HFMQJBNs OS *SSS–CORE* K*1k%+!<%M%k%9%1%8%e!<%j%s%0J}<0
— >\:Y3NN(%b%G%kKh$k@-G=I>2A —

?.9q M[FsO:† >> K\ >O† J? LZ 7I†

J,;6%a%b%j4D6-$GJBNs%W%m%;%9$N8zN(E*$J<B9T$rK8$2$k3HJ/%^%k%A%f!<%6!?%^%k%A%8%g%V4D6-$r 9=C[$9kK$O!"%a%b%j%Z!<%8$JIN<B;q8;$N;HMQ>u67$r9MN8$7$?%9%1%8%e!<%j%s%0$r9T$J$$!"%7%9%F%`A4 BN$N@-G=$r$"$2$k$3$H$,M-8z$G$"$k!#$^$?J#?t$N%W%m%;%9$,JB9T$KF0:n$9$kHFMQE*4D6-$G$O!"<B%a%b%j$, 0n$1$k>l9g$rA[Dj$7$?%7%9%F%`9=C[$,5a$ail$k!#J,;64D6-$G$O!";2>HIQEY5Z$S:F%"%/%;%9$N%3%9%H$K$h $j<B%a%b%j%Z!<%8$r6hJL9l$P!"8zN(E*$JCV49J}<0$,2DG=$G$"$k!#K\9FGO%a%b%j%"%/%;%9Y!<%9$N3NN(%b%G%k>e$G!"6qBNE*$J%a%b%j4IM}J}<0!?%"%/%;%9IQEY!?%"%/%;%9%3%9%H$rIU2C$7$?%7%_%e%l!<%7%g%s$K$h $j!"JBNs%W%m%;%9Kh$K=jM-9k<B%Z!<%8>pJs$rMxMQ$7$?%9%1%8%e!<%j%s%0J}<0!"5Z$S%a%b%jCV49J}<0$NI> 2A$r9T$&!#

Scheduling in General Purpose OS *SSS–CORE*
— An Evaluation by Detailed Probabilistic Simulation —

Yojiro Nobukuni,† Takashi Matsumoto† and Kei Hiraki†

Preventing parallel processes from unexpected ineficiencies is a major concern for constructing multiple user/multiple job environment in distributed memory systems. Systems can achieve high performance by using shcheduling policies which reflects resource comsumption states. For a general environment, which must support concurrent execution of multiple processes, a way is needed to keep systems' effectiveness when phisical memories are full. In distributed systems, memory pages can be classified by access frequencies and required costs for accesses after target pages has been replaced. Selecting victim pages according to the classification may enhance system performance. We built a probabilistic model with a concrete memory management scheme and differntiated memory access costs, and incorporated memory reference frequencies to it. The paper describes an evaluation of scheduling policies using resource informations for each process and of page replacement policies under the model.

1. $O $8 $a $K

NUMA 7?%7%9%F%`$O!"0B2A$J9=@.MWAG$rB??t7k$S$D $1$FBg5,LO$J%7%9%F%`$r9=C[$7!"9b$$=hM}G=NO$rF@$k 3H$,$G$-$kFCD'$r;}$D!#6aG/$N%M%C%H%o!<%/<~JU$N@- G=8~>e$rGX7J$K!"JBNs%"%W%j%1!<%7%g%s$N?$a$N<B9T;~ 1g5!9= [1]!"JBNs4D6-2<GN3F<o:GE,2=5;K!$N8&5f!?3+ H/ [4] [3] $O!" NUMA 7?JBNs7W;;5!>e$G$N9b8zN($JHF MQ@-$r;}$C$?;HMQ7ABV$r2DG=H7DD$"$k!#2f!9$O!" NUMA 7?JBNs7W;;5!>e$KHFMQ$J4D6-$rDs6!9kG=NO$r Hw$($?%*%Z%l!<%F%#%s%0!&%7%9%F%` *SSS–CORE* $r3+ H/Cf$G$"$k!#

J,;6%a%b%j4D6-GO!"%a%b%jXN%"%/%;%9%3%9%H$,%W N%$KhC$F0[$k!#J#?t$N%W%m%;%9$,JB9T$KF0:n$9$kHFMQ E*4D6-$G$O!"%a%b%j%Z!<%8$JIN<B;q8;$N;HMQ>u67$r9M N8$7$?%9%1%8%e!<%j%s%0$r9T$J$$!"%3%9%H$N9b$$%"%/%; %9$r8:$i$9$3HG%7%9%F%`A4BN$N@-G=$r>e2k3H$,2D G=$G$"$k!#$^$?;2>HIQEY5Z$S:F%"%/%;%9$KMW9k%3%9%H $N0-$5$J%a%b%j%Z!<%8$+$iCV49$r9TJ&3HKh$j!"A4 BN$N@-G=8~>e$r7W$k3H$,$G$-$k!#

2f!9O3l^GN8&5f$GMxMQ$7$?%b%G%k [5] $r3HD% $7!"6qBNE*$J%a%b%j4IM}J}<0!?%"%/%;%9IQEY!?%"%/%;%9 %3%9%H$rIU2C$7$?%a%b%j%"%/%;%9Y!<%9$N3NN(%b%G%k$r 9=C[$7$?!#K\9F$GO3$N%b%G%k>e$G$N%7%_%e%l!<%7%g%s Kh$k!"JBNs%W%m%;%9Kh$K=jM-9k<B%Z!<%8>pJs$rMxMQ 7?%9%1%8%e!<%j%s%0K!JiSK!"%a%b%j%Z!<%8$NJ,N` KhC?%a%b%jCV49J}<0$NI>2AKD$$$F=RYk!#

2. SSS–CORE

SSS–CORE [2] $O NUMA 7?JBNsJ,;67W;;5!$rBP>] H7$?HFMQJBNs OS G"$k!#;~J,3d $H%Q!<%F%#%7%g%K

† E15~Bg3XBg3X1!M}3X7O8&5f2J>pJs2J3X@l96
Department of Information Science, Faculty of Science, University of Tokyo

%s%0$rJ;MQ$7$F%^%k%A%f!<%6!?%^%k%A%8%g%V4D6-$rDs6'
$7!"JBNs%"%W%j%1!<%7%g%s$N8zN(NI$$<B9T$r<B8=$9k3
H,L\E*G"$k!#

NUMA 7?$NJBNs7W;;5!$%7%9%F%`GO!"%a%b%j%"%/%;
%9%3%9%H5Z$SDL?.%3%9%H$,5wN%$K1F6A$5lk!#JBNs%"
%j%1!<%7%g%s$r8zN(NI$/<B9T9kKO!"3F%9%l%C%I$rF1
;~$K%9%1%8%e!<%j%s%0$7!"3djEvFil$?MWAG%W%m%;%C
%54V$N5wN%!"5Z$S<B9T;~$N%a%b%j%Z!<%8$N0\F0$r:G>.
$KM^$(k3H,=EMWG"$k!#

SSS–CORE GO<B%a%b%j$N;HMQ>u67$N%9%1%8%e!<%j
%s%0X$NH?1G!"%f!<%6%l%Y%k$+iN%9%1%8%e!<%j%s%0
Ls$NMxMQ!"$=7FM%@hEY$rMxMQ$7$?;q8;$N8xJ?$J3d$jEv
FH$$$&#3DN%"%W%m!<%ArH$k!#

SSS–CORE GO!"7W;;5!$NAj8_7k9gLV$N3,AX9=B$
$H0lCW$7$?9=B$$N;q8;4IM}9=B$$rMQ0U$7!"$3$N9=B$>e$G
%7%9%F%`A4BN$N;q8;>pJs5Z$S!"%W%m%;%9Kh$N;q8;$N;H
MQ>u67Ey$r4IM}$9$k!# 2 %l%Y%k%9%1%8%e!<%j%s%0$r:NMQ
$7!"%+!<%M%k$O3N;q8;>pJs$H3F%W%m%;%9$+$iDs<($5$l
$k%9%1%8%e!<%j%s%0@)Ls$K7?$,$C$F!"%W%m%;%9C10L$K
;q8;$N3dEv$r9TJ&!#;q8;>pJs$rMxMQ$9k3HG!"%?%$
%`%9%i%$%9Kh$N;q8;$N3d$jEv$F>u67$r%9%1%8%e!<%j
$KH?1G$9k3H,2DG=!#99$K!"Ds<($5l?%9%1%8%e
%s%0@)Ls$K=>$C$F%9%1%8%e!<%j%s%0$9k3HG!"%W
%9Kh$K0[$J$k;q8;$XNM_5arK~$?$9$3$H$,$G$-$k!#
4IM}9=B$$OJBNs7W;;5!$N9=B$$H$rH?1G$7$F$$$k$?$a
jEvF$r9T$J$&%W%m%;%C%54V$NDL?.%3%9%H$rGD0.
$&$(GN%9%1%8%e!<%j%s%0$,2DG=$G$"$k!# 2 %l%Y%k%9
%8%e!<%j%s%0G"k?$a!"%W%m%;%9Fb$G$N;q8;3d$j
$O%f!<%6$K0lG$$5lk!#

%9%1%8%e!<%j%s%0$5$l$?%W%m%;%9$O!";HMQ7?;q8;$N
$H%9%1%8%e!<%j%s%0@)Ls$K=>$$M%@hEY$,%($%8%s%0$5
$l!"%?%$%`%9%i%$%9Kh$KM%@hEY=g$K%9%1%8%e!<%j%s
lk!#3lKh$j8xJ?$J%^%k%A%f!<%6!?%^%k%A%?%9
6-$r<B8=$9$k!#

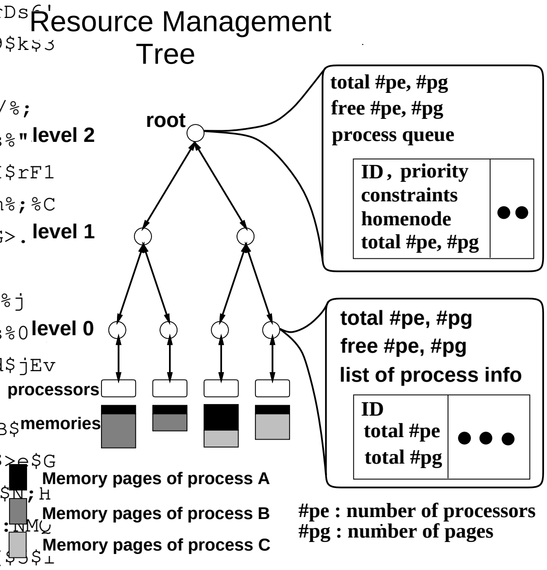
3. SSS–CORE $N%9%1%8%e!<%j%s%0J}<0

3.1 ;q8;4IM}LZ

SSS–CORE GO!"%7%9%F%`$N3,AX9=B$$HF10l$N3,AX
@-$r;}$C$?;q8;4IM}MQ$NLZ9=B$$r2>A[E*$K;}$D!#K\9=B$
O3$N9=B$$N3H$r;q8;4IM}LZ$H8F$V!#;q8;4IM}LZ$G$O
O@M}E*$K3F%N!<%IKh$K!"%N!<%I$r%k!<%H$H9kItJ,LZ$N
NN0h$K4^$^lk%W%m%;%C%5$H<B%Z!<%8$NAm?t$*$h$S!"%U
%j!<$J%W%m%;%C%5$H<B%Z!<%8$NAm?t!"$JiS$K%W%m%;%9
Kh$K ID 5Z$S;HMQ7F$$$k%W%m%;%C%5$H<B%Z!<%8$NAm?t
$r5-21$9$k!#$^$?%k!<%H%N!<%I$KO3$NB>$K!"%W%m%;%9
Kh$K%9%1%8%e!<%j%s%0@)Ls!"M%@hEY!"%[!<%`%N!<%I!J8e
=R!K$rJ];}$9$k!#?^ 1$K 4 %W%m%;%C%59=@.%7%9%F%`$NNc
$r<($9!#;q8;4IM}LZ$rMxMQ$9k3HKhj!";q8;$N>CHq
>u67$rH?1G$7$?%9%1%8%e!<%j%s%0$,2DG=HJ$k!#

3.2 %9%1%8%e!<%j%s%0@)Ls

JBNs%W%m%;%9XN;q8;3dEv$,%W%m%;%9$NMW5a$H0[$J



?^1 ;q8;4IM}LZ

3a$K!"%W%m%;%9<B9T$N@EE*$JM=B,$K4p$E$$$?:GE,2=$,
$;$:!"8zN(E*$J<B9T$,G-J/Jk%1!<%9$,5/$3
$k!#%+!<%M%k$Khk%9%1%8%e!<%j%s%0$,!"%W%m%;%9Kh$K
0[Jk;q8;XNMW5a$rK~$?9?aK!" SSS–CORE $G
$O!<%6$+$i%+!<%M%k$KBP7F%9%1%8%e!<%j%s%0@)Ls$r
Ds<(G-kh$&$K9k!#

Nc$($PBf?t8GDj@)LsGO!"%W%m%;%9$O%+!<%M%k$KBP7
$FJ,$,I,MWH9$kMWAG%W%m%;%C%5?t$r0lDj?t;XDj9k
3H$,$G$-$k!#$^$?2DJQBf?t@)Ls$,$"lP!">/7:DG
$b%W%m%;%9$K%W%m%;%C%5$r3d$jEvFk3H$,2DG=$H$J
$k!#Nc$($P==J,$JJBNs@-$,$"k?aK2DJQ$J%W%m%;%C%5
Bf?t$KBP1~$7$F%W%m%0%i%`$5l?%W%m%;%9KBP7FO!"
3N@)Ls$,M-8z$KF/$/!#

:#2s$N%7%_%e%l!<%7%g%s$G$O%W%m%;%9$NJBNsEY$OJQ2=
7J$$$N$G!"%9%1%8%e!<%j%s%0@)Ls$H7F$OBf?t8GDj@)
Ls$r07$&!#

3.3 M%@hEY$N7W;;K!

M%@hEYOCM,>.$5$$$[$I9b$$!# SSS-CORE GOM%@h
EY$N7W;; [2] [5] K"$?$j!"$^$:0J2<NCMr7W;;9k!#

- U_r ;HMQ7?;q8;NL!'
- R_c @)Ls>r7o$N87$7$5!'
- S_c @)Ls>r7o$NK~B-EY!' $=0$ or 1
- W_r L5BLK7$?;q8;NL!'
- f_w BT$A%W%m%;%9$NM-L5!' $=0$ or 1
- C_r <cJV$j7O?t!'

3liNCM$r!J0lIt$O%W%m%;%9Kh$K!K7W;;$9kH!"<!$N
<0Kh$j%W%m%;%9Kh$N%($%8%s%0$NCM$,5a$ail$k!#

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

$^$?M%@hEYNCMNH/;6rKI0$?$a$K!"D>A0$^$G%9%1
%8%e!<%k5l$F$$$?%W%m%;%9$N%($%8%s%0$NAmOB$r!"BT
$A>uBV$@C?%W%m%;%9$K<cJV$jJ,H7$F8xJ?$K6QEy$KJ,

G[9k!#

4. %7%_%e%l!<%7%g%s!&%b%G%k

4.1 <g $J FC D'

3l$^$G$N8&5f$GMxMQ7?%b%G%k [5] $r3HD%$7!" OS %l%Y%k$N%7%_%e%l!<%7%g%s$N$?$a4JN,2=5l$?%b%G%k [6] $r9=C[$7$?!#BP>]$H9kNOJ,;6%a%b%j4D6-G"$k!#%a%b%j$H%W%m%;%C%5NBPr%/%i%9%?H7!"Aj8_7k9g LV$OLZ9=B$$G$"$k!#%M%C%H%o!<%/$OFs=E2=$5l?%9%C%A%s%0%M%C%H%o!<%/$G!"%9%$%C%A%s%0%N!<%IK*$$$F%a%C%;!<%8$r%P%C%U%!%j%s%0$9$k%o%s%[%C%WDL?.$r9T$&!#%N!<%I$O3F=PNOKBP7$F!"%N!<%I$X$NF~NO?tJ,$N%"%s%H%j$r;}$D%P%C%U%!$r;}$D!#

3F%W%m%;%9KO6&M-6u4V$HHs6&M-6u4V$r!"$=$l$>$l JL!9$N%Z!<%8C10L$N%a%b%j;2>HIQEYI=Kh$jM?$($k!#$3$l6u4V$K$*$1$k;2>HNs$O!";2>HIQEYI=K*1kAmIQEYKBP9$k3F%Z!<%8$N;2>H?trHfH7F3NN(E*$K@8@.$9$k!#$%/%i%9%?K*1kJBNs%W%m%;%9$N<B9T%3%s%F%-%9%H$r%9%l%C%I$H8F$S!"3F%9%l%C%I$O0[$JC?6u4V$rM?$(il$k!#3F%W%m%;%9$OMW5a%W%m%;%C%5Bf?t$HF1?t$N%9%l%C%IKh$j9=@.$5lk!#JBNsEY$O0lDj$G!"@8@.;~$+$i=*N;$^$GJQ2=7J$$!#%9%l%8%e!<%j%s%0Kh$j%9%l%C%I$N3djEvF0LCV$,JQ2=$7$?>l9g$K$O!"%m!<%+%k%Z!<%8$O%M%C%H%o!<%/$r2p$7$F on-demand $K0\F0$9$k!#%Z!<%8$O%j%b!<%HKbB8:_7J$$>l9gKO!"%G%#%9%/%"%/%;%@8$8$k!#6&M-6u4VKBP7FOJ,;66&M-%a%b%j%7%9%F%`$r9=C[$7!"%W%m%;%9$N3F%9%l%C%I$O;2>HIQEYI=$r6&M-$9$k!#%3%R!<%l%s%74IM}$O%"%C%W%G!<%HJ}<0$G!"=>$C$F%Z!<%8$OCV49$5$l$J$$8B$j%a%b%j$K;D$k!#$^$?%a%b%j;2>H%3%9%H$O!"%/%i%9%?Fb $\ll$ %/%i%9%?4V $\ll$ #2<!5-2F$H$$$&2>Dj$rH?1G$9kh$&$K@_Dj9k!#

%W%m%;%9$N<B9T$O%/%m%C%/%Y!<%9$N3NN(%b%G%k$G!"3F%/%m%C%/Kh$K%j!<%IKt$O%i%$%H$N%a%b%j;2>H$r9T$J$&!#$?$@$7!"BP>]H9$k%Z!<%8$,<+%/%i%9%?$N%a%b%j$KB8:_7J$$>l9g$O!"%Z!<%8BT$A>uBVHJ$k!#$^$?%W%m%;%9$N%9%l%C%I$O!"%Q%i%a!<%?$GM?$($il?M-8z<B9T%/%m%C%/4V3V$G%i%s%@%`$JAH9g$;$N%9%l%C%I4V$GF14|$r5/$3$9!#$3$3$GM-8z<B9T!J;~4V!?%/%m%C%/!K$H$O!"%Z!<%8BT$A!?F14|BT$A0J30$NF0:n!J$r$7$?;~4V!?%/%m%C%/?t!K$N$3$H$G$"$k!#%Z!<%8BT$A$^$?$OF14|BT$A>uBV$N>l9g$K$O!"%9%l%C%I$O2?$b<B9T$G$-$J$$!#%7%_%e%l!<%7%g%s$G$O!"%7%9%F%`A4BN$K$*$$$FM-8z<B9T$N@j$a$k3d9g!JM-8z;~8zN(!K$r7WB,9k!#

4.2 %9%1%8%e!<%j%s%0J}<0

%7%_%e%l!<%?>e$K#5$D$N%9%1%8%e!<%j%s%0K!$r<BAu7?!#3FJ}<06&$K!"%?%$%`%9%i%$%9Kh$K;q8;$N@jM-!?>CHq>u67$K1~8?M%@hEY7W;; [5] $r9T$J$$!"M%@hEY$N9b$$%W%m%;%9$+$i=g$K!"$=l>$l0J2<$K<($9J}K!$G%9%1%8%e!<%j%s%0$r9T$J$&!#

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

algo1 %7%9%F%`Cf$N%/%i%9%?$rC<$+$i=gKI,MWJ$@$13djEvF$kJ}<0

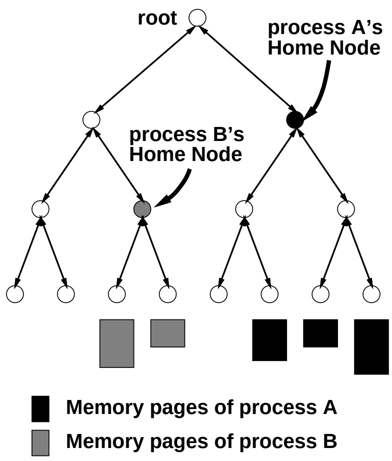
algo2 =iaK%[!<%`%N!<%I0J2<$NNN0h$K3dEv$r;n$_!"<:GT7?>l9gKO%k!<%H%N!<%I0J2<$NNN0h$G!"<+J,$N%Z!<%8$,B8:_9kNN0h$+$i3djEvF$kJ}<0

algo3 %[!<%`%N!<%I0J2<$NNN0h$G%Z!<%8N"$kNN0h$+$i3d$jEvFkJ}<0

algo4 *SSS–CORE* $G;HMQ$9$k!"%Z!<%8$N$"$k%/%i%9%?$r3d$jEvFkJ}<0

$?$@$7>e5-$G%[!<%`%N!<%I$H$O;q8;4IM}LZ>e$N%N!<%I$G!"%W%m%;%9$NMW5aBf?t0J>e$N%W%m%;%C%5$r4^$`ItJ,LZ$KBP1~$9kbNG!":G2<0L%l%Y%kKEv?kbNN3HG"$k!#$9Jo$A!"%[!<%`%N!<%I$O0l$DA0$N%9%1%8%e!<%j%s%0;~$N3dEvNN0h$rBeI=$7$F$$$k!#?^ 2$K%[!<%`%N!<%I$NNc$r<($9!#?^Cf$G!"%W%m%;%C%5$r 3 BfMW5a9k%W%m%;%9 A KBP7FO!" 3 Bf0J>e$N%W%m%;%C%5!J$r4^$`%/%i%9%?!K$rJq4^$9$kItJ,LZ$N%k!<%H$KEv$?$k%N!<%I$,%[!<%`%N!<%I$G$"$k!#

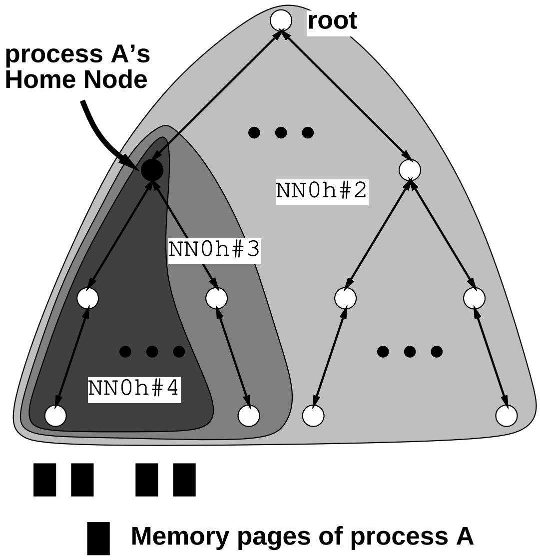
5 DNJ}<0N&$A algo2, algo3, algo4 $,;q8;4IM}LZ9=B$$rMxMQ9kJ}<0G"$k!#$3$N 3 J}<0$N0c$$$O$W%m%;%9$X$N%W%m%;%C%5$N3djEvFNN0h$,!";HMQCf$N<B%a%b%j%Z!<%8$N0LCV$K8G<9$9$kEY9gK"$k!#?^ 3$G$O!"NN0h 2, 3, 4 $,$=l>$l algo2, algo3, algo4 $,3dEv$r;n9k2DG=@-N"$kNN0h$KBP1~7F$$$k!#3N>l9gNN0h 4 $NA02s$N3djEvF0LCV$G!"%W%m%;%9 A $,<B%Z!<%8$r=jM-7F$$$kNN0hG"$k!#$^$?NN0h 3 $,NN0h 4 $KBP1~$9$k%[!<%`%N!<%I$KhC$FBeI=$5lkNN0hG"$k!# algo4 $N>l9g$K$O4pK\E*$K!"%W%m%;%9Kh$N<B%Z!<%8$NB8:_0LCV$KBP1~$7$FKh2sF1$8NN0h$,3d$jEvFilk$,[1] algo3 $N



?^2 ;q8;4IM}LZK*1k%[!<%`%N!<%I$NNc

[1] %W%m%;%9$N<B%Z!<%8$,:F%9%1%8%e!<%k$^$G$K0lIt%/%i%9%?$K$*$$$F40A4$K%/%i%9%?%a%b%j$+$iDI$$=P5l$?>l9g$K$O!"%[!<%`%N!<%I0J2<$NNN0h!JNN0h 3!K$GB-$j$J$$J,$N%W%m%;%C%5$r3NJ]9k!#

>l9gKO!"NN0h 3 K"$?$k%[!<%`%N!<%I0J2<$NNN0h$K$*$$$F3dEv$r;n$_$k!#A02s$N%9%1%8%e!<%k;~$N3d$jEv$FNN0h$,!"B>$N%W%m%;%9$K4{$K3d$jEv$F:Q$_$J>l9g$K$O!"I,MW$JBf?t$,3NJ]$G$-$l$P<B$Z!<%8$r;}$?$J$$NN0h$b3d$jEv$F$k!# algo2 $N>l9g$K$O!" algo3 $NMWNN$GNN0h 3 $GI,MWBf?t$r3NJ]$G$-$J$$>l9g$K!"%7%9%F%`A4BN$KAjEv$9$kNN0h 2 Fb$N;DjNNN0h$G3dEv$r;n$_$k!#7?$,$C$F>5- 3 J}<0$N4VGO algo4, 3, 2 $N=g$K<B%a%b%jN"$kNN0h$r3djEvF$k798~$K$"$j!"$=$N5U=gGW%m%;%C%5$NMQBf?t$,B?$/$J$k2DG=@-$,9b$$$H$$$($k!#



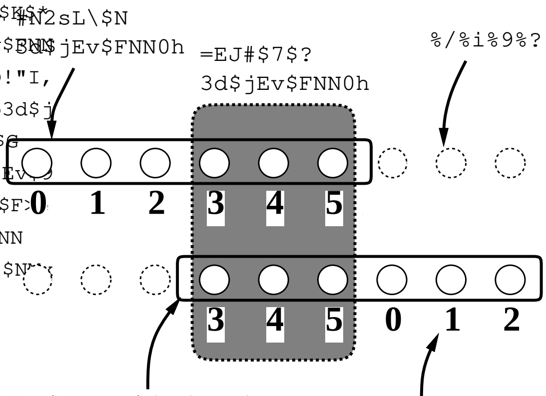
?^3 ;q8;4IM}LZ$H3F%9%1%8%e!<%j%s%0J}<0$N3djEvF
BP>]NN0h

$^$?%W%m%;%9$K3d$jEvFil?%/%i%9%?XN%9%1%C%I$N%9%1%8%e!<%j%s%0$O!"0J2<NDLjG"$k!#

- A02s$N3dEv$H=EJk%/%i%9%?KOF1$8%9%1%C%I$r%9%1%8%e!<%k9k!#
- $=$l0J30$N%/%i%9%?$K$O!";D$j$N%9%1%C%I$r=g$K%9%1%8%e!<%k$9$k!#

?^4$K!"%9%1%C%I%9!&%9%1%8%e!<%j%s%0NNcr<($9!#?^4$NNcGO!"3djEvFNN0h$, N+1 2sL\$H N 2sL\$G=EJC$F$$$kItJ,$N%9%1%C%I 3!" 4!" 5 O=N^$^%9%1%8%e!<%k5l!"3djEvFNN0h$,JQ2=7?%9%1%C%I 0!" 1!" 2 KD$$$F$O%9%1%8%e!<%k$5lk%/%i%9%?$,0\F0$7$F$$$k!#

A0@a$G=R$Y$?$h$&$K!"F10l$N%9%1%C%I$,F10l$N%/%i%9%?$G<B9T5llP!"%m!<%+%k6u4V$O:FMxMQ$5lk!#7+$7!"%9%1%C%I$N%9%1%8%e!<%k0LCV$,0\F0$7$?>l9g$K$O!"%m!<%+%k6u4V$N%Z!<%8$O%/%i%9%?$r1[$($F%M%C%H%o>e$r0\F0$7J1lPJi$J$$!#=>CF!"3djEvFNN0hKJkY$/=E$Jkh$&$K7?J}$,%m!<%+%k%Z!<%8$N0\F0$,>/$J$$!#



?^4 %f!<%6%1Y%k!&%9%1%8%e!<%j%s%0Nc

J*!" *SSS–CORE* GO;~J,3d$N4V3V$rD9$a!J?tI4%_%jIC!A?tICDxEY!K$K@_Dj$9k?$a!"%9%1%8%e!<%j%s%0$KMW9k7W;;;~4V$OAjBPE*$K==J,>.$5$$!#=>CF!"%7%_%e%l!<%7%g%sGO%9%1%8%e!<%j%s%0$N7W;;;~4V$OL5;k9k!#

4.3 %Z!<%8CV49J}<0

J,;6%a%b%j4D6->eGOJ,;66&M-%a%b%j$r2>Dj$9kH!";2>HIQEY5Z$S:F%"%/%;%9;~$N%"%/%;%93%9%H$N0c$$$Khj%Z!<%8$rJ,N`$9$k$3$H$,2DG=$G$"$k!#%Z!<%8$NJ,N`$,G-lP!";2>HIQEY$,>/$J$$/:F%"%/%;%9;~$N%3%9%H$,>.$5$$%Z!<%8$+$iCV49BP>]H9$k8zN(E*$JJ}<0$,2DG=$HJk!#

Nc$($P!"L@i+$K<B9TCf$N%W%m%;%9$,MxMQ$9$k%Z!<%8$H$O!"$=$l0J30$N%W%m%;%9$,=jM-$9$k%Z!<%8$NJ}$,%"%/%;%9$5lK$/$$!#$^$?0lDN%W%m%;%9$N%Z!<%8$NCfGb!"%/%i%9%?$K%m!<%+%k$J%Z!<%8hj$O6&M-%Z!<%8$X$N%"%/%;%9$NJ}$,0lHLE*$K>/$J$$!#$^$?6&M-%Z!<%8O=l,J#?tB8:_9k%3%T!<N&AN0lDG$"$l$P!":F%"%/%;%9;~$K$O1s3VCO$+$i%M%C%H%o!<%/$r7PM3$7$F!"Dc%3%9%H$G%"%/%;%9$9k3H,2DG=G"$k!#$=lKBP7F!":F%"%/%;%9;~$K%G%#%9%/%"%/%;%9$r@8$8$kh&$J%Z!<%8CV49$O6KNOM^$($?J}$,F@$G$"$k!#$=$3$G%Z!<%8$N<oN`Kh$j!"<!$N%h$&$KCV49BP>]H9$k=g=x$rM?$($k3H$,$G$-$k!#0J2<GO%3%T!<$r;}$?$J$$6&M-%Z!<%8$r!"JX59E*$K%9%9%H%o%s!&%Z!<%8$H8F$V!#

(1) B>$N%W%m%;%9$N6&M-%3%T!<%Z!<%8
(2) <B9TCf%W%m%;%9$N6&M-%3%T!<%Z!<%8
(3) B>$N%W%m%;%9$N%i%9%H%o%s!&%Z!<%8
(4) B>$N%W%m%;%9$N%m!<%+%k%Z!<%8
(5) <B9TCf%W%m%;%9$N%i%9%H%o%s!&%Z!<%8
(6) <B9TCf%W%m%;%9$N%m!<%+%k%Z!<%8

CV49J}<0H7FO!"CV49BP>]H9$k%W%m%;%9=g$rINh&$KA*Br$9k+Kh$j!"J#?t$N@oN,$,2DG=$G$"$k!#:#2s$N%7%_%e%l!<%7%g%s$G$O!"<!$NFsDNCV49J}<0$r<BAu$7Hf3S$r9T$JC?!#

I=**1** %W%m%;%9!&%;%C%H!J%;%C%H J2!K

#DP	#PS	Hs6&M-6u4V%5%$%:*%W%m%;%9?t
4	4	$30pages*2, 80pages*2$
8	4	$30pages*4, 80pages*1$
16	2	$30pages*2$
AmJBNsEY 80		AmHs6&M-6u4V 3200pages

#DP: MW5a%W%m%;%C%5?t, #PS: %W%m%;%9?t

I=**2** %W%m%;%9!&%;%C%H!J%;%C%H K2!K

#DP	#PS	Hs6&M-6u4V%5%$%:*%W%m%;%9?t
3	5	$50pages*5, 80pages*2$
6	5	$50pages*5, 80pages*1$
13	1	$30pages*1$
16	1	$30pages*1$
AmJBNsEY 74		AmHs6&M-6u4V 3120pages

#DP: MW5a%W%m%;%C%5?t, #PS: %W%m%;%9?t

J}<0 **1** %Z!<%8$N<oN`!?%W%m%;%9$N6hJLJ7$K!"C1=c$J LRU =g

J}<0 **3** %9%1%8%e!<%j%s%0M%@hEY$NDc$$%W%m%;%9$+$i!" >e5-$N%Z!<%8$N<oN`=g$KA*Br!#3F%W%m%;%9$N6&M-3d$ Hs6&M-6u4VKh$K LRU =g$r4IM}9k

%W%m%;%9$N%9%1%8%e!<%j%s%0$OM%@hEY$N9b$$=g$K9T$J$& 1k$?$a!"M%@hEY$NDc$$%W%m%;%9$N%Z!<%8$[$I;2>H$5$l K/$$!#J}<0 3 O3$N@-<A$rMxMQ9k!#$?$@7IAi $NJ}<0$b!"014S@-=hM}Cf$N6&M-%Z!<%8$N>l9g$OCV49BP$ H7$J$$!#

I=**3** 3F<o%3%9%H5Z$S%Q%i%a!<%?

9`L\	CM
%G%#%9%/%"%/%;%9	10000 clk
%j%b!<%H%"%/%;%9	50 clk
DL?.	10 clk
%W%m%;%C%5?t	16 Bf
1 %a%b%j$N%Z!<%8?t	400 pages
1 %Z!<%8$N%5%$%:	4096 Byte
Am%a%b%jNL	25.6 Mbyte
1 quantum	100000 clk

5. 7k2L5Z$S9M;!

FsAH$N%W%m%;%9AH$KBP7F%7%_%e%l!<%7%g%s$r9T$J$C $?!#I= 1!" 2$,3FAH$NFbLu$G$"$k!#N>%;%C%H$N3F%W%m%; %9$OIl$b 80 %Z!<%8$N6&M-6u4V$r;}$A!"%3%T!<%Z!<%8 $,@8@.$5lk3HKh$j%a%b%j0n$l$,5/$-$k!#$^$?3F %W%m%;%9$O!" 1000 M-8z<B9T%/%m%C%/KhKi%s%@%`$JAH 9g$;$GF14|$9$k!#3F<o%Q%i%a!<%?$OI= 3Nh$&$K@_Dj$7 $?!#%Z!<%8$N0\F0KBP7FO!"%M%C%H%o!<%/$N3F%(%C%8 >e$G%j%b!<%H%"%/%;%9$O%Q%i%a!<%?J,$N%3%9%H$rIU2C$9 $k!#

?^ 5$+$i?^ 8$G3F%9%1%8%e!<%j%s%0J}<0!J2#<4!K$KBP 7F!"%7%9%F%`A4BN$NM-8z<B9TN(!J=D<4!K$r<($7$?!#$J $*%G!<%?$N<hF@$O%7%_%e%l!<%7%g%s3+;O8e!"01$DL\$N%W %m%;%9$,=*N;!J20 %?%$%`%9%i%$%9J,$NM-8z<B9T!K7? D>8e$N;~J,3d$N;~E@$G9T$JC?!#3F%a%b%jCV49J}<0$r:N

MQ7?>l9g$N7k2L$r<(7F$"$k!# 16 Bf9=@.$N>.5,LO%7 %9%F%`$G$N8GDjBf?t@)Ls$rMxMQ$7$?>u67$G$O!"%W%m%;%C %5$NMxMQ8zN($,Bg$-$/I>2A$K1F6A$9$k!#$3$N4D6-$G<B:] $N%7%9%F%`$K$*$$$F==J,$J%W%m%;%C%5$NMxMQ8zN($,$"$k >l9g$NI>2A$r9T$J$&$?$a!"3dEv$+$i1L$l$?%W%m%;%C%5$N <B9T$OM-8z<B9T$K%+%&%s%H7?!#

?^ 5$O%;%C%H J2 $N 2 ?J 4 CJ$N 16 Bf%7%9%F%`9=@.>e $G$N7k2L$G$"$k!#%9%1%8%e!<%j%s%0J}<0 algo4 $,:GNI $N7k2L$r<($7$F$$$k!# algo4 $H algo3 $,F1$8@-G=$J$N $O!" 2 $N6R$NJBNsEY$N%W%m%;%9$N=89g$G$"$k%;%C%H J2 $H%M%C%H%o!<%/$N7A>u$NAj@-$N$?$a!"F1$8%9%1%8%e!< %j%s%0$r9T$J$C$?$+$i$G$"$k!#?^ 7$GF1$8$/%;%C%H J2 $N 4 ?J 2 CJ%7%9%F%`GN7k2L$r8+$k$H!" algo4 $H algo3 KbL@i+$J:9$,8+il$k!#F1MM$K%;%C%H K2 KBP7$F ?^ 6$K 2 ?J 4 CJGN7k2L!"?^ 8$K 4 ?J 2 CJGN7k2L$r<($9!#$dOj algo4 $,:GNI$N7k2L$r<($7$F$$$k!#

=>CFIN7k2LGb!"%9%1%8%e!<%j%s%0J}<0 algo4 $,:GNI$N7k2L$r<($7$F$$$k!#$^$? algo4!" 3!" 2 $rHf 3S$9kH!"%W%m%;%9$r<B%Z!<%8$r=jM-9kNN0h$K3d$j EvFk798~$,9b$$J}<0$[$I!"<B9T8zN($,9b$$$3H,$o $+$k!#%;%C%H J2 $N 4 ?J 2 CJ$N>l9gGN<B9T;~4V$NFbLu $r?^ 4!K$rNc$K8+$k$H!"DL?.!J<g$K%Z!<%8MW5a$d%Z!<%8 $N0\F0!K$dF14|KMW7$?;~4V$K:9$,$"k3H,J,$+$k!# 3l$O!";2>HIQEY$N9b$$%m!<%+%k6u4V$N%Z!<%8$N0\F0 $,>/$J$/$Jkh$&$K%9%1%8%e!<%j%s%0$9$k8z2L$,1F6A$7 $?$H?dDj5l$k!#$5iK%W%m%;%9$N3d$jEv$FNN0h$rIQHK $KJQ99$9kH!"3F%/%i%9%?$K3F%W%m%;%9$N%a%b%j$,=8Cf 7F7^$$!"8_$$$K<B%Z!<%8$NC%$$9g$$$r5/$3$9NL$,A} 2C$9k?$a!" algo4 KHfY$F algo3!" algo2 $,8zN($, 0-$/$JCF$$$k!#

I=**4** F14|/DL?.;~4V(%;%C%H J2, 4 ?J 2 CJ, CV49J}<0 3)

type	algo0	algo1	algo2	algo3	algo4
M-8z<B9T	76.79	80.92	85.27	89.66	92.45
F14|	9.70	7.56	6.71	5.42	4.17
DL?.	13.47	11.48	7.96	4.87	3.32
%G%#%9%/	0.04	0.05	0.06	0.05	0.06

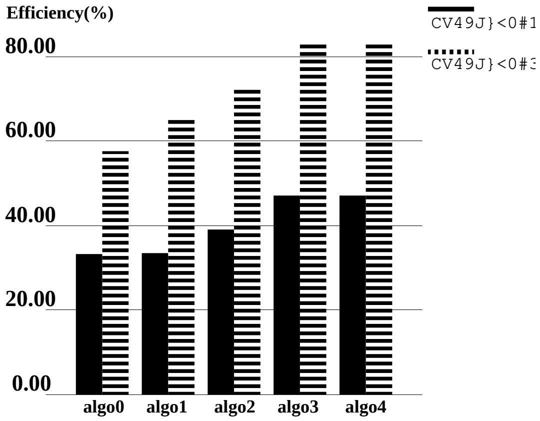
C?%a%b%j$NCV49J}<0$K$D$$$F$_$k$H!"$I$N>l9g$K$b $[$HsIJQoi$:$F!#J}<0 3 $,J}<0 1 $K>!$C$F$$$k!#:G$b2zN($NNI$+$C $?%;%C%H J2 $N 4 ?J 2 CJ$N>l9g$G8+$k$H!"CV49$NMM;R$O I= 5$Nh&KJCF$$$k!#J}<0 3 GO%W%m%;%9$N6&M- %Z!<%8$,CV49$5$lkNKBP7$F!"J}<0 1 GO%W%m%;%9 $N%m!<%+%k6u4V$N%Z!<%8$d%i%9%H$o%s6&M-%Z!<%8$,CV49 5l$k!#7?$,CF!"J}<0 1 O^$:CV49$N2s?t$,J}<0 3 hjB?$/!">l9g$KhCFO:F%"%/%;%9;~$K%G%#%9%/%"% %;%9$rH/@8$7$F$$$k!#

I=**5** %Z!<%8<oN`Kh$NCV492s?t (%;%C%H J2, 4 ?J 2 CJ)

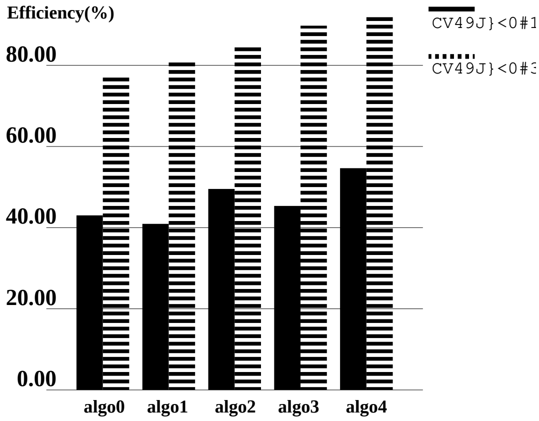
%Z!<%8<oN`	0	1	2	3	4	5
J}<0 1	2815	661	60	1707	46	281
J}<0 3	7820	0	0	0	0	0

%Z!<%8<oN`$O 4.3 @a$G$NJ,N`>e$NHV9f

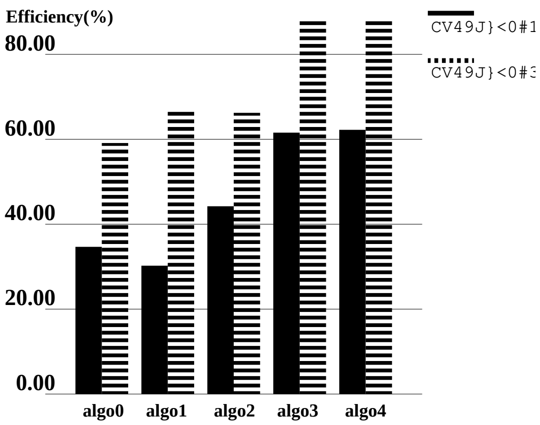
!y >p=hDs=P%P!<%8%g%s$rD{@5$7$?!#



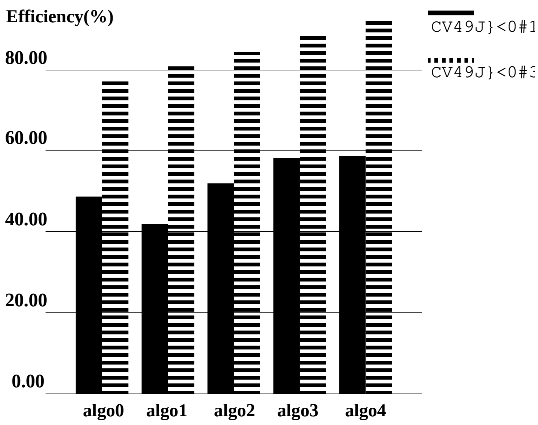
?^**5** %7%_%e%l!<%7%g%s7k2L!J%;%C%H J2!" 2 ?J 4 CJ!K



?^**7** %7%_%e%l!<%7%g%s7k2L!J%;%C%H J2!" 4 ?J 2 CJ!K



?^**6** %7%_%e%l!<%7%g%s7k2L!J%;%C%H K2!" 2 ?J 4 CJ!K



?^**8** %7%_%e%l!<%7%g%s7k2L!J%;%C%H K2!" 4 ?J 2 CJ!K

6. $* $o $j $K

HFMQJBNs OS *SSS–CORE* K*1k;q8;>pJs$rMxMQ 7?%9%1%8%e!<%j%s%0J}<0KD$$$F!"%7%_%e%l!<%7%g%s Kh$jI>2A$r9TJC$?!#$=$N7k2L!"%W%m%;%9$,=jM-9k <B%Z!<%8$,B8:_$9$kNN0h$r3djEvF$kJ}<0$NM%0L@-$,G' ail?!#$=$N860x$O!"%Z!<%8$N0\F0$dCV49$Khk0-1F 6A$rM^$($k8z2LKhk?$aG"kH?dDj5l$k!#$^$?, %Z!<%8$NCV49J}<0KD$$$F$O!";2>HIQEY5Z$S:F%"%/%;%9 $N%3%9%H$,>.5Jab$j%Z!<%8$+$iCV49$r9TJ&J}<0$, NI$$7k2L$r<($7!"%3%T!<%Z!<%8Kh$k%a$b%j0nl,5/$- $kDxEY$NIi2YGO!"3NJ}<0$r:NMQ$9lPJ#?t%W%m%;%9 $N<B9T$K==J,$J8zN($rF@ilk3H,4|BTG-$k!#

<U<-

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

;2 9M J8 8%

1) Thomas E. Anderson, Brian N. Bershad, Edward D.Lazowska, , and Henry M. Levy. Scheduler activations: Effective kernel support for the user-level management of parallelism. *Proceedings of the Thirteenth ACM Symposium on Operating Systems Principles*, Vol.25, No.5, pp. 95–109, October 1991.

2) >>K\>0, 8EAq?J0l, J?LZ7I. HFMQD6JBNs%*%Z%l!<%F%#%s%0 %7%9%F%` SSS–CORE. F|K\%=%U%H%&%'%"2J3X2qBh 11 2s Bg2qO@J8=8, pp. 13–16, October 1994.

3) >>K\>0. %^%k%A%W%m%;%C%5>e$NF14|5!9=$H%W%m%;%C%5%9 %1%8%e!<%j%s%0$K4X$9$k9M;!. 7W;;5!%"!<%-%F%/%A%c8&5f 2qJs9p No.79-1, pp. 1–8, November 1989.

4) >>K\>0. :YN3EYJBNs<B9T;Y1g%^%k%A%W%m%;%C%5$N8!F$. >pJs=hM} 3X2qO@J8;o, Vol. 31, No. 12, pp. 37–42, August 1989.

5) ?.9qM[FsO:, >>K\>0, J?LZ7I. HFMQJBNs#O#SN?aN;q8; >pJs$rMxMQ$7$?%9%1%8%e!<%j%s%0J}<0$N8!F$. ?.3X5;Js, Vol. 95, No. 210, pp. 111–118, August 1995.

6) ?.9qM[FsO:, >>K\>0, J?LZ7I. 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, Vol. 96, No. 23, pp. 19–24, March 1996.