AP1000+>eGN%i%8%*%7%F%#K!$NJBNs2=

—@EE*Ii2YJ,;6$NI>2A$HDL?.$N2~NI$Khk@-G=2~A1—

>eEhL@ ;3:j>!90
{uejima, yamazaki}@hpc.cs.ritsumei.ac.jp

N)L?4[Bg3XM}9)3XIt

35MW

H>5e$r:YJ,2=$7$F2<!85%$%s%?%j!<%VJ}<0$G3F%W%m%;%C%5$K3djEvF$kJBNs%i%8%*%7%F%#K!$NIi2Y6Q9UEY$rI>2A$9$k!%$^$?!$3F%W%m%;%C%5$GJ,;6$7$FIA2h$5l?ItJ,H>5e%G!<%?$rDL?.$7$F!$A4%W%m%;%C%5$,40A4$JIA2h%G!<%?$rF@$?8e!$%U%)!<%`%U%!%/%?$rF1;~$K7W;;$9$kJ}K!$rDs0F$9$k!%%W%m%;%C%564Bf$rHw$($?J,;6%a%b%j7?JBNs7W;;5!AP1000+>e$G$N<B83$G$O!$Ii2Y6Q9UEY$O0.93 ∼ 0.96$G$"$k!%$?$7$$J}K!$rMQ$$$k$HDL?.NL$O%(%l%a%s%H?t$HL54X78$H$J$j!$%W%m%;%C%564Bf$G$NB.EY8~>e$O!$%Y%s%A%^!<%/%7!<%s$G=>Mh$NItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$NLs2G\$N20.4 ∼ 21.8!$8=<BE*$J%7!<%s$G35.0 ∼ 40.2$G$"$k!%

Parallelization of the Radiosity Method on the AP1000+:

Evaluation of a Static Load Balancing Algorithm and Performance Improvement Using an Enhanced Communication Procedure

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Abstract

Load balance efficiency of our parallel radiosity algorithm that subdivides hemispheres into multiple cells and allocates them to each processor is evaluated, and an enhanced communication procedure, in which partial hemisphere data on each processor are communicated and complete hemisphere data are prepared on all processors, is proposed. On the distributed memory parallel computer AP1000+ with 64 processors, the load balance efficiency is 0.93 ∼ 0.96. Since the sizes of communication data are independent of the number of elements in this new procedure, the speedup is 20.4 ∼ 21.8(almost twice than our previous method) for benchmark scenes, and 35.0 ∼ 40.2 for classroom scenes.

1 O8aK

%i%8%*%7%F%#K![1]GO8w$NAj8_H?<M$r9MN8$7$?Hs>o$K%j%"%k$J2hA|$r@8@.$G$-$k$,!$%U%)!<%`%U%!%/%?!J$"$kItJ,$+$iB>$NItJ,$X8w$,E~C#$9$k3d9g!K$r5a$a$k$?$a$KG|Bg$J7W;;NL$,I,MW$H$J$k!%$3$N7W;;NL$O%7!<%s$r9=@.$9$k%W%j%_%F%#%V!J4JpK\7A>u!K$N?t$,B?$/$J$k$K$D$l$FA}2C$7!$C`<!=hM}GOHs8=<BE*$J7W;;;~4V$rMW9k$?$a!$JBNs=hM}$Khk9bB.2=$N8&5f$,?JailF$$$k[2]!%

2f!9$O%^%k%A%H%i%s%9%T%e!<%?%7%9%F%`>eGN%i%8%*%7%F%#K!$NJBNs2=$G!$%X%_%-%e!<%V$r:YJ,2=$7!$$=lrF0E*Ii2YJ,;6$H@EE*Ii2YJ,;6$Khj3F%W%m%;%C%5$K3d$jEvFkJ}K!$rMQ$$$?[3–5]!%@EE*Ii2YJ,;6$O%X%_%-%e!<%V$N2rA|EY$,%W%m%;%C%5?t$NG\?tGJ$$>l9g$K!$F0E*Ii2YJ,;6HHfY$FJBNs2=8zN($,:GBg$G12%0-$/JC$?$,!$B>$N>l9gGON><TKh$k@-G=$N:9$O[$HsIJ+C?!%$=$3$G!$J,;6%a%b%j7?JBNs7W;;5!AP1000+%7%9%F%`>eGNJBNs2=GO!$H>5e$r:YJ,2=$7!$@EE*Ii2YJ,;6Kh$j3F%W%m%;%C%5$K3djEvF$kJ}K!$rMQ$$$?!%0lHIE*$K@EE*Ii2YJ,;6$G$O3F%W%m%;%C%54V$N=hM};~4V$NIT6Q9U$,LdjHJkNG!$Ii2Y6Q9U$r6KNOC#@.G-$kJ,;6J}K!$rMQ$$$k3H$,=EMW$G$"$k!%K\8&5fGO!$:YJ,2=$7$?H>5e$r2<!85$N%$%s%?%j!<%VJ}<0$G3F%W%m%;%C%5$K3djEvFk?$a!$@EE*Ii2YJ,;6K!GbIi2Y6Q9U$r?^$k3H$,$G$-!$$+$DH>5e$N2rA|EY$rHf3SE*<+M3$K@_Dj9k3H$,$G$-$k!%

JBNs2=8zN($O!$%W%m%;%C%51BfGN=hM};~4VrT(1)$!$$nBfG$N=hM};~4V$r$T(n)$$H7?$N>l9g$K$T(1)/nT(n)$$GI=5lkCMH7FDj5A5l$k!%2f!9

$N=>Mh$N8&5f [3–6] GO! $%7! <%s$,J#; (KJkK$D 1FJBNs2=8zN ($,Dc2<$9kH$$$&LdBj$,$"C?! %$3 1O! $JBNs%U%)! <% '%U% !%/%?7W; ;$N:]$K! $%Q%C%A?t $^$?$O% (%1%a%s%H?t$KHfNc7?NL$NItJ,%U%)! <% ' %U% !%/%?%G! <%?$NDL?.$,H/@8$9$k$?$aG"$k! %K\8& 5f$G$O! $JBNs%U%)! <% '%U% !%/%?7W; ;$N:]$NDL?.J}K! $r2~NI$7F3$NLdBj$r2r7h9k! %9JoA! $3F%W%m %;%C5$KJ,; 6$5$1$F$$$kItJ,H>5e%G! <%?$rDL?.$7$F! $ 9YFNH>5e%G! <%?$r=8$a! $$=$N8e! $A4%W%m%;%C5 $GF1; ~$K%U%)! <% '%U% !%/%?$r7W; ;$9$k! %$=7F! $:G Bg$N%]%j%4%s?t$,Ls10 K|8D$NBg5,LO$J%Y%s%A%^! < %/%7! <%s$N=hM}$rItJ,%U%)! <% '%U% !%/%?%G! <%?DL?. $HItJ,H>5e%G! <%?DL?.$N2DLjNJ}K!$G9T$$! $Ii2Y J,; 6$HDL?.J}K!$N4QE@$+$iI>2A$9$k! %

K\O@J8GO! $J,; 6%a%b%j7?JBNs7W; ;5!AP1000+ %7%9%F% '>e$G! $%Y%s%A%^! <%/%7! <%s$H8=<BE*$J65<< $N%7! <%s3F! $3 <dN '$N=hM}$r9T$$! $H>5e$N:YJ,2=$K hk@EE*Ii2YJ,; 6$NI>2A$HDL?.$N2~NI$Khk@-G=2~ A1KD$$$F9M; !$r9T$&! %

2 JBNs7W; ;5!AP1000+

AP1000+$OIY;NDL8&5f=j$G3+H/$5$1$?J,; 6%a%b %j7?$NJBNs7W; ;5!G"$k [7]! %K\8&5f$G$O%;%k$,64 Bf@\B3$5$1$?%7%9%F% '$r;HMQ9k! %3F%;%k$OCF0:n%/ %m%C/<~GH?t50MHz $NSuperSPARC %W%m%;%C5! $ 64M %P%$%H$N%m! <%+%k%a%b%j! $%a%C;! <%8%3%s%H %m! <%i! $$*hS%M%C%H%o! <%/%C%P%$%9$JIG9=@.$5 1k! %3F%;%k$O! $%;%k4V1BP1DL?.MQT-Net! $%[%9%H-%;%k4VDL?.$H%;%k4V$N%V%m! <%I%-%c%9%HDL?. MQB-Net! $$*hS%P%j%"F14|$H%9%F! <%?%9DL?.MQ S-Net $N3 <dN '$N%M%C%H%o! <%/Kh$j7k9g$5$1$k! % G$0U$N%;%k4V$NDL?.$d%V%m! <%I%-%c%9%HDL?.JI$r ;XDj$G$-! $%;%k4V$NDL?.KMW9$k; ~4V$O5wN%K[$\L54X78$G! $DL?.NL$KOMB8$9$k$H$$$&FCD'$,$"$k! % %a%C;! <%8DL?.$O4pK\E*$KHsF14|7?$G! $Aw?.B&$O<u ?.B&$NJVEz$rBTD3HJ$/! $8eB3$N=hM}$r<B9T$G$- $k! %%U%!%$%kF~=PNOJI$N=hM}$O! $%;%k72$H@\B3$5 1?%[%9%H7W; ;5! !$o! <%/%9%F! <%7%g%s! K>e$G9T$&! %

3 %i%8%*%7%F%#K!H=$NJBNs2=

3.1 7W; ;<j=g

%7! <%sCf$NJ*BN$NI=LL$rD9J}7A$H; 03Q7A$N%]%j %4%s$GDj5A$7! $3F! 9N%]%j%4%s$rEy4V3V$KJ,3d7F %Q%C%A! J|<M$N7W; ;C10L! K$5iK$=$1irEy4V3V$K J,3d7F% (%1%a%s%H !E-<M$N7W; ;C10L! KH9$k [6]! %

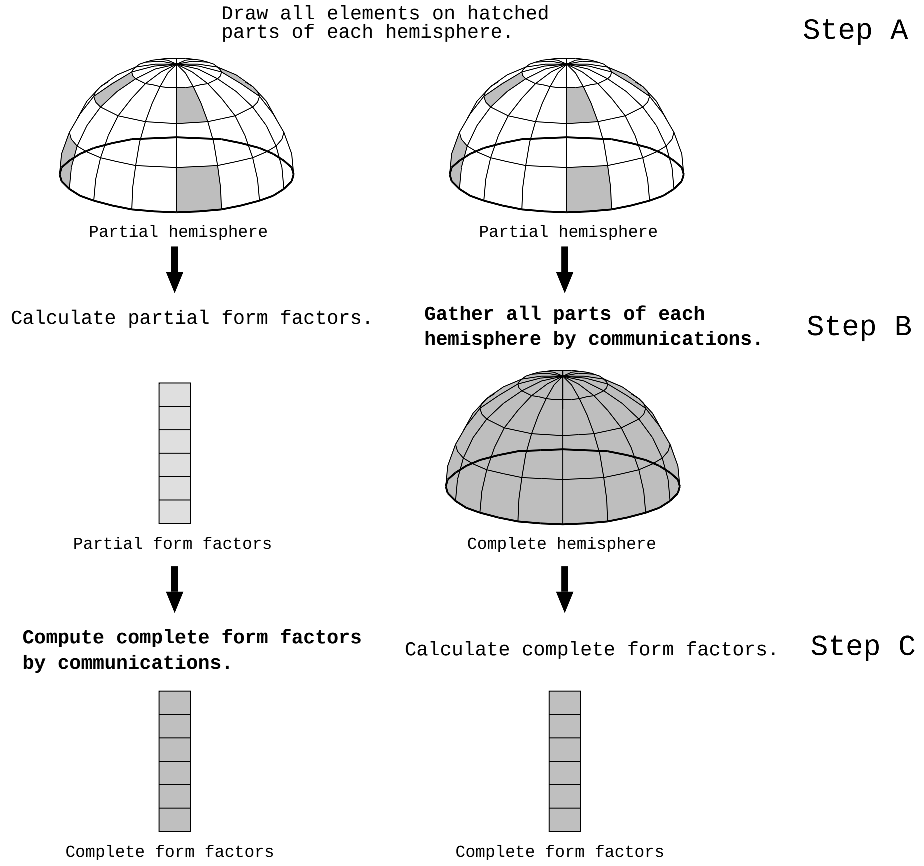
%i%8%*%7%F%#$N=hM}$K$O7W; ;8zN ($N$h$$A2?JK! [8] $rMQ$$$k! %A2?JK!GO! $%i%8%*%7%F%#$NBg$-$$%Q%C %A$+$i=g$K% (%1%a%s%H$X$N8w$NJ|<M$r<}B+$9k^$G 7+$jJV$9! %G$0U$N;~E@$G7W; ;ESCf$N2r$,F@i1! $$+ $D=jMW%a%b%j$NI$r@aLs$G$-$kN,FCD9G"$k! %J|<M $r7W; ;$9$k:]! $%U%)! <% '%U% !%/%?$H8FP1$k! $%Q%C %A$+$i% (%1%a%s%H$X8w$N% (%M%k%.! <$,E~C#9k3d9g $N7W; ;$,I,MWKJ$k! %U%)! <% '%U% !%/%?7W; ;KCH> 5eK! [9] $rMQ$$$k! %H>5eK!GO! $J|<M%Q%C%A$rCf?4 K7$?H>5e$r9M$ (! $$=$NI=LL$r:Y$+$$%a%C7%e$KJ, 3d$7$F! $3F! 9N%a%C7%eXN%U%)! <% '%U% !%/%? !ΔF!K r"i+8a7W; ;7F$*$/! %A4% (%1%a%s%H$rH>5e$K Ej1F7F1#LL>C5n$7! $% (%1%a%s%H$,BP1~E1i1$? %a%C7%e$N$\Delta F$$N9g7W$r5a$a1P! $%Q%C%A$+$iA4% (%1%a%s%H$X$N%U%)! <% '%U% !%/%?$,7W; ;G-$k! %$?$@ $7! $K\8&5f$G$NH>5eK!$N=hM}K*$$$F$O! $% (%1%a%s %H$rD>@\Ej1F9kNGOJ$/! $%]%j%4%s$rH>5e$KEj 1F$7$F1#LL>C5n$r9TC?8e! $3F%a%C7%e$,BP1~9k % (%1%a%s%H$r7hDj$7$F$$$k [6]! %

3.2 %G! <%?G[CV

%7! <%s%G! <%?$NG[CV$G$O! $%]%j%4%s%G! <%?$N%3 %T! <$rA4%W%m%;%C5$K; }$?$;! $%Q%C%A%G! <%?$r3F%W %m%;%C5$K%$%s%?%j! <%VJ}<0$KJ,; 6$5$;$F$$$k! % (%1%a%s%H%G! <%?$O! $$=1r4^$`%Q%C%A%G! <%?$,CV$+ 1k%W%m%;%C5$,J]; }9k! %3NJ}K!GO! $A4%W%m %;%C5$,H>5eXNIA2hKI,MWJ%]%j%4%s%G! <%?$r J]; }$9k?$a! $JBNs%U%)! <% '%U% !%/%?7W; ;$N:]$K:B I8$N%G! <%?$r%W%m%;%C54V$GE>Aw$9kI,MWO$J$$! % 5i$K! $%Q%C%A%G! <%?$H% (%1%a%s%H%G! <%?$r3F%W%m %;%C5$KJ,; 6$7$FG[CV$7! $:GBg%i%8%*%7%F%#CM$r; } $D%Q%C%A$N8!:w$H3F% (%1%a%s%H$N%i%8%*%7%F%#CM$N 99?7$r! $J]; }$9$k%W%m%;%C5$KJ,; 6$7$F9To;k3 HG%a%b%j$N@aLs$r9T$& [6]! %

3.3 JBNs%U%)! <% '%U% !%/%?7W; ;K!

JBNs%U%)! <% '%U% !%/%?7W; ;$N:]! $?^1$K< (9h$& $J! $ItJ,%U%)! <% '%U% !%/%?%G! <%?$NDL?.$HItJ,H>5e %G! <%?$NDL?.$N2DLjNJ}K!$rMQ$$$k! %A0<TGO3F %W%m%;%C5$,ItJ,%U%)! <% '%U% !%/%?%G! <%?$rJBNs$K 7W; ;7?8e! $$=1i$r%W%m%;%C54V$GDL?.7FA4%W %m%;%C5$,4OA4$J%U%)! <% '%U% !%/%?$rF@$k! %8e<T$G $O3F%W%m%;%C5$,C4EvItJ,$rJBNs$KIA2h$7! $$=1i $r%W%m%;%C54V$GDL?.7FA4%W%m%;%C5$,4OA4$JIA 2h%G! <%?$rF@! $$=$N8e3F%W%m%;%C5$,F1; ~$K%U%)! < % '%U% !%/%?$r7W; ;9k! %



(a)部分フォームファクタデータの通信　(b)部分半球データの通信

?^1　2 <dN`$NDL?.J}K!$K$h$kJBNs%U%)!<%`%U%!%/%?7W;;

3.3.1　ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$KhkJ}K!

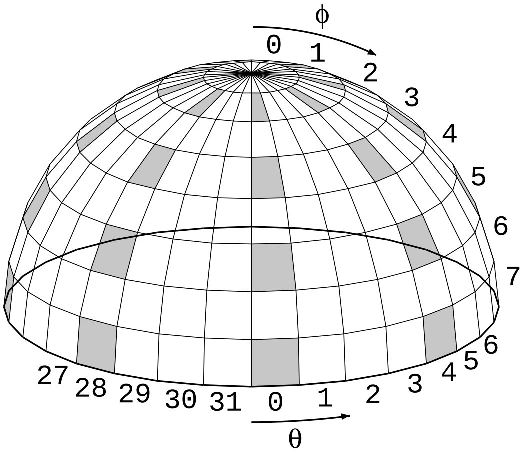
?^1(a) $K<($9h&$K!$$^$:!$3F%W%m%;%C%5$,C4EvItJ,$NIA2h$rJBNs$K9T$&!J%9%F%C%WA!K!%$3$3$G$O!$8Bf$N%W%m%;%C%5$KhkJBNs=hM}$r<($7$F$$$k!%<!$K!$3F%W%m%;%C%5$,$=l>lNIA2hC4EvItJ,$+$iF@il$kItJ,%U%)!<%`%U%!%/%?!Jpartial form factors!K$r7W;;$9$k!J%9%F%C%WB!K!%:G8e$K!$A4%W%m%;%C%5$,ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$Khj40A4$J%U%)!<%`%U%!%/%?$rF@$k!J%9%F%C%WC!K!%%9%F%C%WC $NDL?.$G$O!$3F%W%m%;%C%5$,J];}$9$k(%(%l%a%s%H?t) $\times 4$ %P%$%H$NItJ,%U%)!<%`%U%!%/%?%G!<%?$r1 2U=j$K2s<}7F40A4$J%U%)!<%`%U%!%/%?$r7W;;$7!$$=lrA4%W%m%;%C%5$K%V%m!<%I%-%c%9%H$7$F$$$k!%

FCD9$O!$%9%F%C%WB $N%G%k%?%U%)!<%`%U%!%/%?$N2C;;$K$h$kItJ,%U%)!<%`%U%!%/%?$N7W;;$rJBNs2=G-k3HG!$7gE@$O!$%9%F%C%WC $G%(%l%a%s%H?t$KHfNc7?DL?.NL$,I,MW$HJk3HG"$k!%$3$N7gE@$O!$%(%l%a%s%H?t$NB?$$Bg5,LO%7!<%s$GJBNs2=8zN($,Bg$-$/Dc2<9k860xHJCF$$$?!%

3.3.2　ItJ,H>5e%G!<%?$NDL?.$KhkJ}K!

?^1(b) $K<($9h&$K!$$^$:!$3F%W%m%;%C%5$,C4EvItJ,$NIA2h$rJBNs$K9T$&!J%9%F%C%WA!K!%<!$K!$3F%W%m%;%C%5>e$NItJ,H>5e!Jpartial hemispheres!K%G!<%?$NDL?.$KhjA4%W%m%;%C%5$,40A4$JIA2h%G!<%?$rF@$k!J%9%F%C%WB!K!%:G8e$K!$3F%W%m%;%C%5$,%G%k%?%U%)!<%`%U%!%/%?$N2C;;$K$h$j40A4$J%U%)!<%`%U%!%/%?$N7W;;$r9T$&!J%9%F%C%WC!K!%%9%F%C%WB $NDL?.$G$O!$3F%W%m%;%C%5$,J];}$9$k((H>5e$N%a%C%7%e?t)/(%W%m%;%C%5?t)) $\times 4$ %P%$%H$NItJ,H>5e%G!<%?$r!$=g$K%V%m!<%I%-%c%9%H$7$F$$$k!%

FCD9$O!$%(%l%a%s%H?tGOJ/H>5e$N2J}8~$N2rA|EY$N@Q!J$R_\phi \times R_\theta$!K$KO0MB8$7$?DL?.NL$G=hM}$r9T



?^2 H>5e$N:YJ,2=

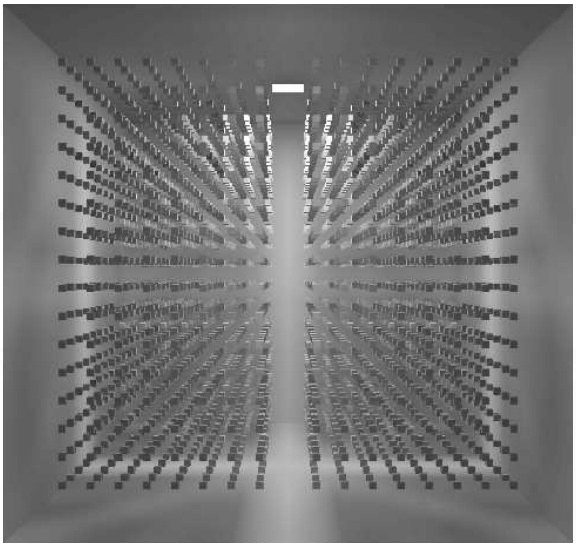
$($k3HG"$k!%

4 H>5e$N:YJ,2=$KhkIi2YJ,;6

4.1 F0E*Ii2YJ,;6$H@EE*Ii2YJ,;6

%U%)!<%`%U%!%/%?7W;;$N:]!$%7!<%s$r9=@.$9$k%]%j%4%s$NG[CV$K0MB8$7$F!$%X%_%-%e!<%V$dH>5e$N3F%a%C%7%eKhNIA2h;~4VKOBg$-$J:9$,@8$8$k2DG=@-$,$"$k!%$=$3$G!$3F%W%m%;%C%54V$N=hM};~4V$r2DG=$J8B$j6QEyK9$k9)IW$,I,MWG"$j!$:YJ,2=7?%X%_%-%e!<%V$dH>5e$r3F%W%m%;%C%5$K3d$jEvFkJ}K!H7$F!$F0E*Ii2YJ,;6$H@EE*Ii2YJ,;6$,9M$($ilk!%A0<TGO!$3F%W%m%;%C%5$NIi2Y$K1~$8$F!$3F%W%m%;%C%5XN3djEvF$r=hM}Cf$KF0E*$K7hDj$9$k!%$=N?$a!$3F%a%C%7%eKhN=hM};~4V$N:9$,Bg$-$$>l9gGbIi2Y6Q9U$r?^$lk,!$F0E*$J3djEvF$r9T$&$?$a$N%*!<%P%X%C%I$,H/@8$9$k!%0lJ}!$@EE*Ii2YJ,;6$G$O!$3F%W%m%;%C%5$X8GDjE*$K3djEvFk?$a!$Ii2Y6Q9U$NE@$G$OF0E*Ii2YJ,;6$hjNtk$,!$3djEvFN?aN%*!<%P%X%C%I$OH/@8$7$J$$!%

2f!9$O%^%k%A%H%i%s%9%T%e!<%?%7%9%F%`>eGN<B83$G!$F0E*Ii2YJ,;6$H@EE*Ii2YJ,;6K!$NHf3S$r9T$C$?[3–5]!%@EE*Ii2YJ,;6$rMQ$$$?>l9g!$%X%_%-%e!<%V$N2rA|EY$,%W%m%;%C%5?t$NG\?tGJ$$>l9g$KJBNs2=8zN($,:GBg$GLs12%0-$/Jk$H$$$&LdBj$,$"kbNN!$B>$N>l9gGOIi2YJ,;6J}K!KhkBg-$J@-G=$N:9OJ$+$C$?!%$9Jo$A!$@EE*Ii2YJ,;6G"CF$b!$3F%W%m%;%C%5KEy7$$?t$N=hM}$r%$%s%?%j!<%VJ}<0$G3djEvFlP!Bg-$JIi2YIT6Q9U$,@8$8$J$$$H9M$($i$l!$K\8&5fGO@EE*Ii2YJ,;6$rMQ$$$k



?^3 %Y%s%A%^!<%/%7!<%sB1

4.2 H>5e$N:YJ,2=$Khk@EE*Ii2YJ,;6

H>5eI=LL$r:YJ,2=$7$?%a%C%7%e$r!$2<!85$N%$%s%?%j!<%VJ}<0$G3F%W%m%;%C%5$K@EE*$K=hM}$r3d$jEvFk!%%W%m%;%C%5$,$(0,0) \sim (3,1)$ $^$G$N8Bf$N>l9g!$H>5e>e$N:BI8$(\phi,\theta) = (p,t)$ $N%a%C%7%e$O!$%W%m%;%C%5$(t \bmod 4, p \bmod 2)$ $K3d$jEvFilk!%?^2 $K2rA|EY$(R_\phi, R_\theta) = (8,32)$ $NH>5e$r<($9!%Nc$($P!$%W%m%;%C%5$(0,1)$ $O?^$NLV3]ItJ,$NIA2h$rC4Ev9k!%H>5eXN%]%j%4%s$NIA2h$N:]KO!$$^$:!$A4%W%m%;%C%5$,C4Ev$9$kItJ,$NIA2h$rJBNs$K9T$&!%$=$N8e!$3.3 $G=R$Y$?2DL$j$NJ}K!$GA4%W%m%;%C%5$,40A4$J%U%)!<%`%U%!%/%?$rF@$k!%

5 <B83$H9M;!

5.1 <B83J}K!

5.1.1 %Y%s%A%^!<%/%7!<%s$N=hM}

I=1 $K<($93 DLjN%Y%s%A%^!<%/%7!<%s$rMQ$$$F!$2DL$j$NJBNs%U%)!<%`%U%!%/%?7W;;K!!$$*hS3 DLjNH>5e$N2rA|EY$KhkI>2A$r9T$&!%=hM}$O$$$:lbA2?JK!$NJ|<M$r100 2s9T$&!%A4%7!<%s$K6&DL7F!$E70f!$>2!$4 Kg$NJI$G0O$^l?6u4VFb$K8w8;$HJ#?t$NN)J}BN$,$"$k!%N)J}BN$O6 8D$N%]%j%4%s$G9=@.$5$l!$3F%]%j%4%s$O2 8D$N%Q%C%A$K!$$5iK3F%Q%C%AO2 \times 2$ 8D$N%(%l%a%s%H$KJ,3d5l$F$$$k!%E70f!$>2!$4 KgNJIN%]%j%4%s$O3F!9$5 \times 5$ 8D$N%Q%C%A$K!$3F%Q%C%A$O2×2 8D$N%(%l%a%s%H$K!$$=

I=1 %Y%s%A%^!<%/%7!<%s

%7!<%s	N)J}BN?t	%]%j%4%s?t	%Q%C%A?t	%(%l%a%s%H?t	J|<M2s?t	%G!<%?NL(MB)
B1	4096	24588	49776	199032	100	5.4
B2	8000	48012	96624	386424	100	10.5
B3	17576	105468	211536	846072	100	23.0

I=2 65<<$N%7!<%s

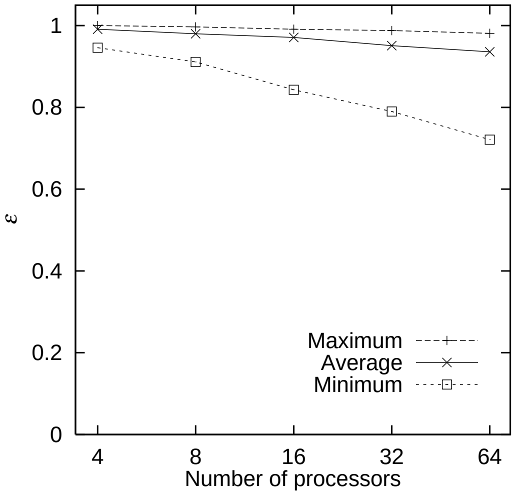
%7!<%s	%]%j%4%s?t	%Q%C%A?t	%(%l%a%s%H?t	J|<M2s?t	%G!<%?NL(kB)
C1	3159	6344	17402	758	642.3
C2	4629	9236	24342	1202	931.2
C3	7592	14941	37127	1751	1502.2

?^4 65<<$N%7!<%sC3

7F8w8;$N6 8D$N%]%j%4%s$O!$3F!9$2 \times 2$ 8D$N%Q%C%A$KJ,3d5l$F$$$k!%7!<%sB1 $N%i%8%*%7%F%#$N7W;;7k2L$r%l%s%@%j%s%0$7$?$bNr?^3 $K<($9!%J*!$$9YF$N%7!<%s$O%m!<%+%k%a%b%j>e$G<B9T2DG=$J5,LOH7F*$j!$%G!<%?NL$,:GBg$N%7!<%sB3 $OLs23M %P%$%HG"$k!%

5.1.2 8=<BE*$J65<<$N%7!<%s$N=hM}

I=2 $K<($9 3 <oN`$N8=<BE*$J65<<$N%7!<%s$rMQ$$$F!$Ii2YJ,;6!$$*$h$S2 DL$j$NJBNs%U%)!<%`%U%!%/%?7W;;K!$NI>2A$r9T$&!%=hM}$O R, G, B $N3F%+%i!<%P%s%I$K$D$$$FA2?JK!$N7W;;$,<}B+9k$^$GH9$k!%$3li$N3F%7!<%s$OIt2 0NBg-5H8w8;!$4y!$0X;RJI$N?t$,0[Jj!$C1, C2, C3 $N=g$KJ#;(KJ$k!%C1, C2, C3 $O3F!936 ?M!$54 ?M!$90 ?M$,F~lk65<<$N%7!<%s$G$"$k!%7!<%sC3 $N%i%8%*%7%F%#$N7W;;7k2L$r%l%s%@%j%s%0$7$?$bNr?^4 $K



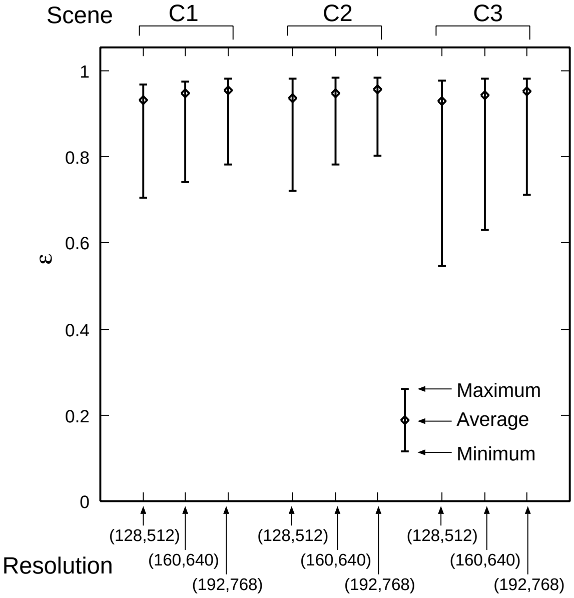
?^5 %W%m%;%C%5?tKh$kIi2Y6Q9U$NI>2A !J%7!<%sC2!K

<($9!%

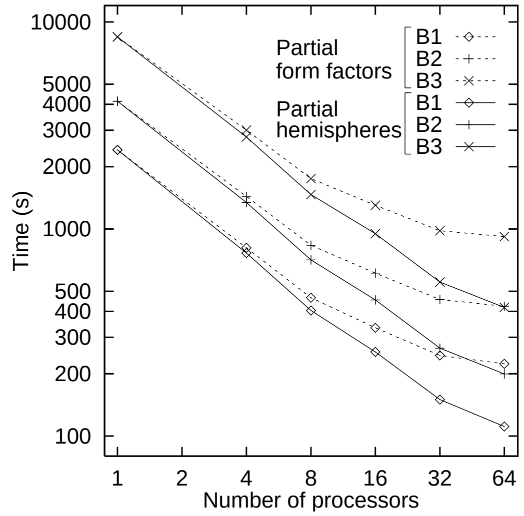
5.2 7k2L$H9M;!

5.2.1 Ii2YJ,;6$NI>2A

A4%W%m%;%C%5NCfN:GC;$N=hM};~4V$r T_{min} !$:GD9$N=hM};~4V$r T_{max} H7$?H-$NIi2Y6Q9UEY$r $\varepsilon = T_{min}/T_{max}$ H9$k!%Ii2Y6Q9U$,40A4KHlF$$$kH-$\varepsilon = 1$ HJ$j!$IT6Q9UKJkKDlFCM,>.5/Jk!%A2?JK!$N1 2s$NJ|<MKhN\varepsilon$ $NJ?6QCM!$:GBgCM!$:G>.CM$rB,Dj7?!%7!<%sC2 $N=hM}$K$*$1$k%W%m%;%C%5?t$KhkIi2Y6Q9U$NI>2A$r?^5 $K<($9!%H>5e$N2rA|EY$O9Y$F(128, 512) H7$F$$$k!%%W%m%;%C%5?t$,B?$/Jk$[$Iε $ODc2<$7!$Ii2Y6Q9U$r?^k3



?^6 %7!<%s$H2rA|EY$KhkIi2Y6Q9U$NI>2A
!&W%m%;%C%564 Bf!K



?^7 DL?.J}K!Kh$kHf3S !&Y%s%A%^!<%/%7!<%s!K

H,Fq7/Jk!%7+$7!$=hM};~4VKBg-$/1F6A$9$kJ?6QCM$O4 Bf$G0.99!$64 BfGb0.94 G"$j!$Ii2Y6Q9U$,$&$^$/?^il$F$$$k3H$,$o$+$k!%

%7!<%s$H2rA|EY$KhkIi2Y6Q9U$NI>2A$r?^6 $K<($9!%W%m%;%C%5?t$O64 Bf$G$"$k!%3F%7!<%sK*$$$F2rA|EY$HIi2Y6Q9U$N4X78GO!$2rA|EY!Jresolution!K$,9b$/$JkH;$,Bg$-$/$J$j!$Ii2Y6Q9U$,$h$/?^$lk3H,o+$k!%$3lO!$2rA|EY$,9b$$$[$I3F%a%C%7%e$NIA2h;~4V$N:9$,>.5/Jk3H!$$*hS3djEvF$k=hM}?t$,A}2C9k3H$,M}M3$H9M$($ilk!%

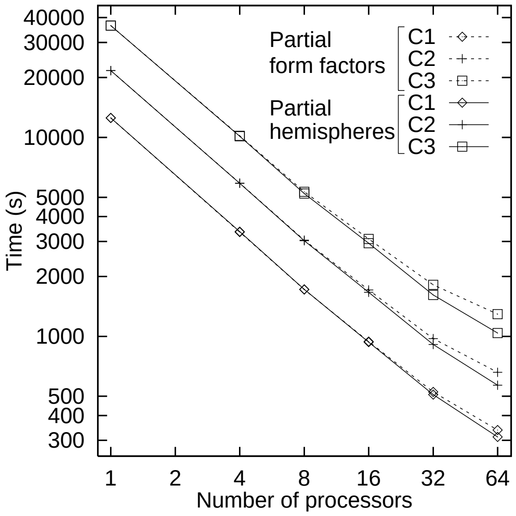
%7!<%s$HIi2Y6Q9U$N4X78GO!$C3 $N:G>.CM$,B>KHfYFDc/!$0.55 ~ 0.71 KJCF$$$k!%3l$O!$%7!<%sC3 $N%]%j%4%s?t$,B?$$$?$a!$H>5e$N3F%a%C%7%e$NIA2h;~4V$N:9$,Hf3SE*Bg$-$/Jk3H!$$*hSA2?JK!$NJ|<M2s?t$,B?$$$?$a!$IT6Q9UHJ$kJ|<M$,8=lk3NN($,9b$/Jk3H$,860x$H9M$($ilk!%$?$@$7!$J?6QCM$H:GBgCM$O2rA|EY$,F1$8>l9g$K%7!<%s$K4Xoi$:$[$\F1Ey$G!$$=l>$l0.93 ~ 0.96!$0.97 ~ 0.99 HJCF$$$k!%

5.2.2 JBNs%U%)!<%`%U%!%/%?7W;;K!$NI>2A

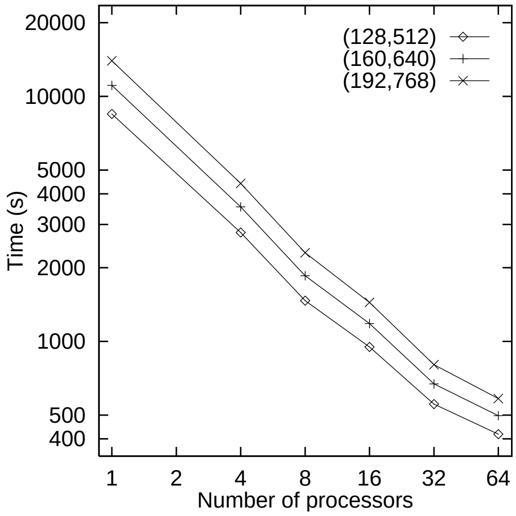
(a) %Y%s%A%^!<%/%7!<%s$N=hM}

7k2L$r?^ 7 $K<($9!%H>5e$N2rA|EY$O9Y$F(128,512) H7$F!$%Y%s%A%^!<%/%7!<%s B1, B2, B3 $N=hM}$r9TCF$$$k!%Partial form factors $,ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.!$Partial hemispheres $,ItJ,H>5e%G!<%?$NDL?.$r<($7$F$$$k!%ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$rMQ$$$F%W%m%;%C%5?t$rA}2C$5$;$?H-!$=hM};~4V$N8:>/$N3d9g$,0-$/$JCF$$$k!%3l$O!$DL?.9kItJ,%U%)!<%`%U%!%/%?%G!<%?NNL,%(%l%a%s%H?t$KHfNc$7$FA}2C$7!FC$K%W%m%;%C%5?t$,B?$$>l9gKO!$$3$NDL?.$Khk%*!<%P%X%C%I$N3d9g$,Bg$-$/Jk$?$aG"$k!%$9YF$N%7!<%s$K$*$$$F!$L@$i$+$KItJ,H>5e%G!<%?$NDL?.$NJ}$,M%$l$F$$$k!%$=$7$F!$DL?.J}K!Kh$k:9$O%W%m%;%C%5?t$,B?$/Jk$[$IBg$-$/8=lF$$$k!%%W%m%;%C%564 Bf$N>l9g$NB.EY8~>e$O!$ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$rMQ$$$?H-9.5 ~ 11.1!$ItJ,H>5e%G!<%?$NDL?.$rMQ$$$?H-20.4 ~ 21.8 HJ$j!$ItJ,H>5e%G!<%?$NDL?.$rMQ$$$k3H$G=hM}B.EY$,Ls2 G\$K8~>e7F$$$k!%

J*!$$3li$N%Y%s%A%^!<%/%7!<%s$G$O%7!<%s$N5,LON_$r%Q%i%a!<%?$H7FI>2A9k$?$a!$A2?JK!$NJ|<M2s?t$r0lDj$N100 2sK7$?$,!$0lHIE*$K$O!$J#;($J%7!<%s$[$IB?$/$NJ|<M2s?t$,I,MWHJ$k!%=hM};~4V$NCfKOA2?JK!$N3+;OA0$N%7!<%s%G!<%?$N%V%m!<%I%-%c%9%H$H!$=*N;8e$N%i%8%*%7%F%#CM$N2s<}$NDL?.;~4V$,4^$^lk!%7?$,$C$F!$J|<M2s?t$,B?$/Jk$[$I!$$3li$NDL?.;~4V$,@jak3d9g$,>/$J$/$Jk?$a!$B.EY8~>eONI/Jk$H9M$(il$k!%



?^8 DL?.J}K!Kh$kHf3S !'5<<$N%7!<%s!K



?^9 H>5e$N2rA|EY$KhkHf3S

(b) 8=<BE*$J65<<$N%7!<%s$N=hM}

7k2L$r?^8 $K<($9!%H>5eI=LL$N2rA|EY$O9Y$F (128,512) H7$F$$$k!%C1 $+$i C3 XH%7!<%s$,J#;($KJkKD$1!$N>DL?.J}K!Kh$k=hM}$;~4V$N:9$,Bg$-$/Jj!$ItJ,H>5e%G!<%?$NDL?.$,$h$jM-8z$HJk!%$?$@$7!$C1, C2, C3 Hb%Y%s%A%^!<%/%7!<%sKHfY$F>.5,LO$G$"$k$?$a!$DL?.J}K!$Khk:9$O>.$5$/$JCF$$$k!%7!<%sC1 GN%W%m%;%C%5?t$,8 Bf0J2<$N>l9g$OItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$rMQ$$$?J}$,$o$:$+$J$,$i@-G=$,NI$$$,!$B>$N>l9g$OItJ,H>5e%G!<%?$NDL?.$rMQ$$$?J}$,@-G=$,NI$/$J$C$F$$$k!%$D$^$j!$%7!<%s$,>.5,LO$G%W%m%;%C%5?t$,>/$J$$>l9g$r=|$$$F!$$[$\$9$Y$F$N>l9g$GItJ,H>5e%G!<%?$NDL?.$NJ}$,M-8z$G$"$k!%%W%m%;%C%5 64 Bf$N>l9g$NB.EY8~>e$O!$ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$rMQ$$$?H-28.2 ~ 37.0!$ItJ,H>5e%G!<%?$NDL?.$rMQ$$$?H-35.1 ~ 40.2 HJ$k!%%Y%s%A%^!<%/%7!<%s$KHfYF>.5,LOG"k?$a!$N>DL?.J}K!Kh$kB.EY8~>e$N:9$b>.$5$/$JCF$$$k!%

5.2.3 H>5e$N2rA|EY$KhkHf3S

7k2L$r?^9 $K<($9!%3 DLjN2rA|EY (128,512), (160,640), (192,768) $rMQ$$$F!$ItJ,H>5e%G!<%?$NDL?.Kh$j%Y%s%A%^!<%/%7!<%sB3 $N=hM}$r9TCF$$$k!%%W%m%;%C%51 BfNH$-!$2rA|EY(192,768) $N=hM};~4V$O2rA|EY(128,512) $N1.65 G\$HJC$F$$$k$,!$%W%m%;%C%564 Bf$N>l9g$O1.40 G\$HJC$F$$$k!%%W%m%;%C%564 Bf$N>l9g$NB.EY8~>eGO!$2rA|EY(128,512) NH$-20.27 G\!$(192,768) NH$-23.91 G\$HJC$F$$$k!%9JoA!$H>5e$N2rA|EY$,9b$$$[$IJBNs2=8zN($,NI$/$JCF$$$k!%$3$1$O!$2rA|EY$r9b$/9k3HKh$kDL?.NL$NA}2C$N3d9g$hjbIA2h;~4V$NA}2C$N3d9g$NJ}$,Bg$-$$$?aG$"$k$H9M$(i1$k!%

6 4XO"9k8&5f

%X%_%-%e!<%V$N:YJ,2=$KhkJBNs2=$r9T$C$?Baum iN8&5f[10] GO!$SGI <R$N6&M-%a%b%j7?%^%k%A%W%m%;%C%5 !&0%i%U%#%C%/%o!<%/%9%F!<%7%g%s$rMQ$$!01D$N%W%m%;%C%5$r%W%m%G%e!<%5!$;D$j$N%W%m%;%C%5$r%3%s%7%e!<%^H7$F$$$k!%%W%m%G%e!<%5$O%X%_%-%e!<%V$X$N%]%j%4%s$NIA2h$r%O!<%I%&%'%"$G=hM}7?8e!$%X%_%-%e!<%V$rJ,3d7F3F%3%s%7%e!<%^$K3d$jEvFk!%3F%3%s%7%e!<%^$OJBNs$K%G%k%?!&%U%)!<%`%U%/%?$N2C;;!$J|<M!$<!$NJ|<M%Q%C%A$NA*Br$r9T$&!%7!<%s%G!<%?$O%W%m%G%e!<%5N_$,;HMQ$9k?$a!$1 2U=j$K=8Cf$7$FG[CV$5$1$k!%@-G=$r8~>e$5$;$k$?$a!$%W%m%G%e!<%5$H%3%s%7%e!<%^$N=hM}$O%*!<%P%i%C%W7F9To1$k!%

Bg5,LO%7!<%s$NJBNs=hM}$r9TC?Sturzlinger iN8&5f[11] GO!$%W%m%;%C%5256 Bf$NJ,;6%a%b%j7?JBNs7W;;5!nCube2S $rMQ$$!$%Q%C%A?t6 K|8D!$%(%1%a%s%H?t13.1 K|8D$N%7!<%s$N=hM}$r9T$C$F$$$k!%%U%)!<%`%U%!%/%?7W;;KO%1%$%-%c%9%F%#%s%0$rMQ$$!$%Q%C%A$r3F%W%m%;%C%5$KJ,;6$5$;$F8r:9H=Dj$r

JBNs2=7F$$$k!%Ii2Y6Q9U$r?^$k$?$a!$%W%m%;%C%5$N%0%k!<%W4V$G=hM}$rF0E*$K0\F0$5$;$kF0E*Ii2YJ,;6K!$,MQ$$$ilk!%B.EY8~>e$O!$4y>e7W;;$G%W%m%;%C%564Bf$NH-Ls20G\!$256Bf$NH-Ls50G\$HJC$F$$$k!%

Baum iN8&5fGO!$%X%_%-%e!<%V$X$NIA2h$r@lMQ%O!<%I%&%'%"$G=hM}$7$F$$$k$,!$K\8&5fGOH>5eXNIA2h$bJBNs2=$7$F$$$kE@$KFCD9$,$"$k!%$^$?!$%Q%C%A?t21.1K|8D!$%(%l%a%s%H?t84.6K|8D$NBg5,LO$J%7!<%s$N=hM}$r9TC?!%3N:]!$ItJ,H>5e%G!<%?$NDL?.Kh$k%U%)!<%`%U%!%/%?7W;;K!$r?7$?$K9M0F$7!$JBNs2=8zN($rBgI}$K2~A1$7$F$$$k!%

7 $*$ojK

H>5e$r:YJ,2=$7$F2<!85$N%$%s%?%j!<%VJ}<0$G3F%W%m%;%C%5$K3d$jEvFk%i%8%*%7%F%#K!$NJBNs2=J}K!$K$*$$$F!$Ii2Y6Q9UEY$rJ?6QCM!$:GBgCM!$$*hS:G>.CM$N4QE@$+$iI>2A$7$?!%$^$?!$ItJ,H>5e%G!<%?$NDL?.$KhkJBNs%U%)!<%`%U%!%/%?7W;;K!$r?7$?$K9M0F$7!$ItJ,%U%)!<%`%U%!%/%?%G!<%?$NDL?.$KhkJ}K!hj$bM%$l$F$$$k3H$r<($7$?!%

Ii2Y6Q9U$NI>2A$G$O!$%W%m%;%C%5?t$NA}2C$HHb$KIi2Y6Q9UEY$,2<$,$k$,!$J?6QCM$O64Bf$N>19gGb0.93 ∼ 0.96 HJ$j!$Ii2Y6Q9U$,$h$/?^$lk3$H!$$*hSH>5e$N2rA|EY$,9b$$$[$IIi2Y6Q9UEY$,9b$/$Jk3H,o+C?!%5i$K!$2rA|EY$,F1$8>19g!$:G>.CM$OJ#;($J%7!<%s$GDc2<9k$,!$J?6QCM$H:GBgCM$O%7!<%s$K4X$oi:$[$\F1Ey$G!$$=l>$l0.93 ∼ 0.96!$0.97 ∼ 0.99 HJ$k!%

JBNs%U%)!<%`%U%!%/%?7W;;K!$NI>2A$G$O!$%Y%s%A%^!<%/%7!<%s$r=hM}$7$?$H$-!$?7$7$$J}K!$,$9YF$N>19g$K$*$$$FM%lF$*$j!$%W%m%;%C%564Bf$G$NB.EY8~>e$O!$=>Mh$NJ}K!$NLs2G\$N20.4 ∼ 21.8 G"$k!%8=<BE*$J65<<$N%7!<%s$N=hM}Gb!$$[$\$9YF$N>19g$K$*$$$F?7$7$$J}K!$,M%$lF*$j!$B.EY8~>e$O35.0 ∼ 40.2 G"$k!%

:#8e$N2]Bj$H7F!$6@LIH?<M@.J,$r4^$`LI$N=hM}$d64Bf$rD6$($k%W%m%;%C%5?tGN@-G=M=B,JI$,$"2ilk!%

<UK-

M-1W$J%3%a%s%H$rD:$$$?K\3XM}9)3XItF@4]1Q>!65<x!$EOItF)65<x$K4 6<U7^$9!%$^$?!$JBNs7W;;5!$rMxMQ$5$;$FD:$$$F$$$k !3Jt!KIY;NDL8&5f=jHPC 8&5f%;%s%?!<JiSK5~ETBg3X9)3XIt>pJs9)3X65<<IYED8&5f<<$K4 6<U$7$^$9!%

;29MJ88%

[1] Goral, C., Torrance, K., Greenberg, D. and Battaile, B.: Modeling the Interaction of Light Between Diffuse Surfaces, *Computer Graphics*, Vol. 18, No. 3, pp. 213–222 (1984).

[2] 0BIt5#, BgLn5AIW, @>EDM'@', 6aF#K.M:, CfEh@5G7: JBNs%0%i%U%#%/%9%"%k%4%j%:%`$N%5!<%Y%$, >pJs=hM}%0%i%U%#%/%9$HCAD 8&5fJs9p, 68–2, pp. 9–16 (1994).

[3] >eEhL@, ;3:j>!90, EOItF), F@4]1Q>!: %^%k%A%H%i%s%9%T%e!<%?%7%9%F%`>e$G$N%i%8%*%7%F%#K!$NJBNs2=, JBNs=hM}%7%s%]%8%&%`JSPP'95 O@J8=8, Vol. 95, No. 2, pp. 19–26 (1995).

[4] >eEhL@, ;3:j>!90, EOItF), F@4]1Q>!: %^%k%A%H%i%s%9%T%e!<%?%7%9%F%`>eGN%i%8%*%7%F%#K!$NJBNs2=, >pJs=hM}3X2qO@J8;o, Vol. 37, No. 7, pp. 1477–1484 (1996).

[5] Yamazaki, K., Uejima, A., Watanabe, T. and Tokumaru, H.: Parallel Radiosity Image Generation on a Distributed Memory Machine, *Proceedings of the 7th Transputer/occam International Conference*, pp. 211–225 (1996).

[6] >eEhL@, ;3:j>!90: J,;6%a%b%j7?JBNs7W;;5!AP1000+>eGN%i%8%*%7%F%#K!$NJBNs2=, EE;R>pJsDL?.3X2qO@J8;o(D-II), Vol. J80–D–II, No. 7, pp. 1852–1859 (1997).

[7] @PH*9(L@, KY9>7r;V, @6?e=S9,, NS7{0l, >.LxMN0l, :#B<?.5., GrLZD9Ip: AP1000+: %G%6%$%s%3%s%;%s%W%H, >pJs=hM}3X2q8&5f2qJs9p, 94–ARC–107, Vol. 94, No. 66, pp. 153–160 (1994).

[8] Cohen, M., Chen, S., Wallace, J. and Greenberg, D.: A Progressive Refinement Approach to Fast Radiosity Image Generation, *Computer Graphics*, Vol. 22, No. 4, pp. 75–84 (1988).

[9] Spencer, S.: The Hemisphere Radiosity Method: A Tale of Two Algorithms, *Eurographics Workshop on Photosimulation, Realism and Physics in Computer Graphics*, pp. 127–135 (1990).

[10] Baum, D. and Winget, J.: Real Time Radiosity Through Parallel Processing and Hardware Acceleration, *Proceedings 1990 Symposium on Interactive 3D Graphics*, pp. 67–75(1990).

[11] Sturzlinger, W., Schaufler, G. and Volkert, J.: Load Balancing for a Parallel Radiosity Algorithm, *IEEE/ACM 1995 Parallel Rendering Symposium (PRS '95)*, pp. 39–45 (1995).