!#$=$3$G2f!9$O!"8=:_3+H/Cf$N<+F0JBNs2=%3%s%Q%$%i **TINPAR** KBP7!"HPF $N Subset $NJ8K!$r2r<aG-$k%U%m%s%H%(%s%I$HJk%W%m%0%i%` $r:n@.$7$3$l$KBP1~$7$?!#$^$?$3$N:]!"$3$l$^$G **TINPAR** $G$O07$($J$+$C$? <jB3$-8F$S=P$7$X$NBP1~$b9T$C$?!#$3$N7k2L!"$h$jJ#;($J?tCM1i;;%W%m%0%i%` $b<B9T$G$-$kh&KJC?!#

$=$3$G!"HPF $N%H%i%s%9%l!<%?$H7F$N **TINPAR** $,$I$NDxEY$N<BNO$r;}$C$F$$$kN+$rB,$k$?$a!"3l$^$G **TINPAR** $G;n$7$?;v$N$J$$FCD'E*$JJBNs8~$1?tCM1i;;%W%m%0%i%`$rMQ$$$F **TINPAR** $N@-G=I>2A$r9T$C$?!#$3$3$G8@$&@-G=I>2A$H$O!"C1$K **TINPAR** $,=PNO$7$?JBNs%3!<%I$NC`<!%W%m%0%i%`$KBP$9$k Bf?t8z2L$N$_$rI=$9$o$1$G$O$J$/!"<+F0%G!<%?J,3dI t$NI>2A$d%W%m%0%i%`$N=q$-d9$5$JINAm9gE*$JI>2A$H7F$$$k!#

07C?%W%m%0%i%`$O%b%s%F%+%k%mK!$N EP(Embarassingly Parallel)!"2<!85 ADI(Alternative Direction Implicit)K!!"THOMPSON 2rK!$K$h$k%a%C%7%e@8@.%W%m%0%i%`$N Tomcatv $N;0$DG"$k!#$3liO=l>$l!"%j%@%/%7%g%s1i;;!"%G!<%?$N:FJ,;6!"FC<l$J%G!<%?J,3dJ}K!$H$$$&FCD'$r;}$CF*$j!"JBNs%Y%s%A%^!<%/%W%m%0%i%`H7Fh$/MQ$$$ilF$$$k!#

$^$:!"3N;0DN%W%m%0%i%`$r8=>u$N **TINPAR** $GJBNs2=$7$?$H$-$NBf?t8z2L!"8zN(E*$JJBNs2=$rK8$2$kMW0xH=$N2r7h<jK!!"2r7h8e$NM=A[5l$k<B9T;~4V$r<(7?!#

7k2L$O!"Ev=iM=B,$7$F$$$?@-G=KO1s$/5Z$PJ+C?!#3liN%W%m%0%i%`$NI>2A$r$9$k$&$A$K!"$3$l$^$G$O5$IU$+$J$+$C$? **TINPAR** $N<eE@$H$b8@$&$Y$-8D=j$,IbD&$j$K$J$C$F$-$?$N$G$"$k!#4pK\E*$J%W%m%0%i%`$NJBNs2=$K4X7F$O35$MNI9%$J7k2L$rF@$F$$$? **TINPAR** $@$,!">/$7J#;($J9=B$$N%W%m%0%i%`KJkH%f!<%6$,$+Jj9)IW7?5-=R$N;EJ}$r7J$$$H!"NI$$Bf?t8z2L$rF@$k3H$,$G$-$J$$3H,o+C?!#$^$?!"8=:_$N **TINPAR** GO$=$N9)IWr9k?

aK$O!"%f!<%6$,JBNs2=%3%s%Q%$%i$NJBNs2=<jK!KD$$$F!"=OCN7F$$$J1lPJiJ$$$H$$$&LdBj$,$"$k!#$3$N860x$H7F!"C1=c$JJBNs2=<jK!$rE,MQ7?8e$N:GE,2=$,=<J,GJ$$$3H,5s2ilk!#

EP GO!"8=:_$N TINPAR $K%j%@%/%7%g%s1i;;$r8!=P9k5!G=$,$J$$$?$a!"4pK\E*$JJBNs2=7+9Tol$:!"%j%@%/%7%g%s1i;;$r9kEY$KDL?.$r5/F0$7$J1lPJiJ$/$J$k!#BP=hK!$H7F$O!"$=$NJQ?t$b7/$OG[Ns$,%j%@%/%7%g%s1i;;G"k3Hr<($9!"HPF $K=`5r$7$?;X<(J8$rF3F~9k3HKh$jBP1~$G$-$k!#

ADI $O%G!<%?$N:FJ,;6KHbJ$&BgNIAw<u?.$,5/3k%W%m%0%i%`G"$k!#$3lKBP7F$ODL?.%i%$%V%i%j$N2~NI$KhkDL?.$N5/F02s?t:o8:$KhjBP1~G-$k!#

Tomcatv $OJ,3d$,;\$5l?G[Ns$+$iJ,3d5l$F$$$J$$G[NsXNBeF~$,$"$j!"C1=c$JJBNs2=$@$1GO%V%m!<%I%-%c%9%H$r>7$$$F7^$&!#BP=hK!$H7F$O**TINPAR** $G=>Mh$+$i9T$olF$$$k%G!<%?%U%m!<2r@O$NBP>]$r%9%+%iJQ?t$+$iG[NsXH3HD%9k3HKh$jBP1~$G$-$k!#

TINPAR $OHs>o$K3HD%@-$,9b$/!"JBNs2=$N:GE,2=<jK!$d!"DL?.%i%$%V%i%j$JIN2~NI$,MF0W$K9T$($kh&$K@_7W$5lF$*$j!">e=R7?<jK!$bHf3SE*MF0W$K<BAuG-kbNH;Wol$k!#

K\Js9p=qGO3liNLdBjE@KBP7!"**TINPAR** $,$3l^$G9T$CF-$?:GE,2=$r>/7@$13HD%$9k3HKhj!"%f!<%6$O??$K%0%m!<%P%k$J%a%b%j6u4V$rA[Dj7?C`<!%W%m%0%i%_%s%0$G!"8zN(E*$JJBNs2=$r9T$(k3Hr<(7?!#

Performance Evaluation of Automatic Parallelizing Compiler TINPAR

Toshihiko TANAKA

Abstract

Recently, HPF(High Performance Fortran) -a data parallel language for distributed memory parallel machines- is widely noticed, and currently standardized to intend to be De-fact standard. So, we are developing an automatic parallelizing compiler 'TINPAR' , and we have made the program which interprets HPF grammar. And, on this occasion, we correspond to subroutine call , which is TINPAR couldn't use before.Consequently, we can execute more complex numerical calculation programs.

So, in order to test the ability of TINPAR as a HPF translator, we evaluate the performance of TINPAR by peculiar numerical calculation program we have never tried , We mean the performance evaluation as to express not only speedup ratio but also the evaluation of an automatic data distribution method and a facility of programming and so on.

We used three programs, EP(Embarrassingly Parallel), two dimensional ADI(Alternative Direction Implicit)method, and Tomcatv:a mesh generation program by THOMPSON solver. Each program has the problems that is reduction operation, data redistribution, and particular data distribution , and these are frequently used as benchmark programs.

We show the speedup ratio of these three programs, the cause to disturb an efficient parallelizing and a few solution , and the estimated execution time after the problems are solved.

The result shows far lower performance than we expected. while trying these programs, we have become aware of the weak points of TINPAR which have never been seen. In case of basic parallel programs,TINPAR shows good result, but in some complex cases, we can't get good scalability unless users use his brains. And at present, to do this, user must know about parallelizing method of TINPAR well. This is due to that optimization is still not enough.

TINPAR can't recognize reduction operation, so applies only basic parallelizing method, processors must communicate each other at any time when reduction operation is occurred. The solution is to introduce the HPF directive `REDUCE`, to make compiler to recognize a scalar or array variables do reduction operations.

ADI is the program which requires much communication at data redistribution time. The solution is approvement of communication library to decrease occurrence of communication.

Tomcatv contains substitution from distributed array to undistributed one, so if simply parallelized , broadcast is occurred. The solution is to change and expand the target of communication optimization.

TINPAR is able to be highly expansioned, so we can easily approve an optimizing method for parallelizing or communication library. We can also implement The method mentioned above comparatively easily.

This report shows that TINPAR can deal with these problems only to expand the existing optimizing method only a little. As a result users can do efficient parallel programming in global memory space as if sequential programming.

<+F0JBNs2=%3%s%Q%$%i **TINPAR** $N@-G=I>2A

L\<!

1 O8aK

<!@BeN7W;;5!$H4|BT$5lkJBNs7W;;5!$,!"@$$K8=lF$+$i$+$JjNG/7n$, 7P2a$7$?!#$7$+$7?tB?$/$N8&5f$d3+H/$K$b4X$oi:!"0MA3H7$F0lHL$N%f!<%6 $,5$7Z$K;HMQ$G$-$kh&$J%7%9%F%`$KOJCF$$$J$$!#3N<g$J860x$H7F!" JBNs%W%m%0%i%_%s%0$N:$Fq5,$"$2il$k!#FC$KJ,;6%a%b%j7?JBNs7W;;5!$N>l 9g!"DL?.$rM[$K5-=R$9k3HG<+J,$,0U?^$9$kJBNs2=!"%?%9%/J,;6$r9T$($kH? LL!"9b@-G=$r=P$9$?$aKO9bEY$JCN<15Z$S5;=QrI,MWH9k$?$aG"$k!#JBNs 7W;;5!<+BN$N7W;;!"DL?.G=NO$rB,Dj$9k?aK$=$l$iDL?.L?Na$r<j$G=q$/$H$$ $&$Ji^$@$7$b!"Bg5,LO$JLdBjrh$j9bB.$K<B9T9k$H$$$&L\E*N?aK$OB? Bg$JO+NOrMW7!"HF$b;H$$$d$9$$$H$O$$$($J$$!#7?$,$$C$F!"%W%m%0%i%`$N K\<A$H$OJLLdBj$NDL?.=hM}$d%G!<%?G[CV$NLdBj$r!"%f!<%6!<$,9MN8$9$k$3$H$J $/C`<!%W%m%0%i%`$N463P$G=q$1!"$J$*$+D"$kDxEY$N@-G=$,=P$;kh$&$J8@8l =hM}7O$,I,?\$G$"$k$H$$$($k!#

6aG/!"J,;6%a%b%j7?JBNs7W;;5!MQ$N%G!<%?JBNs5-=R8@8l$H7FHPF(High Performance Fortran) $,CmL\$r=8$a!";v<B>e$NI8=`$rL\;X$7$F8=:_$bI8=`2=:n6H $,?J$ail$F$$$k!#$=$3$G2f!9$O!"8=:_3+H/CfG"$k<+F0JBNs2=%3%s%Q%$%i **TINPAR**[1] KBP7!"HPF $NSubset $NJ8K!$r2r<aG-$k%U%m%s%H%(%s%I$H$J $k%W%m%0%i%`$r:n@.$7$3$l$KBP1~$7$?!#$^$?$3$N:]!"$3$l$^$GTINPAR $G$O 07$($J$+$C$?<jB3$-8F$S=P$7$X$NBP1~$b9T$C$?!#$3$N7k2L!"$h$jJ#;($J?tCM1i ;;%W%m%0%i%`$b<B9TG-kh$&$KJC$?!#

K\Js9p=qGO!"3l$^$G**TINPAR**>e$G07$C$?$3HN$J$$%?%$%W$N!"FCD'E* $JJBNs8~$1?tCM1i;;%W%m%0%i%`$rMQ$$**TINPAR** $N@-G=I>2A$r9T$C$?!#$3$3$G 8@$&@-G=I>2A$H$O!"C1$K**TINPAR** $,=PNO$7$?JBNs%3!<%I$NC`<!%W%m%0%i%`$K BP$9$kBf?t8z2L$N$_$rI=$9Lu$G$O$J$/!"$h$jAm9gE*$JI>2A$N$3$H$rI=$9$b$N$H $9$k!#$^$?$3$NI>2A$NCJ3,$GL@$i$+$K$J$C$F$-$?$3$H!"$9$J$o$AHPF $N;EMM$r 40A4$K$OK~$?$7$F$$$J$$?$a$K5/$3$k!"%W%m%0%i%`$r=q$/>eGNAj0cE@$dLdBj E@!"%f!<%6!<$+$i8+$?>l9g$N>-Mh$"kY$-;Q$JIK$D$$$F9M;!7?!#

K\Js9p=qGO!"$^$:2>O$GGX7J$H7F<+F0JBNs2=%3%s%Q%$%i **TINPAR** KD $$$F=RY?$"$H!"3>O$GI>2A$KMQ$$$?3F%Y%s%A%^!<%/%W%m%0%i%`$N%"%k%4%j%: %`KD$$$F!"5-=R9k>eGNLdBjE@H=$NBP=hK!$K$D$$$F=R$Y!"@-G=I>2A$r9T $$!"4>O$GAmO@$H7F!"<+F0%G!<%?J,3dItKh$j7hDj$5l?J,3d8uJd$NBEEv@-!"

TINPAR $N8@8l;EMM$HHPF $NHf3SI>2A$r9T$$!"5>OG^Ha$k!#

2 <+F0JBNs2=%3%s%Q%$%i TINPAR

TINPAR $O!"%a%C%;!<%88r497?JBNs7W;;5!N?aNJBNs2=%3%s%Q%$%i$G$"$j!"owner computes rule $rMQ$$$FC`<!%W%m%0%i%`$rJBNs2=$9$k!#

owner compute rule

!V3F%W%m%;%C%5O=l>l,=jM-9k%G!<%?N?aN1i;;$rC4Ev$9$k!W

3lKh$j%f!<%6$O!"C10l%a%b%j6u4V$rA[Dj$7$?C`<!%W%m%0%i%`$rJBNs7W;;5!>e$G<B9T$9k3H,2DG=HJ$k!#

2.1 TINPAR $NF~=PNO

TINPAR $N9=@.$r?^2.1$K<($9!#

TINPAR $OF~NO8@8l$H7F!"Fortran77 $KHPF GDjail$F$$$k%G!<%?J,3d%G%#%l%/%F%#%V(;X<(J8) $r2C$($?$bNr<u1D1k!#%G!<%?J,3d%G%#%l%/%F%#%V$,L5$$$>l9gGb!"<+F0%G!<%?J,3dIt$G:GE,$JJ,3d8uJd$,A*$Plk$?$a!"M}A[E*KO4{K"$kFortran77 $N%W%m%0%i%`$K2?$i<j$r2C$($k3HJ/8zN(E*$JJBNs2=$r9k3H$,2DG=$G$"$k!#

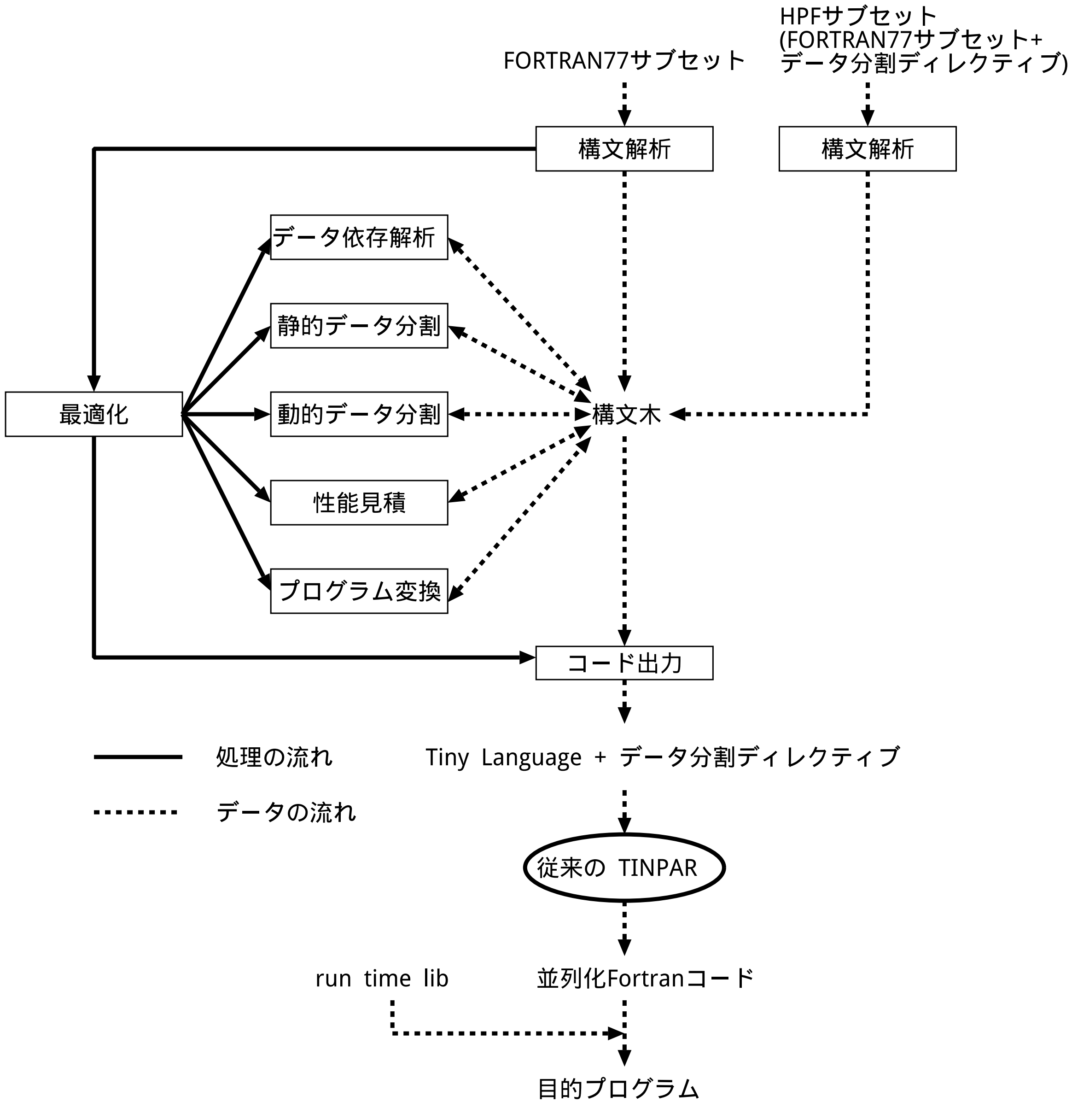
?^$+$io+kh$&$K **TINPAR** $OHPF $NSubset $NF~NO8@8l$r!"3HD%Tiny Language $K%G!<%?J,3d%G%#%l%/%F%#%V$r2C$($?%W%m%0%i%`$KJQ49$9$k%U%m%s%H%(%s%IItJ,$H!"$=$l$r$b$H$KJBNs2=$9$kK\BNItJ,$KJ,$+$l$k!#3HD%Tiny Language $H$O!"%k!<%W:F9=@.%D!<%kTiny[4] $N$?$a$K@_7W$5$l$?C`<!7?8@8l Tiny Language $r3HD%$7$?$bNG$"$j!"Fortran $KN`;w$7$?4J7i$J9=J85,B'$r;}$D!#3HD%7?ItJ,$O!"%G!<%?J,3d%G%#%l%/%F%#%V!"while 9=J8!"%9%3!<%W%k!<%k$NF3F~$JIG$"$k!#[1]

3N%U%m%s%H%(%s%IItJ,$r4V$K$*$/3HKh$j!"=>Mh$N **TINPAR** GO07$($J$+$C$?<jB3$-8F$S=P$7$r5-=R$G$-$kh&KJ$j!"$3l^GO07$($J$+$C$?<o!9$N2J3X5;=Q7W;;$N%W%m%0%i%`$r5-=RG-kh$&$KJC$?!#

2.2 TINPAR $NFbIt9=@.

TINPAR $N%U%m%s%H%(%s%IIt$O0J2<$N7$D$N%b%8%e!<%k$+$i9=@.$5lk!#

1. 9=J82r@OIt
   - FORTRAN77 $N%5%V%;%C%H$G=q$+$l$?F~NO%W%m%0%i%`


HPFサブセット
(FORTRAN77サブセット+
データ分割ディレクティブ)
FORTRAN77サブセット
構文解析
構文解析
データ依存解析
静的データ分割
最適化
動的データ分割
構文木
性能見積
プログラム変換
コード出力
処理の流れ
Tiny Language + データ分割ディレクティブ
データの流れ
従来の TINPAR
run time lib
並列化Fortranコード
目的プログラム

?^2.1: TINPAR $N9=@.

b7$/$O!"

- HPF $K=‘5r$7$?%G!<%?J,3d%G%#%l%/%F%#%V$,A^F~$5l?F~NO%W%m%0%i%‘

$N9=J82r@O$r9T$J$$!"9=J82r@OLZ$r@8@.$9$k!#

2. :GE,2=It

   9=J82r@O8e$N%W%m%0%i%‘$N@)8f$r9T$J$&!#$^$:!"9=J82r@O$N7k2L!"@EE*%G!<%?J,3d$r8F$S=P9+H]$+$r7hDj9k!#B3$$$F%G!<%?0MB82r@O!"@EE*!?F0E*%G!<%?J,3d!"%W%m%0%i%‘JQ49!"@-G=8+@Q$r7+$jJV$78F$S=P$7!":GE,$J%G!<%?J,3d!"%W%m%0%i%‘JQ49$r7hDj$9$k!#:G=*E*$K MPI $N%a%C%;!<%8DL?.$N%3!<%I$,A^F~$5l?9=J82r@OLZ$N%W%m%0%i%‘$r=PNO9k!#

3. %G!<%?0MB82r@OIt

   9=J82r@OLZrbHK%G!<%?0MB82r@O$r9T$J$$!"%G!<%?0MB8%0%i%U$r:n@.$9$k!#$3$N%0%i%U$rbH$K!"3FDO%k!<%W$K$D$$$F!"%$%?%l!<%7%g%s4V$N%G!<%?0MB8$NM-L5$rD4$Y!"9=J82r@OLZ$K$=$N>pJs$rIU2C$9$k!#

4. @EE*%G!<%?J,3dIt

   %k!<%WFb$G;2>H$5lkG[NsJQ?t%G!<%?$N3F%W%m%;%C%5$X$NJ,3d$N8uJd$r7hDj$9$k!#J,3d$N8uJd$O!"3FG[Ns$NB0@-H7$F9=J82r@OLZ$KIU2C5l$k!#

5. F0E*%G!<%?J,3dIt

   8F$S=P$9B&!"8F$S=P$5lkB&$N%W%m%0%i%‘C10L4V$G0z$-EO$5lkG[NsJQ?t$r5a$a!"%G!<%?J,3d$rHf3S$9$k!#%G!<%?J,3d$,0[Jk>l9g$O!"8F$S=P$7B&$N%W%m%0%i%‘C10LK*$$$F!"8F$S=P$5lkB&$N%W%m%0%i%‘C10L$G$N%G!<%?J,3d$K9go;$?G[NsJQ?t%G!<%?$N:FJ,3d$r9T$J$&!#

6. %W%m%0%i%‘JQ49It

   :G=*E*$KF@$il?9=J8LZ$+$i!"Tiny Language + %G!<%?J,3d%G%#%l%/%F%#%V$r=PNO$9$k!#

7. @-G=8+@QIt

   3FDO%k!<%WK*$$$F!"%k!<%W$N7+$jJV$72s?t$*hS%$%?%l!<%7%g%s4V$N0MB8$NM-L5$N>pJsrbHK!"JBNs<B9T7?H-$N<B9T;~4V$r8+@Qbk!#8+@QbG$?<B9T;~4V$r9=J82r@OLZ$NDO%k!<%W$N%N!<%I$NB0@-CM$H7FM?$($k!#

3 JBNs%W%m%0%i%`Kh$k@-G=I>2A

3.1 I>2A4D6-

I>2A$N>r7o$O0J2<NDLjG"$k!#

- 10Mbps $N%9%$%C%A%s%0%O%V$K@\B3$5l?SPARC Ultra-1 4 Bf$N>e$G9T$&!#
- **TINPAR** $,=PNO$9$k%3!<%I$OFortran77 $KMPI $NDL?.L?Na$r2C$($?SPMD (Sigle Program Multiple Datastream) 7A<0$N%W%m%0%i%`$G$"$k!#
- DL?.%i%$%V%i%j$H7FMPI[5] $N<BAu$G$"$kMPICH[6] $rMQ$$$k!#
- 2CB.N($O(C`<!HG$N<B9T;~4V)/(JBNsHG$N<B9T;~4V) H7$F5aa?!#

3.2 ;HMQ7?JBNs%W%m%0%i%`

3l$^$G**TINPAR**>e$GI>2A$7$?%W%m%0%i%`$O!"9TNs@Q!"%,%&%9>C5nK!!"JPHyJ,J}Dx<0$NH?I|2rK!$G$"$k%d%3%SK!$HSOR(Successive Over Relaxation) K!!"$=$7$FFFT(Fast Fourier Transform) $J$I$G$"$C$?!#$3$l$i$O$$$:$l$b<jB3$-8F$S=P$7$,$J$/!"4pK\E*$JJBNs2=$,@53N$K9T$o$l$F$$$k$+$I$&$+!"$^$?!"$"$kDxEY$NBf?t8z2L$,=P$F$$$k$+$I$&$+$r8+$k$?$a$N%W%m%0%i%`$H$$$C$F$$$$!#$=$3$GK\9F$G$O!"$3l^$G**TINPAR**>e$G07C?3HNJ$$%?%$%W$N!"FCD'E*$JJBNs8~$1?tCM1i;;%W%m%0%i%`$rMQ$$**TINPAR**$N@-G=I>2A$r9TC?!#

MQ$$$?%W%m%0%i%`L>$H!"FCD'E*$J@-<A$O0J2<$NDLjG$"$k!#

EP

%k!<%WCf$K<jB3$-8F$S=P$7$H%j%@%/%7%g%s1i;;$,$"$k!#

ADI

:FJ,;6Kh$kBgNLAw<u?.$,5/3k!#

Tomcatv

J,3d7?J}$,NI$$G[Ns$H!"$7$J$$[$&$,NI$$G[Ns$NN>J}$,B8:_9k!#

:#2sMQ$$$?%W%m%0%i%`$N$&$A!"EP $HTomcatv $K$D$$$F$OAPR(Applied Parallel Reserch) $, HPF %3%s%Q%$%i8~$1$K:n@.$7$?%Y%s%A%^!<%/%W%m%0%i%`$r!"ADI $O[14] $K:\$C$F$$$?bN$rE,59JQ99$r2C$($?bN$rMQ$$$?!#

JQ99$7$?E@$O!"

- **TINPAR** $G07$($J$$ASSIGN!"COMMON!"CONTINUE!"DATA!"ENTRY!"EQUIVALENCE!"GOTO!"SAVE $N3FJ8$r%W%m%0%i%`$N0UL#$,JQoi$J$$$h$&$K=q-49($k!#
- J84X?t$r<jB3$-8F$S=P$7$KJQ99$9$k!#

G"$k!#

0J2<!"3F%W%m%0%i%`KD$$$F!"

1. TINPAR $GJBNs2=$7$F<B9T$7$?7k2L
2. JBNs2=$rK8$2$kMW0x$N9M;!
3. 2r7h9k<jK!0F
4. 2~NI8e$NM=A[$5lk<B9T;~4V

$r<($9!#

3.3 EP

EP(Embarassingly Parallel) $O%b%s%F%+%k%mK!$N%W%m%0%i%`G"$k!#Mp?t$N%Z%"$r@8@.$7!"$=$l$rJ?LL>e$N:BI8H_J7!"3FE@$,J?LL>e$K@_1il?10 8D$NNN0h$N$&$AI3$KB0$9k+$r5a$a!"3FNN0h$KB0$9$kE@$N8D?t$r7W;;$9kH$$$&bNG"$k!#

%W%m%0%i%`$NBg6Z$O?^3.1NDLjG"$k!#$J$*9THV9f$K'(%@%C%7%e) $,IU$$$F$$$kNOJQ99$r2C$($?ItJ,$G$"$k!#

D0150 $N3F%$%?%l!<%7%g%s$G!"%5%V%k!<%A%s VRANLC $r8F$S=P7F NK 8D$:$D$NMp?t$r$=$l$>$lG[Ns X,Y $KBeF~$9$k!#$=li$N@hF,$+$i X :BI8!"Y :BI8$N%Z%"$H8+$F3FE@$,B0$9$kNN0h$NHV9f L(0 $+$i 9 $^$G$N?t;z$KJk) $r7W;;$7!"G[Ns Q(L) $r%+%&%s%H%"%C%W$7$F$$$/!#

3N%W%m%0%i%`$rJBNs<B9T$9k3Hr9M$($?H-!":G$b8zN(E*$JNOD0150$N%k!<%W$r3F%W%m%;%C%5$KJ,3d$7!"%W%m%;%C%5$4$H$K3FNN0h$KB0$9$kE@$N8D?t$rG[Ns Q(L) $KJ]B8$7F*$-!":G8e$K Q(L) $N3FMWAG$4HNAmOB$r5a$akH$$$&bNG"$k!#0J2<$K **TINPAR** $G<B9T$9$k>e$G$NLdBjE@$HBP:vK!$r=R$Y$k!#

3.3.1 LdBjE@H=$NBP:v

J,;64p=`HJ$kG[Ns$NIT:_

TINPAR $Oowner computes rule $K4p$E$$$FJBNs2=$r?J$a$F$$$/!#H3m,!"3N%W%m%0%i%`$N>l9g!":G30%k!<%W$N D0150 %k!<%WFb$K%k!<%WJQ?t$G$"$k K $rE:;z$K;}$DG[Ns$,B8:_7J$$$?$a D0150 %k!<%W$OJ,;6G-$J$$!#D0140 %k!<%W$@$1$rJBNs2=$9k3HO2DG=$@$,!"$=$N>l9g D0150 %k!<%W$+$i D0140 %k!<%W$^$G$N4 9TL\$+$i 9 9TL\$^G,!"7W;;NL$,B?$$$K$b4X$oi:JBNs2=5l$:!"3F%W%m%;%C%5$G=EJ#7F<B9T5lk3HKJk!#$=$N$?$aJBNs2=Kh$k8z2L$,>.$5$$!#

```
1       PARAMETER (NN=2**8, NK=2*16)
2       real*8 X(NK),Y(NK), Q(0:9), T1, T2, T3
3       DO 150 K=1, NN
4'         DUMMY(K) = 0.0                 ! %@%_!<G[Ns$rMQ0U
5            :
6             CALL RANDLC(T1,T2,T3)       ! Mp?t$N<o$r@8@.
7            :
8          CALL VRANLC(NK,X,T1)
9          CALL VRANLC(NK,Y,T1)           ! G[NsX,Y $KMp?t$rBeF~
10         DO 140 I=1, NK
11             :
12            IF(FODj$NMp?t$K4X$7$F)
13                L= !D                   ! B0$9$kNN0hHV9f$r5a$a$k
14                Q(L) = Q(L)+1.0         ! J,;6$N4p=`$K$J$1$J$$
                        ⇓
14'               COUNT(I,L) = 1          ! G[Ns$KJ]B8
15             ENDIF
16  140     ENDDO
17'         DO L=0, 9
18'            DO I=1, NK
19'               COUNT(I+1,L) = COUNT(I+1,L)+COUNT(I,L)
20'            ENDDO                      ! AmOB$r<h$k
21'         ENDDO
22  150  ENDDO
```

?^3.1: EP $N%"%k%4%j%:%`$N35N,

$=$3$G!"BP:v$H7F DO150 %k!<%WFb$K%@%_!<$NG[Ns DUMMY(NN) $rMQ0U$7!"3l$rJ,3d$9k3HKhj DO150 %k!<%W$, owner computes rule $K=>$$J,3d5lkh$&$K7?!#

%k!<%WCf$N<jB3$-8F$S=P$7

DO %k!<%WFb$K!"<jB3$-8F$S=P$7$N RANDLC !"VRANLC $,B8:_$9$k!#$3$N<jB3$-8F$S=P$7Kh$jG[Ns$NMWAGNCM,JQ2=9k$H!"0MB84X78$,@8$8$k3H$,$"k?$a!"0lHIE*$K$O%3%s%Q%$%i$O<jB3$-4V2r@OJI$r9T$$!"0MB8$,$"$k>l9g$K$O0MB84X78$,J]$?$lkh$&$KJBNs2=7J1lPJiJ$$!#
RANDLC $H VRANLC $O!"<jB3$-8F$S=P$7Kh$kI{:nMQ$G0MB84X78$O@8$8$J$$$N$G!"$$$oPAH_9~$_4X?t$JIHF1Ey$K07$&3H$,$G$-$k$?$aJBNs2=$N>c32$KOJiJ$$!#

%j%@%/%7%g%s1i;;

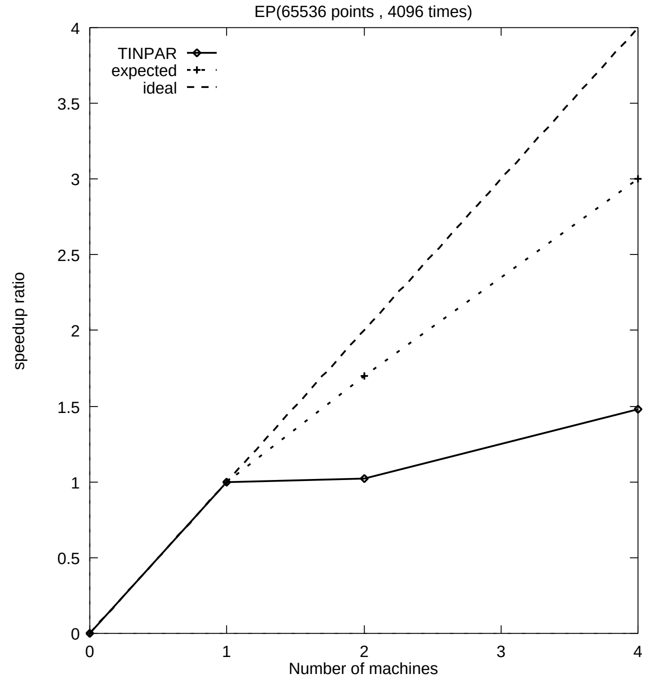
3N%W%m%0%i%`GO14 9TL\$N Q(L) XNBeF~J8$rJBNs2=$9k3H,:G$b:$FqG"$k!#

K\@a$N:G=i$K=RY?h&$K!":G$b8z2LE*$JJBNs2=$N<jK!$O!"%W%m%;%C%5Kh$K3FNN0h$KB0$9$kE@$N8D?t$r5a$a!"G[Ns Q $N3FMWAG$KJ]B8$7$F$*$-!":G8e$K Q $NMWAGKh$KA4%W%m%;%C%5$GAmOB1i;;$r9T$&$H$$$&bNG"$k!#

7+$7!"$3lr9T$&$K$O3F%W%m%;%C%5$,;}$DG[Ns$NMWAGNCM,0[Jk>uBVKJk3Hr5v$7!"$5iK:G8e$KAmOB1i;;$9$kDL?.L?Na$rCV$+$MPJiJ$$!#
8=:_$N **TINPAR** O3li$N!"$$$ofk%j%@%/%7%g%s1i;;$r8!=P$7%3!<%I$r@8@.$9$k5!G=$OJ/!"6&M-7F; }C?G[NsXNBeF~$O%V%m!<%I%-%c%9%H$7$F!"A4%W%m%;%C%5$GCM$rF10l$KJ]H&H9$k!#

3F%$%?%l!<%7%g%sKh$K5/3k3N%V%m!<%I%-%c%9%HrKI0$?$aKO!"%f!<%6B&GJLNJ}K!$r<h$k7+$J$$!#$=$3$G!"DO140 $N%$%?%l!<%7%g%s6u4VJ,$NG[Ns$rMQ0U$73F%W%m%;%C%5$GJ,3d$7!"DO140 %k!<%W$N$"$H$GAmOB$r<hCFJ]B8$7$F$*$/3HK7$?(?^3.1$N14' 9TL\)!#3&9k3HKh$j!"%V%m!<%I%-%c%9%H$,5/$-$k3HOJ$/3F%W%m%;%C%5$G SEND $, DO150 %k!<%W2s?tJ,$N NN(=2^{12}) 2s5/F0$9$k$@$1G9$`!#$3lKhj!">e=R7?<jK!KO5ZPJ$$$bNNDL?.NL$,$+Jj8:k3H,4|BTG-$k!#

DO140 $N%$%?%l!<%7%g%s6u4V$@$1GOJ/!"A4%$%?%l!<%7%g%s6u4VJ,$NG[Ns$rMQ0U$9lP!" DO150 %k!<%W$N8e$GAmOB1i;;$,9T$(k?$a SEND $,0l2s



?^3.2: EP $NBf?t8z2L

G9$`$,!"I,MW$J%a%b%jNL$,

D0150 %k!<%W$N2s?t × D0140 %k!<%W$N2s?t × NN0h$N?t × $sizeof(double)$

$$= 2^{12} \times 2^{16} \times 10 \times 8Byte \cong 20GByte$$

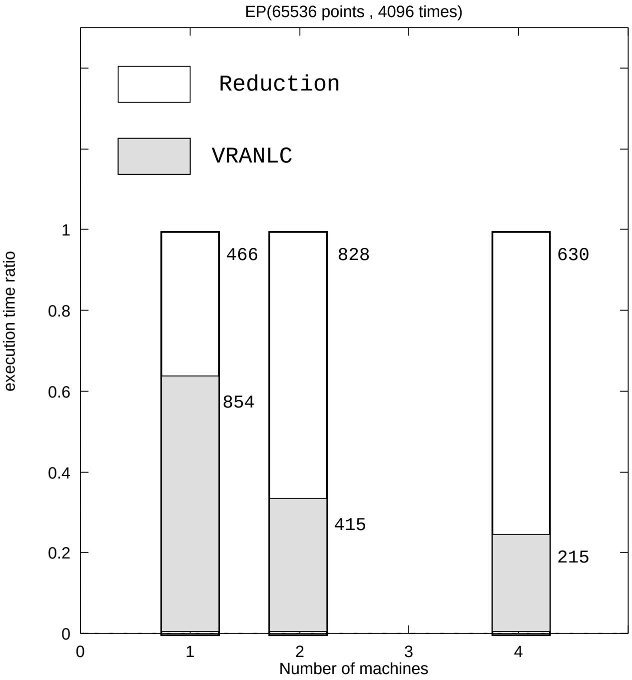
HJ$j!"8=<BE*$GOJ$$!#

J*%j%@%/%7%g%s1i;;KD$$$F$O<!9`$G>\$7$/=R$Y$k!#

3.3.2 9M;!-%j%@%/%7%g%s1i;;-

5F!"3liNLdBj$r2r7h$7$?$H7F$b!"Bf?t8z2L$N9b$$%W%m%0%i%`$,=q$1$k$H$O$+$.$i$J$$!#<B:]!">e$G=R$Y$?;v$K5$$r$D$1$F%W%m%0%i%`$rJQ99$7$?$H$-$NBf?t8z2L$O?^3.2$+ibo+kh$&$K!"4 Bf;HC?H-$NBf?t8z2L$O1.5 G\DxEY$G$"$k!#

CY$/$J$k860x CY$/Jk860xH7FO3.3.1>O$G=R$Y$?LdBj$N$&$A!"dO$j%j%@%/%7%g%s1i;;$N1F6A$,Bg$-$$!#3l$O!"J]B8MQ$NG[NsKBP9$kM>J,$JA`:n$N$;$$$K$h$jC`<!%l%Y%kGN<B9T;~4V$,A}Bg$7F7$^$&3H$H!"DL?.$Khk%*!<%P!<%X%C%I$,I=LL2=$7$F$$$k$+$iG"$k!#?^3.3$+ib%j%@%/%7%g%s1i;;ItJ,$N%9%1!<%i%S%j%F%#$,Dc$$$3H,o+$k!#



?^3.3: EP $N<B9T;~4V$NFbLu

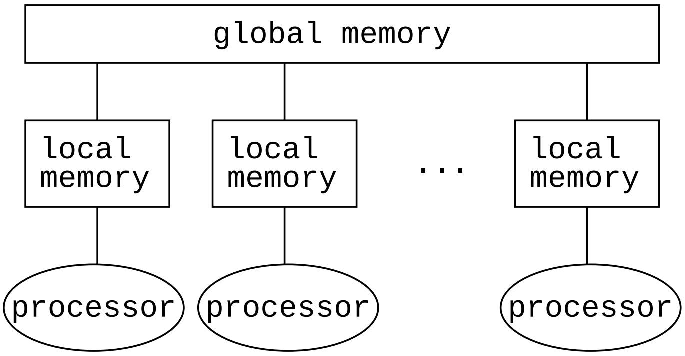
%j%@%/%7%g%s1i;;$O?tCM7W;;%W%m%0%i%`$K$*$$$F!"6KaFI QHK$K8=$l$k%k!<%W%Q%?!<%s$G$"$j!"3l$r8!=P$78zN(h/<B9T5;k3HOA4BN$N@-G=8~>e$+ibHs>o$K=EMW$G$"$k!#FC$KJ,;6%a%b%j7?JBNs7W;;5!$K$*$$$F$O!"$3lr8!=PG-$J$$>19g$N%Z%J%k%F%#$OBg$-$/!"B>$NJBNs2=$N8z2LrBGA>C7F7^$&$[IG$"$k!#

2r>C9k<jK!0F %j%@%/%7%g%s1i;;$,B8:_$9k3Hr%3%s%Q%$%i$,G'<1$7!"8z2IE*$JJBNs2=$r9T$&J}K!H7FO!"

1. 6/NO$J8!=P%"%k%4%j%:%`$KhjH/8+9k!#[10]
2. 8@8l;EMM$KHPF $NREDUCTION $+!"$b7/O=lKN`;w7?;X<(J8$rF3F~$9$k!#[7][11]
3. 8@8l;EMM$K3F%W%m%;%C%5$,;}$DJQ?t$NCM$,0[$JCFbh$$$H$$$&;X<(J8$H!"%j%@%/%7%g%s1i;;$r9T$&J8K!$r2C$($k!#

JI$,9M$(il$k!#

1 $ODL>o!"%3%s%Q%$%i$,%Q%?!<%s%G!<%?$N%G!<%?%Y!<%9$r;}$A!"%W%m%0%i%`$N$"$kFCDj$N7A$r$b$DCGJR$r%$%G%#%*%`H7$FG'<1$7!"3l$rBP1~$9$k<B9T;~%i%$%V%i%j$XJQ49$9k3HG=hM}5lF-$?!#$3Nh$&$J<jK!$,>o$K3N<B$K%j



?^3.4: 2 3,AX%a%b%j%b%G%k

%@%/%7%g%s$r8!=P$9k3H,G-kJ$iLdB j$O$J$$$,!"2>$K8!=P$K<:GT7?>l9g!"K\Js9p=q$HF1MM$N;vBVKJj=$N%W%m%0%i%`$O%f!<%6$,G!2?$K=q-49(h&$H8zN(E*$JJBNs2=OG$-$J$/$JCF7^$&!#

2 $OHPF $NLanguage Specification version2 $N>l9g!"%k!<%W$NB0@-H7$F;X<(9=J8$NINDEPENDENT $,;XDj$5lk$H!"$=$N%k!<%WCf$K%j%@%/%7%g%sl i;;$,$"$k>l9g$G$b%3%s%Q%$%iB&$GBP1~$9kh$&$KJC$F$$$k!#hC$F2 $r<BAu$7$?>l9g!"DO150 %k!<%W$NA0$K%f!<%6$,

!HPF$ INDEPENDENT, REDUCTION(Q)

$H$$$&;X<(9T$r0l9T5-=R$9k3HKhjG[NsQ $,%j%@%/%7%g%sl i;;$r9k3H$r<($7!"%3%s%Q%$%i$O$=$N>pJsrbHK!":GE,2=7J1lPJiJ$$!#

3 ONc($PVPP Fortran[12] $N8@8l;EMM$K$"$k!"%G!<%?$K%0%m!<%P%k/ %m!<%+%k$N2 3,AX$NB0@-$r;}$?$;kH$$$&9M$(J}$HF1$8$G$"$k!#

2 3,AX%a%b%j%b%G%k$N35G0?^$r?^3.4$K<($9!#

2 3,AX%a%b%j%b%G%k

%0%m!<%P%k%a%b%j$OO@M}E*$K%W%m%;%C%54V$G6&M-$5lF$$$k!#%0%m!<%P%k%G!<%?$N%"%/%;%9$KI,MW$JDL?.$HF14|$O=hM}7O$,<+F0@8@.9k$?$a!"%f!<%6$O%0%m!<%P%kJQ?t$r=>Mh$NJQ?t$HF1MM$K;HMQ$9k3H,G-$k!#%m!<%+%k%a%b%j$O3F%W%m%;%C%5$K8GM-$G$"$j!"9bB.$J%"%/%;%9$,J]>Z5l$k!#%W%m%;%C%5$r8Y$$$G%m!<%+%k%a%b%j$K%G!<%?$rJ,;6G[CV9k3HbG$-$k$,!"%G!<%?E>Aw$rL@<(7J$$8B$jB>%W%m%;%C%5$N%m!<%+%k%G!<%?$r%"%/%;%9$9k3HOG-$J$$!#

3 $rF3F~$9$k>l9g!":G8e$K7k2Lr^Hk$?$a$K!"%3%s%Q%$%iB&$,=89gDL?.L?Na$rAH$_9~$_4X?tH7$FDs6!$7J1lPJi$J$$!#?^3.1$G8@$&$H DO150 %k!<

%W$N8e$GAmOB$r<h$k4X?tXXX_SCATTER Nh$&$JbN$r!"%f!<%6$K5-=R5;MPJi$J$$!#

0J>eKh$j!"%f!<%6$KIiC4r+1:!"$=$l$G$$$F%j%@%/%7%g%s1i;;$r3N<B$K8!=P9kJ}K!H7$F!"<+F0%G!<%?J,3dIt$HF1$8$h$&$KDL>o$O%3%s%Q%$%i$,<+F0E*$KH=CG!"8!=P$7!"Jd=uE*$K;X<(J8$bMQ0U$9kH$$$&N,:G$b8=<BE*$J<BAuJ}K!G"kHD s0F9k!#?^3.2$K%j%@%/%7%g%s1i;;$r8z2LE*$KJBNs2=$7$?$H$-$K!"**TINPAR** $,=PNO$9kH;Wol$k%3!<%I$NBf?t8z2L$r:\$;F"$k!#1)

$$$:lK$;$h!"%j%@%/%7%g%s1i;;KBP9kJsi$+$NBP=hr;MP!"**TINPAR** G3$l0J>e$NBf?t8z2Lr"2k3HOG$-$J$$$H$$($k!#

3.4 ADI

2<!85$NADI(Alternative Direction Implicit)K!$O!"2=E%k!<%WCf$G;2>H5l$k2<!85G[Ns$N3F<!85J}8~$K%k!<%W1?HB0MB8$N$"$k%U%'!<%:$,8r8_$K8=lk!#$"$kJ}8~$K1?HB0MB8$N$"$k%U%'!<%:GO!"B>$NJ}8~$K$D$$$F$OF HN)$K<B9TG-$k!#

ADI K!$ONAS Parallel Benchmarks $NSP!"BT JI$NFCD'$HJkItJ,$K8=lk!#$^$?1_7AJPHyJ,J}Dx<0$H7FCNil$k%]%"%=%sJ}Dx<0$N2rK!H7$FMQ$$$il?$j!"%J%S%(%9%H!<%/%9$NJ}Dx<0$r2r$/>l9g$KMQ$$$ilk3Hb"$k!#

ADI K!NBg^$+$JN.lr?^3.5$K<($9!#

3.4.1 LdBjE@H=$NBP:v

%G!<%?$N:FJ,;6%3!<%I ?^3.5$+io$+$kh&$K!"0MB8$,$"$k%U%'!<%:$N;vA0$K%G!<%?$r:FJ,;6$9k3HKhj!":FJ,;6F0:n0J30GODL?.$O5/$3iJ$$!#**TINPAR** KOF0E*:FJ,;65!G=$,<BAu$5lF$$$k$,!"$3lO<jB3$-8F$S=P$7A08e$G%G!<%?J,3dJ}K!$,0[$J$k>l9g$KN_!"<+F0E*$K:FJ,;6%k!<%W$rA^F~9kh&KJCF$$$k!#=>CF!"3N>l9gKOE,MQ5l$:%f!<%6$,:FJ,;6%3!<%I$r5-=R$7J1lPJi$J$$!#

3.4.2 9M;!-DL?.5/F02s?t$N:o8:-

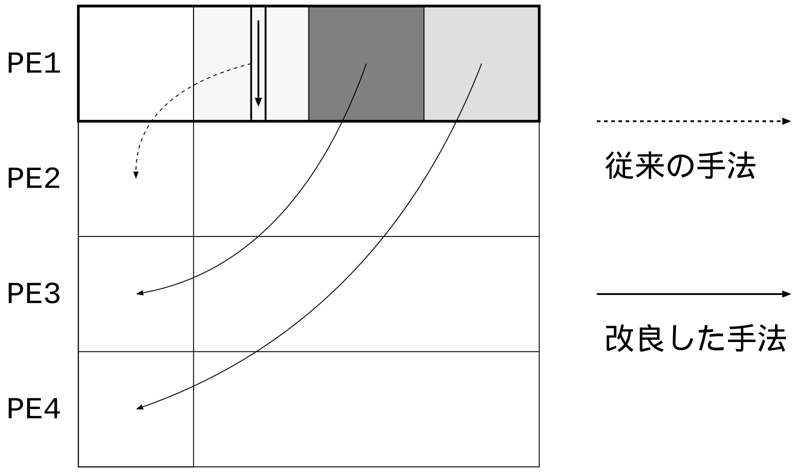
0lHILE*$K!"%a%C%;!<%88r497?$NJBNs7W;;5!GODL?.=hM}$N5/F0%3%9%H$,Bg$-$$$?$a!"$=$N5/F02s?t$r8:i9$3$H$,=EMW$G$"$k!#3N$?$a!"JBNs2=%3%s%Q%$%i$G$O%a%C%;!<%8$N%Y%/%H%k2=$H8F$Plk:GE,2=<jK!$,=>Mh$h$jMQ$$$ilF$$$k!#3l$OAw?.%G!<%?$r$^$HaF1 DND9$$%a%C%;!<%8H7$FAw?.$9k3HK

---

1) ?M<j$G=$@5$r2C$($?!#

```
        PARAMETER (NITER=100)
        REAL U(1:N,1:N),UH(1:N,1:N),B(1:N,1:N)
        REAL UTMP(1:N,1:N),UHTMP(1:N,1:N),BTMP(1:N,1:N)
cHPF$ ALIGN (I, J) with T(I, J)::U, UH, B
cHPF$ ALIGN (I, J) with T(J, I)::UTMP, UHTMP, BTMP
cHPF$ DISTRIBUTE T(BLOCK, *) ONTO P
        CALL INITIO(U, UH, B)            ! 3FJQ?t$N=i4|2=
        DO I=1, NITER
           UH(I,J)=ALPHA*U(I,J)+u(I,J+1)+U(I,J-1)
                  :                        ! x J}8~$N0MB8$N$"$k%U%'!<%:
           DO J=1,N
              DO I=1,N
                 UTMP(I,J)=U(I,J)
                 UHTMP(I,J)=UH(I,J)        ! :FJ,;6
                 BTMP(I,J)=B(I,J)
              ENDDO
           ENDDO
           UH(I,J)=ALPHA*U(I,J)+U(I+1,J)+U(I-1,J)
                  :                        ! y J}8~$N0MB8$N$"$k%U%'!<%:
           DO J=1,N
              DO I=1,N
                 U(I,J)=UTMP(I,J)
                 UH(I,J)=UHTMP(I,J)        ! :FJ,;6
                 B(I,J)=BTMP(I,J)
              ENDDO
           ENDDO
        ENDDO
        END
```

?^3.5: ADI K!$N%"%k%4%j%:%`$N3 5N,



?^3.6: E>CV$KH<$&%G!<%?0\F0

hj!"DL?.=hM}$N5/F02s?t$r8:i9<jK!G"$k!#

TINPAR $N%Y%/%H%kDL?.%i%$%V%i%j **TINPAR** KO3N%Y%/%H%k2=$rF0E*$K9T$&@lMQDL?.%i%$%V%i%j$,<BAu$5lF$$$k!#6qBNE*KO!"SEND J8$,8=$lFbB(:BKOAw?.$;$:%Q%C%-%s%0$7$?>e$G%P%C%U%!$KJ]B8$7!"E,@Z$JD9$5$KJC$?;~E@$GAw?.9k$H$$$&;EAH$_$G$"$k!#

$?$@$7$3Nh$&$J%P%C%U%!%j%s%0$r9T$&>l9g!"$=$N%P%C%U%!$rE,@Z$K%U%i%C%7%e7J1l$PAw?.%P%C%U%!$KL$Aw?.$N%G!<%?$,;D$k3HKJ$j!"$=$N%G!<%?$r<u?.9k%W%m%;%C%5$N<u?.BT$A$,@8$8!"DL?.$H7W;;$N%*!<%P!<%i%C%W$,$G$-$J$$;v$,$"k?$a!"@-G=Dc2<$,5/3k2DG=@-$,$"$k!#$=3G@lMQ%i%$%V%i%j$G$O!"%3%s%Q%$%iKh$k:GE,2=$N<jCJH7$F!"Aw?.%P%C%U%!$N6/@)%U%i%C%7%e5!G=$,Ds6!$5lF$$$k!#

%a%C%;!<%8%P%C%U%!$r%U%i%C%7%e$9$k%?%$%_%s%0$O!"**TINPAR** FbIt$NCf4V%3!<%I$GSEND J8$,$^$H$^$C$F<B9T$5l?$"$H!"9JoASEND J8$r4^$`%k!<%W$N$9$08e$K$J$C$F$$$?!#$7$+$7$3$l$G$O!"?^3.6$G$$$&$H!"0l2s$NAw?.$G6k7AItJ,$7$+Aw$l$J$$$3$H$K$J$k!#:FJ,;6$KH<$&BgNL$N%G!<%?0\F0$,7+$jJV$75/$3$k%W%m%0%i%`GO!"Aw<u?.$,IQHK$K5/F0$7$F7^$$Bg$-$J%*!<%P!<%X%C%IKJCF7^$&!#

$=$3$G!"**TINPAR** $NDL?.%i%$%V%i%j$r2~NI$7!"Fs<!850J>e$NNN0h$N0\F0$,@8$8FbDL?.5/F02s?t$,B?$/Ji$J$$$h$&$K2~NI9k!#(?^3.6)J}?KH7FO!"%a%C%;!<%8%P%C%U%!$r%U%i%C%7%e$9$k%?%$%_%s%0$r!"=PMh$k$@$1CYi;kH$$

	C`<!	2Bf	4Bf
=>Mh$N<jK!	11.50	64.13	110.79
2~NI7?<jK!	”	50.56	61.05

I=3.1: ADI $N<B9T;~4V

$&$bNG$"$k!#

3N<jK!rE,MQ7$?ADI $N<B9T;~4V$rI=3.1$K<($9!#

3.5 Tomcatv

Tomcatv $OTHOMPSON 2rK!$Khk%a%C%7%e@8@.%W%m%0%i%`$N%Y%/%H%kHG$G$"$k!#

<jB3$-8F$S=P7OJ/!"NY@\%G!<%?$N1i;;$,<gG"$k!#

3.5.1 LdBjE@H=$NBP:v

J,3d5lkY$-G[Ns!"$5lkY-GJ$$G[Ns

TINPAR $Oowner computes rule $K=>$C$FJBNs2=$r9kNG!"$^$:!"%G!<%?$r3F%W%m%;%C%5$KJ,3d9k$H$$$&3H$+$i;O$^$k!#8@$$$49$($l$P!"%G!<%?$rJ,3d9k3H$,JBNs2=$KDJ$,$kNG$"$k!#

3N%W%m%0%i%`$N>l9g$N<+F0%G!<%?J,3dIt$NF0:n$K$D$$$F4JC1$K9M;!$9$k!#?^3.7$N8 9TL\$KCmL\$9kH!"rx $NMWAG$Orx(k,i) $Hrx(k+1,i) $K%"%/%;%9$9kN$Grx $r2<!85L\$GJ,3d9k$HDL?.$,5/3i$J$$!#3lKDilk+$?$A$GF1$8<0K"$kG[Nsaa $Hd $b!"2<!85L\$GJ,3d7?$[$&$,NI$$$H$$$&>pJs$,F@$ilk!#3liN>pJs$,C_@Q$5$l!":G=*E*$KO[HsING[Ns$O$$$:l+$N<!85$GJ,3d5l$k!#

$3$3$GLdBj$JN,!"<+F0%G!<%?J,3dItGOG-$k8B$jJ,3d$r;\$=$&$H9k3HG"$k!#J,3d$7J1lPC`<!<B9TKJkN$@$+$i!"$3lOEvA3$N9M$($J}$GO"$k!#3N$+$K!"A4$F$NG[Ns$rJ,3d7h$&$H9M$($?H-$K!"<+F0%G!<%?J,3dIt$,=P$9%G!<%?J,3d8uJd$O!"G-k@$1JBNs@-$rC}=P9kh&KJCF$$$k!#

7+$7?^3.7$N5!"6 9TL\$N2<!85G[Nsx Nh$&$K!"2 J}8~Hb$K%"%/%;%9$,5l7+$b1&JU(;2>H) B&$K7+8=lJ$$>l9g$O!"J,3d$;$:$KA4%W%m%;%C%5$G%G!<%?$r6&M-7F;}CF$$$?J}$,!"M>7W$JDL?.$,5/$3i:$+$(CF=h

```
      DIMENSION aa(n,n),dd(n,n),x(n,n),y(n,n),rx(n,n),ry(n,n),d(n,n)
!HPF$ DISTRIBUTE aa(*,BLOCK)
      PARAMETER (NITER=100)
      DO 310 j = 2 , n-2
         xx = x(j,i+1) - x(j,i-1)
         xy = x(j+1,i) - x(j-1,i)
            :
         rx(k,i) = (rx(k,i) - aa(k,i) * rx(k+1,i)) * d(k,i)
 310  ENDDO
```

?^3.7: Tomcatv $NFCD'ItJ,

M}$,Aa$/Jk3H$,$"$k!#$7$+$7!"$=$3$^$GH=CG9kNO$+$J$j9b@:EY$J@-G=8+@Qbj$,I,MW$KJk!#>/J/HbDL?.@-G=$,$I$NDxEY$G$"$k$+$H$$$&>pJs$OI,?\$G$"$k!#2>O$G=R$Y$?$h$&$K!"**TINPAR** $OHPF Subset $JF~NO8@8l$+$i0lEYtiny KMnH$9%U%m%s%H% (%s%IIt$H!"$=$lrbHKJBNs2=9kK\BNItJ,KJLl$k!#<+F0%G!<%?J,3dItJ,$O3N%U%m%s%H% (%s%IItJ,K"k?$a!"JBNs2=$7$?%3!<%I$r8+k3HOG-$J$$!#%3%s%Q%$%k;~$N;~4V$H%a%b%j$r5$$K7J1l$P!"$3$NJBNs2=%3!<%I$r%H%l!<%9$7$F<B9T;~4V$r=P$9$3$H$O2DG=$G$"$k$,!"**TINPAR** G3lr<BAu9kM=DjOJ$$!#7?$,$C$F!"%f!<%6$K%G!<%?J,3d%G%#%l%/%F%#%V$r=q$$$Fbi$&$7$+$J$$!#

G[NsMWAG$N%9%+%iJQ?t$X$NBeF~

TINPAR Kh$kJBNs2=$G$O!"%9%+%iJQ?t$OA4%W%m%;%C%5$,=jM-<T$HJkh&$KG[CV$5lk!#3N$?$a%G!<%?J,3d$r;\$5l?G[Ns$+$i%9%+%iJQ?tXNBeF~(?^3.7$N5!"6 9TL\) KO!"A0<T$N=jM-<T%W%m%;%C%5$,A4%W%m%;%C%5KBP7$F%V%m!<%I%-%c%9%H$r9T$&%3!<%I$,A^F~5l$k!#(?^3.8, ?^??) %V%m!<%I%-%c%9%H$OC1$J$k0lBP0lDL?.$JIKHf$Y!"%M%C%H%o!<%/$K$+$+$kIi2Y$,MZ$+$KBg$-$$$?$a!"%k!<%WCf$G0lEYGb5/$-$F7^$&$H6KC<$J@-G=Dc2<$NMW0xHJ$k!#$3$NBP:v$H7F0J2<$N;0$D$NJ}K!$,9M$($ilk!#

1. 3F%W%m%;%C%5$,;}$CFk%9%+%iJQ?tNCM,!"B>$N%W%m%;%C%5$NJ];}7F$$$kCM$H0[$JCF$b$$$$$h$&$J@-<A$rM?$($k;X<(J8$rF3F~9k!#
2. :8JU$K%9%+%iJQ?t$OMQ$$$:!"BeF~$OG[NsF1;N$N$_$G9T$&$h$&$K%W%m%0%i%`$r=q$-49$($k!#

3. %G!<%?%U%m!<2r@OKh$j!"I,MW$N$J$$%V%m!<%I%-%c%9%H$r:o=|$9$k!#

1 $OJQ?t$+G[Ns$+$N0c$$$@1G!"3.3.1$G=R$Y$?%j%@%/%7%g%s1i;;$N2r7hJ}K!$N01$D$HF1$8<jK!G"$k!#

2 $O%9%+%i%(%/%9%Q%s%8%g%s$H$$$o1k5;K!G"$k[8]!#%$%?%1!<%7%g%sFb$G01;~JQ?t$H7F;HMQ$5$1$k%9%+%iJQ?t$r!"H?I|2s?tJ,$NMWAG?t$rbDG[Ns$KJQ49$7!"%$%?%1!<%7%g%sKh$KJL!9$NMWAG$r01;~JQ?tH7$FMQ$$$k!#7+$7!"%$%?%1!<%7%g%s6u4VJ,$NG[Ns$,I,MWHJ$j!"I,MW%a%b%jNL$bA}$(!"Ek:\%a%b%jNL$N4X78$G<B8=$G$-$J$$>l9g$,$"$k!#K\<AE*$K$O3.3.1>O$G=RY?!"%j%@%/%7%g%s1i;;$NBP=hK!$HF1$8$G$"$k!#

3 $OBeF~$5$1$?%9%+%iJQ?t$,!"%G!<%?%U%m!<2r@O$Khj!"<u?.7?%W%m%;%C%5$G01EY$b;2>H$5$1$J$$$3H,o+kJiP!"M>J,$JDL?.$O:GE,2=$NCJ3,$G:o=|G-$k[3]!#**TINPAR** KO3N:GE,2=$,<BAu$5$1$F$*$j!"<jB3$-8F$S=P7,L5$$>l9gGN$_;HMQ2DG=$G$"$k!#Tomcatv O3$N>r7o$rK~$?$9NG!"J,3d$5$1$?G[Ns$N%9%+%iJQ?tXNBeF~Kh$jA^F~$5$1$kDL?.$OA4$F<h$j=|$+1k!#

J,3d$5$1$?G[Ns$NJ,3d$5$1$F$$$J$$G[NsXNBeF~

J,3d$5$1$?G[Ns$r!"J,3d7F$$$J$$G[Ns$KBeF~$9$kA`:n(?^3.7 $N8 9TL\)$rC1=c$KJBNs2=$r9k$H!"8e<T$OA4%W%m%;%C%5$,=j;}$7$F$$$k$?$a!">e=R7?NHF1$8M}M3$G%V%m!<%I%-%c%9%H$r0z$-5/$3$7F7$^$&!#

:8JU%,%9$+$iJQ?t$N>l9g$O!"%G!<%?%U%m!<2r@OKh$jM>J,$JDL?.$O:o=|$G$-$k$,!"**TINPAR** $K<BAu$5$1$F$$$k2r@O$OBP>]$r%9%+%iJQ?t$K8BDj$7$F$$$kNG!"3N>l9gOE,MQ5$1$J$$!#

?'!9$H%W%m%0%i%`$r=q$-49$($F$_$F$b$3$NLdBj$O2r>C$;$:!"$I$&$7$F$b%V%m!<%I%-%c%9%H$,F~$C$F$7$^$&!#?^3.9$+$i$bC`<!$KHf$Y6KC<$KCY$/$JCF$$$k3H$,$o$+$k!#

3NLdBjKD$$$F$O<!9`$G9M;!9k!#

3.5.2 9M;!-%G!<%?%U%m!<2r@O$NBP>]$N3HBg

%G!<%?%U%m!<2r@O$GBP>]$K7F$$$kN,%9%+%iJQ?t$K8B$C$F$$$k$?$a3Nh&$JLdBj$,;DCF7^C?!#2r@O$r9T$&BP>]$KG[Ns$b4^$`$h$&$K3HD%$9$1$PBP=h$G$-$k!#

7+$7!"BP>]$rG[Ns$^$G9-2k$HMWAG$4FKBP7F2r@O$;$MPJi:!"2r@OK+$+$k;~4V$OG\A}$7F7$^$&!#$^$?!"8=:_TINPAR GO%W%m%0%i%`Cf$K<j

```
      PARAMETER (N=1024)
      REAL A(1:N),B
      DO I=1, N
         B = A(I) ** 2
           :
      ENDDO
```

⇓

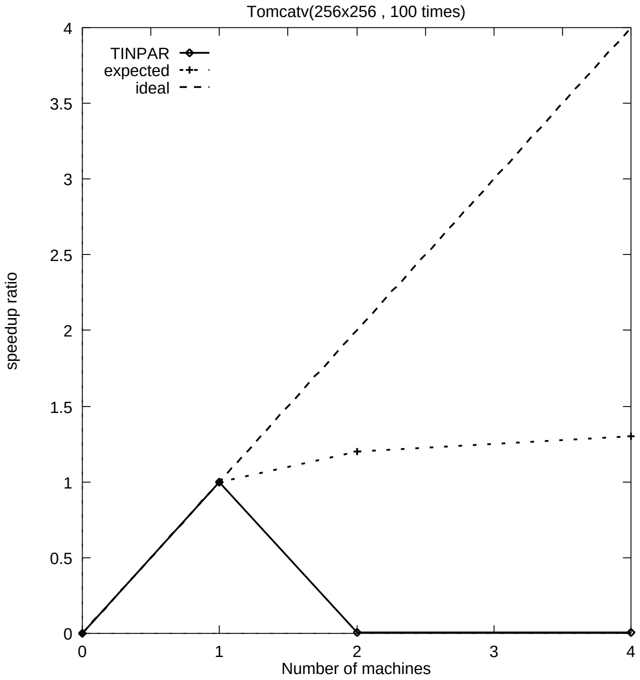
```
For i_outer = ... do
  for i ∈ {i|OWNER(a(i)) == GET_CELL_ID(), 0 ≤ i ≤ n - 1}
  /*=jM-$9$ka(i) $KBP$9$k=hM}*/
    /* a(i) $rAw?. */
    BROADCAST_REAL(a(i))
    tmp = a(i);
        :
  endfor
  /*=jM-$7$J$$a(i) $KBP$9$k=hM}*/
  for i ∈ {i|OWNER(a(i)) != GET_CELL_ID(), 0 ≤ i ≤ n - 1}
    /* a(i) $r<u?. */
    RECV_REAL(owner( a(i)), tmp)
    /* if~$O>C5n$5$l$? */
  endfor
endfor
```

?^3.8: G [NsMWAG$N% 9% +% iJQ?t$X$NBeF~

B3$-8F$S=P7,$"$k$H!"$3$N:GE,2=$,;H$($J$$!#

7+$7!"$3lr2r7h9kNO$=$l$[$IFq7$$$o1GOJ$$!#6qBNE*KO<jB3$-8F$S=P7N0z?t$r8+$F!"2r@OBP>]H9$kJQ?t$,B8:_9l$P:GE,2=$O9ToJ$$$H9kN,:G$b4JC1$G!"2r@OK+$+$k;~4V$,>/$J$/$F9_!"$+$D$[$\@5$7$$:GE,2=$,9T$&3H$,$G$-$k!#

3N:GE,2=$,9T$ol?$H2>Dj$7$F!"<B9T;~4V$r7WC?N,?^3.9 $Nexpected $G<($5l?E@@~G"$k!#



?^3.9: Tomcatv $NBf?t8z2L

4 I>2A

4.1 <+F0%G!<%?J,3d$NI>2A

8=:_**TINPAR** $G07$($k%G!<%?J,3dK!$OC10l<!85J}8~KBP9$k!"G$0U$N%V%m%C%/%5%$%:$N%V%m%C%/%5%$%/%j%C%/J,3dG"$k!#%V%m%C%/%5%$%/%j%C%/J,3d$O%V%m%C%/%5%$%:$r1 H7$?>l9gKO%5%$%/%j%C%/J,3d$KAjEv$7!"!VJ,3d5l$?<!85$NG[NsMWAG?t/ %W%m%;%C%5?t!WH7$?>l9g$K$O%V%m%C%/J,3d$KAjEv9k$?$a!"3lir0lHL2=7?bNG"kH$$$($k!#(?^4.1)

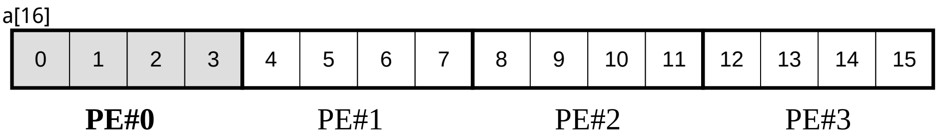
3lKBP7!"HPF GOJ,3d;XDjH7$FALIGN $HDISTRIBUTE $H$$$&FsDN35G0$rMQ$$$?J,3dK!$rMQ$$$F$$$k!#

TINPAR $bJ8K!>e$O$=$Nh&$JJ,3dJ}K!$r5v7F$O$$$k$,!"Cf4V8@8l$?$k tiny K3$N35G0$,$J$$$?$a!"<B:]$K$O%f!<%6!<$,0U?^7?bNHO0[JkJ,3dJ}K!$,E,MQ$5lF7^$&$3H,$"$k!#

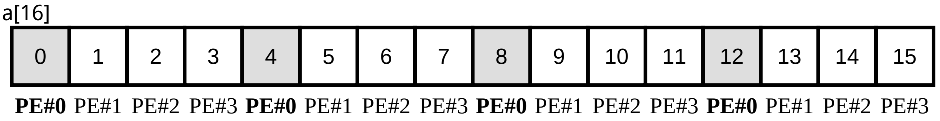
?^4.2$,$=NNcG$"$k!#

MQ0U7?%F%s%W%l!<%H$KG[Ns$rD%jIU1$F@Z$k$H$$$&9M$(J}$O!"3N$+$KJ,3dJ}K!$rA[A|$7d9$/!"$^$?B?:L$JJ,3dJ}K!$,;XDj$G$-$k!#

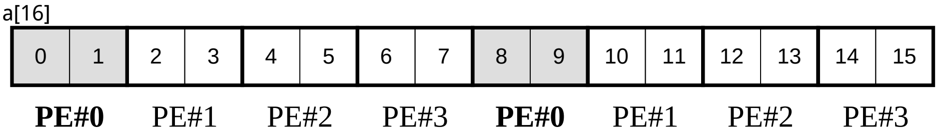
7+$7!"<B:]LdBj$H7F3Nh&$JJ,3dJ}K!$,M-8zG"k+I&$+$H$$$&$N



(a) ブロック長=配列要素数/プロセッサ数 (=ブロック分割)



(b) ブロック長=1 (=サイクリック分割)



(c) ブロック長=2

?^4.1: %V%m%C%/%5%$%/%j%C%/J,3d

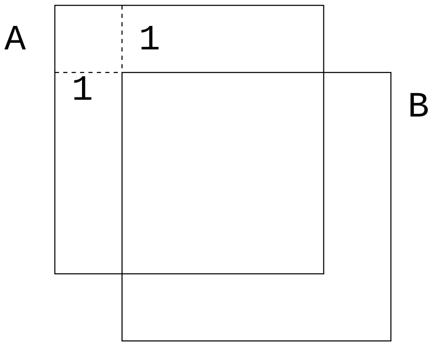
OJLNOCG"$k!#$[HsIN>l9g$,%W%m%0%i%`$N=q$-J}<!Bh$GINh&KGbJ$kLdBj$G$"$j!"3N5!G=$r%5%]!<%H$7$F$$$J$$$+iH$$$CFBg-$J%G%a%j%C%H$G$"$kHO8@$$$Fq$$!#

:#2sMQ$$$?%W%m%0%i%`$N$&$A!"%G!<%?J,3d%G%#%l%/%F%#%V$r;H$o$J$+$C$?$N$OEP $@$1$G$"$j!"$3$N%W%m%0%i%`$O:GE,$JJ,3d8uJd$,A*$PlF$$$?!#$^$?!"Tomcatv $K4X$7FbA4FNG[Ns$rJ,3d$7h&H7$?$H$-$O!"G-k@$1JBNs@-$rCj=P9kh&$J:GE,$JJ,3dJ}K!KJCF$$$?!#

4.2 HPF HNHf3S

HPF $N%Y!<%9$HJk Fortran-D $d Vienna Fortran $N8@8l;EMM$O!"<+F0JBNs2=%3%s%Q%$%i$N8&5f<TC#Kh$j:n@.$5l?!#3NL\E*$O!"<+F0JBNs2=$GI&7Fb&$^$/$$$+$J$$ItJ,$r%f!<%6!<$K;XDj5;k3HK$"$C$?!#$3$NN.$l$r<u$1$F!"HPF $N8@8l;EMM$b!"JBNs2=%3%s%Q%$%i$N8&5f3+H/$r9T$&5;=Q<T$rCf?4$H7F8!F$$5lF$-$?!#3N$?$a!"HPF $N;EMM$,!"K\Ev$K%f!<%6$K;H$$$d$9$$$bNKJk$?$aKO!"%f!<%6$, HPF $r<B:]$K;HCF$_$F!"MxMQ$K:]$7$FIT==J,$JE@$r!"8@8l;EMM$d!"=hM}7O$K%U%#!<%I%P%C%/$9kI,MW,$"$k!#H/$K8=;~E@$G$O!"%f!<%6$,!"8@8l;EMMN_Ji$:!"=hM}7O$NF0:n$r=OCN$7$F$$$J$$$H8zN(

```
!HPF$ PROCESSORS P(4)
!HPF$ TEMPLATE TMPL(N,N)
!HPF$ ALIGN A(i,j) with TMPL(i,j)
!HPF$ ALIGN B(i,j) with TMPL(i+1,j+1)
!HPF$ DISTRIBUTE TMPL(BLOCK) onto P
```



?^4.2: **TINPAR** $G=hM}$G$-$J$$ ALIGN $NNc

$NNI$$JBNs%W%m%0%i%`$r=q$1$J$$$3$H$,B?$$!#$^$?!"5-=RJ}K!$K$h$C$F!"F10l %"%k%4%j%:%`$N%W%m%0%i%`$N@-G=$,Bg$-$/JQ$o$k$3$H$b5)$G$O$J$$!#$3$NLdBj $O!"=i4|$N%Y%/%H%k2=%3%s%Q%$%i$,$=$&$G$"$C$?$h$&$K!"%f!<%6$H=hM}7O3+H/ <T$,0l=o$K$J$C$F<BMQ%W%m%0%i%`$NJBNs2=7P83$r=E$Mk3HKhj2r7h7F$$ $/I,MW$,$"$k!#

3liOA4$F **TINPAR** Kb$$$(k3HG$"$k!# **TINPAR** O3l^$G>o$K 4OA4$J<+F0JBNs2=$rL\;X7F$-$?!#7+$7!"$3$N6aG/$O%f!<%6$K;X<($J8$rA^F~ 5;kH$$$&N.l,<gN.KJCF$-$F$$$k!#%f!<%6$K;X<($5$;$k$H$$$&;vO= l@$1!"%f!<%6$KIiC4r+$1%3%s%Q%$%i$,3Z$r7h$&$H7F$$$k3HKJ$k!# $^$?!"$$$/$iJBNs2=$7K/$$$+iH$$$(Ib!"$=$3$G;X<($J8$rF~$lk3HK$h $jF($2F7$^$&$H!"$=$N;~E@$G8&5f$,;_$^$j!"H/E8$,J/JCF7$^$&!#

HO$$$($**TINPAR** b3N^$^4OA4$J<+F02=$K94CF$$$F$O!"8zN(E*$JJBNs 2=$,=EMh$J$$$+b7lJ$$!#8=:_O=$N=EBg$J4tO)$KN)$?5l$F$$$k$H8@$($k!#

5 $*$ojK

K\Js9p=qGO!"8=:_2f!9$,3+H/$7$F$$$k%a%C%;!<%88r4972JBNs7W;;5!N?$a $N<+F0JBNs2=%3%s%Q%$%i **TINPAR** $N@-G=I>2A$r9TC?!#

F~NO8@8lH7$F Fortran 77 $K HPF $G5,Dj$5lF$$$k%G!<%?J,3d$7<+J,$JJ8 K!$r<u$1IU1k3H$,$G$-!"$^$?<jB3$-8F$S=P$7KbBP1~7?NG!"hjJ#;(

$J%W%m%0%i%`$G$bJBNs2=$G$-$kh&KJC?!#

7+$7$3l^$GI>2A$7$?$3HN$J$$!"FCD'E*$JJBNs8~$1?tCMl i;;%W%m%0%i%`$rBP>]$H$7$?$?$a?7$?$K **TINPAR** $N<eE@$H$b8@$&$Y$-8D=j$,IbD&$j$K$J$C$F$-$?!#4pK\E*$J%W%m%0%i%`$NJBNs2=$K4X7F$O35$MNI9%$J7k2L$rF@$F$$$? **TINPAR** $@$,!">/$7J#;($J%"%k%4%j%:%`$N%W%m%0%i%`KJkH%f!<%6$,$+Jj$N9)IW$r7J$$$H!"NI9%$J%9%1!<%i%S%j%F%#$rF@k3H,G-$J$$$3H,o+C?!#$^$?!"$=$N9)IWr9k?aK$OJBNs2=%3%s%Q%$%i$NJBNs2=<jK!$K$D$$$F!"=OCN7F$$$J1lPJiJ$$!#FC$K!"**TINPAR** KO7W;;7k2L$N0l;~E*JCV->l$H7F;H$&%9%+%iJQ?t$KBP9k:GE,2=$,$^C?$/$H$$$C$F$$$$$[$I<BAu$5lF$$$J$$!#K\Js9p=qGO3lKBP7!"3l$^$G$N:GE,2=$r$[$s$N>/$73HD%9k3HKh$j%9%`!<%:$KBP1~G-k3Hr<(7?!#

<+F0JBNs2=%3%s%Q%$%i$NM}A[$O!"C`<!%W%m%0%i%`$KJs$i<j$r2C$($k3HL5$/?M<jJBNs2=$7$?%W%m%0%i%`$K6a$$@-G=$rF@$k3HG"$k!"$H$$$&3H$+$i9M$($kH^$@$^$@ **TINPAR** OL@.=O$JJBNs2=%3%s%Q%$%iG"k3Hr<(7F$$$k!#

:#8e$N2]Bj$H7F$O!"K\Js9p=q$G5s2?LdBjE@$rAa5^$K2r7h$7!"NAS Parallel Benchmarks $dAPR $NB>$N%W%m%0%i%`$J$I$N$h$jK\3JE*$J%Y%s%A%^!<%/%W%m%0%i%`Kh$k@-G=I>2A$r9T$$$?$$!#

$^$?!"3l$+$iA}$($F$/$kG"m&HPF $G=q$+l?%W%m%0%i%`$KBP1~$9k?$a!"$h$jB?$/$N;X<(J8$rJd=uE*$K%5%]!<%H$7$F$$$-$?$$!#

<UK-

K\8&5f$N5!2q$rM?$($F$/$@5j!"E,@Z$J8f;XF3$r;roC$?IYEDbC<#65<x$K?<?S$J<U0U$rI=7^$9!#

$^$?!"5.=EJ4=u8@$r$$$?$@$$$??9bC0lO:=u65<x!"8^Eg@5M5=u<j$K?<$/46<UCW7^$9!#

5i$K!"6&F18&5f<T$G$"$k7&ED>;;K;a!"C$L&>08c;a!"EDCf?5;J;a$rO8aH7F!"F|:"$+$i8fJ\Z%2<5C$?5~ETBg3XBg3X1!9)3X8&5f2J>pJs9)3X65<<IYED8&5f<<$N=t7;$K46<UCW7^$9!#

;29MJ88%

[1] ;05H0jIW:%a%G%;!<%88r497?JBNs7W;;5!N?aNJBNs2=%3%s%Q%$%iTINPAR

[2] 8eF#?5Li:Hs6Q<A7W;;4D6-8~$1JBNs2=%3%s%Q%$%ihetero-TINPAR

[3] 8eF#?5Li:%G!<%?%U%m!<2r@O$K4p$E$/JBNs2=%3%s%Q%$%i$NDL?.:GE,2=<jK!

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