HFMQD6JBNs OS *SSS–CORE* K*1k%9%1%8%e!<%j%s%0J}<0

?.9q M[Fs0!†† >> K\ >0† J? LZ 7I†

NUMA 4D6-$GJBNs%W%m%;%9$N8zN(E*$J<B9T$rK8$2$k3HJ/%^%k%A%f!<%6!&%^%k%A%8%g%V4D6-$r9=C[$9kK$O!$%a%b%j%Z!<%8JI$N<B;q8;$N;HMQ>u67$r9MN8$7!$M-8z$K;HMQ9k%9%1%8%e!<%j%s%0$r9T$J$$!$%7%9%F%`A4BN$N@-G=$r$"$2$k$3$H$,I,?\$G$"$k!%K\O@J8$G$O!$JBNs%W%m%;%9Kh$K=jM-$9$k<B$Z!<%8>pJs$rMxMQ$7$?%9%1%8%e!<%j%s%0J}<0!$$*$h$S%Z!<%8$NJ,N`$K4p$E$$$?%Z!<%8CV49J}<0$rDs0F$9$k!%99$K!$Ds0F$7$?J}<0$r>\:Y3NN(%b%G%k>e$G!$6qBNE*$J%a%b%j4IM}J}<0!$%"%/%;%9IQEY$*$h$S%"%/%;%9%3%9%H$rIU2C7?%7%_%e%l!<%7%g%sKh$jMM!9$J;HMQ>u67$N2<$GI>2A9k!%I>2A$N7k2L!$<B%a%b%j$N6I=j@-$rMxMQ7?%9%1%8%e!<%j%s%0J}<0$H!$CV49$9$k%a%b%j$rJ,;66&M-%a%b%j%b%G%k>e$N%Z!<%8B0@-$rD>@\MxMQ$9$kJ}<0$,M%l?@-G=$rM?$(k3H,<(5l$?!%

Scheduling Mechanisms for scalable parallel OS *SSS–CORE*

Yojiro Nobukuni,†† Takashi Matsumoto† and Kei Hiraki†

Preventing parallel processes from unexpected inefficiencies is a major concern for constructing multiple user/multiple job environment in NUMA systems. Systems can achieve higher performance by using scheduling policies which reflect resource consumption states. For a general environment, which must support concurrent execution of multiple processes, a way is needed to keep systems' effectiveness when physical memories are full. In NUMA systems, memory pages can be classified by access frequencies and required costs for accesses when target pages are not found locally. Selecting victim pages according to the classification enhances system performance. We built a probabilistic model with a concrete memory management scheme and differentiated memory access costs, and simulated processes sets with given access frequencies. The paper describes an evaluation of scheduling policies using resource information for each process and of page replacement policies based on page coloring under the model.

1. $O $8 $a $K

NUMA 7?%7%9%F%`$O!$0B2A$J9=@.MWAG$rB??t7k9g$9$k$3$H$K$h$j!$Bg5,LO$J%7%9%F%`$r9=C[$7!$9b$$=hM}G=NO$rF@$k3H$,$G$-$kFCD'$r;}$D!%6aG/$N%M%C%H%o%"%/<~JU$N@-G=8~>e$rGX7J$K!$JBNs%"%W%j%1!<%7%g%s$N$?$$N<B9T;Y1g5!9=[6]$dJBNs4D6-2<$G$N3F<o:GE,2=5;K!$N8&5f3+H/[9)8)] Kh$j NUMA 7?JBNs7W;;5!>e$G$N9b8zN($J<B9T7ABV$,2DG=$HJCF-$?!%$7$+$7J,$i!$HFMQ@-$r%k%A%8%g%V!&%^%k%A%W%m%;%9$H$$$&;HMQ7ABVK*$$$F$O?t$NJBNs%"%W%j%1!<%7%g%s$N9b8zN($J<B9T$r<B8=$9kaKO!$8D!9$N%W%m%;%9K*1k8zN(2=$d:GE,2=5;K!$@1GJ/!$%*%Z%l!<%F%#%s%0%7%9%F%`%l%Y%kKh$k%a%V$*hS%W%m%;%9$r8Y$C$?9b8zN(2=$,IT2D7gG"$k!%

;~J,3d$rMxMQ$7$?JBNs4D6-8~$1$N%9%1%8%e!<%j%s%0J}<0$H7F$O gang scheduling $NM%0L@-$,Js9p$5$1$F$$$k[1)]$,%W%m%;%9C1BN$N<B9T@-G=$r9MN8$7$?>l9g!$F14|BTAr6KNO8:i9$3$H$,2DG=$J gang scheduling $OM-8z$G$"$k!%7+7J$,$i!$ gang scheduling $O;~4VE*%9%1%8%e!<%j%s%0$r2r7h9k$@$1G"$j!$%W%m%;%C%53djIU1$NLdBj$O2r7h7J$$!%;q8;>pJs$rMxMQ$7$J$$ matrix algorithms[5)] $O!$%W%m%0%i%`<B9TC10L$N%W%m%;%C%5$X$N3#%C%T%s%0$K$*$1$k%R%e!<%j%9%F%#%C%/%9$KMj$k!%$=N?$a;q8;$N@jM->u67$rL5;k$7$?%^%$%0%l!%$7%g%s$d!$processor fragmentation $,@-G=Dc2<$N860xHJ$k!%$^$?%a%b%j$X$N%"%/%;%9$3%9%H$,5wN%$KhC$F0[$J$k NUMA 7?JBNs7W;;5!$G$O!$%9%1%8%e!<%j%s%0$K<B;q8;$N;HMQ>u67$dDL?.%3%9%H$rH?1G5;k3HKhj%3%9%H$N9b$$%"%/%;%9$r8:>/$5$;$k9b8zN(2=$,I,?\$G$"$k!%

† E15~Bg3XBg3X1!M}3X7O8&5f2J>pJs2J3X@l96
Department of Information Science, Faculty of Science, University of Tokyo
†† %"!<%D%F%C%/!J3t!K
Arts Tech Inc.

†y 0J2<!$$H$/$K=RYJ$$8B$j!$JBNs%W%m%;%9$rI=$9

;q8;>pJs$rMxMQ$9$kJ}<0$K!$=8Cf5-217?JBNs7W;;5!% 8~$1$N cache affinity J}<0[7] $,$"k,!$MFNL$N>.5J %-%c%C%7%eGO8z2L$,=P$J$$!%0lJ}!$Bg5,LO NUMA 7?%7%9%F%`$K$*$$$F$O!$;q8;4V$N5w JBNs7W;;5!>e$G6(D4$7$?;q8;4IM}$r9T$J$&$K$O!$3HD%@N<+A3$JI=8=!$;q8;4IM}$KMQ$$$k;q8;NL$N@)Ls$*hd4IM}8zN($NE@$+$i3,AX2=$5l?OHAH$rIU2C$9k3H,q8;>pJs$r4IM}$9k?aN%*!<%P!<%X%C%I$r9MN8$9$k I,MW$G$"$k!%3,AXE*$J%9%1%8%e!<%j%s%0$r9TJ&bN$K DHC[4] $H Intel Paragon[2] $,$"$k!% DHC $O Buddy %7%9%F%`$Khk3,AX2=4IM}$r9T$$!$%i%&%s%I%m%S%s$N%M K\$H9k$,!$%W%m%;%9?t$K4p$E$$$?Ii2YNJNMx[3] MQ$KN1$^CF$$$k!% Paragon GO=@Fp$J%W%m%;%C%5%W 3d$,2DG=G"k,!$;q8;>pJs$OMxMQ$;$:!$$^$?3F%W%m %;%C%5>e$G$N%9%1%8%e!<%j%s%0$O%+!<%M%k$@$1$,<B9T k?$a=@Fp@-$r;}$?$J$$!%

K\O@J8GO!$3,AX2=$5l?Bg5,LO NUMA 4D6-K*$$ 1kHFMQ$G9b8zN($J%9%1%8%e!<%j%s%0$*$h$S%Z!<%8CV49 J}K!$r5a$a!$I>2A9k!%$^$:!$Bh#2@a$GHFMQD6JBNs$* %l!<%F%#%s%0!&%7%9%F%` SSS–CORE[10] $K$*$1$k%9%1 %8%e!<%j%s%0J}<0$N35N,!$$9$J$o$A!$3,AXE*$K;q8;NMx $r4IM}$9$k;q8;4IM}LZ!$<B%Z!<%8>pJs$rMxMQ$7$?%9%1 %8%e!<%j%s%0J}<0$J$i$S$K!$%a%b%j%Z!<%8$NJ,N`Kh$k %?%Z!<%8CV49J}<0$r<($7!$Bh#3@aGO%9%1%8%e!<%j%s %N%7%_%e%l!<%7%g%s%b%G%k$r<($9!%Bh#4@aK*$$$F$k iN%7%_%e%l!<%7%g%sKh$kI>2A$r<($9!%:G8e$KBh#5@a G^Ha$k!%

2. SSS–CORE K*1k%9%1%8%e!<%j%s%0J}<0

SSS–CORE[10] $O NUMA 7?JBNsJ,;67W;;5!$rBP>] H7$?HFMQD6JBNs OS G"$k!%;~J,3d $H%Q!<%F%#%7%g %K%s%0$rJ;MQ7?%^%k%A%f!<%6!&%^%k%A%8%g%V4D6- 9bB.DL?.4D6-$rDs6!$7!$JBNs%"%W%j%1!<%7%g%s$N8z $$<B9T$N<B8=$rL\E*H9$k!%

NUMA 7?$NJBNs7W;;5!%7%9%F%`$G$O!$%a%b%j%"%/%4 %9%3%9%H$*$h$SDL?.%3%9%H$,$=$N5wN%$K1F6A$5$l!$9T %a%b%j%"%/%;%9$HDL?.$NF14|XN8z2L$,Bg$-$/<B9T8zN($K1F6A9k!%=>CF!$JBNs%"%W%j%1!<%7%g%s$N<B9T8zN $r8~>e$9kK$O!$3F%9%l%C%I$rF1;~$K%9%1%8%e!<%j%s $7!$3djEvFil$?MWAG%W%m%;%C%54V$N5wN%$r:G>.2= $7!$<B9T;~$N%a%b%j%Z!<%8$N0\F0$r:G>.8B$KM^$($k9k $,5a$ail$k!%

$=$l$r;Y1g$9k?$a SSS–CORE GO!$%f!<%6$H%+!<%M %M%k4V$GBg0hE*;q8;>pJs$r3,AX2=7F4IM}$7!$;q8;$N Js$N<uEO7N$?aN5!9=$H7F;q8;4IM}LZ$rMQ$$$k SSS–CORE GO3N5!9=$rMxMQ$7!$<B%a%b%j$N;HMQ >u67$N%9%1%8%e!<%j%s%0$X$NH?1G!$%f!<%6$+$i$N%9% %8%e!<%j%s%0@)Ls$NMxMQ$r2<5-$K<($9J}K!$G<B8=7F$

2.1 SSS–CORE $N;q8;4IM}5!9=

Bg5,LO$J NUMA 7?%7%9%F%`$K$*$$$F$O!$;q8;4V$N5w N%$N<+A3$JI=8=!$;q8;4IM}$KMQ$$$k;q8;NL$N@)Ls$*$h $H$q8;>pJs$r4IM}$9$k$?$a$N%*!<%P!<%X%C%I$r9MN8$9$k $K$K3,AXE*$J;q8;4IM}$,I,?\$G$"$k!%3,AX2=$5$l$?;q8; 4IM}$r<B8=$9$k$?$a!$ SSS–CORE $G$O2>A[E*$J;q8; 4IM}LZ9=B$$rMQ$$$k!%K\O@J8$G$O$3$l$r;q8;4IM}LZ$H8F $V!%;q8;4IM}LZ>e$G$O%7%9%F%`A4BN$N;q8;>pJs$*$h$S!$ %W%m%;%9Kh$N;q8;$N;HMQ>u67Ey$r4IM}$9$k!%;q8;4IM}LZ $N9=B$$r<B%7%9%F%`$N9=@.$KE,1~$5$;$k$3$H$G!$MM!9$J 0[B9=B$$r;}$D%7%9%F%`$r%5%]!<%H$9k3H,2DG=G" $k!%Nc$($P3,AXE*$K@\B3$5$l$? %o!<%/%9%F!<%7%g%s%/%i $9%? K*$$$F$O!$;q8;4IM}LZ$OMWAG=hM}AuCV4V$N5wN%$r $VA3$KI=8=9k!%$^$?!$%a%C%7%e7k9g$ND6JBNs7W;;5!$K $*$$$F$OMWAG=hM}AuCV4V$N5wN%$r6a;wE*$KI=8=9k!%$3 liNNcG$O!$2>A[E*$J;q8;4IM}LZK*1k%N!<%I4V5w N%$,!$3d$jEvFr9TJ&MWAG=hM}AuCV4V$NDL?.%3%9%H$r b9k3HKhj!$DL?.%3%9%H$r9MN8$7$?%9%1%8%e!< %j%s%0$r2DG=$H7F$$$k!%

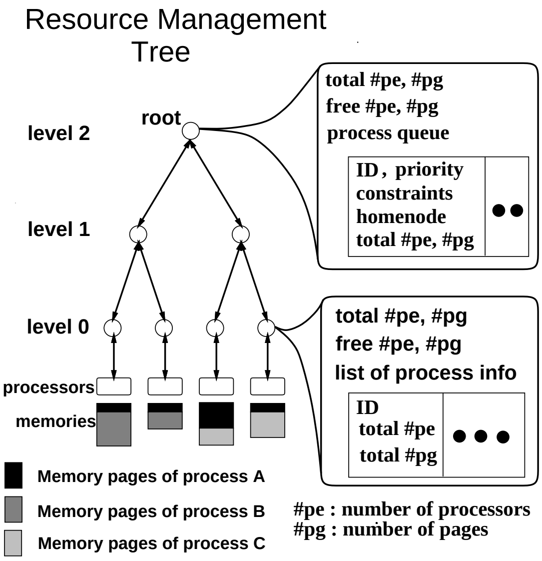
;q8;4IM}LZGO3F%N!<%IKh$KEv3:%N!<%I$r%k!<%HH9 k1J,LZ$NNN0h$K4^$^$l$kMWAG%W%m%;%C%5$H<B%Z!<%8$N Am?t!$%U%j!<$JMWAG%W%m%;%C%5$H<B%Z!<%8$NAm?t!$$J$i SK%W%m%;%9Kh$N ID $H;HMQ$7$F$$$kMWAG%W%m%;%C%5$H <B%Z!<%8$NAm?t$r5-O?$9$k!%$^$?%k!<%H%N!<%I$O3NB> $K!$%W%m%;%9Kh$K%9%1%8%e!<%j%s%0@)Ls!$M%@hEY!$%[!< %`%N!<%I!J8e=R!K$rJ];}9k!%?^ 1 $K 4 %W%m%;%C%59=@. K*1k;q8;4IM}LZ$r<($9!%

2.1.1 %9%1%8%e!<%j%s%0@)Ls

8=:_$NJBNs2=%3%s%Q%$%i$O!$C10l$N%W%m%;%9$,;q8;$r 0[MI$7$F<B9T$9k3Hr2>Dj7F$$$k$?$a!$B?$/$N%W%m %;%9$,;q8;$r6&M-$9$k%^%k%A%f!<%6!&%^%k%A%8%g%VHFMQ 4D6-GO%3%s%Q%$%k;~$N2>Dj$+$i0oC&9k3HKh$k<B T?8zN($NDc2<$,8=lk!%%9%1%8%e!<%j%s%0@)Ls$O!$%W %m%;%9$,%+!<%M%k$K;q8;XNM_5arEA($k!%%9%1%8%e!< %j%s%0@)Ls$NNcH7$F!$Bf?t8GDj@)LsGO%W%m%;%9$O $+!<%M%k$KBP7F<+J,$,I,MW$H9kMWAG%W%m%;%C%5?t$r l=$j?t;XDj9k!%$^$?Bf?t2DJQ@)LsGO>/7:$D%W%m%; %9$KMWAG%W%m%;%C%5$r3djEvFk3H,2DG=HJ$k!%Nc $($P==J,$JJBNs@-$,$"$k$?$a$K2DJQ$J%W%m%;%C%5Bf?t$K $1~$7$F%W%m%0%i%`$5l?%W%m%;%9KBP7FO!$$3$N@) Ls$,M-8z$KF/$/!%:#2s$N%7%_%e%l!<%7%g%s$G$O%W%m%;%9 $NJBNsEY$OJQ2=7J$$$N$G!$%9%1%8%e!<%j%s%0@)LsH7 FOBf?t8GDj@)Ls$rMQ$$$k!%

2.1.2 %9%1%8%e!<%j%s%0M%@hEY

%$%k%A%8%g%V!&%^%k%A%W%m%;%9$r<B8=$9$kHFMQ%*%Z



?^ **1** ;q8;4IM}LZ
Fig. 1 Resource Management Tree

I= **1** M%@hEY7W;;N?aN78?t$NCM
Table 1 Coefficients for priority calculation

M%@hEY7W;;MQ78?t	CM
C_p	1.0
C_m	0.005
C_{wp}	1.0
C_r	1.0

%l!<%F%#%s%0%7%9%F%`$G$O!$3F!9$N%8%g%V!&%W%m%5%9 $,!$=E$_IU$1$5$l$?;q8;MxMQNL$J$I$r4p=`K7$FF1$8M% @hEYHJkh$&!$8xJ?@-$r;}$C$?%9%1%8%e!<%j%s%0$r9T J&3H$,5a$ail$k!%JBNs<B9T$N8zN(2=$rL\E*$H7? %9%1%8%e!<%j%s%0!$%9%1%8%e!<%j%s%0@)Ls$K4pE/%9 %8%e!<%j%s%0$O!$3F%W%m%;%9Kh$N8zN($K1hCF;q8;3d$ EvFr9TJ&$?$a!$%W%m%;%94V$N8xJ?@-$rJ]$?$J$$!% *SSS–CORE* GO@jM-;q8;NL$H%9%1%8%e!<%j%s%0@)Ls$N 6/EY$r4p$K%9%1%8%e!<%j%s%0M%@hEY$r7W;;$7!$M%@hE BP$7$F%(!<%8%s%0$r;\$9$3$HKh$j!$%9%1%8%e!<%j$ K*1k%W%m%;%9$N8xJ?@-$rJ]$D!%

M%@hEYOCM,>.$5$$$[$I9b$$!%$^$:0J2<NCMr7W;;$9 $k!%

- ;HMQ7?;q8;NL!'
  $U_r = C_p *$;HMQ%W%m%;%C%5Am?t $+$
  $C_m *$;HMQ%Z!<%8Am?t
- @)Ls>r7o$N87$7$5!'
  $R_c =$ MW5a%W%m%;%C%5Bf?t/Am%W%m%;%C%5?t
- @)Ls>r7o$NK~B-EY!' $S_c = 0$ *or* 1
- L5BLK7$?;q8;NL!'
  $W_r = C_{wp} * nwp *$
  MW5a%W%m%;%C%5Bf?t/Am%W%m%;%C%5?t
- BT$A%W%m%;%9$NM-L5!' $f_w = 0$ *or* 1
- <cJV$j7O?t!' C_r

$3$3$G!$ nwp $OD>A0$N;~J,3d$G;HMQ$5lJ$+$C$?M% %W%m%;%C%5$N?t$G!$D>A0$^$G%9%1%8%e!<%k5l$F$$$?%W %m%;%9$N4V$G2C=EG[J,7?CM$r%Z%J%k%F%#!<$H$9 $k!%$3liNCMr!J0lIt$O%W%m%;%9Kh$K!K7W;;9k$

<!$N<0$Khj$=$N%W%m%;%9Kh$NM%@hEY$N%(!<%8%s%0CM$, 5a$ail$k!%

$$aging = (U_r R_c S_c + W_r) f_w * t - C_r(1-t)$$

%W%m%;%9<B9T$O!$%?%$%`%9%i%$%9;~$K%9%1%8%e!<%k$5$l k+!$$5lJ$$$+$$$:l+N?$a!$ $t = 0$ *or* 1 G"$k!%

$^$?!$M%@hEY$NCM$NH/;6$rKI$.8xJ?@-$r<B8=9k$? $a!$D>A0$^$G%9%1%8%e!<%k5l$F$$$?%W%m%;%9$NM%@hEY $NAmOB$r!BTA>uBV$@$C$?%W%m%;%9$K%(!<%8%s%0NLH7 $F6QEy$KJ,G[9k!%

@-G=I>2A;~$N%7%_%e%l!<%7%g%s$G$O3F78?t$NCMH7 $F!$I= **1** K"kCMrMxMQ7?!%I= 1 GO!$MWAG%W%m%;%C %5%#1Bf$H%a%b%j 200 %Z!<%8$r;HMQ$9k3H,Ey2AG" k C_{wp}, C_r $OK\O@J8$K$*$1$k%7%_%e%l!<%7%g%s$K$* $$$FBg$-$J@-G=:9$r@8$^$J$$$?aK C_p $HF1$8CMH7 $?!%

2.2 *SSS–CORE* $N%9%1%8%e!<%j%s%0@oN,

SSS–CORE $O!$%f!<%6H+!<%M%kJ,N%$N 2 %1%Y%k%9 %1%8%e!<%j%s%0$r:NMQ$9$k!%%+!<%M%k%9%1%8%e!<%i$O3F %W%m%;%9$,Ds<($9$k%9%1%8%e!<%j%s%0@)Ls!J2.1.1@a!K$H M%@hEY$K=>CF;q8;$r!$3,AX2=4IM}5l$?;q8;>pJs$r$b HK%W%m%;%9C10L$K3d$jEvFk!%3F%W%m%;%9$O%+!<%M%k %9%1%8%e!<%i$Khj3djEvFil$?;q8;$r%f!<%6%9%l%C %I$K:F%9%1%8%e!<%k$9k3HG!$:GE,2=$r?^k3H,2D G=G"$k!%

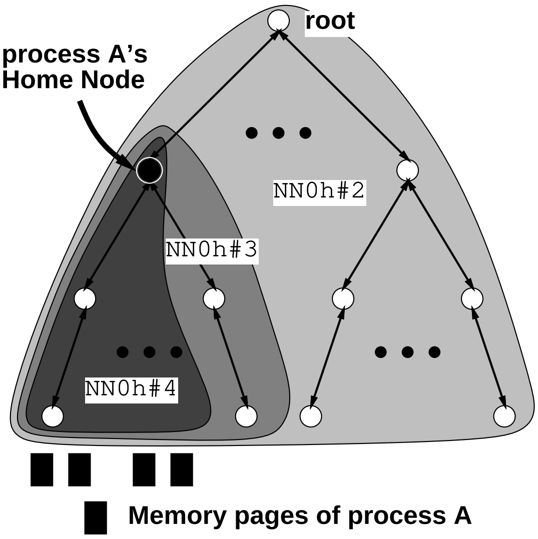
SSS–CORE K*1k%+!<%M%k%9%1%8%e!<%iK*1k %9%1%8%e!<%j%s%0J}<0H7$F 2<5-#5$D$N%9%1%8%e!<%j %s%0J}<0$rMQ$$$k!%3FJ}<06&$K!$%?%$%`%9%i%$%9Kh$KA0 5-$N;q8;;HMQ$N%(!<%8%s%0$r9MN8$7$?M%@hEY7W;;$r9T$J $$!$M%@hEY$N9b$$%W%m%;%9$+$i=g$K!$$=l>$l0J2<$K<($9J}K!$G%9%1%8%e!<%k9k!%J*!$MWAG%W%m%;%C%5$H%a %b%jNBPr%/%i%9%?$H8F$V!%

algo0 %i%s%@%`KI,MWJ?t$@$1%/%i%9%?$rA*Br$73d$j Ev$F$kJ}<0

algo1 %7%9%F%`Cf$N%/%i%9%?$rC<$+$i=gKI,MWJ$@$1 3djEvF$kJ}<0

algo2 =iaK%[!<%`%N!<%I0J2<$NNN0h$K3djEvF$r;n $_!$<:GT7?>l9gKO%k!<%H%N!<%I0J2<$NNN0h$G!$ <+J,$N%Z!<%8$,B8:_9kNN0h$+$i3djEvF$kJ}<0

algo3 =iaK%[!<%`%N!<%I0J2<$NNN0h$G%Z!<%8N"$k



?^ **2** ;q8;4IM}LZ$H%9%1%8%e!<%j%s%0BP>]NN0h

Fig. 2 Target areas of the scheduling in the resource management tree

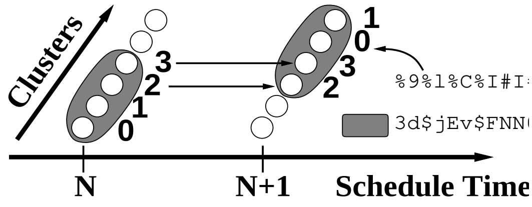
NN0h$r3d$jEv$F!$<:GT9k$H%[!<%`%N!<%I0J2<$NNN0h$G%Z!<%8$N$J$$NN0h$+$i3djEvF$kJ}<0

algo4 %[!<%`%N!<%I0J2<$NNN0h$G87L)$K%Z!<%8$,B8$9$kNN0hN_3djEvF$r;n$_!$<:GT$9kH3djEvF$rD|$a$kJ}<0

$?$@$7!$%[!<%`%N!<%I$H$O;q8;4IM}LZ>e$N%N!<%I$G!$%W%m%;%9$NMW5aBf?t0J>e$N%/%i%9%?$r4^$`ItJ,LZ$KBP1~$9kbNG!$:G2<0L%l%Y%k$K0LCV9kbNN3HG$"$k!%9JoA%[!<%`%N!<%I$O!$0l$DA0$N%9%1%8%e!<%j%s%0;~$N3d$jEv$FNN0h$rBeI=$7$F$$$k!%?^ **2** $K%[!<%`%N!<%INNcr<($9!%?^Cf$G%W%m%;%9 A $N%[!<%`%N!<%I$O<B%Z!<%8$rJ];}$9$kNN0h 4 $rJq4^$9$kItJ,LZ$N%k!<%HKEv?$k%N!<%I$G$"$k!%

Bf?t8GDj%9%1%8%e!<%j%s%0@)Ls$rMQ$$$F$$$k>l9g!$algo2, 3, 4 GO3djEvFBP>]NN0h$KI,MWBf?t$r3NJ]G-$J$$%W%m%;%9$N%9%1%8%e!<%j%s%0$OD|$a!$%9%1%8%e!<%k2DG=KJk^GBTD!%

5 DNJ}<0N&$A algo2, 3, 4 $,;q8;4IM}LZ9=B$$rMQ9kJ}<0G"$k!%$3$N 3 J}<0$N0c$$$O%W%m%;%9XN%/%i%9%?$N3d$jEv$FNN0h$,!$;HMQCf$N<B%a%b%j%Z!<%8$NDLCV$K8G<9$9$kEY9gK"$k!%?^ 2 NNcG$ONN0h 2, 3, 4 O=l>$l algo2, 3, 4 $,3d$jEvFr;n$_$k2DG=@-N"$kNN0h$KBP1~7F$$$k!%$3$3$GNN0h 4 $,A02s$N3djEvF$N0LCV$G!$%W%m%;%9 A $,<B%Z!<%8$r=jM-7F$$$kNN0hG"$k!%$^$?NN0h 3 $,NN0h 4 $KBP1~$9$k%[!<%`%N!<%I$K$h$C$FBeI=$5$l$kNN0h$G$"$k!% algo4 $N>l9g$K$O!$%W%m%;%9Kh$N<B%Z!<%8$NB8:_0LCV$KBP1~$7$FKh2sF1$8NN0h$,3d$jEv$F$i$l$k!% algo3 $N>l9g$K$O!$NN0h 3 $K$"$?$k%[!<%`%N!<%I0J2<$NNN0hK*$$$F3djEvF$r;n$_$k!%A02s$N%9%1%8%e!<%k;~$N3d$jEv$FNN0h$,!$B>$N%W%m%;%9$K4{$K3djEvF:Q$_$J>l9gKO!I,MWJBf?t$,3NJ]$G$-$l$P<B%Z!<%8$r;}$?$J$$NN0hG"CF$b!$NN0h 3 NCfG$"$l$P3d$jEvFk!% algo2 $N>l9g$K$O!$ algo3 $NMWNN$GNN0h 3 $GI,MWBf?t$r3NJ]G-$J$$>l9g$K!$%7%9%F%`A4BN$KAjEv$9$kNN0h 2 Fb$N;DjNNN0h$G3d$jEvFr;n$_$k!%7?$,$C$F>e5-;0J}<0$N4VGO algo4, 3, 2 $N=g$K<B%a%b%jN"$kNN0h$r3djEvF$k798~$K$"$j!$$=$N5U=g$G%/%i%9%?NNMxMQ?t$,B?$/Jk2DG=@-$,9b$$!%



?^ **3** %f!<%6%l%Y%k!&%9%1%8%e!<%j%s%0Nc

Fig. 3 An example of user-level scheduling

$^$?<!@a0J9_GN%7%_%e%l!<%7%g%s$GMQ$$$?!$%W%m%;%9$K3djEvFil$?%/%i%9%?$X$N%9%l%C%I$N%9%1%8%e!<%j%s%0$O!$0J2<NDLjG"$k!%

- A02s$N3d$jEvFH=EJk%/%i%9%?KOA02s$HF1$8%9%l%C%I$r%9%1%8%e!<%k$9$k
- $=$l0J30$N%/%i%9%?$K$O!$;DjN%9%l%C%I$r=g$K%9%1%8%e!<%k9k

?^ **3** $K%9%l%C%I!&%9%1%8%e!<%j%s%0NNcr<($9!%?^ 3 NNcG$O!$3djEvFNN0h$, N+1 2sL\$H N 2sL\$G=EJC$F$$$kNN0h$N%9%l%C%I 2, 3 O=N^$^%9%1%8%e!<%k5l!$3djEvFNN0h$,JQ2=7?%9%l%C%I 0, 1 KD$$$F$O%9%1%8%e!<%k$5lk%/%i%9%?$,0\F0$7$F$$$k!%

J*!$<B9T8zN($N8~>e$rL\E*$H7F;~J,3d$N4V3V$rD9$a!J?tI4%_%jIC!A?tICDxEY!K$K@_Dj$9lP!$%9%1%8%e!<%j%s%0$KMW9k7W;;~4V$OAjBPE*$K==J,>.$5$$!%$3$3GO==J,$KD9$$;~J,3d4V3V$r2>Dj$7!$%7%_%e%l!<%7%g%s$G$O%9%1%8%e!<%j%s%0$N7W;;~4V$rL5;k$9$k!%

2.3 %Z!<%8CV49J}<0

0L?t$N%W%m%;%9$,JB9T$KF0:n$9kHFMQ$J4D6-$G$O!$$D!9$N%/%i%9%?>e$N<B%a%b%j$,0n$l$k>l9g$rA[Dj7?%7%9%F%`9=C[$,5a$ail$k!%$3$N>l9g$N;q8;4IM}GO!$<B%a%b%j$KI,MW$J?7$?$J%Z!<%8$r3djEvFk?aKCV49$9$k

!y %W%m%;%9$N<B%Z!<%8$,:F%9%1%8%e!<%k$^$G$K0lIt%/%i%9%?$K$*$$$F40A4$K%/%i%9%?$N%a%b%j$+$iDI$$=P5l$?>l9g$K$O!$%[!<%`%N!<%I0J2<$NNNN0h!JNN0h 3!K$GB-jJ$$J,$N%/%i%9%?$r3NJ]9k!%

%Z!<%8$NA*BrJ}<0$,<B9T8zN(KBg-$/1F6A$9$k!%
%a%b%j%7%9%F%`$,J,;66&M-%a%b%j$G$"$k>l9gKO!$
%Z!<%8$N6&M->uBV$+$i%"%/%;%9IQEY$*hS:F%"%/%;%9
$N%"%/%;%9%3%9%H$N0c$$$rJ,N`9k3H$,2DG=$G$"$k!#
%Z!<%8$NJ,N`$,G-lP!$%"%/%;%9IQEY$,>/J/:F%"%/
%;%9~$N%3%9%H$,>.$5$$%Z!<%8$+$iCV49BP>]H9k3$H
$,<B9T8zN(8~>e$N$?$a$K5a$ail$k!%

0lHLE*$K!$JBNs%W%m%;%9$N>l9g6&M-NN0h$N%"%/%;%9
$OHs6&M-NN0h$KHfYF>.$5$$$H2>DjG-$k!%$^$?!$$F$
%/%;%9;~$N%3%9%H$K$D$$$F$O!$%M%C%H%o!<%/FbXN%
%;%9$+!$Fs<!5-21XN%"%/%;%9G"k+KhCFJ,N
2DG=G"$k!%$5iK$=$N%3%9%H:9$O%*!<%@!<$H7F0c$
$H2>Dj$G$-$k!%$=$3$G!$D>AK<B9T9k2DG=@-NDc
%m%;%9$N6&M-%3%T!<%Z!<%8$+$iCV49BP>]$H9k3H$
@-G=8~>erO$+$k3H$,2DG=$G$"$k!%0J>erF'^$($F
%Z!<%8$NJ,N`$J$i$S$K!$J,N`4V$NCV49BP>]H9$k=g=x$
<!Nh$&$KM?$($k!%

1) B>$N%W%m%;%9$N6&M-%3%T!<%Z!<%8!$ 2) <B9TCf%W%
%;%9$N6&M-%3%T!<%Z!<%8!$ 3) B>$N%W%m%;%9$N%i%9%H
%s!&%Z!<%8!$ 4) B>$N%W%m%;%9$N%m!<%+%k%Z!<%8!$ 5) <
9TCf%W%m%;%9$N%i%9%H%o%s!&%Z!<%8!$ 6) <B9TCf%W%m%
$N%m!<%+%k%Z!<%8!$$?$@$7$3$liN87L)$J=g=x4X78$O!$
6&M-!&Hs6&M-3FNN0hKD$$$F$N%"%/%;%9IQEY$dMFNL4V$K
%m%;%9$NAH9g$;!$%M%C%H%o!<%/5Z$SFs<!5-21$N@-G=$K0M
B8$9$k!%

:#2s$NI>2A$G$O!$<!NFsD$NCV49J}<0$r<BAu$7Hf3S$
9TJC$?!%

CV49J}<0 **0** %Z!<%8$N<oN`$*hS%W%m%;%9$N6hJL$J$7
C1=c$J LRU =g

CV49J}<0 **1** %9%1%8%e!<%j%s%0M%@hEY$NDc$$%W%m%;%9
$i>e5-%Z!<%8$N<oN`=g$KA*Br!%3F%W%m%;%9$N6&M-%
$?$OHs6&M-6u4VKh$K%Z!<%8$N LRU =g$r4IM}

$?$@7IAi$NJ}<0$b!$0l4S@-=hM}Cf$N6&M-%Z!<%8$N
9g$OCV49BP>]$H7J$$!%

3. %7%_%e%l!<%7%g%s%b%G%k

K\O@J8GOI>2A$N@:EY8~>e$rL\E*H7F3l^G
8&5f$GMxMQ$7$?%b%G%k[11],[12] $r3HD%$7!$ OS %1%Y%k$N%7
%_%e%l!<%7%g%sN?aN4JN,2=5l$?>\:Y3NN(%b%G%k$r
9=C[7?!%

BP>]H9kN$OJ,;66&M-%a%b%j4D6-$G$"$k!%Aj8_7k9
LV$OLZ9=B$$r2>Dj9k!%%M%C%H%o!<%/$OFs=E2=$5l?
%$%C%A$s%0M%C%H%o!<%/$G!$%9%$%C%A$s%0$N!<%I$K$
$F%a%C%;!<%8$r%P%C%U%!%j%s%0$9$k%o%s%[%C%WDL?.
J&!%%N!<%I$O3F=PNO$KBP7F!$%N!<%I$X$NF~NO?t
%(%s%H%j$r;}$D%P%C%U%!$r;}$D!%%Z!<%80\F0$*$h$S
B>$NDL?.$NFsDLjK$D$$$F!$%N!<%I4V$N 1 %[%C%W$rDL2a
9k$?$a$N4pK\%3%9%H$r%Q%i%a!<%?H7$FM?$($k!%%Z!<
%8$N0\F0$*hS$=$NB>$NDL?.$KBP7FO=l>$l!$%Z!<
%80%F04pK\%3%9%H$*$h$SDL?.4pK\%3%9%H$H3F;^$NBS0hG\
N(K+$i;;=P$7$?%3%9%H$rIU2C9k!%?J9TJ}8~$N%P%C
%U%!$*$h$S;^$,6u$$$F$$$J$$>l9gOBT?5l$k!%

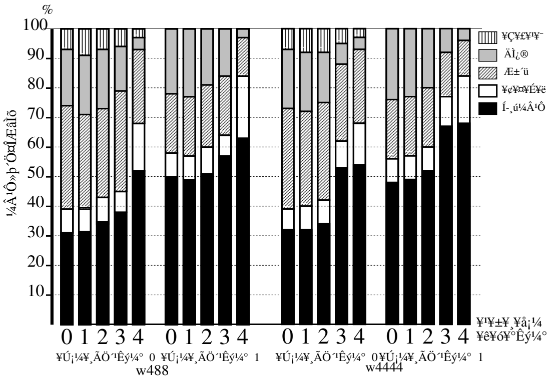
%W%m%;%9$OMW5a%/%i%9%??t$HF1?t$N%9%l%C%I$Khj9=
@.5l$k!%JBNsEY$O0lDj$G!$@8@.;~$+$i=*N;;~$^$GJQ2=
$J$$!%#1%/%i%9%?K*1k%W%m%;%9$N<B9T%3%s%F%-%9
%H$r%9%l%C%I$H8F$V!%3F%9%l%C%I$O%W%m%;%9Fb$K6&M-6u
4V$H8GM-$NHs6&M-6u4V$r;}$D!%3F%W%m%;%9$NN>6u4V$K
$O$$$=l>$lJL!9$N%Z!<%8C10L$N%a%b%j%"%/%;%9IQEYI=
$,$"$j!%3F6u4V$K$*$1$k%a%b%j%"%/%;%9Ns$O!$%a%b%j
%"%/%;%9IQEYI=K*1kAmIQEYKBP9$k3F%Z!<%8$N%a%b
%j%"%/%;%9?trHfH7F3NN(E*$K@8@.$9$k!%

6&M-6u4V$OJ,;66&M-%a%b%j%7%9%F%`$G<B8=9k!%0l4S
@-4IM}$O sequential consistency model KB'C$?%"%C
%W%G!<%HJ}<0$G!$=>CF%Z!<%8$OCV49$5lJ$$8B$j%a
%b%j$K;D$k!%6&M-%Z!<%8XN%"%/%;%9$O%"%/%;%9;~$K
<Be!<$K7R$,$l!$%i%$%H$N>l9gKO%*!<%J!<$+$i$N%"%C
%W%G!<%H$NAw?.$H$=$lKBP9$k Ack $NJV?.$H$,9T$o$l
$k!$%a%b%j%"%/%;%9%3%9%H$O!$%/%i%9%?Fb ≪ %/%i%9%?
4V ≪ #2<!5-21$H$$$&2>Dj$rH?1G$9kh$&$K@_Dj9k!%
%K%8%e!<%j%s%0Kh$j%9%l%C%I$N3djEvF0LCV$,JQ2=
7?>l9gKO!$%m!<%+%k%Z!<%8$O%M%C%H%o!<%/$r2p$7$F
on demand $K0\F0$9$k!%%W%m%;%9$N3djEvFNN0h$,JQ
2=7?>l9gKO!$8=:_$N3djEvFNN0h30$KB8:_$9$k6&M-
%Z!<%8$O%3%9%H 0 $G>C5n$9$k!%

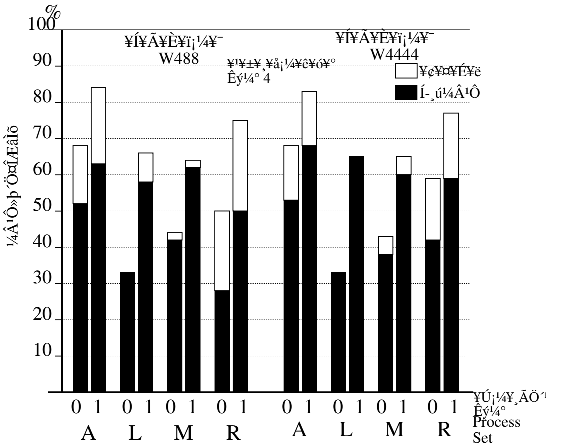
%W%m%;%9$N<B9T$O%/%m%C%/%Y!<%9$N3NN(%b%G%k$G!$F1
0lBTAKtO%Z!<%8BT$A>uBV$GJ1lP3F%/%m%C%/Kh$K%a
%b%j%"%/%;%9$r9T$J$&!%$^$?%W%m%;%9$N%9%l%C%I$O!$M?
$($il?M-8z<B9T%/%m%C%/4V3V$G%i%s%@%`$JAH9g$;$N
%9%l%C%I4V$GF14|$r5/$3$9!%F14|$O!$F14|E@$XE~C#$7$?
%9%l%C%I$+$i%i%s%@%`$KA*Br$5l?%P%j%"$N%k!<%H!&%9
%l%C%IXNAw?.$H!$$=lKBP9kJV?.HG<B8=5l$k!%
$3$3$GM-8z<B9T;~4V!J$9Jo$A/%m%C%/?t!K$H$O!$%Z!<
%8BTA*hSF14|BT$A0J30$NF0:nr7$?;~4V$N3HG"
$k!%

4. <B83$*$h$S9M;!

<B83H7FOI= **2** Nh$&$J%Q%i%a!<%?$r:NMQ$7!$%W%m
%;%5 256 Bf$N 2 <oN`$N%7%9%F%`(%k!<%H3,AX$+$i=g$K
8-8-4 J,4t9k 3 CJ%M%C%H%o!<%/ [w488 $HI=5-]!$$*hS
4-4-4-4 J,4t9k 4 CJ%M%C%H%o!<%/ [w4444]) K*$$
$FI= **3** $N3F%W%m%;%9%;%C%H$r<B9T7?!%<B83$O!$%W%m
%;%9$,0l$D0J>e=*N;9k!J20 %?%$%`%9%i%$%9J,$NM-8z<B

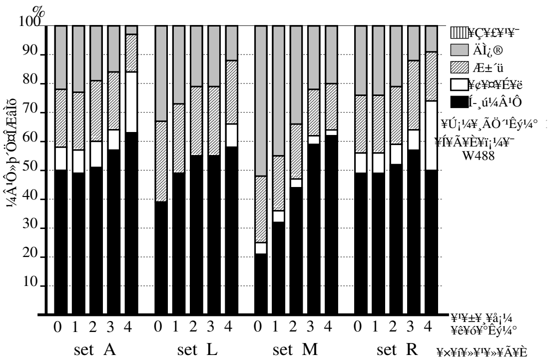


?^ **4** %W%m%;%9%;%C%H #A$N%7%_%e%l!<%7%g%s7k2L
Fig. 4 Simulation result of the process set A



?^ **5** %Z!<%8CV49J}<0$NHf3S (%9%1%8%e!<%j%s%0J}<0#4)
Fig. 5 Comparison of the page replacement policy (scheduling policy 4)

9T8e!K$+!$ 100 %?%$%`%9%i%$%9$N<B9T$r=*$($k$^$G7(
7?!%
%W%m%;%9%;%C%H#AKBP9$k<B83$,=*N;7?;~E@GNI>
2A7k2L$r?^ **4** $N%0%i%U$K<($9!%:8Ns$N%0%i%U$, w488 (2)
1&Ns$, w4444 $N>l9g$N7k2LG"$k!%$^$?!$%0%i%U$N=D
<4$O!$%W%m%;%C%5;~4V$NFbLu$rAjBPHfN($GI=$7$?$bNG
$"$k!%<!$K!$%Z!<%8CV49J}<0$NHf3S7k2L$r?^ **5** $K<($9!%
?^ 5 GO%9%1%8%e!<%j%s%0J}<0 algo4!$ w488 $N%M%C%H
%o!<%/9=@.$rMQ$$$F$$$k!%3l$O%W%m%;%9%;%C%H#A!$
#L!$#M!$#RKD$$$F algo4 $,>o$K0BDj7F:G$bM%$l$F
@-G=$r<($9$3$H$K4p$E$$$F$$$k!%$^$?!$%W%m%;%9%;%C%H
#A!$#L!$#M!$#R$rMQ$$$?%9%1%8%e!<%j%s%0J}<0$NHf3S
2L$r?^ **6** $K<($9!%$3$3GO!$%Z!<%8CV49J}<0#1$rMQ$$$F
$$$k!%



?^ **6** %W%m%;%9%;%C%H#A!$#L!$#M!$#R$N%7%_%e%l!<%7%g%s7k2L
Fig. 6 Simulation results of process sets A, L, M, R

I= **2** 3F<o%3%9%H$*$h$S%Q%i%a!<%?
Table 2 Costs and parameters

9`L\	CM
%W%m%;%C%5?t	256 Bf
%G%#%9%/%"%/%;%9	100000 clk
%Z!<%80\F04pK\%3%9%H	500 clk
DL?.4pK\%3%9%H	50 clk
1 %a%b%j$N%Z!<%8?t	400 pages
1 %Z!<%8$N%5%$%:	4096 Byte
Am%a%b%jNL	409.6 Mbyte
1 quantum	1000000 clk

4.1 %9%1%8%e!<%j%s%0J}<0KD$$$F

A 0J30$N%W%m%;%9%;%C%H$G$O!$6&M-%Z!<%8$N%3%T!<$,
@8@.5lk3HG%Z!<%8CV49$,H/@8$7$F$$$k!%HFMQ$JJ,
;6JBNs4D6-GO3Nh&$J%7%9%F%`$NMxMQ>u67$,<+A3$G
$"$m$&!% algo4 Nh$&$K%W%m%;%9$N3djEvFNN0h$r8GDj
7?>l9g!$%W%m%;%9%;%C%H$NAH9g$;$N@-<A$+$i==J,$K%/
%i%9%?$r3hMQ$7$J$$$?$a!$<B:]$N%7%9%F%`$G$O%"%$%I%k
;~4V$,8:$k2DG=@-H7$F!$0J2<N3H,5s2ilk!%
Bf?t2DJQ@)Ls$N:NMQ$9$k>l9g$K$O!$%W%m%;%C%5Bf
?tKD$$$F<+M3EY$N9b$$%9%1%8%e!<%j%s%0$r9T$J
$&$3H,G-$k!%
FCDj$N%W%m%;%9%;%C%H$KHC$F%9%1%8%e!<%j%s%0
$N “7j” HJ$kNN0h$r!$B>$N%W%m%;%9$,M-8zMxMQ
9k3H$,$G$-$k!%
A0=R7?h&$K!$ algo2, 3, 4 $N0c$$$O%a%b%j%Z!<%8
$NOLCV$K8G<9$9$kEY9gG"$k!%<B837k2L$O!$%W%m%;%9$r
%Z!<%8$r=jM-$9$kNN0h$K3djEvF$k798~$,9b$$J}<0$[
$INI$$$3HrJ*8lCF$$$k!% algo2, 3, 4 $N=g$K%Z!<%8
$N0\F0NL$,B?$$$o1@$,!$?^ 4 $r8+$k$H!$$=$N=g$GDL?.
(%Z!<%8=hM}) $dF14|$,@jak;~4V$,Bg$-$/$JCF$$$k$3
H,J,$+$k!%3l$O!$%a%b%j%"%/%;%9IQEY$N9b$$Hs6&M-
6u4V%Z!<%8$N0\F0$,>/J/Jkh&$K%9%1%8%e!<%j%s%0

I= **3** %W%m%;%9%;%C%H$N35MW

Table 3 Description of process sets

%W%m%;%9 %;%C%H	%W%m%;%9?t	JBNsEY (J#?t$N>l9g$N8D?t)	AmJBNsEY	AmHs6&M- 6u4V%5%$%: [pages]	Am6&M- 6u4V%5%$%: [pages]	%a%b%j$N :GBgMW5aEY [Am<B%a%b%jHf]	F14|4V3V [clocks]
A	12	16,36,48,50(2),64,70 96,100,128,192,200	1050	35500	10120	1.00	1000–2000
L	11	64(5),128(2),192(2),256(2)	1472	68480	7280	1.68	1000
M	23	16(16),50(6),256(1)	812	35480	30320	1.70	1000
R	14	16,36,48,50(2),64,70,96	1514	65320	14980	1.67	1000–3000

9k8z2L$,1F6A$7$?$H?dDj5l$k!$$^$?!$%a%b%j0 $,$[Hs$I5/$-$J$$%W%m%;%9%;%C%H A $N>l9g$K$D$$$F $b!$$I$N;XI8$rMQ$$$F$b algo4 $,:GNI$HJC$F$$$k!$ $10J30$N%9%1%8%e!<%j%s%0J}<0$O!$7k6I%Z!<%8$N0\F0$ %9%H$,9b$/$D$$$F@-G=$,=P$F$$$J$$!%

4.2 %Z!<%8CV49J}<0KD$$$F

%Z!<%8CV49J}<0KD$$$F$OJ}<0 1 $,J}<0 0 $K>o$K>!$C $F$$$k!%J}<0 1 GO%W%m%;%9$N6&M-%Z!<%8$,CV49$5$l$k NKBP7F!$J}<0 0 GO%W%m%;%9$N%m!<%+%k6u4V$N%Z! %8$d%i%9%H%o%s6&M-%Z!<%8$,CV49$5$l$F$$$k!%%a% XNMW5aEY$,7Z$$%;%C%H A, K, L GO!$B>?M$N%3%T! %Z!<%8$rCV49$9k3H7$+$J$$!%b&>/$7%a%b%j$X$NMW 5aEY$,=E$$%;%C%H M GO<+J,$N%3%T!<%Z!<%8$rCV49$ k3Hb$"$k$,!$$h$j%"%/%;%9$5$l0W$$Hs6&M-%Z!<$ DI$$=P5J$$$3HG8zN($NNt2=$rKI$$$G$$$k!%$3$3$ 2?%1!<%9GO!$6&M-%3%T!<%Z!<%8$rM%@hE*$KCV49 8z2L$,6KaFBg$-$/JC$F$$$k$H$$$($k!%0J>e$N3 $i NUMA 4D6-$K$*$$$F$O!$%Z!<%8$r%"%/%;%9IQEY$K$ $SCV498e$N:F%"%/%;%9%3%9%H$r9MN8$7$?J,N`$K4p$E$$ %Z!<%8CV49$r9T$J$&$3HG!$9b8zN($JHFMQ4D6-$rDs6 k3H,2DG=G"k3H,<(5l$F$$$k!%

:#2s$N<B83$GbCHb@-G=$NNI$$!$%9%1%8%e!<%j J}<0 algo4 $GCV49J}<0 1 $N>l9g$N7k2L$G!$M-8z<B9TN($ 50% $+$i 68% DxEYG"$k!%6&M-%Z!<%8$N0l4S@-4IM}$ sequential consistency model $K=>$&$?$a!$%Z!<%8$N %"%C%W%G!<%H=hM}<+BN$N%3%9%H$h$j!$6&M-NN0hXNK %;%9=hM}K*1k@h9T%"%/%;%9=hM}$N=*N;BT$A;~4V$ >oKBg-$$!%

3l$O4KOB$5l?%a%b%j%b%G%k NMQKhj5iK 8~>e9k3H$,2DG=$G$"$k!%$^$?!$4KOB$5l?%a%b%j %G%k$r;H$($P!$%Z!<%8$r0\F0$7$?;~$N%3%9%H$N%W%m%;%9 KBP9$k0-1F6A$N8z2L$O>.5/Jk!%

$^$?K\O@J8K*1k%7%_%e%l!<%7%g%s%b%G%kGO!$%a

[!y] %W%m%;%9$N3d$jEv$FNN0h$N=EJj6q9g$G!$0lItNN0hK*$$$F%Z!<%8CV49$,H/@8$7$F$$$k!%

[!y!y] release consistency model $d weak consistency model Ey F14|$HC`<!2=$r sequential consistency model $HHf3S$7$F8:>/$5$;$?%a%b%j%3%s%7%9%F%s%7%b%G%k

blj%"%/%;%9$H%9%l%C%I4V$NF14|H,FHN)7?;v>]H7 $F%b%G%k2=$5lF$$$k$?$a!$%Z!<%8=hM}$KHqd5lk;~ 4V$N8:>/$O!$$=N^$^F14|;~4V$NC;=LKDJ,$k!% 3>e$N3H$+$i!$K\O@J8$K$*$1$k<B83$G$N7k2L$NCM$N Dc$5$,!$JBNs4D6-K*1k%7%9%F%`$NHFMQ$JMxMQ7ABV$r H]Dj$9k3HO$J$$!%

5. $*$ojK

HFMQD6JBNs OS *SSS–CORE* K*1k;q8;>pJs$rMxMQ %7%9%1%8%e!<%j%s%0J}<0!$$JiS$KJ,;66&M-%a%b%j$r A[Dj7?%a%b%j%Z!<%8$NJ,N`$K=>C?%Z!<%8CV49J}<0$K $F=R$Y$?!%$5iK3l$i;q8;4IM}5!9=$N@-G=$r!$>\ 3NN(%b%G%k>eGN%7%_%e%l!<%7%g%sKh$jI>2A$7$?!% 8N7k2L%9%1%8%e!<%j%s%0J}<0KD$$$F$O!$;q8;4IM}9= KFMxMQ7?!$%W%m%;%9$,=jM-9k<B%Z!<%8$,B8:_$9$k %N!<%I$r3djEvF$kJ}<0$NM%0L@-$,G'$ail!$%Z!<%8CV49 J}<0$K$D$$$F$O!$%Z!<%8$NJ,N`$K=>C?%Z!<%8CV49J}<0 $N@-G=$r<(7?!%3NN>J}<0rAH_9go;$?>l9g$N <B837k2LGO!$Ii2Y>u67$,9b$$!1!<%9GbM-8z<B9TN($K hjI>2A$, 50% DxEY0J>eG"$k!%

SSS–CORE GO!$Bf?t2DJQ@)Ls$rMQ$$$l$,!$:#2sI> 2A7?M-8z<B9TN($K2C$($F3F%/%i%9%?$,"%$%I%k$9$k;~4V $,M-8z$J<B9T;~4VKAH_F~lk3H$,2DG=$HJk!%=>$C $E!$?^ 6 hj 65% $+$i 85% $N<B9T;~4V$,M-8z$K7W;; $KMQ$$$ilk!%3liN3H$+$iK\O@J8$GDs0F$7$?J}<0 Kh$j<BMQE*$K==J,Jl%Y%k$N%9%1%8%e!<%j%s%0@-G=$, $@$5lF$$$k$H9M$(il$k!%

<U<-

K\8&5f$O>pJs=hM}?66=;v6H2q!J#I#P#A!K$,<B;\$7$F$$ $k%"%F%%AOE*>pJs5;=Q0i@.;v6H$N0l4D$H7F9TJC$?!%

;2 9M J8 8%

1) R. Chandra et al. Scheduling and Page Migration for Multiprocessor Compute Servers. In *ACM, ASPLOS VI*, pages 12–24, October 1994.

2) Intel Supercomputer Systems Division. *Paragon User's Guide*, order number 312489 - 003 edition, June 1994.

3) D. G. Feitelson. Packing schemes for gang scheduling. In *Proc. IPPS'96 Workshop on Job Scheduling Strategies for Parallel Processing*, pages 54–66, April 1996.

4) D.G. Feitelson and L. Rudolph. Distributed Hierarchical Control for Parallel Processing. *IEEE Computer*, 23(5):65–77, May 1990.

5) J. K. Ousterhout. Scheduling techniques for concurrent systems. *3rd Intl. Conf. Distributed Computer Systems*, pages 22–30, October 1982.

6) T.E.Anderson et al. Scheduler activations: Effective kernel support for the user-level management of parallelism. *Proc. of the 13th ACM Sympo. on Operating Systems Principles*, 25(5):95–109, October 1991.

7) R. Vaswani and J. Zahorjan. The implication of cache affinity on processor scheduling. In *Proc. of 13th ACM Symp. on Operating Systems Principles*, pages 26–40, October 1991.

8) >>K\>0. %^%k%A%W%m%;%C%5>e$NF14|5!9=$H%W%m%$K %5%9%1%8%e!<%j%s%0$K4X9k9M;!. 7W;;5!%"!<%-%F %/%A%c8&5f2qJs9p *No.79-1*, pages 1–8, November 1989.

9) >>K\>0. :YN3EYJBNs<B9T;Y1g%^%k%A%W%m%;%C%5$N 8!F$. >pJs=hM}3X2qO@J8;o, 31(12):37–42, August 1989.

10) >>K\>0 et al. HFMQD6JBNs%*%Z%l!<%F%#%s%0%7%9%F %' SSS–CORE. F|K\%=%U%H%&%'%"2J3X2qBh *11* 2s Bg2qO@J8=8, pages 13–16, October 1994.

11) ?.9qM[FsO: et al. HFMQJBNs os *sss–core* K*1k %+!<%M%k%9%1%8%e!<%j%s%0J}<0 — >\:Y3NN(%b%G%k Kh$k@–G=I>2A —. >p=h8&Js *96-OS-73*, 96(79), August 1996.

12) ?.9qM[FsO: et al. JBNs#O#S$N@–G=M=B,$r2DG=K9$k %7%_%e%l!<%7%g%s%b%G%k. >p=h8&Js *96-ARC-117*, 96(23):19–24, March 1996.

(J?@. 9 G/107n31F|<uIU)

(J?@.10G/ 4 7n 7 F|:NO?)

?.9qM[FsO:

1971 G/@8. 1997 G/El5~Bg3XBg3X1!M}3X7O8&5f2J>pJs2J3X@l96=$;N2]Dx=*N;.M}3X=$;N!%F1G/#47n$+$i!J3t!K%"!<%D%F%C%/$K6PL3!%JBNsJ,;6%*%Z%l!<%F%#%s%0%7%9%F%`$K6=L#$r;}$D!%

>>K\ >0!J@52q0w!K

1962 G/@8!% 1985 G/El5~Bg3X9)3XIt7W?t9)3X2JB46H!% 1987 G/Bg:e;TN)Bg3XBg3X1!M}3X8&5f2JJ*M}3X@l96=$;N2]Dx=$N;!%F|K\%"%$!&%S!<!&%(%`!J3t!KEl5~4pAC8&5f=j8&5f0w$r7P$F!$1991 G/ 11 7n$h$jEl5~Bg3XBg3X1!M}3X7O8&5f2J>pJs2J3X@l96=u<j!%JBNs7W;;5!%"!<%-%F%/%A%c!$JBNsJ,;6%*%Z%l!<%F%#%s%0%7%9%F%`!$:GE,2=%3%s%Q%$%i$K4X9k8&5f$Ke>;v!%B>$K?tCM7W;;Kh$k@)Ls2r>C7O!$%0%i%U%#%C%/%9!$%K%e!<%i%k%M%C%H%o!<%/Ey$K6=L#$r;}$D!%EE;R>pJsDL?.3X2q!$F|K\%=%U%H%&%'%"2J3X2q!$ ACM 3F2q0w!%

J?LZ 7I!J@52q0w!K

1976 G/El5~Bg3XM}3XItJ*M}3X2JB46H!% 1982 G/F1Bg3XBg3X1!M}3X7O8&5f2JJ*M}3X@l96Gn;N2]Dx=$N;!%M}3XGn;N!% 1982 G/DL>&;:6H>J9)6H5;=Q1!EE;R5;=QAm9g8&5f=jF~=j!% 1988 G/hj#2G/4V IBM <R T!% J!% Watson 8&5f%;%s%?5R0w8&5f0w!% 1990 G/hjEl5~Bg3XM}3XIt>pJs2J3X2J!J8=:_Bg3X1!M}3X7O8&5f2J>pJs2J3X@l96!K$K6PL3!%8=:_!$D6JBNs%"!<%-%F%/%A%c!$D6JBNsD6J,;67W;;!$JBNs%*%Z%l!<%F%#%s%0%7%9%F%`!$%M%C%H%o!<%/%"!<%-%F%/%A%c$J$I$N9bB.7W;;%7%9%F%`$N8&5f$K=>;v!%F|K\%=%U%H%&%'%"2J3X2q2q0w