A+0\E*L7=b$r5vMF$9$k%a%b%j!&b%G%k$K4pE/0l4S@-@)8fJ}<0
A Coherence Control Scheme Based on a Memory Model Allowing Transitional Inconsistency

J!EgD>?M(*FUKUSHIMA Naoto*)

J?@.9G/27n(*Feb. 1997*)

FbMF9<35

=>Mh!"%W%m%;%C%5$+$i$NF10l%V%m%C%/$KBP9k%a%b%j!&"%/%;%9KHbJ$&3F%-%&C%7%e$N>uBVA+0\$dCM99?7$O%-%&C%7%e4V$GF1$8=g=x$G9To1kbNH$5$1F-$?!#$7$+$7!">uBVA+0\$dCM99?7$N=g=x$r%-%&C%7%e4V$G0lCW$5$;$kKOBg$-$J%*!<%P%X%C%IrMW9kN$G!"$3$N=g=x$,%-%&C%7%e4V$G0lCW$7$J$$$3HrG'a1$P7W;;5!$N9bB.2=$,4|BT$G$-$k!#

>uBVA+0\$dCM$N99?7=g=x$,%-%&C%7%e4V$G0lCW$9$k>19g$H7J$$>19gHG$O!"7W;;5!$NMxMQ<T$+$i8+$?%a%b%j$NF0:n$O0[$JkN$G!"5,Dj$5$1$k%a%b%j!&b%G%k$b0[$J$k!#%a%b%j!&b%G%k$G5,Dj$5$1$k9'L\$H7F$O8D!9$N%W%m%;%C%54VGN%9%H%"$N4QB,=g=x$N4X78$d!"%W%m%;%C%54V$G$N%9%H%"$N4QB,=g=x$N4X78$H$$$C$?$bN,$"$k$,!">uBVA+0\$dCM99?7$N=g=x$,%-%&C%7%e4V$G0lCW$9$k;~$H7J$$$H$-$HGO!"%W%m%;%C%54VGN%9%H%"$N4QB,$N=g=xNCfG$bF10l%"%I%l%9$KBP9k%9%H%"$N4QB,=g=x$N4X78$,0[$Jk3HKJk!#

F10l%V%m%C%/KBP9$k>uBVA+0\$dCM$N99?7=g=x$K4X9k@)LsH7FO!"(1)IN%-%&C%7%eKBP7FbF1$8=g=x$G9To1$k(ACS-CC)!"(2)=g=x$O%-%&C%7%e4V$G0[$JkN$G0l;~E*$K$O%-%&C%7%e4V$GL7=b$,@8$:k,!":G=*E*KOL7=b$,$J$/$J$k(TIS-CC)!"(3):G=*E*$K$bL7=b$O@8$:$k$,!Ø$a%b%j!&"%/%;%9$KH<$&0l4S@-@)8f$O9T$o$J$$!K"NA$KFC<1$JL?Na$rH/9T$9k3HKhjL7=b$,$J$/$J$k(NCC)!"$N3<dN'$,9M$(i1$k!#$3N&$A!"ACS-CC$r:NMQ7?7W;;5!$O3$D$N@)Ls$N$&$A$G:G$bJ,$+$jd9$F0:n$r9T$&%a%b%j$rMxMQ<T$KDs6!$G$-$k!#$=$1KBP7$F!"TIS-CC$r:NMQ7?7W;;5!$O<BAu$3%9%H$,$+$+$k0lJ}$G!"MxMQ<T$KBP7F$"$kDxEY<+A3$JF0:n$r9T$&%a%b%j$rDs6!G-kHbK:G$b@-G=8~>e$K9W8%9k3H$,4|BT$G$-!"NCC$r:NMQ7?7W;;5!$O:G$b<BAu$,MF0W$G$"$k!#

TIS-CCKh$k0l4S@-@)8fJ}<0$r<BAu9kKO!"(1)F10l%"%I%l%9XN%a%b%j!&"%/%;%94V$r%7%j%"%i%$%:9kCOE@!Ø7%j%"%i%$%:!&]%$%s%H!KrNc($P<g5-21$K@_$1!"(2)3F%W%m%;%C%5$+iN%9%H%"$KH<$&%-%&C%7%eKBP7FuBVA+0\$dCM99?7$O%7%j%"%i%$%:$5$1$kA0$KEj5!E*$K9T$&!#$=$N8e!"(3):G=*E*KO%-%&C%7%e4V$GL7=b$,@8$8$J$$h$&$K!"%7%j%"%i%$%:$5$1$?8eKb$&0lEY%-%&C%7%e$KBP7F>uBVA+0\$dCM$N99?7$r9T$&$,!"3N:](4)%7%j%"%i%$%:$5$1$?%a%b%j!&"%/%;%9$,3F%-%&C%7%e$KE~C#9k=g=x$,%-%&C%7%e4V$G0lCW9kh&$K!"%7%j%"%i%$%:!&]%$%s%H$K$*$$F%i%s%6%/%7%gsN?J9T$rDd;_$5$;$kJIN@)8f$r9T$&3HKh$j<B8=$G$-$k!#

8=:_3+H/Cf$ND6JENs7W;;5!JUMP-1$OTIS-CCKh$k0l4S@-@)8fJ}<0$r<BAu7F$$k!#JUMP-1GO!"hj@-G=8~>e$r?^$k$?$a$K0l4S@-@)8f$N:GE,2=$r9T$C$F$$k!#$=$N01DK%7%j%"%i%$%:$5$1$kCOE@$rJ#?t@_$1$F$$k!#$3$1Kh$j!"3F%V%m%C%/$r=jM-9k%-%&C%7%e$,$"$k%/%i%9%?Fb$@1G$"$kH-JI$K!"%W%m%;%C%5$N0lCV$H%7%j%"%i%$%:$5$1$k0lCV$H$r6a$/9k3H$,$G$-$kNG!"0l4S@-@)8fK+$+$k;~4V$NC;=L$d&M%C%Ho!<%/$K*$1$kIi2Y$rDc8:9k3H$,$G$-$k!#JUMP-1$K*$1kb$&0l$D$N:GE,2=$H7F!"%7%j%"%i%$%:$5$1$?8e$N:G=*7k2L$N=q$-9~$_$r6KNO8:$i7F$$k3H$,$"$k!#$3$1$O!"(1)%9%H%"KHbJ$$"$k%-%&C%7%e$KBP7FE j5!E*$K=q$-9~$_$r9TC?8e!"$=$N%9%H%"$,4ON;$9$kA0$KB>$N%9%H%"$Khj$=$N%-%&C%7%e$NF10l%V%m%C%/$KBP7F=q$-9~$_$,9T$o1l$?$3Hr8!=P7?;~N_:G=*7k2L$r=q$-9~$'!"(2)$"$k%-%&C%7%e$KE j5!E*$K=q$-9~$_$r9TC?8e$=$N%9%H%"$,4ON;$9k^GOE j5!E*$J=q$-9~$_$r9TC?%V%m%C%/$N>uBV$dCM$,JQ2=$7$J$$h&$KJ]8n$9$k!"$r>u67Kh$j;H$J,1F9TCF$$k!#

Abstract

It is believed that state transitions and value updates for an identical memory block are performed in a consistent order among caches. But due to the large overhead to make the order consistent among caches, speed-up of a computer is expected if inconsistency of the order is allowed.

According to whether or not the inconsistency is allowed, the defined memory model differs because memory behaviors from the point of users differ. An item defined in a memory model is the relations between the order of memory accesses in a program and the order of them in execution. The other is the restrictions on the order of stores observed to processors. The order is consistent among processors in some memory models, and is inconsistent in others. If the order of state transitions and value updates among caches is inconsistent, the observation order of stores for an identical address is also inconsistent among processors. And if consistent, the observation order is also consistent. As such, a part of restrictions on the latter item differs according to whether or not the order of state transitions and value updates among caches is consistent.

Possible restrictions on the order of state transitions and value updates for an identical memory block are, (1) the order is consistent among caches (ACS-CC), (2) the order may be inconsistent, which leads the temporary incoherence of the states and values of the block among caches, but they will be coherent after all the memory accesses to the block will have completed (TIS-CC), and (3) states and values will not be coherent among caches even after all the memory accesses to the block will have completed (coherence control with processor's store is not performed), but they will be coherent if special instructions are issued (NCC). Among these three types of coherence control schemes, computers adopted ACS-CC can present the most comprehensible memories to users. On the other hand, computers adopted TIS-CC will require high implementation costs, but can present pretty comprehensible and high-speed memories. And computers adopted NCC can be easily implemented.

The implementation of TIS-CC coherence control scheme is possible by the following method. That is, (1)

set the serialize point which serializes memory accesses (in main memory, for example), (2) state transitions and value updates of caches by stores are speculatively performed before the stores are serialized. Then, (3) state transitions and value updates of caches are again performed so that states and values will be coherent among caches after all the memory accesses to the block will have completed. And during the above operations, (4) progress of memory accesses is suspended at the serialize point so that the order of state transition and value updates after serialized will be consistent.

The massively parallel computer JUMP-1 implements the TIS-CC coherence control scheme. Several optimizations of coherence control are adopted in JUMP-1 to pursue more speed-up. One of them is to set many serialize points. This method can reduce time taken for each transaction and load of network because the distance between a processor and a serialize point becomes short. Another optimization adopted in JUMP-1 is to reduce the overwrites performed after serialized. This optimization is achieved by introducing the following two mechanisms. Those are, (1) after a state and values are speculatively written to a cache block by a store, if a state and values are written to the cache block by another memory access before the store completes, detect that the cache block is written by another memory access, and overwrite is performed only when such a memory access is detected, (2) protect a state and values of the cache block where speculative write is performed until the access performed the speculative write will have completed.

L\<!

1 O8aK **2**

2 BP>]H9$k7W;;5! **2**

3 %a%b%j!&b%G%k **3**
- 3.1 MQ8l$NDj5A 4
- 3.2 Sequential Consistency 4
- 3.3 %a%b%j!&"%/%;%9!&l%$%F%s%71#JC5;=Q$NF3F~ 4
- 3.4 @)Ls$r4K$/7?%a%b%j!&b%G%k 5

4 %-%&C%7%e4V$NA+0\E*L7=b$rH<$&0l4S@-@)8fJ}<0 **6**
- 4.1 MM!9$J0l4S@-@)8fJ}<0$NDj5A 6
  - 4.1.1 ACS-CC 6
  - 4.1.2 TIS-CC 6
  - 4.1.3 NCC 7
- 4.2 3F0l4S@-@)8fJ}<04V$NHf3S 7
  - 4.2.1 E572E*$J<BAu<jK! 8
  - 4.2.2 Mx32F@<:$NHf3S 9

5 D6JBNs7W;;5!**JUMP-1** K*1k<BAuNc **11**
- 5.1 D6JBNs7W;;5!JUMP-1 $N35N, ... 11
  - 5.1.1 9=@. 11
  - 5.1.2 %a%b%j!&b%G%k 11
  - 5.1.3 0l4S@-@)8f%W%m%H%3%k 12
  - 5.1.4 %H%i%s%6%/%7%g%s 13
- 5.2 0l4S@-@)8f$N:GE,2= 13
  - 5.2.1 %7%j%"%i%$%:!&]%$%s%H$NJ#?tG[CV . . 13
  - 5.2.2 >e=q$-$N:o8: 13
- 5.3 TIS-CC $N<B8=$N$?$a$N5!9=$H@)8f 15
  - 5.3.1 %H%i%s%6%/%7%g%s$N?J9TDd;_ 15
  - 5.3.2 :G=*7k2L$N>e=q$- 17
  - 5.3.3 %H%i%s%6%/%7%g%s$N<cN'JQ99@)8f . . . 18
  - 5.3.4 =q$-9~$_J]8n5!9= 18
- 5.4 F0:nNc 19

6 $*$ojK **20**

1 O8aK

6&M-%a%b%j7?JBNs7W;;5!K*1k0l4S@-@)8fKO%9%H%";~$KB>$N%-%&C%7%e$rL58z2=$9%k$+99?7$9%k$+Ey$Khj!"MM!9$J%W%m%H%3%k$,9M$($i$1!"%W%m%H%3%k$,7W;;5!$N@-G=$KM?$(B$k1F6A$K4X$9%k8&5f$D$$FO3$1$^GK$bB?$/9To1$F$$k!#7+$7!"7W;;5!$N@-G=$r8~>e$5$;$kKO!"INh&$J%W%m%H%3%k$r:NMQ9k$+$NB>Kb0l4S@-@)8f$N<BAuJ}K!$b=EMWG"k,!"@-G=8~>e$rL\;X$7$?<BAuJ}K!$K4X$9%k8&5f$O$[$HsI0Y$5$1$F$$J$!#

$3$1$^$G0l4S@-@)8f$N<BAu$N:]$K!"F10l%V%m%C%/$X$N%a%b%j!&"%/%;%9$KH<$&3F%-%&C%7%e$KBP9k>uBVA+0\$dCM$N99?7$N=g=x!AI+0\=g=x!K$K4X$7FO2?$b9M;!$5$1$F3i1:!"A+0\=g=x$O%-%&C%7%e4V$GF1$8$KJk$H0EL[$N$&$A$K7h$ai1k3H,B?$+$C$?!#$7$+$7!"A+0\=g=x$,%-%&C%7%e4V$GF1$8$KJkI,MWO[HsIJ$/!"$^$?!"A+0\=g=x$rF1$8$K9k$?$aKOBg$-$J%*!<%P%X%C%IrMW9$k!#$hCF!"A+0\=g=x$,F1$8KJ$kJ]>Z$r@_1J1l$P7W;;5!$N9bB.2=$,4|BT$G$-$k!#

$=$3$GK\8&5f$G$OA+0\=g=x$,%-%&C%7%e4V$G0lCW$9kH$O8B$i$J$$0l4S@-@)8fJ}<0$r<($7!"$=$7F3$NJ}<0$N<BAuJ}K!$r=R$Y$k!#

K\8&5fK*$$FO^$:!"A+0\=g=x$,0lCW9kJ}<0H7$J$$J}<0$N4V$N:9$rL@3N$K9k!#Hf3S$N9'L\$H7F!"%a%b%j!&b%G%kK*1k:90[$*$h$S9M$(i1$k<BAuJ}K!$r5s$2!"$=1KbH$E$$F@-G=!"<BAu%3%9%H!"$*$h$S%W%m%0%i%^%S%j%F%#$K4X9kMx32F@<:$r9M;!$9$k!#

$=$N8e!"D6JBNs7W;;5!JUMP-1 K*$$F$OA+0\=g=x$,%-%&C%7%e4V$G0lCW$7JS$0l4S@-@)8fJ}<0$r:NMQ7F@-G=8~>e$r?^$kHb$K!"%a%b%j!&"%/%;%97PO)$NC;=L$d%M%C%H%o!<%/$K$*$1$kIi2Y$NDc8:$r?^$k:GE,2=Kh$j!"$h$j0lAX$N@-G=8~>e$rL\;X$7$F$$$k!#

0J2<!"$^$:2>OGOA0DsH7$FK\8&5f$NBP>]H9$k7W;;5!$N9=@.5Z$SF0:n$r=R$Y!"3>O$G$O%a%b%j!&b%G%k$N35O@KD$$$F=RYFK\8&5f$N0LCV$E1r<($9!#$=$N8e!"4>O$GA+0\=g=x$,0lCW$7JS$0l4S@-@)8fJ}<0$r$r<($9HHbK=>Mh$N0lCW$9$kJ}<0$N4VHNMx32F@<:$r=R$Y!":G8e$K5>O$G3NJ}<0$r:NMQ$7$?7W;;5!$H7F!"8=:_3+H/Cf$ND6JBNs7W;;5!JUMP-1 K*1k<BAuNc$r<($9!#

2 BP>]H9$k7W;;5!

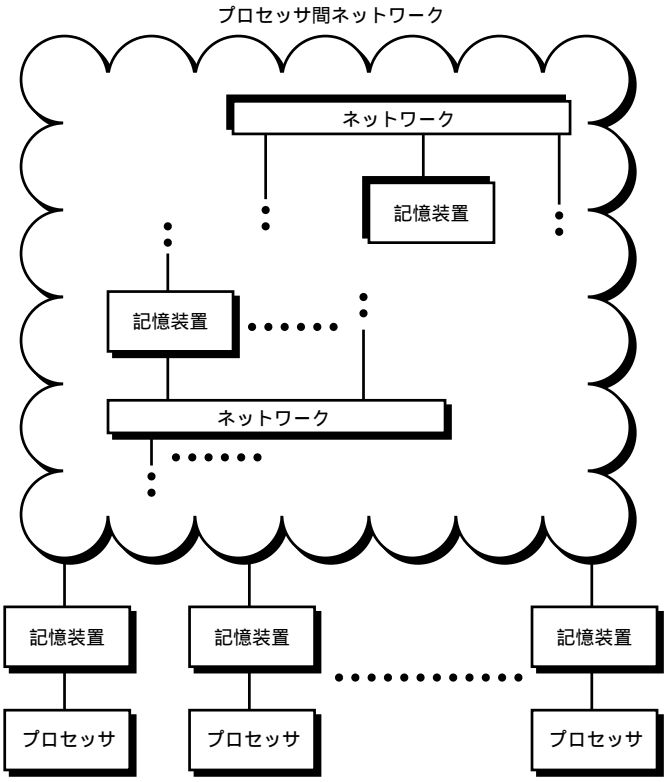
9=@. K\9F$NBP>]$H9k7W;;5!$r?^1$K<($9!#$9Jo$A%W%m%;%C%5Kh$K5-21AuCV$,<h$jD1i1F*$j!"$3$N5-21AuCV$O$"$k%"%I%l%9KBP9$k<g5-21$H7F!"$^$?2B>$N5-21AuCV$KBP9k%-%&C%7%eH7$F5!G=$9$k!#

$^$?!"%W%m%;%C%54V$N%M%C%H%o!<%/$J#?t$N7k9gLV$,Aj8_$K7k9g$5$1$kJ#9g%M%C%H%o!<%/$G9=@.$5$1$F$*$j!"5i$K!"%M%C%H%o!<%/$NCfKO%W%m%;%C%5KOD>@\7k9g$5$1$F$$J$5-21AuCV$,B8:_$7F@$k!#3N5-21AuCV$N5!G=$O%W%m%;%C%5$KD>@\7k9g$5$1$F$$k5-21AuCV$HF1$8$/!"<g5-21$H7F$N5!G=$H%-%&C%7%eH7FN5!G=$r;}$D!#

$?$@$7!"<g5-21$H%-%&C%7%eOHbK>uBVHCMr;}DH8@$&B&LL$+$i8+$k$HF1$8bNG"$k!#0J8e!"K\9F$K$*$$FOFCK

CGj,$J$$8B$j!"<g5-21$H%-%&C%7%e$O6hJL$;$:!"?^1$K$*$1$k
5-21AuCV$rC1$K%-%&C%7%e$H8F$V3HK9$k!#FC$K!"%W%m%;%C
%5$KD>@\7k9g$5l?%-%&C%7%e$OL1%-%&C%7%e$H8F$V!#

F0:n 0l4S@-@)8f$O!"$3N?aKI,MW$J>pJs !NGc$($P%a%b%j!&
%"%/%;%9$N<cN'$d&G!<%?JI!K$,5-=R$5lF$$k%Q%1%C%H$N0\
F0Kh$j?J9T$9$k!#$9Jo$A!"%W%m%;%C%5$+iN%a%b%j!&"%/
%;%9KHbJ$$%Q%1%C%H$,@8@.$5$l!"%Q%1%C%H$,%M%C%H%o!<%/
$r7FM3$7$F3F%-%&C%7%e$d%a%b%j$KE~C#$7!"I,MW$K1~$8$F>uBV
$NA+0\$d&G!<%?$N=q$-9~$_$r9T$&!#$?$@$7!"3N%Q%1%C%H$O?^
2$K<($9h&$K!"0\F0ESCf$GJ#?t$KJ,4t$7$?$j!"$^??^3$K<($9
h&$K0lEYDL2a$7$?%a%b%j$r:FEYDL2a9k3H$,$"C?$j!"$5
iKF1$8%W%m%;%C%5$+$i@8@.$5l?%Q%1%C%HGb%a%b%j!&"%/
%;%9$N<cN'$d>u67KhCF$=$NDL2a7PO)$C0[$J$k!#



?^1: K\9F$NBP>]7W;;5!

3 %a%b%j!&%b%G%k

%a%b%j!&%b%G%k$O6&M-%a%b%j7?JBNs7W;;5!$K$*$$F!"3F%W%m%;%C
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H,G-!"0lJ}3+H/<T$+$i8+kH!"%a%b%j!&%b%G%k$O5vMF$5lk
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%'$N3+H/<T$HMxMQ<T$N4V$N%$%s%?%U%'!<%9$H7F$NLr3d$r;}$D!#
7W;;5!$N3+H/$N:]KO@-G=8~>eN?aK!"Nc$($P%9%H%"!&
%P%C%U%!JI$NMM!9$J%a%b%j!&"%/%;%9!&%l%$%F%s%7$NDc8:<j
K!$,:NMQ$5lk!#%l%$%F%s%7Dc8:<jK!$r:NMQ9k3HKhj!"
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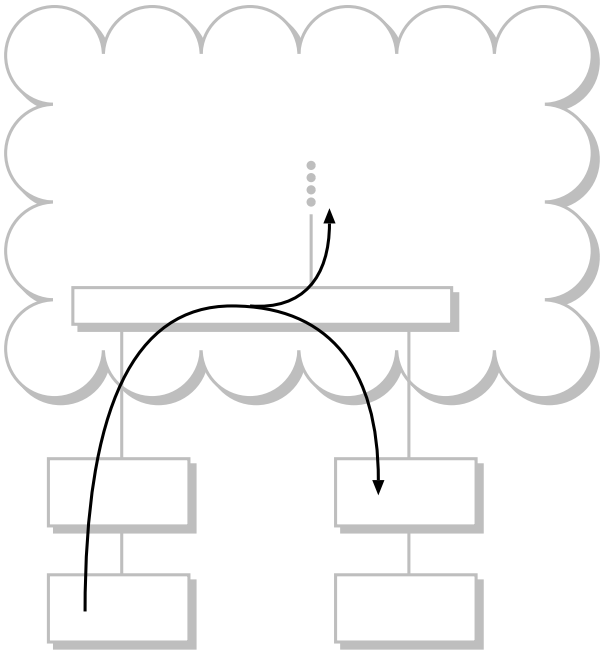

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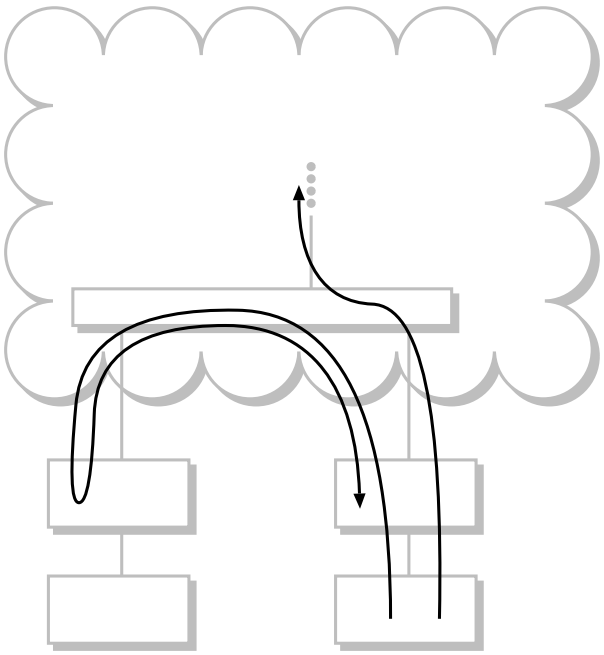

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@h$K=R$Y$?$h$&$K!"K\8&5f$O>uBVA+0\$dCM99?7$N=g=x$,I,$:$7$b%-%&C%7%e4V$G0lCW7J$$0l4S@-@)8fJ}<0$N<EAu$Khj7W;5!$NB.EY8~>e$rL\;X$9!#>uBV99?7$dCM99?7$N=g=x$,I,$:$7$b0lCW$7$J$$3HKhj!"3N=g=x$,0lCW$9$k=>Mh$NJ}<0$r<BAu$7$?7W;5!$HHf3S7F!"MxMQ<T$+$i8+$?%a%b%j$NF0:n$d3+H/<T$KHC$F5vMF$5lk%a%b%j$NF0:n$OJQok3HKJ$k!#

%a%b%j!&b%G%k$O4v$D$+$N%Q%i%a!<%?$NAH9g$o$;$KhjI=8=9k3H$,$G$-$k$,!"K\>O$G$O=>Mh$N0l4S@-@)8fJ}<0$HK\9F$G<($9J}<0$N4V$N:90[$rM}2r9k$?$a$N='Hw$H7F!"%a%b%j!&%b%G%k$N350@$H3F%b%G%k$N:90[$rFCD'E1$k%Q%i%a!<%?$N<dN`KD$$$F=RYk!#

3.1 MQ8l$NDj5A

K\>O$G8=$l$kMQ8l$NDj5A$r9T$&!#

- %a%b%j!&"%/%;%9$N4~0N;
  $"$k%W%m%;%C%5$,9T$C$?%9%H%"$SNCMr%W%m%;%C%5P_i,%m!<%IL?NaKh$jF@$k3H$,$G$-$kh&KJC?H-!"!"¥9%H%"SOP_iKBP7F4~0N;7?!W$H$$$&

  $^$?!"%W%m%;%C%5P_i,9TC?%m!<%IL$K4X$7$F!"%W%m%;%C%5$P_kKh$kF10l%"%I%l%9$X$N%9%H%"$,!"P_iKJVkCM$K1F6A$rM?$($k3H$,$G$-$J$/$JC?;~E@$G!ŁL$OP_kKBP7F4~0N;7?!W$H$$$&!#

  $=$7$F!"%a%b%j!&"%/%;%9M$,9YFN%W%m%;%C%5KBP7$F4~0N;$7$?;~E@$G!ŁM$O4~0N;$7$?!W$H$$$&!#

3.2 Sequential Consistency

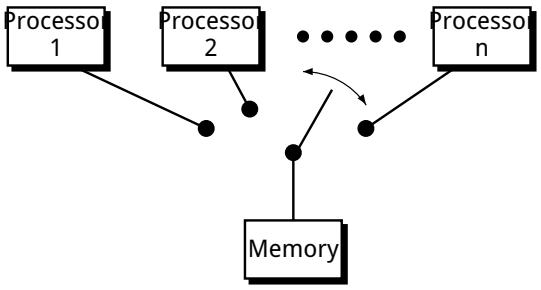
JBNs7W;5!K*1kJBNs%W%m%0%i%`$KBP$9$k%a%b%j$NF0:n$r5-=R$9$k0l$D$NJ}K!$H$7$F!"MxMQ<T$K$H$C$F$O$"$?$+$b$"$kC10l%W%m%;%C%5>e$GJ#?t$N%W%m%;%9$,<B9T$5$l$F$$$k$h$&$K8+$;$k<jCJ$,5s$2$i$l$k!#$9$J$o$AMxMQ<T$K$O!"UBNs7W;5!>e$NUBNs%W%m%0%i%`$O!"$"$kC10l%W%m%;%C%5$K$*$$FUB9T%W%m%;%9$,%s%s%?%j!<%V<B9T$5lF$$$kNHF1$8F0:n$r9kh$&$K8+$;$k!#3l$r7A<OE*$KDja?N,Sequential Consistency [4] G"$k!#$3lO!"Lamport Kh$j0J2<$Nh&KDjail$F$$k!#

> Dj5A1: **Sequential Consistency**
> %W%m%;%C%5$N<B9T$9$kL?Na$rA4BNH7FO$"$kC`<!$N=g=x$G<B9T$7!"$+$D!"8D!9$N%W%m%;%C%5$NL?Na$,$3$N=g=x$K$*$$F%W%m%0%i%`$G<($5lkNHF1$8=g=x$G$"$iol$F$$$kJi$P!"$=$N^%k%A!&W%m%;%C%5$OSequential Consistent G"$k!#

Sequential Consistency $NF0:n$OMxMQ<TKHCF$O:G$b<+A3JbNG$"$k!#?^4$KSequential Concistency $NF0:n$N350?^$r<($9!#3F%W%m%;%C%5$O%W%m%0%i%`$K<(5l$?=g=x$NDLjK%a%b%j!&"%/%;%9$rH/9T$7!"3F%"%/%;%9$O%a%b%j$KhC$F!Ł>$A$K!W=hM}$5lk!#9JoA!"3F%"%/%;%9$O%a%b%j!&"%/%;%9$KBP7F%"%H%_%C%/$K<B9T$5lk!#$^?!"%a%b%j$,<!KI$N%W%m%;%C%5$+iN%a%b%j!&"%/%;%9$r=hM}$9k+$OHs7hDjE*$K7hDj5l$k!#

3.3 %a%b%j!&"%/%;%9!&l%$%F%s%71#JC5;=Q$NF3F~

%a%b%j!&"%/%;%9$NB.EY$O%W%m%;%C%5$NF0:nB.EY$KHfYFCx7/CY$$!#7?$,,$C$F!"7W;5!$N@-$r8~>e$5$;$k$?$aKO!"3N:9$rJd=~$9$k5;=Q$rF3F~9k3H$,=EMW$HJk!#Nc$($P!"%W%m%;%C%5N9$030B&$K%9%H%"!&P%C%U%!$r@_$1$F!"%W%m%;%C%5$,



?^4: Sequential Consistency $K4p$E$/%a%b%j

%9%H%"$rH/9T$7$?8e!"$=l,4~0N;9k$^$G%W%m%;%C%5$r%9%H!<%k5$;F*/NGOJ$/!"%9%H%"!&P%C%U%!$KCM$r=q$-9~$\$@1G$=$N%W%m%;%C%5KHCF$O%9%H%"$,4~0N;7?3HK7!"<!$NL?Na$K?J$^$;k3HKhj!"%9%H%"$KH<$&%l%$%F%s%7$r:o8:9k!#7+$7!"$3Nh$&$J%a%b%j!&"%/%;%9%N%l%$%F%s%7$rl#JC5;=Q$NF3F~$Khj7W;5!$,Sequential Consistency $OK~$?5lJ/Jk!#

Dj5A1$NSequential Consistency $rK~$?9H$O8@$$4$9$(lP!"8D!$N%W%m%;%C%5$+iN%a%b%j!&"%/%;%9$O%W%m%0%i%`$N=g=xDL$j$K<B9T$5$l!"$+$D$9$Y$F$N%a%b%j!&"%/%;%9$OB>$KBP$7$F86;RE*$K9T$o$l$F$$k$h$&$K8+$($J$1$l$P$J$i$J$$$H$$$&&3$H$G$"$k!#$3$l$i$O=$l$>$l%W%m%0%i%`!&"%/%;%9$NMW5a(Program Order Requirement)!"%"%H%_%7%F%#$NMW5a(Atomicity Requirement)$H8F$Plk[5]!#0J2<$G!"%a%b%j!&"%/%;%9!&l%$%F%s%71#JC5;=Q$NF3F~$Khj!"INh&$K3$NFsDN>r7o$,K~$?5lJ/Jk$+$r=RYk!#

%W%m%0%i%`!&*!<%@$NMW5a %W%m%;%C%5$K$h$C$F$O%Q%$%W%i%$%s$K$*$$F;q8;6%9g$,H/@8$7$?$H$-$J$I$K!"%a%b%j!&"%/%;%9$NH/9T=g=x$r%W%m%0%i%`$N=g=x$H$O5UE>$5$;$k>19g$,$"$j!"$3lKhj%W%m%0%i%`!&*!<%@$NMW5a$,K~$?$5$l$J$$2DG=@-$,@8$:$k!#$7$+$7!"%W%m%;%C%5$,%W%m%0%i%`$N=g=xDL$j$K%a%b%j!&"%/%;%9$rH/9T7?H7Fb0J2<Nh$&$KJCF7$^$&2DG=@-$,@8$:$k!#

$^$:$O%9%H%"!&P%C%U%!$r9M$($k!#7W;5!$N@-G=$KBP7FBg$-$J1F6A$rM?$(kN%9%H%"K+$+$k;~4VGOJ/!"%m!<%I$+$+$k;~4V$G$"$k!#3N3H$+$i$"%k%9%H%"$N7k2L$,$%9%H%"!&P%C%U%!$K%P%C%U%!j%s%0$5lF$$k:]$K!"%W%m%;%C%5$,8eB3$N%m!<%IL?Na$rH/9T9k$H!"%m!<%IL?Na$r9bB.$K=hM}$9k?aK%9%H%"!&P%C%U%!$r%P%$%Q%9$9$k5;=Q$,:NMQ$5lk>19g$,$"$k!#$3$N>19g!"@h9T%9%H%"$H8eB3%m!<%I%O%W%m%0%i%`$K4~0N;$7$J$$2DG=@-$,@8$:$k!#

5i$K!"%M%C%H%o!<%/$KhCFb%a%b%j!&"%/%;%9N=g=xD,F~lBXo$k2DG=@-$,"$k!#Nc($P!"%M%C%H%o!<%/KhCFOIi2YJ,;6$r?^$k?aKF1$8%W%m%;%C%5$+$iH/9T$5l?FsDN%a%b%j!&"%/%;%9Gb0[Jk7PO)$rDl2a$9k3H,$"$k!#3N;~!"$"$k%W%m%;%C%5$,Fs$D$N%9%H%"($S_a, S_b : S_a$,@h$KH/9T)$rO"B3E*$KH/9T7?H-!"b7FsDN%9%H%"$N4V$G%M%C%H%o!<%/K*1l$P!"$INh$&$KbS_b$,@h$K40N;9k2DG=@-$,"$k!#

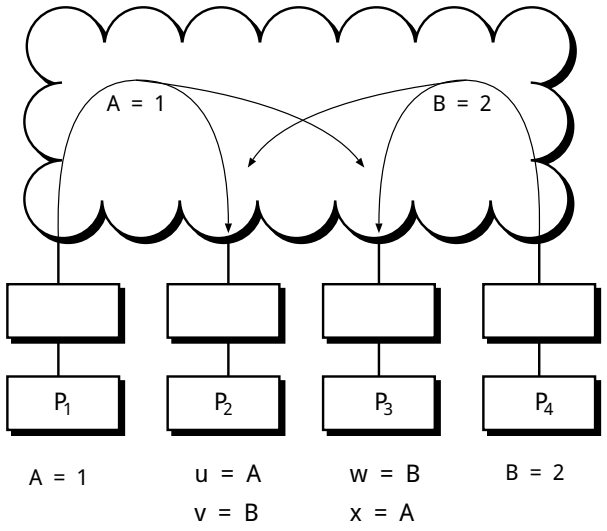
%"%H%_%7%F%#$NMW5a %-%&C%7%e!&a%b%j$NF3F~$O%a%b%j!&"%/%;%9N%l%$%F%s%7Dc8:5;=QH7$FHs>o$K=EMWG"$k!#$7$+$7!"%-%&C%7%e$NF3F~$Khj!"3F6&M~G!<%?$O7W;5!Fb$KJ,;6$7$F

J#?tB8:_7F$$k3HKJ$k!#3F%G!<%?$,J,;6$5$l$FB8:_$7$F$$k$?$a!"%a%b%j!&"%/%;%9$,"%H%_%C%/$K9Tolkh$&$K9kNO:FqHJk!#

%-%&%C%7%e$r:NMQ$9$k6&M-%a%b%j7?$NJBNs7W;;5!$O%9%H%"$NEYK3li$r:G?7$NCM$KJ]$D$?$a$N%-%&%C%7%e!&3%R!<%l%s%9@)8f!"9JoA!"%9%H%"NEYKJ,;6$7$FB8:_7F$$k%G!<%?$rL58z2=$7$?$j!"$=$liNCM$r?7$7$$CM$K99?7$9k3H,9Tol$k!#Nc$($P!"<!$N%W%m%0%i%`$r9M$($k!#

P_1	P_2	P_3	P_4
A = 1;	u = A;	w = B;	B = 2;
	v = B;	x = A;	

:G=i!"IN%W%m%;%C%5$NL1%-%&%C%7%e$K$bM-8z$J?G!<%?$N3%T!<$,B8:_7F$*$j!"$=$NCMOOG$"$kH7!"%-%&%C%7%e!&3%R!<%l%s%9@)8f$O99?77?$G9TolkH9k!#$3$3G!"P_1HP_4,$[$\F1;~K=l>$l A,B KBP9$k%9%H%"$r9T$&$H9k!#3N;~!"P_1OJQ?t A $NB>$N%3%T!<$r1$K!"P_4OJQ?t B $N%3%T!<$r2$K99?7$9k?aN%3%R!<%l%s%9@)8f$r3+;O$9$k!#$7$+$7!"%W%m%;%C%54V$N5wN%$N:9JI$NM}M3$N$?$a!"P_2HP_3N4VG3li$N99?7%Q%1%C%H$r<u$1<h$k=g=x$,5U$KJk2DG=@-$,@8$8F@$k!#Nc$($P?^5$K<(9h$&$K!"P_2OP_1+iN99?7%Q%1%C%H$r@h$K<u$1<h$j!"$=$N8eGP_4$+$i$N99?7%Q%1%C%H$r<u$1<h$k$,!"$P_3OP_4$+$i$N99?7%Q%1%C%H$r@h$K<u$1<h$k>u67$,5/3jF@$k!#$3$N7k2L!"$(u, v, w, x) = (1, 0, 2, 0)$ HJk3H,5/3jF@$F!"Sequntial Consistency $rK-$?5J$/$J$k!#$3lO!"6&M-%G!<%?A,B $,J,;6$7$FJ#?tB8:_$7F*$j!"N><T($P_2,P_3$) KBP9$k99?7$r%"%H%_%C%/$K9TCF$$$J$$$?aK@8$:$k7k2LG"$k!#



?^5: %"%H%_%7%F%#$NMW5a$,K-$?$5lJ$$>u67

0J>e$K<($7$?$h$&$K!"7W;;5!$NB.EY8~>e$N$?$a$K%9%H%"!&%P%C%U%!$d%-%&%C%7%e!&a%b%jJIMM!9$J%a%b%j!&"%/%;%9!&l%$%F%s%7Dc8:5;=Q$,F3F~$5lk!#7+$7!"$3li$N5;=Q$NF3F~N?aKSequential Consistency $OK~$?5lJ/Jk!#

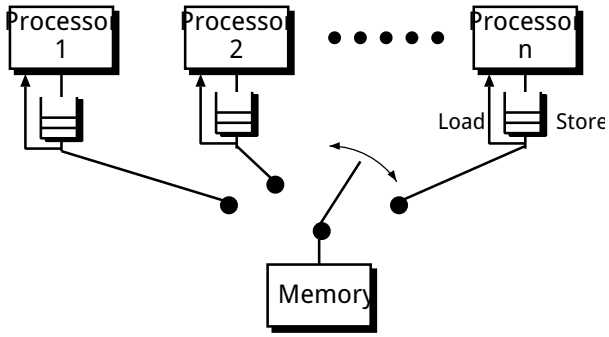
3.4 @)Ls$r4K$/7?%a%b%j!&b%G%k

A0@a$G<($7$?$h$&$K!"%a%b%j!&"%/%;%9$N%l%$%F%s%7$rDc8:59$k5;=Q$rF3F~$9k3HKhjSequential Consistency $rK~$?9?aN>r7oG"$k%W%m%0%i%`!&*!<%@$NMW5a$H%"%H%_%7%F%#$NMW5a$,$OK~$?$5lJ$$$2DG=@-$,@8$:$k!#

3N3H+$i!"%l%$%F%s%7Dc8:5;=Q$r:NMQ$9$k?$a$K!"%a%b%j$NF0:nKBP7$F2]$5lk@)Ls$rSequential Consistency KBP7$F4K$/7?MM!9$J%a%b%j!&b%G%k$,Ds0F5l$F$$k!#8=:_$^$G$KDs0F$5lF$$k<g$J%a%b%j!&b%G%k$K$*$$F$Q@)Ls$r4Ka?7k2L!"%W%m%0%i%`!&*!<%@$H%"%H%_%7%F%#$NMW5a$O0J2<$Nh&$KK~$?5lJ/Jk!#

%W%m%0%i%`!&*!<%@$H<B9T;~$N4O;=g=x$NLT0lCW

IBM-370 %b%G%k[6] $O?^6$K<($935G0?^$Khj%a%b%j!&b%G%k$,Dj$ail$k!#IBM-370 %b%G%k$K$*$$F$O3F%W%m%;%C%5Kh$K FIFO $N%9%H%"!&P%C%U%!$K=q$-9~$`$@$1$i$l$F$*$j!"%9%H%"$r9T$&$H$3$N%P%C%U%!$K=q$-9~$`$@$1$G<!$NL?Na$K?J$_!"$^?!"%9%H%"!&%P%C%U%!$KL$4O;$N%9%H%"$,B8:_$7$F$$kH-$K%m!<%I$,9TolkH!#9%H%"$HF10l%"%I%l%9$X$N%m!<%I$G$J$$$H$-$O!F%9%H%"hj$b%m!<%I$,@h$K=hM}$5lkH7$F$$k!#3N7k2LIBM-370 %b%G%kGO@h9T$N%9%H%"$H8eB3$N%m!<%I$N4O;=g=xO=li$,0[$J$k%"%I%l%9$KBP9kbNG"kJiP%W%m%0%i%`!&*!<%@DLjK4O;9k3H$OJ]>Z$5lJ$$!#



?^6: IBM-370 %b%G%k$N35G0?^

$^$?!"Total Store Ordering(TSO)[7] K*$$F$O!"?^6$HF1MM$N35G0?^$Khj%a%b%j!&b%G%k$,Dj$ail$F$$k!#$?$@$7!"8eB3%m!<%I,@h9T%9%H%"$HF1$8%"%I%l%9$N>l9g$O%9%H%"!&P%C%U%!$+$iD>@\%W%m%;%C%5$KBP7FCM$,JV$5lk%U%)%o!<%G%#%s%0$,9T$olkbNH7$F$$k!#3N7k2L!"@h9T%9%H%"$H8eB3%m!<%I$N4V$N4O;=g=x$OIBM-370 HO0[Jj!"F10l%"%I%l%9G"m&$,$HFb!"%W%m%0%i%`!&*!<%@DLjK4O;9k3H$OJ]>Z$5lJ$$!#

5i$K!"Partial Store Ordering(PSO)[7] K*$$F$OTSO KHfY$F%9%H%"!&P%C%U%!$OFIFO GO$J$$H5l$F$$kNG!"@h9T%9%H%"$H8eB3%9%H%"$N4V$N4O;=g=x$b%W%m%0%i%`!&*!<%@DLjH$O8B$i$J$$!#

0lJ}!"Weak Ordering (WO) [3] $dRelease Consistency (RC) [8] $O%a%b%j!&b%G%k$rD jakK"$?$C$F!"%W%m%0%i%`$NF14|E@$G$N$_5$7$?$CM$,8+$($l$PNI$$H$&$&$K9M$($K4p$E$$F$$k!#$3$N$?$a$K%W%m%;%C%5$+$iH/$;$i$l$k%"%/%;%9$KOF14|L?Na$HHsF14|L?Na$,$"$k$K$7$?$^$C^J$$F!"F14|L?Na$r$O5$^$J$$F$s$D$NHsF14|L?Na4V$N4O;=g=x$K4X$9$k@)Ls$OB8:_$;$:!"@h9T/8eB3L?Na$N<oN`(%m!<%I/%9%H%")Khi:%W%m%0%i%`!&*!<%@DL$j$K4O;$9$kJ]>Z$O$J$$!#WO $HRC $N4V$G$OF14|L?Na$N<oN`$,Bg$-$/0[$J$k!#WO GO!"0l<oN`$NF14|L?Na$,MQ0U$5$l$F$*$j!"%W%m%0%i%`%`Cf$KF14|L?Na$rA^F~$9$k$3$H$G$=$NA08e$N4O;=g=x$O%W%m%0%i%`$N=g=x$,J]$?$5lk!#0lJ}!"RC K*$$F$Oacquire,release $NFs<oN`$NF14|L?Na$,MQ0U$5lF$*$j!"acquire $H8eB3%"%/%;

%9$N4V!"5Z$S@h9T%"%/%;%9$Hrelease $N4V!"$=7FF14|L?Na4V $N40N;=g=x$OJ]$?$l$k[1]!#8@$49$($l$P!"acquire $O6&M-JQ?t$K BP9k%"%/%;%98"$N3MF@$r!"release $O%"%/%;%98"$N2rJ|$r0UL# 7F$$k!#

%"%H%_%C%/<B9T$N4KOB %9%H%"$,%"%H%_%C%/$K<B9T$5lkJi $P!"8@$49$($l$P%9%H%"$,D>AK40N;9kJi$P!"!O[$J$k%W%m %;%C%5$+$iH/$;il$?$bNb4^aF!K9YFN%9%H%"OI$N%W %m%;%C%5$KBP7F$bF1$8=g=x$G4QB,$5lk!#7+$7!"%a%b%j!& %b%G%k$KhOFO%W%m%;%C%5$+$iH/$;$il?%9%H%"$OD>$AKO 40N;7J$$H5,Dj5lk?aK!"%9%H%"$N4QB,=g=x$,%W%m%;%C %54V$G0[$J$k2DG=@-$,@8$:$k!#

Nc$($P!"TSO $dPSO K*$$F$O%9%H%"$C01C6%9%H%"!&P%C %U%!$K3JG<$5lF$+$i%a%b%j$K=q$-9~$^$l!"5i$K%9%H%"!&P%C %U%!Fb$NCM$O<+%W%m%;%C%5$+iOD>AK4QB,2DG=G"kHDj$a il$F$$k!#3N$?$a!"%9%H%"$N7k2L$,P%C%U%!$KB8:_$7$F$$ $k4V$KB>$N%W%m%;%C%5$,%9%H%"$r9T$&$H%9%H%"$N4QB,=g=x$O%W %m%;%C%54V$G0lCW7J$/$J$k!#

7+$7TSO $dPSO K*1k%9%H%"!&P%C%U%!$O!"K\Mh$O %a%b%j!&"%/%;%9$N%W%m%0%i%`K*1k=g=x$H<B9T;~$N40N;=g =x$r5,Dj9k3H$rL\E*$H7F$*$j!"3N%P%C%U%!Kh$j%"%H %_%C%/<B9T$N4KOB$,$J5lkH$$&3H$OI{:nMQE*$KDj$^$k$K 2a$.$J$$!#$^$?!"WO $dRC K*1kHsF14|L?NaNh$&$K%"%H %_%C%/$+H]$+$,L@5-$5lF$$J$%b%G%k$b$"$k[2]!#3Nh&$K!" %"%H%_%C%/<B9T$N4KOBKD$$F$OL@5-$5lF$$J$%a%b%j!&b %G%k$,B?$$!#

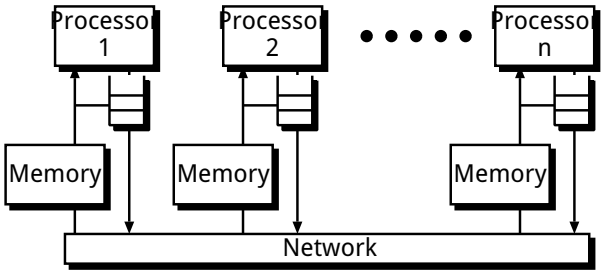
$=$NCfGb!"Processor Consistency[8] $O%"%H%_%C%/<B9T $N4KOB$,9MN8$5$l$F$$k!#PC $O

1. %m!<%I$,B>$N3F%W%m%;%C%5KBP7$F40N;$9$kA0$K!"$=$l0J A0N9YF$N%m!<%I$O40N;7F$$J1lPJiJ$$!#
2. %9%H%"$,B>$N3F%W%m%;%C%5KBP7$F40N;$9$kA0$K!"$=$l0J A0N9YF$N%"%/%;%9 !#m!<%I!"%9%H%"!K$O40N;$7$F$$J 1lPJiJ$$!#

H@$1Dj$ail$F$$k$,!"PC $O?^7$Nh&$J7W;5!9=@.!"$9 Jo$A3F%W%m%;%C%5Kh$K%U%)%o!<%G%#%s05!G=rb$D%9%H%"!& %P%C%U%!$H!"A4%"%I%l%9$NFbMF$rJ];}9k%a%b%j!&3%T!<$r=j M-$9k3HrA[D]7F$*$j!"%a%b%j$N%3%T!<$,J#?tB8:_9k$? $a!"A4%a%b%j!&3%T!<$N99?7$r%"%H%_%C%/$K9T$&$3HO=PMh$J $$3H,A0DsHJCF$$k!#3N$?$a!"?^5Nh$&$K%9%H%"$N 4QB,=g=x$,%W%m%;%C%54V$G0lCW$7J2DG=@-$,$"kbNH5l $F$$k!#$?$@$7!"3F%"%I%l%9$NFbMF$O%a%b%j4V$GL7=b$,@8$8$J $$h$&$KF10l%"%I%l%9XN%9%H%"OI3+$G%7%j%"%i$%:5l $F!"$=$N=g=xDL$j$K3F%3%T!<$K=q$-9~$^lkH7$F$$k[9]!#

4 %-%&C%7%e4V$NA+0\E*L7=b$rH<$&0l4S@-@)8fJ}<0

8=:_$^$G$K3+H/$5lF$-$?6&M-%a%b%j7?JBNs7W;5!$NB?$/$O!" F10l%V%m%C%/$KBP9k%a%b%j!&"%/%;%9Kh$kCM99?7$d>uBVA+ 0\$O%-%&C%7%e4V$GF1$8=g=x$G9T$olk!#3N$?$a$K!"3F%V%m%C %/$KBP9k%a%b%j!&"%/%;%9$r7W;5!$FbN"$k0lE@$G=g=xIU$1 7F!"3N=g=xNDLj$K3F%-%&C%7%e$N>uBVA+0\$dCM99?7$r9T $&@)8f$r9TCF$$k!#7+$7!"=g=xIU$1K+$+$k%*!<%P%X%C%I $O>.$5$$H$O8@$($J$$N$G!"=g=xIU$1$r9T$A0$K>uBVA+0\$dCM



?^7: Processor Consistency $N35G0?^

99?7$r9T$($P!"=g=xIU$1K+$+$k%*!<%P%X%C%I$r1#JC$9k3$H $,$G$-!"7W;5!$N@-G=8~>e$K9W8%$9kH9M$($ilk!#

K\>OGO$^$:!"%-%&C%7%e4V$NA+0\E*L7=b$rH<oJS0l4S @-@)8fJ}<0$HH<$&$=$l$ND j5A$r9T$$!"0l4S@-@)8f$NA+0\E*L7=b $r5vMF$9k3HG9bB.$J0l4S@-@)8f$N<BAu$r2DG=$H9kJ}<0$G $"$k TIS-CC $H!"TIS-CC HNHf3S$NBP>]$H7F0l4S@-@)8f$r 9ToJ$$J}<0G"$k NCC $r<($9!#$=$N8e!"3F0l4S@-@)8fJ}<0 $NE57?E*$J<BAuJ}K!$r=R$Y$?8e!"$3$N<BAuJ}K!$K4p$E$$$F3FJ} <0$NHf3S$r@-G=!"<BAu%3%9%H!"%W%m%0%i%^%S%j%F%#$N4QE@$+$i 9T$&!#

4.1 MM!9$J0l4S@-@)8fJ}<0$ND j5A

4.1.1 ACS-CC

8=:_$^$G$K3+H/$5l?B?$/$N6&M-%a%b%j7?JBNs7W;5!K*$$ FOF10l%V%m%C%/KBP9$k0l4S@-@)8f$KhkCM99?7$d>uBVA+0\ $O%-%&C%7%e4V$GF1$8=g=x$G9Tol$k!#$3$N0l4S@-@)8fJ}<0$r ACS-CC(Always Coherent Scheme of Cache Coherence) $H 8F$V3HK7!"7A<0E*KO<!Nh$&$KDjak!#

Dj5A**2:**
Always Coherent Scheme of Cache Coherence
3F%"%I%l%9KBP7$F!"%m!<%IL?Na$Khj4QB,G-kCM,$I $N%W%m%;%C%5$KBP7F$bF1$8=g=x$GJQ2=$7$F$$$/H-!"0l 4S@-@)8f$OACS-CC Kh$j9TolkH$$&!#

3l$OA0>O$G=RY?%a%b%j!&b%G%k$K>H$i9H!"%"%H%_%C %/<B9TNCfG$bF10l%"%I%l%9$KBP9k%9%H%"$N4QB,=g=x$O%W%m %;%C%54V$GF1$8KJ$k3$H$r6qBNE*$K5s2k$H!"Nc$(P" $k%"%I%l%9$NCM$,$I$N%W%m%;%C%5$+$i8+$F$b0 G"kH$-$K!" 3N%"%I%l%9KBP7F[$\F1;~$K%W%m%;%C%5 P_1 $O1 $r!"$P_2$O 2 $r!"$P_3$O3 $r%9%H%"$7$?$H9k$H!"

P_1:	0 "*1 "*2 "*3		P_1:	0 "*1 "*3 "*2
P_2:	0 "*1 "*2 "*3	Kt$O	P_2:	0 "*1 "*3 "*2
P_3:	0 "*1 "*2 "*3		P_3:	0 "*1 "*3 "*2

EyNh$&$KIN%W%m%;%C%5KBP7FbF1$8=g=x$GCM$,JQ2=$7$F $$/3H$rJ]>Z$7$F$$k!#

4.1.2 TIS-CC

ACS-CC Kh$k0l4S@-@)8fJ}<0$Nh&$K!"F10l%V%m%C%/$KBP 9k0l4S@-@)8fKh$kCM99?7$d>uBVA+0\$,%-%&C%7%e4V$GF1$8 =g=x$G9T$olk$?$a$K0Bg$-$J%*!<%P%X%C%I$rMW9k!#0lJ}!"

[1] 87L)KO RC KO RC_{SC} $H RC_{PC} $NFs<oN'$"j!"K\J8f$K<($7$?$N RC_{SC} G"$k!#$RC_{PC}$ $K*$$F$Q@h9Trelease $HBeB3acquire $N4V$N=g=x$,J] $?$lk3HOJ]>Z5l$J$$!#

[2] WO $dRC K*1kHsF14|L?Na$O%"%H%_%C%/$GOJ$$3HO%a%b%j!&b%G %krDja$kGX7J$+$i?dB,$9k3HOG-$k!#

%U%)!<%k%9!&7%'%"%j%s%0$O%3%s%Q%$%iKh$jH/@8$,M^$($ilk$H2>Dj$7!"F10l%V%m%C%/Fb$N0[$J$k%"%I%l%9%KBP$7F[$\F1;~$K%a%b%j!&"%/%;%9%,9Tolk3HO$J$$$H9k$H!"F10l%V%m%C%/$KBP9k%"%/%;%9%,$[$\F1;~$K9T$olk3H$O>/$J$$H9M$($ilk!#J<Ji!"F10l%"%I%l%9%X$N%a%b%j!&"%/%;%9%O%/%j%F%#%+%k!&;%/%7%g%sG"k3H,B?$$$+iG$"$k!#3N$?$a!"F10l%V%m%C%/XN%a%b%j!&"%/%;%9%KH<$&%-%d%C%7%e$N>uBVA+0\$dCM99?7$N=g=x$,%-%d%C%7%e4V$G0lCW$9$kJ]>Z$r@_1J$/$F$b!":G=*E*$K$O%-%d%C%7%e4V$GL7=b$,@8$8$J$$3H5$(J]>Z$5lF$$l$P!"7W;;5!$NMxMQ<T$+$i8+$?<B<AE*$J%a%b%j$NF0:n$OACS-CC Kh$k0l4S@-@)8f$r9T$&$H$-$H$[$HsIJQoi$:!"$+$D>uBVA+0\$dCM99?7$N=g=x$,%-%d%C%7%e4V$G0lCW$9kNKI,MWG$"$C$?;~4V$r1#JC9k3H$,$G$-$k$H9M$(il$k!#

3lKbHE$/0l4S@-@)8fJ}<0$rTIS-CC(Transitionally Incoherent Scheme of Cache Coherence) $H8F$V3HK7!"7A<0E*KO<!Nh$&$KDjak!#

Dj5A 3: Transitionally Incoherent Scheme of Cache Coherence

3F%"%I%l%9%KBP$7!"Ev3:%"%I%l%9%KBP$9kL40N;$N%9%H%"$,%7%9%F%`Fb$KB8:_$7J1lP!"IN%W%m%;%C%5$+$i8+FkF1$8CM$,4QB,G-kH$-!"0l4S@-@)8f$oTIS-CC Kh$j9T$olF$$k$H$$&!#

Dj5A3$O%a%b%j!&b%G%k$K>Hi9$H!"0[$J$k%"%I%l%9%KBP$9$k%9%H%"$N4QB,=g=x$d%W%m%0%i%`!&*!<%@$H<B9T;~$N40N;=g=x$N0lCW$K4X$7FO2?$b8@5Z$7$F$$J$$N$ODj5A2$HF1$8$G$"$k$,!"F10l%"%I%l%9%KBP$9$k%9%H%"$N4QB,=g=x$O%W%m%;%C%54V$G0lCW9kHO8BiJ$$?$a!"3F%"%I%l%9%NCM$O%W%m%;%C%54V$GL7=b$,@8$:$k2DG=@-$,$"$k!#$7$+$7!"3Nh&$JL7=b$OA+0\E*JbNG$"$j!"$[$\F1;~$K0[$J$k%W%m%;%C%5$+$i%9%H%"$,9TolF$b:G=*E*$K$OF1$8CM$r4QB,$G$-$k!#

ACS-CC K*1kNc$HF1MM$N6qBNNcKEvFOakH!"TIS-CC K*$$F$O:G=*E*$K$OF1$8FbMFKJk,$=$NESCf7P2aOLdo$J$$3H+$i

P_1 :	0	"*1 "*2 "*3		P_1 :	0 "*1 "*3 "*2
P_2 :	0	"*1 "*2 "*3	Kt$O	P_2 :	0 "*3 "*1 "*2
P_3 :	0	"*2 "*1 "*3		P_3 :	0 "*1 "*3 "*2

Nh$&$KJQ2=$N=g=x$,%W%m%;%C%54V$G0[$JG?$j!"$^$?

P_1 :	0	"*1 "*2 "*3		P_1 :	0 "*1 "*3 "*2
P_2 :	0	"*1 "*2 "*3	Kt$O	P_2 :	0 "*2
P_3 :	0	"*3		P_3 :	0 "*1 "*3 "*2

Nh$&$K4QB,5l$J$$%9%H%"$,$"C?$j!"$5iK

P_1 : 0 "*1 "*2 "*3
P_2 : 0 "*2 "*1 "*2 "*3
P_3 : 0 "*1 "*2 "*3

Kt$O

P_1 : 0 "*1 "*3 "*2
P_2 : 0 "*1 "*3 "*2
P_3 : 0 "*3 "*1 "*3 "*2

Nh$&$K$$o$P0l$D$N%9%H%"$,$"$k%W%m%;%C%5$+$iFs2s4QB,5lFb!":G=*E*KOF1$8CM$,4QB,G-lP$h$$!#

TIS-CC Kh$k0l4S@-@)8fJ}<0$O!"Processor Consistency(PC) K*1k$=$l$HN`;w$7$F$$k!#PC K*$$F$O!"F10l%"%I%l%9%X$N%9%H%"$KH<$&3F%a%b%j!&3%T!<$NCM99?7$O%a%b%j!&3%T!<4V$GF1$8=g=x$G9T$olkH7$F$$k$,!"?^7$K<(9h$&$K%U%)%o!<%G%#%s%05!G=$r;}$D%9%H%"!&P%C%U%!$r;}$DbNH7$F$$kNG!"!¥W%m%;%C%5$+$i8+$?CM$NUQ2=g=x!W$O%W%m%;%C%54V$G0[JjF@$k!#

$?$@$7!"TIS-CC Kh$k0l4S@-@)8fJ}<0$OPC K*1k$=lH<!$NE@$G0[$JCF$$k!#9JoA!"PC K*1k0l4S@-@)8fGOF10l%"%I%l%9%X$N%9%H%"$KH<$&3F%a%b%j!&3%T!<$NCM997$N=g=x$OF1$8$KJk$HD j$ail$F$$kNG!"3N7k2L!"Ev3:%"%I%l%9%X$N%9%H%"$r9ToJ$$%W%m%;%C%54VGO%W%m%;%C%5$+$i8+$?CM$NUQ2=g=x$OF1$8KJ$k!#0lJ}TIS-CC GO!"Ev3:%"%I%l%9%X$N%9%H%"$r9ToJ$$%W%m%;%C%54VGb!"%W%m%;%C%5$+$i8+$?CM$NUQ2=g=x$O0[$J$jF@$k!#

9JoA!"TIS-CC $oPC K*1k0l4S@-@)8f$K4X9k@)Ls$r5i$K4K$/7?bNHHi(k3$H,G-$k!#

4.1.3 NCC

3F%V%m%C%/KBP7$F%9%H%"$,9TolFbB>%-%d%C%7%e$NL58z2=$d99?7$O9T$o$:$K!"NA$K%W%m%;%C%5$,2?i+$NFC<lL?Na!0UJ8e%3%R!<%l%s%9L?Na!K$rH/9T$9k3HKhj%W%m%;%C%54V$G4QB,$5lkCM$,F1$8CMKJ$k?$a$N@)8f$r9T$&J}K!$b9M$($ilk!#3l$rNCC(No Coherence Control) $H8F$V3HK7!"7A<0E*KO<!$K<($9h&KDja$k!#

Dj5A4: No Coherence Control

3F%W%m%;%C%5$,9T$C$?%9%H%"$NCM$rB>$N%W%m%;%C%5$+$i4QB,G-kh$&$K9k?aK$O"2?$i$+$NFC<lL?Na$r%W%m%;%C%5$,H/9T9kI,MW$,$"kH$-$O7W;;5!$oNCC G"kH$$&!#

Dj5A4$r%a%b%j!&b%G%k$K>Hi9$H!"@h$NFsDHF1MM$K0[$J$k%"%I%l%9%KBP$9$k%9%H%"$N4QB,=g=x$d%W%m%0%i%`!&*!<%@$H<B9T;~$N40N;=g=x$N0lCW$K4X$7FO2?$b8@5Z$7$F$$J$!#^$?!"F10l%"%I%l%9%X$N%9%H%"$K$D$$$FO!"%9%H%"$r9T$C$?8e$K%3%R!<%l%s%9L?Na$rH/9T$9k3HKhjB>$N%W%m%;%C%5$K4QB,5lk,!"4QB,=g=x$b%W%m%;%C%54V$G0lCW9kHO8BiJ$$!#

ACS-CC, TIS-CC $N9'$G5s2?NHF1$8%9%H%"7CNs$rNc$K5s$2kH!"NCC K*$$F$O%9%H%"$r9TC?$@$1GB>$N%W%m%;%C%5$NL58z2=5Z$S99?7$r9ToJ$$3H+$i

P_1 :	0	"*1
P_2 :	0	"*2
P_3 :	0	"*3

HJ$k!#

%W%m%;%C%54V$G4QB,$G$-$kCM$r0lCW$5$;$k$?$a$NJ}K!$K$O MM!99M$(ilk,!"Nc$($P%-%d%C%7%e!&U%i%C%7%eKh$j%W%m%;%C%54V$GCM$,0lCW$9k3Hr?^kH9k$H!"$=$N8e$NCM$NUQ2=$O

P_1 :	1	"*2 "*3		P_1 :	1 "*1 "*1
P_2 :	2	"*2 "*3	Kt$O	P_2 :	2 "*2 "*1
P_3 :	3	"*3 "*3		P_3 :	3 "*2 "*1

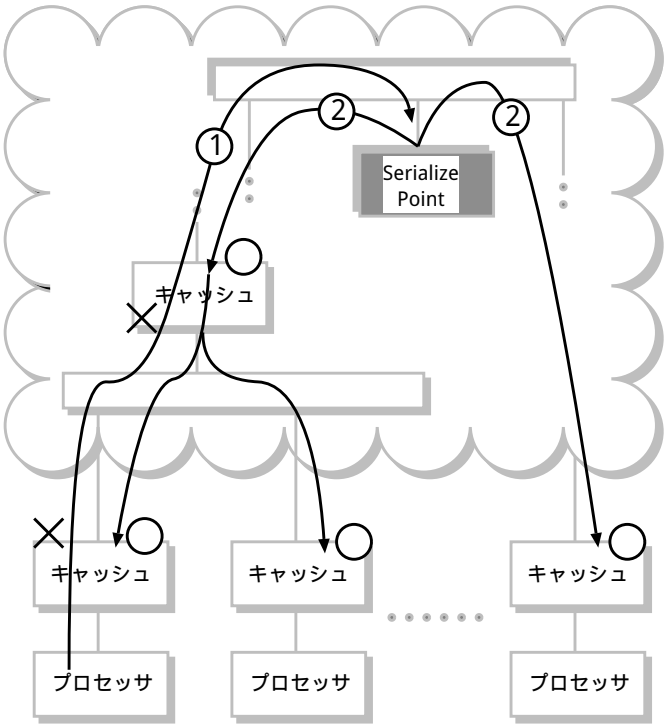
Nh$&$KJk!#:8NNcG$O!"$P_1$!"$P_2$!"$P_3$$N=g$G%-%d%C%7%e$,%U%i%C%7%e5l!"1&NNcGOP_3$!"$P_2$!"$P_1$$N=g$G%-%d%C%7%e$,%U%i%C%7%e5lkH7F$$k!#

4.2 3F0l4S@-@)8fJ}<04V$NHf3S

K\@aGO$^$:ACS-CC, TIS-CC, NCC $NE572E*$J<BAuJ}K!KK$D$$$F=R$Y!"$=$N8e!"$3$N<BAuJ}K!$K4p$E$$$F!"@-G=!"<BAu%3%9%H!"%W%m%0%i%^%S%j%F%#$N4QE@$+$i3F%b%G%k4V$NMx32F@<:$r9M;!$9$k!#

4.2.1 E57?E*$J<BAu<jK!

ACS-CC ACS-CC K*$$F$OF10l%"%I%l%9$KBP9k%9%H%"$N4QB,=g=x$,%W%m%;%C%54V$G0lCW$9k3H,MxMQ<IKBP7$FJ]>Z$5lk!#3N$?$aKO3F%"%I%l%9Kh$K=g=xIU$1$r9T$&COE@(0J8e%7%j%"%i%$%:!&]%$%s%H)$r@_$1$kJ}K!$,9M$($ilk!#3N;~$N014S@-@)8f$N=hM}$NN.$1$r?^8 $K<($9!#9JoA!"%9%H%"$KH<$$@8@.5l$?%Q%1%C%H$O$^$:I,$:%7%j%"%i%$%:!&]%$%s%H$K8~$+$o$;$k!#$?$H$(%7%j%"%i%$%:!&]%$%s%H$K8~$+$&ESCfKI3+$N%~%&C%7%e$rDL2a7F$b!"><uBVA+0\$dCM$N99?7$JIO9ToJ$$!#$=$7$F%7%j%"%i%$%:!&]%$%s%H$KE~C#7?8e!"2~aF3F%~%&C%7%e$K8~$1$FL58z2=$d99?7$N%Q%1%C%H$rAw$j!"$3l,3F%~%&C%7%e$KE~C#$7$?;~E@$G><uBVA+0\$dCM$N99?7$r9T$&!#



① %9%H%"KHbJ$$@8@.5l$?%Q%1%C%H$O%7%j%"%i%$%:!&]%$%s%H$X8~$+$&!#%?$@$7!"$3$N:]DL2a$9$k%~%&C%7%e$K$O=q$~9~$_$r9ToJ$$($×0u)!#

② %7%j%"%i%$%:!&]%$%s%H$+$i:F$S%7%9%F%`3FIt$X%Q%1%C%H$rAw?.$9$k!#$3$N:]DL2a$9$k%~%&C%7%e$K$O=q$~9~$_$r9T$&(◯0u)!#

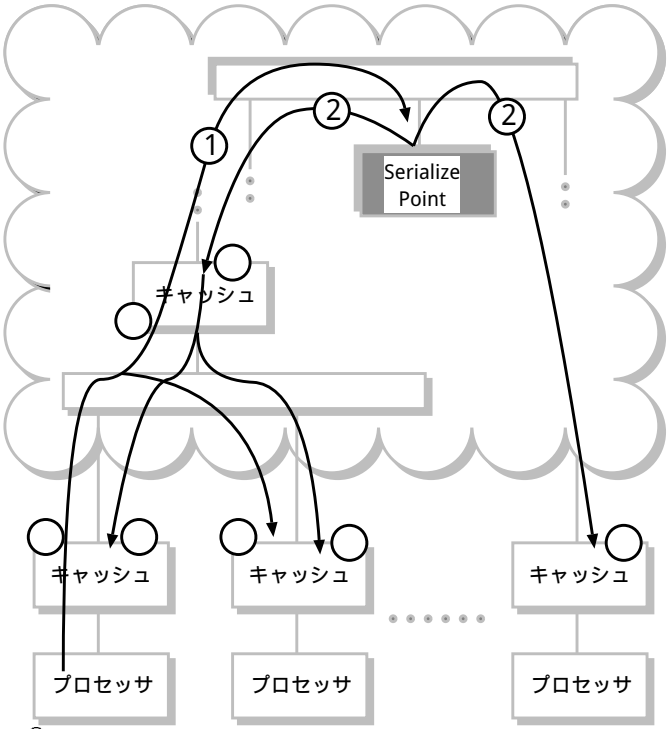
?^8: ACS-CC $NE57?E*$J<BAu<jK!

$?$@$7!"?^8$NN.1O%7%j%"%i%$%:!&]%$%s%H$rDL2a$7$?8e!"%Q%1%C%H$NDI$$1[7JICH/@8$;$:!"3F%~%&C%7%e$K%Q%1%C%H$,E~C#9k=g=x$O%7%j%"%i%$%:!&]%$%s%H$rDL2a7?~g=x$,J]B8$5lk3H$,A0Ds$G$"$k!#3NA0Ds$,@.N)$7$J$$JiP!"><uBVA+0\$dCM99?7$,9T$olk=g=x$,%~%&C%7%e4V$G0lCW5;k?aK!"No$($P%7%j%"%i%$%:!&]%$%s%HK*$$F014S@-@)8f$N?J9T$rDd;_5;kJIN@)8frJLK9T$&I,MW$,$"$k!#

3Nh&$K!"$"kFsD$N014S@-@)8f$KBP7F!"><uBVA+0\$dCM99?7$N9T$olk=g=x$r%~%&C%7%e4V$G0lCW5;k?aK0Y5l$k@)8f$r0J8e%7%j%"%i%$%:$H8F$V!#

TIS-CC TIS-CC K*$$F$O!"ACS-CC HC0[Jj!"%9%H%"$N4QB,=g=x$O%W%m%;%C%54V$G0[JCFbNI$$!#7+$7!":G=*7k2L$K$D$$F$O%W%m%;%C%54V$G0lCW9k3H$rJ]>Z$9$k!#

3N3H$+$iTIS-CC $N<BAu$O4pK\E*$K?^9$K<(9h$&$K7F9T$&$3H,G-$k!#$9Jo$A!"ACS-CC F1MM$K%7%j%"%i%$%:!&]%$%s%H$O@_$1k,!"%7%j%"%i%$%:!&]%$%s%H$rDL2a$9$kA0$G$b%~%&C%7%e$N>uBV$r=q$~9~sG$bNI$$!#8e$K%7%j%"%i%$%:!&]%$%s%H$rDL2a7?%Q%1%C%HKhCF>uBVHCMr>e=q$~$9k3HKhj!"%W%m%;%C%54V$G4QB,$G$-$kCM$,0lCW$9k3HrJ]>Z9k!#



① %9%H%"KHbJ$$@8@.5l$?%Q%1%C%H$O%7%j%"%i%$%:!&]%$%s%H$X8~$+$&!#%?%j%"%i%$%:!&]%$%s%H$X8~$+$&ESCfK"kd$=$N6a$/$N%~%&C%7%eKBP7$F=q$~9~$_$r9TCFNI$$!#

② %7%j%"%i%$%:!&]%$%s%H$+$i:F$S%7%9%F%`3FIt$X%Q%1%C%H$rAw?.$9$k!#$3$N:]DL2a$9$k%~%&C%7%e$K$b=q$~9~$_$r9T$$!":G=*7k2L$,%W%m%;%C%54V$G0lCW9k3H$rJ]>Z$9$k!#

?^9: TIS-CC $NE57?E*$J<BAu<jK!

TIS-CC K*$$F$b4QB,$5lk:G=*7k2L$O%W%m%;%C%54V$G0lCW9k$?$a$K014S@-@)8f$r%7%j%"%i%$%:$9$k!#

NCC NCC $O%9%H%"$KH<$$&014S@-@)8f$O9T$o$J$$!#8e$K%W%m%;%C%5$,%3%R!<%l%s%9L?Na$,H/9T$5l?H-$K%W%m%;%C%54V$GCM$r0lCW$5$;$k@)8f$r9T$&!#

%3%R!<%l%s%9L?Na$N<BAuJ}K!$K$OMM!"9$JJ}K!$,$"$k!#$7$+$7!"NCC $OMF0W$K<BAu2DG=$J3$H$,:GBg$N%a;j%C%H$H9M$(ilkN$G!"%3%R!<%l%s%9L?Na$N<BAu$bMF0W$G$"$kN,K>$^$7$$!#

%3%R!<%l%s%9L?NaH7$F%~%&C%7%e!&U%i%C%7%e$rMxMQ9kNOMF0W$K<BAu$G$~$k<jK!G"$k!#$9Jo$A!"%9%H%"$r9TC?8e$H%m!<%I$r9T$&A0$K%~%&C%7%e!&U%i%C%7%e$r9T$($P3F%W%m

%;%C%5$+$i4QB,G-kCMOF1$8$KJk3H$,$8@$($k!#

0J2<$G!"3F%b%G%k4V$NMx32F@<:$r9M;!$9k,!"NCC $O%3%R!<%l%s%9L?Na$H7F%-%&%7%e!&U%i%C%7%e$rMxMQ$9kH9k!#

4.2.2 Mx32F@<:$NHf3S

@-G= 7W;;5!$N@-G=$N8~>e$O!"$$$+$K3F%W%m%;%C%5$NF0:nDd;_;~4V$r>/$J$/$9k,$,=EMW$HJk!#F0:nDd;_;~4V$r>/$J$/$9kK$O!"%m!<%I!"%9%H%"$N3FA`:n$K$+$+$k;~4V$rC;$/$9$k$3$H!"$=$7$F%W%m%;%C%54V$NDL?.;~4V$rC;$/$9$k$3$H$,=EMW$G$"$k!#0J2<$G3F9`L\$K4X9kHf3S$r9T$&!#

1. %9%H%"K+$+$k;~4V
   %9%H%"A`:n$K$+$+$k;~4V$O%9%H%"!&P%C%U%!$r:NMQ$9$k$3$H$GC;$/$9$k$3$H$,$G$-$k!#$9$J$o$A!"%9%H%"$r9T$C$?:]%W%m%;%C%5$N$9$O$=$P$K@_$1$i$l$?%9%H%"!&P%C%U%!$K=q$-9~$`$@$1$G%W%m%;%C%5$KHCFO%9%H%"$,40N;$7$?$3HK$7!"<!$NL?Na$K?J$`!#%9%H%"!&P%C%U%!$O014S@-@)8fJ}<0$N<dN`Khi::NMQ2DG=G"kN$G!"%9%H%"$K$+$+$k;~4V$K4X7F$OJ}<04V$G:9OJ$$!#

2. %m!<%IK+$+$k;~4V

   - L1 %-%&%C%7%e!&_%9
     L1 %-%&%C%7%e$K%_%9$7$?$H$-$OB>$N%-%&%C%7%e$+$i%G!<%?$rHCF/$k!#$3$N:]$K$+$+$k;~4V$O%M%C%H%o!<%/$N%H%i%U%#%C%/$,>/JJ}$,C;$/Jk$H9M$(il$k!#3 DN%b%G%kN&$A!"NCC $O%9%H%"$KH<$&014S@-@)8f$r9ToJ$$N$G:G$b%H%i%U%#%C%/$,>/$J$$$H;Wol$k!#$hCF!"L1 %-%&%C%7%e!&_%9K+$+$k;~4V$ONCC $,0lHVC;$$$H9M$($i$l!"B>$NFs$D(ACS-CC $HTIS-CC) $N4V$G$O:9$O@8$8$J$$H9M$($ilk!#

   - L1 %-%&%C%7%e!&R%C%H
     L1 %-%&%C%7%e$K%R%C%H$7$?>19g!"ACS-CC K*$$FOCMNUQ2=g=x$r%W%m%;%C%54V$G0lCW5;k?aK!"%W%m%;%C%5KCMrJV9NrCYi$;$k3H$,I,MW$HJk>19g$,$"$k!#$3lO$"$k%W%m%;%C%5$,%9%H%"$r9T$$!"$=$ND>8e$KF1$8%W%m%;%C%5$,F10l%"%I%l%9$KBP9k%m!<%I$r9T$C$?$H$-$KI,MWHJ$k!#$J$<$J$i!"?^8$K<(9h$&$K!"<+J,$,9T$C$?%9%H%"$N7k2L$O0lC6%7%j%"%i%$%:7F:F$S%Q%1%C%H$,<+%-%&%C%7%eKJVCF-$?8e$G$J$$$H;2>HG-$J$$$N$G!"%9%H%"$ND>8e$K%m!<%I$r9T$&$H%Q%1%C%H$,JV$CF/k^$G%W%m%;%C%5$KCMrJV9NrBT$?$5J1lPJi$J$$!#

   0lJ}TIS-CC $dNCC GO<+J,$,9TC?%9%H%"NCMOD>AKMxMQG-$k!#

   0lHL$K%W%m%0%i%`$K$O;2>H$N6I=j@-$,$"$k$3$H$,CN$i$l$F$*$j!"$"$k%W%m%;%C%5$K$h$C$F%9%H%"$5$l$?%"%I%l%9$O<=$ND>8e$KF10l%W%m%;%C%5$+$i;2>H$5$l$k$3$H$,B?$$H$$($k!#h$C$F!"%9%H%"$ND>8e$N%m!<%I$N%l%$%F%s%7$O%W%m%0%i%`$KBg$-$J1F6Ar*h\$9$H9M$(il!"3N%l%$%F%s%7$rD08:G-$kACS-CC $dTIS-CC O3NLLGACS-CC hj@-G=$KM-8z$G$"$k$H9M$(il$k!#$5iK!"3N@-G=:9$Cv3:JQ?t$r;2>H9k%W%m%;%C%5$,B?$$$[IBg-$$$H9M$($ilk!#J<Ji!";2>H9k%W%m%;%C%5$,B?$$$[$I!"%W%m%;%C%5$H%7%j%"%i%$%:!&]%$%s%HHN4V$N5wN%$OBg$-$$$H9M$($ilk3H$+$i!"%9%H%"$r9T$C$?8e:F$S%Q%1%C%H$,JV$CF/k^GN;~4V$bD9$/Jk$H9M$(ilk+iG$"$k!#

3. %W%m%;%C%54V$NDL?.;~4V
   $3$3$G8@$&DL?.;~4VHO!"$"$k%W%m%;%C%5$,%9%H%"$r9TCF$+$i!"B>$N%W%m%;%C%5$N%m!<%I$,$3$N%9%H%"$NCM$r%W%m%;%C%5$KJV9^GN;~4V$r0UL#$9$k!#

   %W%m%;%C%54V$NDL?.;~4V$rC;$/$9kNKOTIS-CC $,:G$b8~$$$F$$k!#%9%H%"KHbJCFEv3:%"%I%l%9$N%3%T!<$r;}$DB>%-%&%C%7%e99?7%Q%1%C%H$rD>@\Aw?.$9kN$,!"DL?.;~4V$r:G$bC;$/9kNOIN%W%m%;%C%5$+$iG"kN$+$r;W$$=9k$H$$$&3HG9!#3Nh&$J>uBV$G$O!"$=l>lN%W%m%;%C%5$,<+J,$N%-%c%C%7%eKO$J$$%G!<%?$r;}$A$^$ok3HKJj!"$=$liN%G!<%?$r<hF@$9k?aK$O!"$=l>lN%W%m%;%C%5$K%Q%1%C%H$rAw?.7J1lPJiJ$$$3HKJk!#3Nh&$K!"%W%m%;%C%5$,<+J,$N%-%c%C%7%e$KOJ$$%G!<%?$r;}$A$^$ok3HKhC$F!"%W%m%;%C%5$,<+J,$N%-%c%C%7%e$KOJ$$%G!<%?$r<hF@$9k?aK$O!"$=l>lN%W%m%;%C%5$K%Q%1%C%H$rAw?.7J1lPJiJ$$$3HKJk!#3Nh&$K

<BAu$N%3%9%H 0l4S@-@)8f$r<BAu$9%k:]$K:GbFq7$$N$O!"F10l%V%m%C%/$X$N0l4S@-@)8f$,7W;;5!Fb$rF1;~$K?J9T$9%k>u67$K$*$1$k=hM}$G$"$k!#3N;~$O!"3F%"%I%l%9$NCM$,0l4S@-@)8fJ}<0$NDj5A$rK~$?$9%h$&$K%W%m%;%C%5$K4QB,$5$1kh$&$K@)8f7J1lPJiJ$$3HNB>$K!"%U%)!<%k%9!&7%'%"%j%s%0KbN10U7J1lPJiJ$$!#9JoA!"0l4S@-@)8f$NC10L$,%W%m%;%C%5$+$i%N%"%/%;%9C10LhjBg$-$$>19g!"$"$kFsDNUQ?t$,$?$^$?$^F1$8%V%m%C%/KO$$k3HKh$jK\Mh$J$i%W%m%;%C%54V$G6&M-7J$/$F$bNI$$JQ?t$r6&M-$7F7$^$&2DG=@-$,$"kN$G!"F10l%V%m%C%/Fb$N0[Jk%"%I%l%9XN%9%H%"$,Fs$D$N%W%m%;%C%5$+i[$\F1;~$K9Tol$J$$$h$&$K$b!"$IAi$N%9%H%"$NCM$b<:$olJ$$$h$&$K0l4S@-@)8f$r9T$&I,MW$,$"$k!#

%3%R!<%l%s%9L?Na$K%-%&C%7%e!&U%i%C%7%e$r:NMQ9kNCCGO%U%)!<%k%9!&7%'%"%j%s%0K+$+$k<BAu%3%9%H$O>.$5$/$F:Q$'!#$J$<$J$i!"%-%&C%7%e$r%U%i%C%7%e9k:]$K%V%m%C%/A4BN$r=q$-La$9NGOJ$/<+%W%m%;%C%5$,=q$-9~$s$@%"%I%l%9$@1rA*BtE*$K=q$-La$9$3HKhj%U%)!<%k%9!&7%'%"%j%s%0$XSOBP=h$G$-!"$3$1$K$+$+$k%3%9%H$O>.$5$5$+$iG"$k!#

0lJ}!"ACS-CC $dTIS-CC K*1k%U%)!<%k%9!&7%'%"%j%s%0XNBP=hJ}K!$O!"MM!9$"kH9M$($i$l!"0l4S@-@)8fJ}<04V$G0l35$KHf3S$9kN$O:$FqG"kN$G0lHIE*$J9M;!KD5F$OK\9F$NBP>]30H9$k!#$7$+$7!"%-%&C%7%e!&U%i%C%7%e$r:NMQ$9$kNCC hj4JC1$K9T$&3H$O=PMh$J5H9M$($ilk!#

0J2<GO%H%%k!<!&7%'%"$J%V%m%C%/$,3F0l4S@-@)8fJ}<0$NDj5A$rK~$?$9%?aN%3%9%H$K4X$7$F9M;!$9$k!#

$^$:!"%-%&C%7%e!&U%i%C%7%e$rMxMQ$9$kNCC K*5F$O0l4S@-@)8f$O9To:!"$^$?!"CM$r%W%m%;%C%54V$G0lCW5;k3HbC1=c$K%-%&C%7%e$r%U%i%C%7%e7F<g5-210J30KOM-8z$J%3%T!<$OB8:_5;J5$3$HKh$j<B8=2DG=$G$"$kNG!"<BAu$,MF0W$G$"$k3H$O<+L@$G$"$k!#

ACS-CC $HTIS-CC $N4V$N0c5O!"%9%H%"4V$N=g=x$,Dj$^$kA0K=$N%9%H%"$NCM$,$"$k%W%m%;%C%5$+$i4QB,$G$-$kh&KJGF$bNI$$$+$I&$+G"$k!#ACS-CC GO=g=x$,Dj$^k^GO4QB,G-FOJi$J$$!#0lJ}TIS-CC GO=g=x$,Dj$^$k0JA0$K4QB,G-FbNI$$!#7+$7!"TIS-CC K*5F$b:G=*E*$J7k2LOI$N%W%m%;%C%5$+$i8+Fb0lCW5;$J1lPJiJ$$NG!"F10l%"%I%l%9KBP9$kJ#?t$N%9%H%"$,$[$\F1;~$KH/@8$7$?>19g!"Ej5!E*$J=q$-9~$_$N<:GT$+$i$N2sI|$N@)8f$r9T$&I,MW$,$"$k!#4pK\E*$KO3$1$O?^9$K<($9h&$K%7%j%"%i$%:$5$1$?8e:F$S>e=q$-$9k3HG<B8=G-k,!"3N2sI|$N@)8f$O5i$K@-G=8~>e$r8+9~ak<jK!$,B8:_$9$k!#$3$N<jK!$NNc$O5>O$G=RYk$,!"2sI|5!9=$KhGFO<BAuOFq7$/$J$k!#

7+$7!"SPARC Ey$N%-%&C%7%e$rFbB"$9$k%W%m%;%C%5$K$*$$$F$O%9%H%"$HF1;~$KFbB"%-%&C%7%e$KBP9k=q$-9~$_$r9T$&bNb"kN$G!"ACS-CC $N>19g$Gb=Nh$&$J%W%m%;%C%5$rMQ$$$kH-$O!"TIS-CC $HF1MM$JEj5!E*$J=q$-9~$_<:GT$+iN2sI|5!9=$r<BAu$9kI,MW,$"$k!#$3$1$OTIS-CC $HF1MM$K!"8e$K>e=q$-9k3H$G<B8=$G$-$k$,!"$3$N2sI|$OTIS-CC ObAm$sACS-CC Gb9T$&I,MW@-$,@8$8F@$k!#7+$7!"TIS-CC K*$$$FO5iK@-G=8~>e$r5a$ak?aKMM!9$J<jK!$,B8:_$7!"$3$N<jK!$KhGFO<BAuOFq7$/$J$k!#

$^$?!"ACS-CC GOIN%W%m%;%C%5$+$i$bF1$8=g=x$G4QB,$G$-$JS1lPJi$J$$3H+$i!"=g=xIU$1$,9T$olkA0$K%W%m%;%C%5$,%-%&C%7%e$K%"%/%;%9$7$?>19g$O!"CMrJV9Nr%7%j"%i%$%:$,9Tolk^GCYi$;$k$?$a$N@)8f$,I,MWHJ$k!#$3N?$a!"ACS-CC $O%-%&C%7%e!&R%C%H$7$?m!<%I$rBT$?$;$k=hM}$r9T$&E@$GTIS-CC hj<BAu%3%9%H$,$+$+$k!#$?$@$7!"%m!<%I=hM}$rBT$?$;$k5!9=$N<BAu$O:$FqJ3HGOJ$$$!#

%W%m%0%i%^%S%j%F%# @)Ls$r4KOB$7$?%a%b%j!&b%G%k$r:NMQ9k7W;;5!K*1k%W%m%0%i%_%s%0$N:]$K$O!"I,MW$K1~8F%W%m%0%i%`!&*!<%@$rJ]B8$9$kEy$N$?$a$K%W%m%0%i%`Cf$KFCJL$JL?Na$rA^F~$9$k!#@5$7$?%W%m%0%i%`$r=q$/$3$H$@$1$,L\E*$G$"$l$P!"$3$NFC<lL?Na$r%W%m%0%i%`Cf$NE~kH3mKKda9~aPC#@.G-k,!"$3$1GO4KOB7?%a%b%j!&b%G%k$r:NMQ$9k3HKhk2870C$r<u$1il$:!"7W;;5!$N@-G=$r0z$-=P$9$3HOG-$J$$$!#hO$F!"%W%m%0%i%_%s%0$N:]KO7W;;5!$N@-G=$r0z$-=P$9$?a$KFC<lL?Na$O?$KI,MWJH3mKN$_Kd$a9~$^$J1lPJiJ$$!#%W%m%0%i%`K*$$FFC<lL?Na$,?$KI,MWJH3m$,$I3JN+$r8+6K$ak?aN<j4V$,%a%b%j!&b%G%k$KKhGF0[Jj!"3N$?$a%W%m%0%i%^%S%j%F%#$b0[$J$k!#

8=:_$^$G$KDs0F$5lF$$k%a%b%j!&b%G%k$O!"%W%m%0%i%`!&*!<%@N@)Ls4KOB$K<g$J=EE@$,$*$+$l$F$*j!"FC<lL?Na$b<g$K%W%m%0%i%`!&*!<%@$rJ]B8$9$k<jCJ$rDs6!$9kbNG$"$k!#0J2<$G!"3F0l4S@-@)8fJ}<0$r:NMQ9k:]KINh$&$J>u67GINh$&$JFC<lL?NarI,MWHJk$+$r9M;!9k$,!"$=liO9YF3F%"%I%l%9$NFbMF$r%W%m%;%C%54V$G0lCW$5$;$k$?$a$N<jCJ$r9M;!9kbNG"$k!#%W%m%0%i%`!&*!<%@$rKd$a9~$`$3HK$D$$FO3$3$G$OL5;k$9$k!#

$^$:!"ACS-CC K*$$F$OF10l%V%m%C%/$X$N%9%H%"$N4QB,=g=x$O%W%m%;%C%54V$GEy$7$$N$G!"3F%"%I%l%9$NFbMF$r%W%m%;%C%54V$G0lCW5;k?aNL?Na$OITMW$G$"$k!#

<!$K!"TIS-CC K*$$F$O!"J#?t$N%W%m%;%C%5$,$[$\F1;~$K%9%H%"$r9T$C$?$O%-%9%H%"$N4QB,=g=x$,%W%m%;%C%54V$G0[$J$k2DG=@-$,$"$k!#3N$?$a!"ACS-CC hj%W%m%0%i%^%S%j%F%#$,0-2=$9kh$&$K;W$($k,!"8=<B$N%W%m%0%i%_%s%0$N:]KO=l[LJQoiJ$$$HM=A[5l$k!#

$=$NM}M3H7F^:5s2ilkNO!"$"$k6&M-JQ?tKBP7$F%9%H%"$r9T$&%W%m%;%C%5$O0lD@1G$"$k3H$,B?$$H9M$($ilk$+$iG"$k!#Nc($P%W%m%;%C%54VDL?.$G:G$bE57?E*JbNH7F!"Producer-Consumer $,$"k,!"3N>19g%9%H%"$r9T$&NOProducer B&$@$1G"$j!"Consumer B&$O%m!<%I7+9ToJ$$!#^$?!"%"%W%j1!<%7%g$sKhCF$O3FUQ?t$KBP9k1i;;$r9T$&%W%m%;%C%5$,7h$^CF$$$kowner-computes-rule $K=>$C$F$$$kbNb"kH9M$($ilk!#3N>19g$b3FUQ?t$KBP7F%9%H%"$r9T$&NO"$k0l$D$N%W%m%;%C%5$@1G$"$kNG!"%7%9%F%'$,3F%"%I%l%9$NCM$NUQ2=g=x$r%W%m%;%C%54V$GF1$8K9$k@)8f$r9ToJ$/$Fbh$$$3HO<+L@G"$k!#

$^$?!"$"$kJQ?tKBP7$FJ#?t$N%W%m%;%C%5$,%9%H%"$r9T$$F@kH$-$Gb=$NUQ?t$O%/%j%F%#%+%k!&;%/%7%gsKhjJ]8n5l$k>19g$,B?$$H9M$($ilk!#3N>19g!"F10l%"%I%l%9KBP9$k%a%b%j!&b%G%k$r:NMQ9k3HOJ$$$($"$k%9%H%"$,40N;$9$kA0$KB>$N%9%H%"$,3+;O5lk3HO$J$$$h$&$K9kGSB>@)8f$OMxMQ<T$Khj9Tol$k!#GSB>@)8f$,@5$7$/9Tol$F$$$k8BjO!"TIS-CC $rMQ$$?H7FbJQ2=g=x$,%W%m%;%C%54V$G0lCW9k3H$O<+A3$KK~$?$5lk!#

3liN3H$+$i!"$"kJQ?t$,%W%m%;%C%54V$G6&M-$5$l!"$+$DEv3:JQ?t$KBP9k%9%H%"$,%W%m%;%C%54V$G$[$\F1;~$K5/$3$jF@$F!"5iK=$N%9%H%"$N4QB,=g=x$,%W%m%;%C%54V$GF1$8$KJiJlPJi$J$$JQ?t$O>/$J$$H9M$($ilk!#

3N$?$aTIS-CC K*$$F$O!"$"kJQ?t$,%W%m%;%C%54V$G6&M-5l!"$+$DEv3:JQ?tKBP9$k%9%H%"$,%W%m%;%C%54VG[$\F1;~$K5/3jF@$F!"$5iK$=$N%9%H%"$N4QB,=g=x$,%W%m%;%C%54V$GF1$8KJNon-Cachable H7$F%"%/%;%9$9kJINU}K!$,I,MW$HJk!#7+$7!"8=<B$N%W%m%0%i%_%s%0K*$$FO3Nh$&$JUQ?t$OF14|JQ?t$JIK;HMQMQES$O8B$ilkNG!"TIS-CC K*1k%W%m%0%i%^%S%j%F%#$OACS-CC K*1k$=1HJQ2=$J$$$H8@$($k!#

0lJ}!"NCC K*$$F$O3F%"%I%l%9$NFbMF$r%W%m%;%C%54V$G0lCW5$;$k$?$a$K%-%&%C%7%e!&U%i%C%7%e$r9T$&!#C1=c$K$O%9%H%"$N8e$*$h$S%m!<%I$NA0$K%U%i%C%7%e$9lPhS!#7+$7!"6&M-JQ?t$KBP7F%9%H%"$r9T$OFb!"Nc$($P1i;;$NESCf7k2L$N%9%H%"JI!"I,$:$7$bB>%W%m%;%C%5$+$i4QB,$G$-$kI,MWOJ$S!#$^$?!"%m!<%I$NA0$N%U%i%C%7%e$b!"Ev3:%"%I%l%9KBP7$FB>%W%m%;%C%5$,%9%H%"$r9T$&3H$,$JS3H,J]>Z5lFSlPITMWG"$k!#$7$?$,CF!"%7%9%F%`$N@-G=$r0z$-=P$9KO%W%m%0%i%_%s%0$N:]$K3Nh&J3Hr9MN8$9$kI,MW$,$"$k!#$3N?$a!"$[Hs$I2?$b9MN8$7$J$/$F$bNI$$ACS-CC $dTIS-CC KHfYFFq7$/Jk!#

9M;!N^Ha 0J>e8+F-$?$h$&$K!"@-G=LIK*$$F$OTIS-CC $,B>$KHfYFM-MxG"$k!#$5iK3l$O!"%7%9%F%`$5,LO$,Bg$-$$$[$I82Cx$G$"$k$N$G!":#8eH/E8$,4|BT$G$-$kD6JBNs5,LO$N%7%9%F%`$X$N<BAu$K8~$$F$$k!#7+$b!"TIS-CC $O=>Mh$NJ}K!G"$kACS-CC KHfY$F%W%m%0%i%^%S%j%F%#b[$HsIJQoi$J$$!#

TIS-CC $,M#0l%M%C/$HJjF@kN$O<BAu%3%9%H$G$"$k$,!"<BAu$,Fq7/JkNO!"hj@-G=$rD15a$9$k>19g$G$"$j!"C1=c$J<BAu$N:]KOACS-CC H[HsIJQoiJ$$!#@-G=$rD15a$9$k:]$KI,MW$J5!9=$H@)8fKD$$F$O<!>O$G=RYkD6JBNs7W;;5!JUMP-1 K*$$F:NMQ5l$F$$kJ}K!$,:#8e$N%7%9%F%`3+H/$N:]$NM-0U$J;29M:`NAKJkH9M$($i$l!"7P83$r@Q$_=E$Mk3HKhCF3N5;=Q$O3NN)$5lkbN$H9M$($k!#

0J>eN3H+ib!";0DNU}<0N&$ATIS-CC $,:G$b>-Mh M-K>$J<jCJ$G$"$k$H9M$(il$k!#

5 D6JBNs7W;;5!JUMP-1 K*1k<BAuNc

K\>OGO!"A0>O$G=R$Y$?TIS-CC Kh$k0l4S@-@)8f$r:NMQ7?7W;;5!NNcH7F!"D6JBNs7W;;5!JUMP-1[13] K*1k<BAuNc$r=R$Y$k!#

JUMP-1 GO!"4.2@a$G=R$Y$?TIS-CC $N<BAuJ}K!$r$?$@C1=c$K<B8=$9k@1GOJ$/!"$h$j@-G=$r8~>e5;k?aK$N:GE,2=$,J5lF$$k!#0J2<!"$^$:JUMP-1 $N35N,$r=R$Y!"<!$K!"hj@-G=$r8~>e$5$;$k$?$a$KJUMP-1 $G:NMQ$7$F$$k:GE,2=$N<jK!$r5s2k!#$=$N8e!":GE,2=$r?^C$?0l4S@-@)8f$r<B8=$9k?aKJUMP-1 $GMQ0U$5lF$$k5!9=$H9T$olF$$k@)8fKD$$F=RYk!#

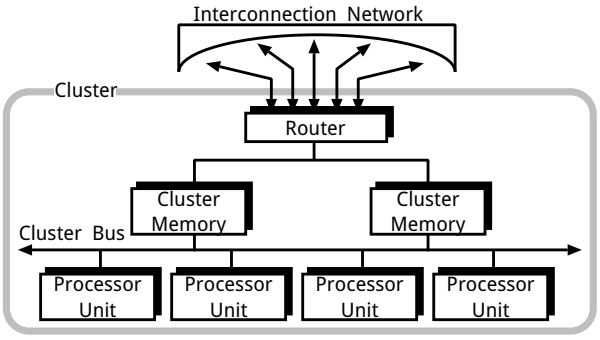
5.1 D6JBNs7W;;5!JUMP-1 $N35N,

5.1.1 9=@.

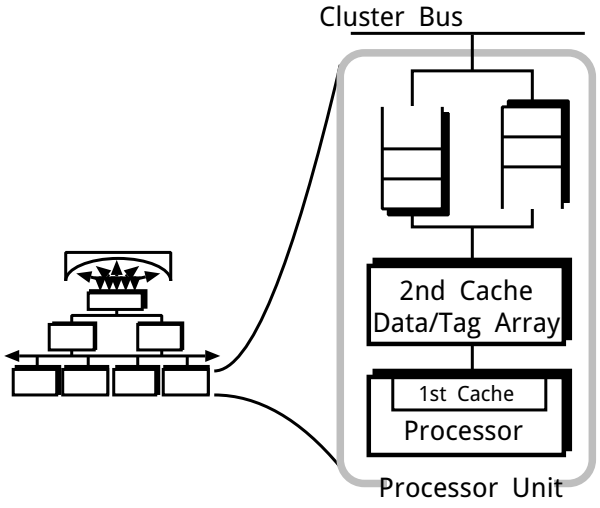
D6JBNs7W;;5!JUMP-1 $O!"%/%i%9%?9=B$$r:NMQ7?6&M-%a%b%j7?JBNs7W;;5!G"$k!#3F%/%i%9%?$O!"RDT[14] $H8F$Plk%M%C%H%o!<%/$G7k9g$5lF$$k!#

%/%i%9%?$N9=@.$r?^10$K<($9!#9=@.MWAGH7FO!"4pK\E*$K4 DN%W%m%;%C%5!&f%K%C%H!"2 DN%/%i%9%?!&a%b%j!"5Z$SRDT HN%$%s%?%U%'!<%9$HJk%k!<%?$,$"2ilk!#%W%m%;%C%5!&f%K%C%H$H%/%i%9%?!&a%b%j$O%/%i%9%?!&P%9$H8F$Plk%P%9$G@\B3$5lF$$k!#JUMP-1 $OJ,;66&M-%a%b%j7?$NJBNs7W;;5!G"$j!"<g5-21$O3F%/%i%9%?KJ,;6$7$FG[CV5l$F$$k!#

3F%W%m%;%C%5!&f%K%C%HFb$N9=@.$r?^11$K<($9!#%W%m%;%C%5!&f%K%C%H$O0l<!%-%&%C%7%e$rFbB"9k;THN$N9b@-G=RISC %W%m%;%C%5(SuperSPARC+) $H30IU$1$N2<!%-%&%C%7%e$+iJJ$k!#$^$?!"$3$N?^$K<(9h$&$K!"%P%9HN4V$G%Q%1%C%H$rAw<u?.9k$?$a$N%P%C%U!$O2<!%-%&%C%7%ehj$b%P%9B&$K@_1ilF$*$j!"%W%m%;%C%5$+$i%9%H%"$,9T$olkH^$:2<!%-%&%C%7%e$X$NEj5!E*$J=q$-9~$_$r9T$$!"$=$N8e!"%Q%1%C%H$r%P%9$XAw=P9k!#



?^10: %/%i%9%?$N9=B$



?^11: %W%m%;%C%5!&f%K%C%H$N9=B$

5.1.2 %a%b%j!&b%G%k

3>O$G=R$Y$?$h$&$K!"%a%b%j!&b%G%k$G5,Dj$5lk9'L\$H7F$O8D!9$N%W%m%;%C%5$+$iH/$;$ilk%a%b%j!&"%/%;%9$N%W%m%0%i%'$K<(5l$F$$k=g=x$H<B9T;~$K$*$1$k=g=x$N4X78$d!"%W%m%;%C%54V$G$N%9%H%"$N4QB,=g=x$N4X78$H$$$C$?$b$N,$"$k!#JUMP-1 K*$$F3F9'L\$GDjailF$$k@)Ls$r0J2<$K<($9!#

%W%m%0%i%'!&*!<%@$N4KOB JUMP-1 $GMQ$$kMWAG%W%m%;%C%5SuperSPARC+$O%m!<%IL?Na$rH/9T9kH=NCM,JVCF$/$k$^$G$O8eB3L?Na$OH/9T;$:$K%W%m%;%C%5$NF0:n$CDd;_9k!#3N3H+$i!"@h9T$N%m!<%IL?Na$HBeB3$NL?Na$N4V$N4QN;=g=x$O%W%m%0%i%'!&*!<%@$H0lCW9k3H$O<+A3$KJ]>Z5l$k!#

0lJ}!"%9%H%"L?Na$O=$N4QN;rBT?:$K8eB3$NL?Na$,H/9T$5lk!#$3N3?aSuperSPARC+$K$O@h9T$N%9%H%"L?Na$,$9$YF4QN;$9$k^$G8eB3$NL?Na$NH/9TrBT?;$k%9%H%"!&P%j%"L?Na$,MQ0U5l$F$$k!#9JoA!"MxMQ<T$,%W%m%0%i%'f$K%9%H

%"!&P%j%"L?Na$rA^F~$9k3HKhC$F@h9T%9%H%"$H8eB3L?Na$N4V$N4ON;=g=x$,%W%m%0%i%`!&*!<%@$H0lCW9k3H$,J]>Z$5lk!#

3Nh&$K!"JUMP-1 GO@h9T$N%9%H%"L?Na$H8eB3$NL?Na$N4V$N4ON;=g=x$O!"FsDNL?Na$N4V$K%9%H%"!&P%j%"L?Na$,A^F~$5lF$$$J1lP=$N4ON;=g=x$O%W%m%0%i%`!&*!<%@$H0lCW$7$J$$2DG=@-$,$"$k!#

%"%H%_%7%F%#$N@)Ls4KOB F101%"%I%l%9$KBP9k0lO"$N%9%H%"$K4X7F$O4>O$G=RY?TIS-CC G"$j!"7W;;5!Fb$KL$4ON;$N%9%H%"$,B8:_$7$J$$$H$-$N$_4QB,$G$-$kCM$,%W%m%;%C%54V$G01CW9k3H$rJ]>Z$9$k!#$^$?0[$J$k%"%I%l%9$KBP9k%9%H%"$N4V$K$OProcessor Consistency %b%G%k$HF1$8h&$KA4=g=x4X78$CB8:_$;$:!"%W%m%;%C%54VG=li$r4QB,$9$k=g=x$,01CW9kJ]>ZOJ$$!#

5.1.3 0l4S@-@)8f%W%m%H%3%k

JUMP-1 K*1k%-%&C%7%e4V$N0l4S@-@)8f$K$O!"3F%W%m%;%C%5!&f%K%C%HFb$N1<!%-%&C%7%e-2<!%-%&C%7%e4V$N0l4S@-@)8f!"$=7F%W%m%;%C%5!&f%K%C%H4VK^$?$,$k2<!%-%&C%7%e4V$H%/%i%9%?!&a%b%j$N4V$N0l4S@-@)8f$,$"$k!#

$^$?!"JUMP-1 K*1k0l4S@-@)8f$O32%P%$%HC10L$G9T$olk!#0J8e!"0l4S@-@)8f$,9T$olkC10L$r%V%m%C%/$H8F$V!#

2<!%-%&C%7%e4V-%/%i%9%?!&a%b%j$N0l4S@-@)8f $^$:!"%9%H%"$r9T$C$?$H$-!"B>%W%m%;%C%5$N2<!%-%&C%7%eNCMrL58z2=9k$+99?7$9k+$OMxMQ<T$,3F%"%/%;%9KhK;XDjG-$k!#$=7F%/%i%9%?!&a%b%j$N99?7$OCM$NE>Aw$,%/%i%9%?FbKJD8$k>19g$O9To:!"%/%i%9%?4VK^$?$,kH$-$N$_9T$&!#

$^$?!"2<!%-%&C%7%e4V$N0l4S@-@)8f$O%/%i%9%?Fb$O%9%L!<%WJ}<0!"%/%i%9%?4VN=lO%G%#%l%/%H%jJ}<0$G9T$o$k!#%/%i%9%?4V$N0l4S@-@)8f$O%G%#%l%/%H%jJ}<0$Khj9Tolk?$a!"<g5-21$K$*$$EM-8z$J%3%T!<$,B8:_9k%/%i%9%?$d%m!<%I$KBP7FFCMrJV$9@UG$$r;}$D%3%T!<$,B8:_9k%/%i%9%?$,4IM}$5lF$$$k!#D^$j!"%-%&C%7%e$NL58z2=/99?7@)8f$dCMFI$_@$7A`:n$,%/%i%9%?4VK^$?$,$k>19g$O0lC6I,$:<g5-21$K%Q%1%C%H$,Aw$ilk!#$=$N8e<g5-21$+$i3F%/%i%9%?KBP7$F99?7/L58z2=@)8f$dFI$_9~$_MW5a$,Aw$ilk!#

JUMP-1 K*1k2<!%-%&C%7%e$N>uBV$rI=2$K<($9!#3F2<!%-%&C%7%e$O!"%-%&C%7%e4V$N6&M->uBV$rDL>o$N!E>$N%-%&C%7%e$dk<g5-21KOM-8z$J%3%T!<$CB8:_7J$$!W(Exclusive)$dl!E>$N%-%&C%7%e$dk<g5-21$K$bM-8z$J%3%T!<$,B8:_$7F@$k!W(Shared)$K2C$($F!"6&M->uBV$,%/%i%9%?Fb$KJD8F$$$k(Local)$+%/%i%9%?4V$K$^$?$,$C$F$$$k(Global)$+$H$$$&3H$b4IM}$9$k!#$3lKhjLocal G"lP!"L58z2=/99?7@)8f$N:]$K<g5-21$N%G%#%l%/%H%j$r0z$/<j4V$,>J$1!"8e$K=RYk%7%j%"%i%$%:!&]%$%s%H$N:GE,2=$KDJ$,$k!#

$^$?!"%-%&C%7%e$N>uBV$K$OGlobal Shared Dirty $CB8:_$7$J$$!#3lO!"@hKb=RY?h$&$K%/%i%9%?!&a%b%jXO%/%i%9%?4VGCMNE>Aw$,9T$olkH-N_=g$-9~$_,9Tolk+iG$"$k!#9JoA!"$"$k%V%m%C%/$N%3%T!<$,%/%i%9%?4VK^$?$,CFB8:_9kH-$KEv3:%V%m%C%/$NCM$r99?7$7h&H7$?H$-!"$^$?%-%&C%7%e!&_%9$KH<$C$FB>%/%i%9%?$+iCMr%U%%C%A9kH-$K%/%i%9%?!&a%b%j$NCM$b99?7$5lkNG!"Global G"lPClean G"k3H,J]>Z5l$k!#

2<!%-%&C%7%e$N>uBVA+0\I=$rI=3$+$iI=5$K<($9!#

1<!%-%&C%7%e-**2**<!%-%&C%7%e4V$N0l4S@-@)8f SuperSPARC+$,FbB"%9$k1<!%-%&C%7%e$O!"JUMP-1 K*$$F$O%i%$%H!&%9%k!<$N%-%&C%7%e$H7FF0:n9k!#

$^$?!"B>%W%m%;%C%5$+$i$N%9%H%"$KH<$&0l4S@-@)8f$C0l<!%-%&C%7%e$NL58z2=$Khj9T$&!#$9Jo$A!"%/%i%9%?!&a%b%j$X$O%/%i%9%?4V$GCM$NE>Aw$,9TolkH$-$N$_=g$-9~$_,9T$olk$+$i99?7/L58z2=%Q%1%C%H$r<u$1<hkHSuperSPARC+$NFbB"%-%&C%7%e$KBP$7FEv3:%V%m%C%/$rL58z2=9k3H$rMW5a$9$k!#

I=2: #2<!%-%&C%7%e$N>uBV

>uBV	@bL@
Invalid	Ev3:%V%m%C%/$OL58z2=$5lF$$$k!#
Exclusive Dirty	Ev3:%V%m%C%/$N:G?7%G!<%?$O!"<+%W%m%;%C%5!&f%K%C%H$N%-%&C%7%e$K7+B8:_7J$$$3H,J]>Z5l$F$$k!#
Local Shared Clean	Ev3:%V%m%C%/$O%/%i%9%?Fb$G&M-5l$F$$k2DG=@-$,$"$k!#
Local Shared Dirty	Ev3:%V%m%C%/$O%/%i%9%?Fb$G&M-5l$F$$k2DG=@-$,$"$k!#FbMF$O<g5-21HO0[Jj!"<g5-21XN=q$-La$7$N@UG$$r;}$D!#
Global Shared Clean	Ev3:%V%m%C%/$O%/%i%9%?4V$G&M-5l$F$$k2DG=@-$,$"$k!#FbMF$O<g5-21HEy7$$!#

I=3: 2<!%-%&C%7%e$N>uBVA+0\I=!J+%W%m%;%C%5$+iN%/%;%9Kh$kA+0\!K

8=>uBV	%m!<%I	99?7%9%H%"	L58z2=%9%H%"
Invalid	(*1)	(*2)	Ex. Dirty
Ex. Dirty	—	—	—
Local Clean	—	Local Dirty	Ex. Dirty
Local Dirty	—	—	Ex. Dirty
Global	—	—	Ex. Dirty

*1 6&M->u67$K1~$8$FLocal Clean!"Local Dirty!"Global $N$$$El+KJ$k!#F101%/%i%9%?Fb$NDirty %V%m%C%/$+$iCM$,JV$CF-$?>19g$OLocal Dirty!#

*2 6&M->u67$K1~$8$FLocal Dirty $+Global NIAi$+$KJk

— >uBV$OJQ2=$7$J$$

I=4: 2<!%-%&C%7%e$N>uBVA+0\I=!J/%i%9%?Fb$N%W%m%;%C%5$+$i$N%/%;%9$KhkA+0\!K

8=>uBV	%m!<%I	99?7%9%H%"	L58z2=%9%H%"
Invalid	—	—	—
Ex. Dirty	Local Clean	Local Clean	Invalid
Local Clean	—	—	Invalid
Local Dirty	Local Clean	Local Clean	Invalid
Global	—	—	Invalid

I=5: 2<!%-%&C%7%e$N>uBVA+0\I=!8/%i%9%?30$N%W%m%;%C%5$+$i$N%"%/%;%9%K$h$kA+0\!K

8=>uBV	%m!<%I	99?7%9%H%"	L58z2=%9%H%"
Invalid	—	—	—
Ex. Dirty	Global	Global	Invalid
Local Clean	Global	Global	Invalid
Local Dirty	Global	Global	Invalid
Global	—	—	Invalid

5.1.4 %H%i%s%6%/%7%g%s

JUMP-1 K*$$F$C%9%H%"$KH<$&B>%-%&C%7%e$NL58z2=/99?7!"5Z$S%m!<%I!&_%9$KH<$&%G!<%?$NFI$_=P$7$O%Q%1%C%H$N0\F0Kh$j9T$olk!#0J8e!"%Q%1%C%H$N0\F0$Khj9Tol$k%-%&C%7%e$N>uBVA+0\5Z$S%G!<%?$N99?7$r%H%i%s%6%/%7%g%s$H8F$V!#$^$?!"$"$k%H%i%s%6%/%7%g%s$Khj$"$k%-%&C%7%e$N>uBVA+0\$dCM$N99?7$,9Tol$?$H$-!"$=$N%H%i%s%6%/%7%g%s$O$=$N%-%&C%7%e$KE~C#$7$?$H$$&3HK9$k!#F1MM$K!"Nc$($P<g5-21K*$$F%G%#l%/%H%j$r0z$/3HKh$j!"$"$k%-%&C%7%e$KO"$k%H%i%s%6%/%7%g%s$Khk>uBVA+0\$JI,9Tol$J$$3H,H=L@9l$P!"H=L@$7$?;~E@$G%H%i%s%6%/%7%g%sO=$N%-%&C%7%e$KE~C#7?$H8@$&!#

%H%i%s%6%/%7%g%s$O!"%a%b%j!&"%/%;%9$N<cN`!8m!<%I/%9%H%"!K"Fs<!%-%&C%7%e$N>uBV!"0l4S@-@)8f$NJ}?K!I58z2=/99?7!K$N%Q%i%a!<%?$NAH9g$o$;$+$i$=$N<cN`$,7hDj$5lk!#$^$?!"%H%i%s%6%/%7%g%sKhCF$O!"B>$N%-%&C%7%e$d%a%b%j$+iN1~Ez$,I,MW$HJkbN$bB8:_$9$k!#JUMP-1 K*1k<g$J%H%i%s%6%/%7%g%s$N<cN`$rI=6 $K<($9!#I=6$K<($90J30Kb"%H%_%C%/!&m!<%I!&9%H%"$KH<$&%H%i%s%6%/%7%g%s$dJUMP-1 $K<EAu$5lF$$k9b5!G=%a%b%j!&"%/%;%9MQ$N%H%i%s%6%/%7%g%sEy$,$"$k!#

5.2 0l4S@-@)8f$N:GE,2=

TIS-CC $N<EAu$O?^9$K<($9h&$K!"4pK\E*$K$O3F%V%m%C%/$KBP7F7W;;5!Fb$K%7%j%"%i%s%:!&]%$s%H$r0lE@@_$1!"%H%i%s%6%/%7%g%s$,I,$:%7%j%"%i%s%:!&]%$s%H$rDL2a9kh&$K@)8f$9$k0lJ}$G!"%7%j%"%i%s%:!&]%$s%H$rDL2a9kA0KbE5!E*$K>uBVA+0\$dCM$N99?7$JIr9T$5!"$5iK%7%j%"%i%s%:!&]%$s%H$rDL2a7?%Q%1%C%HKh$j:G=*7k2L$r>e=q$-$9k3HG<B8=G-$k!#

7+$7!"JUMP-1 GOTIS-CC $r<EAu$9kK$"$?$j!"$h$j@-G=8~>e$rDI5a9k$?$a$K0J2<$K<($9:GE,2=<jK!$,:NMQ5l$F$$$k!#

1. %7%j%"%i%s%:!&]%$s%H$NJ#?tG[CV
   4pK\E*KO%7%j%"%i%s%:!&]%$s%H$O7W;;5!FbN"$k0lE@!"Nc$($P<g5-21$KN_B8:_7F$$$k$P0l4S@-@)8f$O<B8=G-$k!#$7$+$7!"JUMP-1 GO%7%j%"%i%s%:!&]%$s%H$r7W;;5!Fb$N3F=j$K@_$1!"3F%V%m%C%/$,$"$k%/%i%9%?Fb%m!<%+%kG"kH$-Ey!"6I=jE*$JItJ,K7$+B8:_$7$J$$3H,J]>Z5l$F$$k>l9g$O<g5-21$r7PM3$;$:Hb%H%i%s%6%/%7%g%s$N4V$N%7%j%"%i%s%:$r2DG=$H9k3H$G!"%H%i%s%6%/%7%g%s$NDL2a7PO)$NC;=L!"$=7F%Q%1%C%H$NN.NI$NDc8:$r?^$k!#J*!"3N:GE,2=$OTIS-CC $N@-<A$H$OL54X78$G!"ACS-CC KbE,MQG-$k!#

2. :G=*7k2L>e=q$-$N:o8:
   4.2@a$G=R$Y$?$h$&$K%H%i%s%6%/%7%g%s$OI,$::G8e$K:G=*7k2L$r>e=q$-$9kh$&$K9lP:G$bMF0W$K<B8=2DG=G"$k!#$7$+$7!"%U%)!<%k%9!%7%"%j%s%0$O%C%3%s%Q%$%iKhCFM^$($k3H,G-kH2>Dj9k$H!"F101%"%I%l%9$KBP9k%"%/%;%9$O%/%j%F%#%+%k!&%/%7%g%s$G$"$k3H,B?$$$H9M$($ilk3HEy$+$i!"U#?t$N%W%m%;%C%5$,$[$\F1;~$KF101%V%m%C%/$KBP9k%9%H%"$r9T$&6ILL$O>/$J$J$$H9M$($ilk!#D$^j!"K\Ev$K>e=q$-$7J1lPJiJJ$$6ILL$O>/$J$J$$N$G!">e=q$-$r9T$&NOJkY/:G>.8BKHIak3HG7W;;5!$NIi2Y$NDc8:$r?^$k!#

0J2<$G!"$3liFsDN<jK!$N>\:Y$r=RYk!#

5.2.1 %7%j%"%i%s%:!&]%$s%H$NJ#?tG[CV

%7%j%"%i%s%:!&]%$s%H$O7W;;5!FbN"$k0lE@!"Nc$($P<g5-21$KKN$_B8:_$9lP!"%H%i%s%6%/%7%g%s$N%7%j%"%i%s%:$O2DG=G"$k!#$7$+$7!"$"$k%V%m%C%/$N6&M->uBV$,0lDN%/%i%9%?FbKJD8$F$$k>l9g$O!"%H%i%s%6%/%7%g%s$N%7%j%"%i%s%:$r<g5-21$GOJ$/$=$N%/%i%9%?Fb$G9T$&$3H,G-kNJi!"%H%i%s%6%/%7%g%s$NDL2a7PO)C;=L$d%Q%1%C%H$NN.NI$NDc8:$,?^$lkN$G!"7W;;5!$N@-G=8~>e$KLrN)$D$H9M$(il$k!#

3N$?$a$K!"JUMP-1 GO%7%j%"%i%s%:!&]%$s%H$r7W;;5!Fb$NE~$kH3mK@_$1!"3F%V%m%C%/$N6&M->u67$K1~$8$F<B:]$K%7%j%"%i%s%:$,9T$olkCOE@$,JQ2=$9$k<jK!$r:NMQ7F$$k!#6qBNE*KO!"3F2<!%-%&C%7%e!"3F%/%i%9%?$N%/%i%9%?!&P%9!"$=7F<g5-21$r%7%j%"%i%s%:!&]%$s%HHDja!"8GB'E*$K3F%H%i%s%6%/%7%g%s$,DL2a9k9YFN%7%j%"%i%s%:!&]%$s%H$K$*$$FB>$N%H%i%s%6%/%7%g%s$H%7%j%"%i%s%:9k!#3N<jK!Kh$j!"7W;;5!Fb$rF1;~$K?J9T$9kG0UNFsD$N%H%i%s%6%/%7%g%s$N4V$G%7%j%"%i%s%:$r9T$&$3H,G-!"$+$D%H%i%s%6%/%7%g%s$NDL2a7PO)$NC;=L$r?^$k3H$,$G$-$k!#

Nc$($P!"$"$k%V%m%C%/$r=jM-$9kN$,0l$D$N%/%i%9%?Fb$NJ#?t$N2<!%-%&C%7%e!8m!<%+%k!K$G$"$kH-$K!"$3$N<jK!$Khj!"%H%i%s%6%/%7%g%s$O!"%7%j%"%i%s%:!&]%$s%H$rDL2a$9$k!#$3$N<jK!$Khj!"%H%i%s%6%/%7%g%s$,I,$:%7%j%"%i%s%:!&]%$s%H$rDL2a9kh&$K@)8f$9$k0lJ}$G!"%7%j%"%i%s%:!&]%$s%H$rDL2a9kA0KbE5!E*$K>uBVA+0\$dCM$N99?7$JIr9T$5!"$5iK%7%j%"%i%s%:!&]%$s%H$rDL2a7?%Q%1%C%HKh$j:G=*7k2L$r>e=q$-$9k3HG<B8=G-$k!#

5i$K!"%H%i%s%6%/%7%g%s,DL2a$9k9YF$N%7%j%"%i%s%:!&]%$s%H$G%7%j%"%i%s%:$r9T$&$3HKhj!"6&M->u67$rJQ2=$5$;$k%H%i%s%6%/%7%g%s,?J9T7F$$kH-KbG$0U$NFsDN%H%i%s%6%/%7%g%s$r%7%j%"%i%s%:$G$-$k!#Nc$($P?^12$K<($9h&$K!"$"$k%V%m%C%/$,$"$k0lD$N%/%i%9%?(Cluster 4) KN$_B8:_7F$$kH-$K!"JL$N%/%i%9%?(Cluster 2) $+$i#m!<%I$,9T$olk$H!"$3$N%H%i%s%6%/%7%g%s$O<g5-21(Cluster 1) $r7PM3$7$FCluster 4 KFO1il$k!#3N:]!"Cluster 2 $HCluster 4 $N%/%i%9%?!&P%9$d<g5-21K*$$F$bB>%H%i%s%6%/%7%g%s$H%7%j%"%i%s%:9k3H$G!"Cluster 4 $+$iH/$;$il?%H%i%s%6%/%7%g%sHOCluster 4 $N%/%i%9%?!&P%9$G!"Cluster 2 $+$iH/$;$il?%H%i%s%6%/%7%g%sHOCluster 2 $N%/%i%9%?!&P%9$G!"$=$7$FB>$N%/%i%9%?(Cluster 3) $+$iH/$;$il?%H%i%s%6%/%7%g%sHO<g5-21K*$$F%7%j%"%i%s%:5l!"IN%H%i%s%6%/%7%g%sHb%7%j%"%i%s%:9k3H$,$G$-$k!#

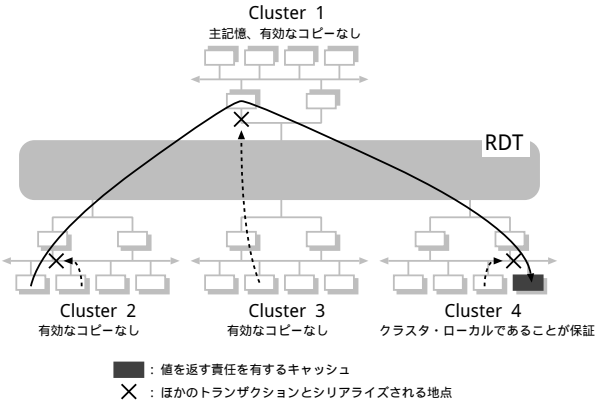
5.2.2 >e=q$-$N:o8:

>e=q$-:o8:$N$?$a$N%"%W%m!<%A I,$:7b:G=*7k2L$r>e=q$-7J$$$?aN%"%W%m!<%AH7$F!"<!$NFs$D,9M$(il$k!#

I=6: %H%i%s%6%/%7%g%s$N<cN`

%m!<%I/%9%H%"	CCP	>uBV	%H%i%s%6%/%7%g%s	1~Ez
%m!<%I	—	Invaild	CMFI$_$@$7	M-
		Otherwise	(H/@8$7$J$$)	
%9%H%"	L58z2=	Invalid	L58z2=7sCMFI$_=P$7*1	M-
		Global	L58z2=7sCMFI$_$@$7*1	M-
		Ex. Dirty	(H/@8$7$J$$)	
		Otherwise	L58z2=	L5
	99?7	Invalid	CMFI$_=P$7+ 99?7*2	M-
		Ex. Dirty	(H/@8$7$J$$)	
		Otherwise	99?7	L5

CCP 0l4S@-@)8fJ}?K
>uBV 2<!%-%&C%7%e$N>uBV
1~Ez 1~Ez$NM-L5
*1 CMFI$_$@7HL58z2=$rF1;~$K9T$&
*2 CMFI$_$@7r9T$$!"40N;7?8e99?7



?^12: J#?t$NCOE@$GB>$N%H%i%s%6%/%7%g%s$H%7%j%"%i%$%:$5lk>u67

- Ej5!E*$K=q$-9~$_$r9TC?8e!"$=$N%H%i%s%6%/%7%g%s$,40N;$9$kA0$KJL$N%H%i%s%6%/%7%g%s$KhC$FF1$8%V%m%C%/KBP7$F=q$-9~$_$,9Tol$?$3Hr8!=P7F!"3N>l9g$@$1>e=q$-$r9T$&!#
- Ej5!E*$K=q$-9~$_$r9TC?8e!"$=$N%H%i%s%6%/%7%g%s$,40N;$9k^GO=q$-9~$_$r9T$C$?%V%m%C%/$NCM$d>uBV$,JQ2=7J$$$h$&$KJ]8n9k!#

A0<T$NJ}K!$r:NMQ9k:]KO!"2?i+$NJ}K!$KhGFJLN%H%i%s%6%/%7%g%sKhCF=q$-9~$_$,$J5l$?$3Hr8!=P9k$?$a$N5!9=$H!"3l$r8!=P$7$?:]$K%H%i%s%6%/%7%g%s$N<cN`$dDL2a7PO)JI$rJQ99$9k?aN5!9=$rMQ0U$9k3HKhj<B8=9k3H$,$G$-$k!#3liFsD$N5!9=$N<B8=$OI,$:7bMF0W$K9T$(kH$O8B$i$:!"<BAu$N$?$a$N%3%9%H,A}Bg$9$k2DG=@-$b$"$k$,!"$3$NJ}K!$O%Q%1%C%H$NN.NL$r8:i9$?$aKOM-8z$J<jK!$G$"$k!#

0lJ}!"8e<T$NJ}K!$N<BAuO=l[$I:$FqGO$J$$,!"3N<jK!$O7k6I:G8e$K=q$-9~$_6X;_$r2r=|$9kI,MW,$"$kNG!":NMQ9k>u67KhCF$O!":G=*7k2L$r>e=q$-$9kNH[$\F1$8=hM}$,I,MW$HJjF@$F!"Ii2Y$NDc8:KDJ,iJ$$2DG=@-N"k3HK$OCm0U$9kI,MW,$"$k!#

JUMP-1 K*1kJ}K! JUMP-1K*$$F$O7W;;5!$NIi2Y$NDc8:$r?^k?aK>eNFsD$N<jK!$r:NMQ7F$$$k!#0lJ}$G!"I,$:>e=q$-$r9TCFbBg-$J@-G=Dc2<$KODJ,iJ$$H9M$($ilk>u67GO!"7W;;5!$N@)8f$rMF0WK9k?aKI,$:>e=q$-$r9T$&!#

JUMP-1>e$G<B9T$5lk%"%W%j1!<%7%g%sGO!"JQ?t$N6&M->uBV$,%/%i%9%?FbKJD8kbNbB?$$H9M$($ilk!#3N$?$a!"%/%i%9%?4VK^$?$,$k%H%i%s%6%/%7%g%s$O=l[$IB?$/$OH/@8$7$J$$$,!"%/%i%9%?FbKJD8$k%H%i%s%6%/%7%g%s$OIQH/9k$H9M$(il$k!#$hCF!"6&M->u67$,%/%i%9%?4V$K$^$?$,$C$F$$k>l9g$O:G=*7k2L$N>e=q$-$r:G>.8BKHIak3HG!"%7%9%F%`K+$+$kIi2Y$r:o8:$9k3H,2DG=G"kHM=A[5l$k!#$9Jo$A!"JUMP-1$G$O6&M->u67$,%/%i%9%?4VK^$?$,CF$$k>l9g$OI,$:>e=q$-$r9T$&$,!"%/%i%9%?FbKJD8$F$$k>l9gKD$$$F$O>e=q$-$r9T$&Nr:G>.8BKHIa$k!#

>e=q$-$r:G>.8BKHIak?$a!"6&M->u67$,%/%i%9%?FbKJD8$F$$k:]$K!"%9%H%"$KHbJE$j5!E*$K%-%&C%7%e$N>uBV$rJQ2=5;$?$jCM$r=q$-9~s@>l9g$O!"%H%i%s%6%/%7%g%s$,40N;9kA0$K

1. F10l%V%m%C%/KBP7$FL58z2=MW5a$,J5l?>l9g$O!"L58z2=$5l?3H$r8!=P$7$F!"8e$K>e=q$-$r9T$&!#
2. $=$10J30$NMW5a$,J5l?>l9g$O!"$=$NMW5a$KhkEv3:%V%m%C%/$N>uBVA+0\$*hS%9%H%"$r9T$C$?%I%l%9$NCM$,JQ2=$7$J$$$h$&$KJ]8n9k!#

J}K!$r:NMQ$7$F$$$k!#

L58z2=5l$?>l9g$@$107$$,JLJN$O!"F10l%V%m%C%/$X$N0[$J$k%"%I%l%9$KBP7F[$\F1;~$KJ#?t$N%W%m%;%C%5$,%9%H%"$r9T$$!"$=$lKHbJ$$$N>J}$,$*8_$$$rL58z2=7h$&$H9k>u67$KBP1~$9k?aG$"$k!#>\:Y$O5.4@a$G=RYk!#

$^$?!"@h$K>uBV$dCM$rJ]8n$9$k<jK!$OIi2Y$NDc8:$K9W8%7J$$2DG=@-$,$"kH=RY?$,!"6&M->uBV$,%/%i%9%?FbKJD8$F$$k>l9g$O!">uBV$dCM$NJ]8n$OIi2Y$NDc8:$K=-J,9W8%9k!#J<Ji!"JUMP-1K*$$F$OJ]8n5!9=$O%W%m%;%C%5!&f%K%C%H$NAw?.%P%C%U%!$N3F%(%s%H%j$K@_$1il$F$$k$+$iG"$k!#%W%m%;%C%5,%9%H%"$r9T$&$H!"E j5!E*$K2<!%-%&C%7%e$K=q$-9~$_$r9T$&$HF1;~$KAw?.%P%C%U%!$K%(%s%H%j$r3dIU1FB>%-%&C%7%e$r99?7$b7/$OL58z2=$9k?aN%Q%1%C%H$r=q$-9~$`!#$3

$N:]!">uBV$dCM$rJ]8n$9%k$?$aKI,MWJ>pJs$bF1$8%(%s%H%j$K=q$-9~$`!#$=$N8e!"Aw?.%P%C%U%!$KB8:_7F$$?%Q%1%C%H$,%/%i%9%?!&P%9$rDL2a$9%k$H!"6&M->uBV$,%/%i%9%?Fb$KJD8F$$$kNG!"3N;~E@$G%H%i%s%6%/%7%g%s$,40N;7?$H8@$($k!#$^$?!"%Q%1%C%H$N%/%i%9%?!&P%9$NDL2a$HF1;~$KAw?.%P%C%U%!$K3dIU1ilF$$?%(%s%H%j$O2rJ|$5$l!"F1;~$K>uBVdCMNJ]8n$b2r=|$5lk!#%(%s%H%j$N2rJ|$O2<!%-%&%C%7%e$KIi2Y$rM?$($:$K2DG=$G$"$k$+$i!"%H%i%s%6%/%7%g%s$N40N;$rbC$FJ]8n$N2r=|$b<+A3$K9Tol!"$+$D2<!%-%&%C%7%e$KIi2Y$rM?$($:$K9T$olk!#=>CF!"%9%H%"$KH<$&2<!%-%&%C%7%eXN%"%/%;%9$O:G=i$KEj5!E*$K=q$-9~$`$H$-$@$19T$olkNG!"8e$K>e=q$-$r9T$&J}K!hj$b2<!%-%&%C%7%e$K$+$+$kIi2Y$O>.5/9k3H$,$G$-$k!#

5.3 TIS-CC $N<B8=$N$?$a$N5!9=$H@)8f

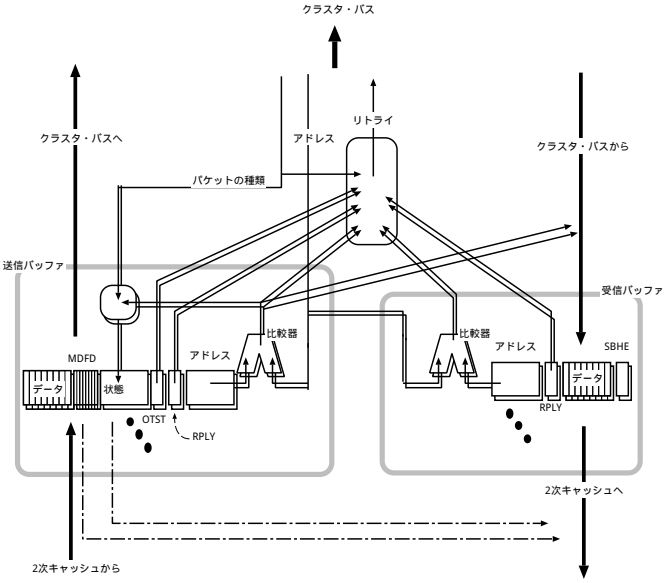
4.2@a$G=R$Y$?TIS-CC $N<B8=$KI,MW$J4pK\E*$J=hM}!"9JoA!"%H%i%s%6%/%7%g%s$N%7%j%"%i%$%:$d:G=*7k2L$N>e=q$-$r<B8=9k$?$a!"$=$7$F5.2@a$G=RY?:GE,2=!"9JoA!"%7%j%"%i%$%:!&]%$%s%H$NUJ#?tG[CV$d:G=*7k2L$N>e=q$-$r:o8:$9k?aN=hM}$r<B8=$9k?$a!"JUMP-1 K*$$F$O%W%m%;%C5!&f%K%C%HFb$NAw<u?.%P%C%U%!$=$7$F<g5-21$K$*$$FMM!9$J5!9=$,@_1ilF$$k!#

%W%m%;%C5!&f%K%C%HFb$NAw<u?.%P%C%U%!$GMQ0U5l$F$$$k5!9=$r?^13$K<($9!#?^13$K$*$$F!"%"%I%l%9$d&G!<%?0J30$N5!9=$NLr3d$O<!NDLjG"$k!#

- MDFD
  %b%G%#U%!%$%I!&S%C%H!#%V%m%C%/$N%P%$%H?t$HF1$8$@1N%S%C%H?tG"$k32%S%C%HMQ0U$5lF$$$k!#Aw?.%P%C%U%!$K=q$-9~$^$l$?%Q%1%C%H$,<+%W%m%;%C5$+$i$N%9%H%"$KH<$&%Q%1%C%H$N;~N_0UL#$r;}$D!#Ev3:%V%m%C%/NCfN%9%H%"$r9T$C$?%"%I%l%9$K$O%S%C%H$,$?$C$F$$$k!#
- >uBV
  Ev3:%"%I%l%9$N2<!%-%&%C%7%e$N>uBV$rI=$9!#3l$H%W%m%;%C5$+iN%"%/%;%9$N<dN`$J$I$+$i%/%i%9%?!&P%9$KN.$9%Q%1%C%H$N<dN`$r7hDj9k!#
- OTST
  %"%&%H!&9%?%s%G%#%s0!&S%C%H!#L~Ez$,I,MW$J%H%i%s%6%/%7%g%s$r%/%i%9%?!&P%9$KAw=P7?8e!"1~Ez$,JV$CF/k^$G%S%C%H$,N)CF$$$k!#
- RPLY
  Aw?.%P%C%U%!K*$$F$O!"Ev3:%(%s%H%j$KF~CF$$$k%Q%1%C%H$,B>$N%W%m%;%C5XNl~Ez$Q%1%C%H$G$"$k3H$r!"<u?.%P%C%U%!$K$*$$F$OB>$N%W%m%;%C5XNl~Ez$,I,MW$J%Q%1%C%H$r<u$1<hC?3H$r0UL#$7$F$$k!#
- SBHE
  Aw?.%P%C%U%!$KF10l%V%m%C%/$X$N%Q%1%C%H$,B8:_7F$$k3H$r<($9!#

$^$?!"%/%i%9%?!&a%b%jK*1k5!9=$r?^14$K<($9!#%/%i%9%?!&a%b%j$K$*$$F$O%G%#%l%/%H%j$NB>$K!"0J2<$N5!9=$,MQ0U$5lk!#

- %W%m%;%9!&F!<%V%k
  8=:_?J9TCf$N%H%i%s%6%/%7%g%s$N%F!<%V%k!#8eB3%H%i%s%6%/%7%g%s$N?J9T$r%/%i%9%?!&a%b%j$GDd;_$5$;$kI,MW$,$"lk>l9g!"%W%m%;%9!&F!<%V%kK=$N%"%I%l%9$Dd;_5;$k%H%i%s%6%/%7%g%s$N<dN`$r5-O?$9$k!#
- %5%9%Z%s%I!&P%C%U%!?J9T$,Dd;_$5lF$$k%H%i%s%6%/%7%g%s$r5-O?$9$k!#



MDFD：モディファイド・ビット
OTST：アウト・スタンディング・ビット
RPLY：応答ビット
SBHE：送信バッファ・ヒット・エントリ

?^13: TIS-CC <B8=N?aN5!9=(%W%m%;%C5!&f%K%C%HFb)

- %l%G%#!<!&~%e!<
  0lC6?J9T$rDd;_$5l?$,$^$??J9T2DG=$KJC$?%H%i%s%6%/%7%g%s$,r5-O?9k!#

3liN5!9=$rMQ$$F!"4.2@a$G5s$2$?4pK\E*$JTIS-CC $N<B8=$J}K!$K2C$($F!"5.2@a$G5s2?:GE,2=<jK!$r<B8=$9k?aN@)8f$r9T$&!#0J2<$G!"TIS-CC $r<B8=$9k?aK9Tol$k@)8f$K$D$$F=Yk!#

5.3.1 %H%i%s%6%/%7%g%s$N?J9TDd;_

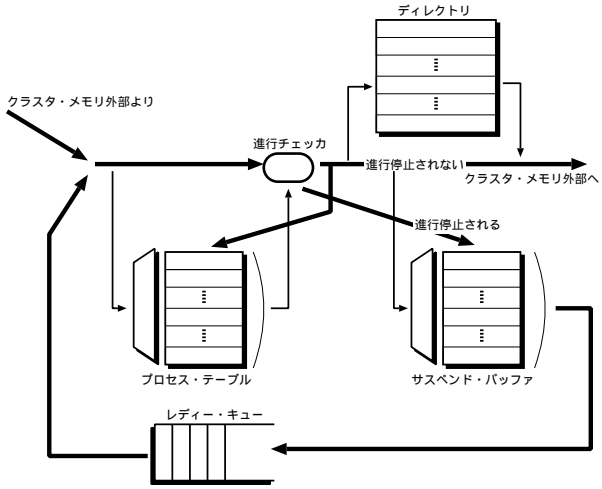
4.2@a$G=R$Y$?$h$&$K!"3F%W%m%;%C5$+$i4QB,G~kCM,:G=*E*$KF1$8KJk?aK!"%7%j%"%i%$%:$5l?%H%i%s%6%/%7%g%s$,3F%~%&%C%7%e$d&a%b%j$KE~C#$9$k=g=x$O%7%j%"%i%$%:$5l?=g=x$rJ]$Dh&$K@)8f$r9T$&!#$3lO!"8eB3%H%i%s%6%/%7%g%s$,%7%j%"%i%$%:!&]%$%s%H$rDL2a$9%k$H!"@h9T%H%i%s%6%/%7%g%shj$b@h$K!"$"$k%(%s%H%j%(%s%H%j$KE~C#$9$k2DG=@~$,$"$k>l9g$O!"8eB3%H%i%s%6%/%7%g%s$NDL2arBT?$;$k3HKh$j<B8=$9$k!#

8eB3%H%i%s%6%/%7%g%s$,@h$KE~C#$7F@$k>l9gH7$F0J2<$NFsD,9M$($ilk!#

- %M%C%H%o!<%/K*$$F%Q%1%C%H$NDI$$1[7,H/@8$9$k
- %7%j%"%i%$%:!&]%$%s%H$rDL2a8e$N7PO)$,@h9T%H%i%s%6%/%7%g%s$H8eB3%H%i%s%6%/%7%g%s$N4V$G0[Jk

JUMP-1 K*$$F!"3liO0J2<$N;~$K5/3jF@$k!#

1. %Q%1%C%H$NDI$$1[$7
   JUMP-1 K*$$F%Q%1%C%H$NDI$$1[$7O!"RDT K*$$FH/@8$7F@$k!#RDT KOPoint-to-Point DL?.$N7PO)$H%^%k%A%~%c9%H$N7PO)$,JL$K@_$1ilF*$j!"@h9T%H8eB3%H%i%s%6%/%7%g%s$N0lJ}$,Point-to-Point DL?.$G9T$o$l!"



?^14: TIS-CC <B8=N?aN5!9=(<g5-21Fb)

B>J}$,%^%k%A%-%c%9%H$rH<$&%H%i%s%6%/%7%g%s$G$"$1$P%Q%1%C%H$NDI$1[$7$,H/@8$9$k!#$3$1$O:G$bC1=c$K$O!"3F%/%i%9%?$O Point-to-Point $N%Q%1%C%H$r RDT $KN.$7$?$H$-$O!"$=$1$,A}<j$KF~O$/$^G^%k%A%-%c%9%H!&Q%1%C%H$rN.$5$:!"$=7F!"$=$N5U$b9T$&3HKh$}=g=x$rJ]>Z9k3H$,2DG=$G$"$k!#

2. DL2a7PO)$N0[$J$j

DL2a7PO)$N0[$JjO!"@h9T%H%i%s%6%/%7%g%s$,1~Ez%Q%1%C%H$rH<$&>l9g$KH/@8$7F@$k!#@h9T%H%i%s%6%/%7%g%s$,1~Ez%Q%1%C%H$rH<$&>l9g!"0lC6JL$N%-%c%c%7%e$d%a%b%j$r7HM3$7$F$+$i!"$=$N%H%i%s%6%/%7%g%s$r3+;O$7$?%W%m%;%C%5$KJVk?$a!"8eB3$N%H%i%s%6%/%7%g%sHN$"$$@$G7PO)$,0[Jk!#

3N>u67$r?^15$K<($9!#$^$:!"$P_1$,1~Ez$rI,MWH9$k%H%i%s%6%/%7%g%s$rH/$7!"$=1,%7%j%"%i%$%:!&]%$%s%H$rDL2a$9$k!#$=1,1~EzrJV9%W%m%;%C%5(P_3)KFO-!"P_3O<+%-%c%c%7%e$N>uBV$rJQ2=5;!"$=$1HHbK1~Ez%Q%1%C%H$r@8@.$7FP_1K'1FAw?.9k!#7+$7!"$3$N4V$KB>$N%W%m%;%C%5($P_2$)$NH/7?%H%i%s%6%/%7%g%s$,%7%j%"%i%$%:!&]%$%s%H$KE~C#$7!"$=$N;~D>$AKP_1K'1F%Q%1%C%H$rAw?.$9$1$P!"P_2+iN%Q%1%C%H$NJ}$,P_3+iN1~Ez%Q%1%C%Hhj@hKP_1$KE~C#$7F@$k!#$3N?aK!"1~Ez$rH<$&%H%i%s%6%/%7%g%s$,%7%j%"%i%$%:!&]%$%s%H$rDL2a9k$H8eB3$N%H%i%s%6%/%7%g%sO=$N%7%j%"%i%$%:!&]%$%s%H$KE~C#7?;~E@$G?J9T$,Dd;_$5$1$k!#

$?$@$7!"@h9T%H%i%s%6%/%7%g%s$,1~Ez%Q%1%C%HrI,MWH9k>l9gGb<!$K<($9>l9g$O8eB3%H%i%s%6%/%7%g%s$NDd;_OJ$5$1$J$$

(a) %7%j%"%i%$%:$,9To1kN$,2<!~%c%C%7%e$N;~3N;~O?H(1~Ez$,I,MW$G$"$CFb1~Ez%Q%1%C%H$OD>$A$K%7%j%"%i%$%:!&]%$%s%H$rDL2a9k3H$+$i;v<B>e8eB3%H%i%s%6%/%7%g%s$N?J9T$,Dd;_$5$1k3HO$J$$!#

(b) %/%i%9%?!&P%9K*1kNc30

%/%i%9%?!&P%9K*$$F!"?^16$K<($9h&$KRDT rDLG$F%/%i%9%?!&a%b%j$+$iH/$;i1$?%H%i%s%6%/%7%g%s(A)KD$$F$O!"$?H(!"$=$N%/%i%9%?Fb$K1~Ez$,I,MWJL40N;%H%i%s%6%/%7%g%s(B)$,B8:_$7$F$$F$b!"%V%m%C%/$N6&M->uBV$,%/%i%9%?4V$K$^$?$,$C$F$$kH-$O?J9T$rDd;_7J$$!#

J<Ji!"6&M->uBV$,%/%i%9%?4V$K$^$?$,$C$F$$kH-$O!"%H%i%s%6%/%7%g%sA$Khj<g5-21K*$$F%H%i%s%6%/%7%g%sB $N?J9T$,Dd;_$5$1$F$$k2DG=@-$,$"kN$G!"%/%i%9%?!&P%9$K$*$$F%H%i%s%6%/%7%g%sB Kh$jA $N?J9T$,Dd;_$5$1kH%G%I%m%C%/$K4Y$k!#6&M->uBV$,%/%i%9%?4V$K$^$?$,$C$F$$kH-$O<g5-21$K$*$$F%7%j%"%i%$%:$5$1$k$H$$&9M$($+$i!"%/%i%9%?!&P%9$K$*$$F$O?J9T$rDd;_5;$J$$!#

J*!"@h9T%H%i%s%6%/%7%g%s$,%/%i%9%?Fb$KJD8k;~$O!"%/%i%9%?!&a%b%j$+$iH/$;i1$?%H%i%s%6%/%7%g%s$b?J9TDd;_$5$1$k!#

>e5-$r<B8=$9k?aN%H%i%s%6%/%7%g%s$N?J9TDd;_@)8f$O?^13$*$h$S?^14 $K<($95!9=$rMQ$$F<!Nh$&$K9T5o1$k!#

1. %/%i%9%?!&P%9K*1k?J9TDd;_

%/%i%9%?!&P%9K*1k?J9TDd;_$O!"%P%9$KN.l?%Q%1%C%H$NL58z2=$H:EAw$rMW5a$9$k%j%H%i%$$5!9=$rMQ$$F<B8=$5$1$k!#

%/%i%9%?!&P%9K*1k%j%H%i%$$5!9=$r?^17$K<($9!#?^17 $O!"?^13$N$&$A$N%j%H%i%$$K4X78$9$kItJ,N_$r<B@~$GI=7?bNG"$k!#

%/%i%9%?!&P%9$K%Q%1%C%H$,N.lk$H!"F10l%V%m%C%/$X$N%Q%1%C%H$,<+J,$NAw<u?.%P%C%U%!$KB8:_9k$+$I$&$+$r3F%(%s%H%jKh$K@_1il?Hf3S4o$rMQ$$F8!:w9k!#$=$N7k2I%R%C%H7?%(%s%H%j$,$"lP!"Aw?.%P%C%U%!$+$iO=$N%(%s%H%j$,1~EzBTA+I&$+$r<($9OTST %S%C%H$H!"B>KBP9$k1~Ez%Q%1%C%H$+I&$+$r<($9RPLY %S%C%H$,!"<u?.%P%C%U%!$+$iO=$N%(%s%H%j$,1~EzrI,MWH9kMW5aG"k3Hr<($9RPLY %S%C%H$,!"%j%H%i%$$MW5a5!9=KEA(il$k!#

$=$7$F!"0J2<$N>r7o$,@.N)$7$?$H$-$K%j%H%i%$$rMW5a9k!#

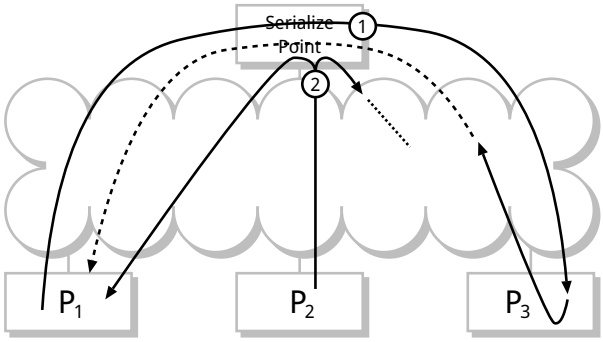
- OTST $,N)$O$F$$$kAw?.%P%C%U%!$K%R%C%H$7!"$+$D%P%9$K%Q%1%C%H$rN.7?N,%/%i%9%?!&a%b%jGO$J$$$!#
- RPLY $,N)$O$F$$$kAw?.%P%C%U%!$"$k$$$O<u?.%P%C%U%!$K%R%C%H$7$?!#

A0<I$N>r7o$Khj!"1~EzBTAN;~$KB>$N%W%m%;%C%5!&f%K%C%H$,%P%9$K%H%i%s%6%/%7%g%s$rN.$9Nr6X;_9k!#$=$7$F!"%H%i%s%6%/%7%g%s$,%/%i%9%?FbKJD8kH$-$O!"%/%i%9%?!&a%b%j$+$iH/$;$i1?%H%i%s%6%/%7%g%sG"CF$b?J9T$rDd;_9k$?$a$N%H%i%s%6%/%7%g%s$,%/%i%9%?Fb$N%W%m%;%C%5!&f%K%C%H$G$"$k!"W$H$$&3HKh$j8!=P$9$k!#

2. <g5-21K*1k?J9TDd;_

<g5-21K*1k?J9TDd;_@)8f$NN.$l$r?^18 $K<($9!#

$^$:!"1~Ez$,I,MW$J%H%i%s%6%/%7%g%s$O<g5-21$rDL2a9k:]$K!"8eB3$N%H%i%s%6%/%7%g%s$rDd;_$5$;$k?aK!"%W%m%;%9!&F!<$V%k$KBP7F1~Ez$,I,MW$JL$40N;%H%i%s%6%/%7%g%s$,B8:_9k$+$I$&$+$rD4$Y$k①!#$3$3G!"B8:_$9kJi=$N%H%i%s%6%/%7%g%s$r%5%9%Z%s%I!&%P%C%U%!$KEPO?$9$k②!#



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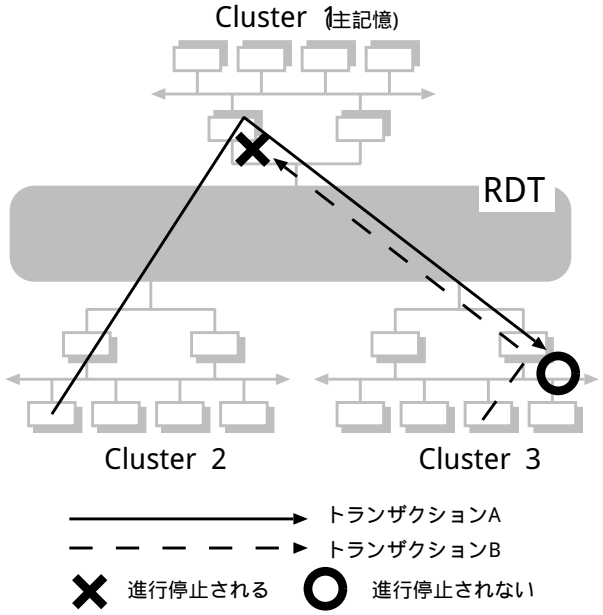
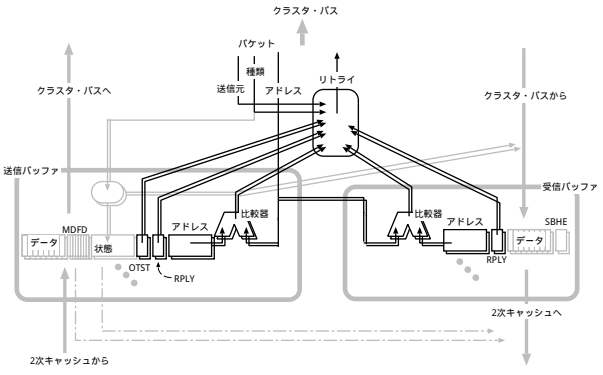


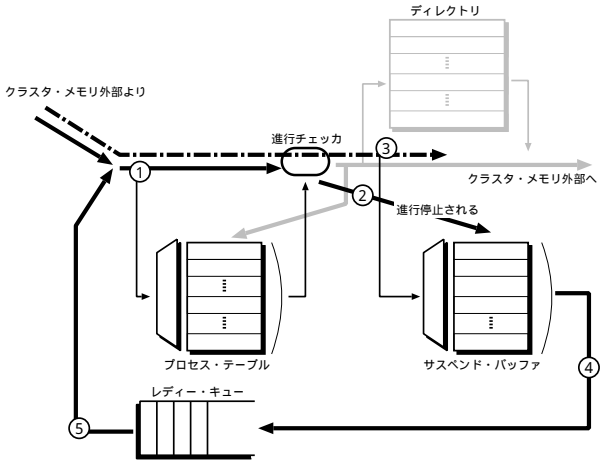
- %V%m%C%/$N6&M->uBV$O%/%i%9%?4VK^$?$,CF $$$k
- %H%i%s%6%/%7%g%sA,B Hb$K1~Ez$rI,MWH9$k

?^16: %H%i%s%6%/%7%g%s$N%G%C%I%m%C%/$N2sHr



?^17: %/%i%9%?!&P%9K*1k%j%H%i%$5!9=

8e$K!"@h9T%H%i%s%6%/%7%g%s$N1~Ez$,<g5-21$KJVCF$/$k $H!"%5%9%Z%s%I!&P%C%U%!$r8!:w7FDd;_5l$F$$$k%H%i %s%6%/%7%g%s$,B8:_$9k+8!:w9k③!#b7!"B8:_9k$N Ji$=$N%H%i%s%6%/%7%g%s$r%l%G%#!<!&-%e!<$K0\$9④!# %l%G%#!<!&-%e!<$K0\$5l?%H%i%s%6%/%7%g%s$O!"$7Pi $/$?C?8eb&0lEY%W%m%;%9!&F!<%V%k$r8!:w$9kH3m $+$i:F3+9k⑤!#



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3. RDT K*1k=g=xJ]>Z

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5.3.2 :G=*7k2L$N>e=q$-

5.2@a$G=R$Y$?$h$&$K!":G=*7k2L$N>e=q$-$OL58z2=$^$?$O99?7%H %i%s%6%/%7%g%s$,%/%i%9%?4V$K$^$?$,$k>l9g$H!"%/%i%9%?Fb$K JD8kH-$GbEj5!E*$K%9%H%"$N7k2L$r=q$-9~$s$@2<!%-%&C %7%e$,L58z2=5l$?$H$-$K9T$&!#

1. %/%i%9%?4VK^$?$,$k99?7%H%i%s%6%/%7%g%s$Khk>e=q$- %/%i%9%?4V$K$^$?$,$k99?7%H%i%s%6%/%7%g%sKh$k>e=q $-$O!"%7%j%"%i%$:$5l?8e$KEj5!E*$K=q$-9~$_$r9T$C$? %-%&C%7%e$K%Q%1%C%H$,:F$SE~C#9k$H!">uBV$rA+0\$5$; kHbK!"%V%m%C%/FbN&A%9%H%"$,9T$ol?%"%I%l%9 NCMr%-%&C%7%e$K=q$-9~$'$3HG9T$&!#

2. %/%i%9%?4VK^$?$,$kL58z2=%H%i%s%6%/%7%g%s$Khk>e=q $- 0lJ}!"%/%i%9%?4V$K$^$?$,$kL58z2=%H%i%s%6%/%7%g%s$N;~ $O!"CM$rJV$9@UG$$r;}$D%-%&C%7%e$^$?O%a%b%j!ø*!<&J!K $+$i%V%m%C%/A4BNNCMrFI$_=P$7$?8e!"%H%i%s%6%/%7%g%s $r3+;O$7$?%W%m%;%C%5!&f%K%C%H$K1~EzrJV7$F!"$=$N1~ Ez%Q%1%C%H$Khj>uBVA+0\$HCM$N99?7$r9T$&!#%*!<&J$+$i CM$rFI$_=P$9NO!"F10l%V%m%C%/Fb$N0[$J$k%"%I%l%9KJ# ?t$N%W%m%;%C%5$,$[$\F1;~$K%9%H%"$r9T$C$F!"$=1KHb $J$$L58z2=%H%i%s%6%/%7%g%s$,$[$\F1;~$K3+;O5lk3

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3. Ej5!E*=q$-9~$_$r9T$C$?%-%&%C%7%e$,L58z2=5l$?$H$-$3$N;~$O!"L58z2=5l$?%W%m%;%C%5!&f%K%C%H$Khj3+;O5l$?%H%i%s%6%/%7%g%s$O%*!<%J$+$iCM$rF I$_=P$7!"$=7FL58z2=5l$?%-%&%C%7%e$N>uBVA+0\$HCM$N99?7$r9T$&!#$?$@$7!"L58z2=5l$?%-%&%C%7%e$NCM99?7$N;~$K$O!"<+%W%m%;%C%5$,%9%H%"$r9T$C$?%"%I%l%9$K$O=q$-9~$_$r9ToJ$$!5J.4@a;2>H!K#

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5.3.3 %H%i%s%6%/%7%g%s$N<dN`UQ99@)8f

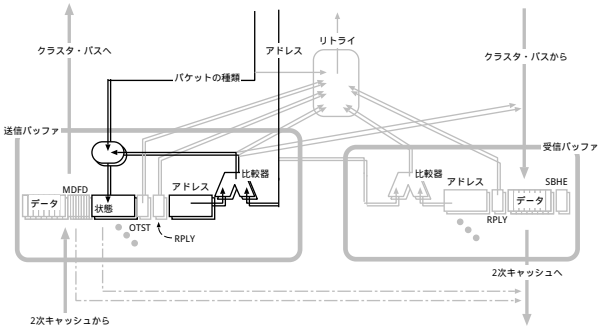
5.2@a$G=R$Y$?$h$&$K!"%H%i%s%6%/%7%g%s$,%/%i%9%Fb$KJD8kH-$O!"2<!%-%&%C%7%e$KEj5!E*$K=q$-9~$^$l$?8e!"%H%i%s%6%/%7%g%s$,4 0N;7?$H$$&3H$,$G$-$k!#=>CF!"L58z2=5l$?$3HN8!=P$O%W%m%;%C%5!&f%K%C%H$NAw?.%P%C%U%!K*$$F9T$&!#

L58z2=5l$?$3HN8!=P$H!"$=lKHb$J$$8e$K>e=q$-5;k?aN@)8f$r?^19$K<($9!#%Q%1%C%H$,Aw?.%P%C%U%!$KB8:_$9kH$-$K%P%9r%Q%1%C%H$,N.$lkH!"Hf3S4o$rMQ$$FAw?.%P%C%U%!$KB8:_$9$k%Q%1%C%H$H%"%I%l%9$,0lCW$9k+I&$+8!=P$9$k!#$b$7!"%"%I%l%9$,0lCW$7!"$+$D%P%9$rN.l?%Q%1%C%H$N<oN`$,%-%&%C%7%e$rL58z2=$9$k%Q%1%C%H$G$"$l$P!"Aw?.%P%C%U%!$K5-O?5l$F$$$k%-%&%C%7%e$N>uBV$rInvalid H9$k!#$3lKhj!"Aw?.%P%C%U%!$KB8:_$9k3$N%Q%1%C%H$,%P%9$KAw=P$5lk:]KO%9%H%"!&_%9$KH<$&$H%i%s%6%/%7%g%s$H7FH/$;$ilk3HKJ$k!#$hCF!"8e$KB>$N%-%&%C%7%e$^$?$O%a%b%j$+$i1~Ez$,JV$j!"1~Ez%Q%1%C%H$r%-%&%C%7%e$K=q$-9~$`$3HG>e=q$-$,9Tol$k!#

$^$?!"3N5!9=$O2<!%-%&%C%7%e$K=q$-9~$s$@$H$-$O%/%i%9%Fb%m!<%+%kG"C?%H%i%s%6%/%7%g%s$r%/%i%9%?4V$K$^$?,$k%H%i%s%6%/%7%g%s$KJQ99$5$;k?aK$bMQ$$$k!#9JoA!"2<!%-%&%C%7%e$K=q$-9~s@H-$Olocal shared {clean/dirty}G"C?NK!"%/%i%9%?!&P%9$KAw=P$5lkA0$Kglobal shared clean KJC?H-!"3N5!9=$rMQ$$F>uBV$rglobal H7$F!"%P%9$KAw=P9k:]KO%/%i%9%?4V%H%i%s%6%/%7%g%sHJkh$&$K@)8f7F$$k!#

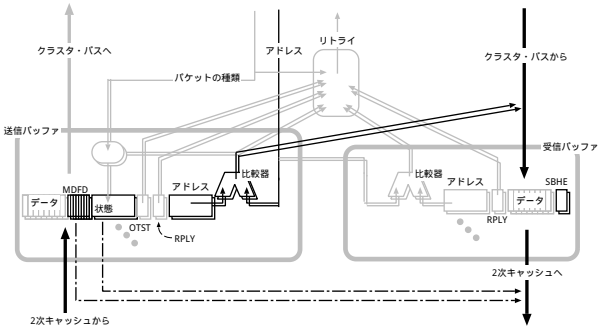
5.3.4 =q$-9~$_J]8n5!9=

5.2@a$G=R$Y$?$h$&$K!"6&M->uBV$,%/%i%9%Fb$KJD8F$$kH-$K!"2<!%-%&%C%7%e$KEj5!E*$K=q$-9~$_$r9TC?8e!"$=$N%H%i%s%6%/%7%g%s$,4 0N;$9k^GO !L58z2=5l$k>l9g$r=|$-!kEv3:%V%m%C%/$N>uBVA+0\5Z$S%9%H%"$r9TC?%"%I%l%9$,JQ2=$7$J$$$h$&$KJ]8n9k!#@h$K=R$Y$?h$&$K%9%H%"!&R%C%H$N%H%i%s%6%/%7%g%s$O%P%9%K%Q%1%C%H$rN.$9$3H,G-$?;~$K%9%H%"$KH<$&$Q%1%C%H$,Aw?.%P%C%U%!$K%Q%1%C%H$r=q$-9~$`$,!"$=$N:]Ev3:%V%m%C%/$N$&A$N$I$N%"%I%l%9$K%9%H%"$r9T$C$?%+$r%b%G%#%U%!$S%C%H$K5-O?$9$k!#%Q%1%C%H$,Aw?.%P%C%U%!$KB8:_$7$F$$k;~$K!"UL%W%m%;%C%5$+$i$N%Q%1%C%H$,%P%9$rN.$l$F!"$=$N%Q%1%C%H$r<u$1<h$k$J$i$P!"<u?.%P%C%U%!$K=q$-9~$`H-$KAw?.%P%C%U%!$KB8:_9k%Q%1%C%H%H%"%I%l%9$rHf3S$7$F!"F10l%V%m%C%/$X$N%Q%1%C%H$,B8:_9kJi$PAw?.%P%C%U%!$NIN%(%s%H%j$H0lCW$7$?$+$rSBHE $K=q$-9~$`!#<u?.%P%C%U%!$+$i2<!%-%&%C%7%e$K=q$-9~$`$H$-$K!"$^$@Aw?.%P%C%U%!$K%Q%1%C%H$,B8:_9l$P%b%G%#%U%!$S%C%H$H>uBV$rAw?.%P%C%U%!$+$iF I$_=P$9!#Aw?.%P%C%U%!$+$iF I$_=P$7$?2<!%-%&%C%7%e$N>uBV$+$i!"Aw?.%P%C%U%!$KB8:_$9kN$,%9%H%"!&R%C%H$KH<$&$Q%1%C%HG"lP!">uBVA+0\$O !L58z2=9k>l9g$r=|$$F$O!K9T$o$:!"$^$?!"%b%G%#%U%!$S%C%H$,$?GF$$k%"%I%l%9KO=q$-9~$_$r9T$oJ!#



?^19: %H%i%s%6%/%7%g%s$N<dN`UQ99@)8f

$$$h$&$KJ]8n9k!#@h$K=R$Y$?$h$&$K%9%H%"!&R%C%H$N%H%i%s%6%/%7%g%s$O%P%9%K%Q%1%C%H$rN.$9$3$H$,$G$-$?;~$K%9%H%"$KH<$&$Q%1%C%H$,Aw?.%P%C%U%!$K%Q%1%C%H$r=q$-9~$`$,!"$=$N:]Ev3:%V%m%C%/$N$&A$N$I$N%"%I%l%9$K%9%H%"$r9T$C$?%+$r%b%G%#%U%!$S%C%H$K5-O?$9$k!#%Q%1%C%H$,Aw?.%P%C%U%!$KB8:_$7$F$$k;~$K!"UL%W%m%;%C%5$+$i$N%Q%1%C%H$,%P%9$rN.$l$F!"$=$N%Q%1%C%H$r<u$1<h$k$J$i$P!"<u?.%P%C%U%!$K=q$-9~$`$H$-$KAw?.%P%C%U%!$KB8:_$9$k%Q%1%C%H%H%"%I%l%9$rHf3S7F!"F10l%V%m%C%/XN%Q%1%C%H$,B8:_$9kJiPAw?.%P%C%U%!NI$N%(%s%H%j$H0lCW7?$+$rSBHE $K=q$-9~$`!#<u?.%P%C%U%!$+$i2<!%-%&%C%7%e$K=q$-9~$`$H$-$K!"$^$@Aw?.%P%C%U%!$K%Q%1%C%H$,B8:_9l$P%b%G%#%U%!$S%C%H$H>uBV$rAw?.%P%C%U%!$+$iF I$_=P$9!#Aw?.%P%C%U%!$+$iF I$_=P$7$?2<!%-%&%C%7%e$N>uBV$+$i!"Aw?.%P%C%U%!$KB8:_$9kN$,%9%H%"!&R%C%H$KH<$&$Q%1%C%HG"lP!">uBVA+0\$O !L58z2=9k>l9g$r=|$$F$O!K9T$o$:!"$^$?!"%b%G%#%U%!$S%C%H$,$?GF$$k%"%I%l%9KO=q$-9~$_$r9T$oJ!#



?^20: =q$-9~$_J]8n@)8f

$^$?!"%b%G%#%U%!$S%C%H$OF10l%V%m%C%/Fb$N0[$J$k%"%I%l%9$KF sDN%W%m%;%C%5$,$[$\F1;~$K%9%H%"$r9T$C$F!"$=lKHbJL58z2=%H%i%s%6%/%7%g%s$r9T$&>l9g$K!"$IAi$+$N%-%&%C%7%e$KN>J}$N%9%H%"$N7k2L$r;D9?aK$bMQ$$$ilk!#5.4@aG3$N;~$NF0:n$N>\:Y$r=RYk!#

5.4 F0:nNc

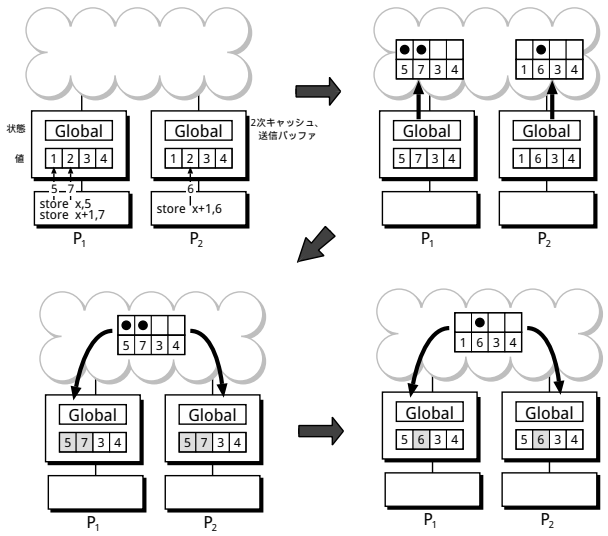
5.3@a$G=R$Y$?5!9=5Z$S@)8fKh$j!"F10l%"%I%l%9$KBP7FJ#?t$N%W%m%;%C%5$+$i%a%b%j!&"%/%;%9$,J5l?H-Kb!"$=$7$FF10U%V%m%C%/Fb$N0[Jk%"%I%l%9KBP7$FJ#?t$N%W%m%;%C%5$+$i%a%b%j!&"%/%;%9$,$J5l$?$H$-$K$b!¥@G=*E*$K$O%-%&C%7%e4V$GL7=b$,@8$8$J$$!W3H$,K~$?5l$F$$$k!#

K\@aGO4vD+$N>u67$K$*$1$kF0:n$KBP7F:G=*E*KOL7=b$,@8$8$J$$3H,K~$?$5lk3H$r<($9!#K\@a$G5s$2$k0J30$N>u67K*$$F$b!"0J2<$G5s2kF0:nNc$HF1MM$J=hM}$,9T$olk3HKh$j:G=*E*$K$OL7=b$,@8$8$J$$3H,K~$?$5lF$$$k!#

6&M->uBV$,%/%i%9?4V$K$^$?$,$kH-$N99?7%9%H%"$N6%9g

$^$:!"%V%m%C%/$N6&M->uBV$,%/%i%9?4VK^$?$,CF$$k>u67$G!"Fs$D$N%W%m%;%C%5$,$[$\F1;~$K99?7%9%H%"$r9TC?;~$N=hM}$NN.lr<($9!#

JUMP-1 GO!"99?7%9%H%"KHbJ$B>$N%-%&C%7%eNCMr99?7$9$kH-$O!"%V%m%C%/FbA4It$NCM$r99?7$9kNGOJ/!"%9%H%"$,9T$ol?%"%I%l%9NCM@1r99?7$9$kh&KJCF$$k!#3N;~$N=hM}$NN.lr?^21$K<($9!#



?^21:%0%m!<%P%k$N>u67$G$N99?7%9%H%"$N6%9g

$^$:!"P_1,%"%I%l%9$x+1$*hSxKBP7$FO"B3E*$K99?7%9%H%"$r9T$!"P_2,%"%I%l%9$x+1$KBP7F99?7%9%H%"$r9T$C$?$H9k!#3N:]!"P_1+iNFsDN%9%H%"$O%^!<%8$5lF!"0lDN%H%i%s%6%/%7%g%s$GB>%-%&C%7%e$N99?7=hM}$,9T$olkH9$k!#

3N%9%H%"KHbJ$!"3F%W%m%;%C%5!"%f%K%C%H$NFs<!%-%&C%7%eOCM,Ej5!E*$K=q$-4 9$($i$l!"B>%-%&C%7%e$r99?7$9$k$?$a$N%Q%1%C%H$,Aw=P5l$k!¤3^210lCJL\1&!K#$3$N%Q%1%C%H$KO!"%V%m%C%/FbNI$N%"%I%l%9$KBP7F%9%H%"$,9T$ol?;~+$,5-O?$5lF$$k!●0u!K#

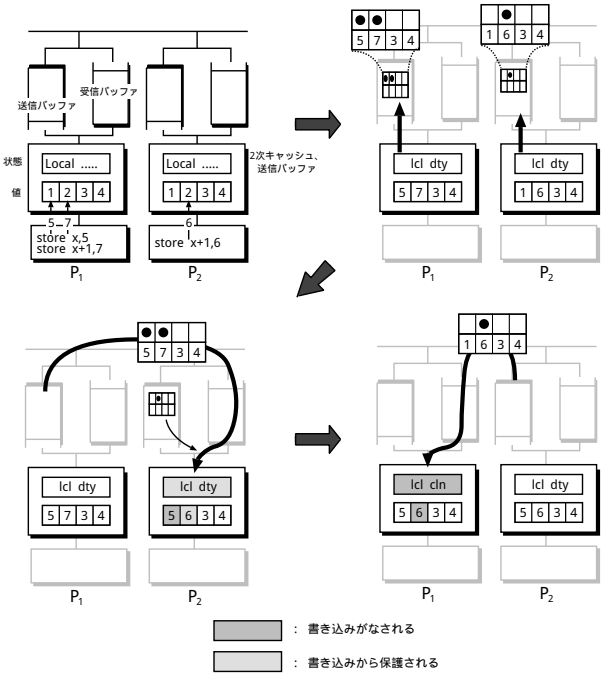
$=$N8e!"FsDN%H%i%s%6%/%7%g%s$,%7%j%"%i%$:5l$k!#$IAi$N%H%i%s%6%/%7%g%sb6&M->uBV$,%/%i%9?4V$K$^$?$,$C$F$$k;~$N%9%H%"$KH<$&%H%i%s%6%/%7%g%s$G$"$k$+$i!"5.2@a$G=R$Y$?$h$&$K%7%j%"%i%$:$5l?8eI,$:A4It$N%-%&C%7%e$r>e=q$-9k!#3N;~P_1+iN%H%i%s%6%/%7%g%s$,!¶h!W$KJC$?$H9k$H!"N>J}$N%-%&C%7%eKP_1$+$i$N%9%H%"$KH<$&99?7%Q%1%C%H$,E~C#9k!#$=$7$F!"%Q%1%C%H$NCf$K5-O?$5lF$$k!¤9%H%"$,9T$ol?%"%I%l%9!W$rMxMQ$7$F%-%&C%7%e$NCM$r99?7$9$k!Ø^21FsCJL\:8!K#$=$N8e!"$P_2$+$i$N99?7%Q%1%C%H$bE~C#9k!#3N%Q%1%C%H$,E~C#$7$?;~$-$bF1MM$J=hM}Kh$j=q$-9~$_$,9Tolk!Ø^21FsCJL\1&!K#

0J>e$N=hM}$NN.lKhj!"?^21$K<($9h&$K:G=*E*$K$ON>J}$N%-%&C%7%e4V$KL7=b$O@8$8$J$$!#

6&M->uBV$,%/%i%9?Fb$KJD8kH-$N99?7%9%H%"$N6%9g >e

$G=R$Y$?;h$&$K!"99?7%9%H%"$KH<CFB>%-%&C%7%e$r99?7$9kH$-$O%V%m%C%/A4ItNCMr=q$-4 9$(kNGOJ/!"%V%m%C%/Fb$N%9%H%"$r9T$G;?%"%I%l%9$@$1=q$-4 9$($k!#3l$O6&M->uBV$,%/%i%9?4VK^$?;~,$C$F$$h$&$K$^$?;~,CF$$h$&$KJD8F$$k$&$KJD8F$$h$&$,F1$8$G$"$k!#

6&M->uBV$,%/%i%9?4V$K$^$?;~,CF$$kH-$H%/%i%9?Fb$KJD8F$$kH-HG0[JkNO!"Ej5!E*=q$-9~$_$r9T$C$?%-%&C%7%e$KBP9k>e=q$-r$9k+7J$$+G"$k!#$9Jo$A!"%/%i%9?4V$K$^$?;~,CF$$kH-$O>e$G=RY?h$&$K%7%j%"%i%$:$5l?8eI,$:A4It$N%-%&C%7%eKBP7$F>e=q$-$r9T$&$,!"0lJ}!"%/%i%9?Fb$KJD8F$$kH-$O5.2@a$G=RY?h$&$K!"Ej5!E*$K=q$-9~$_$,9Tol$?%-%&C%7%e!¤&V%m%C%/$N>uBVA+0\$*hS$=$N%V%m%C%/Fb$N%9%H%"$,9Tol$?%"%I%l%9$NCM$N99?7$,J]8n5l$k!#



?^22:%m!<%+%k$N>u67$G$N99?7%9%H%"$N6%9g

6&M->uBV$,%/%i%9?Fb$KJD8F$$kH-KFsD$N%W%m%;%C%5$+i[$\F1;~$K99?7%9%H%"$,9T$ol?>$N=hM}$NN.lr?^22$K<($9!#@hNNcHF1MMKP_1$,%"%I%l%9$x+1$*$h$Sx+1$KBP7FO"B3E*$K99?7%9%H%"$r!"P_2,%"%I%l%9$x+1$KBP7F99?7%9%H%"r=l>$l9T$S!"5i$K!"$P_1$+$iNFsD$N%9%H%"$O%^!<%8$5$l$F!"0l$D$N%H%i%s%6%/%7%g%s$GB>%-%&C%7%e$N99?7=hM}$,9TolkH9k!#

$^$:!"$=$l$>$l$N%9%H%"$KHbJ!"3F%W%m%;%C%5!¤f%K%C%H$NFs<!%-%&C%7%e$KBP7FE.j5!E*$JCM99?7$H>uBVA+0\$,9Tol$k!#$=lHF1;~$KAw?.%P%U%!$KB>%-%&C%7%e$r99?7$9k?

aN%Q%1%C%H$,=q$-9~$^$1$k!#$3$N;~Aw?.%P%C%U%!$NMDFD %U%#!<%k%I!Ø^13;2>H!K$K%V%m%C%/Fb$NIN%"%I%l%9$K%9%H%"$,9Tol$?$+$bF1;~$K5-O?5l$k!Ø^220lCJL\1&!K#

3N8e!"IAi+$N%W%m%;%C%5!&f%K%C%H$+$i%Q%1%C%H$,%P%9KBP7$FAw=P$5lk!#:#!"P_1+iN%Q%1%C%H$,@h$KAw=P5l$?$H9k!#3N%Q%1%C%H$,$P_2$N<u?.%P%C%U%!$KFO$$?H-!"?^20$N5!9=$rMQ$$FP_2NAw?.%P%C%U%!$r8!:w$9kHF10l%V%m%C%/XN99?7%Q%1%C%H$,B8:_$7$F$$k3H$,J,$+$k!#$3N?a!"P_1+iN99?7>pJs$r2<!%-%&C%7%e$K=q$-9~$':]$K%-%&C%7%e!&%V%m%C%/$N>uBVA+0\$H%"%I%l%9x+1$NCM99?7$O9ToJ$$!Ø?$@$7!"%"%I%l%9x$NCM99?7$O9T$&!#K#

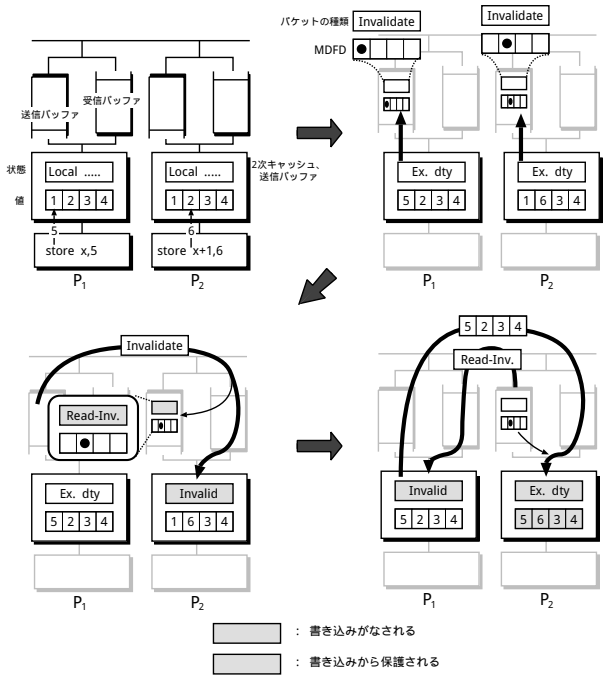
$=$N8e!"P_2+$i%Q%1%C%H$,Aw=P5l$k!#$3$N%Q%1%C%H$,P_1KFO$$?H-KO!"P_1NAw?.%P%C%U%!KO4{$K99?7%Q%1%C%H$OB8:_7F$$J$$NGP_1$N2<!%-%&C%7%e$KBP7F$CDI>o$N99?7=hM}!"9JoAlocal clean XN>uBVA+0\$H%"%I%l%9x+1$NCM99?7$,9Tol$k!#

0J>e$K<($9N.1Khj!":G=*E*$K%-%&C%7%e4V$GL7=b$,@8$8$F$$$J$$3H,J,$+$k!#

6&M->uBV$,%/%i%9?Fb$KJD8kH-$NL58z2=%9%H%"$N6%9g

FsDN%W%m%;%C%5$+$i$[$\F1;~$KF10l%V%m%C%/Fb$N0[Jk%"%I%l%9$XL58z2=%9%H%"$,9Tol$?$H$-$K$O!"$IAi$+$N%W%m%;%C%5!&f%K%C%H$N2<!%-%&C%7%e$KN>J}$N%9%H%"$N7k2L$r;D$9$?a$N=hM}$,$J5l$k!#

3N$?a$KJUMP-1 K*$$F$O!"5.3.29'$N:G=*7k2L$N>e=q$-@)8f$d5.3.39'$N%H%i%s%6%/%7%g%s$N<oN'JQ99@)8f!"$=7F5.3.49'$N=q$-9~$_J]8n5!9=$r%U%k3hMQ7F$$k!#=hM}$NN.$l$r?^23$K<($9!#



?^23: %m!<%+%k$N>u67$G$NL58z2=%9%H%"$N6%9g

P_1,%"%I%l%9x KBP7$FL58z2=%9%H%"$r!"P_2,%"%I%l%9x+1KBP7$FL58z2=%9%H%"$r$=$l$>$l9T$G?$H9k!#$^$:!"$=$l$>$l$N%9%H%"$KHb$J$$!"3F%W%m%;%C%5!&f%K%C%H$NFs<!%-%&C%7%e$KBP7FEj5!E*$JCM99?7$H>uBVA+0\$,9Tol$k!#$=1HF1;~$KAw?.%P%C%U%!$KB>%-%&C%7%e$rL58z2=$9k?a$N%Q%1%C%H$,=q$-9~$^1k!#3N;~Aw?.%P%C%U%!$NMDFD %U%#!<%k%I!Ø^13;2>H!K$K%V%m%C%/Fb$NIN%"%I%l%9$K%9%H%"$,9Tol$?$+$bF1;~$K5-O?5l$k!Ø^230lCJL\1&!K#$3$3$^GO!"%V%m%C%/$N6&M->uBV$,%/%i%9?FbKJD8$F$$$kH-KFsD$N%W%m%;%C%5$+$i99?7%9%H%"$,9Tol$?$H$-$H$[$\F1$8N.$1$G=hM}$5lk!#

3N8e!"P_1+$i%Q%1%C%H$,%P%9$KN.$1FP_2$KFO$$?H-!"2<!%-%&C%7%e$rL58z2=$9k,!"3N:]K^19N5!9=$rMQ$$F!"P_2NAw?.%P%C%U%!$+$iH/$;$i1k%Q%1%C%H$N<oN'$rJQ99$9$k@)8f$,9T$olk!#3N%Q%1%C%HJQ99@)8fKh$j!"$P_2$+$iH/$;$i1k%Q%1%C%H$OL58z2=%9%H%"$,9T$-%&C%7%e!&_%9$7$?:]$KH/$;$i1k%Q%1%C%H!"9JoAI=6$K<($9%h$&$KL58z2=7sFI$_$@$7%H%i%s%6%/%7%g%s$N$?a$N%Q%1%C%HHJ$k!Ø^23FsCJL\1&!K#

$=$N8e!"P_2+$i%Q%1%C%H$,H/$;$i1k!#$?$@$7!"$3$N%H%i%s%6%/%7%g%s$O1~EzrMW9k?a%Q%1%C%H$rAw=P$7$FbAw?.%P%C%U%!$N%(%s%H%j$r2rJ|$7$J$$!#P_2+iN%Q%1%C%H$,$P_1$KE~C#$9kH!"P_1N%-%&C%7%e$OL58z2=$5$1$k$HF1;~$KP_2KBP7F1~EzrJV9!#$=$7$F!"1~Ez$,P_2KFO$/$3HKhj:G=*7k2L$N>e=q$-$,9T$olk!5J.3.29';2>H!K#$?@$7$3$N:]P_2N%9%H%"$N7k2L$b%-%&C%7%e$K;D$9$?a$K!"5.3.49'$G=R$Y$?$h$&$KAw?.%P%C%U%!$KB8:_$9$k%b%G%#%U%!$S%C%H$rMxMQ$9$k!#$9Jo$A!"1~Ez$,P_2KJVCF$-$?H-%V%m%C%/$A4BN$NCM$r=q$-4$9($kNGOJ$/!"%b%G%#%U%!$S%C%H$,N)$C$F$$k%"%I%l%9NCM$O=q$-4$9($J$$!Ø^23FsCJL\1&!K#

0J>e$K<($9=hM}$NN.$lKh$j!"$P_1,P_2$NN>J}$N%9%H%"$N7k2L$,P_2N%-%&C%7%e$KB8:_$9$k3$H$,J,$+$k!#

6&M->uBV$,%/%i%9?4V$K$^$?,kH$-$NL58z2=%9%H%"$N6%9g

3N;~$O6&M->uBV$,%m!<%+%k$N;~$H$[$\F1$8N.$1$G9T$olk!#0[JkNO"%H%i%s%6%/%7%g%s$NJQ99@)8f$,9Tol$J$$3HG$"$k!#D^$j!"6&M->uBV$,%m!<%+%k$N;~$OE*=q$-9~$_$r9T$C$?-%&C%7%e$,L58z2=$5$1l?H-N_:G=*7k2L$r>e=q$-9kh&$K!"?^23FsCJL\1&!K<($9h&$KL58z2=$5$1$?3H$r8!=P$7$F%H%i%s%6%/%7%g%s$N<oN'$rJQ99$9$k@)8f$,9Tol$k!#0lJ}!"6&M->uBV$,%0%m!<%+%k$N;~$OE*=q$-9~$_$r9T$G$?-%&C%7%e$,L58z2=$5$1h&$,$,l?H-N_:G=*7k2L$r>e=q$-9k$?a%Q%1%C%H$,=q$-4$9lk!#

6 $*$ojK

K\9FGO!"A+0\E*L7=b$rH<$&0l4S@-@)8fJ}<0G"$kTIS-CC $r<($7!"3NJ}<0$ND6JBNs7W;;5!JUMP-1 KBP9$k<BAuNc$r=RY?!#

4.2@a$G=R$Y$?$h$&$K!"TIS-CC $O=>MhJ}<0$KBP7F!"%W%m%0%i%^%S%j%F%#rFq7/9k3HJ/@-G=8~>e$,4|BT$G$-!"$5iK4|BTG-$k@-G=8~>e$O:#8e5;=Q$N?JUb$KhjH/E8$,8+9~$^1k!"5,LO$,Bg$-$JUBNs7W;;5!$[$I82Cx$G$"$k3H$,M=A[$5$1$k!#

0lJ}$G!"TIS-CC Oh$j@-G=8~>e$rL\;X9H<BAu$3$9H,9b$/$Jk?a!"8=:_$^$G3NJ}<0$r<BAu7?7W;;5!O[HsIJ$$!#7$+$7!"JUMP-1 K*1k<BAuNc$G<($7$?$h$&$K!"<BAu$3$9HO7h7FHs8=<BE*JbNGOJ$$!#JUMP-1 K*1k<BAuNc$r:#8e$N7W;;5!3+H/$N:]$N;29MH7!"?tB?$/$N7W;;5!KBP7$F<BAu$9k3HG!"<BAu5;=Q$N3NN)$OJ5$1$kbN$H9M$($k!#

:#8e$N2]Bj$H7F$O!"TIS-CC $N<BAu5;=Q$r3NN)9k3H$H!"TIS-CC $N87L)$J@-G=I>2A$r9T$&3H$,5s$2i1$k!#

<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$$?$@$$?CfEg9@=u65<x!"?9bC0lO:=u65<x!"8^Eg@5M5=u<j$K?<$/46<UCW7^$9!#

5i$K!$6&F18&5f<TG"$k=.K\0l5W;a!";3K\9M?−;a$rO8aH7F!$F|:"$+$i8fJ\Z%2<$5C?5~E1Bg3XBg3X1!9)3X8&5f2J>pJs9)3X65<<IYED8&5f<<$N=t7;$K46<UCW7^$9!#

;29MJ88%

[1] John L.Hennessy,David A.Patterson !JYEDbC<#!"B<>eOB>4!"?7Ui<#CKLu!K !¥3%s%T%e!<%?!&"!<%−%F%/%A%c!WF|7PBP<R 1992 G/12 7n

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